# CHAPTER 502

# Traffic Design

| Design Memorandum | Revision Date | Sections Affected |
|---|---|---|
| 14-01 | Feb. 2014 | Ch. 75, 76, 77, 78 superseded by Ch. 502 |
| 15-19 | Sept. 2015 | 502-2.01(03) |
| 16-02 | Jan. 2016 | Sections 502-4.01 thru 502-4.07 |
| 16-03 | Jan. 2016 | 502-3.03(02), 502-3.03(05), and 502-3.04(05) - Editorial |
| 16-36 | Nov. 2016 | 502-3.03(05), item 4 |
| 17-09 | May 2017 | 502-1.01(05) |
| 17-14 | Jul. 2017 | 502-1.03(08) |
| 18-18 | Aug. 2018 | Figures 502-2J and 502-2L |
| 19-01 | Feb. 2019 | 502-2.09, 502-2.10, and Figures 502-2Q and 502-2R |
| 20-20 | Oct. 2020 | 502-3.03(05) and 502-3.04(05) |

| | | |
|---|---|---|
| 21-24 | Dec. 2021 | 502-2.01(03) New,<br>502-2.01(04) thru 502-2.01(08),<br>502-2.02(01) thru 502-2.02(04),<br>502-2.02(06) thru 502-2.02(07), 502-2.02(12), 502-2.02(16),<br>502-2.02(17), 502-2.02(21), 502-2.06(04), 502-2.06(05),<br>502-2.09(02), 502-2.09(03), 502-2.10, and 502-2.11,<br>Figures 502-2A, 502-2B, 502-2C, 502-2D, 502-2R and 502-2Q |
| 22-10 | Jul. 2022 | 502-4.01(03), 502-4.01(04), 502-4.02, 502-4.02(01) thru 502-4.02(14) (Del.) |
| 22-16 | Aug. 2022 | 502-5.0<br>Figures 502-5A thru 502-5F (Del.) |
| 25-02 | Jan. 2025 | 502-1.01(06), 502-1.01(14), 502-1.02(09), 502-3.06(07), 502-4.03(05), 502-4.07, and Figure 502-1E |

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**CHAPTER 502**

# TRAFFIC DESIGN

## 502-1.0 ROADWAY SIGNING

The majority of the information required for the selection, design, and placement of highway signs is shown in the *Indiana Manual on Uniform Traffic Control Devices* (*IMUTCD*), the INDOT *Standard Drawings*, and the INDOT *Standard Specifications*. The intent of this section is not to reiterate the information provided in these sources but, rather to supplement these references and, where deemed necessary, to provide the user with additional guidance.

The *IMUTCD* shall be used for each public highway, street, or private road open to public travel for guidance related to the installation, maintenance, and replacement of signs.

### 502-1.01 General Criteria

A sign should be used only where it is warranted by the *IMUTCD* criteria, accident history, or field studies. A sign should provide information for a regulation, a hazard which is not self-evident, or a highway route, direction, destination, or point of interest. Each traffic-control device should be in accordance with the basic requirements as follows:

1. fulfill an important need;
2. command attention;
3. convey a clear, simple meaning;
4. command respect of road users;
5. be located to give adequate time for response; and
6. be sanctioned by law if it controls or regulates traffic.

#### 502-1.01(01) References

The following is the list of publications for selecting, designing, manufacturing, or installing highway signs.

1. *Indiana Manual on Uniform Traffic Control Devices*;
2. FHWA *Standard Highway Signs*;
3. AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*;

4. INDOT *Standard Specifications*;
5. Institute of Transportation Engineers, *Traffic Engineering Handbook*;
6. *Manual* Chapter 302;
7. American Institute of Steel Construction, *Manual of Steel Construction*;
8. INDOT pre-approved materials list on INDOT website, http://www.in.gov/indot/div/M&T/appmat/appmat.htm;
9. AASHTO *Roadside Design Guide;* and
10. AASHTO *Guidelines for Selection of SGS for Traffic Generators Adjacent to Freeways*.

### 502-1.01(02) Reflectorization

All signs should be reflectorized. They may also be illuminated. The INDOT *Standard Drawings* and INDOT *Standard Specifications* provide the reflectorization criteria for signs. For a local facility, reflectorization will be based on the city or county preference in accordance with *IMUTCD* guidelines. The following describes the reflective sheeting types that are available.

1. Encapsulated-Lens. This reflective sheeting consists of spherical glass beads which are adhered to a synthetic resin and encapsulated by a flexible, transparent waterproof plastic having a smooth surface. This sheeting type is identified as high-performance grade or high-intensity grade sheeting.

2. Prismatic-Lens. High-intensity prismatic-reflective sheeting is similar to encapsulated-lens sheeting, except that it uses non-metallic prismatic reflectors instead of glass beads. Super-high intensity reflective sheeting is similar to high-intensity sheeting except that it uses cube-corner prismatic lens.

For additional information on reflective materials, see the following publications:

1. FHWA/DF-88/001, *Retro-reflectivity of Roadway Signs for Adequate Visibility: A Guide*, November 1987.
2. NCHRP Report 346, *Implementation Strategies for Sign Retro-reflectivity Standards, TRB*, April 1992.
3. ASTM D 4956, *Standard Specification for Retro-reflectivity Sheeting for Traffic Control*.

### 502-1.01(03) Illumination

Most signs are designed to be illuminated by vehicular headlights and the sign message reflected back to the motorist. Therefore, external sign lighting and related appurtenances such as a sign lighting walkway will not be required for an overhead-sign or box-truss structure, and should not be shown on the plans. However, conduit and grounding for the structure should be specified to be installed in the foundations. A structure handhole should be specified to be placed toward the base of the sign support.

If a lighting-support assembly or walkway must be retrofitted, sign-structure mounting height should be specified as described in Section 502-1.01(06).

Lighting may be provided for the sign preceding a truck weigh station which indicates that the station is open or closed. This is accomplished with an internally-lighted sign. For sign luminaire placement on a retrofitted or new light support assembly, see Figure 502-1A.

The decision to provide overhead sign lighting will be made by the Department on a project-by-project basis.

### 502-1.01(04) Sign Placement

The *IMUTCD* and the INDOT *Standard Drawings* provide criteria for the placement of a sign next to or over the roadway. These sources also provide requirements for the maximum and minimum allowable horizontal and vertical clearances.

A warning sign is to be placed in advance of the condition to which it calls attention, in accordance with *IMUTCD* guidelines. A regulatory sign is placed where its mandate or prohibition applies or begins. A guide sign is placed at a variable location to inform motorists of their route of travel, destination, or point of interest. Desirably, spacing between guide signs should be a minimum of 800 ft.

Minimum spacing between sheet signs should be 200 ft for a highway with a posted speed limit of 40 mph or lower, or 300 ft for a highway with a posted speed limit of 45 mph or higher.

The uniform position of each sign, although desirable, is not always practical to achieve because the alignment and design of the road often dictates the most advantageous position for the sign. For determining the sign location, appropriate engineering judgment should be used.

Accordance with the criteria provided in the *IMUTCD* and INDOT *Standard Drawings* is not always practical. Actual sign placement may be adjusted to satisfy field conditions. The placement problem areas that should be avoided are as follows:

1. at a short dip in the roadway;
2. beyond the crest of a vertical curve;

3. where a sign can be obscured by parked cars;
4. where a sign can create an obstruction for pedestrians or bicyclists;
5. where a sign can interfere with a motorist's visibility to hazardous locations or objects;
6. where sign visibility can be impaired due to existing overhead illumination;
7. where a sign is vulnerable to roadside splatter or to being covered with snow by plowing operations; or
8. where it is too close to trees or other foliage that can cover the sign face.

**502-1.01(05) Ground-Mounted Sign Supports [Rev. May 2017]**

The following provides guidelines regarding placement of a ground-mounted sign and post selection for a ground-mounted panel sign.

Chapters 49 and 55 describe the Department's criteria for clear zone, roadside barriers, impact attenuators, and other roadside safety issues. These are also applicable to roadside signs. The following should also be considered.

1. <u>Ground-Mounted Sheet-Sign Support</u>. The support for each ground-mounted sign should be made breakaway or yielding within the clear zone. Posts should be of the square cross section type shown on the INDOT *Standard Drawings* series 802-SNGS for sheet signs. Support types I and II should be in accordance with district traffic office preference, with unreinforced or reinforced anchor base. Support type III shall be an unreinforced anchor base only. Criteria for use of support type I, II, or III are based on sign dimensions and are provided on the INDOT *Standard Drawings*.

   For a local agency project, channel posts may be used if desired by the local agency. A new sign support behind guardrail should have adequate clearance to the back of the guardrail post to provide for the guardrail's dynamic deflection (see Chapter 49).

2. <u>Ground-Mounted Panel-Sign Support</u>.

   a. Placement/Offset. A sign with an area of over 50 $ft^2$ on slipbase breakaway supports should not be placed where the opportunity exists for it to be struck at a point that is more than 9 in. above the normal point of vehicular bumper impact. Normal bumper height may be assumed as 1'-8". To avoid being struck at an improper height, a sign should be placed in accordance with the INDOT *Standard Drawings* series 802-SNGP and as follows.

      1) Fill Slope. A sign should be located at a desirable offset of 30 ft from the edge of the travel lane to the nearest edge of the sign. If a 30-ft offset is not

available, the sign can be located closer to the travel lane with approval from the Traffic Division, Office of Traffic Design.

2) Cut Slope 3:1 or Steeper. Vertical clearance between the ground and the bottom of the sign shall be a minimum of 5 ft for the width of the sign. The 30-ft horizontal offset shall be adjusted as needed to allow for appropriate post lengths.

3) Roadside Appurtenance. A large breakaway sign support should not be located in or near the flow line of a ditch. If such a support is placed on a backslope, it should be offset at least 3 ft from the toe of the backslope of the ditch. If possible, signs should be placed such that posts are not located on both sides of the ditch.

4) Exit Gore Sign. An exit gore sign must be placed in each gore area of a freeway in accordance with *IMUTCD* requirements and as shown on Figure 502-1B.

5) Foundation Placement on Steep Slopes. Foundations on slopes 2:1 or steeper should be located at least 2.5 ft. from edge of ditch.

6) Bi-directional Upper Joint. For median or non-divided highways installation of bi-directional upper joint should be noted on the plans. The bi-directional upper joint consists of a perforated fuse plate on both the sides of structure and is detailed in the standard drawings.

b. Post Sizing and Plan Detailing for Panel Signs. The following guidance should be applied when determining the appropriate W-beam post sizes and for providing proper plan detailing for ground-mounted panel signs:

1) Determining sign area. The entire area of the sign, including any exit number panels, should be considered when selecting the w-beam post size. Exit number panel sizes may be converted into an equivalent area. Equivalent area may be determined by either partial height over the entire width of the sign or more conservatively by considering that the panel width matches the width of the main part of the sign.

2) Post length for signs with exit number panel. Where a signs includes an exit number panel, at least one of the w-beam posts should extend to the top of the exit number panel.

3) Supplemental signs. Supplemental signs should not be mounted below the fuse plate/hinge plate connection.

4) Other attachments. The equivalent surface area of any flashing beacons or other attachments should be added to the height and or width.

c. Post Selection Tables for Panel Signs. INDOT *Standard Drawings* series 802-SNGP contains the required W-beam post size, number of posts, and post spacing to be used with a ground-mounted panel sign. The following procedure should be utilized to select the appropriate post size.

1) Determine the height and width of the sign and the clear height. The clear height is the elevation difference between the top of the foundation and bottom of the sign.

2) Select the table based on the clear height. The clear height used should be that for the post with the lowest elevation, i.e. the largest value. Clear heights range from 8 ft to 22 ft, in 2-ft increments.

   For instances where a post size is not indicated for a particular combination of sign height-sign width-clear height then the designer may contact the Traffic Design Office for recommendations on how to proceed.

d. Ground Elevation. The elevation of the ground in the area of the sign should be no more than 33 ft above the adjacent property/land particularly if there is no barrier (e.g. woods, buildings) to impede winds. Elevations differences greater than 33 ft need a special analysis to determine the wind loading which may necessitate larger posts- see ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, for additional guidance.

e. Standard Foundation Dimensions and Details. Foundations as detailed in the standard drawings have been developed for all soil conditions except where peat, marl, or other very soft soils are present or if the foundation is to be placed in embankments comprised of sand or b borrow. An alternative foundation design may be needed where these soils are known to exist or are discovered.

   Where the foundation is located on a slope steeper than 3:1, the depth of the foundation should be increased by a dimension equal to the foundation diameter.

### 502-1.01(06) Overhead Sign [Rev. Jan. 2025]

The following provides guidelines regarding placement of an overhead sign.

1. Lane Control. An overhead sign should be considered where the message is applicable to a specific lane. If the sign is placed over the lane, lane use can be made more effective, where additional guidance is required for a motorist who is unfamiliar with the area. The decision to utilize overhead lane control signage will be made at the district level. See section 502-1.02(05) for additional guidance on Two-Way Left Turn Only signs.

2. Visibility. An overhead sign should be considered where traffic or roadway conditions are such that an overhead mounting is necessary for adequate visibility, e.g., vertical or horizontal curve, closely spaced interchanges, three or more through lanes in one direction.

3. Divergent Roadways. An overhead sign should be considered at, or just in advance of, a divergence from a heavily traveled roadway, e.g., at a ramp exit where the roadway becomes wider and a sign on the right side is usually not in the line of sight for the motorist.

4. Exit. An overhead panel sign should be considered where a left-hand or multi-lane exit ramp is in place. An overhead exit direction sign should be located at the painted gore.

5. Left Lane Drop on High-Speed Facility. An overhead panel sign shall be used to indicate left lane drop on a high-speed facility. The overhead sign should be placed at 1 mi and 1/2 mi in advance of the lane drop and at the beginning of lane drop taper point.

6. Interchange. An overhead panel sign should be considered at a complex interchange where there can be motorist confusion, where there are closely-spaced interchanges, where there is an interstate-to-interstate interchange, or where there are lane drops on the exit ramp or mainline within the interchange.

7. Trucks. An overhead sign should be used where a number of large trucks can block a passenger-car driver's visibility to a ground-mounted sign.

8. Limited Right of Way. An overhead panel sign should be considered where there is limited space for a sign on the roadside, e.g., where right-of-way is narrow.

9. Roadside Development. An overhead sign should be considered where roadside development detracts from the effectiveness of a roadside sign, e.g., a brightly-lighted area.

10. Uniformity. An overhead sign may be used to be consistent with other signs on a specified section of highway.

11. Sign Lighting. As standard practice, INDOT no longer lights overhead signs. Sign lighting should only be specified upon direction from the district traffic engineer. Unless directed otherwise, sign lighting equipment should not be specified and should not be considered when developing cross sections and identifying the pole height needed to achieve the minimum sign mounting height.

12. Lateral Offset. Overhead sign structures should be set back at least 5 ft behind the face of guardrail, desirably 6’-8”.

Each new overhead sheet sign installation will require a minimum vertical clearance of 17’- 6” above the roadway and shoulders’ highest point, but not greater than 19’- 0”. Each new overhead panel sign will require a vertical clearance above the roadway and shoulders’ highest point of 17’-6”. This includes an additional 6 in. clearance for a future overlay. An existing overhead sign may have a vertical clearance of 17’-0”. For a dynamic message sign, the minimum vertical clearance shall be a minimum of 18’-0” above the roadway.

An overhead sign containing sign lighting should not be placed on a bridge overpass. A non-lighted sign may be placed on an overcrossing structure provided that the vertical clearance of the sign exceeds the vertical clearance of the overcrossing structure by at least 6 in.

**502-1.01(07) Sign Priority**

Providing motorists with too much information can cause improper driving and impair safety. Where sign-information overload can be a problem, the priority by sign type is as follows;

1. regulatory, e.g., speed limit, stop, turn prohibition;
2. warning, e.g., curve, crossroad, narrow bridge;
3. guidance, e.g., destination, routing;
4. emergency services, e.g., hospital, telephone;
5. motorist services, e.g., fuel, food, camping;
6. public-transportation, e.g., park and ride, bus stop;
7. traffic-generators, e.g., museum, stadium, historic building; and
8. general information, e.g., county line, city limit.

Within each sign group, the sign bearing the most important message should supersede the others.

**502-1.01(08) Computer Software**

Computer software programs are available that can be used in the design of highway signing, including sign layouts, legends, quantities, structural supports, etc. Not all software packages are applicable to Indiana. The Office of Traffic Design should be contacted to determine which programs and versions are acceptable for use for a project. The following is a summary of the programs currently acceptable to the Department.

1. SignCAD. This program helps to determine the appropriate panel size for each guide sign along a freeway.

2. GuidSIGN. This program provides standardized guide-sign layouts, text fonts, letter spacing, and sign sizes.

The designer shall include a complete set of the panel sign and unique sheet sign shop drawings as part of the appropriate stage of signing plan submittals.

### 502-1.01(09) Symbology

Where the *IMUTCD* permits the use of either words or symbols on the sign, the preferred practice is to use only the symbol message.

### 502-1.01(10) Sign Structure Selection Guidance and Design Criteria

The overhead sign structure types are as follows:

1. box truss;
2. sign cantilever structure;
3. tri-chord truss structure;
4. butterfly sign cantilever structure;
5. dynamic message sign structure;
6. monotube bridge sign structure;
7. bridge-attached sign structure for large panel signs;
8. bridge bracket for crossroad signing; and
9. cable span sign structure.

Figure 502-1C(1) provides box truss selection guidance. Figure 502-1C(2) provides sign cantilever structure selection guidance.

For structure and foundation details for structures 1 thru 5, 8, and 9 listed above, see the INDOT *Standard Drawings*.

Monotube or bridge-attached overhead sign structure use will be determined on an as-needed basis. Monotube and bridge attached structure design calculations shall be submitted by the designer to INDOT for approval. The designer should refer to INDOT Specifications Section 910 for the material specification options that may be used for these structures. Structures must be designed for safety and should be designed economically. See section 502-1.01(11) for sign structure design criteria and 502-1.01(12) for foundation design criteria. Drawings should include cross sections of each structure showing the actual loadings. The drawings and calculations must be signed and stamped by the designer and Quality Assurance reviewer.

Butterfly sign cantilever structures are normally placed on the concrete median walls of divided highways and INDOT's Standard Drawings are developed accordingly. A unique plan detail is needed should the designer specify placement in a grass median or off the outside shoulder.

Drainage shall be accounted for in the vicinity of the sign structure foundations. Drainage improvements to accommodate gravel barrel arrays, sign structures located near driveways, etc, shall be designed as needed.

Median drainage is not required for overhead sign structure installatiom, if one or more of the following conditions are met:

1. The foundation is at the highest point of a vertical curve

2. The foundation is at the lowest point of a vertical curve.

3. As determined by field conditions.

A barrier wall foundation shall have a transition taper of 30:1 to transition to an existing or new barrier wall. An expansion joint shall be provided at the barrier wall transition points and at all pavement joint locations within the transition area.

**502-1.01(11) Design Criteria for Traffic Sign Structure**

A sign structure shall be designed to satisfy the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*.

1. Design Loads. An overhead cantilever, box truss, or bridge-attached sign structure shall be designed using the allowable stress design (ASD) approach in accordance with the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaries, and Traffic Signals.* The sign structure should be analyzed for dead, wind, ice, and fatigue loads and their load combinations. Loading criteria are as follows.

2. Dead Load.

   Aluminum: 169 lb/ft$^3$
   Steel: 490 lb/ft$^3$
   Traffic message panel sign: 2.48 lb/ft$^2$, aluminum extruded panels 12-in. height.
   Traffic message sheet sign: 2 lb/ft$^2$
   DMS sign: minimum load of 5000 lb shall be used unless a different load is specified by the sign manufacturer.

3. Wind Load.

50 year service life
Wind speed (basic) = 90 mph
Wind Importance Factor, $I_r$ = 1, AASHTO Art. 3.83
Height and Exposure Factor, $K_z$ = 1 for height less or equal to 33 ft, Table 3-5
For height above 33 ft, see AASHTO Art. 3.8.4
Gust Effect Factor, $G$ = 1.14
Mean Velocity for Natural Wind Gust = 11.2 mph
Wind Drag Coefficient, $C_d$, depends on sign length and width, AASHTO Table 3-6, e.g., for sign panel length of 15 ft and width of 3 ft use $C_d$ = 1.20.

4. Ice Load. The load for horizontal or vertical supports should be in accordance with AASHTO Art. 3.9.2 and 3.9.3.

Ice load = 3 lb/ft$^2$. Ice is assumed to form around the entire surface of the structure's members, but on one side of the sign only, in accordance with AASHTO Art. 3.7.

5. Fatigue Load. Applied to all components, mechanical fasteners, and welds of support structures in accordance with AASHTO Art. 11.5. It is applicable for an overhead cantilevered or non-cantilevered sign structure.

Fatigue category $I_F$ = 1, (Art.11.6)

Truck speed for truck induced gusts = 65 mph.

The design of a special structure should be in accordance with above parameters.

**502-1.01(12) Design Criteria for Sign Structure Foundation**

Soil borings will be required for an overhead sign structure to determine if the soil is cohesive or sand, the soil-bearing capacity, and the friction coefficient. INDOT standard drawings reflect a foundation design based on clay soil with a minimum undrained shear strength of 750 psf, or sandy soil with a minimum friction angle of 30 deg. If the shear strength or friction angle is lower, the foundation should be designed and its details should be shown on the plans. Each such foundation should be designed and analyzed in accordance with AASHTO *LRFD Bridge Design Specifications*, using loads and load combinations determined for the overhead sign structure design. Foundation design calculations and details shall be submitted to INDOT for approval.

A geotechnical investigation shall be requested at the preliminary field check for each project requiring overhead sign traffic structures.

### 502-1.01(13) Applications

For all signs, the documents referenced in Section 502-1.01(01) should be reviewed to determine the appropriate sign application. The use of an experimental traffic control device is acceptable provided that its approval is in accordance with the criteria shown in the *IMUTCD*. The following regarding regulatory, warning, and guide signs provide additional guidance or supplementary information for specific signs.

### 502-1.01(14) Scoping Guidelines for 3R and 4R Projects [Rev. Jan. 2025]

Sheet signs and square/U-channel posts, panel signs and breakaway steel posts, overhead panel signs, and overhead sign structures on 3R (Resurfacing, Rehabilitation and Restoration) and 4R (Resurfacing, Rehabilitation, Restoration and Restructuring) projects should be replaced if corridor age replacement is not scheduled within two years of the projected letting date and if any of the following conditions are met.

1. Sheet Signs and Square/U-Channel Posts
    a. Signs are 18 years or older
    b. Lacks the horizontal or vertical clearance described in IDM Chapter 502
    c. Mounted on back-to-back Type A or Type B U-channel posts.
    d. QA results indicate 50% or more of its original reflectivity has been lost.
    e. Signs are inside a regrading area

2. Ground Mounted Panel Signs and Breakaway Steel Posts
    a. Signs are 20 years old or older
    b. Mounted on non-breakaway posts or otherwise not per INDOT standards
    c. Lacks the horizontal or vertical clearance per INDOT *Standard Drawings*
    d. One or more additional destinations are added to the sign
    e. Letter height does not meet *IMUTCD* recommendations
    f. Inside a regrading area
    g. Existing signs are button copy

3. Overhead Panel Signs
    a. Signs are 20 years old or older
    b. One or more additional destinations are added to the sign
    c. Letter height does not meet *IMUTCD* recommendations

4. Overhead Sign Structures
    a. Cracking on structure is detected
    b. Anchor bolts are noticeably deteriorating
    c. Inside a regrading area or otherwise interferes with construction
    d. Lacks the minimum vertical clearance described in standard drawings
    Area of new sign(s) is greater than the area of the existing sign(s)

    When reuse of an overhead sign structure is being considered, all repair or replacement needs identified through INDOT's inspection program should be included in the project scope. Contact the Office of Traffic Administration for the applicable inspection reports.

Sign modernization is not required with resurfacing projects.

**502-1.02 Regulatory Sign**

**502-1.02(01) Official Action**

An Official Action will be required if there is a proposed change in the regulatory nature of a sign or situation affecting a facility. For example, an Official Action is required if changes are made to the intersection control, e.g., installing a "Stop" sign at an existing uncontrolled intersection, parking restrictions, no-passing zones, traffic signals, or certain work-site speed zones. For an existing Department-maintained facility, approval must be obtained for the proposed change from the appropriate district traffic engineer prior to implementation of the change. For an existing local facility, approval must be obtained from the appropriate jurisdiction prior to implementation. For a new facility, the designer shall coordinate with the appropriate INDOT district traffic office or local agency to obtain approval for installations.

**502-1.02(02) "Stop" or "Yield" Sign**

1. General. A "Stop" sign should be installed at each at-grade, non-signalized local road or street which intersects a Department-maintained highway. A "Yield" sign may be used if the intersection is operating in a merge condition, e.g., channelized intersection with a turning roadway, or at an entrance ramp to an access-controlled facility.

    The warrants provided in the *IMUTCD* should be followed. For additional information, the following publications can be reviewed to determine the need for a "Stop" or "Yield" sign.

    a. Report No. FHWA/RD-81/084, *Stop, Yield, and No Control at Intersections*, FHWA, June 1981; or

b. NCHRP 320, *Guidelines for Converting Stop to Yield Control at Intersections*, TRB, October 1989.

2. Multiway Stop Control. The *IMUTCD* describes the warrants for where a multiway "Stop" sign installation may be considered. However, it should not be used unless the traffic volume for each approach leg of the intersection is approximately equal. For traffic signal installation, an engineering study should be performed to determine the validity of signal installation.

### 502-1.02(03) Speed Limit Sign

The district traffic office is responsible for determining the speed limits on each Department-maintained facility. Each request for a speed-limit determination must be transmitted to the appropriate district office. For a local facility, each local jurisdiction is responsible for determining the appropriate speed limits within its boundaries. This occurs after a speed study has been conducted. In determining a speed limit, the considerations are as follows:

1. the 85th-percentile speed;
2. the design speed used during project design;
3. the road-surface characteristics, shoulder condition, grade, alignment, and sight distance;
4. functional classification and type of area;
5. type and density of roadside development;
6. the accident experience during the previous 12 months;
7. parking practices and pedestrian activity; and
8. the maximum or minimum speed permitted by state law.

The *IMUTCD* indicates the elements that should be reviewed in an engineering study. The ITE *Manual of Traffic Engineering Studies* provides guidance on how to conduct a speed study. Each public road's speed is controlled by means of a regulatory speed limit, either through a speed limit sign or a speed limit established by state law.

### 502-1.02(04) "No U-Turn" Sign

On a freeway, two "No U Turn" signs, placed back to back on one sign post, should be placed at each median crossover.

### 502-1.02(05) Two-Way Left Turn Only (TWLTO) Sign

Lane-control signs should be provided at the beginning and end of a two-way left-turn-only lane. In an urban area, lane control signs should also be placed at approximately every 1000 ft along the lane. In a suburban or built-up rural area, the intermediate TWLTO sign spacing may be increased to 1200 ft. For the beginning and end, the supplementary "Begin" and "End" plaques should also be included.

A TWLTO sign should also be used on the back side of a "Left Turn Only" sign where a two-way left-turn-only lane is transitioned into a one-way left-turn lane. The supplementary "Begin" and "End" plaques are not included for this situation. Figures 502-2G and 502-2H illustrate the pavement markings used for this transition.

The signs should preferably be installed as ground-mounted unless existing overhead structures can be utilized. Signs should be placed on an overhead structure only if the district traffic engineer deems necessary.

### 502-1.02(06) "Do Not Pass" Sign

"Do Not Pass" signs will not normally be used on an undivided highway of 2 or 3 lanes. "Do Not Pass" signs should be used in an area of transition from a 4-lane divided roadway to a 2-lane roadway, or a 2-lane roadway to a 4-lane divided roadway.

If signing is used or needed in a transition area for improved conspicuity, a "No Passing Zone" sign should be installed as needed in accordance with Section 502-1.03(06).

### 502-1.02(07) Parking Signs

The generic symbolic "No Parking" sign should be used where practical on a Department-maintained facility. Where necessary, signs with other messages regarding parking restrictions or permissions may be used as shown in the *IMUTCD*.

### 502-1.02(08) "No Turn on Red" Sign

After conducting an engineering study as defined in the *IMUTCD*, the designer will submit a recommendation on the need for eliminating turn-on-red movements to the district traffic office or to the appropriate local jurisdiction. The district traffic office or local jurisdiction will have final approval for each turn-on-red restriction. Once the decision has been made to eliminate the turning movement, the proper "No Turn on Red" sign should be placed as specified in the *IMUTCD*.

### 502-1.02(09) "Wrong Way" Sign Treatment at Interchanges [Add. Jan. 2025]

Older drivers and impaired drivers may have difficulty navigating interchanges where the exit ramp is adjacent to the entrance ramp, such as partial cloverleaf or folded diamond interchanges. With approval from the District Traffic Engineer, the "Do Not Enter" and "Wrong Way" signs may have a 3-ft mounting height to be more conspicuous and/or include flashing LEDs in the sign border that are on 24 hours a day, seven days a week. See Section 502-3.06(07)for information on the use of wrong way vehicle detection systems.

## 502-1.03 Warning Signs

A warning sign is used where it is deemed necessary to warn a motorist of an existing or potentially hazardous condition on or adjacent to a highway or street. Each warning sign must be located in advance of the condition to which it applies. The use of warning signs should be kept to a minimum. Overuse of warning signs at a hazardous location tends to cause non-compliance for all signs.

### 502-1.03(01) Placement of Advance Warning Signs

Placement of Advance Warning Signs should be in accordance with the *IMUTCD*.

### 502-1.03(02) Advance Turn or Advance Curve Symbol Sign

The *IMUTCD* describes the horizontal-alignment signs, but it does not identify where to use these signs. The decision to use an advance turn or curve symbol sign is dependent upon posted speed, alignment, accident history, etc. It is impractical and uneconomical to place an advance warning sign at every horizontal curve. Before using an advance turn or curve sign, the following should be considered.

1. Speed Determination. In determining whether or not to place an alignment warning sign and advisory speed plaque, the appropriate speed for negotiating the curve must first be determined. If the curve radius and superelevation rate are known, the appropriate negotiation speed can be calculated as described in the AASHTO *Policy on Geometric Design of Highways and Streets*. If the radius of the curve is unknown, then a field study is warranted. This type of study is done using a ball-bank indicator. The ball-bank indicator test involves driving a test vehicle around a curve at various speeds and reading a curved level to determine an appropriate negotiation speed for the curve. Figure 502-1D, Ball-Bank Indicator Readings, lists the maximum recommended negotiation speed for a curve

based on a minimum of three ball-bank readings. Test runs should be conducted in both directions.

2. <u>Highway Alignment</u>. The highway alignment and *IMUTCD* Section 2C.07 should be reviewed to determine if advance curve signs are warranted. An unexpected curve after a long tangent section is a candidate for placement of an advance curve sign. A curve on a winding highway may not warrant the use of an advance curve sign, because the motorist will be expecting the curve. An advance curve sign should be provided where the vertical alignment obstructs the motorist's vision of the horizontal curvature. Where a Level One design exception for horizontal or vertical alignment is required, additional warning signs may be warranted as determined by the designer and reviewer.

3. <u>Posted Speed</u>. A highway with a posted or statutory speed limit of lower than 30 mph will not warrant an advance warning sign.

4. <u>Crash History</u>. The crash history should be reviewed to determine if there are a disproportionate number of run-off-the-road accidents that can be attributed to the horizontal curve. A high-accident location will likely warrant an advance curve sign, an advisory speed plaque, or chevron symbol signs.

5. <u>Motorist Familiarity</u>. On an arterial or a recreational road, a motorist can be less familiar with the highway, so, additional warning signs may be required.

6. <u>Combination Curve</u>. A combination curve consists of two or more successive curves. They can be connected with or without a short tangent section, and they can be in the same or in opposite directions. If either of the curves requires an advance curve or advance turn symbol sign, a reverse curve symbol sign should be used instead. For three or more successive curves, the winding road symbol sign should be used. If an advisory speed plaque is necessary, the lowest recommended negotiation speed for all of the curves should be shown on the plaque.

**502-1.03(03) Chevron Symbol Sign**

The *IMUTCD* provides the criteria for placement of chevron signs. At least three chevron symbol signs should be placed where chevron signs are required.

**502-1.03(04) Signal Ahead Symbol Sign**

In addition to the *IMUTCD* guidance, a signal ahead symbol sign should be installed at an isolated signalized intersection or in advance of the first intersection in a series of signalized intersections.

In an urban area with multiple signalized intersections along a corridor, the signal ahead signs should not be used.

**502-1.03(05) Advisory Exit Speed Sign**

An advisory exit speed sign should be placed at each exit ramp gore where the ramp design speed is lower than the mainline design speed in accordance with the *IMUTCD*. The "Exit ____ MPH" sign should be used on the ramp. If the ramp connects two freeways or expressways, the "Ramp ____ MPH" sign should be used.

**502-1.03(06) "No Passing Zone" Sign**

The beginning of a no-passing zone is marked with a "No Passing Zone" sign on the driver's left side of the roadway. A "No Passing Zone" sign is not required for a zone marked due to presence of a railroad crossing, nor at a zone marked due to the presence of an intersection or in an urbanized area.

**502-1.03(07) Advance Street or Road Name Sign**

An advance street or road name sign may be provided before each major street crossing. Placement will be determined for each location as dictated by sight distance and traffic volume. This supplementary sign is used in conjunction with the cross road sign, side road sign, or signal ahead symbol sign.

**502-1.03(08) Use of Fluorescent Yellow Sign Sheeting [Rev. Jul. 2017]**

The use of fluorescent yellow sign sheeting for horizontal alignment warning signs has proven to be an effective, low cost treatment for road departure crashes. Safety benefits may be realized in other applications as well, such as with advance traffic control signs (e.g. "Stop Ahead"). Beginning with the 2018 *Standard Specifications*, the Department requires fluorescent yellow sheeting on all warning signs except those for school zones and work zones. The suffix "FY" is no longer required to be added to the MUTCD sign code. The required background sheeting remains fluorescent yellow-green for school zones and fluorescent orange for work zones.

**<u>502-1.04 Guide Sign</u>**

The *IMUTCD*, the INDOT *Standard Specifications*, and INDOT *Standard Drawings* provide additional guidance relative to the design of guide signs.

**502-1.04(01) General Sign Design Requirements [Rev. May 2017]**

Shop drawings for guide signs shall be prepared by the designer using either GuidSIGN or SignCAD software and shall be submitted for approval in accordance with the INDOT Plan Development Procedure. Spacing rules and arrow dimensions for panel sign design are included in Figures 502-1E and 502-1F. Letter and Numeral sizes that should be used for all for advance guide, exit direction, gore and overhead guide signs are provided in Figure 502-1E. Freeway to freeway interchanges are classified as ‘system interchanges’.

Standard crossroad signage at an expressway or freeway interchange is shown in Figures 502-1G through 502-1W. For signage involving a frontage road, see the *IMUTCD*.

A city or town must be incorporated and have direct access from the interchange to be a destination on a freeway or expressway guide sign.

All distances for guide signs should be measured from the beginning or end of the deceleration or acceleration lane taper.

For crossroad signing at an interchange a 90 degree extension of an over head arrow (tail end arrow) is justified if one of the following conditions are met.

1. Overhead sign is 600 ft or more from the intersection.

2. Overhead sign is in front of an overpass bridge and the full lane width entrance ramp is at the other side of the bridge

Details for route marker assemblies consisting of multiple routes are shown in Figure 502-1X.

Details pertaining to letter sizes and letter series on Indiana-specific signs shall be obtained from the Office Traffic Design.

**502-1.04(02) Post-Interchange Sign Sequence**

After each grade-separated interchange on a freeway or expressway, a sequence of signs is required as shown in Figure 502-1Y. One component of the sequence is the distance sign. A distance sign can display two or three destination points and the distances to these destinations. Destination points should be arranged on the distance sign as follows:

1. Top Line. The top line should include the name of the next meaningful community, number of the next intersecting route, or name of the next intersecting highway, and distance in miles to it, on which the traveler's route passes.

2. Middle Line. The middle line, if used, should include the name of a community, number of an intersecting route, or name of an intersecting highway, and distance in miles to it, that is beyond the destination listed in the top line and is of general interest to the traveler. Figure 502-1Z provides a list of the regional control cities for use on distance signs along the Interstate System and major US routes. Regional control cities are the intermediate cities between the major control cities that are located within the State's boundaries.

3. Bottom Line. The bottom line should include the name of the next national control city and the distance in miles to it. Figure 502-1Z provides a list of the major control cities for use on distance signs along the Interstate System. National control cities are those cities which have national significance for the through traveler.

Another component of the post-interchange sign sequence is the truck lane usage sign. This sign is a panel sign, and shall be installed as shown in Figure 502-1Y. For a 2-lane section, the R4-Y9 sign shall be used. For a section of 3 lanes or more, the R4-Y10 sign shall be used.

**502-1.04(03) General Services Sign**

For gas, food, and lodging, general services signs shall be utilized only at an interchange where business logo signs are not present. If additional services such as camping, hospital, etc., are required at an interchange, the general services sign may be installed as a supplement to logo signs to accommodate those services as requested. For placement of general services signs, see Figure 502-1AA.

**502-1.04(04) Logo Signing**

A logo sign is a specific-information panel that has a separately-attached sign consisting of a single or multicolored symbolic design unique to a product, business, or service facility. It is used to identify traveler services that are available on a crossroad at or near an interchange or an intersection. Information on INDOT's logo signing policy appears in the state statutes, or by contacting the Office Traffic Administration. These signs are placed and maintained through an independent contract with INDOT. However, logo signs are a part of the INDOT signing system. They may be relocated or temporarily removed as deemed necessary by the contractor and as coordinated with the Indiana Logo Sign Group. The *IMUTCD* should be consulted in the design, layout, and placement of each logo sign. For a project with logo signs, the contact information for the Indiana Logo Sign Group shall be included in the project list of utilities. For Indiana Logo Sign

Group information, the Office of Traffic Administration should be contacted. For typical logo sign placement, see Figure 502-1AA.

### 502-1.04(05) Supplemental Guide Sign and TODS Sign

Figure 502-1AA provides the Department's guidelines for placement of supplemental guide signs.

Supplemental guide sign eligibility requirements for traffic generators, i.e., cities, attractions, other major traffic generators, appear in the supplemental guide sign policy, on the Indiana Department of Tourism website, at http://www.in.gov/tourism/marketing/attraction_signs.html. Also, see AASHTO *Guidelines for Selection of Supplemental Guide Signs for Traffic Generators Adjacent to Freeways*.

For tourist-oriented destination sign (TODS) requirements, see the TODS policy, on the Indiana Department of Tourism website, also at http://www.in.gov/tourism/marketing/attraction_signs.html.

For a project with TODS signs, the contact information for the Indiana Business Logo Company shall be included in the project list of utilities.

### 502-1.04(06) Rest Area, Weigh Station, and Destination Signage

Rest area and weigh station signage shall be in accordance with the *IMUTCD*. For D1 and D2 series signs, the D1-1a, D1-2a, and D1-3a series signs shall not be used. The maximum length of D1 and D2 signs shall be 10 ft, with a maximum height of 3 ft. For details of D1 and D2 signs wider than 7 ft, see the INDOT *Standard Drawings*.

### 502-1.04(07) Street Name Sign

A street name sign is helpful to the motorist and should be legible for a sufficient distance in advance of the cross street to permit the motorist to perceive and react in time to make the desired maneuver in a safe manner. To provide adequate sign visibility, sign letter heights for an overhead street name sign placed on a multi lane highway with a posted speed limit of 50 mph or greater should be 12" upper case and 9" lower case. Letter heights for signs placed on other roadways should be 8" upper case and 6" lower case.

Signs that are 11 ft or wider when designed with the recommended letter height may be reduced in width by adjusting the character spacing or by using a smaller letter height.

If a new overhead street name sign is to be mounted on an existing cantilever structure the new sign should be designed not to exceed the area of the existing unless a structural analysis shows the additional loading can be adequately supported.

Where ground mounted street name signs are provided in advance of the intersection on multi lane highways with posted speed limits of 50 mph or greater; the letter size for overhead street name signs, if used, may be 8” upper case and 6” lower case.

Each overhead street name sign shall be in a combination of upper case and lower case letters.

Each ground-mounted street name sign shall be in a combination of upper case and lower case letters, with dimensions in accordance with *IMUTCD* requirements for upper case and lower case letters. INDOT normally does not install ground mounted street name signs at the intersection. Per the *IMUTCD*, this is the responsibility of the local agency
Each street name sign shall be designed to a 6-in. length and height increment.

**502-1.04(08) Reference Markers, D10-1 thru D10-5 Series**

Reference markers and enhanced reference markers shall be installed on all interstate routes.

The Office of Traffic Design, shall be contacted to obtain appropriate sample reference marker shop drawings.

On a state or US route, route reference posts (RRP) shall be provided. Bridge reference posts (BRP) shall also be provided on each route to indicate the bridge location.

The designer shall contact the Office of Traffic Design, to obtain RRP and BRP shop drawings guidelines. The designer shall contact the appropriate district technical services division to determine the road or bridge reference post number.

Where traffic management systems are deployed, ramp reference signs shall be installed on all interchange ramps. The designer shall coordinate with the Traffic Management Division for sign message information.

Figure 502-1BB provides a listing of the reference marker and enhanced reference marker locations. The designer shall confirm the reference marker locations with the Traffic Management Division.

**502-1.04(09) Railroad Grade Crossing Signing**

Placement of railroad grade crossing signs should be in accordance with *IMUTCD* Section 8B.04.

## 502-1.05 Sign Plan Notes and Legend Items

Figures 502-1CC and 502-1DD show the typical plan notes and legend items to be utilized on signing plans.

# 502-2.0 PAVEMENT MARKINGS

## 502-2.01 General

### 502-2.01(01) Functions and Limitations

The *IMUTCD* will serve as the basis for pavement marking design and installation on each INDOT-maintained highway.

This Section is intended to supplement, not repeat, the information and figures provided in the *IMUTCD*. Information that is provided herein will apply as follows.

1. Define the policy for use of specific pavement markings and clarify INDOT's requirements if pavement marking alternatives are shown in the *IMUTCD*.

2. Provide additional conditions where an *IMUTCD* option is a standard pavement marking practice.

3. Offer design criteria for the application of specific pavement markings.

The information provided herein addresses minimum pavement marking requirements. Engineering judgment should be used to determine if these requirements should be exceeded to improve safety at a location or within a corridor.

Each local public agency (LPA) or private owner should work toward accordance with the policies and guidance provided herein to provide for the uniform usage of traffic control measures throughout the state.

### 502-2.01(02) Standardization of Application

The application of pavement markings has been standardized to the maximum extent possible. Figure 502-2A provides intersection pavement markings.

Figure 502-2B provides the standard pavement markings lines and applications.

The plans shall identify existing pavement markings within the limits of the project. The plans shall identify which markings will remain in place through construction and become part of the final pavement markings.

All existing pavement markings that are not part of the final pavement markings shall be identified to be removed on the plans or the temporary traffic control plans, if markings can result in motorist confusion during the phasing of traffic through a multi-phased construction project.

### 502-2.01(03) Pavement Marking Retro-reflectivity [New Dec. 2021]

The Department has implemented performance-based quality control measures for pavement markings. As a result, retro-reflectivity testing should normally be included as a pay item, except for contracts with small quantities of pavement markings (i.e. less than 50,000 lft of longitudinal paint lines or less than 10,000 lft of thermoplastic, multicomponent, or preformed plastic longitudinal markings). See Section 808.07 of the INDOT *Standard Specifications* for additional information.

### 502-2.01(04) Materials and Application [Rev. Sept. 2015, Dec. 2021]

An overview of the pavement marking material application is provided in Figure 502-2C. See the INDOT *Standard Specifications* for materials properties and application requirements during construction. The following provides additional guidance regarding the materials.

1. Paint. Paint-applied markings are less expensive than other materials. They are used where the additional cost of durable pavement markings cannot be justified. A short project length, by itself, does not prevent the use of durable markings materials. A disadvantage of paint is that it can be quickly worn away on a high-traffic-volume roadway. Therefore it often needs to be reapplied more than once a year.

   Paint should be used for longitudinal lines as follows:

   a. Where the AADT is less than 3,000 vehicles; or
   b. Where the remaining surface life of the pavement is less than four years, or where the pavement is scheduled for resurfacing within eight years; or
   c. For marking non-mountable islands and raised curbs; or
   d. On pavement surface treatments with a warranty. (e.g., Micro-surface, UBWC, etc.).

2. Durable Marking Materials. Durable marking materials provide enhanced retro-reflectivity and a longer service life. The INDOT *Standard Specifications* require that longitudinal lines be grooved when durable materials are used. There is an exception to the grooving requirement for longitudinal lines on bridge decks and RCBAs, where the line delineates a radius, and where there is in sufficient space adjacent a curb for the grooving equipment. At least one foot is needed from the face of curb for grooving equipment. Where the exception applies, longitudinal lines should be surface-applied. The contractor will provide a warranty for both surface-applied and grooved durable markings which covers presence, retro-reflectivity, and color. This practice serves to protect the additional investment in durable markings. INDOT uses the following types of durable markings.

   a. Thermoplastic. Hydrocarbon and alkyd thermoplastic markings may be used on asphalt pavement under the following conditions.

      i. Longitudinal Lines. These may be used for the center line, edge lines, or lane lines at a location that is not proposed or scheduled for resurfacing within the next four years and where the AADT is at least 3,000 vehicles.

         The use of thermoplastic should not be specified with longitudinal rumble stripes unless directed by the district traffic engineer.

      ii. Transverse Markings. These may be used for transverse markings as shown in Figure 502-2C.

      iii. Painting Cycles. These may be used on a road that requires two or more applications of paint lines per year.

      iv. Decision Point. These may be used where there is a need for more-positive lane identification because of alignment, transitions, or channelization.

   b. Multi-Component. Multi-component markings may be used for the center line, lane lines, or edge lines. They are not typically used for transverse markings or for marking a non-mountable island or raised curb because of problems that can develop with the intermittent application and dry time. Multi-component markings are typically used on concrete or polymeric concrete pavements. They can also be used on asphalt pavements. In general, they can be used under the following conditions:

i. Longitudinal Lines. These may be used for the center line, edge line, or lane lines at a location that is not proposed or scheduled for resurfacing within the next four years.

ii. Transverse Markings. Except for transverse crosshatch markings in gore areas or channelized turn lanes, multi-component material should not be used for transverse markings.

iii. Painting Cycles. These may be used on a road that requires two or more applications of paint lines per year.

iv. Decision Point. These may be used where there is a need for more-positive lane identification because of alignment, transitions, or channelization.

c. Preformed Plastic. The criteria for multi-component markings are also applicable for permanent applications of preformed plastic markings. Temporary preformed plastic markings are used in a construction zone. Temporary preformed plastic markings should not be used for permanent applications.

Preformed plastic markings are more durable, and have retained retro-reflectivity, increased detection distance, and wet retro-reflectivity characteristics. However, these markings are more expensive due to material and installation costs. A typical application is for lane lines on a divided highway where the life-cycle cost has been shown to be favorable.

d. Polyurea. The use of polyurea as a substitute for thermoplastic or multicomponent markings should be considered when the completion date for a project will be between November 15 and March 15. Polyurea has a minimum application temperature of 35°F compared to 50°F for thermoplastic and 40°F for multicomponent markings. Polyurea is more expensive and requires a special provision to be included in the contract documents.

3. Wet Reflective Markings and Raised Pavement Markers. Pavement marking materials may be supplemented with elements that provide retro-reflectivity during wet weather conditions. Research has identified a safety benefit to the use of wet reflective markings on freeways and multilane highways. As a result, for preformed plastic markings, the wet reflective version should normally be specified. At this time, wet reflective preformed plastic markings must have a proprietary material justification as there is only one suitable product. See Section 17-1.05 for more information on the use of proprietary materials. The wet reflective version of other thermoplastic or multicomponent markings may be

specified with approval from the district Traffic Engineer.

See Sections 502-2.02(12) through 502-2.02(15) for information about the use of raised pavement markers.

The Pavement Marking Material Summary, available for download from the Department's Editable Documents page, must be completed for each contract. Variations from the design guidance in this subsection or Figure 502-2C must be approved by the Traffic Engineering Division.

**502-2.01(05) Contrast Markings [New Dec. 2021]**

When PCCP is used for the pavement design, black markings should be used in combination with the white or yellow markings at freeway system interchanges or freeway segments with 8 or more continuous lanes to provide sufficient contrast with the PCCP. Figure 502-2D shows the arrangement of the contrast markings for edge lines and lane lines.

**502-2.01(06) Coordination with Other *IMUTCD* Chapters [Rev. Dec. 2021]**

The information provided herein does not address pavement marking applications for low-volume road, temporary traffic control, school area, highway-rail grade crossing, or bicycle facilities, etc. These shall be considered in accordance with the appropriate *IMUTCD* chapters, and with the use of other traffic control devices.

**502-2.01(07) References [Rev. Dec. 2021]**

For additional information on pavement markings, see ITE, *Traffic Control Devices Handbook*, or *Traffic Engineering Handbook*.

**502-2.01(08) Official Action [Rev. Dec. 2021]**

Where a new or revised pavement marking alters the regulation of an existing condition, an Official Action is required. For a state-maintained highway, the designer must coordinate and obtain an approval for the proposed change from the appropriate district technical services division before implementation of the proposed change. For example, adding a new no- passing zone or revising the length of an existing no-passing zone will require an Official Action. See Section 502-1.02(01) for information about Official Actions for signs and Section 502-3.01(01) for information about Official Actions for signals. For a locally maintained facility, approval must be obtained from the appropriate jurisdiction before implementation

## 502-2.02 Pavement and Curb Markings

### 502-2.02(01) Yellow Center Line Pavement Markings and Warrants [Rev. Dec. 2021]

Figure 502-2E provides for the standardized location of a double-yellow center line with respect to the centerline of the roadway pavement. The center line marking is placed 3 in. on either side of the longitudinal joint to minimize the need for re-applying the marking after a joint-sealing operation.

At a signalized intersection, a center line of 50 ft length should be provided on a minor facility if it has no markings.

For a non-INDOT highway, a center line is recommended at each of the locations as follows:

1. Roadway Width. In a rural area, a center line should be provided on a 2-lane roadway which has a surface width of 16 ft or more with a speed limit higher than 30 mph.

2. Undivided Highway. A center line should be provided if the highway has four or more lanes.

3. Urban Area. In a residential or business district, a center line should be provided on each through highway or on other highways where the AADT is at least 3000.

4. Low-Volume Road. On a paved low-volume road, a center line should be provided where the AADT is at least 300.

5. Horizontal Curve. If not provided elsewhere, a center line marking should be provided on a horizontal curve with a radius of 2300 ft or less. The marking should begin about 1000 ft in advance of the PC, continue through the curve and end about 1000 ft beyond the PT.

6. Bridge. If not provided elsewhere, a center line marking should be provided at a narrow bridge where the approaching roadway's width is 18 ft or greater, including paved shoulders, or where the bridge width is less than the approaching roadway's width. The marking should begin about 1000 ft in advance of the restricted bridge, continue across the bridge and end about 1000 ft beyond the bridge.

7. Field Conditions. A center line marking should be provided as necessary to satisfy field conditions or where engineering studies indicate a need.

### 502-2.02(02) No-Passing-Zone Pavement Markings and Warrants [Rev. Dec.2021]

1. Horizontal or Vertical Curve. Where a center line is installed, no-passing zones will be established at each vertical or horizontal curve or elsewhere on a 2- or 3-lane highway where an engineering study indicates that passing must be prohibited due to inadequate sight distance or other conditions. Figure 502-2F provides the minimum distance that should be used for determining a no-passing-zone marking location. This value provides sufficient distance for the passing vehicle to abort the passing maneuver. This value should not be confused with the minimum passing sight distance provided in Section 42-3.0, which is used for geometric design purposes and assumes that the passing vehicle will be able to complete the passing maneuver.

2. Roadway Obstacle. Passing should not be allowed prior to or around an obstacle which is located next to or within the roadway, e.g., bridge pier. The location of the no-passing zone in the immediate vicinity of such an obstruction will be reviewed and determined by the district traffic engineer for an INDOT highway, or the local authority for a non-INDOT facility.

3. Bridge. The following no-passing zone determinations will apply at a bridge.

    a. For a bridge width that is narrower than the full approach-roadway width or for a 1-lane bridge, passing will not be allowed on the bridge. Figure 502-2F provides minimum criteria for implementing the no-passing zone in advance of the bridge.

    b. For a bridge width which matches the full approach-roadway width or for a narrow bridge where the full approach-lane widths are carried across the bridge, the need for no-passing markings will be determined based on the criteria in item 1.

4. Intersection or Railroad Crossing. Passing is not allowed prior to or through a major intersection or railroad crossing. Figure 502-2F provides the minimum length for implementing the no-passing criteria in advance of a major intersection or railroad crossing.

5. Gap. *IMUTCD* Table 3B-1 provides the minimum distances for passing between successive no-passing zones. If this distance cannot be attained, the no-passing zones should be connected. If the distance from the end of a preceding zone and the no-passing zone for an intersection is less than the minimum allowable gap shown in the *IMUTCD*, the no-passing line should be continued to the intersection.

6. Traffic Volume. A no-passing zone may be established where the opposing traffic volume is such that it is impractical or unsafe to allow passing maneuvers, e.g., urban area. This

determination will be determined for each project.

7. Boundaries. A review of the no-passing zones should be conducted for a sufficient distance prior to and beyond the marking area to ensure that the area will be properly marked, e.g., eliminating less-than-minimum gaps.

**502-2.02(03) No-Passing-Zone Record [Rev. Dec. 2021]**

A no-passing-zone record is required for Official Action purposes on an INDOT roadway and is recommended for a non-INDOT roadway. This also assists in the remarking of each no-passing-zone due to worn out markings or after resurfacing. Existing no passing zone information may be seen from aerial images. Updating the record for a project, if applicable, involves recording the location of the beginning and ending points of each no-passing- zone line on the plans and may require field measurements. In updating the no-passing-zone record to reflect changes from a project or for a new road or new alignment, the following applies for an INDOT highway.

1. Beginning and Ending Points. The record should begin and end at the project limits for each state route in the project. For an even-numbered route, the record should begin at the west project limit. The record should proceed easterly and terminate at the east project limit. For an odd-numbered route, the record should begin at the south project limit. The record should proceed northerly and terminate at the north project limit.

2. Field Measurements. If the pavement marking plans cannot be used to update the no-passing-zone record and field measurements are needed, the beginning reading is at zero and measurements will be made in feet. The measuring device should be calibrated to measure within 10 ft per mile. For a survey route of longer than 10 mi, the record should be stopped at an intersection and reset to zero to eliminate accumulated errors resulting from distance measuring. All the elements described below should be referenced in feet from the beginning of the record.

3. Elements to be Recorded. The recorder should identify the following in the updated no-passing-zone record.

    a. The center line of each intersecting city street, county road, or state highway should be measured, and its length recorded. The name or number of the street or road should also be recorded.

b. The recorder should locate and identify each permanent-type landmark, including railroad crossing, narrow or one-lane bridge, obstruction, or city or town limit, as identified by a sign designating such limit.

c. Each bridge not included above should be identified in the record under the Special Reference notation. This will allow the name of a stream or river to be identified in the record.

d. All reference markers from the roadway reference system should be shown.

4. Submitting the Record. The recorder must submit the updated no passing zone record for a project to the district Traffic Engineer prior to Stage 2 plan review.

A record for a non-INDOT facility can be prepared similarly to that for an INDOT highway

**502-2.02(04) Other Yellow Longitudinal Pavement Markings [Rev. Dec. 2021]**

Figures 502-2G and 502-2H show yellow lines for two-way left turn markings and two way lane-turn lane transition markings.

Median lines are required on each divided highway of 4 lanes or more. Gaps are to be provided at each at-grade intersection or median crossover. The following provides the median line applications based on the median-curb type.

1. No Curbs. A 6 in. wide, solid, yellow, median line should be provided at the left edge of the travelway.

2. Curb Offsets. For a facility with curbs and curb offsets, a 6 in. wide, solid, yellow, median line should be provided at the left edge of the travel lane. The median marking should be placed a minimum of 4 in. on either side of the longitudinal joint between the roadway and the curb and gutter.

3. No Curb Offsets. For a facility with curbs but no curb offsets, the curb itself may be painted yellow, or a 6 in. wide, solid, yellow line may be applied to the pavement adjacent to the curb.

**502-2.02(05) White Lane Line Pavement Markings and Warrants**

See *IMUTCD* Section 3B-04.

### 502-2.02(06) Other White Longitudinal Pavement Markings

Figure 502-2B shows the line patterns for white longitudinal markings. See INDOT *Standard Drawings* series E808-DLIM for additional details of dotted line markings at interchanges and intersections.

A normal-width dotted line is the same width as the line it extends, i.e. 6 in. A wide dotted line is 10 in.

For dotted lines, the patterns are as follows.

1. Dotted Lines as Lane Lines. A line segment of 3 ft, followed by a gap of 9 ft is used as follows:

   a. a normal-width line for a deceleration or acceleration lane;
   b. a normal-width line for a through lane that becomes a mandatory exit or turn lane;
   c. a normal-width line for an auxiliary lane between an entrance ramp and an exit ramp with length of 2 mi or less;
   d. a normal-width line for an auxiliary lane between two intersections that is 1 mile or less in length;
   e. a wide line in advance of lane drops at exit ramps to distinguish a lane drop from a normal exit ramp;
   f. a wide line in advance of freeway route splits with dedicated lanes;
   g. a wide line to separate a through lane that continues beyond an interchange from an adjacent auxiliary lane at a cloverleaf interchange;
   h. a wide line in advance of lane drops at intersections to distinguish a lane drop from a through lane;
   i. a wide line to separate a through lane that continues beyond an intersection from an adjacent auxiliary lane between two intersections.

2. Dotted Lines at an Intersection. A line segment of 2 ft, followed by a gap of 2 to 6 ft is used to extend longitudinal markings through an intersection. Dotted lines may be used based on intersection geometrics or reduced visibility conditions that make it desirable to guide vehicles through an intersection.

See Figure 502-2 I and *IMUTCD* Section 3B.05 for exit gore markings.

### 502-2.02(07) Edge Line Pavement Markings [Rev. Dec. 2021]

Edge lines are to be used on each INDOT-maintained highway. The right-hand edge line is a 4-in.-width, solid white, reflectorized line. The following provides guidelines for edge-lines placement.

Edge lines should be placed approximately 4 in. from a longitudinal construction joint to eliminate the need for repainting after joint-sealing operations. See Figure 502-2E for the locations of edge and center lines.

1. Intersection or Driveway. A gap must be provided at each public-road intersection but not provided at a driveway.

2. Interchange. See *IMUTCD* Section 3B-04.

3. Paved Shoulder or Curb Offset. For a roadway with curbs and no curb offsets, the curb itself may be painted with white paint, or a 6 in. wide, solid white line may be applied to the pavement adjacent to the curb.

4. Unpaved Shoulders. For a roadway with unpaved shoulders, the edge line should be placed 12 in. from the edge of the pavement if the resultant lane width is at least 10 ft and not more than 12 ft, or if the width of the pavement is at least 11 ft and the road section has at least 2 ft of stabilized shoulder, or 4 ft of usable earth shoulder. See Figure 502-2E for locations of edge lines.

   If the above criteria result in a lane width greater than 12 ft, the center line and edge line locations should be changed, so that only a 12-ft lane is provided.

5. Uniformity. An edge line should be located to provide a constant lane width, as practical, throughout the roadway section. The widest lane practical, up to 12 ft, should be provided.

6. Bridge. Edge lines should be continued straight across a structure if the lane widths across the bridge are as wide as or wider than the lane widths approaching the bridge. Where the lane width on the structure is less than the approaching lane width, the edge line alignment should be tapered to meet the narrower roadway width across the bridge.

### 502-2.02(08) Warrants for Use of Edge Lines

For edge-line warrants for a local project see *IMUTCD* Section 3B.07. INDOT provides edge lines on all state highways as described in Section 502-2.02(07) above.

### 502-2.02(09) Extension through Intersection or Interchange

See *IMUTCD* Section 3B.08.

### 502-2.02(10) Lane Reduction Transition Markings

Figure 502-2J provides the minimum taper rate and taper length that should be used for lane reduction. The INDOT *Standard Drawings* provide additional information on the placement of traffic-control devices, including edge lines across a bridge structure. Figures 502-2L, 502-2M, and 502-2N illustrate the typical pavement marking patterns used for transitioning from 4 to 2 lanes.

### 502-2.02(11) Approach Markings for Obstruction

See *IMUTCD* Section 3B.10.

### 502-2.02(12) Raised Pavement Markers (RPMs) [Rev. Dec. 2021]

Snowplowable RPMs provide a supplemental method of delineation and are positive guidance devices. They should not be used as a replacement for pavement markings or roadside delineation. The INDOT *Standard Drawings* provide details on the placement and color locations for RPMs. The following should be considered.

1. Location. Site selection should be based on the need for additional alignment delineation in an area of frequently inclement weather, e.g., fog, smoke, rain, or in an area of low roadway illumination. Placement of RPMs should be considered where vehicles are leaving the roadway, in an area showing excessive wear of existing pavement markings, or in an area with skid marks, interchange ramp, etc. RPMs that supplement the centerline pavement markings should be used for urban highways, rural multi-lane highways, and rural two lane highways when the factors described in paragraphs 4 and 5 below are present.

   RPM's that supplement lane lines should be used for multi-lane highways when the factors described in paragraphs 4 and 5 below are present.

2. Pavement Life. RPMs should not be placed at a location that is scheduled for resurfacing or reconstruction within the next four years.

3. Illumination. RPMs may be omitted at a location that is illuminated with approval from the district Traffic Engineer

4. Traffic Volume. RPMs should be used where AADT exceeds 3000 for a 2-lane roadway, or 6000 for a 4-lane roadway. On a lower-volume road, an engineering investigation should be conducted to determine whether RPMs are appropriate to supplement the other traffic-control devices.

5. Spacing. The spacing on a tangent section is 120 ft; the spacing used in conjunction with a no-passing zone may be reduced to 40 ft. Six RPMs spaced at 40 ft may be used in advance of and following a delineated no-passing zone. Two locations or zones of RPMs should be connected where the distance between them is less than 3000 ft. See the INDOT *Standard Drawings* for additional details for spacing at other locations.

6. Special Locations. RPMs should not be used exclusively with edge lines or gore markings. RPM's may be used at a pavement transition, 1-way or narrow bridge, channelization area, or where there is justification for installation of the devices.

7. Color. The retroreflection color of RPMs is the same as the color of the marking that it supplements, substitutes, or serves as a positioning guide. Two colors are used in each RPM on a divided highway for 200 ft in advance of an intersection, with white visible in the direction of travel and red visible to traffic proceeding in the wrong direction. A blue RPM may be used to help emergency personnel locate a fire hydrant. If used, the locations of RPMs with blue retroreflectors should be shown on the plans.

**502-2.02(13) Raised Pavement Markers as Vehicle Positioning Guides with Other Longitudinal Markings**

See *IMUTCD* Section 3B.11.

**502-2.02(14) Raised Pavement Markers Supplementing Other Markings**

See *IMUTCD* Section 3B.13.

**502-2.02(15) Raised Pavement Markers Substituting for Pavement Markings**

RPMs shall not be used as a substitute for other pavement markings on an INDOT-maintained highway. RPMs shall be used only to supplement other pavement markings.

### 502-2.02(16) Transverse Markings [Rev. Dec. 2021]

Pavement-marking letters, numerals, and symbols shall be in accordance with the dimensions and configurations shown in the INDOT *Standard Drawings.* See Section 502-2.10 for information on the use of transverse rumble strip markings.

### 502-2.02(17) Stop and Yield Lines [Rev. Dec. 2021]

For a state facility, the stop line is a 24 in. wide, solid white line. The stop line should extend across each approach lane. It should be placed 4 ft in advance of the nearest crosswalk line and should be perpendicular to the center line. The stop line should be parallel with the crosswalk lines. In the absence of a marked crosswalk, the stop line should be placed at the desired stopping point and perpendicular to the line of travel. The stop line should not be placed more than 30 ft or less than 4 ft from the nearest edge of the crossing travel lane or point of potential conflict, e.g., crosswalk, turn lane, turning vehicle path.

For yield lines, see *IMUTCD* Section 3B.16 and *the INDOT Standard Drawing* series E 808-MKPM. Yield lines are formed from a series of triangles placed across the pavement. The length of a yield line is measured transversely across the lane(s), and the width is measured longitudinally. The normal width of a yield line is 27 in.

If it is not possible to place a stop line at a location within the parameters provided above, the intersection should be redesigned so that these criteria can be satisfied.

The location of the stop line may be adjusted to fit field conditions. For example, where turning trucks are known to encroach into the opposing lane, the stop line should be placed beyond the point of potential conflict. Therefore, it can be appropriate to stagger the stop line on some lanes. This can occur at a signalized intersection where clearance times can be substantial.

### 502-2.02(18) Do-Not-Block-Intersection Markings

See *IMUTCD* Section 3B.17.

### 502-2.02(19) Crosswalk Markings

Crosswalk lines are solid white, reflectorized lines of not less than 6 in. in width. They are used to mark both edges of the crosswalk. The distance between lines is determined by the width of the sidewalks to be connected. However, they should not be spaced less than 6 ft apart. The crosswalk must encompass all curb ramps. For information on curb ramps and the crosswalk width, see Chapter 51. The *IMUTCD* provides additional information on other crosswalk types.

Two parallel transverse lines as shown on the top approach of *IMUTCD* Figure 3B-19, are used to designate crosswalks. However, parallel longitudinal lines, as shown on the bottom approach in *IMUTCD* Figure 3B-19 may be used to enhance the conspicuity of the crossing. The following factors may be considered in determining whether parallel longitudinal lines should be used:

1. crosswalk location is unexpected by motorists (i.e. midblock crossing);
2. vehicular turning movements;
3. pedestrian volumes;
4. channelization is desirable to clarify pedestrian routes for sighted or sight impaired pedestrians;
5. discouragement of pedestrian jaywalking; and
6. consistency with markings at adjacent intersections or within the same intersection.

A crosswalk delineated as two parallel lines with diagonal cross hatching as shown on the right approach of *IMUTCD* Figure 3B-19, are not allowed on an INDOT maintained roadway.

A crosswalk delineated as shown in *IMUTCD* Figure 3B-20 may be used only at a signalized intersection in an urbanized area where an all-red pedestrian interval is included as part of the traffic signal timing, provided that the all-red pedestrian interval provides sufficient time for pedestrians to complete the diagonal movement.

**502-2.02(20) Parking-Space Markings**

On-street parking markings placement will be determined based on local requirements.

Parking spaces shall be delineated only if the design and layout of parking stalls has been included in the project. See Section 45-1.04.

**502-2.02(21) Pavement Word and Symbol Markings [Rev. Dec. 2021]**

Figure 502-2 O provides information on the layout of pavement word and symbol markings near an at-grade intersection. The use of additional word and symbol markings within each lane requires approval of the district traffic engineer. Conditions that can warrant additional word and symbol markings include sight distance restrictions or obstruction of the primary markings by queued vehicles. The “ONLY” word marking is not used except where a through lane becomes a mandatory turn lane.

Route shields may be considered at freeway interchanges with unusual geometry, a history of driver navigation issues, or at major route splits. When used, the routes shields should be supplemented with the appropriate cardinal direction word message, “NORTH”, EAST”, “SOUTH”, or “WEST” that are placed 40 ft after the route shields. Route shields and the cardinal direction word messages should normally be located approximately 1,600 ft in advance of the ½ mile advance guide signs for the interchange. At this time, route shields must have a proprietary material justification as there is only one suitable product. See Section 17-1.05 for more information on the use of proprietary materials.

**502-2.02(22) Speed Measurement Markings**

See *IMUTCD* Section 3B-21.

**502-2.02(23) Speed Reduction Markings**

See *IMUTCD* Section 3B.22.

**502-2.02(24) Curb Markings**

1. <u>Curb Marking as Edge Line</u>. For a roadway with curbs where the curb is offset from the edge of pavement, the longitudinal edge line shall be placed as required. Painting the curb is not an acceptable substitution for providing an edge line. Painting the curb is permitted in addition to placing the edge line if additional visual clarity is deemed necessary at a location under consideration.

   For a roadway with curbs and no curb offsets, the curb itself may be painted white, or the edge line may be applied to the pavement adjacent to the curb.

2. <u>Curb Marking as Center Line</u>. For a roadway with curb offsets, the center line shall be placed as required. Painting the curb is not an acceptable substitution for providing the center line. Painting the curb is permitted in addition to placing the center line if additional visual clarity is deemed necessary at a location under consideration.

   For a roadway with curbs and no curb offsets, the curb itself may be painted yellow, or the center line may be applied to the pavement adjacent to the curb.

3. <u>Curb Marking at Raised Median</u>. Yellow paint should be placed on the approach end of a raised median, or a curb of an island that is located in the line of traffic flow where the curb

serves to channel traffic to the right of the obstruction. Yellow raised pavement markers may also be used to supplement the yellow paint on the approach ends for delineation and visibility purposes.

**502-2.02(25) Chevron and Diagonal Crosshatch Markings**

See *IMUTCD* Section 3B.24.

**502-2.02(26) Speed-Hump Markings**

See *IMUTCD* Section 3B.25.

**502-2.02(27) Advance Speed-Hump Markings**

See *IMUTCD* Section 3B.26.

## 502-2.03 Markings for Roundabout Intersection [Rev. Dec. 2021]

See Section 51-12.10(02) for pavement marking design at roundabouts and *IMUTCD* Chapter 3C.

## 502-2.04 Markings for Preferential Lane

See *IMUTCD* Chapter 3D.

## 502-2.05 Markings for Toll-Road Plaza

See *IMUTCD* Chapter 3E.

## 502-2.06 Delineators

See *IMUTCD* Chapter 3F.

**502-2.06(01) General**

Delineators are lightweight retro-reflecting devices mounted along the roadside, which are used to guide the motorist where the alignment can be confusing or at a pavement-width transition. Delineators are classified into the following categories:

1. Delineators. Delineators are identified based on the number of reflecting devices on the post. A type D2 delineator consists of two yellow or white delineators on a post. The delineator itself can consist of either a reflective element of 3-in. diameter or a rectangle unit that substitutes for two circular units.

2. Flexible Delineator Posts. Flexible delineator posts are identified based on the type of installation. A Type I flexible delineator post is offset from the shoulder and mounted in the ground while a Type II flexible delineator post is mounted to the roadway surface. There are two attachment methods for Type II flexible delineator posts, the first method uses a base with an adhesive or bolt to secure the flexible delineator to the pavement. The second method uses an anchor cup that is embedded in the pavement. When surface mounted flexible delineator posts will be used on a project, designers should consider specifying the first method for applications on bridge decks or raised medians, and the second method for applications that will be more exposed to repeated vehicle impacts.

3. Barrier Delineators. Barrier delineators are attached to concrete barrier wall and may be side mounted or top mounted. The use of barrier type delineators on guardrail may be considered on a case-by-case basis.

4. Lane Separators. Lane separators are a combination of modular curb and flexible delineator posts or tubular markers and are used to divide vehicular traffic. Lane separators are a channelization device and may be considered on a case-by-case basis for locations where there is a substantial need for vehicle channelization such as at turn lanes with significant queuing or railroad crossings to help eliminate gate drive-arounds. Use of lane separators should be confirmed with the district Traffic Engineer. When specifying lane separators, RSP 804-T-204 should be included in the contract documents.

**502-2.06(02) Delineator Details**

See *IMUTCD* Section 3F.02.

**502-2.06(03) Delineator Application [Rev. Dec. 2021]**

See Figure 502-2K for Delineator Application, Placement, and Spacing summary.

1. Color. The delineator color should match the color of the edge line. If the edge line is white, the delineator will be white. For the median side of a divided highway, the delineator, if used, must be yellow. A red delineator may be used on the reverse side of a delineator post to alert a motorist who is traveling the wrong way on a one-way roadway, e.g., ramp. A blue delineator may be used to indicate the location of a fire hydrant.

2. Freeway or Expressway. Single delineators should be provided on the outside-shoulder side of a freeway or expressway and on at least one side of each interchange ramp. Yellow single delineators may also be provided on the left side of the ramp.

3. Interchange. Single delineators should be provided along the outside of each curve on an interchange ramp. Double or vertically-elongated delineators should be installed at 100-ft intervals along each acceleration or deceleration lane. Delineators may also be included in a gore area to enhance the visibility of the diverging or merging ramp with the main roadway.

4. Temporary Roadway. Delineators may be used along a temporary roadway, such as a median crossover or temporary runaround, as a supplement to the channelizing devices *IMUTCD* Table 3F-1 provides the maximum spacing for delineators around a horizontal curve on temporary roadways. See the INDOT *Standard Drawings* for details.

5. Transition. Delineators should be used to guide the motorist through a lane-narrowing transition or lane merge. Figures 502-2L, 502-2M, 502-2N, and 502-2P, and the *INDOT Standard Drawings* provide illustrations on where to place delineators within these transition areas. Where continuous delineation is provided on one or both sides of the highway, the delineation should be continued through the transition area. A closer spacing can be warranted.

6. Lighting. Where lighting is provided, the need to use delineators on tangent sections in the area will be determined as required for each project.

7. Guardrail. Barrier delineators are required on each run of median barrier, temporary concrete barrier, concrete railing, or metal beam guardrail.

8. Island. Delineators may be used to outline a raised island. A yellow reflectorized panel should be used where the island channelizes traffic to the right. Where traffic can pass on either side of the island, a white reflectorized panel should be used. A continuous median island is not delineated unless deemed necessary.

9. No-Passing Zone. The end of the no-passing zone is indicated on the right side of the roadway with three horizontally aligned, white delineators.

10. Raised Pavement Markers. Delineators are not required on the tangent sections of a freeway or expressway where raised pavement markers are used continuously on all curves and on all tangents to supplement pavement markings.

### 502-2.06(04) Delineator Placement and Spacing [Rev. Dec. 2021]

The INDOT *Standard Drawings* provide criteria for the placement of delineators. They also illustrate the placement of delineators next to a roadway approaching a narrow bridge. See Figure 502-2K for Delineator Application, Placement, and Spacing summary. In addition to the criteria shown on the INDOT *Standard Drawings*, the following should be considered.

1. Height. The top of the delineator should be placed so that the bottom of the retroreflective component is approximately 4 ft above the surface of the nearest travel lane.

2. Placement. Delineators should be placed at a constant distance from the roadway edge unless guardrail or another obstruction intrudes into the space between the pavement edge and the extension of the line of delineators. Delineators should not be placed less than 2 ft or more than 8 ft from the outside edge of the shoulder.

3. Spacing. For a tangent section on interstates or other divided facilities, delineators should be spaced 400 ft apart. When used on conventional roadways, delineators on tangent sections should be spaced 500 ft apart. Where uniform spacing is interrupted by a driveway, crossroad, etc., the delineator should be moved to either side provided the distance does not exceed one-quarter of the normal spacing. If this criterion is exceeded, the delineator should be deleted.

   For a horizontal curve, the delineator spacing should be adjusted so that several delineators will always be visible to the driver. For maximum spacing for delineators around a horizontal curve, see *IMUTCD* Table 3F. 1.

### 502-2.06(05) Truck-Climbing or Passing Lane [Rev. Dec. 2021]

Section 44-2.0 provides criteria for truck-climbing or passing lane warrants and design. Figure 502-2P illustrates the pavement markings that should be used with a truck-climbing or passing lane.

## 502-2.07 Colored Pavements

See *IMUTCD* Chapter 3G.

## 502-2.08 Islands

### 502-2.08(01) General

Where used, an island shall be sized so that there is a 2-ft gap between the lane line of the adjacent lane and the edge of the raised island.

The configuration for a raised triangular or elongated island is provided on Figures 502-2Q and 502-2R.

### 502-2.08(02) Island Object Markers

Island object markers shall be type 2 or type 3. The inside edge of the marker should be in line with the inner edge of the island.

### 502-2.08(03) Island Delineators

Delineators may be used to outline a raised island. A yellow reflectorized panel should be used where the island channelizes traffic to the right. Where traffic can pass on either side of the island, a white reflectorized panel should be used. A continuous median island is not delineated unless deemed necessary.

## 502-2.09 Milled Longitudinal Pavement Corrugations [Rev. Feb. 2019]

Milled longitudinal pavement corrugations, also known as longitudinal rumble strips in the *IMUTCD*, provide an audible and vibratory warning to a motorist leaving the travel lane. They are an effective means of reducing lane departures and may be specified in conjunction with a pavement resurface/reconstruction project or as a stand-alone project.

The use of pavement corrugations should be coordinated with the appropriate district Traffic Engineer.

### 502-2.09 (01) Pavement Corrugation Type [Add. Feb. 2019]

The Department utilizes two milled corrugation patterns, conventional and sinusoidal. The sinusoidal corrugation pattern has been shown to reduce the amount of noise generated from vehicles travelling over the corrugation.

The pavement corrugation type – shoulder corrugation, shoulder rumble strip, and edge line or centerline rumble stripe – is based the corrugation pattern and the presence or absence of a longitudinal pavement marking within the corrugation. A general description of each type is below. See Section 502-2.09(02) for selection criteria.

1. <u>Shoulder Corrugation</u>. A shoulder corrugation is a milled conventional corrugation pattern used without a pavement marking and placed in the shoulder near the travel lane. Shoulder corrugations are used on rural two-lane and multi-lane undivided facilities with PCC shoulder pavement and on freeways and divided highways regardless of pavement type. The minimum paved shoulder width to utilize shoulder corrugations is 4 ft.

   See INDOT *Standard Drawings* series E606-SHCG for conventional shoulder corrugations and corrugation limits (gaps).

2. <u>Shoulder Rumble Strip</u>. A shoulder rumble strip is a milled sinusoidal corrugation pattern used without a longitudinal pavement marking and placed in the shoulder near the travel lane. Shoulder rumble strips are used on rural two-lane and multi-lane undivided facilities with HMA shoulder pavement. The minimum paved shoulder width to utilize shoulder rumble strips is 4 ft.

   See the INDOT *Standard Drawings* series E606-SHCG for the sinusoidal corrugation pattern and breaks in corrugation limits (gaps).

3. <u>Edge line and Centerline Rumble Stripe</u>. A rumble stripe is a milled sinusoidal corrugation pattern with a longitudinal pavement marking installed within the corrugation. The use of a conventional corrugation pattern for a rumble stripe may be considered where noise is not a concern and is at the discretion of the district Traffic Engineer.

   Rumble stripes are used on rural two-lane facilities with HMA pavement and placed at either the edge of the travel lane or the centerline. The milled sinusoidal corrugation should be quantified separately from the associated pavement marking.

   See the INDOT *Standard Drawings* series E606-SHCG, for the sinusoidal corrugation pattern and breaks in corrugation limits (gaps).

**502-2.09 (02) Pavement Corrugation Type Selection [Rev. Feb. 2019, Dec. 2021]**

The designer should consider the roadway type and design criteria to determine whether to specify shoulder corrugations, shoulder rumble strips, rumble stripes, or combination thereof. Criteria that preclude the use of pavement corrugations are listed in item 3 below.

For the purposes of this determination, "rural" is a function of roadway characteristics and prevailing land use, not necessarily a location outside an urban area boundary.

See Figure 502-2S, Pavement Corrugation Type Selection Summary, for an overview of the selection criteria.

When the pavement design selected is PCCP, only shoulder corrugations may be specified.

1. <u>Selection by roadway type</u>.
   a. Rural Two-lane Facility
      1) Segment with posted speed limits ≥ 50 mph. Shoulder rumble strips or edge line or centerline rumble stripes should be specified based on lane and HMA paved shoulder width. Shoulder corrugations should be specified for based on lane and PCCP paved shoulder width.
      2) Segment with posted speed limits < 50 mph. Edge line rumble stripes, shoulder rumble strips, and shoulder corrugations generally should not be used, although special circumstances may justify their use, e.g., the presence of significant history of run-off-road crashes. Centerline rumble stripes are not applicable.

   b. Rural Multi-lane Undivided Facility
      1) Segment with posted speed limits ≥ 50 mph. Shoulder rumble strips and shoulder corrugations should be specified based on paved shoulder width and pavement type. Edge line and centerline rumble stripes are not applicable.
      2) Segment with posted speed limits < 50 mph. Shoulder rumble strips and shoulder corrugations may be specified if special circumstances justify their use, e.g., the presence of significant history of run-off-road. Edge line and centerline rumble stripes are not applicable.

   c. Rural Freeway, Interstate, or Divided Highway. Shoulder corrugations must be specified for rural freeways, interstates, and divided highways. Rumble strips, edge line and centerline rumble stripes are not applicable.

2. <u>Design criteria for selecting corrugation type and combination of types</u>. Where the combination of centerline and edge line rumble stripes or centerline rumble stripes and shoulder rumble strips is not viable, the use of only centerline rumble stripes should be specified. Where centerline rumble stripes alone are not viable, edge line rumble stripes alone or shoulder rumble strips alone should be specified.

   a. Centerline and edge line rumble stripes in combination. The combination of centerline and edge line rumble stripes may be considered when the following criteria are met:
      1) the posted speed limit is 50 mph or above; and
      2) the design lane width is at least 11 ft; and
      3) the design paved shoulder width is at least 2 ft but less than 4 ft.
   b. Centerline rumble stripes and shoulder rumble strips in combination. The combination of centerline rumble stripes and should rumble strips may be considered when the following criteria are met:
      1) the posted speed limit is 50 mph or above; and
      2) the design lane width is at least 11 ft; and
      3) the design paved shoulder width is at least 4 ft.

   c. Centerline rumble stripes only. Centerline rumble stripes alone may be considered when the following criteria are met:
      1) the posted speed limit is 50 mph or above; and
      2) the design lane width is at least 10 ft but less than 11 ft.

   d. Edge line rumble stripes only. Edge line rumble stripes alone may be considered when the following criteria are met:
      1) the posted speed limit is 50 mph or above; and
      2) the design paved shoulder width is at least 2 ft but less than 4 ft.

   e. Shoulder rumble strips only. Shoulder rumble strips alone may be considered when the following criteria are met:
      1) the posted speed limit is 50 mph or above; and
      2) the design paved shoulder width is at least 4 ft.

3. <u>Design criteria that preclude the use of pavement corrugations</u>. Pavement corrugations should not be specified for new or reconstructed pavement or retrofitted on an existing pavement where the roadway segment has one or more of the following:

   a. Horse-drawn vehicles are known to regularly use the shoulder and shoulder width is less than 10 ft;

b. Pavement has a chip seal (seal coat) surface that is less than a year old;

c. Pavement has a surface treatment with an active warranty, e.g., Microsurface or ultrathin bonded wearing course (UBWC) are less than 3 years old.

d. Pavement is in poor condition as determined by the Division of Pavement Design or the district Pavement Engineer; or

e. Resurfacing is expected within the next 3 years; or

f. PCC pavement (precludes use of rumble strips and rumble stripes only).

Consultants should contact their project manager to obtain information regarding pavement warranties or district resurfacing project schedules.

**502-2.09 (03) Corrugation Limits [Rev. Feb. 2019, Dec. 2021]**

1. <u>Bicycle Gaps</u>. To accommodate bicyclists, 12-ft longitudinal gaps are provided every 60 ft in edge line rumble stripes and shoulder rumble strips.

2. <u>Intersection and Turn Lane Gaps</u>. Centerline rumble stripes and inside shoulder corrugations on divided roadways should be gapped where turn lanes are developed at intersections or where two-way left turn lanes are present.

3. <u>Raised Pavement Markers (RPMs)</u>. Rumble stripes generally should be used in combination with centerline or edge line RPMs, but rather used instead of RPMs. In special circumstances, RPMs may be omitted from segments with rumble stripes with approval from the Traffic Engineering Division.

**502-2.09 (04) Plan Details and Quantities [Rev. Feb. 2019]**

Shoulder corrugations, rumble strips, and rumble stripes should be shown on the Typical Section and Pavement Marking Details plan sheets. Shoulder corrugations and rumble strips are paid for a milled [pavement type] corrugations, conventional or sinusoidal, respectively. For rumble stripes, the milled corrugation and longitudinal pavement marking are paid for separately. In the case of a retrofit project, removal of existing lines is paid for separately.

**502-2.10 Transverse Rumble Strips [Add. Feb. 2019]**

Transverse rumble strips are used to alert drivers to an unexpected traffic condition that is approaching. Transverse rumble strips typically consist of sets of raised pavement markings with the spacing as shown in Figure 502-2T. The profile is the same as temporary buzz strips and thermoplastic is normally used. See INDOT *Standard Drawings* series 801-TCDV.

The use of more than two rumble strip sets is for situations where additional warning may be appropriate. The decision sight distance (DSD) may be used for the spacing of the rumble strip sets at particularly complex locations where the driver reaction time may exceed 2.5 seconds. Use of transverse rumble strips must be approved by the district Traffic Engineer.

Noise can be an issue with transverse rumble strips. Alternative safety improvements should be considered if the location is close to a residential area.

**502-2.11 Pavement Markings for Traffic Contracts [Add. Dec. 2021]**

Traffic contracts often consist of several intersections or other spot locations that are not in the same county or general area. Therefore, it may be impractical for a contractor to install the recommended pavement marking materials at an individual location even if the total quantity on the contract is significant. As a result, paint may be used for the longitudinal markings at an individual location in a traffic contract if the quantity is less than 500 ft and grooving may be omitted at an individual location in a traffic contract if the quantity is less than 1,000 ft.

## 502-3.0 TRAFFIC SIGNALS

### 502-3.01 General

The design of a traffic signal is one of the most dynamic fields of traffic engineering. Although this chapter addresses traffic signal design issues, it is impractical to provide a complete traffic signal design guide. For more design information, the references cited herein should be reviewed. The intent of this chapter is to provide the user with an overview of traffic signal design issues and to provide INDOT's applicable positions, policies, and procedures and guidance for local agencies.

#### 502-3.01(01) Official Action

Where a new traffic signal is to be installed or an existing traffic signal is to be removed, an Official Action is required. For a state highway, the designer must obtain an approval for the proposed change from the Deputy Commissioner of Highway Management. The request for an Official

Action should be sent to the appropriate district traffic engineer before implementation of the proposed change. If the district traffic engineer concurs with the request to install or remove a traffic signal, an Official Action will be drafted and sent to the District Deputy Commissioner for approval of the new traffic signal or existing traffic signal removal. For a locally controlled facility, approval must be obtained from the appropriate jurisdiction before starting design. An Official Action can also be required where other regulations are revised in association with a traffic signal, e.g., “No Turn On Red” sign.

**502-3.01(02) Plans Development**

Chapter 14 provides the criteria for developing a set of plans which are applicable to a traffic-signal project. Chapter 14 also includes information on scales, CADD requirements, plans sheet requirements, quantities, specifications, etc.

**502-3.01(03) Request for a New Signal**

A request for a new signal can be generated by an INDOT district office, another INDOT division, local officials, a developer, or a local citizen. Each request for a new traffic-signal installation should first be forwarded to the appropriate district traffic engineer. If the district traffic engineer determines that the request merits further investigation, he or she will then begin coordinating the collection of the necessary traffic data.

For an in-house request, the district traffic engineer, possibly in conjunction with others, will conduct the appropriate traffic studies to obtain accurate and current traffic data and projections. For another type of request, the current traffic data, projections, and warrant study should be forwarded with the request. The data collector will need to refer to the *IMUTCD*, which provides the warrants for traffic signals, to determine the appropriate information required.

If it is determined that a traffic signal is warranted, the designer will prepare the design for the proposed traffic signal. The district traffic engineer will be responsible for determining the traffic signal timings. A local agency or consultant can be responsible for determining the traffic signal timings.

**502-3.01(04) Responsibilities**

INDOT will fund the design and installation of a traffic signal only where a state-maintained highway intersects another road, or where a freeway exit or entrance ramp intersects with a local facility. For a state highway intersecting a private drive or road, or a public road where large traffic volume is generated from a private source, the private entity will be responsible for funding the design, installation, and energy costs of the new signal.

Each traffic signal on a state highway is maintained by INDOT or through a contract with others. A local municipality, through a formal contract, will rarely assume responsibility for the maintenance of a traffic signal on a state-maintained route.

## 502-3.02 Preliminary Signal Design Activities

The district traffic office is responsible for making the determination for the need for a new or existing traffic signal. This determination is based on traffic volume, accident history, schools, pedestrians, local needs, driver needs, construction costs and maintenance costs. The following sections provide guidelines, policies, procedures, and factors used by INDOT to make these determinations. These are also applicable to a local agency project.

### 502-3.02(01) Signal Warrant

Each new traffic-signal proposal should satisfy at least one or more of the primary warrants listed in *IMUTCD* Chapter 4C. The *IMUTCD* provides the criteria and procedures that should be used to determine if the warrant is satisfied.

### 502-3.02(02) Additional Considerations for Traffic-Signal Installation

Though the traffic volume can be high enough to satisfy one or more of the warrants, the installation of a traffic signal may not always be the most prudent choice. In addition to the *IMUTCD* warrants, the information in *IMUTCD* Section 4B should be considered.

## 502-3.03 Traffic-Signal Equipment and Operations

All traffic-signal equipment should satisfy the criteria set forth in the *IMUTCD, NEMA Traffic Control Systems,* INDOT *Standard Drawings* and INDOT *Standard Specifications.* For an INDOT location, the equipment choice should be made at the preliminary field inspection with the approval of the designer and the district traffic engineer.

### 502-3.03(01) Traffic-Signal Controller

A traffic-signal controller is a micro-processor based, menu-driven, fully-actuated device, including internal coordinator and preemption, mounted in a cabinet for controlling the sequence and phase duration of the traffic signal. Right of way is assigned by turning the green indication on or off. A controller can have pre-timed, semi-actuated, and fully-actuated modes of operation. Sections 502-3.04(08) through 502-3.04(10) describe the phasing and timing aspects of controllers. INDOT uses fully-actuated operation for a new traffic signal.

As established by the National Electrical Manufacturers Association (NEMA), a controller has standard functions and input/output formats, and uses microprocessing to provide those functions. NEMA controllers are interchangeable between manufacturers, except where used in a coordinated system. If changes or upgrades to the controller are desired, the controller unit hardware is replaced. A traffic signal controller operates one intersection. However, it can be more efficient for one controller to operate multiple intersections such as a tight diamond interchange or closely spaced offset intersections.

INDOT uses the NEMA criteria for all of its traffic signal controllers. At a minimum, each INDOT-maintained traffic controller must satisfy the INDOT *Standard Specifications* and NEMA TS-2 criteria. Each controller is subject to accordance with the Department's *Traffic Signal Control Bench Test Procedures*. A list of all approved controller equipment is provided in the Department's *Approved Materials List of Traffic Signal and ITS Control Equipment.*

1. <u>Pre-timed Mode of Operation</u>. In the pre-timed mode, a controller can be programmed to provide different timing plans based on the time of day or day of week.

   The pre-timed mode should be used where traffic volume and patterns are consistent from day-to-day, e.g., downtown area, where variations in volumes are predictable, and where control timing can be preset to accommodate variations throughout the day.

   An advantage of the pre-timed mode is the cost savings realized by not installing traffic detection equipment around the intersection. The disadvantages of the pre-timed mode are the lack of flexibility in timings, the inefficiency of traffic movements where vehicle arrivals are largely random, and the inability to automatically count traffic volume.

   The pre-timed mode should not be used where the posted speed limit on one or more approaches is greater than or equal to 40 mph.

2. <u>Semi-Actuated Mode of Operation</u>. The semi-actuated mode requires detection on one or more, but not all, approaches. Vehicular detectors or pedestrian detectors are installed only on the minor approaches, for left turns on the major approaches, and where traffic is light and sporadic. The through movements on the major approaches are kept in the green phase until a vehicle on a minor approach, or a major approach left turn, is detected. If there is a demand on a detected approach or movement, and the minimum green time for the major approach has elapsed, the right of way will then be assigned to the detected approach or movement. Controller timing is set to provide enough time to clear two vehicles. Additional time is added for each new detection up to the predetermined limit for the maximum green time. Once the detected approach demand has been satisfied, or the

maximum green time has been reached, the right of way returns to the major approaches and the cycle begins again.

An advantage of the semi-actuated mode is the reduced cost of installation because detection is not needed on some approaches and operation is more efficient.
The semi-actuated mode should not be used where the posted speed limit of an approach is equal to or greater than 40 mph due to the lack of indecision zone protection.

Section 502-3.04(10) further discusses the indecision zone requirements.

3. Fully-Actuated Mode of Operation. The fully-actuated mode requires detection devices for all approaches or movements at the intersection. The green interval for each street or phase is determined on the basis of volume demand. Continuous traffic on one street is not interrupted by an actuation demand from the side street until a gap in the traffic appears or once the preset maximum green time has elapsed. Once the minor approaches' or movements' demand has been satisfied, right of way is returned to the major approaches.

The fully-actuated mode is the appropriate design choice as follows:

a. where the posted speed limit on an approach is 40 mph or greater;
b. at an isolated location where the traffic volume on all approaches is sporadic;
c. at a location where a traffic signal is warranted for only short periods of the day; or
d. at a location where turning movements occur often only during specific time periods and do not occur during the remainder of the time.

The advantages of the fully-actuated mode are as follows.

a. It can efficiently control high traffic volume.
b. It is efficient at an isolated intersection.
c. It can handle varying traffic demands such as a complex intersection where one or more movements are sporadic or subject to wide variations in traffic volume.
d. It can count traffic volume for all detected movements.

The disadvantage of the fully-actuated mode is the additional costs of installing and maintaining detection equipment on all of the approaches.

### 502-3.03(02) Pedestrian Control [Rev. Jan. 2016]

The pedestrian feature works in conjunction with the signal controller. This feature allows for the timing of the "Walk" and "Don't Walk" cycles and can be actuated by pedestrian pushbutton assemblies. *IMUTCD* Chapter 4E describes pedestrian control features. See Section 502-3.04(05) for information on the use of pedestrian signals and accessible pedestrian signals.

Advantages of the pedestrian feature include the following.

1. It provides additional time for crossing pedestrians.
2. Where there is minimal pedestrian demand, disruption to the vehicular phases can be minimized.

Disadvantages of the pedestrian feature are as follows.

1. Where pushbutton assemblies are required, they must be located in a convenient, accessible location.
2. Pedestrian cycles concurrent with green time can delay right-turning vehicles.
3. It can increase the required minimum green time on the minor street if the major street is wider than the minor street.

### 502-3.03(03) Preemption

Preemption is the modification of a signal's normal operation to accommodate an occurrence such as the approach of an emergency vehicle, the passage of a train through a nearby grade crossing, priority passage of transit vehicles, or the opening of a moveable bridge. With a microprocessor-based controller, all preemption routines are performed by the controller software. The only necessary external equipment is the preemption call detection device.

Preemption sequences should be shown in the plans or in the special provisions. For information on preemption equipment, the designer should contact the manufacturer. The following describes situations where preemption is used.

1. <u>Railroad Crossing Preemption</u>. The purpose of the preemption is to clear vehicles from the railroad crossing before the arrival of a train. Where a signalized intersection is within 200 ft of a railroad grade crossing with active warning devices, preemption is required. Where this distance is between 200 ft and 600 ft, a queue analysis should be performed to determine if a highway traffic queue has the potential for extending across a nearby rail crossing. If the analysis indicates that this potential exists, the traffic signal should be interconnected with active warning devices at the railroad crossing. The Federal *MUTCD,* the Indiana *MUTCD,*

and the *FHWA Railroad-Highway Grade Crossing Handbook* describe preemption strategies and define the requirements for grade-crossing preemption.

Railroad crossing preemption requires interconnection between the traffic signal controller and the grade-crossing signal equipment. The preemption routine at the traffic signal controller is initiated by the approach of a train, as detected by the railroad's controller, and starts with a transition from the current phase into the Track Clear Green interval (TCG). The TCG interval is used to clear vehicles which can be stopped between the railroad crossing stop line and the intersection. Subsequent signal displays include only those that are not in conflict with the occupied grade crossing. Once the railroad preemption call is cleared, after the train has passed, the traffic signal is returned to normal operations. On a state route, this type of preemption requires an agreement between the State and the Railroad.
Railroad crossing preemption shall be designed using either simultaneous or advance preemption sufficient to provide for Right-of-Way Transfer Time (RTT) to transition into the TCG interval. The TCG interval shall be sufficient to clear the last vehicle in the queue past the Minimum Track Clear Distance (MTCD), avoid vehicle-gate interaction, and provide separation time as required. Traffic control signals with railroad preemption should be provided with a backup power supply.

Best- and worst-case scenarios shall be considered with regard to the signal phase state and all known preemption traps, such as the advance, second train, failed circuit, and vehicular-yellow preemption traps. Pre-signals, queue-cutter signals, and not-to-exceed timers should be considered as options where an engineering study determines that the queue extends into the track area.

Other options to consider for railroad preemption are blank-out signs for protected or permitted left turns, optically programmable heads for pre-signals, and pavement markings and signage to prevent vehicles from stopping on the tracks if inadequate storage distance exists for the design vehicle.

2. <u>Fire Station or Fire Route Preemption</u>. The most common preemption method is the activation of the preemption sequence at a fixed point, e.g., a pushbutton located within the fire station. On a state route, this type of preemption requires an agreement between the State and the appropriate local public agency.

The simplest form of fire station preemption is the installation of a traffic signal, at the fire station driveway intersection with a major through street. The signal remains in the through-street green display until called by an actuation in the fire station. The signal then provides a timed green indication to the driveway to allow emergency vehicles to enter the major street.

Where the fire station is near a signalized intersection, a preemption sequence can be designed to display a movement permitting the passage of emergency equipment through the intersection.

Where emergency vehicles frequently follow the same route through more than one nearby signal, a fire route preemption operation should be provided. Actuation of the fire station pushbutton will be transmitted to all of the signals along the route and, after a variable timed delay, each signal will provide a preempt movement display. This will provide a one-way green wave away from the fire station, allowing the optimal movement of emergency equipment.

3. Emergency Vehicle Preemption. The preemption equipment causes the signals to advance to a preempt movement display. On a state route, this type of preemption requires an agreement between the State and the appropriate local governmental agency.

   The system used on a state route for identifying the presence of the approaching emergency vehicle uses a light emitter on the emergency vehicle and a photocell receiver for each approach to the intersection. The emitter outputs an intense strobe light flash sequence, coded to distinguish the flash from lightning or other light sources. The electronics package in the receiver identifies the coded flash and generates an output that causes the controller unit to advance through to the desired preempt sequence.

   This system requires a specialized transmitting device on each vehicle for which preemption is desired, and it requires that an emergency vehicle driver activate the transmitters during the run and turns off the transmitter after arriving at the scene. This system also provides directionality of approach and a confirmation light at the signal that notifies the approaching emergency vehicle that the preemption call has been received by the equipment in the traffic controller cabinet.

4. Transit Vehicle Priority. Most transit priority systems are designed to extend an existing green indication for an approaching bus and do not cause the immediate termination of conflicting phases, as occurs for emergency vehicle preemption. On a state route, this type of preemption requires an agreement between the State and the appropriate local public agency.

   One system is a light emitter and receiver system, using the coded, flash-strobe light emitter. An infrared filter is placed over the emitter, so that the flash is invisible to the human eye, and a flash code is used to distinguish the transit preemption call from that for an emergency vehicle. The intersection receiver can be configured to provide both emergency vehicle preemption and transit priority with the same equipment. Another system uses the same type of radio transmitter and receiver equipment as used for emergency vehicle preemption.

Two other types of transit vehicle detectors have been used and are available. One, a passive detector, can identify the electrical signature of a bus traveling over an inductive loop detector. The other, an active detector, requires a vehicle-mounted transponder that replies to a roadside polling detector.

**502-3.03(04) Controller Cabinet**

A controller cabinet is an enclosure designed to house the controller unit and its associated equipment, providing for its security and environmental protection. Each controller cabinet must satisfy the INDOT *Standard Specifications*. Section 502-3.04(04) provides roadside-safety considerations for the placement of the cabinet. Foundation requirements for each cabinet type are shown on the INDOT *Standard Drawings.* The following cabinet types are used by the Department.

1. P-1 Cabinet. The P-1 cabinet is a ground-mounted cabinet. This cabinet is the preferred Department cabinet.

2. R-1 Cabinet. The R-1 cabinet is a taller version of the P-1 cabinet. It is used only where equipment needs dictate the additional space.

3. M Cabinet. The M cabinet is a ground-mounted cabinet. This cabinet should be used where space limitations or sight restrictions are a factor at the intersection.

4. M Stretch Cabinet. The M stretch cabinet is a ground-mounted cabinet installed on a type M foundation. This cabinet should be used where space limitations or sight restrictions are a factor at the intersection and where equipment needs dictate additional space.

5. G Cabinet. The G cabinet is a pedestal-mounted or pole-mounted cabinet. The Department no longer uses this cabinet due to its limited size. However, this cabinet type may be used, if practical, for matching or upgrading existing local signals.

**502-3.03(05) Detector [Rev. Jan. 2016, Nov. 2016, Oct. 2020]**

1. Operation. The purpose of a detector is to determine the presence or the passage of a vehicle, bicyclist, or pedestrian. This presence or passage detection is sent back to the controller

which adjusts the signal accordingly. There are many types of detectors available that can detect the presence or passage of a vehicle. INDOT uses only inductive loop detectors in its signal design. The inductive loop detector is preferred because it can be used for passage or presence detection, vehicular counts, and speed determinations. It is accurate and easy to maintain. Although the inductive loop detector is the system of choice, this does not prevent recommendation of the use of new devices in the future. If, in the designer's opinion, a different detector should be considered, its use must first be coordinated with the district traffic engineer and the Traffic Control Systems Division to determine the acceptability of the recommended device and to determine maintenance requirements or equipment needs.
The detection device can operate in the modes as follows.

a. Passage, or Pulse, Detection. A passage detector detects the passage of a vehicle moving through the detection zone and ignores the presence of a vehicle stopped within the detection zone. The detector produces a short output pulse once the vehicle enters the detection zone. The loop is a single loop with a diameter of 6 ft, or a regular octagon shape with sides of 2.5-ft length at a spot location upstream of the stop line.

b. Presence Detection. A presence detector is capable of detecting the presence of a standing or moving vehicle in the detection zone. A signal output is generated for as long as the detected vehicle is within the detection zone, subject to the eventual tuning out of the call by some types of detectors. The long loop design for a long detection area is considered to be a presence detector.

c. Locking Mode. The controller memory holds the call once a vehicle arrives during the red or yellow display after the vehicle leaves the detection zone, until the call has been satisfied by a green display.

d. Non-Locking Mode. For a non-locking operation, the call is held only while the detector is occupied. The call is voided once the vehicle leaves the detection area. The non-locking mode is used with a presence detector.

e. Delayed Detection. Delayed detection requires a vehicle to be located in the detection area for a certain set time before detection is recorded. If a vehicle leaves the area before the time limit is reached, no detection is registered. This application is appropriate where a right-turn-on-red is allowed.

f. Extended-Call or Stretch Detection. With extended-call detection, the detection is held by the detector after a vehicle has left the detection area. This operation is performed to hold the call until the passing vehicle has had time to reach a predetermined point beyond the detection zone. With a solid-state controller, the extended-call detection is handled by the controller software.

Where the controller is part of a coordinated signal system design, extended or delayed detection should be used to ensure that the local controller will not adversely affect the timing of the system.

2. Inductive Loop Detector. An inductive loop detector consists of four or more turns of wire embedded in the pavement surface. As a vehicle passes over the loop, it changes the inductance of the wire. This change is recorded by an amplifier and is transmitted to the controller as a vehicular detection. NEMA criteria define the requirements for detector units and the *Approved Products List of Traffic Signal and ITS Control Equipment* identifies the detector units approved for use.

The advantages of a loop detector are as follows:

a. it can detect vehicles in both presence and passage modes;
b. it can be used for vehicular counts and speed determination; and
c. it can be designed to satisfy the various site conditions.

A disadvantage of the loop detector is that it is vulnerable to pavement surface problems, e.g., potholes, which can cause breaks in the loops. To alleviate this problem, a sequence of loops should be used.

The types of loop detectors are the long loop, which is rectangular at 6 ft x 20 ft to 65 ft and the short loop, that can be of regular octagon or circular shape. INDOT uses the short loop. The long loop, as a single entity, is being supplanted by a sequence of short loops which emulate the long loop. The INDOT *Standard Drawings* illustrate typical loop layout and installation details. The layout shown in the INDOT *Standard Drawings* is for illustrative purposes only. Each intersection should be designed individually to satisfy local site conditions.

A sequence of loops is used at an intersection for presence detection of vehicles stopped at the traffic signal. A set of loops before the intersection is used to determine the passage of vehicles. The distance from the stop line to these loops is based on the posted speed limit. Section 502-3.04(10) provides additional information on detector locations. Section 502-3.04(11) provides information on loops set up to count traffic.

A preformed loop is a detector loop constructed of the designated number of turns of wire contained inside a protective jacket. It is paved over with concrete or asphalt pavement. A preformed loop may be installed in a 1-, 2-, 3-, or 4-loop configuration. Wires from preformed loops are spliced to the 2-conductor lead-in cable in a handhole or detector housing. The *Approved Products List of Traffic Signal and ITS Control Equipment* identifies the preformed loops approved for use.

3. Other Detector Types. INDOT uses the inductive-loop detector. However, the following other detector types are also available.

   a. Magnetic Detector. A magnetic detector consists of a small coil of wires located inside a protective housing embedded into the roadway surface. As vehicles pass over the device, the detector registers the change in the magnetic field surrounding the device. This signal is recorded by an amplifier and relayed back to the controller as a vehicular detection. A problem with this detector is that it can detect only the passage of a vehicle traveling at a speed of 3 mph or higher. It cannot be used to determine a stopped vehicle's presence. The advantages are ease of installation and resistance to pavement-surfacing problems.

   b. Magnetometer Detector. A magnetometer detector consists of a magnetic metal core with wrapped windings, similar to a transformer. This core is sealed in a cylinder with a diameter of 1 in. and length of 4 in. The detector is placed in a drilled vertical hole about 1 ft into the pavement. A magnetometer detector senses the variation between the magnetic fields caused by the passage or presence of a vehicle. The signal is recorded by an amplifier and is relayed to the controller as a passage or presence vehicle. A magnetometer detector is sufficiently sensitive to detect a bicyclist or to be used as a counting device. A problem with the magnetometer detector is that it does not provide a sharp cutoff at the perimeter of the detection vehicle, i.e., it can detect vehicles in adjacent lanes.

   c. Wireless Vehicle Detector. A wireless vehicle detector is similar to a magnetometer detector except that it uses a low-power radio to transmit the signal to a wireless repeater or receiver processor. The signal is recorded by an amplifier and is relayed to the controller as a passage or presence vehicle. The detector is placed in a drilled vertical hole of 0.2 ft depth into the pavement. The wireless repeater and receiver processor should be mounted to the signal structures. The ethernet cable for the receiver processor may be placed across the span wire on a span and strain pole installation. A wireless vehicle detector is sufficiently sensitive to detect a bicyclist or to be used as a counting device. A disadvantage is that it must be replaced at least every 10 years and the wireless repeater's batteries must be replaced every 2 years. See Figures 502-3A and 502-3B for installation details.

d. Microloop Detector. A microloop detector is similar to a magnetometer detector. The microloop is installed by drilling a hole of 3 in. diameter to a depth of 1'-6" into the pavement structure, by securing it to the underside of a bridge deck, or inserting a conduit of 3 in. diameter under the pavement to accommodate a non-invasive microloop system. A disadvantage is that it requires motion to activate the triggering circuitry of the detector and it does not detect a stopped vehicle. This type of detector requires two detectors placed side-by-side per lane due to its limited field of detection.

e. Video-Image Detector. The video-image detector consists of one to six video cameras, an automatic control unit, and a supervisor computer. The computer detects a vehicle by comparing the images from the cameras to those stored in memory. The detector can work in both the presence and passage modes. This detector also allows the images to be used for counting and vehicular classification. A housing is required to protect the camera from environmental elements. Problems have been experienced with video detection during adverse weather conditions, e.g., fog, rain, or snow. INDOT allows video detection only for a temporary signal.

4. Pedestrian Detector. The most common pedestrian detector is the pedestrian pushbutton assembly. Where pedestrian signals are provided at pedestrian street crossings, they must include pedestrian pushbutton assemblies complying with INDOT *Standard Drawing* series 805-PBBA, Section 51-1.06 and Section 502-3.04(05).

An accessible pedestrian signal (APS) is an integrated device that communicates information about the "Walk" and "Don't Walk" intervals at signalized intersections in visual and non-visual formats, i.e., audible tones and vibrotactile surfaces, to pedestrians who are blind or have low vision. These features are in addition to the traditional pedestrian signal head and pedestrian pushbutton.

The Department refers to traditional pedestrian pushbuttons as non-APS and these must have an actuator with a minimum diameter of 2 in., although they do not have the audible and vibrotactile features of APS.

See Section 502-3.04(05) for information on the use of a pedestrian signals, APS, and Non-APS.

5. Bicycle Detector. The following methods are used for bicycle detection.

   a. PushButton Detector. With the pushbutton detector, the bicyclist must stop and push the detector button for the controller to record the detection. This can require the bicyclist to leave the roadway and proceed on the sidewalk to reach the detector.

   b. Inductive-Loop Detector. The inductive-loop detector can detect the bicycle without the bicyclist's interaction. For the detector to be most sensitive, the bicycle should be ridden directly over the wire. A problem with a bicycle inductive-loop detector is that it requires metal to be activated. A bicycle tends to include more non-magnetic, man-made materials to increase its strength and reduce its weight. This has reduced the metal content that can be detected.

6. Decision-Making Criteria for Consideration of Other Types of Detection. A detection system other than inductive loops requires plans details. See Figures 502-3A and 502-3B for typical plans details. To use a type of detection other than inductive loops, the designer must provide and submit documentation that one or more of the following conditions have been satisfied.

   a. An inductive loop design will not function because of a physical limitation, e.g., right of way, geometrics, pavement conditions, or obstructed conduit paths.
   b. A full inductive loop design has been considered and there is a post-design lifecycle cost advantage to using a detection system other than loops. No design time cost or labor savings will be considered in lifecycle cost calculations.
   c. A hybrid design using loops at the stop line and wireless magnetometers for advance vehicle detection has been considered and evaluated where a wireless magnetometer has been evaluated for advance vehicle detection only, and the hybrid design is the most cost effective for post-design lifecycle cost.

   Written concurrence is required from the Office of Traffic Control Systems or the district traffic engineer, or the local agency for a local project, before another type of detection may be used at a specific location.

### 502-3.03(06) Traffic Signal-Head Components

The traffic-signal head consists of the signal head, signal face, optical unit, visors, etc. The criteria set forth in *IMUTCD* Part 4, the INDOT *Standard Specifications*, and ITE's *Equipment and Material Standards of the Institute of Transportation Engineers* should be followed in determining appropriate signal display arrangements and equipment. The following additional guidance is provided for the selection of the signal display equipment.

1. Signal-Head Housing. The signal head housing is made from polycarbonate plastic. For new traffic signal installations on the state highway system, the signal-head housing should have a black color. For traffic signal modernization projects on the state highway system, the existing yellow signal heads may be reused if approved by the district traffic engineer.

2. Signal Faces and Flashing Yellow Arrow Indications. Section 502-3.04(01) provides the face arrangement for use on a state highway. The signal lenses should be placed in a vertical line rather than horizontally except where an overhead obstruction can limit visibility. Where protected left turns are followed by permissive left turns, the four-section signal head with a flashing yellow arrow indication should be used. *IMUTCD* Part 4 provides additional information on the arrangement of signal heads.

   Considerations when specifying a flashing yellow arrow (FYA) signal indication include:

   a. Offset. Lateral position signal heads that include FYA for PPLT will be offset 4 ft right from the extension of left side of the left turn lane.

   b. Number of Sections and Alignment. The signal head display should be a four-section signal face that is aligned vertically. Vertically aligned heads should be top justified, that is the red or top indication should be at the same elevation and towards the upper span cable.

      Where signal head height limitations exist so that it not feasible to use a vertical four-section signal head, consideration may be given to mounting the head horizontally.

   c. Wiring. A 7C-14 signal cable is needed from each four-section head to the disconnect hanger, and a 9C-14 cable should be specified from the disconnect hanger to the controller.

   d. Supplemental Sign. To supplement traffic signal control, a "Left Turn Yield On Flashing Yellow Arrow" sign should be provided adjacent to the left-turn signal face when a FYA is used.

   e. Modernizations and Additional Heads for Through Movements. When converting a PPLT to a four-section FYA head, additional heads for the through movement may be needed to satisfy *IMUTCD* requirements for the number of through heads as follows:

      1) one for each through lane for approaches with multiple through lanes.

2) two heads for approaches with a single through lane.

3. Lens Size. Only lenses having diameter of 12 in. should be used.

4. Signal Illumination. Light-emitting diodes should be used for all signal heads.

5. Visors. A visor should be used with each signal face. These visors are used to direct the signal indication to the appropriate approaching traffic and to reduce sun phantom. A tunnel visor provides a complete circle around the lens. A cutaway visor is a partial visor, with the bottom cut away. A partial visor reduces water and snow accumulation, and does not let birds build nests within the visor. The decision on which visor type should be used is determined on a site-by-site basis. For a department installation, partial visors should be used. Visors are made of the same material as the housing.

6. Louvers. Louvers can be used to direct the signal indication to a specific lane. Louvers are used where signal heads can cause confusion for an approaching motorist. One example of this problem is where an intersection has its approaches at an acute angle and the signal indications can be seen from both approaches. The decision on whether to use louvers depends on site conditions and will be determined on a project-by-project basis.

7. Optically-Programmable Signals. Like louvers, optically programmable signals are designed to direct the signal indication to specific approach lanes and for specific distances. An advantage is that they can be narrowly aligned so that motorists from other approaches cannot see the indications. Applications include closely-spaced intersections and intersections where the approaches are at an acute angle. Optically-programmable signals should be mounted to keep the signal indication properly aligned. The cost is higher than louvers but the improved visibility can offset the cost. The decision on whether to use an optically-programmable signal depends on site conditions and will be determined on a project-by-project basis.
The lanes and limits of where optically-programmed heads are to be visible to motorists should be shown on the plans. This may be done by means of shading or other technique.

8. Backplate. A signal indication loses some of its contrast value if viewed against a bright sky or other intensive background lighting, e.g., advertising lighting. A backplate placed around a signal assembly enhances the signal's visibility and has been shown to provide a benefit in reducing crashes. However, a backplate also adds weight to the signal head and can increase the effect of wind loading on the signal. Normally backplates should be used on all signal heads unless directed otherwise by the district traffic engineer. A backplate is required by the INDOT *Standard Specifications* on all overhead 3-section signal heads for

through lanes. Backplates to be installed with heads other than 3-section through movement should be identified on the plans.

Backplates for heads installed on existing cantilever structures should be specified to have louvers (slotted openings) to reduce wind load. Louvers should comprise no more than 40% of the backplate area.

The INDOT *Standard Specifications* require backplates to include a 2-in. yellow retroreflective strip around the perimeter of the backplate to enhance the conspicuity of the signal head at night. For non-INDOT projects where the reflectorized surface is not desired, the plans or special provisions should so indicate.

Backplates may be retrofitted onto existing traffic signal heads when the existing LEDs have some service life remaining and should be reused but backplates are needed. Currently LED indicators have a service life of about 6 years. The INDOT *Standard Specifications* require a retrofit to include a new signal housing along with the backplate. Retrofits should be indicated on the plans and are paid for under the Traffic Signal Head Retrofit pay item.

9. <u>Pedestrian-Signal Head</u>. A pedestrian-signal head controls the movement of pedestrians across designated approaches of a signalized intersection. Pedestrian signal heads with lenses of 18 in. x 18 in., are used with international symbols and pedestrian clearance interval countdown displays.

**502-3.03(07) Signal-Support Structure**

Traffic-signal heads are installed using span, catenary, and tether cables on four steel strain poles, or with cantilever structures on all four corners. Pedestal or pole-mounted supplemental signals may be used if necessary. Pedestrian-signal heads are mounted on pedestals or poles.

*IMUTCD* Section 4E.08 provides guidance on the location of pedestrian pushbuttons.
A post-mounted signal has the following advantages:

1. low installation costs;
2. ease of maintenance, with no roadway interference;
3. considered most aesthetically acceptable;
4. acceptable locations for pedestrian signals and pushbuttons; and
5. provides visibility where a wide median with left-turn lanes and phasing exist.

A post-mounted signal has the following disadvantages:

1. requires underground wiring which can offset low installation costs;
2. does not provide visibility of signal indications for a motorist due to lateral placement of signal heads;
3. signal indications can be blocked by signs or trees;
4. may not provide a mounting location such that a display with understandable meaning is provided;
5. height limitations can be a problem where the approach is on a vertical curve; and
6. is subject to vehicular impact if installed close to the roadway, particularly in a median.

A cable-span-mounted signal has the following advantages:

1. ease of installation, with less underground work required;
2. allows lateral placement of signal heads for maximum visibility;
3. allows for future adjustments to signal heads;
4. allows signal placement with respect to the stop line;
5. can provide convenient post locations for supplemental signal heads and pedestrian signals and pushbuttons;
6. permits bridles to reduce distance from the stop line at a wide intersection as shown on Figure 502-3C; and
7. allows for proper placement of signs.

A cable-span mounted signal has the following disadvantages:

1. seen by some users as aesthetically unpleasing;
2. requires periodic maintenance for span tightening; and
3. prevents passage of over-height vehicles.

A cantilever-mounted signal has the following advantages:

1. allows lateral placement of signal heads and placement relative to the stop line for maximum visibility of signal indications;
2. may provide post locations for supplementary signals or pedestrian signals and pushbuttons;
3. accepted as an aesthetically pleasing method for installing overhead signals in a developed area;
4. rigid mountings provide the most positive control of signal movement in wind; and
5. allows better clearance to an overhead obstruction.

A cantilever-mounted signal has the following disadvantages:

1. costs are the highest;

2. on a wide approach, it can be difficult to properly place signal heads; and
3. limited flexibility for addition of new signal heads or signs on an existing cantilever.

For the span, steel strain poles provide greater strength, are easier to maintain, and require less space. Wood poles are limited to temporary installations and require the use of down-guy cables.

Each traffic signal cantilever structure shall be designed to satisfy the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals.* Signal cantilever structures and foundations should be as shown on the INDOT *Standard Drawings.* See Section 502-3.03(08) for design criteria for a non-standard structure.

At a rural signalized intersection, overhead highway lighting may be provided where warranted; see Section 502-4.02(03). A traffic signal cantilever structure may be used for the overhead highway lighting. Figure 502-3D provides an illustration of a combination signal-luminaire cantilever structure.

**502-3.03(08) Signal Cantilever Structure Selection Guidance and Design Criteria**

1. Selection Guidance. The INDOT *Standard Drawings* provide details for standardized signal-cantilever structures, pole section 2, combination arm, and both drilled-shaft and spread foundations.

   If soil-borings information is available for a roadwork project that the signalized intersection is part of, it should be used to determine whether the soil is cohesive or sand, the soil-bearing capacity, and the friction coefficient. Otherwise, the designer should contact the Office of Geotechnical Services. If soil-properties information is unavailable, one boring should be made at the intersection to be signalized. Once the soil properties are known, and the values are equal to or higher than those shown in Figure 502-3EE, the foundation type can be determined as shown in Figure 502-3EE.

   If the soil properties are such that the values are lower than those shown in Figure 502-3EE, the foundation should be designed, and its details should be shown on the plans.

   A signal cantilever structure should be designed to provide a minimum clearance of 17.5 ft under each signal head or sign. Clearance should be the vertical distance from the lowest point of the signal head or sign to a horizontal plane to the pavement surface below the signal head or sign.

   A 3-section signal head may be placed where a 5-section signal head is shown on the INDOT *Standard Drawings*.

The structure should be provided with vibration-mitigation devices if either of the following conditions applies:

a. structure has an arm length in excess of 50 ft; or
b. structure is located where the speed limit exceeds 35 mph and the ADT exceeds 10,000, or the ADTT exceeds 1000. ADT and ADTT are for one direction regardless of the number of lanes.

The foundation location and type, pole height, arm length, and sign designations and messages should be shown on the plans. The true arm length should be shown from the center of the pole to the end of the arm. Such length, for pay item determination purposes, should be rounded to the higher 5-ft increment. The plans should show ADT and ADTT for each direction.

2. Design Criteria. If a structure shown on the INDOT *Standard Drawings* cannot be used, its foundation, pole, arm, and connections should be designed utilizing the following design conditions:

a. wind speed of 90 mph;
b. service life of 50 yr;
c. Fatigue Category II;
d. galloping considered;
e. wind gusts considered with truck speed of 60 mph;
f. backplates included for signal heads; and
g. $C_d$ for structure members = 1.1 for fatigue and in accordance with AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, Table 3-6 for working loads.

The device weights and areas are listed in Figure 502-3FF.

If necessary, the combination arm can be added by including pole section 2 of diameter of either 17 in. or 24 in. Where used, the combination arm length should be equal to or less than the length of the signal cantilever arm.

The pole's maximum allowable horizontal deflection should be limited to 2.5% of the structure height in accordance with AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaries, and Traffic Signals,* Section 10.4.2, group 1 load combination.

## 502-3.04 Traffic Signal Design

### 502-3.04(01) Design Criteria

INDOT has adopted the *IMUTCD* criteria for the placement and design of traffic and pedestrian signals. The INDOT *Standard Specifications*, *Standard Drawings* and the following provide additional information.

1. All electrical service should be metered.
2. All parking regulations should be reviewed for a distance of at least 150 ft from the stop line or back to a detector.
3. All signal heads should be placed in accordance with *IMUTCD* Section 4D-15.
4. The necessary signal heads should be verified for the traffic movements as shown in the phase diagram.
5. All signal equipment should satisfy the lateral clearances as specified in Chapter 49.
6. Placement of signal structures and indications should consider the requirements of the Americans with Disabilities Act (ADA), with regard to the placement of pedestrian features.
7. Steel strain pole support height is 30 ft or 36 ft.
8. Preformed loop detection should be used where new pavement is constructed or pavement is to be replaced. The designer should contact the district traffic engineer before specifying preformed loops.
9. All existing signal components should be field-verified.
10. Position and direction of aiming for all signal heads should be in accordance with Section 502-3.04(02).
11. Count loops should be provided in each travel lane approaching an INDOT project signalized intersection. The count loops shall be identified in the loop tagging table.
12. The location of detectors for the indecision zone is discussed in Section 502-3.04(10).
13. For a signal cantilever structure, see Section 502-3.03(08).

### 502-3.04(02) Signal Displays

The *IMUTCD* requires that there be at least two signal heads for each through approach to an intersection or other signalized location. A single head is permitted for control of an exclusive turn lane, provided that this single head is in addition to the minimum two for through movements. For multiple left turn lanes, one head per lane shall be provided.

Supplemental signal indications may be used if the two signal indications are marginally visible or detectable. One signal head per approach lane has been shown to provide a benefit in reducing crashes. Situations where supplemental indications can improve visibility include the following:

1. approach in excess of two through lanes;
2. location where there can be driver uncertainty;
3. where there is a high percentage of trucks which can block the signal indications; or
4. where the approach alignment affects the continuous visibility of normally-positioned signal indications.

The following figures illustrate the placement of signal heads.

1. Figure 502-3E, Rural Two-Lane Road with Obstructed Sight Distance
2. Figure 502-3F, Offsetting Intersection
3. Figure 502-3G, Rural Two-Lane Road with Truck Blocking View of Signal Heads
4. Figure 502-3H, Approaching Lanes with Permissible Phase and Parking on Near Side
5. Figure 502-3 I, Approaching Lanes with Left-Turn Lane with Permissible Phase and Parking on Far Side
6. Figure 502-3J, Approaching Lanes with Left-Turn Lane with Protected Phase
7. Figure 502-3K, Approaching Lanes with Left-Turn Lane with Permissible Phase
8. Figure 502-3L, Approaching Lanes with Left-Turn Lane with Protected/Permissible Phase
9. Figure 502-3M – Multi-Lane Roadway Approaching Lanes with Left-Turn Lane Protected Phase
10. Figure 502-3N, Approaching Lanes with Two Left-Turn Lanes with Protected Phase
11. Figure 502-3 O, Approaching Lanes with Right-Turn Overlaps

### 502-3.04(03) Visibility Requirements

The minimum visibility for a traffic signal is defined as the distance from the stop line at which a signal should be continuously visible for various approach speeds. *IMUTCD* Section 4D-15 discusses the number and location of signal indications by approach.

Signal heads for one approach should be mounted no less than 10 ft apart between the centers of the heads, measured perpendicular to the direction of travel.

### 502-3.04(04) Placement of Signal Equipment

Available options are limited in determining acceptable locations for the placement of signal pedestals, signal poles, pedestrian detectors, and controller cabinets. Considering roadside safety, these elements should be placed as far back from the roadway as practical. However, due to visibility requirements, limited signal cantilever structure arm lengths, limited right of way, restrictive geometrics, pedestrian requirements, or overhead or underground utility conflicts, traffic signal equipment must be placed relatively close to the travelway. The following should be considered in determining the placement of traffic signal equipment.

1. Traffic Signal Support. A traffic signal support should be placed to provide the lateral clearance as specified in Chapter 49.

2. Controller Cabinet. In determining the location of the controller cabinet, the following should be considered.

   a. The controller cabinet should be placed in a position so that it is unlikely to be struck by an errant vehicle. It should be outside the obstruction-free zone.
   b. The controller cabinet should be located where it can be accessed by maintenance personnel.
   c. The controller cabinet should be located so that a technician working in the cabinet can see the signal indications in at least one direction.
   d. The controller cabinet should be located where the potential for water damage is minimized.
   e. The controller cabinet should not obstruct intersection visibility.
   f. The power service connect should be close to the controller cabinet.
   g. Where a utility must perform additional work to provide power to the service point, such information should be included in the contract special provisions.

3. Pedestrians. If the signal pole must be located in the sidewalk, it should be placed to minimize pedestrian conflicts. The signal pole shall not be placed so as to restrict wheelchair access to curb ramps. Pedestrian pushbuttons must be conveniently located. *IMUTCD* Sections 4E.08 through 4E.13 provide criteria for ADA accessibility**.**

**502-3.04(05) Pedestrian Signal [Rev. Jan. 2016, Oct. 2020]**

Pedestrian signal indications should be provided on a new or modernized traffic-signal installation in accordance with *IMUTCD* Section 4E.03.

Unless technically infeasible on a project, accessible pedestrian signals (APS) must be used for all pedestrian signal installations on the state highway system, on all federal-aid projects, and on 100% LPA funded projects. APS may be technically infeasible at a location if right-of-way constraints, such as historic districts, wetlands, or cemeteries, prevent the installation of an M (NEMA Size 5) or larger controller cabinet or if the ambient noise levels are above 100 dB. The determination of technical infeasibility for locations on the state highway system or for a LPA project must be made by the Department's ADA Technical Advisory Committee or LPA, in accordance with Section 40-8.04(01).

The percussive tone should be specified for APS when the pushbuttons at a curb ramp are separated by 10 ft or more. The speech walk message should be specified for APS when the pushbuttons at a curb ramp are separated by less than 10 ft. The speech walk message should normally be patterned after the model, "Broadway. Walk sign is on to cross Broadway." The speech walk message must not include commands or tell pedestrians that it is safe to cross. The speech walk message should also avoid superfluous street name terms such as "street" or "avenue" unless necessary to avoid confusion. When a speech walk message is required the RSP 805-T-202, Accessible Pedestrian Signals with Speech Walk Messages should be completed and inserted into the contract. The tactile arrows on APS should be aligned parallel, or as close as practical, to the direction of travel on the associated crosswalk. *IMUTCD* Section 4E.11 through 4E.13, Section 51-1.06, and the INDOT *Standard Drawing* series 805-PBBA provide additional information regarding the placement, programming, and assembly of APS.

Where a median cut through is less than 6 ft in the direction of pedestrian travel, the signal should be timed for a complete crossing of the street.

Where crosswalks are longer or the ambient noise level is greater, it may be necessary to specify speakers or baffling for the APS.

**502-3.04(06) Signing and Pavement Markings**

Signal structures such as signal overhead structures, cantilevers, and span cables, can include regulatory and informational signs, e.g., left-turn lane only sign or street-name sign. See *IMUTCD* Tables 2B-1 and 2C-2. The effects on the signal overhead structure of wind loading and the weight of the sign should be considered. The number of signs should be limited on a traffic signal structure. Section 502-1.0 provides additional guidance on the placement and design of signs.

For a cable-span signal installation, lane-use-control signs should be placed over the lane on the near-side span. Street-name signs should be placed on right side of the far-side span.

Internally-illuminated street-name signs provide increased visibility at night. INDOT does not install these signs, but a local agency may request their installation along with an INDOT-controlled traffic signal. Their installation requires a contract between INDOT and the local agency.

Section 502-2.0 provides the criteria for the application of pavement markings at an intersection. Pavement markings are used to supplement the traffic-signal indication and lane-use signs.

**502-3.04(07) Electrical System**

The electrical system consists of electrical cables or wires, connectors, conduit, handholes, etc. Electrical connections between the power supply, controller cabinet, detectors, and signal poles are carried in conduit. The following should be considered in developing the traffic signal wiring plan.

1. Service Connections. Service connections from the local utility lines should go directly to the signal service and then to the controller cabinet. The lines should be as short as practical. The signal service should be located as close to the controller cabinet as practical to minimize the power loss due to the length of cable. The connection between the signal service and the controller cabinet will be placed underground in separate conduits from other signal wires.

   The designer should contact the local utility company and obtain a written estimate of the service connection cost which should be placed in the project file. The District Utility Engineer can provide contact information and assistance.

   A unique special provision should be created for the service connection cost if this cost is greater than the amount that is recoverable through the first two and a half years of energy billing and, if applicable, the cost of the REMC membership fee. Currently this recoverable amount is about $750. The special provision should indicate the additional non-recoverable part of the estimated costs of the service connection and that the additional non-recoverable costs are included in the cost of Signal Service.

2. Electrical Cables. The number of conductor cables should be kept to only 3 or 4 types of cables, to reduce inventory requirements. A 7-or-greater conductor cable is used between the controller cabinet and the disconnect hangers or cantilever base. A 5-conductor cable is used between the disconnect hanger or cantilever base and 3-section signal indications. A 7-conductor cable is used between the disconnect hanger or cantilever base and 5-section signal indications. A 5-conductor cable is used between the controller cabinet and each pair of pedestrian signal indications located in the same corner of the intersection. A 5-conductor cable is used between the controller cabinet and each pair of pedestrian push buttons located in the same corner of the intersection. Where only one push button is used, a 3-conductor cable should be used. Connections to flashers use only a 3-conductor cable.

3. Cable Runs. All electrical cable runs should be continuous between the following:

   a. controller cabinet to base of cantilever structure or pedestal;
   b. controller cabinet to disconnect hangers;
   c. controller cabinet to signal service;
   d. disconnect hanger to signal indications;
   e. base of cantilever structure to signal indications; and
   f. controller cabinet to detector housing.

4. <u>Handholes</u>. Handholes should be located outside the travel lane and shoulder pavement adjacent to the controller cabinet, each signal structure, and each detector location.

   Type I handholes are made of reinforced concrete pipe; Type II handholes are made of polymer concrete; and Type III handholes are a special design requiring the cover and ring to be secured to the handhole. The material type that should be used will depend on the location as follows.

   a. A Type I (concrete) handhole should be used for a location that will be closer to motor vehicles, such as in the shoulder or immediately adjacent to the unprotected edge of pavement.

   b. A Type II (polymer concrete) handhole should be used for a location that will not be exposed to motor vehicles, such as on a sidewalk, behind guardrail or non-mountable curb, or as directed by the District Traffic or District Maintenance Office.

   c. A handhole that will be placed directly in a travel lane should be designated as a Type III and will require a special design and plan detail that includes a means by which the cover and ring are secured to the handhole.

   The INDOT *Standard Drawings* provide details of handholes and wiring. The maximum spacing between handholes in the same conduit run is 250 ft.

5. <u>Underground Conduit</u>. Underground conduit is used to connect the controller cabinet, traffic signal structures, and loop detectors. A conduit of 2 in. diameter should be used. The *National Electrical Code* should be checked to determine the appropriate number of electrical cables that can be contained within the conduit. For a run with additional cables, the conduit size may need to be increased. The INDOT *Standard Drawings* provide details on the placement of underground conduit.

   The designer should indicate which material type should be used. The conduit type should be determined based on the following guidelines.

   a. PVC Schedule 40, HDPE Schedule 40, or rigid fiberglass should be used for conduit placed in a trench.

   b. HDPE Schedule 80 should be used for conduit to be jacked or bored, e.g., underneath pavement.

c. Galvanized Steel should be used if requested or confirmed by the District Traffic Office.

d. PVC Schedule 80 or rigid fiberglass should be used for conduit on bridges or other structures.

6. Grounding. Each overhead signal structure, controller cabinet, signal pedestal, warning flashing beacon, etc., must be grounded. The INDOT *Standard Drawings* illustrate the correct procedures for grounding these devices.

7. Detector Housing. A detector housing should be a cast-aluminum box encased in concrete. A detector housing is used to splice the wires from the loops to the lead-in cable to the detector amplifier. The INDOT *Standard Drawings* provide additional information on detector housings, including wiring details.

8. Disconnect Hanger. A disconnect hanger is used for cable-span-mounted signals to provide a junction box between the signal heads and the controller.

9. Interconnect Cable. For a closed loop system using an interconnect cable, fiber optic cable should be used. Other types of interconnect cable are 7C/14 signal wire and 6-pair twisted cable.

**502-3.04(08) Phasing**

The designer, in consultation with the district and Traffic Management, is responsible for determining the signal phasing. The selected phase diagram must be shown on the plans on the signal details sheet and should include the roadway preferentiality.

A NEMA controller is configured to operate as a dual-ring controller unless circumstances warrant the use of additional rings. Figure 502-3P illustrates the appropriate phasing sequence for a dual-ring controller. A multi-ring controller unit includes two or more rings that are arranged to time in a preferred sequence and to allow concurrent timing of all rings, subject to the restraint of a barrier. For the controller to advance beyond each barrier, a set of phases must cross the barrier line at the same time, i.e., no conflicting phases are displayed at the same time.

The controller selects and times each individual phase. Each phase is programmed as a single-entry operation in which a single phase can be selected and timed alone if there is no demand for service in a non-conflicting phase. For a controller with 5 to 8 phases, the phases can be timed concurrently, e.g., dual-ring controller. For example, a through movement can be timed concurrently with its accompanying left turn or its opposing through movement, e.g., Phase 2 can be timed concurrently with Phase 5 or Phase 6, but not with another phase or vice versa. This concurrent timing is not an overlap because each phase times individually. An overlap is dependent on the phase or phases with which it is overlapped for time and is terminated as the phase or phases terminate.

1. Phasing Types. A signal phase is defined as the part of the traffic-signal cycle allocated to a combination of traffic movements receiving the right of way simultaneously during one or more intervals. Each cycle can have 2 or more phases. Though a controller is capable of up to 16 phases, there should be no more than 8 phases per cycle, and desirably fewer. A controller should be operated as an 8-phase dual-ring controller. As the number of non-overlapping phases increases, the total vehicular delay at the intersection will increase due to the lost time of starting and clearing each phase. The minimum number of phases should be used that will accommodate the existing and anticipated traffic demands. A capacity analysis should be conducted to determine if the proposed phasing is appropriate. Phases 2 and 6 should be used as the preferential phases. The following are the applications for phase operations.

    a. Three-Phase Operation. A 3-phase operation is appropriate with a T-intersection with single lanes. Dedicated turn lanes will be required if there is a high turning volume on the through street. Figure 502-3Q illustrates this.

    b. Four-Phase Operation. The following describes where a 4-phase operation may be used.

        1) A 4-phase operation will be required for a T-intersection with multiple lanes if there is a high turning volume on the through street. The 4-phase operation allows a number of options depending on the traffic volumes and geometrics of the intersection, e.g., left- and right-turn lanes. Figure 502-3R illustrates this.

        2) A 4-phase operation is appropriate with a 4-way intersection that has moderate turning movements and low-pedestrian volume. Figure 502-3S illustrates a 4-phase operation. Disadvantages of a 4-phase operation are that left turns are in conflict with traffic from opposite directions, and that right- and left-turning traffic is in conflict with pedestrian flow. It is most appropriate for actuated control with detection on all approaches.

        3) A 4-phase operation is appropriate for a 4-way intersection where the major or minor street has non-concurrent, or split, phases. A 4-phase operation with non-concurrent phases may be used where there is high left-turning

demand and there is inadequate pavement width to provide a left-turn lane or the intersection geometry prevents opposing left-turn movements from running concurrently; see Figures 502-3T and 502-3U. This option is inefficient, as only one approach is serviced at a time.

c. Five-Phase Operation. A 5-phase operation is appropriate with an exclusive pedestrian phase. This option is used where there is a significant number of pedestrians, e.g., university campus, downtown business district, and where the signal normally operates in a 4-phase operation, i.e., minimum number of left-turns. Figure 502-3V illustrates a 5-phase operation with an exclusive pedestrian phase. During the exclusive pedestrian phase, pedestrians can use all crosswalks or can walk diagonally across the intersection.

d. Six-Phase Operation. A 6-phase operation is appropriate on a major street with left-turn lanes. Left-turn phases will reduce the number of left-turn accidents. Figure 502-3W illustrates this.

e. Eight-Phase Operation. An 8-phase operation provides the maximum efficiency and minimum conflicts for a high-traffic-volume intersection with high turning movements. Left-turn lanes should be provided on all approaches. It is most appropriate for actuated control with detection on all approaches. The 8-phase operation allows for the skipping of phases or selection of alternate phases depending upon traffic demand. Figure 502-3X illustrates a typical 8-phase dual ring operation. An 8-phase operation uses a NEMA dual-ring controller.

f. Other Phases. For other phase operations, one of the above phase operations can be used by eliminating the non-applicable phase from the sequence.

g. Overlap. An overlap is a controller output to the signal-head load switch that is associated with two or more phases. See Figure 502-3 O.

Figures 502-3Q through 502-3Y also illustrate the movements that should be assigned to the various numbered phases. For a 4- or 8-phase operation, the through phases are assigned to the even-numbered phase diagram locations, and the left turns are assigned to the odd-numbered phase diagram locations.

Computer programs are available that can assist in determining the appropriate phasing requirements. See Section 502-3.04(12). The Traffic Control Systems Division can be contacted for more information on the software packages or versions used by INDOT.

2. Phase Numbering and Conventions. Phase numbers are the labels assigned to the individual traffic movements around the intersection. For an 8-phase dual ring controller, the major-road through movements are assigned phases 2 and 6. Even numbers are used for through traffic. Odd numbers are used for left-turn traffic. Figure 502-3Y shows typical vehicle movements and phase numbering.
For signals in a coordinated system, phases 2 and 6 are the coordinated phases.

Intersection vehicle movements and corresponding NEMA phase assignments shall be shown on the plans in the phase diagram according to U.S. route numbering convention and priority routes as defined below.

a. Priority Intersection Route. The priority, or major, intersection route shall be determined based on the following:

1) route classification, as U.S. route, state route, or local route, respectively; and
2) on equally classified routes, higher vehicular volume.

b. Phase Assignment Labeling, NB, SB, EB, WB. Phase assignment labels for the highest-priority road or major road shall be assigned according to route numerical designation with odd-numbered route as NB/SB, and even-numbered route as EB/WB, without respect to the cardinal direction of the major road at the intersection. Phase 2 will be assigned to the major road northbound for an odd-numbered route or eastbound for an even-numbered route. For example, an east-west even-numbered state road will have the eastbound and westbound through phases labeled as phases 2 and 6, respectively, regardless of the heading, or direction of travel of the state road at the intersection. This can result in an even-numbered route with phase 2 on the approach traveling south through the intersection if the eastbound lanes of the major route are actually heading south at the intersection.

The minor phase directional labels shall be assigned as relative directions to the highest-priority northbound or eastbound route. Where two equally-classified routes, both even or both odd, intersect, phase 2 shall be assigned to the highest volume northbound or eastbound through movement regardless of the cardinal direction.

c. Phase Assignments.

1) Standard 4- or 8-Phase Intersection. Phase 2 shall be assigned to the major road, NB or EB route, at the intersection. The remaining even-numbered

through phases 4, 6, and 8 shall be assigned to vehicle movements clockwise around the typical intersection. See Figure 502-3Y. Clockwise from phase 2, phase 4 follows, then phase 6 followed by phase 8. Odd-numbered phases shall be assigned to each corresponding left-turn phase by NEMA convention, also increasing numerically in the clockwise direction.
Deviation from the above priority convention is permitted to maintain the integrity of an existing or planned coordinated system by assigning phase 2 and 6 as the coordinated phases.

2) T-Intersection. A three-leg or T-intersection shall follow the standard 4- or 8-phase intersection convention, skipping those phases that otherwise are assigned to the missing vehicle movements.

3) Split-Phase Intersection. Phase assignments should follow those for the standard 4- or 8-phase intersection. NB and EB movements shall be assigned a lower phase number than the phase assigned to SB and WB movements, respectively.

   Grade-separated intersection and interchange ramps that terminate and intersect at numbered U.S. and state routes shall use the through surface-route numerical designation to determine the NB/EB phase 2 assignment regardless of route priority. NB/WB ramp movements will be assigned to phase 8. SB/EB ramps will be assigned to phase 4.

   A ramp terminating at a local street may use either the numbered interstate or state route as directional reference, or the nearest NB/EB cardinal direction of the local arterial movement in determining arterial orientation for assigning phase 2 as NB or EB. Regardless, phase 2 shall be labeled NB or EB and the remaining above conventions applied.

4) TTI 4-Phase and Single Controller Diamond Interchange. A single-controller diamond interchange should incorporate a flexible ring structure that allows TTI 4-phase, extended 3-phase, standard 3-phase, or two separate intersection modes by time of day selection in the controller. Phases will not likely strictly follow the above convention. The Traffic Control Systems Division should be contacted for more information on this type of operation.

d. Examples.

1) SR 32 at SR 38, East or West side of Noblesville. SR 32 is the through movement, Phase 2 is EB SR 32.

2) SR 32 at SR 37 in Noblesville. SR 37 has the higher volume. Phase 2 is NB SR 37.

3) I-465 at US 31 in Hamilton County. US 31 is the odd-numbered NB route. Phase 2 is NB US 31.

4) I-465 at Allisonville Road in Indianapolis. Phase 2 is NB Allisonville Road.

5) US 30 at SR 15 in Warsaw. Grade Separated. SR 15 is the arterial route. Phase 2 is NB SR 15.

3. Left-Turn Phases. The added phases are for protected left-turns, such that left-turning vehicles get a green arrow without conflicting movements. A left-turn phase can be either a leading left, where the protected left turn precedes the opposing through movement, or a lagging left, where the left-turn phase follows the opposing through movement. Opposing left turns may both be leading, lagging, or a combination. The decision on whether to use either a leading-left or a lagging-left turn will be determined on a project-by-project basis. Leading left turns should be used. A combination of leading and lagging or lagging left turns can provide more efficient operation in a coordinated signal system. Figure 502-3Z provides a comparison for each left-turn phase alternative.

Not all signalized intersections will require a separate left-turn phase. The decision on where to provide exclusive left-turn phases is dependent upon traffic volume, delays and crash history. This will be determined on a site-by-site basis by the district traffic engineer or the Traffic Control Systems Division. For an intersection with exclusive left-turn lanes, the following should be used to determine the need for a left-turn phase.

a. Capacity. A left-turn phase should be considered where the demand for left turns exceeds the left-turn capacity of the approach lane. The left-turn capacity, $C_L$, of an approach lane can be determined by using the equation as follows:

$$C_L = 1200G - V_{OPP}$$

Where $G$ = percent green time, and $V_{OPP}$ = opposing traffic volume.

$C_L$ shall not be less than two vehicles per cycle.

b. Delay. A left-turn phase should be considered where the delay time for left-turning vehicles is excessive for 4 h during an average day. Delay is considered excessive if left-turning vehicles are delayed for more than two complete signal cycles.

c. Miscellaneous. Intersection geometrics, total volume demand, crash history, posted speeds, etc., should also be considered.

d. Non-INDOT Facility. The ITE *Manual of Traffic Signal Design* provides alternative guidelines for where left-turn phasing may be considered.

On an approach without an exclusive left-turn lane, the decision on whether to include a left-turn phase is determined on a site-by-site basis. The inclusion of a left-turn phase at an intersection without an exclusive left-turn lane will require split phasing. Where practical, opposing left-turn arrows should also be provided.

4. Assignment of Right of Way. The assignment of right of way, also referred to as preferentiality, at a traffic signal determines which heads at an intersection will flash yellow if the traffic signal goes to a flash condition.

For an intersection on the state highway system, none of the signals at a signalized intersection will flash yellow. Therefore, none of the approaches will have preferentiality over the others. This condition is also referred to as all red flash.

A local agency may assign preferentiality to one of the roads at an intersection. This will permit the preferential road's signal to flash yellow while the crossroad's signal will flash red.

**502-3.04(09) Pre-timed Traffic Signal Timing**

1. Signal Timing. For a state highway, the district and the Traffic Control Systems Division will be responsible for timing the signal after it has been installed. For a local facility, the consultant will be responsible for determining the signal timing. However, the designer must understand the aspects of traffic-signal timing so that the appropriate equipment will be selected, and an efficient design can be provided.

a. Phases. The number of phases should be kept to a minimum. Each additional phase reduces the effective green time available for the movement of traffic flows, i.e., increased lost time due to starting delays and clearance intervals. Adding concurrent phases may not reduce capacity.

b. Cycle Length. A short cycle length provides the lowest average delay, provided the capacity of the cycle to pass vehicles is not exceeded. The following should be considered regarding cycle length.

   1) Delay. For 4-phase operation, a cycle length of 50 to 60 s produces the shortest delay.

   2) Capacity. A cycle length of greater than 60 s will accommodate more vehicles per hour if there is a constant demand during the entire green period on each approach. A longer cycle length provides higher capacity because there are fewer starting delays and clearance intervals.

   3) Maximum. A cycle length of 120 s should be the maximum used, irrespective of the number of phases. For a cycle of longer than 120 s, there is an insignificant increase in capacity and a rapid increase in the total delay.

c. Green Interval. The division of the cycle into green intervals will be approximately correct if made proportional to the critical lane volumes for the signal phases. The critical lane volumes can be determined by using the *Highway Capacity Manual*'s Planning Methodology or the Highway Capacity Software's Signalized Intersections Module. The green interval should be checked against the following.

   i. Pedestrians. If pedestrians will be accommodated, each green interval must be checked to ensure that it is not less than the pedestrian clearance time required for pedestrians to cross the respective intersection approaches plus the initial walk interval time.
   ii. Minimum Length. Relative to motorist expectations, a major movement should not have a green interval of less than 15 s. An exception to this may be for special turn phases.

d. Capacity. For an intersection approach with a high left-turn volume, the capacity of an intersection should be checked to determine the need for a separate left-turn lane; see Section 502-3.04(08) item 2.c.

e. Phase-Change Interval. Each phase-change interval, yellow plus all red, should be designed in accordance with Section 502-3.04(09) item 1.b. to ensure that approaching vehicles can either stop or clear the intersection during the change interval.

f. Coordination. Traffic signals within 2600 ft of each other should be considered for coordinated together in a system. Section 502-3.05 further discusses signal-system coordination.

g. Field Adjustments. Each signal-timing program should be checked and adjusted in the field to satisfy the existing traffic conditions.

2. <u>Cycle Determination</u>. In determining the appropriate cycle length and interval lengths, the following should be considered.

   a. General. Cycle length should be within range as follows.

      1) 4-Phase Operation: 50 to 80 s.
      2) 6-Phase Operation: 60 to 100 s.
      3) 8-Phase Operation: 80 to 120 s.

   b. Phase-Change Interval. The yellow-change interval advises motorists that their phase has expired and that they should stop prior to the stop line, or allows them to enter the intersection if they are too close to stop. The phase-change interval length should be determined using Equation 502-3.1. The yellow change interval should be followed by a red-clearance interval, or all-red phase, of sufficient duration to permit traffic to clear the intersection before conflicting traffic movements are released. For a more efficient operation, start-up time for the conflicting movements may be considered in setting the length of the all-red interval.

$$Y + AR = t + \frac{V}{2a \pm 64.4g} + \frac{W+L}{V} \qquad \text{[Equation 502-3.1]}$$

Where:

$Y + AR$ = sum of the yellow and all-red intervals
$t$ = perception/reaction time of driver, s, assumed to be 1 s
$V$ = approach speed, ft/s posted speed limit
$a$ = deceleration rate, ft/s$^2$, assumed to be 10 ft/s$^2$
$W$ = width of intersection, ft
$L$ = length of vehicle, ft, assumed to be 20 ft

$g$ = approach grade, percent of grade divided by 100. Add for upgrade and subtract for downgrade

The yellow-change interval range is 3 to 6 s.
The all-red interval range is 1 to 4.4 s.

c. Green Interval. To determine the cycle division, the green-phase interval should be estimated using the proportion of the critical lane volumes for each phase. The following equations illustrate how to calculate this proportion for a 2-phase system. A signal with additional phases can be similarly determined.

$$G = C - Y_a - Y_b \qquad \text{[Equation 502-3.2]}$$

$$G_a = \frac{V_a \ x \ G}{V_a + V_b} \qquad \text{[Equation 502-3.3]}$$

$$G_b = \frac{V_b}{V_a + V_b} x \ G \qquad \text{[Equation 502-3.4]}$$

Where:

$G$ = total green time available for all phases, s
$G_a$ and $G_b$ = green interval, s, calculated for street A or B
$V_a$ and $V_b$ = critical lane volume on street A or B
$Y_a$ and $Y_b$ = phase change interval, s, on street A or B, yellow and all red
$C$ = cycle length, s

The effect the pedestrian clearance interval will have on the green interval should be considered where there is an exclusive pedestrian phase, or if the pedestrian phase occurs concurrently with traffic at a wide intersection with short green intervals. If pedestrians walk during the green indication or a Walk indication, the minimum green interval should be determined using Equation 502-3.5. The walking distance is from the edge of the near roadway to the edge of the far roadway.

$$G = P + \frac{D}{S} = Y \qquad \text{[Equation 502-3.5]}$$

Where:

$G$ = minimum green time, s
$P$ = pedestrian start-off period, assumed as 4-7 s
$D$ = walking distance, ft
$Y$ = yellow interval, s

$S$ = walking speed, ft/s, assumed as 3.5 ft/s

Where there are fewer than 10 pedestrians per cycle, the lower limit of 7 s is adequate as a pedestrian start-off period. A walking speed of 3.5 ft/s can be assumed for an average adult pedestrian. Where elderly, handicapped, or child pedestrians are present, a reduced walking speed should be considered.

d. Recheck. After the cycle length and interval lengths have been selected, the design should be rechecked to ensure that sufficient capacity is available. Several cycle lengths should be checked to ensure that the most efficient cycle length and interval lengths are used. If the initial design is inadequate, the following should be performed.

1) select a different cycle length;
2) select a different phasing scheme; or
3) make geometric or operational changes to the intersection approaches, e.g., add left-turn lanes.

Software programs are available to assist in determining the most efficient design. Section 502-3.04(12) discusses these programs.

**502-3.04(10) Traffic-Actuated Signal Timing**

For an actuated controller, the district and the Traffic Control Systems Division will be responsible for timing on a state highway after the controller is installed. However, the designer must understand how the signal timing will affect the efficiency of the actuated signalized intersection. With an actuated controller, the designer must understand how the signal timing will affect the placement of the traffic detectors.

The design of actuated control is a trade-off process where optimization of the location of vehicular detection provides safe operation while providing controller settings that will minimize the intersection delay. The compromises that must be made among these conflicting criteria become difficult to resolve as approach speed increases. For example, on an approach with speed of higher than 35 mph, the detector should be located in advance of the indecision zone. The indecision zone is the decision area, on such an approach, where the motorist needs to decide whether to go through the intersection or to stop once the yellow interval begins. Depending on the distance from the intersection and vehicular speed, the motorist may be uncertain whether to stop or continue through the intersection, thus, creating the indecision problem. Figure 502-3AA further defines the indecision zone. The design considerations for an actuated controller are as follows.

1. Advanced-Design Actuated Controller. An advanced-design actuated controller is used at an isolated intersection with fluctuating or unpredictable traffic demands, and approach speed higher than 35 mph. INDOT uses this type of controller, irrespective of the approach speed. An advanced-design actuated controller is one that has a variable initial interval. It can count waiting vehicles beyond the first one, and can extend the initial interval to satisfy the needs of the number of vehicles actually stored between the stop line and the detector. As with basic-actuated control, the small-area detection requires that the controller have a locking memory.

   The timing requires judgment. Therefore, field adjustments are often required after the initial setup. The considerations in signal timing and detector placement are as follows.

   a. Detector Placement. For an approach with speed of higher than 35 mph, the detector should be located in advance of the indecision zone (see Figure 502-3AA). This will place the detector at about 5 s of passage time from the intersection. The speed selected should be the posted speed of the approach roadway. Figure 502-3BB provides the appropriate detector set-back distance for each combination of passage time and approach speed. Figure 502-3BB also provides the passage time that is appropriate for other types of detection.

   b. Vehicular Extension. The vehicular extension setting fixes both the allowable gap and the passage of time at one value. The extension should be long enough so that a vehicle can travel from the detector to the intersection while the signal is held in the green phase. However, the allowable gap should be kept short to ensure transfer of the green phase to the side street. Headway between vehicles in a platoon averages between 2 and 3 s. Therefore, the minimum vehicular extension time should be at least 3 s. For the maximum gap, a motorist waiting during the red phase finds that a gap of 5 s or longer is too long and inefficient. Therefore, the vehicular extension should be set between 3 and 5 s. For faster phase changes, a shorter gap should be used.

   c. Minimum Initial. Because the advanced-design actuated controller can count the number of vehicular arrivals, the minimum initial time should be long enough only to satisfy motorist expectancy. The minimum initial interval is set at 8 to 15 s for a through movement, and 5 to 7 s for a left turn.

   d. Variable Initial. The variable initial is the upper limit to which the minimum initial can be extended. It must be long enough to clear all vehicles that have accumulated between the detector and the stop line during the red phase. The minimum assured green phase (MAG) should be between 10 and 20 s for each major movement. The actual value selected should be based on the time it takes to clear all possible stored vehicles between the stop line and the detector. If the MAG is too short, the stored vehicles may be unable to reach the stop line before the signal changes. This time can be calculated using Equation 502-3.6.

$$MAG = 3.7 + 2.1\ n \qquad \text{[Equation 502-3.6]}$$

Where:

$MAG$ = minimum assured green, s
$n$ = number of vehicles per lane which can be stored between the stop line and the detector

The minimum green time selected should be able to service at least two vehicles per lane. Using Equation 502-3.6, this translates into approximately 8 s. Assuming that two vehicles occupy approximately 45 ft, the detector should not be placed closer than 45 ft from the stop line. Closer placement will not reduce the MAG.

Where pedestrians must be accommodated, a pedestrian detector, e.g., pushbutton, should be provided. Where a pedestrian call has been detected, the MAG must be sufficient enough for the pedestrian to cross the intersection. The minimum time for a pedestrian, as discussed in Section 502-3.04(09) for a pre-timed signal, is also applicable to an actuated system.

e. Number of Actuations. The number of actuations is the number of vehicles that can be accommodated during the red phase that will extend the initial green phase to the variable initial limit. This is a function of the number of approach lanes, average vehicle length, and lane distribution. It should be set based on vehicles being stored back to the detector.

f. Passage Time. The passage time is the time required for a vehicle to pass from the detector to the stop line. This is based on the posted speed limit of the approach roadway.

g. Maximum Green Interval. This is the maximum time that the green interval should be held for the green phase, given a detection from the side street. For a low to moderate traffic volume, the signal should gap out before reaching the maximum green time. However, for a period with high traffic volume, the signal will rarely gap out. Therefore, a maximum green interval is set to accommodate the waiting vehicles. The maximum green interval can be determined assuming a pre-timed intersection; see Section 502-3.04(09). It may be made longer to allow for peaking.

h. Allowable Gap. A density-type controller permits a gradual reduction of the allowable gap to a preset minimum gap based on one or more cross-street traffic parameters of time waiting, vehicles waiting, or density. Time waiting has been determined to be the most reliable and usable. As time passes after a conflicting call, the allowable gap time is gradually reduced. The appropriate minimum gap setting will depend on the number of approach lanes, the volume of traffic and the various times of day. Adjustments will need to be made in the field.

i. Clearance Interval. The clearance interval should be determined as for a pre-timed signal. See Section 502-3.04(09).

j. Semi-Actuated Controller. For a minor street with semi-actuated control, the signal is held on green for the major street. To ensure that the major street is not interrupted too frequently, a long minimum green period should be used on the major street. The low-volume minor street is expected to experience delay.

k. Intermediate Traffic. Where vehicles can enter the roadway between the detector and intersection, e.g., driveway, side parking, or where a vehicle may be traveling so slow that it does not clear the intersection in the calculated clearance time, the signal controller will not register its presence. A presence detector at the stop line may be required to address this.

2. Actuated Controller with Large Detection Area. A large-area detector is used with an actuated controller in the non-locking memory mode, and with the initial interval and vehicular extension set at or near zero. This is loop occupancy control (LOC). A large-area detector is used in the presence mode, which holds the vehicle call for as long as the vehicle remains over the loop. An advantage of a large-area detector is that it reduces the number of false calls due to right-turn-on-red vehicles. A large-area detector consists of four octagonal 6 ft x 6 ft or circular 6-ft diameter small loops, 9 ft apart connected in series; see the INDOT *Standard Drawings*. With a large area detector, the length of the green time is determined based on the time the area is occupied. However, a minimum initial time should be provided for motorist expectancy. Applications for LOC are as follows.

a. Left-Turn Lane. An LOC arrangement is appropriate for a left-turn lane where left turns can be serviced on a permissive green or yellow clearance or where vehicles can enter the left-turn lane beyond the initial detector. The following should be considered in using the LOC for left turns.

1) To ensure that the motorist is committed to making the left turn, the initial loop detector may need to be installed beyond the stop line to hold the call.

2) Where motorcycles are part of the vehicular volume, the vehicular extension may need to be set to 1 s so that a motorcycle will be able to hold the call as it passes from loop to loop. An alternative is to use the extended-call detector.

b. Through Lanes for a Low-Speed Approach. For a low-speed approach of 35 mph or lower, the indecision zone protection is not considered a problem. The detection area length and controller settings are determined based on the desired allowable gap. For example, assuming an approach speed of 30 mph and desired allowable gap of 3 s, the LOC area length is calculated to be as follows:

$$\frac{30\ mi}{h}\ x\ 3\ s\ x\ \frac{5280\ ft}{mi}\quad x\quad \frac{h}{3600\ s}\quad =\ 132\ ft$$

The vehicular length of 20 ft should be subtracted from the LOC, so that the required detector area length is 112 ft. The loop layout length is only 45 ft, therefore, for a 30-mph approach speed, the vehicular extension setting should be set at 1.5 s to provide the 3 s gap.

If the initial interval is set at zero and the vehicular extension is between zero and 1 s, under light traffic conditions, a green interval as short as 2 or 4 s may occur. The presence of pedestrian or bicyclists should be determined. If so, the minimum green time for their crossing should be provided. Motorist expectancy should also be considered. A motorist for a major-road through movement expects a minimum green interval of 8 to 15 s.

c. Through Lanes for a High-Speed Approach. For a high-speed approach of speed higher than 35 mph, it is not practical to extend the LOC beyond the indecision zone, or 5 s of passage time back from the stop line. To solve the indecision-zone problem, an extended-call detector is placed beyond the indecision zone. This detector is used in a non-locking mode. The time extension is based on the time for the vehicle to reach the LOC area. Intermediate detectors may be used to discriminate the gaps.

Concerns with using the LOC concept for a high-speed approach include the following.

1) The allowable gap is higher than the desired 1.5 to 3 s. The controller's ability to detect gaps in traffic is impaired. As a result, moderate traffic will extend the green interval to the maximum setting, which is undesirable.

2) An LOC should be used only if the route's ADT is 8,000 to 10,000. A high-speed approach with a higher volume is more efficiently served with a density controller. The intersection of a high-speed artery with a low-speed crossroad is more efficiently served with a density controller on the artery and an LOC for the crossroad.

**502-3.04(11) Count Loops**

A new or modernized traffic signal should include count loops. These are inductive loop detectors that, in addition to detecting the presence or passage of a vehicle, provide a count pulse once a vehicle passes over the loops. The traffic-signal controller stores the counts in a format that can be uploaded either remotely or onsite to a personal computer.

Detection devices appear on the Approved Products List of Traffic Signal and ITS Controller Equipment that are count-capable. The considerations for the layout of these detection devices for counting are similar to those for inductive loops.

The configuration of count loops and determination of which loops are used to count vehicles at a signalized intersection are dependent on the geometry of the intersection. The considerations are as follows.

1. Encroachment. This occurs where a vehicle from one movement drives over the loops providing vehicle count for another movement, causing that movement to over-count. Each lane with an encroachment issue should use only loop numbers 4 or 1 to count, depending on the extent of encroachment.

2. Late Entrance and Early Departure. This occurs where a vehicle enters or exits the side of a count loop series and does not cross every count loop in the series, causing that movement to under-count.

3. Lane Changes Within the Loop System. A vehicle changing lanes within 50 ft of the stop line is unpredictable and cannot be eliminated. This is a minor issue. For a lane where this is a major issue, count loops should be numbers 1 or 4, avoiding issues 1 and 2 above.

4. Truck and Trailer. A truck and trailer can be counted once or multiple times due to the difference in height of the bed and the axles. This is inconsistent between trucks, and variables cannot eliminate this issue. For a lane where this is a major issue, using all four loops as count loops can minimize over-counting.

5. Shared Lane for Through and Right Movements. Figure 502-3CC shows two methods of counting through and right-turn movements where they share a lane. The minimum distance between the loops in the through lane and the loop in the radius for right-turning vehicles shall be 6 ft. Method A should be chosen if the radius is large enough that a right-turning vehicle will not cross the front loop in the lane. If a right-turning vehicle will pass partially or completely over the front loop in the lane, Method B should be used.

   Figures 502-3CC and 502-3DD illustrate the effects of these factors and suggested count loop configurations.

**502-3.04(12) Preferred Counting Configurations**

One loop will provide the most accurate count but at a higher cost in hardware and detector lead-ins than for a four-loop series. Some detectors are not as accurate with one loop.

Two loops can increase accuracy for a detector that is not as accurate counting with one loop. Counting with two loops is equal in cost to counting with one loop of a four-loop series. Counting with two loops can decrease accuracy due to encroachment, late entrance, early departure, or lane changes within the count zone. Therefore, approval for counting with two loops shall be a District Office of Traffic decision.

Four loops provide an accurate count installation with the lowest cost. However, this can decrease count accuracy if there are encroachments, late entrances, early departures, or lane changes within the count zone.

The preferred counting configurations, listed from most to least desired, are as follows:

1. four loops: loops 1, 2, 3, and 4;
2. one loop: loop 4;
3. one loop: loop 1;
4. two loops: loops 3 and 4, requires district Office of Traffic approval; and
5. two loops: loops 1 and 2, requires district Office of Traffic approval.

Only one movement can be counted per lane. As many movements should be counted at the intersection as feasible.

### 502-3.04(13) Computer Software

Software programs are available to assist the designer in preparing traffic signal designs and timing plans. New programs and updates to existing programs, are being developed. These programs are used for the optimization of coordinated-signal systems, not basic controller settings. Before using these programs, the designer should contact the Traffic Control Systems Division to determine which software packages or versions INDOT is using. The following programs are used for signal timing optimization.

1. <u>SYNCHRO®/SIMTRAFFIC®</u>. SYNCHRO is a traffic-signal simulation program that develops timing plans for isolated signal and arterial signal systems. It will optimize timings for fixed and actuated traffic signals. SIMTRAFFIC is a companion microscopic simulation and animation program that uses SYNCHRO files. Both programs will estimate measures of effectiveness for a timing plan.

2. <u>PASSER II®</u>. Progression Analysis and Signal System Evaluation Routine (PASSER II) is a bandwidth-optimization program. It develops a timing plan that maximizes the through progression band along an arterial for up to 20 intersections. It functions in unsaturated traffic conditions and where turning movements onto the arterial are relatively light. PASSER II can also be used to develop arterial phase sequencing for input into a stop-and-delay optimization model such as TRANSYT-7F.

3. <u>TRANSYT-7F®</u>. The Traffic Signal Network Study Tool (TRANSYT-7F) develops a signal-timing plan for an arterial or grid network. The objective of this program is to minimize stops and delays for the system as a whole, rather than maximizing arterial bandwidth.

4. <u>AAP®</u>. The Arterial Analysis Package (AAP) allows the user to access PASSER II and TRANSYT-7F to perform an analysis and design of arterial signal timing. The package includes a user-friendly forms display program so that data can be entered interactively on a microcomputer. Through the AAP, the user can generate an input file for two component programs to evaluate arterial signal-timing designs and strategies. The package also links to the Wizard of the Helpful Intersection Control Hints (WHICH®) to facilitate design and analysis of individual intersections. The program interfaces with TRANSYT-7F, PASSER II, and WHICH.

5. <u>HCS®</u>. The Highway Capacity Software (HCS) replicates the procedures described in the *Highway Capacity Manual*. It is a tool that increases productivity and accuracy, but it should be used only in conjunction with the *Highway Capacity Manual* and not as a replacement for it.

6. PASSER III-98®. PASSER III-98 is a diamond-interchange optimization software. The program can evaluate existing or proposed signalization strategies, determine signalization strategies which minimize the average delay per vehicle, and calculate signal timing plans for interconnecting a series of interchanges on a one-way frontage road.

**502-3.04(14) Maintenance Considerations**

After a signal is installed, the district will be responsible for its maintenance. Therefore, district personnel should be consulted early in the design process regarding the feasibility of the selected signal equipment and its location, e.g., controllers, cabinets, signal heads, etc. The selected equipment must satisfy the operator's capability to adjust the signal and maintain it.

For a signal on a local facility, it will be the responsibility of the local agency to operate and maintain the signal. The designer should review the local jurisdiction's existing traffic signal hardware and maintenance capabilities. If practical, the local jurisdiction's existing hardware should be matched. This will reduce the municipality's need for additional resources and personnel training. However, this should not limit the designer's options, as there are engineering consultants who can assist a local agency in operation and maintenance of a traffic signal.

**502-3.04(15) Traffic-Signal Loop Tagging Table**

The Loop Tagging Table, available for download from the Department's Editable Documents page, shall be completed for the signalized intersection plan, including properly-identified loop numbers, vehicle directional movements with associated lane designations, phase assignments, individual loop numbers, and count output numbers. The completed Loop Tagging Table should be included in the Contract Information Book. Instructions for completing the Loop Tagging Table are also available for download from the Editable Documents page.

**502-3.05 Coordinated-Signal-System Design**

Coordination is an enhanced mode which is used to provide progression through a system of two or more signals. Coordination can be achieved with either a timed-based coordination (TBC) system or a closed-loop system. A TBC system operates on an internal time clock which is used to automatically select timing plans based upon the time of day and day of week. In a closed-loop system, the signals are interconnected using cables or another communication mechanism.

As traffic volume continues to increase, installation of coordinated signal systems should be used to improve traffic flow. By coordinating two or more traffic signals together, the overall capacity of the highway can be increased. Traffic signals which are 2600 ft or less apart should be considered for coordination. The use of a coordinated traffic signal system can satisfy the traffic needs of the highway for several years. It is also a relatively inexpensive method of improving capacity, thereby reducing delay, with minimal disruption to the highway as compared to the construction of additional lanes.

Wireless communication is often used to enable data collection, monitoring, and adjustment of the system from a remote location. This is accomplished using either wireless cell modems or radio connection to an ITS network where available.

**502-3.05(01) System-Timing Parameters**

The system-timing parameters used in a coordinated system include the following.

1. Cycle. The period of time in which a pre-timed controller, or an actuated controller, with demand on all phases, displays a complete sequence of signal indications. The cycle length is common to all intersections operating together and is called the background cycle.

2. Split. The proportioning of the cycle length among the phases of the local controller.

3. Offset. The time relationship determined by the difference between a specific point in the local signal sequence, the beginning of the major street green interval, and a system-wide reference point.

4. Time of Day or Day of Week. The time-of-day or day-of-week system selects system timing plans based on a predefined schedule. The timing plan selection can be based not only on the time of day but also on the day of week and week of year. The selection of the plan can be based upon a specific day of the year.

5. Traffic Responsive. A traffic responsive system implements timing patterns based on varying traffic conditions. This system selects from a number of predefined patterns. This system uses a computerized library of predefined timing patterns that are based on data collected by the system to develop the timing plan for the system.

**502-3.05(02) System Types**

Methodologies are available to coordinate traffic signals. Most of these take advantage of computer technology. As new signal controllers, computers, and software are developed, the design of coordinated traffic signal systems will continue to improve. These systems should match existing systems or be coordinated with nearby systems. A traffic-signal system is designed by those who specialize in such systems. To maintain consistency, each traffic-signal-system design must be coordinated through the Traffic Control Systems Division. System types are described below.

1. Interconnected Time-of-Day System. The interconnected time-of-day system is applicable to pre-timed and actuated controllers, in either a grid system or along an arterial system. The configuration for this type of system includes a field-located, timeclock-based master controller generating pattern selection and synchronization commands for transmission along an interconnecting cable or via radio modem. Local intersection coordination equipment interprets these commands and implements the desired timing.
   An interconnected time-of-day system can use the physical interconnection solely for the purpose of synchronizing the timeclocks in the local controller. The local controller selects the desired timing from pre-programmed plans stored in the local controller.

2. Time-Base Coordinated Time-of-Day System. Operationally equivalent to the interconnected time-of-day system, this type of system uses accurate timekeeping techniques to maintain a common time of day at each intersection without physical interconnection. Time-base coordination is tied to a 60 Hz AC power supply, with a battery backup if a power failure occurs.

   Time-base coordination allows for the inexpensive implementation of a system, because the need for an interconnect cable is eliminated. However, a time-base system requires periodic checking by maintenance personnel, because the power company's 60-Hz reference can be inconsistent. A power outage can affect only portions of a system, resulting in drift between intersections that continue to operate on power company lines and those that maintain time on a battery backup.

   Time-base coordination can be used as a backup for a computerized signal system.

3. Traffic-Responsive Arterial System. The traffic-responsive arterial system concept is used with semi-actuated controllers along an arterial. The field-located system master selects predetermined cycle lengths, splits, and offsets based upon current traffic flow measurements. These selections are transmitted along an interconnect cable or radio modem to coordination equipment at the local intersections.
   Cycle lengths are selected based on volume or occupancy level thresholds on the arterial where higher volumes correspond to longer cycles. Splits are selected based on the side-street volume demands. Offsets are selected by determining the predominant direction of flow along the arterial.

   System sampling detectors, located along the arterial, input data back to the master controller along the interconnect cable or radio modem. The current system has the capability to implement plans on a time-of-day basis and through traffic-responsive techniques.

4. Distributed-Master, or Closed-Loop, System. The distributed-master, or closed-loop, system advances the traffic-responsive arterial system by adding a communications link between the field-located master controller and an office-based microcomputer. The system is designed to interface with a personal computer over dial-up telephone lines. This connection is established only if the field master is generating a report or if the operator is interrogating or monitoring the system. With proper equipment, systems can share a single office-based microcomputer.

   The system permits the maintenance of the controller database from the office. The controller's configuration data, phase and timing parameters, and coordination patterns can be downloaded directly from the office.

   The distributed-master system provides remote monitoring and timing plan updating capabilities for only a minor increase in cost. The increase consists of only the expense of the personal computer and the monthly costs of a business telephone or cell phone line. Graphics displays are provided to assist in monitoring the system.

5. Central Computer, or Interval-Command System. This system can control large numbers of intersections from a central computer. This system requires constant communications between the central computer and each local intersection. The central computer determines the desired timing pattern parameters, based either on time-of-day or traffic-responsive criteria, and issues commands specific to each intersection once per second. These commands manipulate the controller into coordinated operation.

   The system also monitors each intersection once per second. Detector data, current green phase, and other information is transmitted back to the computer for necessary processing. The system can include a large wall-size map display, with indicators showing controller and detector status and other informational displays, as well as a color graphics monitoring system.

   A system of this type requires a large minicomputer, complete with a conditioned, environmentally controlled computer room.

6. Central Database-Driven Control System. This system is based on the qualities of the distributed-master system and the central-computer system. Although communications are maintained continuously with each intersection, timing pattern parameters are

downloaded to each controller, eliminating most of the second-by-second approach. This allows a larger number of intersections to be controlled by a less powerful computer.

The reduction in communications data required also allows an increase in monitoring data being returned to the computer. Thus, the complex graphics displays in a distributed-master system can also be implemented in a large-scale system.

**502-3.05(03) Communications Techniques**

Radio interconnection is the Department's preferred communication method if the radio site survey is satisfactory. The use of other interconnection methods will be determined on a system-by-system basis.

The district or the designer will conduct a site survey and submit the completed radio site survey report to the district traffic engineer. The radio site survey should be conducted with foliage on deciduous trees in the vicinity to ensure a minimum level of communications during the summer months. An approved digital Ethernet radio should be used for the survey. The Radio Site Survey Report form is available for download from the Department's Editable Documents page. A copy of the radio site survey report should be included in the Contract Information book.

The district or the designer will determine, based on the results of the radio site survey, what type of radio antenna should be used and the number of repeaters, if necessary, for the signal system.

## 502-3.06 Flashing Beacon

A flashing beacon is used to alert road users to a specific condition, call attention to a specific sign, or provide a warning.

**502-3.06(01) Intersection-Control Beacon**

An intersection-control beacon should be used where traffic or physical conditions do not justify conventional traffic signals, but where conditions indicate a hazard potential. *IMUTCD* Section 4L.02 provides guidance for the use of an intersection control flashing beacon.

An intersection control beacon consists of one or more sections of a standard traffic signal head, having flashing, circular yellow or circular red indications in each face. Each intersection leg must have at least two indications. Indications should flash simultaneously. Supplemental indications may be required on one or more approaches to provide adequate visibility to approaching motorists.

**502-3.06(02) Warning Beacon**

A warning beacon should be used only to supplement an appropriate warning or regulatory sign or marker. *IMUTCD* Section 4L.03 provides guidance for the use of a warning beacon.

**502-3.06(03) Speed Limit Sign Beacon**

*IMUTCD* Section 4L.04 provides guidance for the use of a speed limit sign beacon.

**502-3.06(04) Stop Sign Beacon**

*IMUTCD* Section 4L.05 provides guidance for the use of a stop sign beacon.

**502-3.06(05) General Flashing Beacon Design**

A flashing-beacon unit and its mounting must satisfy the design requirements for traffic-control signals. These include the following:

1. Lens. Each signal unit lens should have a visible diameter of at least 12 in. The lens must satisfy the ITE *Standard for Adjustable Face Vehicle Traffic Control Signal Heads.*

2. Sight Distance. While illuminated, the beacon should be visible to all motorists that it faces for a distance of 1200 ft under normal atmospheric conditions, unless otherwise physically obstructed.

3. Flashing. The flashing contacts should be equipped with filters for suppression of radio interference. A beacon must flash at a rate of at least 50 but not more than 60 flashes per minute. The illumination period of each flash should be between one-half and two-thirds of the total cycle. Where hazard identification beacons have more than one section, they may flash alternately.

4. Hours of Operation. A hazard identification beacon should be operated only during those hours when the hazard or regulation exists, e.g., school opening or closing. See *IMUTCD* Part 7.

5. Traffic Signal. A flashing yellow beacon used with an advance traffic-signal warning sign may be interconnected with a traffic-signal controller.

6. Alignment. If used to supplement a warning or regulatory sign, individual flashing-beacon units should be horizontally or vertically aligned. The edge of the housing should be located no closer than 1 ft to the nearest edge of the sign.

7. Location. The obstruction or other condition warranting the beacon will govern the location of the beacon with respect to the roadway. If used alone and located at the roadside, the bottom of the beacon unit should be at least 8 ft, but not more than 16 ft, above the pavement. If suspended over the roadway, the beacon clearance above the pavement should be at least 17 ft, but not more than 19 ft.

**502-3.06(06) Pedestrian Hybrid Beacon**

A pedestrian hybrid beacon is used to warn and control traffic at an unsignalized location to assist pedestrians in crossing a street or highway at a marked crosswalk. *IMUTCD* Section 4F provides guidance for the design and use of a pedestrian hybrid beacon.

**502-3.06(07) Wrong Way Vehicle Detection System [Add. Jan. 2025]**

A wrong way vehicle detection system is used to provide an alert to a driver traveling in the wrong direction. The system consists of vehicle detection, one or more controller cabinets, and flashing "Wrong Way" signs that are activated by the vehicle. Power may be provided by an electric service point or by solar power.

With approval from the District Traffic Engineer, wrong way vehicle detection systems may be installed at interchanges where the exit and entrance ramps are adjacent to each other, such as partial cloverleaf or folded diamond interchanges. Incidence of wrong way driving may be more pronounced at locations near bars, nightclubs, and entertainment venues where alcohol is served. See Section 502-1.02(09) for additional information on "Wrong Way" sign treatments at interchanges.

## 502-4.0 HIGHWAY LIGHTING

### 502-4.01 General

The purpose of highway lighting is to provide a safe and comfortable environment for the night-time motorist. Due to the voluminous nature of highway-lighting-system design, it is impractical for this chapter to provide a complete highway-lighting-design guide. For additional design information, see the references listed in Section 502-4.01(01). The intent of this chapter is to provide the user with a synopsis of the highway-lighting-design process and to provide INDOT's criteria, policies, and procedures regarding these issues.

**502-4.01(01) References**

1. AASHTO, *An Informational Guide for Roadway Lighting;*
2. FHWA, *Roadway Lighting Handbook*;
3. FHWA, *Roadway Lighting Handbook*, Addendum "Designing the Lighting System - Using Pavement Luminance";
4. Illuminating Engineering Society, *Roadway Lighting*, RP-8 (not used on an INDOT project);
5. TRB, NCHRP Report No. 152, *Warrants for Highway Lighting*, (not used on an INDOT project);
6. TRB, NCHRP Report No. 256, *Partial Lighting of Interchanges*, (not used on an INDOT project);
7. *Indiana Design Manual* Chapter 49, Roadway Design;
8. AASHTO, *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*;
9. INDOT *Standard Drawings*;
10. INDOT *Standard Specifications*;
11. National Electrical Code;
12. National Electric Safety Code; and
13. *Highway Safety Manual*.

**502-4.01(02) Definitions of Terms**

1. Average Maintained Illuminance. The average level of horizontal illuminance on the roadway pavement once the output of the lamp and luminaire is diminished by the maintenance factors; expressed in average foot-candles for the pavement area.

2. Candela (cd). The unit of luminous intensity.

3. Candela per Square Foot (cd/ft$^2$). The unit of photometric brightness, or luminance. The unit is equal to the uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of 1 lm/ft$^2$ or the average luminance of a surface emitting or reflecting light at that rate.

4. Effective Mounting Height. The vertical distance between the foundation of the light standard and the center of the light source in the luminaire.

5. Footcandle. The illuminance on a surface of 1 $ft^2$ in area on which there is uniformly distributed a light flux of 1 lm, or the illuminance produced on a surface for which all points are at a distance of 1 ft from a uniform point source of 1 cd.

6. Glare. The optical sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted and which causes annoyance, discomfort, or loss in visual performance and visibility.

7. Illuminance. The density of the luminous flux incident on a surface. It is the quotient of the luminous flux divided by the area of the surface where the latter is uniformly illuminated.

8. Lamp Lumens Depreciation Factor (LLD). A depreciation factor that indicates the decrease in a lamp's initial lumen output over time. For design calculations, the initial lamp lumen value is reduced by an LLD to compensate for the anticipated lumen reduction.

9. Longitudinal Roadway Line. A line along the roadway parallel to the curb or shoulder line.

10. Lumen (lm). A unit of measure of the quantity of light.

11. Luminaire. A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply.

12. Luminaire Dirt Depreciation Factor (LDD). A depreciation factor that indicates the expected reduction of a lamp's initial lumen output due to the accumulation of dirt on or within the luminaire over time.

13. Luminance. The luminous intensity of a surface in a given direction per unit of projected area of the surface as viewed from that direction.

14. Maintenance Factor (MF). A combination of light-loss factors used to denote the reduction of the illumination for a given area after a period of time compared to the initial illumination on the same area. MF = LLD x LDD.

15. Mounting Height. The vertical distance between the roadway surface and the center of the light source in the luminaire.

16. Nadir. The vertical axis which passes through the center of the luminaire light source.

17. Spacing. The distance in feet between successive lighting units.

18. Transverse Roadway Line. A line across the roadway that is perpendicular to the curb or shoulder line.

19. Uniformity Ratio. The ratio of average maintained lux of illuminance on the pavement to the maintained lux at the point of minimum illuminance on the pavement. A uniformity ratio of 3:1 means that the average lux value on the pavement is three times the lux value at the point of least illuminance on the pavement.

**502-4.01(03) State and Local Responsibilities [Rev. Jul. 2022]**

See Operations Memorandum 22-01 for revised policy on state and local responsibilities.

**502-4.01(04) Lighting Studies [Rev. Jul. 2022]**

See Operations Memorandum 22-01 for revised policy on lighting studies.

**502-4.02 Warrants [Rev. Jul. 2022]**

See Operations Memorandum 22-01 for revised policy on warrants.

**502-4.02(01) Warrant Criteria for Freeways [Del. Jul. 2022]**

**502-4.02(02) Warrant Criteria for Interchanges [Del. Jul. 2022]**

**502-4.02(03) Warrant Criteria for Non-Freeways [Rev. Jan 2016, Del. Jul. 2022]**

**502-4.02(04) Criteria for Highway-Sign Lighting [Del. Jul. 2022]**

**502-4.02(05) Criteria for Rest Area [Del. Jul. 2022]**

**502-4.02(06) Criteria for Truck Weigh Station [Del. Jul. 2022]**

**502-4.02(07) Criteria for Bridge Structure [Del. Jul. 2022]**

**502-4.02(08) Criteria for Tunnel or Underpass [Rev. Jan. 2016, Del. Jul. 2022]**

**502-4.02(09) Criteria for Roundabout [Rev. Jan. 2016, Del. Jul. 2022]**

**502-4.02(10) Criteria for Other Facilities [Del. Jul. 2022]**

**502-4.02(11) Reduction or Removal of Lighting [Rev. Jan. 2016, Del. Jul. 2022]**

**502-4.02(12) Alternative criteria for urban streets [Added Jan. 2016, Del. Jul. 2022]**

**502-4.02(13) Transition Lighting [Added Jan. 2016, Del. Jul. 2022]**

**502-4.02(14) Adaptive Lighting [Added Jan. 2016, Del. Jul. 2022]**

## 502-4.03 Lighting Equipment

A number of options are available in selecting luminaire equipment that will satisfy the desired design criteria. Figure 502-4A, Typical Light-Pole Installation, provides an illustration of the parts of the lighting standard and luminaire. In addition to the INDOT *Standard Drawings* and the INDOT *Standard Specifications,* the following provides guidance regarding INDOT's approved lighting equipment.

The selected equipment should be determined to be in accordance with standard hardware designs. Specialized equipment and designs can increase the installation and maintenance costs, thereby reducing the cost effectiveness of the lighting system.

**502-4.03(01) Foundation**

Upon determining the foundation design, the following should be considered.

1. Material. Each foundation for a permanent installation should be concrete class A. It may be either cast-in-place or precast.

2. Design. The INDOT *Standard Drawings* provide the details for depth, width, reinforcing, etc., for both conventional and high-mast light standards. For a high-mast foundation, a soil survey is required to determine if additional support is required.

3. Placement and Grading. The INDOT *Standard Drawings* and Section 502-4.06(05) provide the criteria for the placement of a light standard relative to the roadway and ditch lines. They also provide criteria for grading around the light standard foundation.

### 502-4.03(02) Light Standard or Pole

A factor in highway lighting design is the selection of the luminaire and the mounting height. A higher mounting height will reduce the number of light standards required. The INDOT *Standard Specifications* and the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* provide the Department's criteria for light standards. The following describes the light standards used by the Department.

1. Conventional. This type of pole is used most often. It has a mounting height ranging from 30 ft to 50 ft. INDOT practice is to use a light pole with a mounting height between 40 ft and 50 ft. The recommended minimum mounting height is 40 ft. Details for conventional light poles appear in the INDOT *Standard Drawings*.

2. High-Mast. A high-mast pole can range from 80 ft to 200 ft in height. This type should be used where there is a large area that requires lighting, e.g., interchange. The use of high-mast lighting and higher-wattage lamps reduces the number of poles, yet retains the quality of the lighting. High-mast lighting should be considered where practical. Details for high-mast towers appear in the INDOT *Standard Drawings*.

3. Materials. Light standards for a permanent installation are made of galvanized steel, stainless steel, or aluminum. Wood poles are used as service poles or for temporary lighting, e.g., in a construction zone.

4. Base. Unless otherwise protected, a breakaway base should be provided for each light pole within the clear zone along a rural or high-speed urban highway. However, where pedestrians are present, a breakaway base should not be used. Section 502-4.06(05) provides additional criteria on the appropriate application of where to use a breakaway or non-breakaway base. Each breakaway base should be in accordance with the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires*, *and Traffic Signals*. The base types include the following.

    a. Breakaway Transformer Base. A transformer base consists of an aluminum apron between the concrete foundation and the base of the pole. The breakaway transformer base is designed to be struck by a car's bumper. Once hit, the base deforms and breaks away. All wiring inside the base must also be connected to the breakaway device. The cast-aluminum transformer base should be used.

    b. Non-Breakaway Steel Transformer Base. A steel transformer base is similar in design to an aluminum base. However, it is not in accordance with the AASHTO breakaway criteria. Section 502-4.06(05) discusses the appropriate locations where a breakaway base is not required.

c. Breakaway Support Coupling. A breakaway support coupling is an aluminum connector or sleeve which is designed to shear once the pole is hit. The bottom of the coupling is threaded onto the foundation anchor bolts, and the light standard is attached to the top of the coupling. Four couplings are used with each light standard. The support coupling length is 5 in.

d. Anchor Base. An anchor base is a metal plate which is welded to the bottom of the luminaire support. The plate allows the post to be bolted to the foundation without an intermediate breakaway device or to a breakaway coupling, slip plate, or transformer base.

5. Structural Design. Each light standard should be designed in accordance with the structural design criteria described in the INDOT *Standard Specifications*, including the criteria for wind loading, maximum horizontal deflection, maximum stresses, luminaire loads, material strengths, welds, bolts, etc.

6. Effective Mounting Height. A light standard must be constructed so that it provides a luminaire mounting height above the roadway pavement as shown in Figure 502-4A, Typical Light-Pole Installation. After determining the mounting height, the appropriate pole length can then be determined.

7. Lighting Location Identification Numbering System.

   Lighting identification numbers should be incorporated into the plans and should be determined as follows:

   a. Overall Numbering Format.

      1) The first set in the identification is the county number in which the lighting system is located.

      2) The county number is followed by a 1-, 2-, or 3-digit route number of the mainline route or major road on which the system is located.

      3) The mainline route number is followed by the cross road number.

         If the cross road is a numbered route on the state highway system the 1-, 2-, or 3-digit route number of the cross road should be used.

If the cross road is not a numbered state highway system route then a special identifier is needed for the county road, city street, exit number, rest area or weigh station. See item 7.b for details.

4) The last set is the 1-, 2-, or 3-digit number specifying the individual pole, sign, or underpass location.

b. Specialized Numbering for Cross Roads that Are Not Numbered State Routes.

1) Intersection of an Interstate Route and a County Road or City Street.

The cross road should be labeled with “EX” (for exit) as a special identifier followed by the mile marker exit number of the interchange.

2) Intersection of S.R. or U.S. Route and a County Road.

The cross road special identifier should be “CR” (for County Road) followed by the county road number.

3) Intersection of S.R. or U.S. Route With a City Street.

The first two letters of the city’s name should be used as the special identifier followed by a three- or four-letter abbreviation of the crossroad’s name.

4) Rest Area Located on the Interstate.

“NR”, “SR”, “ER” or “WR” (for northbound rest area, southbound rest area, eastbound rest area or westbound rest area respectively) should be used as the special identifier followed by the 1-, 2-, or 3-digit mile marker number closest to the rest area.

5) Rest Area Located on a S.R. or U.S. Route.

“RA” should be used as the special identifier followed by a three- or four-letter abbreviation of the rest area’s name.

6) Weigh Station Located on the Interstate.

“NW”, “SW”, “EW” or “WW” (for northbound weigh station, southbound weigh station, east bound weigh station, or westbound weigh station respectively) should be used as the special identifier followed by the 1-, 2-, or 3-digit mile marker number closest to the weigh station.

7) Weigh Station Located on a S. R. or U.S. Route.

The special identifiers are to be used in the same manner as for weigh station on interstates routs with the exception that instead of using a 1-, 2-, or 3-digit mile marker numbers, there will be a four-letter unique identifier created for that particular weigh station.

When more than two routes intersect at a location, only the two most primary or major route numbers shall be used to identify the location.

When two routes intersect more than once in a county, then the letters “NJ”, “SJ”, “EJ” or “WJ” shall be used after the 1-, 2-, or 3-digits of the crossroad route number and before the hyphen to indicate that a given intersection is the north junction, south junction, east junction, or west junction respectively.

**502-4.03(03) Mast Arm**

A mast arm allows placement of the light source near the edge of the travel lane. The use of a longer mast arm is recommended, although the initial costs may be higher. A longer mast arm allows the pole to be placed farther from the traveled way, thus providing a safer roadside environment. Otherwise, the use of a longer mast arm can have a negative effect on the loading capabilities of the base. In addition to the INDOT *Standard Specifications*, the following provides information and design guidance regarding the use of a mast arm.

1. Material. Mast arms are made of the same material as the light standard.

2. Mast Arm. The following should be used to determine the appropriate mast-arm type.

    a. Less than 8 ft. This may be either of the single-member or the truss-type design. The design should be consistent with other nearby mast arm types.

    b. 8 ft or Longer. This should be of only the truss-type design.

3. Mast-Arm Length. The length of the mast arm should be such that the luminaire is placed over the center of the width of the shoulder.

4. Bridge. Each mast arm for a bridge-deck light standard should be of the truss-type design.

5. Rise. Figure 502-4B, Mast-Arm Rise, provides the maximum rise that should be used, based on the mast-arm length. See Figure 502-4A for Typical Light-Pole Installation and illustration of Mast-Arm Rise.

**502-4.03(04) Luminaire [Rev. Jan. 2016]**

A luminaire is defined as a complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute light. The INDOT *Standard Specifications*, along with the following, provide the Department's criteria for luminaire hardware. Section 502-4.06(03) item 1 discusses the light distributions for a luminaire. For additional information, the designer should contact the Traffic Administration Manager, Traffic Engineering Division for the latest products and specifications.

1. Light Source. Only a high-intensity discharge light source should be used. The following provides information on the light sources that may be used.

   a. High-Pressure Sodium (HPS). The HPS lamp produces a soft, pinkish-yellow light by passing an electric current through a sodium-and-mercury vapor.

   b. Low-Pressure Sodium (LPS). Its disadvantage is that it requires long tubes and has poor color quality. INDOT does not allow the use of LPS on a state facility. However, a local agency can consider the use of an LPS lighting source. The LPS lamp produces a yellow light by passing an electrical current through a sodium vapor.

   c. Metal Halide (MH). A metal-halide lamp produces color at higher efficiency than a mercury vapor (MV) lamp. However, life expectancy for a traditional MH lamp is shorter than that for an HPS or MV. An MH lamp is also more sensitive to lamp orientation than other light sources. The traditional MH luminaire is used for lighting a sports arena or major sports stadium, for high-mast lighting, or for lighting a downtown area or park. Metal Halide luminaires utilizing solid state ballasts are viable options for general roadway applications. Metal halide produces good color rendition. Light is produced by passing a current through a combination of metallic vapors.

   d. Light Emitting Diode (LED). LEDs are arranged in clusters which are attached to a panel. Various designs utilize different LED types Heat sinks are built into the housing to facilitate heat dissipation and maximize luminaire service life. Light is directly emitted from the lens, so reflectors are not required, resulting in the light being delivered more efficiently than the HPS type and also resulting in less light pollution. LEDs are energy efficient, have a long life, and generate a full color spectrum resulting in good color rendition. Due to the manner in which light is emitted the arrays must be carefully arranged to provide sufficient light distribution and yet be energy efficient. Properly arranged LEDs can provide energy efficient, effective light distribution.

LED retrofits are available for existing high mast luminaires. LED modules are attached to a threaded rod which is fit into the existing housing. Luminaire dimensions should be verified as housing diameters less than 16 inches may require an attachment plate as well as the threaded rod, pending the retrofit manufacturer's specific design.

e. Light Emitting Plasma. Plasma lamps generate light by exciting gas with radio frequency power. They produce visible light without phosphor conversion which results in a higher luminaire efficiency and which eliminates color shift. The point-source light they generate results in an even distribution of light through highly efficient optics. Plasma luminaires have no electrodes which reduces maintenance requirements. They are highly efficient, have a long life, and generate a full color spectrum resulting in good color rendition. Heat sinks are built into the housing to facilitate heat dissipation and maximize luminaire service life.

f. Induction Lighting. Magnetic induction lamps also contain no electrodes resulting in an extended service life. The power used to generate light is transferred from outside the lamp to inside via electromagnetic fields. Induction lamps are also efficient light generators compared to HPS lamps.

2. <u>Optical System</u>. The optical system consists of a light source, a reflector (except for LED), and also a refractor (or lens for LED).

   a. Light Source. Item 1 above discusses light sources that should be considered.

   b. Reflector. The reflector is used in optical control to change the direction of the light rays. Its purpose is to take that portion of light emitted by the lamp that otherwise will be lost or poorly utilized, and to redirect it to a more desirable distribution pattern. A reflector is designed to work either alone or with a refractor. Reflectors are specular or diffuse. A specular reflector is made from a glossy material that provides a mirror-like surface. A diffuse reflector is used where the intent is to spread the light over a wider area.

c. Refractor. The refractor is another means in optical control to change the direction of the light. A refractor is made of transparent high-strength glass or plastic. Plastic is used in a high-vandalism area. However, plastic can yellow over time due to heat and ultraviolet exposure. The refractor, through its prismatic construction, controls and redirects both the light emitted by the lamp and the light reflected off the reflector. It can also be used to control the brightness of the lamp source.

3. Ballast/Power Driver. Each luminaire must operate with an input voltage variation of ±10% of the rated operating voltage specified, with non-solid state technologies this is accomplished through a built-in ballast. A ballast is used to regulate the voltage to the lamp to ensure that the lamp is operating within its design parameters. It also provides the proper open-circuit voltage to start the lamp. The ballast should be an auto-regulator type. Figure 502-4C, Lamp Data, provides the approximate expected operating wattage for a ballast based on the lamp wattage.

   For solid state technology luminaires the input voltage is controlled by a power driver. Power drivers are completely electronic and are considered to be the controlling component in the performance and service life of the luminaire. Electronic power drivers allow for the light source to be dimmed so they provide an opportunity to reduce energy consumption through adaptive lighting (reduced light levels after a certain time at night).

4. Housing Unit. Luminaire housing requirements are dependent upon the application type. In selecting a luminaire housing, the following should be considered.

   a. Roadway-Lighting Luminaire. The housing unit should allow access from the street side and allow for adjustments to the light. The luminaire should also have a high-impact, heat-resistant, glass, or plastic prismatic refractor.

      Since LEDs generate a substantial amount of heat and since they are sensitive to heat buildup, their housings are provided with apparatus known as heat sinks to dissipate heat in an effective manner. The typical heat sink is a shape or plate placed in contact with the LED panel. The shape or plate is usually made of a conductive metal such as aluminum.

   b. Sign Luminaire. A sign luminaire requires the same housing as a roadway-lighting luminaire, except that it should also provide a durable, plastic, vandal-resistant shield that blocks the view of the refractor from an approaching motorist. The unit is attached to the sign walkway as shown on the INDOT *Standard Drawings.* The mounting attachment is adjustable to allow for directing the light onto the sign.

c. Underpass Luminaire. An underpass luminaire requires the same housing as a roadway-lighting luminaire, except that it should also provide a durable, plastic, vandal-resistant shield. The ballast should be placed as shown on the INDOT *Standard Drawings*. An underpass luminaire may be attached to the vertical-side surface of a bridge bent structure, or may be suspended by the use of a pendant.

d. High-Mast Luminaire. A high-mast luminaire is an enclosed unit with a reflector and a borosilicate glass refractor. The luminaire is attached to the mast ring. The mounting attachment is adjustable to allow for directing the light.

5. <u>Backlight, Uplight, and Glare (BUG) Rating</u>. I.E.S.N.A. has recently adopted a system of classifying the amount of light that is generated in three distinct directions from the luminaire. The BUG rating system is an alternative to the conventional "cut-off" system as a means of classifying light distribution.

Backlight is defined as the light distributed away from the street (towards sidewalk, shoulder, etc.) and below the luminaire. Uplight is the amount of light that is directed above the luminaire either to the front or back. Glare, or offensive light, results from light distributed to the street side below the luminaire and towards the driver at an acute angle from the luminaire (less than 30 degrees from horizontal).

BUG ratings can be specified to limit or control the amount of glare, sky glow and light trespass effecting the environment of the lighting system. For example for locations adjacent to observatories and planetariums it may be desirable to keep the amount of uplight to a minimum thereby reducing sky glow and interference with astronomical observations. In urban settings a certain amount of backlight on sidewalk and parking lot areas may be desirable for added security. For luminaires mounted at lower heights (less than 30 ft) the designer should consider models with a glare rating no greater than 3.
Each of the three ratings is on a scale of 0 to 6, higher the number the greater the affect.
For additional information on the BUG rating system refer to the following I.E.S.N.A. publication: *https://www.ies.org/pdf/education/ies-fol-addenda-1-%20bug-ratings.pdf*.

### 502-4.03(05) Wiring and Other Equipment [Rev. Jan. 2025]

In developing a highway-lighting system, the equipment component can affect the design of the system. The elements include the following and are addressed in the INDOT *Standard Drawings,* the INDOT *Standard Specifications* and the manufacturer's criteria.

1. Wiring. Four No.4 copper conductors are used for the pole-to-pole underground circuits. Three No. 10 copper conductors should be specified for the pole circuit: one hot wire, one neutral and one wire to connect the ground lug at the base of the pole to the luminaire.

2. Electric Components. See Section 502-4.03(04) for a discussion of electrical components for various light sources, including ballasts, fuses, photoelectric controls, wiring, conduit, handholes, connections, breaker boxes, circuit breakers, relay switches, etc.

3. High-Mast Light Standard. The components include the luminaire ring assembly for attaching a luminaire, head frame assembly, winch assembly, external drive system used to lower the luminaire for maintenance, cable terminator, and lightning rod.

4. Utility Service. Many electric providers have not yet adopted a flat billing rate for solid state light sources. When solid state is to be used, specifying a metered service should be considered so that the owner may better realize the benefit of reduced energy consumption. This will involve coordination with the electric provider and either the district office or the agency of jurisdiction.

## 502-4.04 Lighting Methodologies

The lighting-design methodologies are those for illuminance, luminance, and small-target visibility. The Illuminating Engineering Society (IES) of North America has been the leader in the development of these procedures. Only the illuminance methodology should be used in the design of highway lighting. For additional information on these procedures, see the references listed in Section 502-4.01(01).

### 502-4.04(01) Illuminance

Illuminance is defined as the density of the luminous flux incident on a surface measured in footcandles. The methodology is concerned with the measurement of the light's intensity striking a particular point on the pavement. The brightest spot will occur directly under the luminaire and diminish the farther a motorist is away from the source. The disadvantage of this methodology is that one does not see incident light, but instead sees the light reflected from an object or surface. This sensation is known as brightness, with objects distinguished by the difference in brightness or contrast. Brightness can be expressed mathematically as luminance, or the luminous intensity per unit area directed towards the eye.

The factors in illuminance methodology are the measurement of average maintained horizontal illumination, $E_h$, and the uniformity ratio of the average-maintained illuminance to the minimum-maintained illuminance.

### 502-4.04(02) Luminance

Luminance is defined as the luminous intensity of a surface in a given direction per unit of projected area of the surface as viewed from that direction. It is measured in candelas per square foot. The luminance methodology is concerned with the measurement of light from the luminaire reflecting off the pavement surface to the motorist's eyes. This measurement is affected by the pavement's reflectivity characteristics. To obtain the lighting measurements for the roadway, readings are taken from a set of observation points spread across the roadway in a grid pattern. Compared to the illuminance methodology, the luminance methodology is considered a more-accurate representation of the motorist's visibility requirements. However, the methodology is more complicated to understand and use. Also, the pavement reflectivity must be estimated for the current time and for the future.

The design factors in luminance design include average maintained luminance ($L_{avg}$), minimum luminance ($L_{min}$), maximum luminance ($L_{max}$), maximum veiling luminance ($L_v$), and ratios of $L_{avg}$ to $L_{min}$, $L_{max}$ to $L_{min}$, and $L_v$ to $L_{avg}$. This methodology should not be used in lighting-determination design.

### 502-4.04(03) Small-Target Visibility (STV)

IES has proposed the STV methodology in an effort to better-define actual visibility requirements of the motorist. This methodology is similar to the luminance methodology in measurement of the light's reflectivity but, instead of measuring the pavement's reflectivity, it measures the reflectivity of a flat, square target of 7 in. diameter with 20% diffuse reflectance against the pavement background. The target is perpendicular to the roadway surface and is located a fixed distance of 270 ft ahead of the observer. The observer's target sight line is parallel to the centerline of the roadway. The STV methodology is more complex than the other methodologies and is considered impossible to calculate manually. Therefore, a computer is required. The STV methodology should not be used.

## 502-4.05 Design Procedure [Rev. Jan. 2016]

For additional design information, see the references listed in Section 502-4.01(01).

Lighting-system design should consider various light sources and may require several iterations for each type of light source to produce an acceptable design. After the first run, if the design criteria are not satisfied, the initial parameters should be changed, e.g., pole spacing, mounting height, light

source, luminaire wattage, and lamp lumen output. The design should be rechecked to determine if it then satisfies the criteria. This process is repeated until the design is optimized and all criteria are satisfied.
As part of the scope of work on a project the designer may be given specific parameters for the lighting system, e.g., tower or conventional, pole height, and luminaire type, to supplement or supersede the guidance provided in this section.

Lighting in the interchange area should be maintained at the same level or better as on the crossroad approaches. Partial interchange lighting should include the merge and diverge areas- see Figure 502-4M.

Conflict points, protected turn lanes, and approaches to divided areas and traffic islands should be illuminated when intersection lighting is provided.

### 502-4.05(01) Computerized Design [Rev. Jan. 2016]

To determine an acceptable lighting system requires iterations using variables. The chance for error in manually solving its equations is high. Therefore, one of the commercial computer software packages that are available should be used.

Each software package requires the same input and performs the same calculations. However, the method of input can vary. The user should first determine which programs are currently acceptable to INDOT. The PC-based program VISUAL®, developed by Acuity Brands, or AGi32, by Lighting Analysts should be used for its lighting calculations. These programs are used to generate templates for design and to check lighting levels and uniformity.

The design model files for a lighting design prepared by a consultant, should be provided to the Traffic Design and Review Team, Traffic Engineering Division.

### 502-4.05(02) Design Process [Rev. Jan. 2016]

Lighting may be designed under four different scenarios. The procedural steps in designing a lighting system for each are as follows.

1. Spot Lighting. Spot lighting comprises no more than one or two lights at an intersection or other particular spot along the roadway where it is deemed necessary to identify that roadway feature at nighttime.

In this circumstance AASHTO design criteria need not be applied so it is not necessary for the designer to perform light level computations.

The design should be developed as follows:

a. Coordinate with the utility company to determine the availability of electric service and to identify the location of the service point. Reimbursement costs to the utility company should be identified in a special provision and the cost incorporated into the bid estimate.

b. Develop a plan sheet for the location. The plan sheet should include the roadway geometry, the location of the service point indicating the voltage being supplied, location of the pole(s), the orientation of the luminaire(s), the light source type and luminaire wattage, as well as any underground wiring, conduit, handholes, and cable duct markers needed.

2. Luminaire Replacement or Partial Modernizations. This type of project involves the replacement of luminaires on existing poles. Other equipment may also be replaced.

   The design should be developed as follows:

   a. Assembly of Information. Obtain a plan of the existing lighting system.

   b. Verification of Plan. Verify that the geometrics and lighting system are accurately detailed on the existing plan sheet.

   c. Confirmation of Scope. Confirm which elements in the system are to be modernized. This should be coordinated with the district Traffic Office.

   d. Selection of Design Criteria. Select the appropriate AASHTO design criteria based on the type of roadway. See 502-4.06(02) for more information.

   e. Selection of Light Source Type. Select the optimal light source type and wattage to satisfy the design criteria in a cost effective manner. Because calculations by computer are relatively quick and easy, the designer should try a number of alternative light source types even if the first design satisfies the criteria since more than one alternative may be satisfactory. Systems with 40-ft height poles will typically utilize a luminaire that provides approximately 28,000 or 50,000 lumens of initial light output in a M-S-Type II, III or Type IV IES distribution classification. See Figure 502-4C for more information on lumen output and Figure 502-4 I for information on the IES classification system.

At a minimum the alternatives should include one HPS, one LED, one plasma, and one metal halide model. Other light source types may also be considered. For systems utilizing a shorter mounting height (e.g. with streetscape projects utilizing pedestal poles), induction lighting may be viable. Only luminaire types and models that have an accessible IES light distribution file can be used. For a list of manufacturers that have approached INDOT about use of their luminaires go to Y:\TrafficManagement\Luminaire Manufacturers. Consultants and local agencies may contact their Project Manager or the Office of Traffic Administration to obtain this information.

Design optimization should include an analysis for the purpose of minimizing service costs. The lowest service cost per year alternative should be selected. The service cost is defined to be:

Service Cost per Year =
Annual Energy Cost + Annual Routine Luminaire Maintenance Costs
+ Installation Cost/Service Life

Where:

Annual Energy Cost = (Total Luminaire Wattage of the System) x (Hours Operated per Year) x (Cost of Electricity)

Hours Operated per Year = 4380 h

Cost of Electricity (estimated) = $0.10 per kWh (as of Oct. 2014)
The average cost of electricity for the transportation sector in the state of Indiana is available from the U.S. Energy Information Administration's Electric Monthly Report, table 5.6.b, at

*http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_06_b*.

The electric provider or district may have a more location specific unit cost.

Maintenance Cost for HPS should be based on re-lamping the entire system every 3 years as well as other miscellaneous work. Currently this cost is estimated at $60 per year for each 250-watt or 400-watt luminaire and $105 per year for each 1000-watt high-mast luminaire. The cost for non-HPS light sources may be estimated at $25 per year for roadway luminaires and $50 per year for high-mast luminaires plus any additional maintenance costs that are specific to the type and model. The designer should confer with the manufacturer for these specific maintenance costs; however, typically plasma emitters will need to be replaced after 50,000 (11 years). LED arrays and power drivers may also need to be replaced within the expected service life- these additional maintenance costs should be included. If manufacturer specific information is not available additional annual maintenance costs of $15 per LED or plasma roadway luminaire and $20 per LED or plasma high mast luminaire may be used; bringing the total estimated annual maintenance costs for the lighting system to $40 per roadway luminaire and $70 per year for high mast.

Recent bid history as obtained on the INDOT website should be used to estimate the cost of HPS luminaires. Cost of luminaires utilizing alternative light sources should be obtained from the manufacturer along with an estimate of the cost to install for about 1 hour of labor per luminaire. A $75 estimate can be used for labor cost.

Service life may be estimated at 20 years, including the luminaire regardless of light source type.

Warranty Period is defined to be 5 years or the manufacturer's specific warranty period if greater than 5 years. The designer should verify the warranty period as some manufacturers provide longer coverage periods.

A Service Costs Analysis for Luminaire Modernization worksheet should be completed for each alternative considered and placed in the project file. An editable version of this worksheet is available for download from the Design Manual Editable Documents web page, http://www.in.gov/dot/div/ contracts/design/dmforms/. If the service cost analysis does not yield a clear choice, other factors such as the light color or district preferences should be weighed into the decision regarding the type of light source.

f. Electric Design. Once the luminaire model has been selected, the designer will need to determine the voltage drop for the system. Section 502-4.06(07) provides information on how to determine the voltage drop for the lighting system. If the most cost effective model results in too much voltage drop the designer may either check the voltage drop of the second most cost effective design for use or may try additional luminaire models.

g. Preparation of Plans. The plan sheet should indicate the average illumination level and uniformity ratio and should show the location of the existing equipment being reused with an indication of what items are being replaced or added. Equipment includes the service point indicating voltage being supplied, pole(s), and the orientation of the luminaire, underground wiring, conduit, handholes, and cable duct markers. The light source type, luminaire wattage, total initial lumen output, estimated light loss factor, and the IES file type used will be given on the plans with a note that the distribution pattern of the actual luminaire to be supplied will be equivalent, e.g., "Luminaire shall provide a light distribution equivalent to IES distribution type GE 452918.IES." This distribution pattern is based on how a specific luminaire model distributes light, i.e., how it is designed, and also corresponds to the lumen output and power draw of the fixture. If a particular backlight/uplight/glare rating is needed this information should also be specified on the plans. The luminaire table, service point amp table, and the lighting ID numbers should also be included on the plans.

h. Utility Notification. If there is a change in service location or an increase in the power required the designer must coordinate with the electric provider. Reimbursement costs to the utility company should be identified in a special provision and the cost incorporated into the bid estimate.

**i.** Working (Shop) Drawing Check. As part of the working drawing approval the contractor will submit the IES photometric distribution file for each model when the IES file number is different from that indicated on the plans, i.e., when the contractor is submitting a different model than that on which the design is based. In these cases, the IES files will be provided to the design engineer of record for his/her review and concurrence that the design light level criteria will be satisfied.

3. New Lighting System or Full Modernizations. This procedure should be followed when designing a new system or when modernizing and the existing poles and foundations will not be reused.

a. Assembly of Information. Necessary information to be assembled includes the following.

1) Contact the Traffic Review Team for the current design policies and procedures applicable to the project, sample plans, schedules, pay quantities, and example calculations.
2) Gather roadway and bridge plans including plan and profile sheets and details sheets, e.g., those for overhead signs.
3) Determine existing and expected utility locations.
4) Discuss special considerations with the road or bridge designer.
5) Conduct field reviews. Note areas of high ambient lighting and facilities that are sensitive to light trespass or sky glow (e.g. farms, observatories).
6) If this project is a local-agency project, hold discussions with local officials.

b. Determination of Classifications. The roadway classification and environmental conditions should be determined. If not already included in the project report, this information can be obtained from the Environmental Policy Team. The roadway classifications, for lighting purposes, are defined in Section 502-4.06(01).

c. Selection of Design Criteria. The pertinent design methodology described in Section 502-4.04 should be selected, along with the appropriate criteria based on the classification selected in Step 2. See Section 502-4.06(02) for information. For an INDOT-route lighting project, only the illuminance design methodology should be used.

d. Selection of Optimum Design and Light Source Type. Because recalculations by computer are relatively quick and easy, the designer should try several alternatives even if one design satisfies the criteria. There is often more than one satisfactory alternative.

At a minimum, the alternatives should include one HPS, one LED, one plasma, and one metal halide model, although other light source types may also be considered. For systems utilizing shorter mounting height (e.g. with streetscape projects utilizing pedestal poles) induction lighting may be viable. Only luminaire types and models that have a published IES light distribution can be used. For a list of manufacturers that have approached INDOT about use of their luminaires go to Y:\TrafficManagement\Luminaire Manufacturers-list. Consultants and local agencies may contact their Project Manager or the Office of Traffic Administration to obtain this information.

Design Optimization should include an analysis for the purpose of minimizing service costs. The lowest service cost per year alternative should be selected. The service cost is defined to be:

Service Cost per Year =

Annual Energy Cost + Annual Routine Luminaire Maintenance Costs
+ Installation Costs/Service life

Where:

Annual Energy Cost = (Total Luminaire Wattage of the System) x (Hours Operated per Year) x (Cost of Electricity)

Hours Operated per Year = 4380 h

Cost of Electricity (estimated) = $0.10 per kWh (as of Oct. 2014)
The average cost of electricity for the transportation sector in the state of Indiana is available from the U.S. Energy Information Administration's Electric Monthly Report, table 5.6.b, at

http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_06_b.

*The electric provider or district may have a more location specific unit cost.*

Maintenance Cost for HPS should be based on re-lamping the entire system every 3 years as well as other miscellaneous work. Currently this cost is estimated at $60 per year for each 250-watt or 400-watt luminaire and $105 per year for each 1000-watt high-mast luminaire. The cost for non-HPS light sources may be estimated at $25 per year for roadway luminaires and $50 per year for high-mast luminaires plus any additional maintenance costs that are specific to the type and model. The designer should confer with the manufacturer for these specific maintenance costs; however, typically plasma emitters will need to be replaced after 50,000 (11 years). LED arrays and power drivers may also need to be replaced within the expected service life- these additional maintenance costs should be included. If manufacturer specific information is not available additional annual maintenance costs of $15 per LED or plasma roadway luminaire and $20 per LED or plasma high mast luminaire may be used; bringing the total estimated annual maintenance costs for the lighting system to $40 per roadway luminaire and $70 per year for high mast.

Installation Cost should include poles and foundations as well as the luminaires. Recent bid history as obtained on INDOT website should be used. Cost of luminaires utilizing other light sources should be obtained from the manufacturer along with an estimate of the cost to install for about 1 hour of labor per luminaire. A $75 estimate can be used for labor cost.

Service life may be estimated at 20 years, including the luminaire regardless of light source type.

A Service Costs Analysis for New or Fully Modernized Lighting worksheet should be completed for each alternative considered and placed in the project file. An editable version of this worksheet is available for download from the Design Manual Editable Documents web page, http://www.in.gov/dot/div/contracts/design/dmforms/. If the service cost analysis does not yield a clear choice, other factors such as the light color or district preferences should be weighed into the decision regarding the type of light source.

1) Selection of Equipment and Light Output Characteristics. In the preliminary design, initial assumptions should be made regarding the equipment composition and light output. This includes mounting height, pole setback distance, light source, mast-arm length, light source type, lamp wattage, etc. Typically a 40-ft height pole is used with a luminaire that provides approximately 28,000 or 50,000 lumens of initial light output in an M-S-Type II, III or Type IV IES distribution classification. See Figure 502-4G for information on the IES classification system. Figure 502-4C, Lamp Data, provides the information on lighting levels for lighting sources. See Sections 502-4.03 and 502-4.06(03) for additional information on equipment selection. After selecting the luminaire equipment, the photometric data sheet should be obtained from the manufacturer for the luminaire selected.

   Normally mounting heights and mast arm lengths will be uniform through the project limits. If the project ties into adjacent lighting systems consideration should be given to matching these considerations.

2) Selection of Layout Arrangement. Section 502-4.06(04) provides information on the commonly used lighting arrangements. The selection of the appropriate layout design depends upon local site conditions and engineering judgment. Section 502-4.06(05) provides the roadside-safety considerations in selecting the lighting arrangements. Section 502-4.06 (06) provides other layout considerations.

3) Luminaire Spacing. For an INDOT-route lighting project, the illuminance methodology should be used to determine the appropriate luminaire spacing. This step is conducted by the computer.

4) Check for Uniformity. Once the spacing has been determined, the uniformity of light distribution should be checked and compared to the criteria selected in Item c. Use the following equation to determine the uniformity ratio.

$$Uniformity\ Ratio = \frac{Average\ Maintained\ Illumination\ Value}{Minimum\ Maintained\ Illumination\ Value} \quad \text{(Equation 502-4.05)}$$

When comparing alternative designs that yield approximately equivalent annual service costs the designer should also consider the number of poles- from a safety consideration the fewer the better.

e. Electric Design. Once the type, number, size, and location of the luminaires are determined, the electric voltage drop should be determined for the system. Section 502-4.06(07) provides this information.

f. INDOT Pre-Design Approval. For a consultant-designed project, the consultant should submit the service cost analysis worksheets and discuss the optimum alternatives with the Traffic Review Team prior to preparing the plans to expedite project development. Upon approval from INDOT, FHWA if necessary, and the local utility company, the final development of the plans may proceed.

g. Preparation of Plans. Once the final design has been selected, the plan sheets, quantities, cost estimate, voltage drop calculations, circuit schematic layouts, and special provisions, should be submitted to the Traffic Review Team for review. The light source type, luminaire wattage, total initial lumen output, estimated light loss factor, luminaire table, service point amp table, and the lighting ID numbers should be included on the plans. Additionally the IES file type used in the design will be given on the plans with a note that the distribution pattern of the actual luminaire to be supplied will be equivalent, e.g., "Luminaire shall provide a light distribution equivalent to IES distribution type GE 452918.IES." If a particular backlight/uplight/glare rating is needed this information should also be specified on the plans

h. Working (Shop) Drawing Check. As part of the working (shop) drawing approval the contractor will submit the IES photometric distribution file for each model when the IES file number is different from that which is indicated on the plans, i.e., when the contractor is submitting a different model than that on which the design is based. In these cases, the IES files will be provided to the design engineer of record for review and concurrence that the design light level criteria will be satisfied.

4. Design-Build Projects. The following provides the procedural steps in designing a lighting system as part of a roadway design-build project. The design-build team will complete the following:

    a. Assembly of Information. Necessary information to be assembled includes the following.

        1) Contact the Traffic Review Team for the current design policies and procedures applicable to the project, sample plans, schedules, pay quantities, and example calculations.

        2) Gather roadway and bridge plans including plan and profile sheets and details sheets, e.g., those for overhead signs.

        3) Determine existing and expected utility locations.

        4) Discuss special considerations with the road or bridge designer.

        5) conduct field reviews.

        6) If this project is a local-agency project, hold discussions with local officials.

    b. Determination of Classifications. Determine the roadway classification and environmental conditions. If not already included in the project report, this information can be obtained from the Environmental Policy Team. The roadway classifications, for lighting purposes,are defined in Section 502-4.06(01).

    c. Selection of Design Criteria. Based on the above information, the designer will select the pertinent design methodology and the appropriate criteria based on the classification selected in item b. See Section 502-4.04 for design methodologies. For an INDOT-route lighting project, only the illuminance design methodology should be used.

    d. Selection of Equipment. In the preliminary design, the designer will need to make some initial assumptions regarding the equipment composition. This includes mounting height, pole setback distance, mast arm length, light source type, luminaire wattage, photometric distribution pattern (INDOT typically uses M-S-Type II, III, or IV), and initial lumen output (typically 28,000 or 50,000). See Sections 502-4.03 and 502-4.06(03) for additional details on equipment selection.

Normally mounting heights and mast arm lengths will be uniform through the project limits. If the project ties into adjacent lighting systems consideration should be given to matching these considerations.

At a minimum the alternatives should include one HPS, one LED, one plasma, and one induction model, although other light source types may also be considered. Only luminaire types and models that have an accessible IES light distribution file can be used. For a list of manufacturers that have approached INDOT about the use of their luminaires go to Y:\TrafficManagement\Luminaire Manufacturers. Consultants and local agencies may contact their Project Manager or the Office of Traffic Administration to obtain this information.

e. Selection of Layout Arrangement. Section 502-4.06(04) provides information on commonly used lighting arrangements. The selection of an appropriate layout design depends upon local site conditions and the engineer's judgment. Section 502-4.06(05) provides the roadside safety considerations in selecting the lighting arrangements. Section 502-4.06(06) provides other layout considerations.

f. Luminaire Spacing. For an INDOT-route lighting project, use the illuminance methodology to determine the appropriate luminaire spacing. This step is conducted by the computer.

Normally for a tangent alignment where roadway width is constant, spacing will be uniform through the project limits. If the project ties into adjacent lighting systems consideration should be given to matching the spacing.

g. Check for Uniformity. Once the spacing has been determined, the designer should check the uniformity of light distribution and compare this to the criteria selected in Item c. Use Equation 502-4.05 to determine the uniformity ratio.

h. Selection of Optimum Design. Because recalculations by computer are relatively quick and easy, the designer should try several alternatives even if the first design satisfies the criteria. There is often more than one satisfactory alternative. Design Optimization should include an analysis for the purpose of minimizing service costs. The service cost is defined to be:

Service Cost per Year =

Annual Energy Cost + Annual Routine Luminaire Maintenance Costs + Installation Cost/Warranty Period

Where:

Annual Energy Cost = (Total Luminaire Wattage of the System) x (Hours Operated per Year) x (Cost of Electricity)

Hours Operated per Year = 4380 h

Cost of Electricity (estimated) = $0.08 per kWh
The electric provider or district may have a more location specific unit cost.

Maintenance Cost for HPS should be based on re-lamping the entire system every 3 years as well as other miscellaneous work. Currently this cost is estimated at $60 per year for each 250-watt or 400-watt luminaire and $105 per year for each 1000-watt high-mast luminaire. The cost for non-HPS light sources may be estimated at $25 per year for roadway luminaires and $50 per year for high-mast luminaires plus any additional maintenance costs that are specific to the type and model. The designer should confer with the manufacturer for these specific maintenance costs.

Estimated Cost of the system should include poles, foundations, wiring, conduit, handholes, service points as well as the luminaires. Recent bid history as obtained on INDOT website should be used. Cost of alternative technology luminaires should be obtained from the manufacturer along with an estimate of the cost to install for about 1 hour of labor per luminaire. A $75 estimate can be used for labor cost.

Warranty Period is defined to be 5 years or the manufacturer's specifc warranty period if greater than 5 years The designer should verify the warranty period as some manufacturers provide longer coverage periods.

A Service Costs Analysis for New or Fully Modernized Lighting worksheet should be completed for each alternative considered and placed in the project file. An editable version of this worksheet is available for download from the Design Manual Editable Documents web page, http://www.in.gov/dot/div/contracts/design/dmforms/. If the service cost analysis does not yield a clear choice, other factors such as the light color or district preferences should be weighed into the decision regarding the type of light source.

i. Electric Design. Once the type, number, size, and location of the luminaires are determined, the designer will need to determine the appropriate electric voltage drop for the system. Section 502-4.06(07) provides information on how to determine the voltage drop for the lighting system. For light source types other than HPS, the design current (amperage) requirement should be obtained from the manufacturer.

j. Preparation of Plans. Once the final design has been selected, the lighting designer will prepare and submit to the Traffic Review Team the plan sheets, design criteria, initial lumen output, photometric files, service cost analysis worksheets, luminaire shop drawing, quantities, cost estimate, voltage drop calculations, circuit schematic layouts for review. The plan sheet shall indicate the IES photometric distribution file number used in the design, the luminaire type and initial lumen output, and should include the luminaire table, service point amp table, and the lighting ID numbers .

k. Plans Submission. Plans should be submitted in accordance with the project witness and hold point schedule.

## 502-4.06 Conventional Lighting Design

The elements or factors to be considered have been standardized by the IES. However, not all elements are appropriate. In addition to the following, Figure 502-4D, Lighting Design Parameters, provides guidance regarding the design values used for a lighting design.

### 502-4.06(01) Roadway Classification

In selecting the appropriate design criteria, the highway's functional classification must be determined as mentioned in Section 502-4.05(02), items 3.b. and 4.b. The following definitions are used to define roadway classification for highway-lighting purposes only.

1. Freeway. A divided major roadway with full control of access with no crossings at grade. This definition applies to a toll or non-toll road. An interstate highway is a freeway.

2. Expressway. A divided major roadway for through traffic with partial control of access and with interchanges at major crossroads. An expressway for noncommercial traffic within a park or park-like area is considered a parkway.

3. Arterial. That part of the roadway system which serves as the principal network for through-traffic flow. Such a route connects areas of principal traffic generation and rural highways entering a city. For an INDOT route, use the city-street design criteria.

4. Collector. This is a distributor roadway servicing traffic between an arterial and local roadway. This is used for traffic movements within a residential, commercial, or industrial area. For an INDOT route, use the city-street design criteria.

5. Local Road. This is used for direct access to residential, commercial, industrial, or other abutting property. It does not include a road which carries through traffic. A long local road will be divided into short sections by collectors. For an INDOT route, use the city-street design criteria.

6. Sidewalk. A paved or otherwise improved area for pedestrian use, located within the public-street right of way which also includes the roadway for vehicular traffic.

7. Pedestrian Walkway. A public walk for pedestrian traffic not necessarily within the right of way for a vehicular-traffic roadway. This includes a skywalk or pedestrian overpass, subwalk or pedestrian tunnel, walkway providing access to a park or block interior, or mid-block street crossing.

8. Isolated Interchange. A grade-separated roadway crossing which is not part of a continuously lighted system, with one or more ramp connections with the crossroad.

9. Isolated Intersection. The area where two or more non-continuously lighted roadways join or cross at the same level. This area includes the roadway and roadside facilities for traffic movement in that area. One type of isolated intersection is the channelized intersection in which traffic is directed into definite paths by means of islands with raised curbs.

10. Bikeway. A road, street, path, or way that is specifically designated as being open to bicycle travel, regardless of whether such facility is designed for the exclusive use of bicyclists or will be shared with other transportation modes.

    a. Type A, Designated Bicycle Lane. A portion of a roadway or shoulder which has been designated for use by bicyclists. It is distinguished from the portion of the roadway for motor-vehicle traffic with a paint stripe, curb, or other similar device.

    b. Type B, Bicycle Path. A separate trail or path from which motor vehicles are prohibited and which is for the exclusive use of bicyclists or the shared use of bicyclists and pedestrians. Where such a trail or path forms a part of a highway, it is separated from the roadway for motor-vehicle traffic with an open space or barrier.

### 502-4.06(02) Design Criteria [Rev. Jan. 2016]

The lighting criteria vary according to the design methodology, highway classification, area classification, and pavement type. The following provide AASHTO and INDOT lighting design criteria.

1. Figure 502-4G provides the roadway illuminance design criteria.

2. NCHRP *Report 672*, *Roundabouts: An Informational Guide,* provides the recommended illuminance design criteria for roundabout lighting.

The Uniformity Ratios given in Figure 502-4G should be regarded as target values. A driver's visual ability may be adversely affected by lighting that varies significantly from the recommended uniformity value, i.e. it is possible for lighting to be too uniform or too non-uniform.

### 502-4.06(03) Equipment Considerations [Rev. Jan. 2016]

Figure 502-4F, Luminaire Geometry, illustrates the terms used in defining and designing luminaires, e.g., mounting height, overhang, rotation. Other equipment considerations for design are as follows.

1. Light Distribution. In determining the lighting-design layout, the expected light distribution must be known for the luminaire. Photometric data can be obtained from luminaire manufacturers. The proper distribution of light from the luminaire is a factor in the design of efficient lighting. Figure 502-4G, Luminaire Classification System, provides the IES classifications for luminaire light distributions: width, spacing, and glare control. Figure 502-4H, Luminaire Placement and Light Type, provides additional guidance for the selection of luminaires based on these classifications. Figure 502-4 I, Plan View for Luminaire Coverages, illustrates a plan view of a roadway which has been modified to show a series of Longitudinal Roadway Lines (LRL) and Transverse Roadway Lines (TRL) and how these distribution factors are interrelated. The following describes these classifications.

    a. Vertical Light Distribution. This can be short, medium, or long. The selection of a vertical light distribution is dependent upon the mounting height and light source. Pavement brightness is increased if the vertical light angle is increased. The vertical-light distribution types are defined as follows.

1) Short Distribution. The maximum luminous intensity strikes the roadway surface between 1 and 2.25 mounting heights from the luminaire. The theoretical maximum spacing is 4.5 mounting heights.

2) Medium Distribution. The maximum luminous intensity is between 2.25 and 3.75 mounting heights from the luminaire. The theoretical maximum spacing is 7.5 mounting heights. This is the most commonly-used distribution type.

3) Long Distribution. The maximum luminous intensity is between 3.75 and 6 mounting heights from the luminaire. The theoretical maximum spacing is 12 mounting heights.

b. Lateral Light Distribution. The IES has developed the lateral light distributions which are provided in Figure 502-4 I. The following provides information on the placement for lateral light distribution.

1) Type I. The luminaire is placed in the center of the street or area where lighting is required. It produces a long, narrow, oval-shaped lighted area. Some types of high-mast lighting are also considered a modified form of Type I.

2) Type I, 4-Way. The luminaire is placed in the center of the intersection and distributes the light along the four legs of the intersection. This type applies to high-mast lighting.

3) Type II. The luminaire is placed on the side of the street or edge of the area to be lighted. It produces a long, narrow, oval-shaped lighted area which is applicable to a narrow-width street.

4) Type II, 4-Way. The luminaire is placed at one corner of the intersection and distributes the light along the four legs of the intersection.

5) Type III. The luminaire is placed on the side of the street or edge of the area to be lighted. It produces an oval-shaped lighted area and is applicable to a medium-width street.

6) Type IV. The luminaire is placed on the side of the street or edge of the area to be lighted. It produces a wider, oval-shaped lighted area and is applicable to a wide street.

7) Type V. The luminaire is placed in the center of the street, intersection, or area where lighting is required. It produces a circular, lighted area. Type V can be applied to high-mast lighting.

c. Control of Distribution. As the vertical light angle increases, discomforting glare also increases. To distinguish the glare effects on the motorist from the light source, IES has defined the glare effects as follows.

1) Cutoff. This occurs where the luminaires' light distribution is less than 25,000 lm at an angle of 90 deg above nadir, or vertical axis, and less than 100,000 lm at a vertical angle of 80 deg above nadir.

2) Semi-cutoff. This occurs where the luminaires' light distribution is less than 50,000 lm at an angle of 90 deg above nadir, and less than 200,000 lm at a vertical angle of 80 deg above nadir. This is the distribution used for lighting design.

3) Non-cutoff. This occurs where there is no limitation on the zone above the maximum luminous intensity.

d. Veiling Luminance. The designer should select lighting system equipment that minimizes veiling luminance, or glare. Glare hinders visibility.

Optical devices such as shields, reflectors, refractors may be utilized to reduce the possibility of disabling glare and the mounting height selected should take into account the probability that glare will be created. The higher the luminaire is mounted, the further it is above normal line of vision and the less glare it creates. Mounting heights less than 20 feet cannot be considered a good practice for typical roadway lighting.

e. Light trespass. Light trespass is commonly understood to mean light that falls beyond its intended target, and across a property line so as to create a perceived nuisance. Spill light of this kind, if it emanates at a high angle from the luminaire, can be a public nuisance and contribute to light pollution. Light trespass is somewhat subjective because it is difficult to define when, where, and how much light is unwanted.

A common cause of light trespass is the inappropriate selection, tilting, or aiming of luminaires. To minimize the likelihood of light trespass the designer should:

1) consider the surrounding area during the design, and select luminaires, locations, and orientation that minimize spill light into adjacent properties.

2) specify luminaires with an appropriate light distribution type- luminaires are available with either asymmetric or symmetric distributions and can be equipped with shields to control light at the desired lines.

3) indicate aiming of luminaires so that the entire light output falls within the area intended to be lit.

4) Consider light trespass when selecting pole heights.
Refer to I.E.S.N.A. RP 33-99 for additional information on Light Trespass.

2. Mounting Height. There are two criteria for determining a preferred luminaire mounting height: the desirability of minimizing direct glare from the luminaire and the need for a reasonably uniform distribution of illumination on the street surface. A higher-wattage bulb allows the use of a higher mounting height, fewer luminaires, and fewer support poles, and still provides the lighting quality. A higher mounting height tends to produce the most efficient design. For practical and aesthetic reasons, the mounting height should remain constant throughout the system. The manufacturer's photometric testing results are required to determine the appropriate adjustments for mounting height. The mounting height for INDOT projects should be at least 30 ft but no more than 50 ft, using an even 5-ft increment.

3. Coefficient of Utilization. The coefficient-of-utilization curve defines the percentage of bare-lamp lumens that are required to light the desired surface. Figure 502-4J illustrates a sample coefficient-of-utilization curve. The curve and the isolux diagram are used to determine the amount of illumination to a given point on the pavement. The curve provides a value for the street side of the luminaire and the private-property side. If the luminaire is located over the roadway, the private-property-side value should also be used to determine the level of illumination. The manufacturer is required to provide these charts with its photometric testing results.

4. Light-Loss Factor, or Maintenance Factor. The efficiency of a luminaire is reduced over time. This reduction must be determined to properly estimate the light available at the end of the lamp or LED service life. The maintenance factor for HPS lighting can range from 0.50 to 0.90 and from 0.5 to 0.70 for LED lighting. Figure 502-4D, Lighting Design

Parameters, provides the factors used for designing a lighting system. The maintenance factor is the product of the following.

a. Lamp/LED Lumen Depreciation Factor (LLD). As the light source progresses through its service life, the lumen output of the lamp or LEDs decreases. The initial lumen value is adjusted by means of a lumen depreciation factor to compensate for the anticipated lumen reduction by the end of the light source's service life. This ensures that a minimum level of illumination will be available at the end of the assumed service life of 20 years, even though lumen depreciation has occurred. This information should be provided by the manufacturer. For HPS, a typical LLD factor of 0.90 may be used. Since LED depreciation may vary greatly from one manufacturer to another a test verified lumen depreciation factor specific to the model should be used. The factor should estimate the lumen depreciation at 85,000 hrs., In lieu of manufacturer specific information a default value of 0.70 may be used. Lumen depreciation for plasma emitters and other light source types should be confirmed with the manufacturer.

b. Luminaire Dirt Depreciation Factor (LDD). Dirt on the exterior and interior of the luminaire, and to an extent on the lamp, reduces the amount of light reaching the roadway. Various degrees of dirt accumulation can be anticipated depending upon the area in which the luminaire is located. Industry, exhaust of vehicles, especially large diesel trucks, dust, etc., all combine to produce dirt accumulation on the luminaire. A higher mounting height, however, tends to reduce vehicle-related dirt accumulation. Information on the relationship between the area and the expected dirt accumulation is shown in Figure 502-4K. An LDD factor of 0.87 should be used. This is based on a moderately-dirty environment and three years exposure time. If deemed necessary, another value may only be used with approval from the Office of Traffic Administration.

c. Equipment Factor (EF). Accounts for inefficiencies inherent in the manufacture and operation of the equipment. A factor of 0.95 may be used.

d. LED Survival Factor (LSF) The LSF applies only to LED luminaires and takes into account any failures early in the expected service life (at least 50,000 hrs). This factor may be conservatively estimated at 0.98 but can be adjusted per the manufacturer.

### 502-4.06(04) System Configuration

Figure 502-4L, Lighting-System Configurations, illustrates the layout arrangements used. Figure 502-4L also illustrates the recommended illuminance calculation points for the arrangements. See Section 502-4.05(02), step 7. A light standard should not be placed in the median unless a barrier wall is present. A light standard should be placed in such a location to avoid being struck by an errant vehicle, i.e., not on an outside-edge barrier wall at a ramp on a horizontal curve.

Figure 502-4M illustrates a layout for partial lighting of an interchange.

### 502-4.06(05) Roadside-Safety Considerations

The placement of a light standard should be such that it will not reduce roadside safety. However, the physical roadside conditions can dictate the light-standard location. Such limitations should be considered in the design process. An overpass, sign structure, guardrail, roadway curvature, right-of-way limitation, gore clearance, proximity of another existing roadside obstacle, or the limitations of the lighting equipment are all factors that must be considered in design. The roadway and area classification, design speed or posted speed limit, safety, aesthetics, economics, environmental impacts, etc., should also be considered.

There should be adequate right of way, driveway control, or utility clearance to allow the placement of the proposed light standards according to the safety requirements. Otherwise, additional right of way, driveway control, or utility relocations will be required. The following should be considered when determining the location of light poles relative to roadside safety.

1. Breakaway. A conventional light pole placed within the clear zone or the obstruction-free zone will be provided with a breakaway device except at a location with a sidewalk. The following should be considered.

    a. Pedestrians. A pole should not be mounted on a breakaway device in an area, including a rest area, where pedestrian traffic exists or is expected.

    b. Support. The maximum projection of the portion of a breakaway lighting support that remains after the unit has been struck is 4 in. See Figure 502-4N, Breakaway Support Stub Clearance Diagram.

c. Breakaway Device. Each breakaway device should be in accordance with the applicable AASHTO requirements for structural supports. It may be one that has been approved for use as a breakaway device. See Section 502-4.03(02).

d. Wiring. Each pole that requires a breakaway device should be served by underground wiring and should be designed with breakaway connections. No. 4 copper wire should be used between poles. No. 10 copper wire should be used up the poles to the luminaire. See the INDOT *Standard Drawings* for wiring details.

2. Grading. Grading at a breakaway light standard should be as described in Chapter 49.

3. Gore Area. A pole should be located to provide adequate safety clearance in the gore area of an exit or entrance ramp, with a minimum of 50 ft, as illustrated in Figure 502-4 O, Pole Clearance for Ramp Gore.

4. Horizontal Curve. A pole should be placed on the inside of a sharp curve or loop.

5. Maintenance. In determining a pole location, a hazard which can be encountered while future maintenance is being performed on the lighting equipment should be considered.

6. Barrier. The placement of a light standard in conjunction with a roadside barrier should be as described in Section 49-5.0. The following should also be considered.

   a. Placement. A light standard should be placed behind the barrier.

   b. Deflection. A pole behind a guardrail should be offset by at least the deflection distance of the guardrail. See Section 49-5.0 for information. This will allow the railing to deflect without hitting the pole. If this clearance distance is not available, such as in a 2:1 side-slope condition, or if the pole is located within the approach end of the railing, a breakaway device should be added. A breakaway device should be used behind guardrail.

   c. Concrete Median Barrier. A pole that is shielded by a rigid or non-yielding barrier will not require a breakaway device.

   d. Impact Attenuator. A pole, either with or without a breakaway device, should be located such that it will not interfere with the functional operation of an impact attenuator or other safety breakaway device.

7. <u>Protection Feature</u>. A feature such as a curb, barrier, or other obstacle constructed should not be constructed primarily to protect a light pole.

8. <u>High-Mast Tower</u>. An unprotected high-mast tower should be at least 80 ft from the nearest edge of the mainline or ramp travel lane. The minimum clear distance will be the roadway clear-zone width through the area where the high-mast lighting is located. Access for service vehicles should be provided for each high-mast tower or service pole.

9. <u>Existing Installation</u>. An existing breakaway light standard should be evaluated to determine if it is necessary to relocate it, re-grade around its base, or upgrade the breakaway mechanism to current criteria. The determination of the work necessary on an existing breakaway light standard involves a review of variables. Therefore, this decision must be made by the Highway Design and Technical Support Division. If federal-aid funds will be used for construction, the project is on the National Highway System, or it is not exempt from FHWA oversight, the FHWA should also be consulted.

**502-4.06(06) Other Considerations [Rev. Jan. 2016]**

1. <u>Sign</u>. A pole should be placed to minimize interference with the motorist’s view of a highway sign. The luminaire brightness should not detract from the legibility of the sign at night. Conversely to avoid adversely impacting the light distribution light poles should be located at a minimum separation of 60 ft (for 40 ft E.M.H poles) and 40 ft (for 30 ft E.M.H. poles).

2. <u>Overhead Sign</u>. Sign lighting will be provided only where it is determined by the district Traffic Office that the reflective sign sheeting by itself is not sufficient for nighttime visibility. If needed, an existing overhead sign’s lights should be tied into the new lighting system’s circuits.

3. <u>Structure</u>. A pole should be placed far enough away from an overhead bridge or overhead sign structure so that the light from the luminaire will not cast distracting shadows on the roadway surface or produce unnecessary glare for the motorist.

4. <u>Tree</u>. A tree should be pruned so that it does not cause shadows on the roadway surface or reduce the luminaires’ efficiency. The luminaire should be designed with the proper height and mast-arm length to account for the effect of a tree on lighting distribution.

5. <u>Retaining Wall</u>. A pole may be located either on top of or behind a retaining wall. A pole mounted atop a retaining wall will require consideration in the retaining-wall design.

6. Median. Although not desirable, a pole may be placed in a median where the width of the median is adequate or if a barrier will be used. The median width should be equal to or greater than the pole's mounting height. Where twin poles are used, the mast arms on both sides should have the same length.

### 502-4.06(07) Voltage-Drop Determination

A highway-lighting distribution circuit consists of two 240-V circuits provided by a multiple-conductor armored cable. Power supply to the lighting system is 240/480 V, single phase, 60-cycle alternating current. The designer shall be responsible for determining the service requirements of each individual location. The lights are alternately connected to each side of the four-wire circuit. Ground rods are provided at each light standard. Voltage drop should not be over 10% to the last light in the circuit, or 5% to the last light in the circuit for bridge underpass lighting. Figure 502-4P provides the design amperages for various luminaires. Figure 502-4Q provides resistances for various wire types. Equation 502-4.1 should be used to determine the voltage drop between two adjacent luminaires.

$$E = IR \qquad \text{[Equation 502-4.1]}$$

Where:

$E$ = voltage, or electric potential (V)
$I$ = current (A/mi)
$R$ = resistance (Ω)

Figure 502-4R illustrates the voltage drop between two adjacent luminaires

### 502-4.07 High-Mast Lighting Design [Rev. Jan. 2016, Jan. 2025]

The design of a high-mast lighting system consists of the same procedures as discussed in Section 502-4.05(02). If reuse of towers is being considered any repair or replacement needs that have been identified through INDOTs inspection program should be included in the project scope. Contact Traffic Administration for the applicable inspection reports. The following should also be considered.

1. Lighting Source. For HPS designs a 130,000 lumen (1000 watt) light source should be used. For LED and plasma design the lumen and wattage requirements may vary. The number of required luminaires should be determined based on the area to be lighted and target design criteria as shown in Figure 502-4S. At a minimum the designer should consider one HPS, one LED, and one plasma model when determining the optimal design.

2. Effective Mounting Height (EMH). The INDOT *Standard Specifications* allow an EMH range from 100 to 200 ft. Once determined, it should be specified to the higher 5-ft increment. An EMH of 100 to 160 ft is the most practical. An EMH of 165 ft or greater requires more luminaires to maintain the illumination level. However, such an EMH allows for fewer towers and provides more uniformity. Use of such an EMH should be confirmed with the district traffic engineer.

3. Location. When determining the location for a tower, the plan view of the area should be reviewed to determine the more critical areas requiring lighting. In selecting the appropriate location for a tower, the following should be considered.

   a. Critical Area. A tower should be located such that the highest localized level of illumination occurs within a critical-traffic area, e.g., freeway/ramp junction, ramp terminal, merge point.

   b. Roadside Safety. A tower should be located at a distance from the roadway so that the probability of a collision is virtually eliminated. It should not be placed at the end of a long tangent.

   c. Sign. A tower should be located so that it is not within a motorist's direct line of sight to a highway sign.

4. Design. The methodologies for checking the adequacy of uniformity are the point-by-point method and the template method. The point-by-point method checks illumination by using the manufacturer's isolux diagram. The total illumination at a point is the sum of the contributions of illumination from all luminaire assemblies within the effective range of the point. The template methodology uses isolux templates to determine the appropriate location for each tower. The templates may be moved to ensure that the minimum-maintained illumination is provided, and that the uniformity ratio has been satisfied.

   A retaining wall should be included with the concrete pad at the base of the tower if the surrounding ground's slope is steeper than 5:1. The height of the retaining wall should be determined from Figure 502-4T.

5. Foundation and Soil Test. After the final location of each tower is determined, a geotechnical investigation should be requested from the Office of Geotechnical Services. The standard foundation of 20-ft depth and 4-ft diameter should be specified for each tower where the soil properties are as follows.

a. Soft Clay. Undrained shear strength of 750 $lb/ft^2$, density of 120 $lb/ft^3$, and strain of 0.01 at half the maximum stress for an undrained triaxial test. The soil should not include excess rock.

b. Sand. Angle of internal friction of 30 deg, density of 115 $lb/ft^3$, and modulus of subgrade reaction of 20 $lb/in.^3$. The soil should include a minimum of gravel or clay.

If a tower of 180 ft or higher is required where soil is sandy, a foundation of 22-ft depth and 4.5-ft diameter should be specified, and its details should be shown on the plans.

The standard foundation has been designed with the assumption that no groundwater is present. The Office of Geotechnical Services should be contacted if groundwater is present or if excess rock is present in clay soil.

For other soil conditions or properties, the Office of Geotechnical Services can recommend an alternate foundation. Such an alternate foundation should be shown on the plans.

6. Information To Be Shown on Plans. This includes the tower location, foundation details if not standard, estimated mounting height, retaining-wall height if applicable, and number of luminaires. The IES file type used in the design will be given on the plans with a note that the distribution pattern of the actual luminaire to be supplied will be equivalent, e.g., "Luminaire shall provide a light distribution equivalent to IES distribution type GE 452918.IES." The plans should indicate the light source type and also include luminaire wattage, total initial lumen output, luminaire table, service point amp table, and the lighting ID numbers.

   When a high mast luminaire retrofit is selected as the best option, the designer should include a unique special provision that incorporates any needed changes to the standard specifications on High Mast Luminaires, as well as information on the existing high mast luminaire since the housing will be re-used. At a minimum this information should include manufacturer, model name/number, and dimensions of the housing. Additionally the designer should include a pay item for Luminaire, High Mast, Retrofit, ___ (watts),….each. The unique special provision should include a basis of payment section indicating that in addition to the cost of the LEDs and mounting hardware, the cost of all work necessary to remove, disassemble, re-assemble with the new LED modules, and then reinstall the existing luminaire is included in the Retrofit pay item.

## 502-5.0 INTELLIGENT TRANSPORTATION SYSTEM (ITS) [REV. AUG. 2022]

### 502-5.01 General [Rev. Aug. 2022]

The Federal Highway Administration (FHWA) defines ITS in the Final Federal Rule (23 CFR 940) on ITS Architecture and Standards Conformity (Final Rule) as, "electronics, communications, or information processing used singly or in combination to improve the efficiency or safety of a surface transportation system." The full text of FFR 23 CFR 940 can be found at https://www.fhwa.dot.gov/legsregs/directives/fapg/cfr0940.htm. ITS is the physical infrastructure that supports a variety of traffic management strategies. For example, closed-circuit television (CCTV) roadway surveillance supports the dispatch of Hoosier Helpers, the Department's Freeway Safety Patrol initiative.

#### 502-5.01(01) Purpose of ITS [Rev. Aug. 2022]

1. Provide Information for the Driving Public. ITS gathers and distributes information to the traveling public through means such as roadside messaging and our online CARS 511 data portal that enables them to make informed decisions. The CARS 511 website can be found at https://511.in.org.

2. Improve Roadway Safety. ITS gathers information that helps emergency response personnel identify and respond to traffic incidents to restore traffic flow as quickly as possible improving the safety of the roadway system. Providing the traveling public with better information can help reduce congestion and reduce the likelihood of back-of-queue crashes.

3. Reduce Environmental Impacts. ITS reduces congestion and helps keep the average arterial speed close to the speed limit which facilitates the lowering of emissions from idling automobile engines.

4. Collect Traffic Data. ITS gathers traffic information for research, operational, and planning needs.

#### 502-5.01(02) National And Regional Architecture [Rev. Aug. 2022]

On January 8, 2001, the Final Federal Rule (23 CFR 940) on ITS Architecture and Standards Conformity (Final Rule) and the Final Policy on Architecture and Standards Conformity (Final Policy) were enacted by the FHWA and Federal Transit Administration (FTA) respectively. The Final Rule/Final Policy ensures that an ITS project carried out using funds from the Highway Trust Fund including the Mass Transit Account is in accordance with the National ITS Architecture and applicable ITS standards. This will be accomplished through the development of regional ITS architectures and the use of a systems engineering process for ITS project development.

1. FHWA Rule on ITS Architecture and Standards Conformity. This rule is provided to ensure that an ITS project carried out using funds made available from the Highway Trust Fund is in accordance with the National ITS Architecture and applicable standards.

2. FTA Policy on ITS Architecture and Standards Conformity. This policy is provided to ensure that an ITS project carried out using Mass Transit Funds from the Highway Trust Fund is in accordance with the National ITS Architecture and applicable standards.

Both of these documents appear at http://www.iteris.com/itsarch.

Each ITS project involving federal funds must be in accordance with the National ITS Architecture and the Systems Engineering Process as defined in 23 CFR 940. The designer should work with the system owner to ensure all system engineering requirements are met. For INDOT projects the designer's role in the systems engineering process will be defined in their contract. For INDOT projects the designer's role in alternative development and cost-benefit analysis will be defined in their contract. A Systems Engineering form should be completed and submitted to the FHWA for review and approval on each federally-funded non-INDOT ITS project. Contact INDOT ITS to obtain this form. For more information about the systems engineering process, refer to the FHWA Systems Engineering and ITS Project Development Website at https://ops.fhwa.dot.gov/plan4ops/sys_engineering.htm.

The Systems Engineering form should be submitted to FHWA for review subsequent to project Notice to Proceed and prior to preliminary plans development. In conjunction with final plans submission, the form should be resubmitted, including the most current project revisions and Department review comments.

The National ITS Architecture can be accessed via http://www.iteris.com/itsarch/. For Statewide ITS Architecture, contact the Department. Regional ITS Architectures appear on the website of the state's Metropolitan Planning Organizations (MPOs).

**502-5.01(03) Coordination with Traffic Management Division [Rev. Aug. 2022]**

For both new ITS construction and ITS relocation projects, the designer should coordinate with INDOT ITS regarding the maintenance of existing ITS equipment such as dynamic message signs, sensors, and cameras during construction.

**502-5.01(04) ITS Project Milestones [New Aug. 2022]**

1. Scoping. During the scoping process, scoping teams should coordinate with INDOT ITS for the following purposes:

    a) To capture the cost and scope of required ITS facility relocations or replacements in the project scope and scoping cost estimate.
    b) To allow potential bundling of new ITS construction with other nearby projects for MOT and economies of scale savings

    This coordination does not replace the required coordination with department owned lines described in Chapter 104.

2. Preliminary Field Check. The designer and the Department should discuss information including constructability and communication issues for each proposed site and adjust locations if necessary. The designer should notify INDOT ITS of this an all other field activities to enable INDOT ITS representatives to participate.

3. Stage 1. The designer should provide the high-level, conceptual ITS design for the project including device locations and preliminary communication network plan.

4. Stage 2. The designer should provide preliminary cost estimate and special provisions as well as plans of the following:

    a) site locations;
    b) communication information;
    c) constructability requirements;
    d) driveway or fencing;
    e) drainage;
    f) grounding; and electrical service connections and utility coordination.

5. Stage 3. The designer should provide the final design package, which should include the following:

    a) title and index sheets;
    b) plans sheets;
    c) site details;
    d) construction details including but not limited to foundations, grounding, driveways, pipes, fences and gates;
    e) cabinet details;
    f) electrical and communication schematics;
    g) electrical wiring diagrams;
    h) quantities;
    i) design calculations including but not limited to drainage, communications line of sight, driveways, guardrail, voltage drops;

j) cost estimate; and
k) special provisions.

**502-5.01(05) Viewshed Analysis and Survey [New Aug. 2022]**

During the design process after preliminary site selection and prior to final site selection approval, the designer should verify the viewing areas of new cameras and the line of sight for the wireless communication by performing a viewshed analysis. A viewshed survey may be required if necessary and feasible. A bucket truck or unmanned aerial system (UAS) may be used to perform the viewshed survey. The designer should provide equipment and personnel if INDOT ITS determines a viewshed survey is warranted.

**502-5.02 Use of the ITS Strategic Deployment Plan [Del. Aug. 2022]**

**502-5.03 Design Criteria [Rev. Aug. 2022]**

Elements including to but not limited to drainage, slopes, clear zone, and access to electrical power should be considered in the site selection process. Final component locations require approval by INDOT ITS. Specific site locations should be called out in the plans with approximate mile markers in addition to project stationing. Where feasible, ITS devices should be collocated to reduce cost of providing power and communications.

**502-5.03(01) General Site Selection and Safety [Rev. Aug. 2022]**

Each site should be designed to accommodate easy and safe access for construction and maintenance operations. Each site should be accessible from Department maintained right-of-way and should not be located behind sound barrier. A minimum of 12 ft of lateral clearance between the edge of a traveled lane and the nearest impassible obstacle such as guardrail, barrier wall, or unrecoverable shoulder is required for maintenance personnel to park on the shoulder and perform maintenance safely. If the design does not provide this minimum clearance, the designer should provide documentation justifying their decision and identifying what alternatives were evaluated, such as an aggregate driveway or bumping out guardrail.

The radius and width of a driveway entrance should accommodate a single-unit (SU) truck as defined in Section 46-12.0. The driveway should be designed such that an SU truck can turn around in the driveway before reentering traffic. Sight distance for the driveway should comply with Section 42-2.0. If a driveway will impact existing drainage, a hydraulic analysis should be performed per Chapter 203. A driveway is required under any of the following conditions:

1. Site components are located more than 50 feet from the edge of the road or existing parking area
2. A drainage feature between the shoulder and the site is deeper than 4 feet and is expected to hold water or is otherwise unsafe to cross on foot

The decision to provide a driveway should be made on a site-by-site basis and driveway locations must be approved by INDOT ITS.

All ITS infrastructure, device, and support structure placement should comply with guidance in Chapter 49 concerning the clear zone and the treatment of any obstructions therein.

**502-5.03(02) Electrical Service Points [Rev. Aug. 2022]**

All INDOT ITS sites should be powered by AC electrical service.

1. Utility Coordination. The designer should coordinate with the local power company and provide the following information.

    a. Pole number from which power will be delivered to the new service point.

    b. Additional service connection fees. The power company is responsible for providing the service connection to the right-of-way line. If the local power company requires an additional fee to bring power to the right-of-way line, it should submit plans and an estimate of related costs to the designer for approval by the Department. Payment for each connection should be included in the cost of the individual service point.

    Utility coordination correspondence including plans and contact information should be included in the project documentation. Additional service point related fees should be included in the average service point unit price in the contract Engineer's Estimate. Additional location-specific service point-related fees should be described in a unique special provision.

2. Design Considerations. Each ITS site should be metered. The designer should coordinate with the local power company to determine the appropriate overhead or underground service point location. The meter should be located within 15 feet of the utility connection point, or as close to the utility connection point as can be located on state right-of-way.

    For overhead service, all wires between the weather head and the service meter should be UV-resistant, black, and phase-taped.

Each ITS site requires a single-phase, three-wire system, 2 hot lines and 1 neutral plus ground electrical service of 120/240VAC 100 A. Power wires (black, red), and Neutral (white) should be #2 copper. Ground wire should be green #6 copper.

The service point should be specified on the plans as having a multi-position, 100 A, 600 V, main circuit breaker with separate branch circuit breakers rated for the current consumption of each field device but no less than 30 A. A NEMA 3R enclosure should be specified. The service point should be placed on a steel H-frame. Contact INDOT ITS for H-frame details.

The designer should verify the voltage drop does not exceed 7% across a circuit. If the voltage drop is found to exceed 7% across a circuit, the power wire should be increased as needed to meet voltage drop requirements. Buck-boost transformers should not be used without prior INDOT ITS approval.

An additional service disconnect is required if one of the following conditions exist at the project site:

a. when the service point is on the same side of the road as the cabinet and is more than 150 ft from the cabinet or not clearly visible from the cabinet;

b. when the service point and the cabinet are on the opposite sides of the roadway; or

c. when an obstruction exists between the service point and the cabinet that prevents immediate access by maintenance personnel including but not limited to:

    1) Fencing
    2) Steep slope/drop off
    3) Drainage ditch expected to hold water
    4) Overgrowth
    5) Sound wall

If an additional service disconnect is required, the designer should specify a 2-pole disconnect and show it located within 30 ft of the cabinet. Service disconnect should be placed on a steel H-frame. Contact INDOT ITS for H-frame details.

**502-5.03(03) ITS Cabinet [Rev. Aug. 2022]**

1. <u>General</u>. An ITS control cabinet provides a protected space for communication and control equipment needed to operate ITS installations. A free-standing, base-mounted control

cabinet should be used. A pole-mounted cabinet may be used for monopole closed circuit television (CCTV) camera installations. If the site location does not allow for a free-standing, base-mounted cabinet, a pole-mounted control cabinet can be considered with INDOT ITS approval. A single cabinet should be provided when collocating multiple ITS devices at the same site provided all necessary communication and control equipment for each device can fit in the same cabinet.

2. Installation Requirements. Each cabinet should be installed in a safe, easily accessible location. A technician should be able to safely observe the situation on the roadway while troubleshooting or repairing equipment. Cabinets for Travel Time Signs (TTS) and Truck Parking Information Management System (TPIMS) Truck Parking Information Signs should be located so technicians can observe the front of the sign while working on the cabinet. Traffic Monitoring System cabinets should be oriented so technicians can observe traffic passing over the sensor array while working at the cabinet.

   a. Free-Standing ITS Control Cabinet. The cabinet should be installed on the standard foundation. For cabinet foundation details, see the INDOT *Standard Drawings*.

   b. Pole-Mounted Control Cabinet. The top of the cabinet should be 6 feet above ground level at the base of the pole.

### 502-5.03(04) Support Structure [Rev. Aug. 2022]

The following support structures should be used for ITS equipment.

1. Monopole. A monopole is typically used to support CCTV cameras and traffic detection hardware for roadway surveillance. The monopole height should be based on the required elevation of the attached equipment

   The contractor shall provide structural designs, calculations, and engineering drawings signed and sealed by a professional engineer registered in the state of Indiana for each new monopole and monopole foundation. The foundation design should be based on the site-specific soil boring results and should consider the existing and proposed site conditions as shown on the plans for each individual monopole site. A monopole foundation should not interfere with natural or constructed drainage or runoff.

2. Standard Light Pole. A standard roadway light pole should be used for mounting traffic detection devices and associated communication equipment. The top of the pole should not extend more than 10 ft above the height of the equipment.

3. Dynamic Message Sign (DMS) Box Truss. A box truss should be used to support overhead DMS. Box truss structure design and box truss foundation design should be as shown on the INDOT *Standard Drawings*.

4. DMS Cantilever. A DMS cantilever structure should be used to support a ground or median-mounted Dynamic Message Sign. Contact INDOT ITS for DMS cantilever structure and foundation details.

5. Cantilever. Cantilever TTS supports and foundations should be as shown on the INDOT *Standard Drawings*.

6. Self-Supporting Tower. A self-supporting tower is used to support CCTV cameras and traffic detector hardware for roadway surveillance and additional communications equipment that cannot be accommodated on other support structure types. Self-supporting towers should only be considered for installations requiring a structure more than 100 ft in height or installations required to support communications equipment that cannot be accommodated on other support structure types.

   The tower height should be determined based on the required elevation of the tower equipment such that the top of the tower does not extend more than 10 ft above the height of the equipment.

   The tower materials should comply with the Lighting section of the *Standard Specifications*. The contractor shall provide structural designs, calculations, and engineering drawings signed and sealed by a professional engineer registered in the state of Indiana for each new tower and tower foundation. The foundation design should be based on the site-specific soil boring results and should consider the existing and proposed site conditions as shown on the plans for each individual tower site. A tower foundation should not interfere with natural or constructed drainage or runoff. Each tower should be designed in accordance with ANSI requirements.

**502-5.03(05) ITS Handhole [New Aug. 2022]**

Handholes provide access to underground conduit and wire without having to mobilize excavation equipment. Handholes should be installed at every change in direction of underground conduit. Handholes should not be located in the traveled way or paved shoulder. ITS Handholes should be type I (concrete) as shown in the *Standard Drawings* for traffic signals. High-voltage power distribution cables should not terminate in the same handhole as low-voltage power cables or fiber optic cable. Handholes should be labeled as follows:

1. “Traffic Management Power” – for handholes used for high-voltage power distribution cables
2. “Traffic Management Fiber” – for handholes used for fiber optic cable
3. “Traffic Management System” – for all other handholes

**502-5.03(06) ITS Vault [New Aug. 2022]**

Vaults provide a protected space for fiber optic cable splices enclosures and allow access to fiber optic cable splice enclosures. Vaults should be installed at all planned fiber optic splice location and otherwise every 2,000 ft along backbone fiber optic cable. Contact INDOT ITS for ITS Vault details.

**502-5.03(07) Conduit [New Aug. 2022]**

Conduit provides a protected space for power and communication wires and fiber optic cable. Unless otherwise directed by INDOT ITS, the designer should specify Schedule 80 HDPE or PVC conduit for underground applications and galvanized steel for above ground. Conduit size should be selected based on the number and diameter of cables in the conduit per National Electrical Code (NEC) requirements, but should not be less than 1.25 in. High-voltage power distribution cables should not be in the same conduit as low-voltage power cables or fiber optic cable.

When a conduit run will cross a feature also crossed by a Department-owned bridge such as a body of water, railroad, or roadway, the conduit should be bored under the feature. If boring under the feature is infeasible, the conduit can be attached to the bridge with INDOT ITS approval.

**502-5.03(08) Communication [New Aug. 2022]**

The purpose of the communication network is to provide stable unrestricted data flow between field sites and Traffic Management Centers. Means of communication should be selected based on the following local conditions:

1. Nearby existing communications infrastructure
2. Project funding
3. Bandwidth requirements
4. Distance between communicating sites
5. Line of sight availability

All field sites require a field ethernet switch to combine all outgoing communications into a single stream and route all incoming communications to the appropriate device. Most new ITS field devices use IP protocols and can communicate directly with the ethernet switch without the need for a field processor. If a field device requires a field processor, contact INDOT ITS for further direction.

The means of communication between field sites and the Traffic Management Centers are described as follows:

1. <u>Fiber Optic Cable</u>. Fiber optic cable is the most reliable and stable form of communication and provides the greatest bandwidth capacity and should be the first communication option considered. If fiber optic cable is not feasible, the remaining communication options may be considered.

   A fiber optic system connects a field site to the TMC through a network of physical infrastructure consisting of the following:

   a. Cable. Cable should be armored and contain fiberglass strands, or fibers, in increments of 12. One field site requires two fibers: one for ingoing and one for outgoing data streams. Four fibers per field site are required if redundancy is specified. Connecting remote sites to the main communication network should be accomplished by means of providing dedicated fibers connecting each remote site to the nearest communication shelter, and to the nearest communication shelter in either direction if redundancy is specified. The number of fibers required is dependent on the number of field sites on each backbone fiber run.

   b. Backbone Fiber. High strand count fiber that provides the physical infrastructure for data to be transmitted from field sites to the TMCs, often via communication shelters along the way. Backbone fiber runs should have a minimum of 96 strands of fiber.

   c. Drop Cable. Lower strand count fiber that is spliced to the backbone fiber to interface between the backbone fiber optic cable and a field site. The proper wavelength and termination means should be selected and shown on the plans.

   d. Patch Panel. Termination points for individual fibers. The size of the patch panel should be determined by the number of fibers being terminated.

   e. Patch Cable. Connects fibers from their port on a patch panel to a port on a switch

   f. Small Form Pluggable Transceiver (SFP). This is required at the switches at both ends of each active fiber strand to convert electronic signals into pulses of light, amplify them, and at the other end convert pulses of light back to the electronic signals. SFPs should be selected for each connection based on the distance between the links and the bandwidth required. 1 gigabit SFPs should be specified for communication to and from individual sites and 10 gigabit SFPs should be specified for multi-link trunking (MLT) communication between communication shelters.

g. Communication Shelter. A small climate-controlled outbuilding typically positioned at the confluence of two or more runs of backbone fiber optic cable containing core ethernet switches and fiber optic patch panels to facilitate the flow of data to and from the TMCs. For shelter equipment details and specifications, contact INDOT ITS

h. Installation. Appropriate means are as follows:

1) Fiber optic cable should be placed in conduit.

2) Fiber optic cable should be installed beneath the outside shoulder or median. If installed beneath the outside shoulder, the cable should be placed as far from the edge of the road as possible. Fiber optic cable should never be installed behind sound barrier wall. Where cable is to be installed beneath the median, the FHWA must be contacted for approval.

3) Splices in the fiber optic backbone should be used where ITS sites connect to backbone fiber or where new backbone fiber ties into existing backbone fiber. The number of splice locations along the backbone fiber should be limited as much as possible to preserve signal strength.

4) New splices should not be introduced when repairing or relocating existing fiber optic cable backbone. Fiber should be replaced between existing splices.

5) After installation, fiber optic cable should be located with copper wire or other industry-accepted method as approved by INDOT ITS.

6) Fiber optic locator posts should be placed at each vault. If backbone fiber optic cable crosses a divided highway, a locator post should be placed on either side of the crossing.

7) Spare conduits should be provided along backbone fiber runs for future system expansion. 2 spare conduits should be specified.

8) Cable route marking should be identified via flexible cable markers. Flexible cable duct markers should be spaced every 250 ft along straight segments, provided at every fiber optic cable handhole and vault, provided at every significant change in direction, and placed such that the proceeding markers can be seen from any marker.

9) Networking. Each new component or group of components should be organized to allow accommodation of the new components into the existing network. All networking equipment should be compatible with the existing network infrastructure. INDOT ITS will provide a schedule of IP addresses. The naming convention should be provided for all new components in accordance with Department requirements.

2. <u>Cellular Data Connection</u>. This method of communication can be used if INDOT ITS fiber optic is not available or feasible. A cellular data connection is possible anywhere there is cellular data service. A cellular data connection consists of a cellular modem and approved antenna to be installed at each site. Cellular modem and equipment can be found on the ITS Qualified Products List. INDOT ITS will provide configuration settings and IP structure.

3. <u>Wireless</u>. This method of communication can be used if INDOT ITS fiber optic is not available or feasible. A wireless application is possible where there are no obstructions to the line of sight between the ends of the link, and the recommended hardware is capable of producing a signal strong enough to be received by each end of the proposed link. Wireless hardware that is compatible with existing network equipment should be selected.

A frequency band in compliance with FCC requirements should be selected. New hardware should be determined to be compatible with existing. The 5.4 - 5.8 GHz band is utilized for licensed radio applications. The 2.4 GHz frequency is utilized for unlicensed radio applications. Depending on bandwidth capability, wireless devices are classified as High Speed, approximately 50 Mbps and higher throughput, or Low Speed, 10 to 40 Mbps throughput, used as follows:

a. High Speed Radio is used to connect video streams with one or more sources to backbone nodes.

b. Low Speed Radio is used to connect vehicle detection sites to the camera towers and to receive information for DMSs and TTSs.

4. Hybrid. This method of communication can be used if INDOT ITS fiber optic is not available or feasible. Hybrid communication combines the fiber optic and wireless systems described above. CCTV sites, or cluster hubs, are connected with fiber optic cable to create a local back-bone structure. Individual vehicle detection sites, DMSs, TTSs, and Traffic Monitoring Systems located in proximity to a cluster hub communicate wirelessly to the base unit located at the hub.

   Third Party Internet Service Provider (ISP). This method of communication can be used if INDOT ITS fiber optic is not available or feasible. This method of communication provides a wired or wireless connection from a CCTV site or cluster hub into a private carrier's network infrastructure. These carriers can provide a secure virtual private network/VPN-style tunnel connectivity from the remote site into the TMC data center. Such examples include traditional cable TV telephone operators which can provide business-class high speed internet points of presence located within serviceable distance to the cluster hub.

## 502-5.04 Field Devices [Rev. Aug. 2022]

Some of the devices used in an ITS System are proprietary. To use them on an FHWA-funded project, a Public Interest Finding (PIF) form should be submitted and approved by the Department and FHWA. Some devices have achieved programmatic approval and do not require a separate PIF filing. A list of such devices appears at http://www.in.gov/indot/2684.htm under Programmatic Proprietary Material Approvals for ITS.

All equipment should be compatible with existing INDOT ITS network and communication processes and protocols. Contact INDOT ITS for questions about equipment compatibility.

### 502-5.04(01) Dynamic Message Signs (DMS) [Rev. Aug. 2022]

This device is used to convey information to the traveling public about prevailing road and traffic conditions and important events. DMS locations should be selected based on availability of electrical service and the guidance provided in the *IMUTCD*. All planned DMS locations must be approved by INDOT ITS.

DMSs do not require ITS cabinets. The communication and control equipment for the sign are contained inside the DMS enclosure. For electrical service and disconnect placement at a DMS, the base of the ladder should be considered the cabinet.

For gantry mounted DMSs, the access ladder should be on the outside (non-median) side of the road. See the INDOT *Standard Drawings* for DMS details.

**502-5.04(02) Travel Time Sign (TTS) [Rev. Aug. 2022]**

This device is used to convey near real-time downstream travel times to the traveling public.

1. Location. Each TTS location should comply with guidance provided in the *IMUTCD* and must be approved by INDOT ITS.

2. Equipment. TTS should consist of a standard panel sign with a white legend and border on blue background with information including the distance and current travel time to downstream destinations determined by INDOT ITS. The travel time should be displayed on a dynamic LED information panel, or panels, inserted in the panel sign.

    a. The panel sign should be in accordance with the INDOT *Standard Specifications* and *IMUTCD* requirements.

    b. The Travel Time Sign Information Panel (TTSIP) should be capable of communicating with the ATMS network using accepted protocols. The TTSIP assembly should display 3 digits, sized in accordance with *IMUTCD* requirements.

2. Support Structure. The TTS should be installed on a standard overhead sign structure, selected according to overall sign area. The TTS should not be located over travelled lanes so maintenance activities can be performed without closing lanes. The TTS can be located over paved shoulders.

**502-5.04(03) Closed Circuit TV (CCTV) Camera System [Rev. Aug. 2022]**

This system provides live video to TMC personnel or selected external recipients as determined by the Department. The CCTV cameras should be pan/tilt/zoom capable.

An operator receives real-time video streams and manages control of the camera views. Videos are used to monitor and analyze roadway incidents and to facilitate Hoosier Helper and other emergency response deployment. Media outlets have access to delayed video streams, but they do not have control over the cameras. CCTV system specifics are described below.

1. Location. The designer should select locations given the following considerations. All locations of planned CCTV installations must be approved by INDOT ITS

    a. Each camera should provide a clear overview of the longest possible segment of roadway. Locations should be identified where more than one camera is needed at a tower site to provide necessary functionality.

b. The distance between the CCTV tower site and overhead electrical lines should be greater than the height of the support structure, with a preferred distance of more than 150 ft.

2. Camera and Interface Equipment. This consists of the central camera unit, weatherproof protective housing with clear lens on the bottom, interface unit, and two CAT6 ethernet cables, a main and a spare, to be powered by power-over-ethernet (POE).

3. Camera Lowering Device (CLD). The camera lowering device should include a permanent winch with handle and a 1-1/8-in. socket. The CLD should include a guide wire to direct the camera while it is being lowered. This wire should be secured to the bottom of the support structure while the CLD is not in use. The CLD should provide for the guide wire to be positioned at the appropriate angle to the tower leg while the CLD is in the working position.

4. Support Structure. A monopole or self-supporting tower should be used as the support structure. A high-mast tower or light pole may be used when:

   a. One of the structures exists and is available for use in the vicinity of the selected location; and
   b. It is unsuitable to build an additional structure at the selected location.

**502-5.04(04) Detection [Rev. Aug. 2022]**

Detection is used by the Department to monitor real-time traffic characteristics. The Department uses two vehicle detection systems: side-fire microwave and wireless magnetometers. Detectors should be located to detect traffic volume and vehicle speeds on the lanes of a multi-lane highway and on the on-ramps at a system (freeway-to-freeway) interchange. The two detection alternatives are described below.

1. Side-Fire Microwave Detector. Each site provides vehicle speed and volume data from the detector units, mounted above and adjacent to the roadway. Each detector unit can obtain data from 4 to 10 lanes of traffic.

   a. Location. Each specific location should be verified based on the following considerations:

      1) Traffic flow is consistent. Vehicles do not change lanes often.

      2) Control cabinet and detector should be safely accessible for maintenance.

3) Pole-mounted detector assemblies should be located outside the clear zone or in areas protected by guardrail. Refer to manufacturer specifications for site-specific detector assembly setback distance and mounting height. If recommended height cannot be used due to pole height, detector unit should be mounted as high as possible within the range recommended by the manufacturer.

b. Equipment. A detection unit, which includes a sequence generator/receiver, an ethernet based communication device, and a power supply with surge protection should be provided at each site.

c. Installation. A microwave detector should be installed adjacent to the roadway shoulder attached to an existing traffic or ITS structure where possible. If no existing structure is available, the microwave detector should be installed on a new support structure. The distance from the detector to the control cabinet, or communication cable length should not exceed the manufacturer's recommendations.

2. Wireless Magnetometer. Each site provides speed and volume data from probes cored into the pavement. Each lane has two probes spaced per the manufacturer's recommendations (typically 20 feet). The probes communicate wirelessly to an access point mounted on an ITS support structure which is connected to equipment inside the cabinet.

a. Location. Locations should be selected based on the following considerations:

1) Traffic flow is consistent. Vehicles do not change lanes often
2) Control cabinet and wireless access point should be safely accessible for maintenance
3) Pole-mounted assemblies should be located outside the clear zone or in areas protected by guardrail. Refer to manufacturer specifications for site-specific detector assembly setback distance and mounting height

b. Equipment. Pavement detector probes and a wireless access point. A wireless repeater may be required if the distance between probes and the wireless access point exceeds manufacturer's recommendations.

c. Installation. The wireless access point should be installed adjacent to the roadway shoulder attached to an existing ITS support structure where possible. If no existing structure is available, the wireless access point shall be installed on a new ITS support structure. Wireless repeaters may be installed on sign post or INDOT ITS approved equivalent.

**502-5.04(05) Field Controller [Del. Aug. 2022]**

**502-5.04(06) Communication [Del. Aug. 2022]**

**502-5.04(07) ITS Handhole and Conduit [Del. Aug. 2022]**

**502-5.04(08) Closed Circuit TV Site Requirements [Del. Aug. 2022]**

**502-5.04(09) Traffic Monitoring System [Rev. Aug. 2022]**

A traffic monitoring system consists of a Weigh-in-Motion (WIM) sensor, Automatic Traffic Recorder (ATR), or Virtual Weigh-in-Motion (VWIM) station.

The Code of Federal Requirements (23 CFR 500 Part B), available at http://ecfr.gpoaccess.gov/23CFR500, establishes a systematic process for the collection, analysis, summary, and retention of highway vehicular traffic data for a traffic monitoring system.

To comply with Federal requirements, VWIM, WIM, ATR, and DCS stations exist throughout the state. WIM and VWIM stations are also utilized as vehicle weight screening stations for police enforcement activities.

INDOT ITS should be contacted to determine if a traffic monitoring station is required.

INDOT ITS should be contacted to coordinate the design and review process. See the INDOT *Standard Drawings* for controller cabinet foundation details. Final layout drawings should be developed for review by INDOT ITS.

ATR, WIM, and VWIM design criteria are described as follows.

1. Physical Station Requirements. The designer should coordinate with INDOT ITS to determine where the station may be built within the project limits. The location should be in accordance with the following.

a. The site should not be located within 1000 ft of an intersection or signal or within 500 ft of likely lane changes such as entrance and exit ramps.

b. Horizontal Alignment. The horizontal curvature of the roadway for 200 ft in advance of and 100 ft beyond the system sensors should have a radius of not less than 5700 ft measured along the centerline of the roadway.

c. Vertical Alignment. The grade of the roadway surface for 200 ft in advance of and 100 ft beyond of the sensors is not to be steeper than 2%.

d. Cross Slope. The cross slope of the roadway surface for 200 ft in advance of and 100 ft beyond the sensors preferably should not be steeper than 3%. However, up to 4% is acceptable, but a grade steeper than 2% is allowable only in the leftmost travel lanes.

e. Lane Width. Stations should not be placed where the lane width is less than 11.5 ft or greater than 14 ft.

2. Pavement. Adequate pavement structure and surface smoothness is required to ensure optimum performance of the sensors throughout the service life of the system. PCCP is preferred for all Traffic Monitoring System applications. If on a freeway or principal arterial highway, the station should be centered within a 450-ft segment of concrete pavement.

a. HMA. HMA pavement is allowable in some instances for ATR stations but should be avoided for WIM or VWIM applications

b. Reinforced PCCP. Reinforced pavement panels are required where roadway sensors are to be placed. The reinforcing bars should be placed in the lower half of the depth of pavement to minimize interference with loop detectors. In jointed PCCP where transverse joints are spaced at 18 ft, the reinforced PCCP section is within the center 50 ft of the 450-ft PCCP section.

Continuously reinforced PCCP can be used with a traffic monitoring system only if the reinforcement is sufficiently below the pavement surface to accommodate sensor depth requirements and to not interfere with the loop detectors. Continuously reinforced PCCP at traffic monitoring system station should provide no less than 4 in. of cover from the top of reinforcing bars to the top of the pavement surface.

c. Pavement Smoothness. The surface of the roadway a minimum of 200 ft in advance of and 100 ft beyond the system sensors should be tested prior to sensor installation.

The designer should specify that the contractor use ASTM E 1318 Section 6.1.5.1 as the basis for testing. Test results must be submitted to INDOT ITS for approval prior to sensor installation.

d. Pavement Transitions. Pavement should be free of transitions, such as HMA to PCCP or pavement to bridge abutment, at least 200 ft in advance of and 100 ft beyond a WIM or VWIM sensor array.

3. Electronic Equipment.

a. System Controller/Recorder. A system controller/recorder is used with each Traffic Monitoring System. INDOT ITS should determine which type of system is to be specified, including the appropriate sensor array.

A controller/recorder should operate from 120 VAC, be accessible via IP-based communication systems, have an onboard ethernet connection, provide on-site data storage, be capable of generating a digital per vehicle data file in an approved format, and interface with roadway sensor arrays.

b. A communication method should be provided as discussed in section 502-5.05.

c. VWIM Imaging System. The purpose of the VWIM imaging system is to provide images of vehicles passing over the sensors so that they can be linked to the data record. These images should be able to be viewed in real time or stored for future use. Each VWIM imaging system consists of the following components:

1) camera, lens, and weatherproof enclosure;
2) pole and foundation. See the INDOT *Standard Specifications* and *Standard Drawings*;
3) illuminator system, infrared for night vision; and
4) Virtual Weigh Station (VWS or ICP) controller

The orientation of the camera(s) should be as recommended by the manufacturer and should be reviewed for approval by INDOT ITS.

4. Station Components. Contact INDOT ITS for typical drawings. Each station should include the following components:

a. Cabinet. The cabinet should be in accordance with Section 502-5.04(02) and the INDOT *Standard Drawings*. Traffic Monitoring Systems should have their own dedicated cabinet and should not share a cabinet with other ITS field devices.

b. Cabinet Foundation. The cabinet foundation should be in accordance with the INDOT *Standard Drawings.*

c. Traffic Monitoring Handhole, Ring and Cover. At least one handhole should be installed no farther than 10 ft from the foundation. See Section 502-5.04(04) for additional details.

d. Traffic Monitoring Detector Housing. This should be installed in accordance with the INDOT *Standard Drawings.*

e. Galvanized Steel and PVC Conduit. Galvanized steel and PVC conduit should be shown on the plans, should be in accordance with the INDOT *Standard Drawings* and should be labeled as follows:

   1) PVC conduit of 2-in. diameter should be used between the traffic monitoring handhole and traffic monitoring detector housing, between the traffic monitoring handhole and camera pole, and from the service point to the camera pole.

   2) PVC conduit of 3-in. diameter should be used between the traffic monitoring handhole and camera pole, and between all traffic monitoring handholes.

   3) Galvanized steel conduit of 2-in. diameter should be used for each above-ground cable run.

   4) High density polyethylene EHMW (HDPE) pipe may be used in place of PVC conduit in a trench, with the same diameter as the PVC conduit.
   5) Flexible joints should be installed when transitioning from a buried conduit to conduit attached to a permanent structure to reduce vibration and movement damage.

f. Roadway Sensor Array. The sensors in use are as follows:

   1) Presence Detection. Two round 6 ft loop detectors per lane should be used for presence detection and should be in accordance with the INDOT *Standard Drawings.*

2) Axle Detection. Piezo sensors should be used on ATR stations. Quartz or strain gauge axle sensors should be used on WIM and VWIM stations unless otherwise specified by INDOT ITS.

3) Temperature Sensor. One temperature sensor is required for each controller and should be in accordance with controller manufacturer recommendations.

Sensor placement should be such that saw slots are no closer than 2 ft to transverse pavement joints. Sensors should be offset from the leftmost lane to the right approximately 6.75 ft in a downstream direction. The designer should coordinate details with INDOT ITS.

**502-5.04(10) Roadside Weather Information System (RWIS) [New Aug. 2022]**

A Roadside Weather Information System (RWIS) consists of atmospheric and in-pavement sensors that provide the Department with real-time information about atmospheric and road conditions. Where possible, RWIS sensors should be installed on other existing or planned ITS support structures, rather than on their own dedicated support structure. Contact INDOT ITS for sensor suite details.

**502-5.04(11) Truck Parking Information Management System (TPIMS) [New Aug. 2022]**

The Truck Parking Information Management System (TPIMS) informs truck drivers of the number of available truck parking spaces at upcoming rest areas. TPIMS consists of the following:

1. <u>Truck Parking Monitoring System.</u> A truck parking monitoring system is used to monitor and verify the number of available truck parking spaces at a particular rest area, and consists of the following:

   a. Vehicle Detection. Vehicle detection should be provided at the entrance and exit of the truck parking area to provide an accurate real-time count of truck parking spaces available. Detection should be in accordance with Section 502-5.06(04).

   b. Overview CCTV Cameras. CCTV cameras should be in accordance with Section 502-5.06(03) and should be installed to provide complete coverage of the truck parking area to allow the Department to visually verify the number of available truck parking spaces. The designer should provide a viewshed analysis of proposed overview CCTV camera installations to demonstrate their height and location will allow a truck in any parking space to be uniquely identified if the lot is full and any landscaping is fully grown with full foliage. For this analysis, all trucks can be assumed to be 72 ft long, 13.5 ft tall, and 8.5 ft wide.

c. ITS Cabinets. A pole-mounted ITS cabinet should be provided at the entry and exit vehicle detection points and each CCTV Camera location. ITS cabinets should be in accordance with 502-5.04(02).

d. Communication. One of the pole-mounted ITS cabinets at a CCTV camera location should be identified as the central communication cabinet. The central communication cabinet should contain all the necessary equipment to connect to the ITS network. All other cabinets should be connected to the central communication cabinet via fiber optic cable. Communication should be in accordance with 502-5.05.

e. Power. Should be in accordance with 502-5.04(01). Each cabinet location should be within 50 ft of either a main or remote service disconnect.

2. Truck Parking Information Sign. Truck parking information signs display the number of open truck parking spaces at upcoming rest areas, and consist of the following:

   a. ITS cabinet. Should be in accordance with Section 502-5.03(04)

   b. Panel sign. Should be in accordance with INDOT *Standard Drawings* and *IMUTCD* specifications with dynamic message punch-outs able to display 3 digits.

   c. Communication. Should be in accordance with Section 502-5.05.

**502-5.05 Plan Development Procedure [Del. Aug. 2022]**

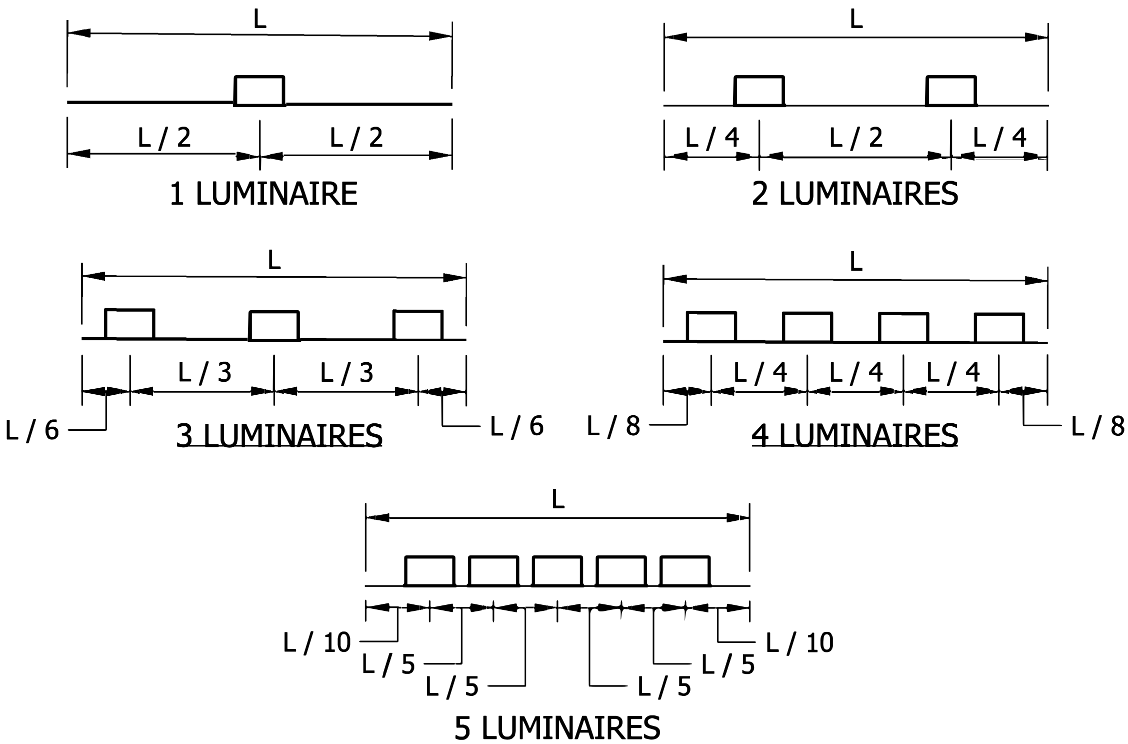
**502-5.05(01) Site Reviews [Del. Aug. 2022]**

**502-5.05(02) Bucket Truck Survey [Del. Aug. 2022]**

**502-5.05 Plan Development Procedure [New Aug. 2022]**

This section provides additional documentation that may be considered throughout the project development process. This is list is not all-inclusive, and guidance in these documents does not supersede guidance provided in the Indiana Design Manual.

1. Federal Highway Administration *Research List of Online Reports and Technical Publications*
https://www.fhwa.dot.gov/publications/lists/021.cfm
2. Federal Highway Administration *Ramp Management and Control Handbook*
https://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/pdf/rm_handbook.pdf
3. Federal Highway Administration *Use of Freeway Shoulders for Travel – Guide for Planning, Evaluating, and Designing Shoulder Use as a Traffic Management Strategy*
https://ops.fhwa.dot.gov/publications/fhwahop15023/index.htm#toc
4. Federal Highway Administration *Road Weather Information System/Environmental Sensor Station Siting Guidelines*
https://ops.fhwa.dot.gov/publications/ess05/index.htm
5. Federal Highway Administration *Systems Engineering Guidebook for ITS*
https://www.fhwa.dot.gov/cadiv/segb/index.cfm
6. United States Department of Transportation *Systems Engineering for Intelligent Transportation Systems, FHWA-HOP-07 069, January 2007*
https://ops.fhwa.dot.gov/publications/seitsguide/index.htm
7. Minnesota Department of Transportation *Intelligent Transportation Systems (ITS) Design Manual*
https://www.mndot.org/its/docs/itsmanual.pdf
8. Federal Highway Administration *Tool for Operations Benefit-Cost Analysis (TOPS-BC)*
https://transportationops.org/tools/tool-operations-benefit-cost-analysis-tops-bc



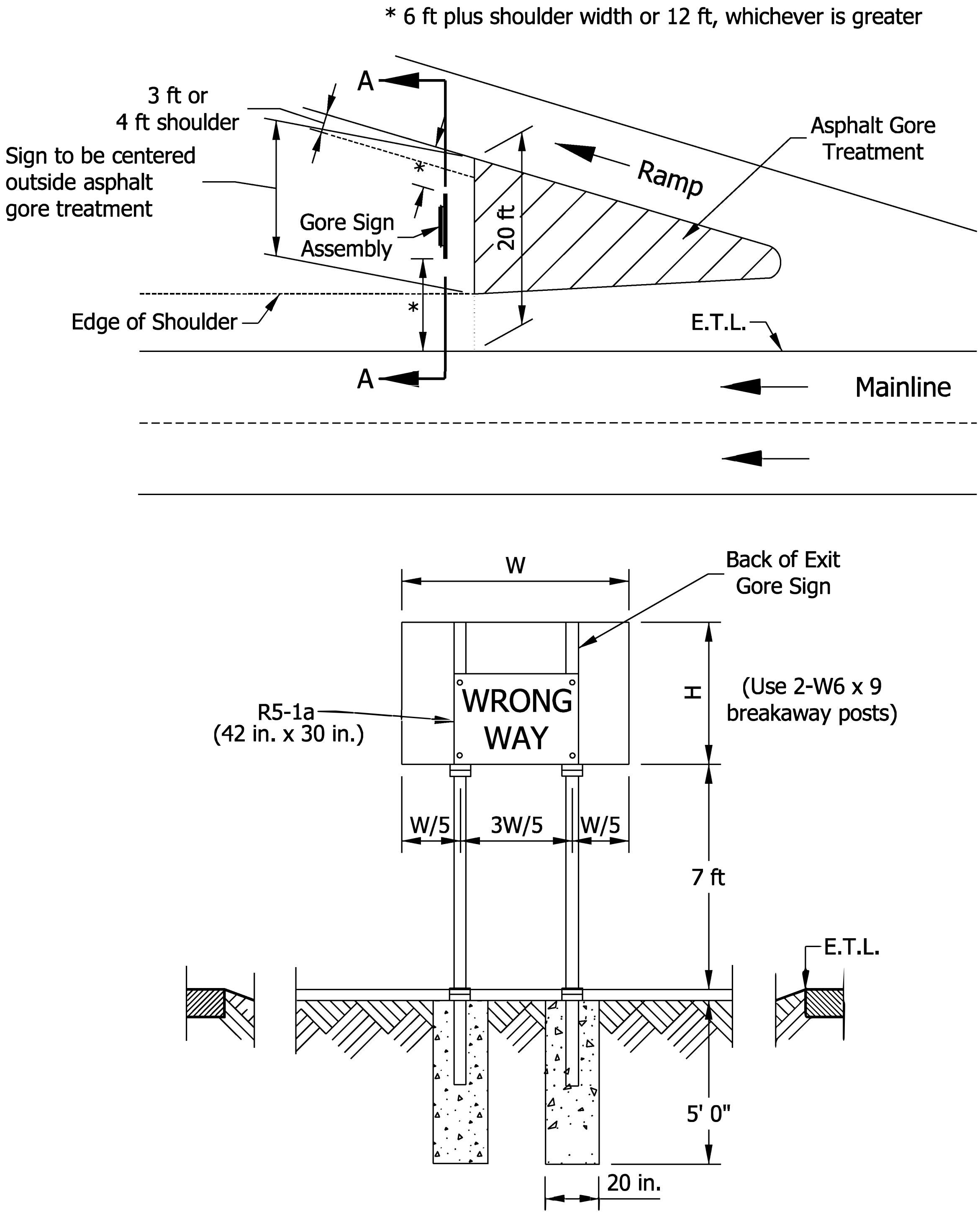

| SIGN HEIGHT ≤ 9 ft * | |
|---|---|
| SIGN LENGTH, L | NO. OF LUMINAIRES |
| 5 ft to 7 ft | 1 |
| 8 ft to 16 ft | 2 |
| 17 ft to 24 ft | 3 |
| 25 ft to 28 ft | 4 |

| SIGN HEIGHT > 9 ft * | |
|---|---|
| SIGN LENGTH, L | NO. OF LUMINAIRES |
| 5 ft to 7 ft | 1 |
| 8 ft to 14 ft | 2 |
| 15 ft to 19 ft | 3 |
| 20 ft to 24 ft | 4 |
| 25 ft to 28 ft | 5 |

** This dimension also includes the height of the exit sign panel.*

LUMINAIRE PLACEMENT DIMENSIONS FOR OVERHEAD SIGNS

Figure 502-1A




SECTION A-A

SIGN GORE TREATMENT

Figure 502-1B

| Truss Type | Max. Sign Area (Sq. Ft). | Span (Ft.). | Maximum Mounting Height |
|---|---|---|---|
| A | 500 | 130 | 28’ 6” |
| B | 700 | 100 | |
| C | | 130 | |
| D | 900 | 100 | |
| E | | 130 | |

# SIGN BOX TRUSS STRUCTURE SELECTION GUIDANCE

Figure 502-1C(1)

| Str. Type | Max. Span (ft) | Max. Sign Area (Sq. Ft.) | Maximum Mounting Height |
|---|---|---|---|
| A | 10 | 180 | 24’ 0” |
| B | 15 | 280 | |
| C | 20 | 380 | |
| D | 25 | 300 | |
| E | 30 | | |
| F | 35 | | |
| G | 25 | 400 | |
| H | 30 | | |
| I | 35 | | |

- Type A, B, C are Double Arm Cantilever Structures
- Type D, E, F, G, H, I are quadric-Chord Cantilever Structures

# SIGN CANTILEVER STRUCTURE SELECTION GUIDANCE

## Figure 502-1C(2)

| VEHICULAR SPEED | BALL-BANK READING | MAXIMUM RECOMMENDED SPEED OF CURVE |
|---|---|---|
| 20 mph or lower | 16º or greater | Speed at which the 16º reading occurs |
| 25 or 30 mph | 14º | Speed at which the 14º reading occurs |
| 35 mph or higher | 12º | Speed at which the 12º reading occurs |

BALL-BANK INDICATOR READINGS

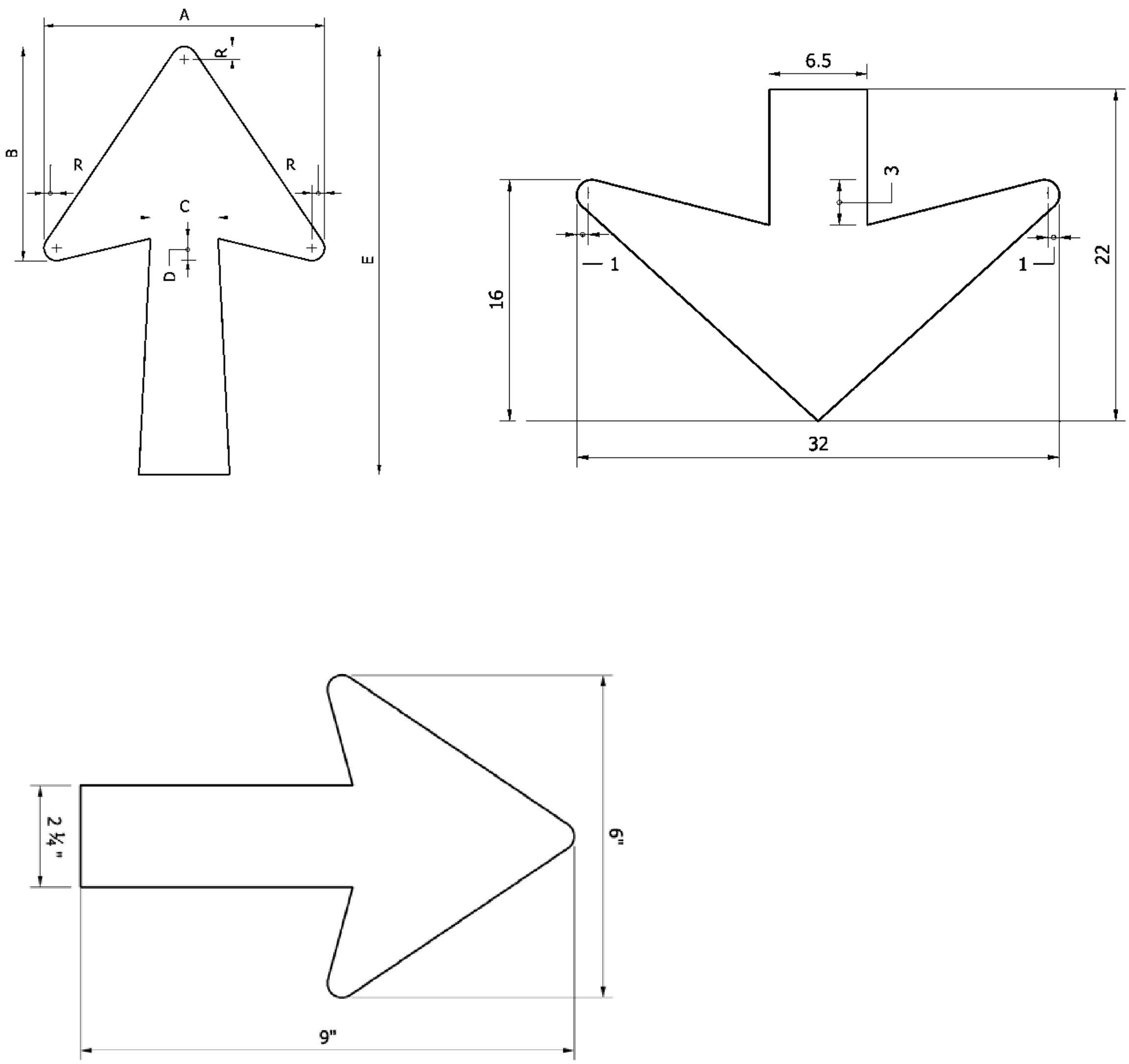
Figure 502-1D

| SIGN LETTER SIZE | 20”-15” | 16”-12” | 13.3”-10” | 8”-6” | 12” | 8” UC | 6”- | 4” |
|---|---|---|---|---|---|---|---|---|
| **BORDER** | | | | | | | | |
| RADIUS | 9” | 9” | 9” | 9” | 9” | 9” | 2” | |
| BORDER | 2” | 2” | 2” | 2” | 2” | 2” | 1” | |
| SUBPANELS | NONE | NONE | NONE | NONE | NONE | NONE | NONE | |
| PANEL SIZE | 12” | 12” | 12” | 12” | 12” | 12” | 6” | |
| **SIGN CLEARANCE** | | | | | | | | |
| LEFT | 20” | 16” | 13” | 8” | 12” | 8” | 6” | |
| RIGHT | 20” | 16” | 13” | 8” | 12” | 8” | 6” | |
| ROUND X | 12” | 12” | 12” | 12” | 12” | 12” | 6” | |
| TOP | 9” | 9” | 9” | 9” | 9” | 9” | 6” | |
| BOTTOM | 9” | 9” | 9” | 9” | 9” | 9” | 6” | |
| ROUND Y | 12” | 12” | 12” | 12” | 12” | 12” | 6” | |
| **EXIT PANEL,** EXIT PANEL HEIGHT SHALL BE 36” | | | | | | | | |
| LEFT | 10” | 10” | 10” | | | | | |
| RIGHT | 10” | 10” | 10” | | | | | |
| ROUND X | 6” | 6” | 6” | | | | | |
| TOP | 10” | 10” | 10” | | | | | |
| BOTTOM | 10” | 10” | 10” | | | | | |
| ROUND Y | 12” | 12” | 12” | | | | | |
| **SPACING BETWEEN ADJACENT LINES** | | | | | | | | |
| FONT | E(M) | E(M) | E(M) | E(M) | E(M) | E(M) | D | C |
| LETTER HEIGHT ROW 1 | 20” | 16” | 13” | 8” | 12” | 8” | 6” | 4” |
| LETTER HEIGHT ROW 2 | 20” | 16” | 13” | 8” | 12” | 8” | 6” | 4” |
| SPACING | 15” | 12” | 10” | 6” | 9” | 6” | 4” | 3” |
| **ARROW WIDTH** | | | | | | | | |
| DOWN | 32” x 22” | 32” x 22” | 32” x 22” | ---- | ---- | ---- | ---- | ---- |
| DIRECTIONAL | 22” x 35” | 22” x 35” | 18” x 28” | | ---- | ---- | | |
| **INTERSTATE GORE SIGN** | | | | | **NON-INTERSTATE GORE** | | | |
| LEFT | 12” | | | | 6” | | | |
| RIGHT | 12” | | | | 6” | | | |
| TOP | 9” | | | | 6” | | | |
| BOTTOM | 9” | | | | 6” | | | |
| TEXT SIZE, letters or numeral | 12”/18” | | | | 10” | | | |
| ROUTE SHIELD SIZE | --- | | | | 24” | | | |
| ARROW SIZE | 13.5” x 28” | | | | 15” x 18” | | | |
| SINGLE SPACE REQUIRED BETWEEN NUMERAL AND ALPHA i.e., EXIT 99 B | | | | | | | | |
| 6” SPACING REQUIRED BETWEEN EXIT NUMBER AND ARROW | | | | | | | | |
| “EXIT ONLY” PANEL SHOULD BE 36” HEIGHT | | | | | | | | |
| SPACE BETWEEN SHIELD AND FIRST LINE SHOULD BE 15” | | | | | | | | |
| SPACE BETWEEN SHIELD AND CARDINAL DIRECTION SHOULD BE 12”, AND SHALL BE TOP ALIGNED | | | | | | | | |
| FOR DIAGRAMMATIC SIGN,THE SPACE BETWEEN ARROW AND SHIELD OR WORD SHOULD BE 12” | | | | | | | | |
| FOR D1 OR D2 SIGN, SPACE BETWEEN WORD, NUMERAL AND ARROW IN A LINE SHOULD BE 6” | | | | | | | | |
| PANEL SIGN SIZE SHOULD BE TO THE NEAREST 1FT. INCREMENT | | | | | | | | |

**SIGN SOFTWARE INPUT AND SPACING REQUIREMENTS**

**Figure 502-1E**

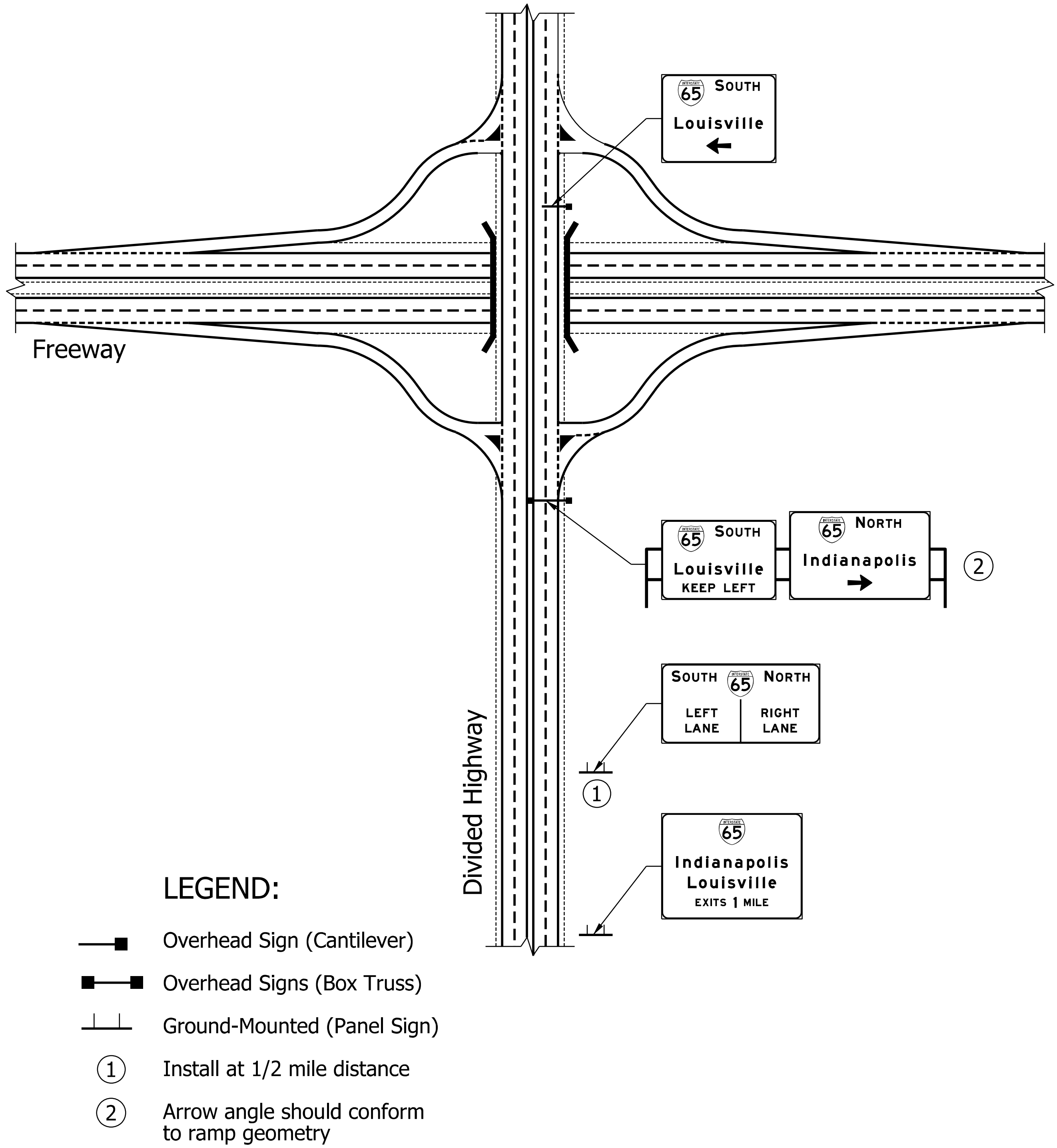
| LETTER SIZE (UPPER CASE) | DIMENSIONS | | | | | |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | R |
| 8” | 15 1/8” | 11 9/16” | 3 ¾” | 1 5/16” | 17”- 25” | 13/16” |
| 10”- 13 1/3” | 18 ¼” | 14” | 4 ½” | 1 ½’ | 20”- 30” | ¾” |
| 16”- 20” | 22 ¼” | 17” | 5 3/8” | 1 ¾” | 25”- 35” | 1” |




NOTE: For arrows with a tail, use standard arrow with 1’ extension.

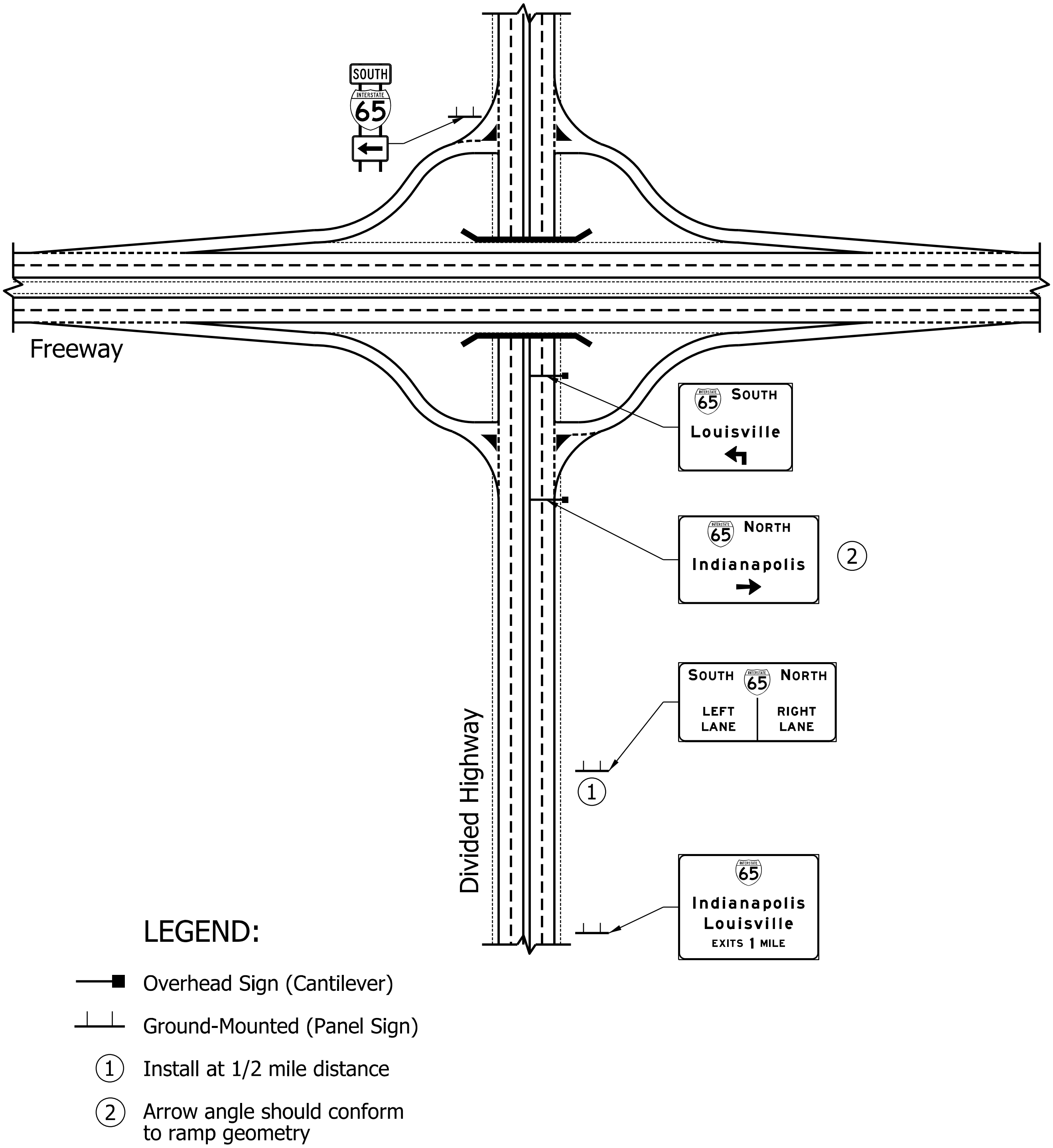
**ARROW DIMENSIONS**

**Figure 502-1F**



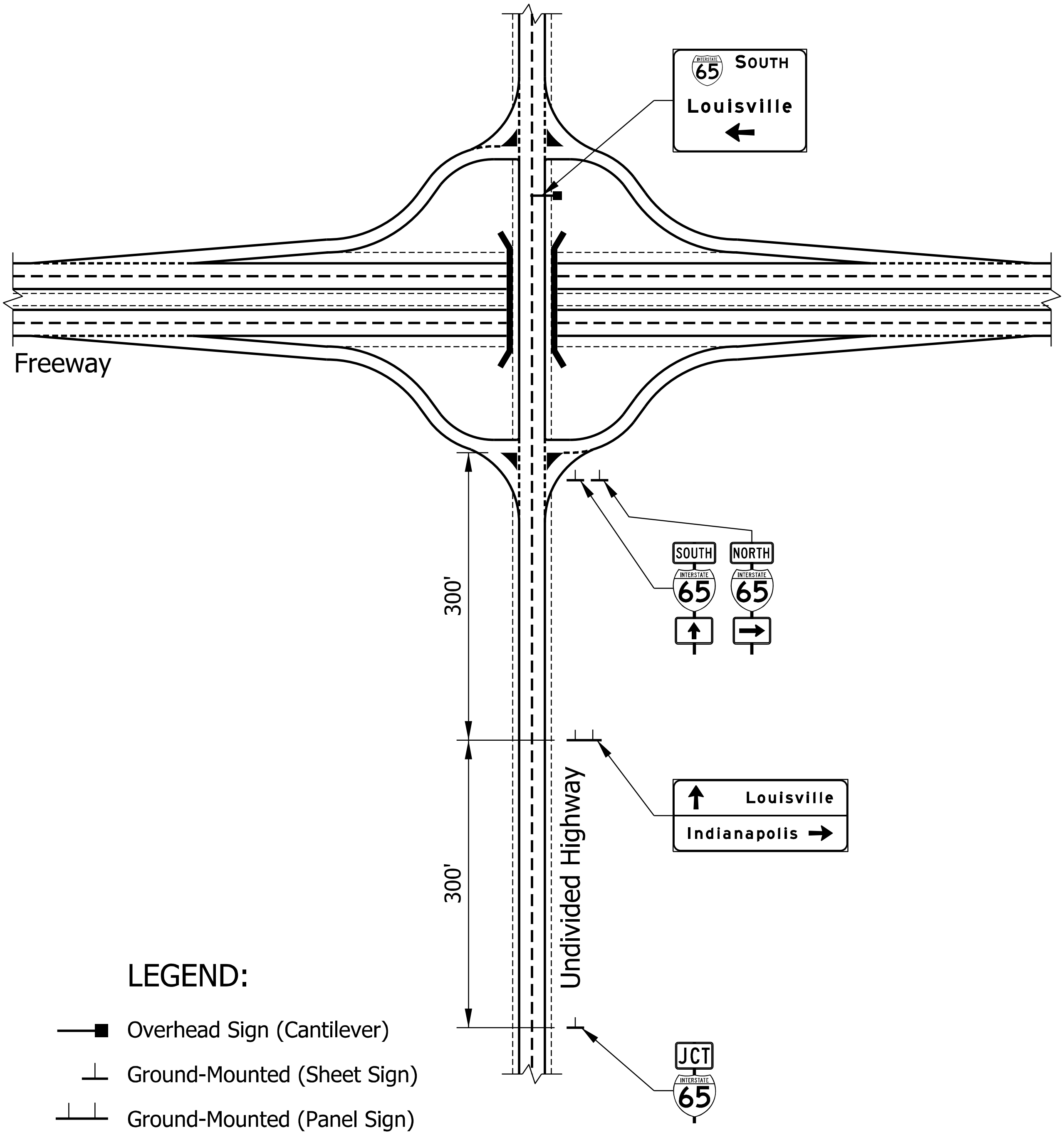

DIAMOND INTERCHANGE SIGNING
Divided Highway over Freeway

Figure 502-1G



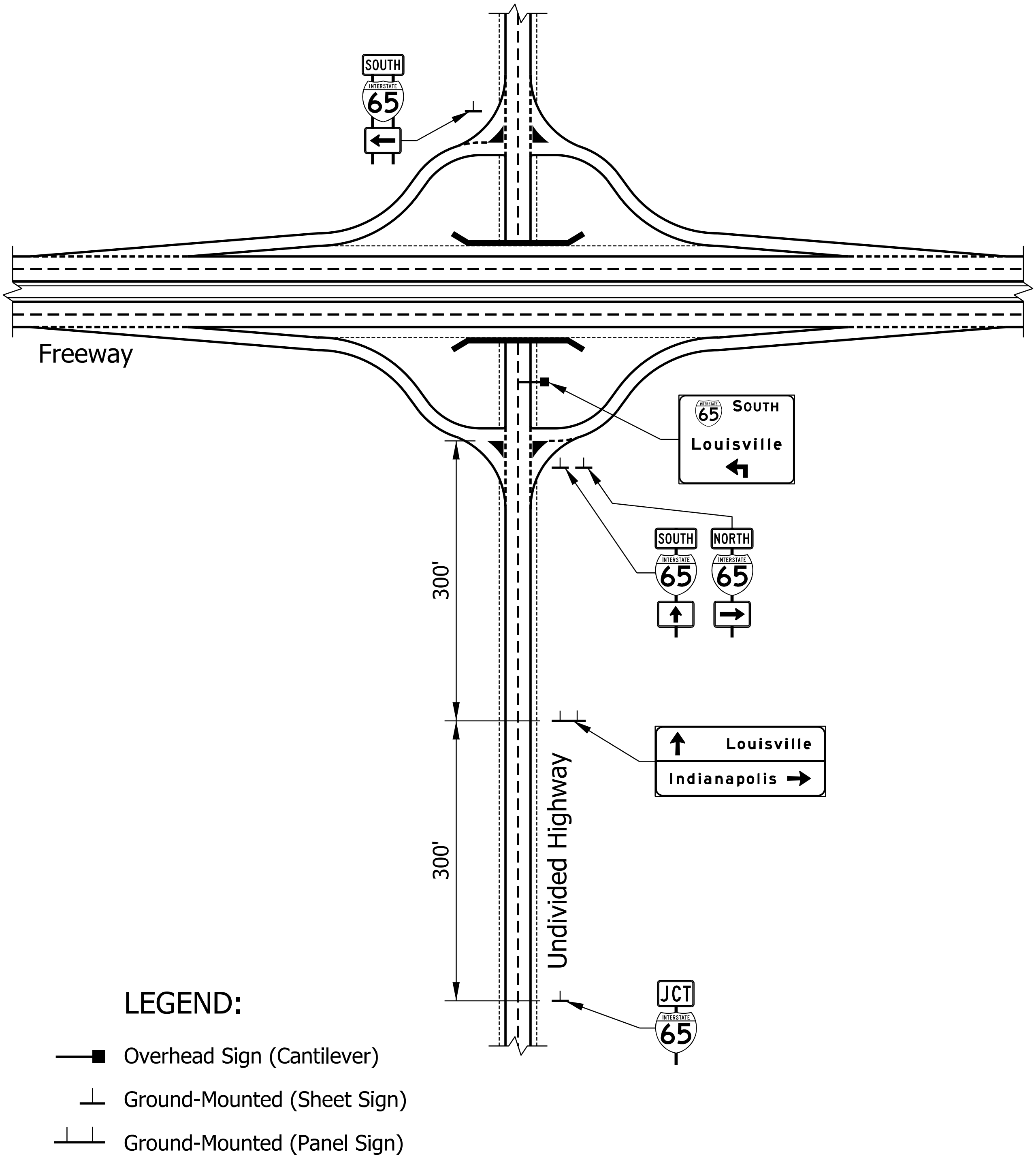

DIAMOND INTERCHANGE SIGNING
Divided Highway under Freeway

Figure 502-1H



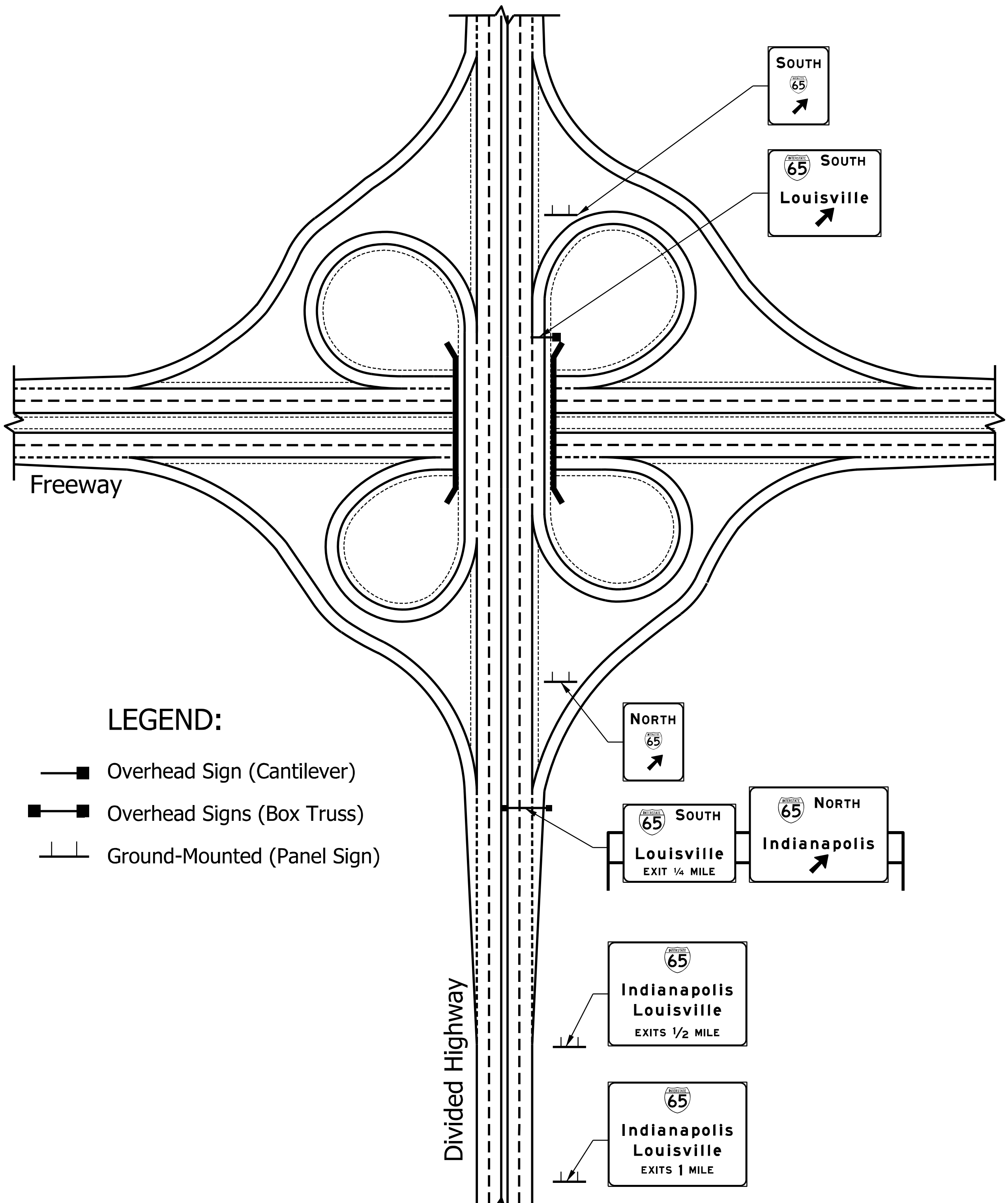

DIAMOND INTERCHANGE SIGNING
Undivided Highway over Freeway

Figure 502-1 I



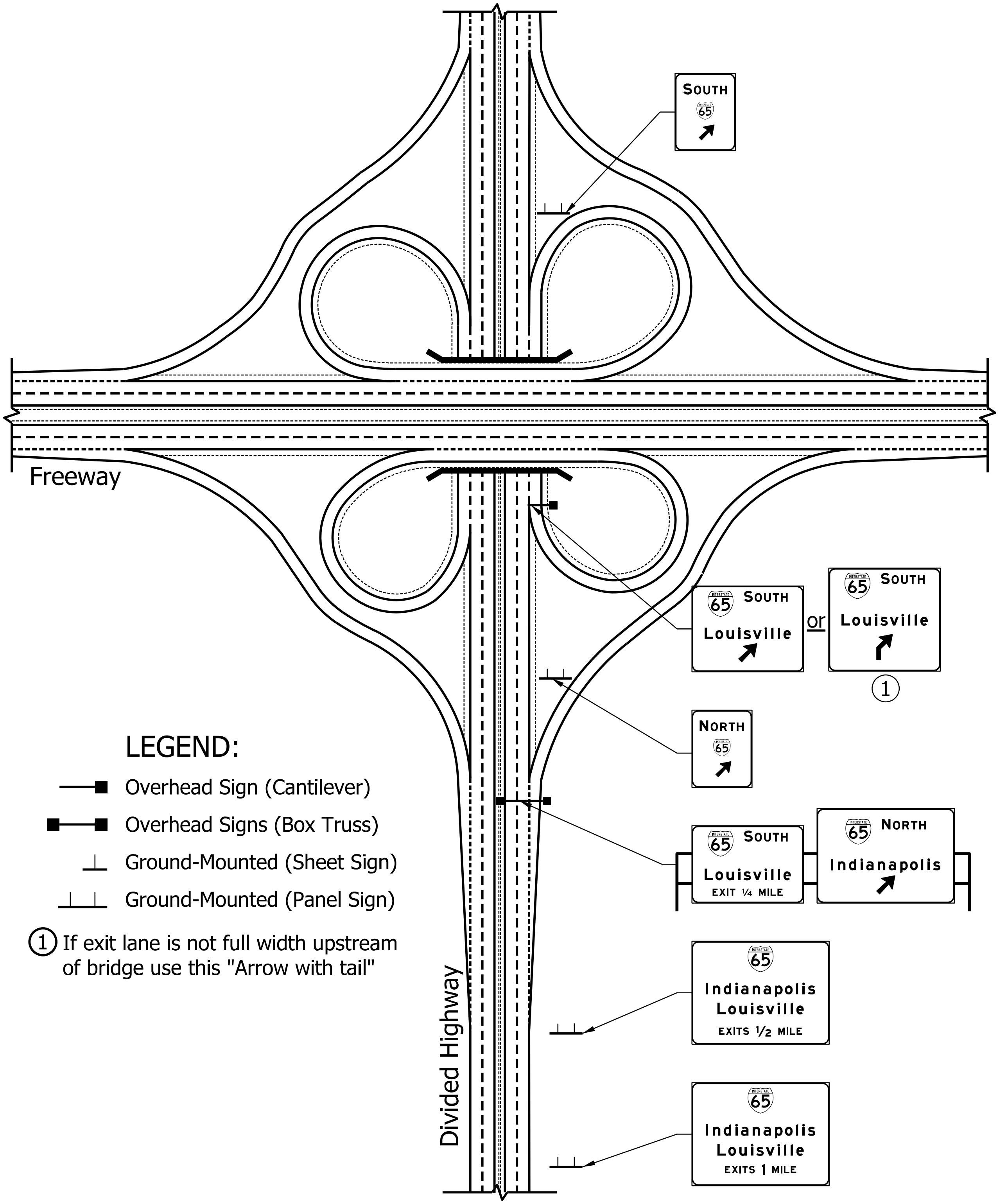

DIAMOND INTERCHANGE SIGNING
Undivided Highway under Freeway

Figure 502-1J



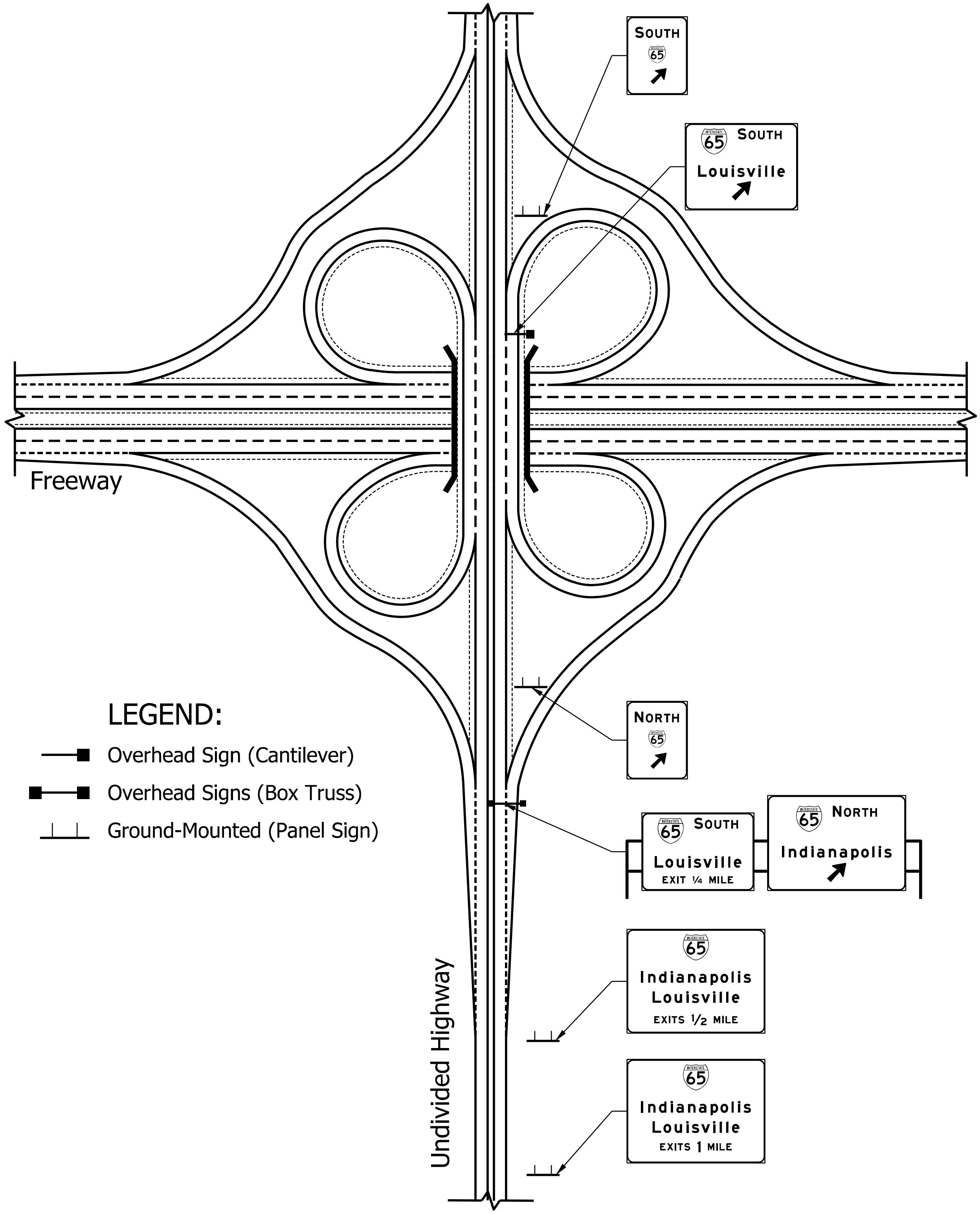

FULL CLOVERLEAF INTERCHANGE SIGNING
Divided Highway over Freeway

Figure 502-1K



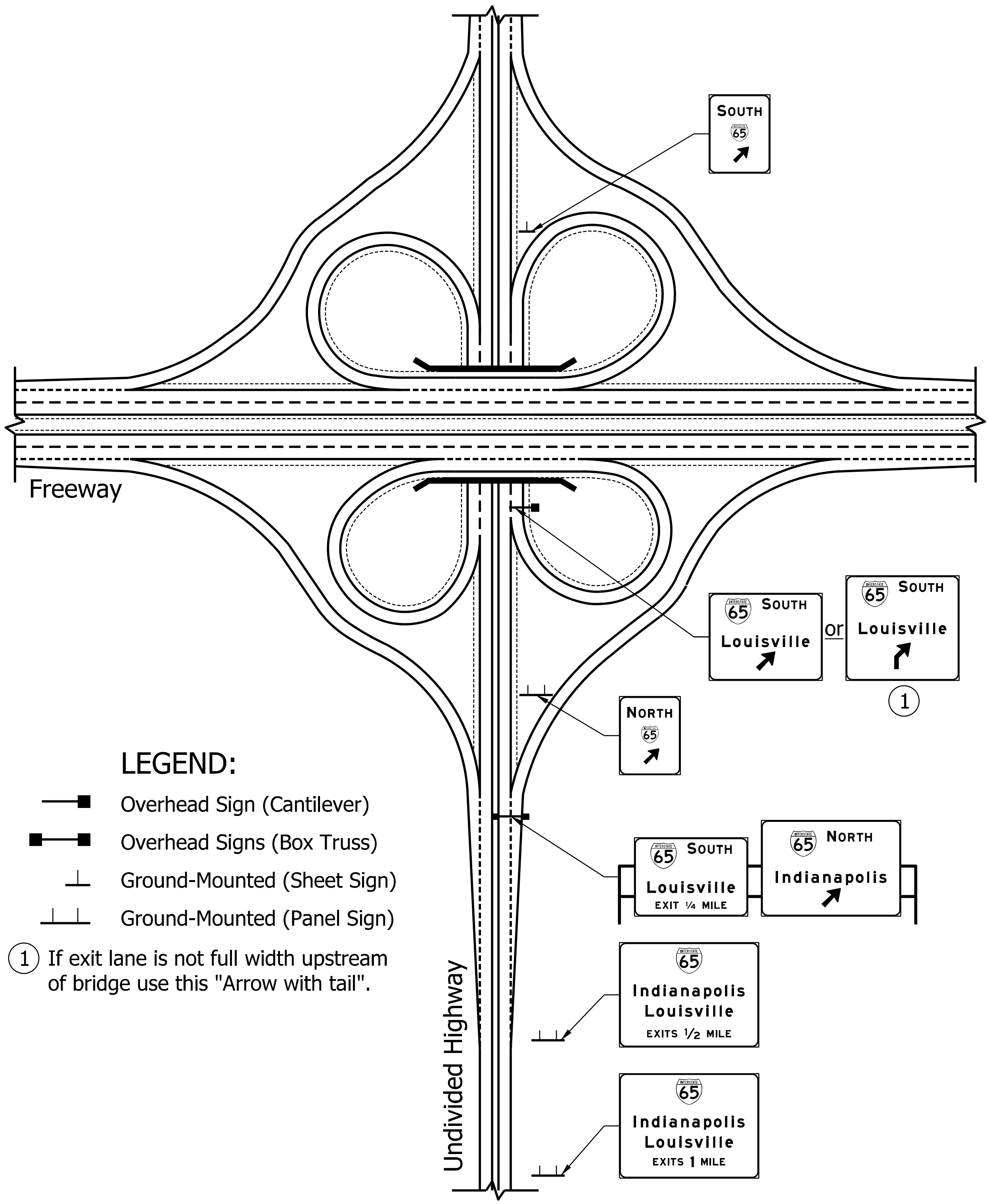

# FULL CLOVERLEAF INTERCHANGE SIGNING
## Divided Highway under Freeway

Figure 502-1L



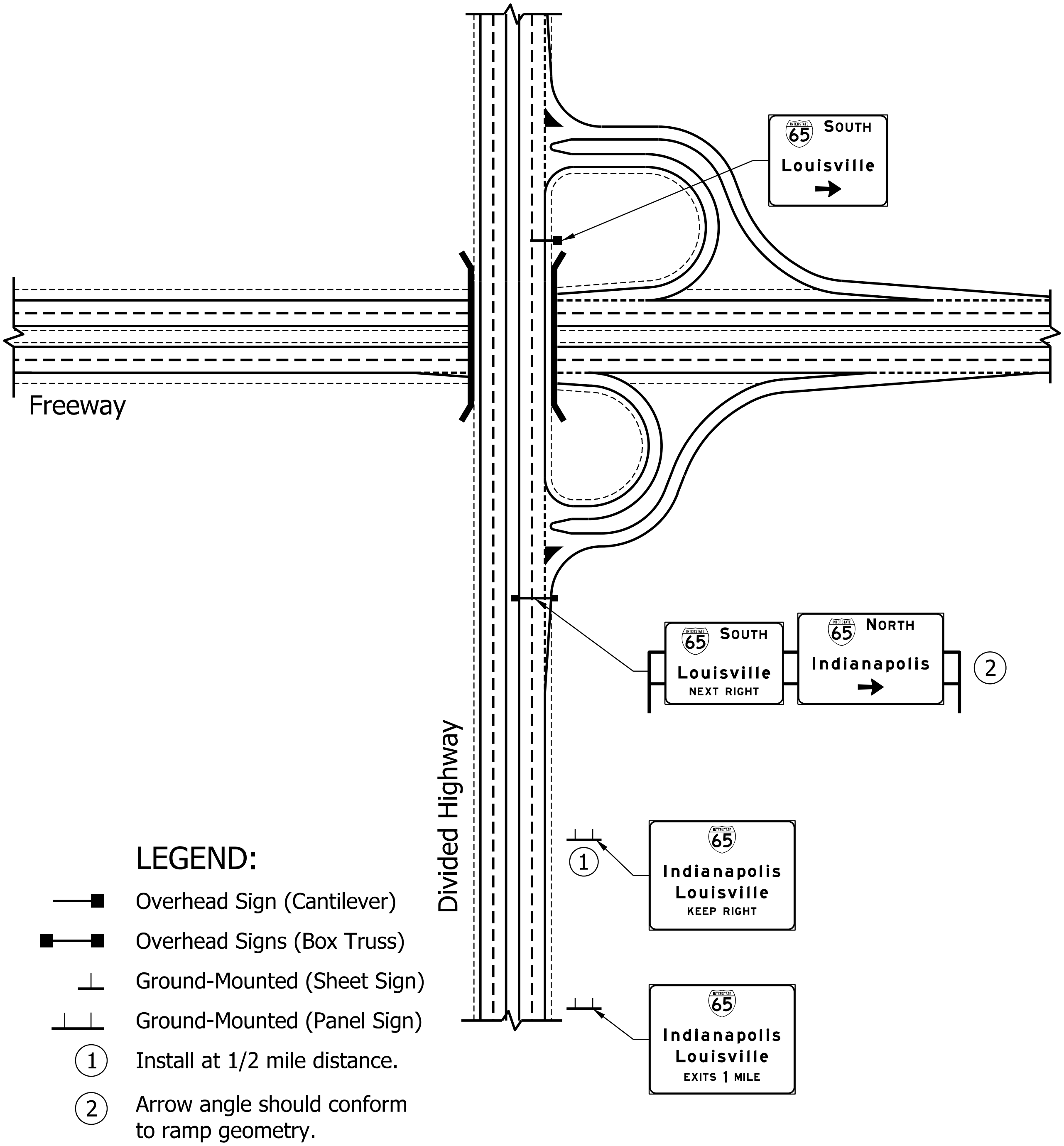

FULL CLOVERLEAF INTERCHANGE SIGNING
Undivided Highway over Freeway

Figure 502-1M




FULL CLOVERLEAF INTERCHANGE SIGNING
Undivided Highway under Freeway

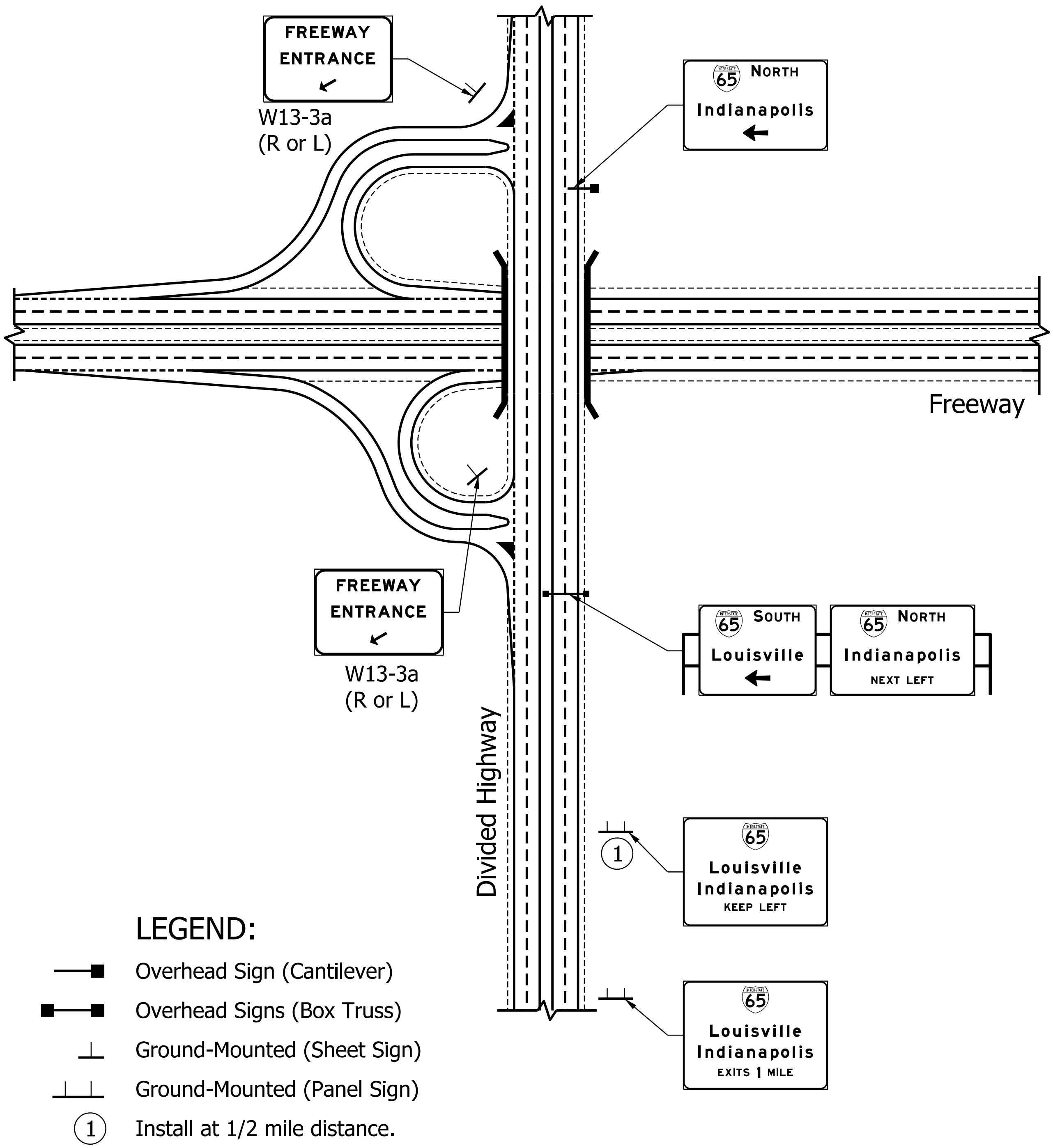
Figure 502-1N




*(See Figure 502-1P for opposite direction of travel.)*

PARTIAL CLOVERLEAF INTERCHANGE SIGNING
Divided Highway over Freeway

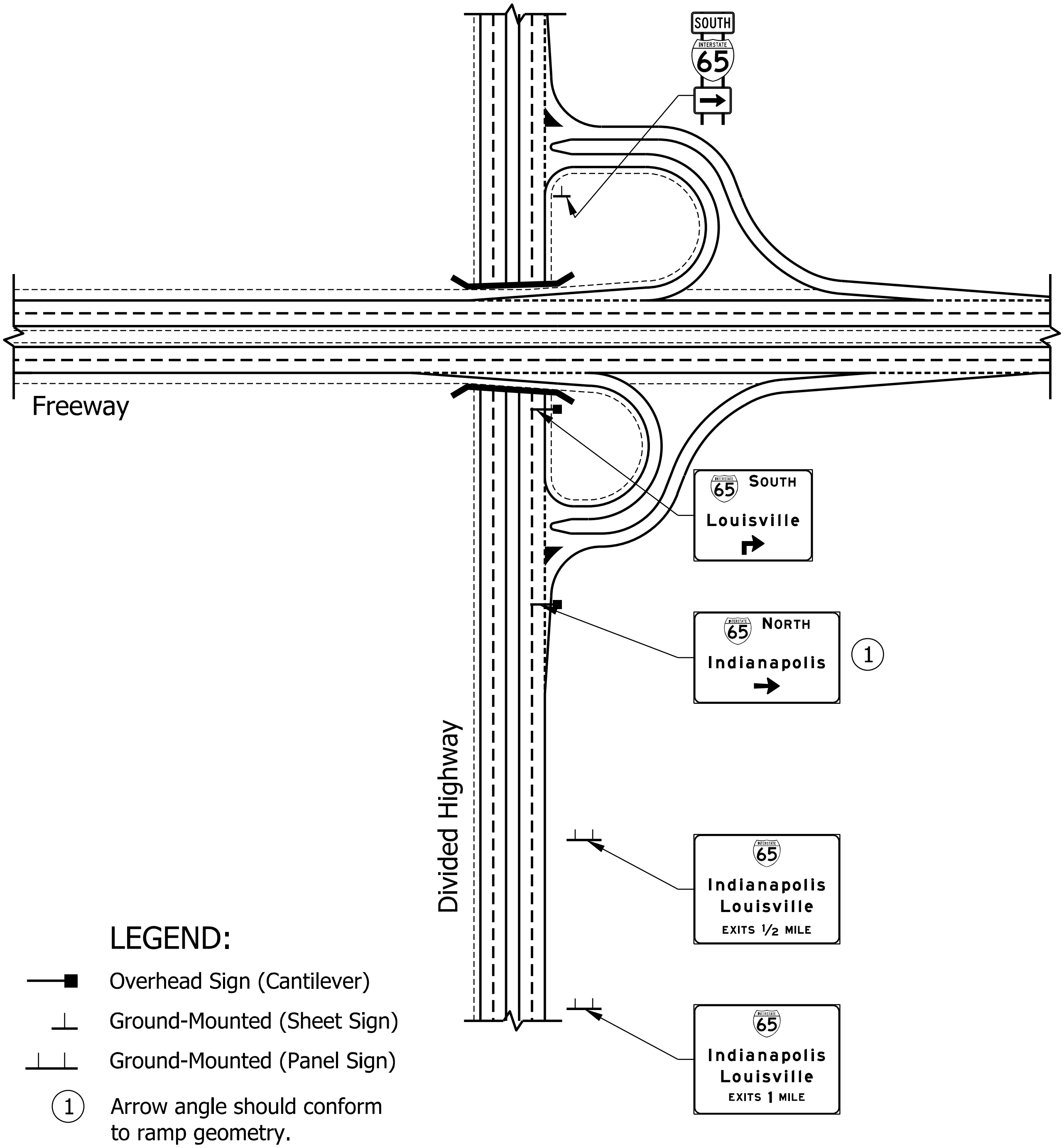
Figure 502-1 O




*(See Figure 502-1 O for opposite direction of travel.)*

PARTIAL CLOVERLEAF INTERCHANGE SIGNING
Divided Highway over Freeway

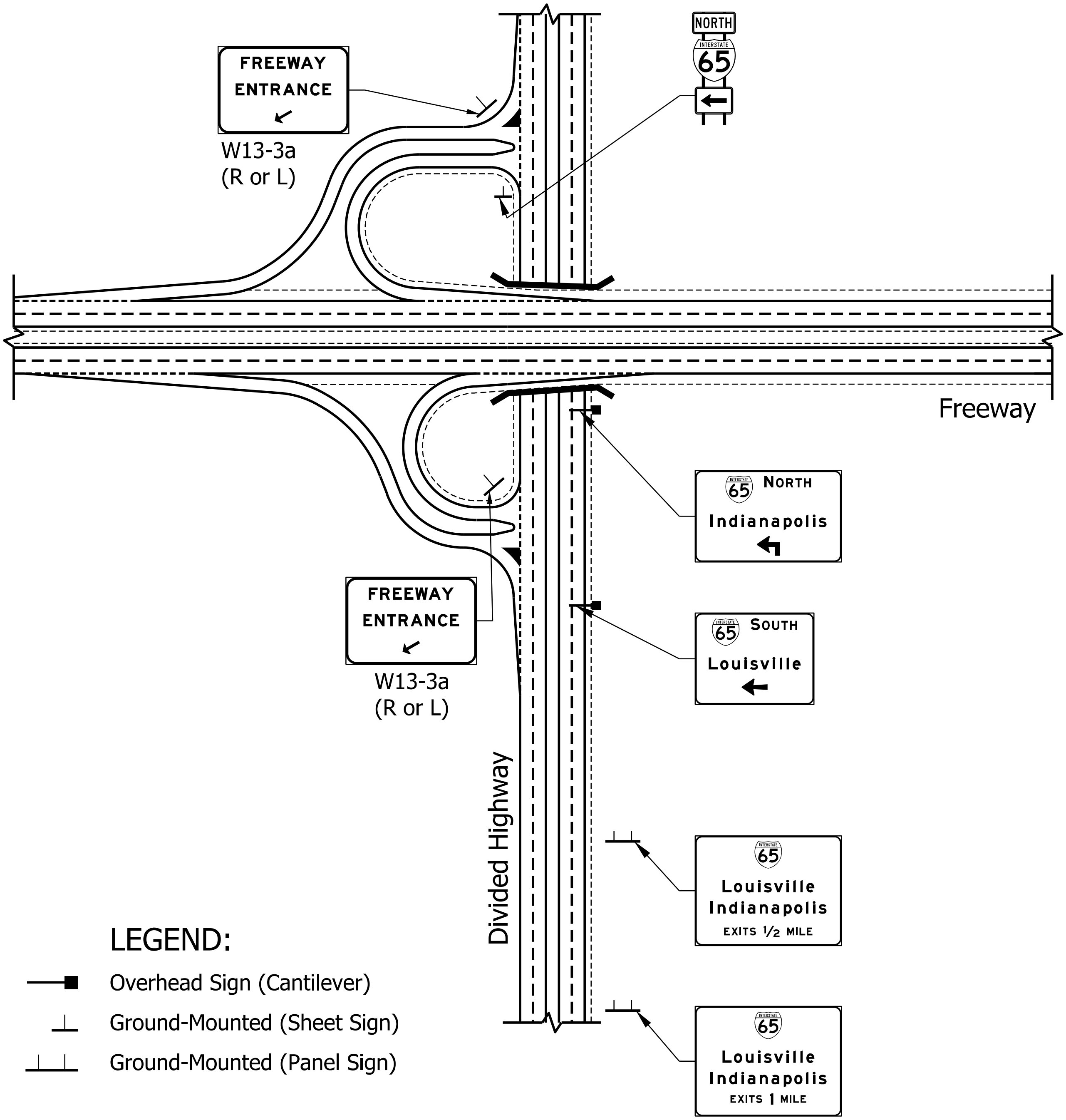
Figure 502-1P




*(See Figure 502-1R for opposite direction of travel.)*

PARTIAL CLOVERLEAF INTERCHANGE SIGNING
Divided Highway under Freeway

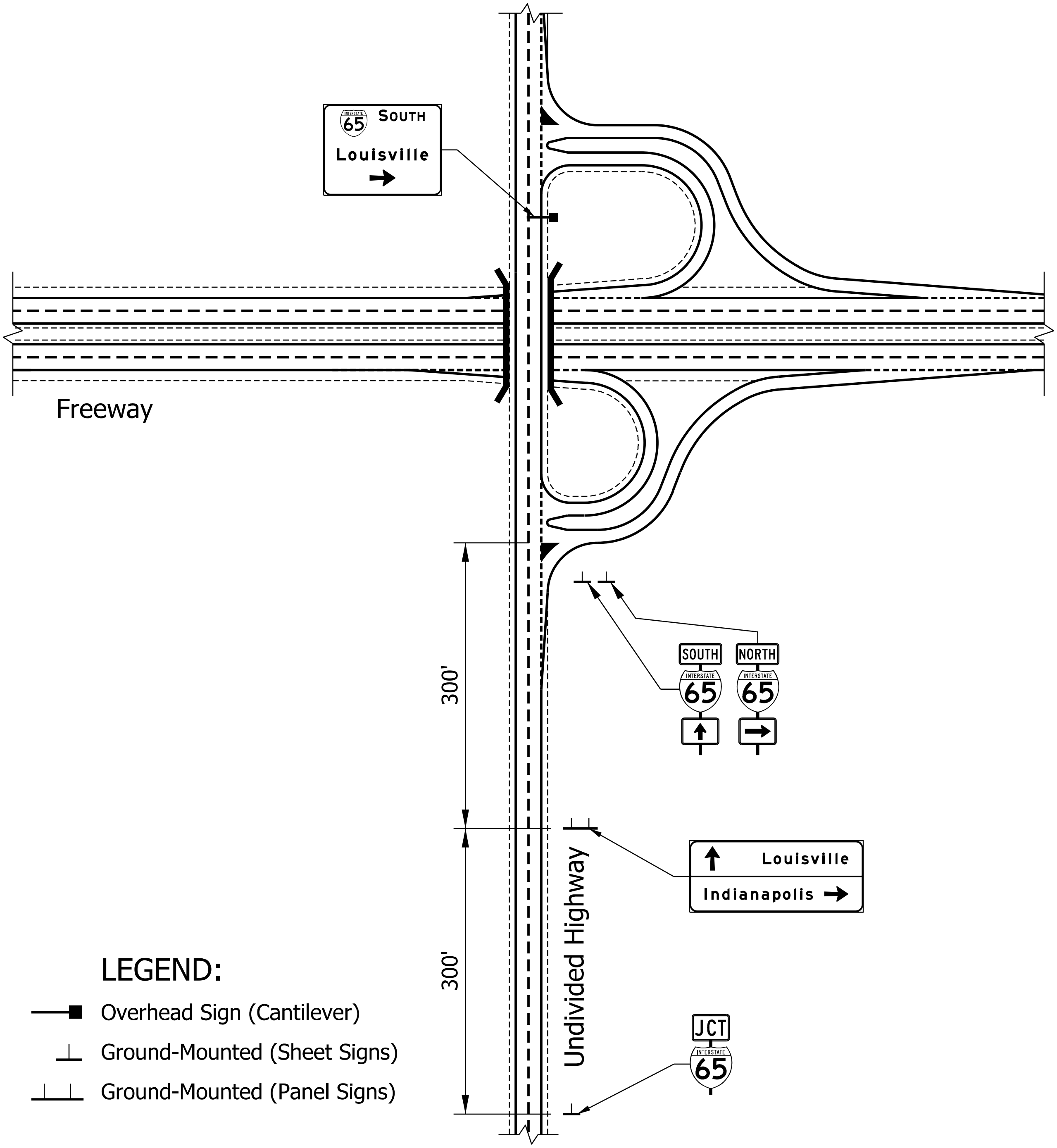
Figure 502-1Q




*(See Figure 502-1Q for opposite direction of travel.)*

PARTIAL CLOVERLEAF INTERCHANGE SIGNING
Divided Highway under Freeway

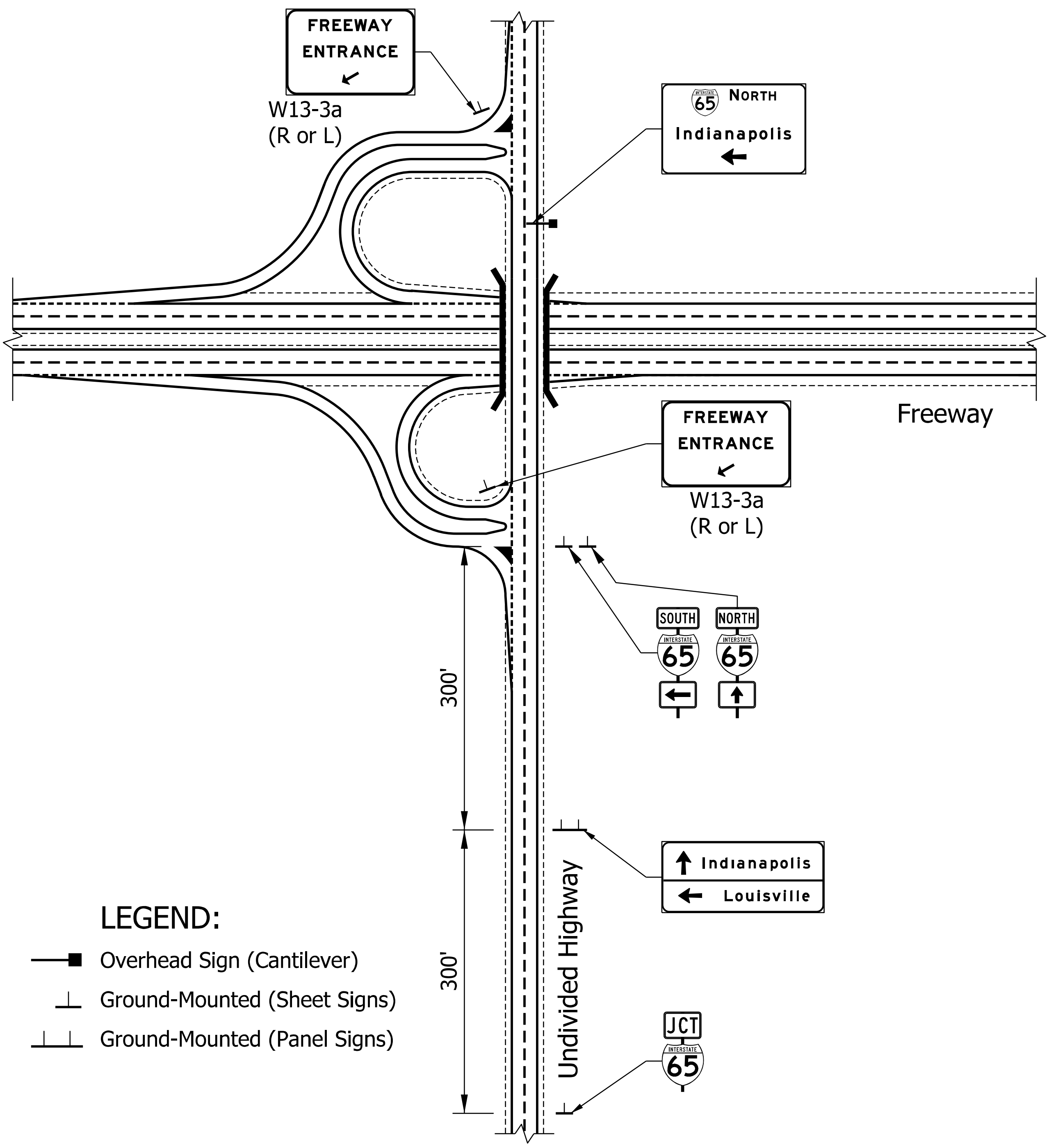
Figure 502-1R




*(See Figure 502-1T for opposite direction of travel.)*

PARTIAL CLOVERLEAF INTERCHANGE SIGNING
Undivided Highway over Freeway

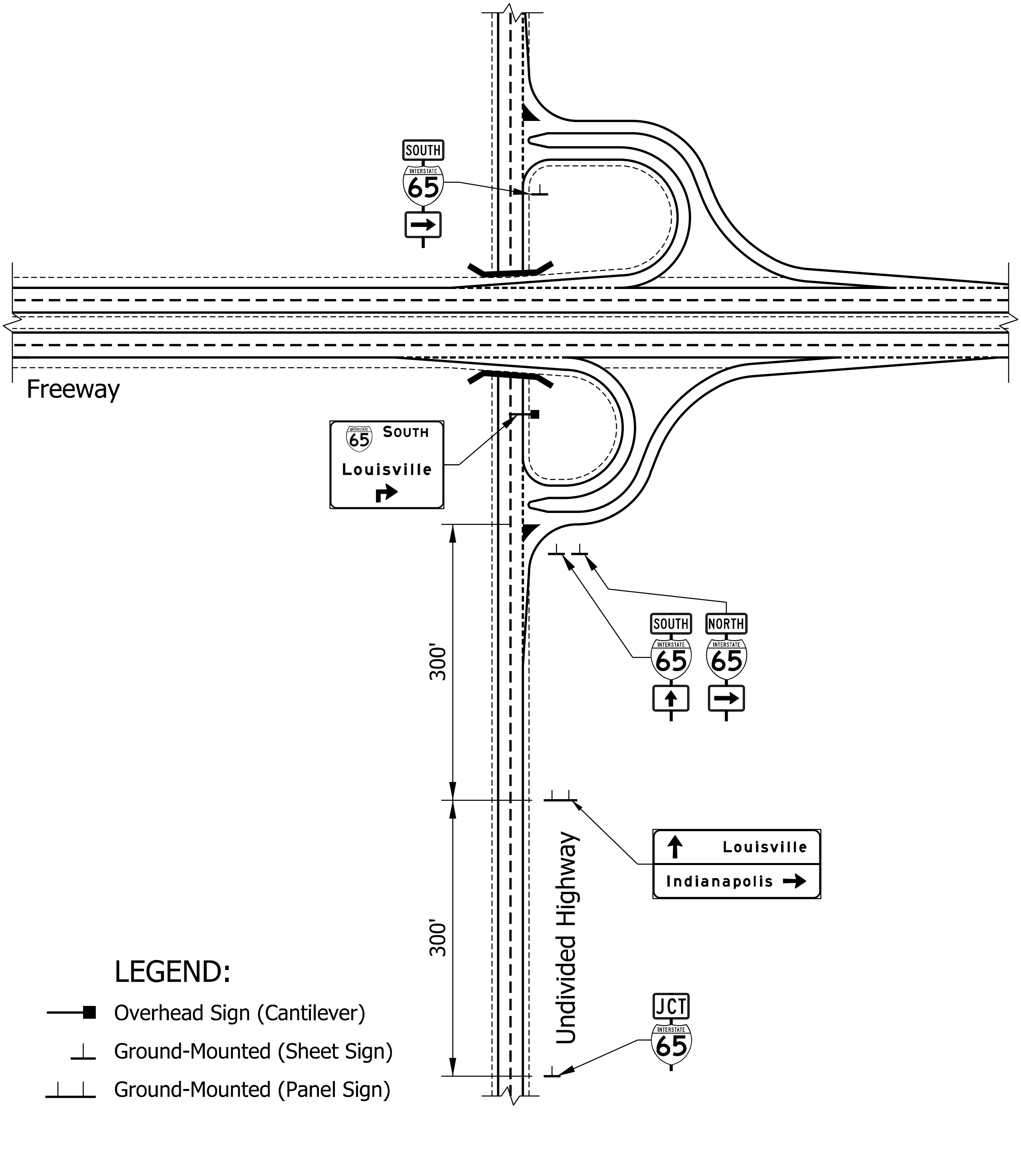
Figure 502-1S




*(See Figure 502-1S for opposite direction of travel.)*

PARTIAL CLOVERLEAF INTERCHANGE SIGNING
Undivided Highway over Freeway

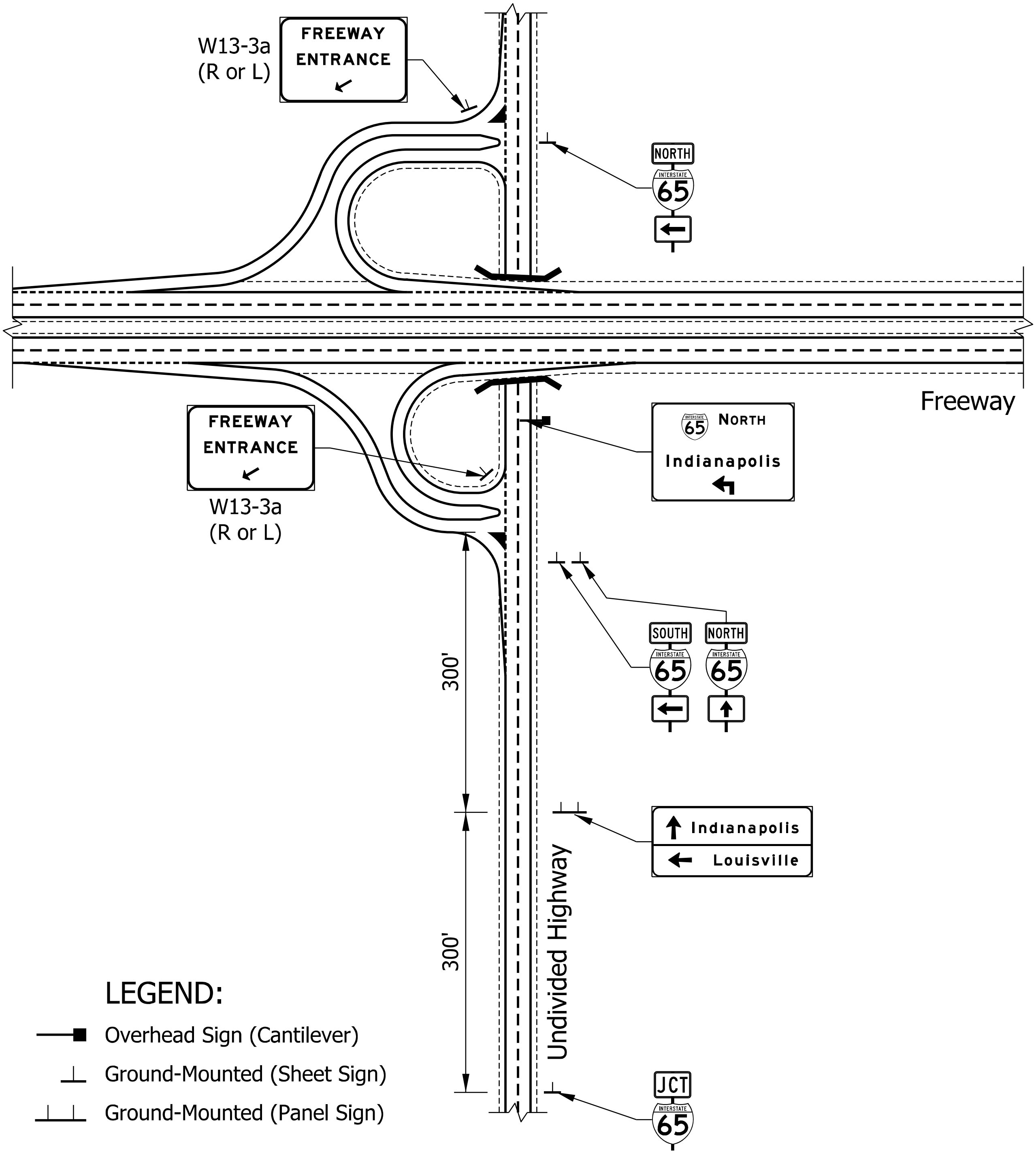
Figure 502-1T




*(See Figure 502-1T for opposite direction of travel.)*

PARTIAL CLOVERLEAF INTERCHANGE SIGNING
Undivided Highway under Freeway

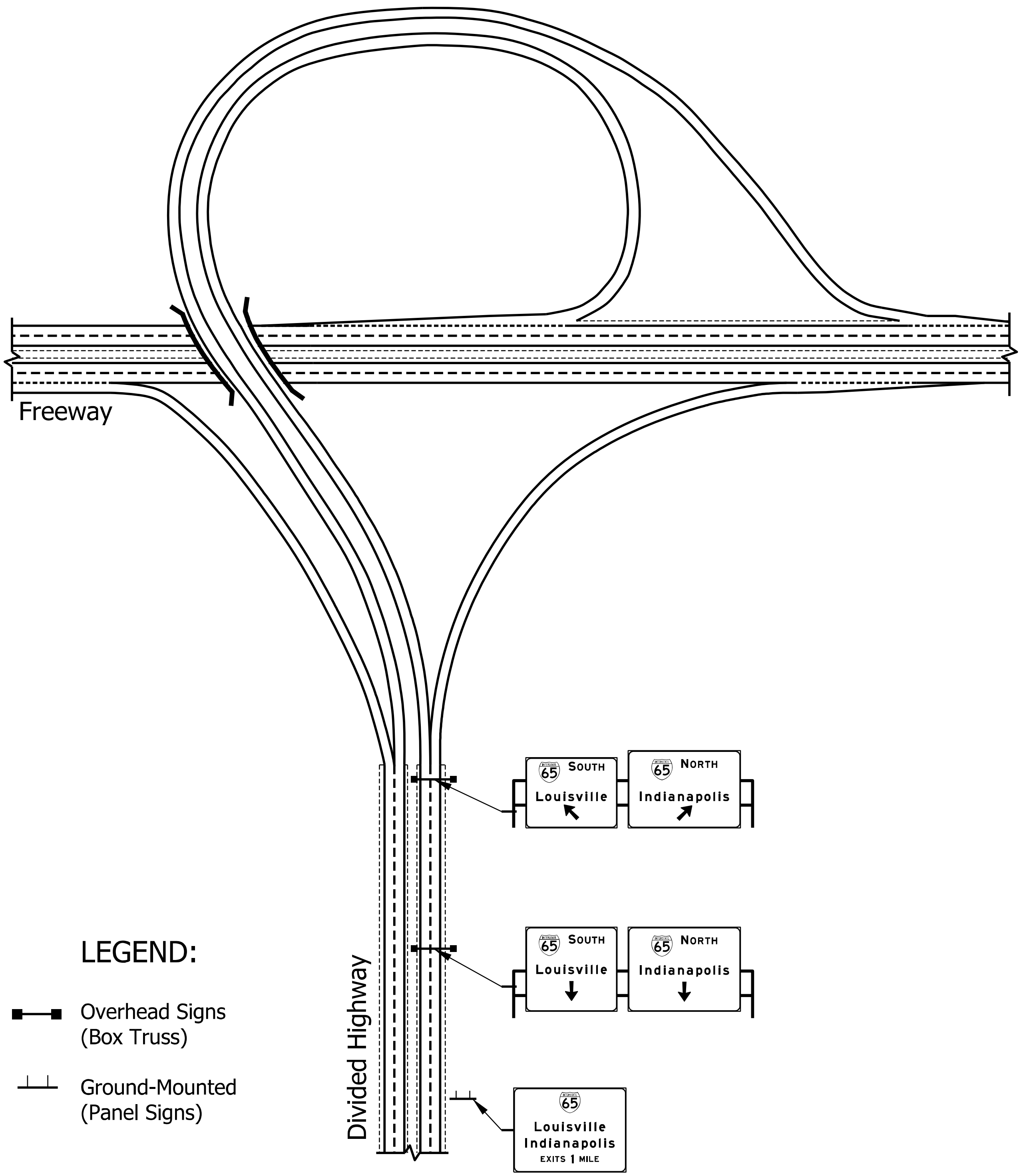
Figure 502-1U




*(See Figure 502-1U for opposite direction of travel.)*

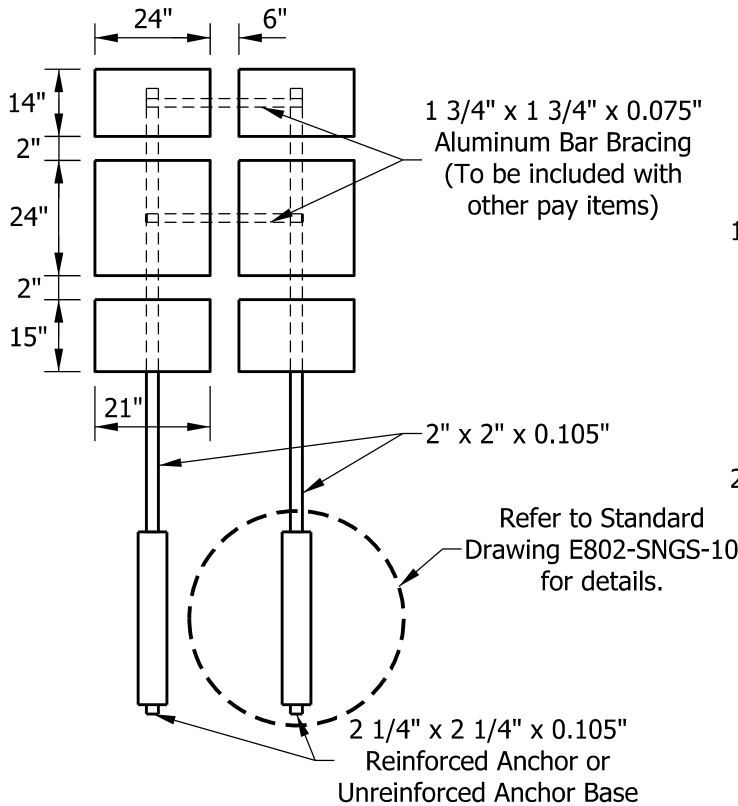
PARTIAL CLOVERLEAF INTERCHANGE SIGNING
Undivided Highway under Freeway

Figure 502-1V

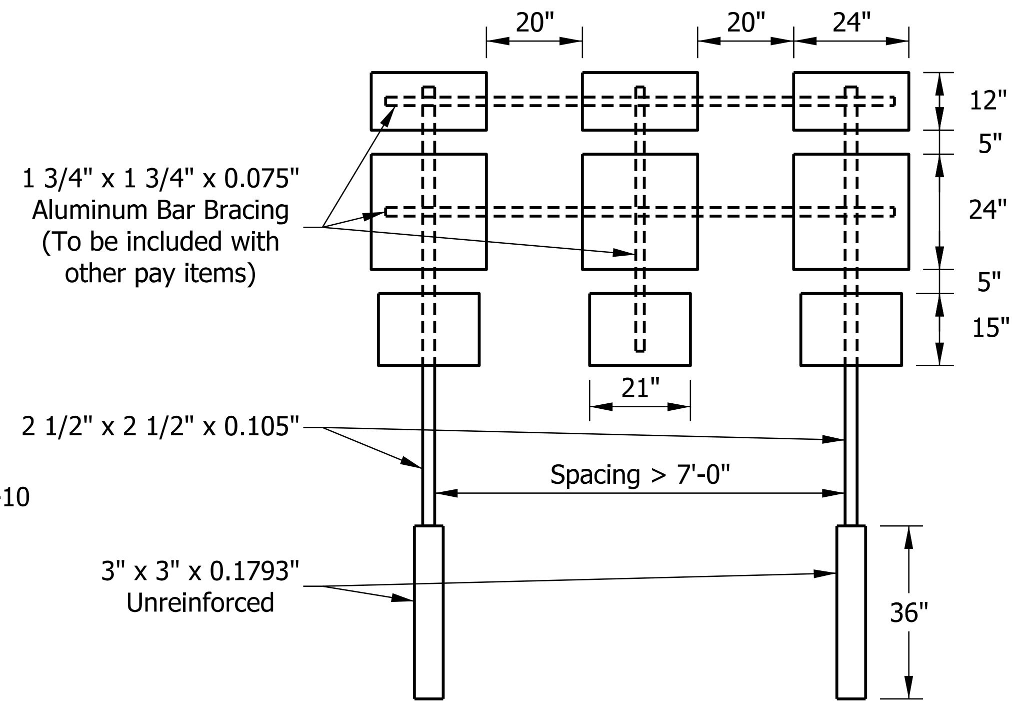



TRUMPET INTERCHANGE SIGNING
System Interchange

Figure 502-1W




2 SHIELDS ASSEMBLY

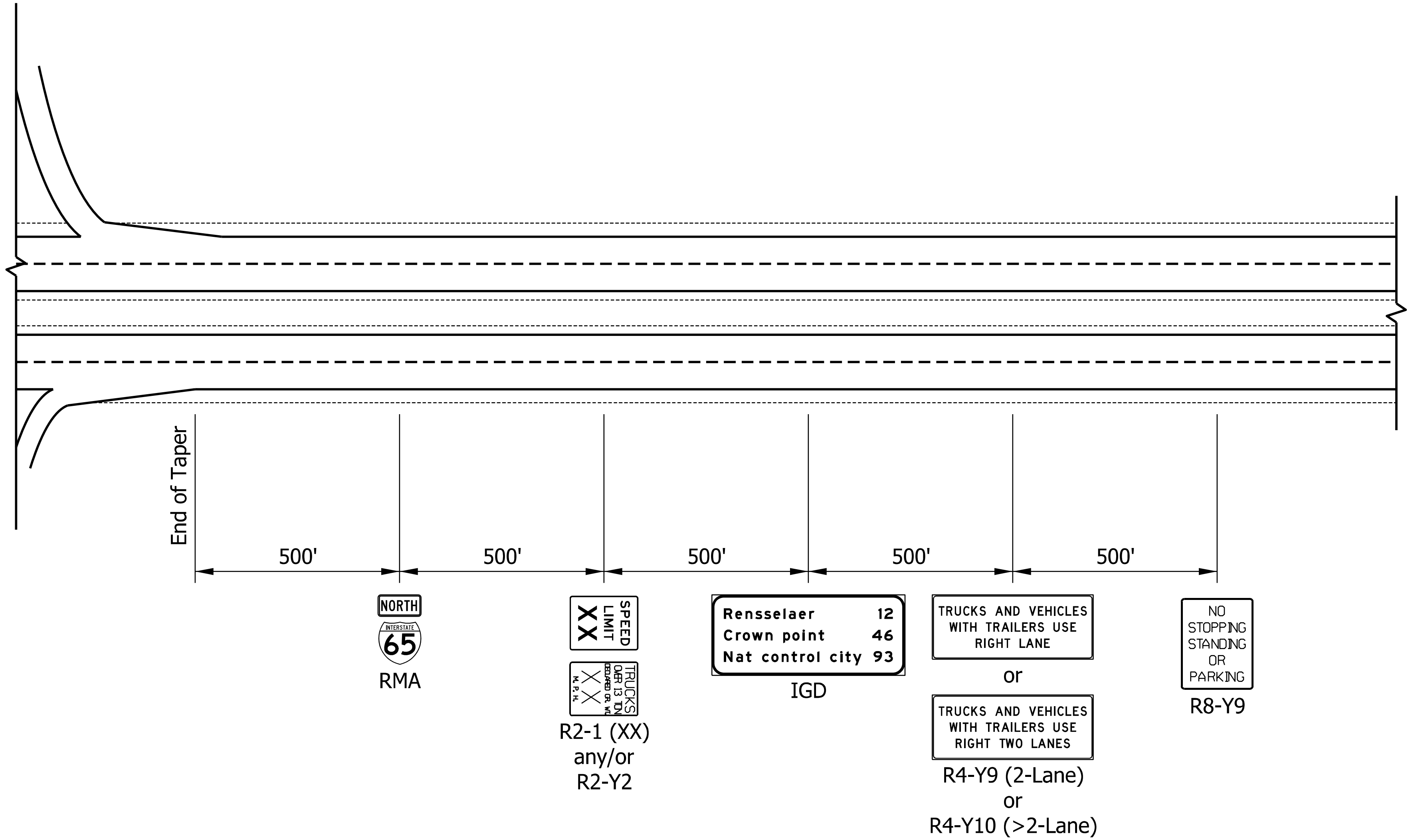



3 SHIELDS ASSEMBLY

NOTE: The detail above is for 24" RMA series and posts.

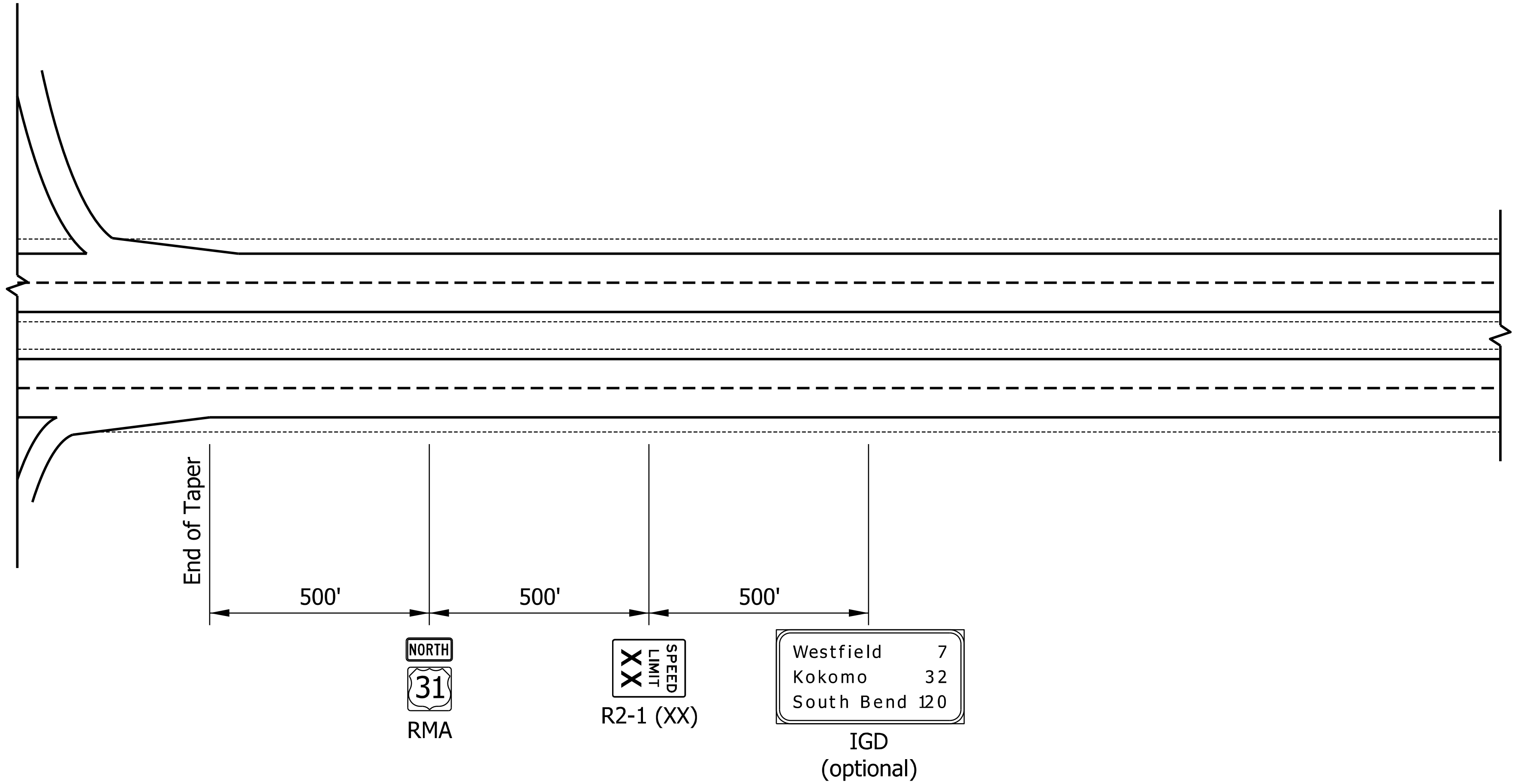
# ROUTE MARKER ASSEMBLY POST DETAILS

Figure 502-1X




POST-INTERCHANGE SEQUENCE SIGNS
FOR INTERSTATE FREEWAY

Figure 502-1Y
(Page 1 of 2)




POST-INTERCHANGE SEQUENCE SIGNS
FOR NON-INTERSTATE FREEWAY OR EXPRESSWAY

FIGURE 502-1Y
(Page 2 of 2)

| ROUTE | NATIONAL CONTROL CITIES |
|---|---|
| I - 64 | St. Louis, Louisville |
| I - 65 | Louisville, Indianapolis, Chicago |
| I - 69 | Indianapolis, Fort Wayne, Lansing |
| I - 70 | St. Louis, Indianapolis, Dayton |
| I - 74 | Peoria, Indianapolis, Cincinnati |
| I - 90 | Chicago, Toledo |
| I - 94 | Chicago, Detroit |

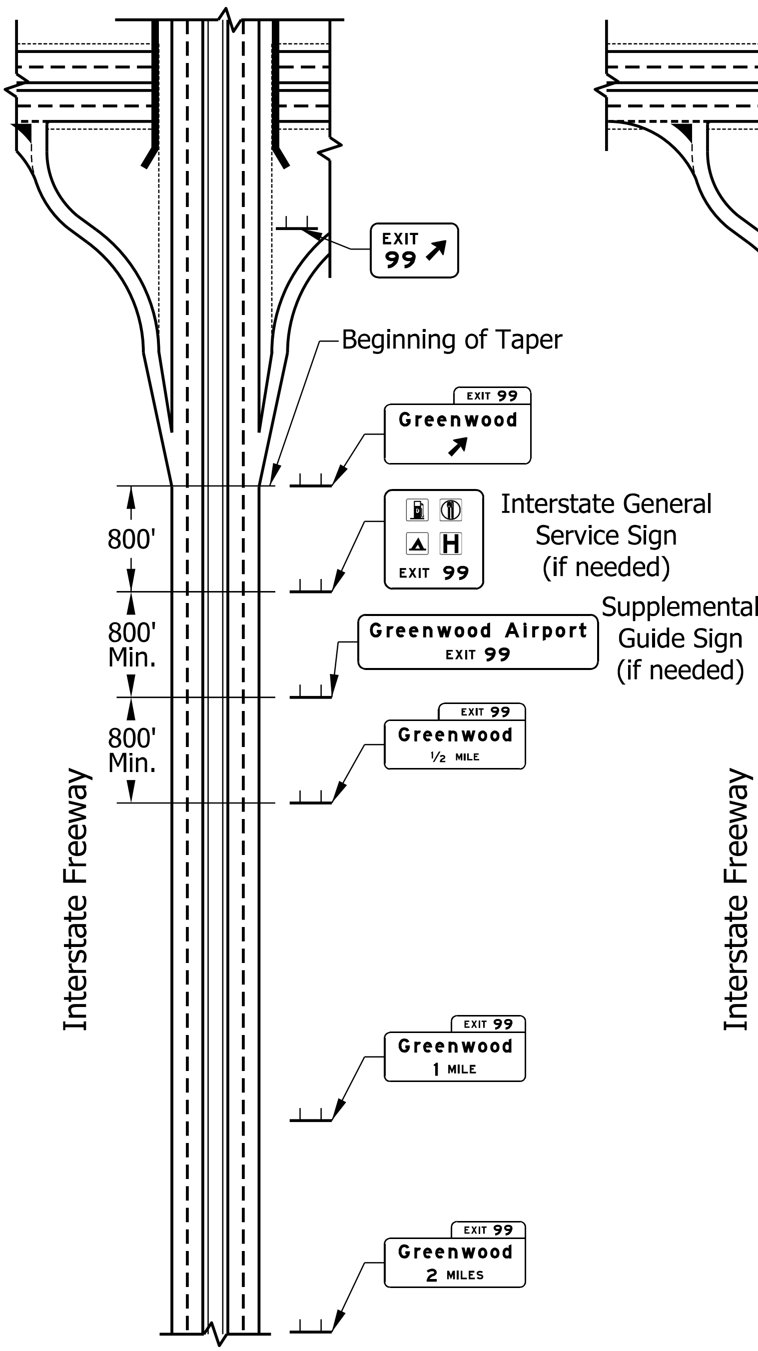
| ROUTE | REGIONAL CONTROL CITIES |
|---|---|
| I - 64 | Evansville |
| I - 65 | Lafayette, Columbus, Gary |
| I - 69 | Anderson, Angola |
| I - 70 | Terre Haute, Richmond |
| I - 74 | Crawfordsville, Shelbyville |
| I - 90 | See Note 2 |
| I - 94 | Gary, Michigan City |
| US - 20 | Gary, South Bend, Elkhart |
| US - 24 | Lafayette, Fort Wayne |
| US - 30 | Valparaiso, Plymouth, Fort Wayne |
| US - 31 | Louisville, Columbus, Indianapolis, Westfield, Kokomo, South Bend |
| US - 40 | Terre Haute, Indianapolis, Richmond |
| US - 52 | Lafayette, Indianapolis, Cincinnati |

NOTES:
1. I - 80 follows same alignment as I - 90 or I - 94.
2. I - 90 regional control cities determined by Indiana Toll Road.
3. Regional control cities for US routes are recommendations. They should be verified with the appropriate district.

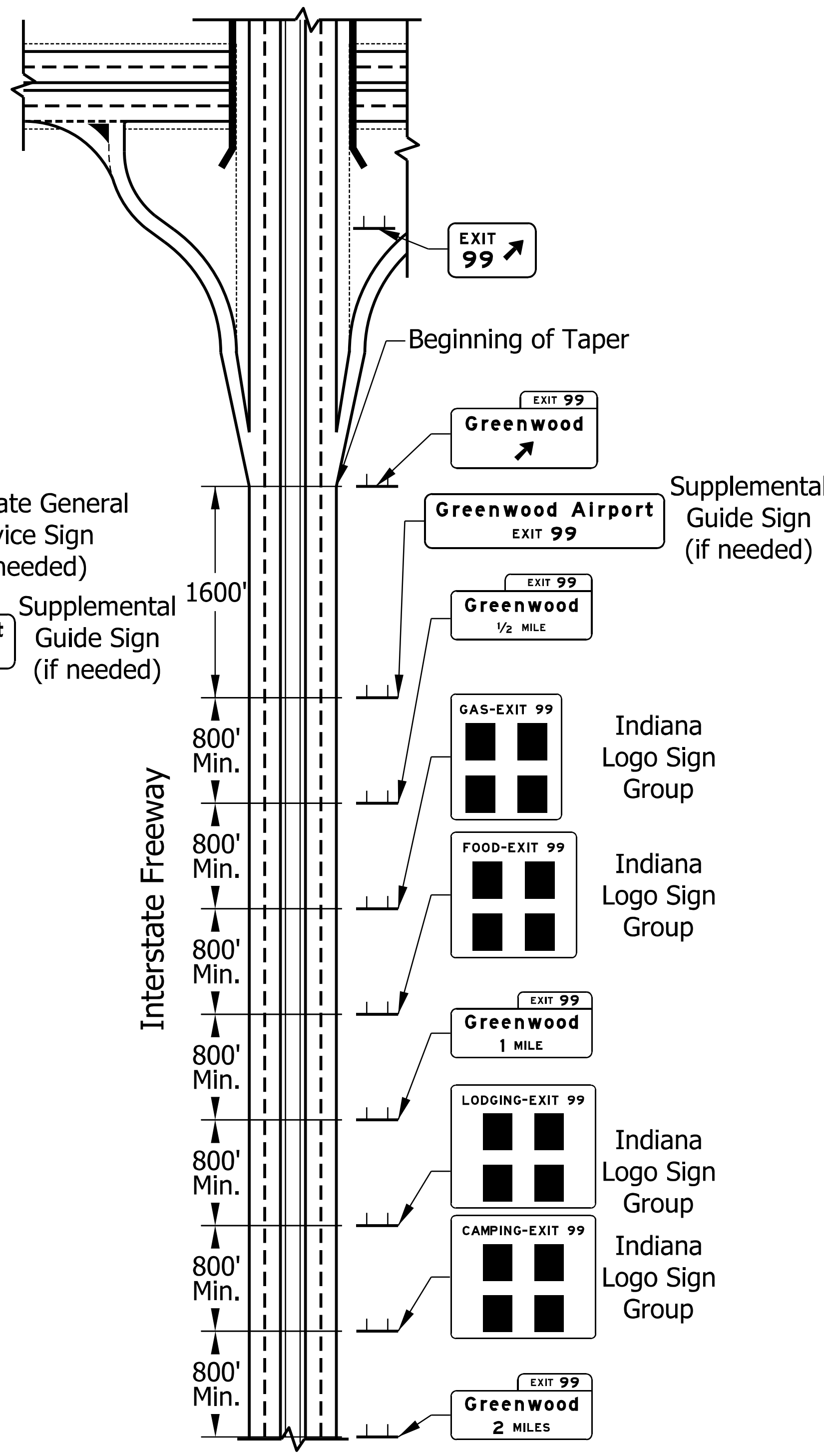
**NATIONAL AND REGIONAL CONTROL CITIES FOR INTERSTATE AND MAJOR U.S. ROUTES**

**Figure 502-1 Z**

## INTERSTATE WITHOUT LOGO SIGN




## INTERSTATE WITH LOGO SIGN




LEGEND:

Ground-Mounted (Panel Sign)

# GENERAL SERVICE SIGNS AND SUPPLEMENTAL GUIDE SIGN PLACEMENT

Figure 502-1AA

**I-64**

| | |
|---|---|
| Mile 0 to Mile 117: | 1/2 Mile Reference Marker |
| Mile 117 to Mile 124: | 2/10 Mile Enhanced Reference Markers |

**I-65**

| | |
|---|---|
| Mile 0 to Mile 6: | 1/10 Mile Enhanced Reference Markers |
| Mile 6 to Mile 16: | 2/10 Mile Enhanced Reference Markers |
| Mile 16 to Mile 86: | 1/2 Mile Reference Markers |
| Mile 86 to Mile 99: | 2/10 Mile Enhanced Reference Markers |
| Mile 99 to Mile 123: | 1/10 Mile Enhanced Reference Markers |
| Mile 123 to Mile 150: | 2/10 Mile Enhanced Reference Markers |
| Mile 150 to Mile 235: | 1/2 Mile Reference Markers |
| Mile 235 to Mile 253: | 2/10 Mile Enhanced Reference Markers |
| Mile 253 to Mile 259: | 1/10 Mile Enhanced Reference Markers |
| Mile 259 to Mile 262: | 2/10 Mile Enhanced Reference Markers |

**I-69, Evansville to Indianapolis**

| | |
|---|---|
| I-64 to 2 miles S of SR 144: | 1/2 Mile Reference Markers |
| 2 miles S of SR 144 to Smith Valley Rd: | 2/10 Mile Enhanced Reference Markers |
| Smith Valley Rd to I-465: | 1/10 Mile Enhanced Reference Markers |

**I-69, Indianapolis to Michigan**

| | |
|---|---|
| Mile 0 to Mile 6: | 1/10 Mile Enhanced Reference Markers |
| Mile 6 to Mile 29: | 2/10 Mile Enhanced Reference Markers |
| Mile 29 to Mile 94: | 1/2 Mile Reference Markers |
| Mile 94 to Mile 117: | 2/10 Mile Enhanced Reference Markers |
| Mile 117 to Mile 157: | 1/2 Mile Reference Markers |

**I-70**

| | |
|---|---|
| Mile 0 to Mile 55: | 1/2 Mile Reference Markers |
| Mile 55 to Mile 69: | 2/10 Mile Enhanced Reference Markers |
| Mile 69 to Mile 81: | 1/10 Mile Enhanced Reference Markers |

I-70 follows I-65

| | |
|---|---|
| Mile 82 to Mile 91: | 1/10 Mile Enhanced Reference Markers |
| Mile 91 to Mile 107: | 2/10 Mile Enhanced Reference Markers |
| Mile 107 to Mile 156: | 1/2 Mile Reference Markers |

**REFERENCE MARKER/ENHANCED REFERENCE MARKER LOCATIONS**
**Figure 502-1BB**
**(Page 1 of 2)**

| | |
|---|---|
| **I-74** | |
| Mile 0 to Mile 65: | 1/2 Mile Reference Markers |
| Mile 65 to Mile 73: | 2/10 Mile Enhanced Reference Markers |
| I-74 follows I-465 | |
| Mile 94 to Mile 100: | 2/10 Mile Enhanced Reference Markers |
| Mile 100 to Mile 171: | 1/2 Mile Reference Markers |
| **I-80/94** | |
| Mile 0 to Mile 15.5: | 1/10 Mile Enhanced Reference Markers |
| **I-94** | |
| Mile 15.5 to Mile 19: | 1/10 Mile Enhanced Reference Markers |
| Mile 19 to Mile 46: | 2/10 Mile Enhanced Reference Markers |
| **I-164** | |
| Mile 0 to Mile 21: | 1/2 Mile Reference Markers |
| **I-265** | |
| Mile 0 to Mile 9: | 2/10 Mile Enhanced Reference Markers |
| Mile 9 to Ohio River Bridge: | 2/10 Mile Enhanced Reference Markers |
| **I-275** | |
| Mile 0 to Mile 3: | 1/2 Mile Reference Markers |
| **I-465** | |
| Mile 0 to Mile 53: | 1/10 Mile Enhanced Reference Markers |
| **I-469** | |
| Mile 0 to Mile 31: | 2/10 Mile Enhanced Reference Markers |
| **I-865** | |
| Mile 0 to Mile 5: | 2/10 Mile Enhanced Reference Markers |
| **US 31 Freeway, Hamilton County** | |
| I-465 to 216th St: | 1/10 Mile Enhanced Reference Markers |
| **SR 912 / Cline Avenue** | |
| Mile 4 to Mile 11: | 2/10 Mile Enhanced Reference Markers |
| **All other freeways**: | 1/2 Mile Reference Markers |

**REFERENCE MARKER/ENHANCED REFERENCE MARKER LOCATIONS**
**Figure 502-1BB**
**(Page 2 of 2)**

(1) No change required to existing sign and supports.

(2) Remove existing panel sign from ground mounted supports.

(3) Remove existing sheet sign from supports.

(4) Remove existing panel sign from overhead sign structure.

(5) Remove existing sheet sign from overhead sign structure.

(6) Remove existing sign foundation.

(7) Remove existing sheet sign and supports.

(8) Remove existing ground mounted panel sign, supports, and foundations.

(9) Remove existing overhead sign, supports, and foundations.

(10) Remove existing sign and bridge bracket assembly.

(11) Existing sheet sign on new supports.

(12) Existing panel sign on new supports.

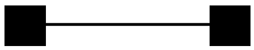
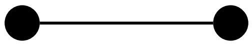
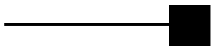
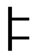
(13) Existing panel sign on new overhead structure.

(14) New panel sign on existing ground mounted supports.

(15) New panel sign on existing overhead structure.

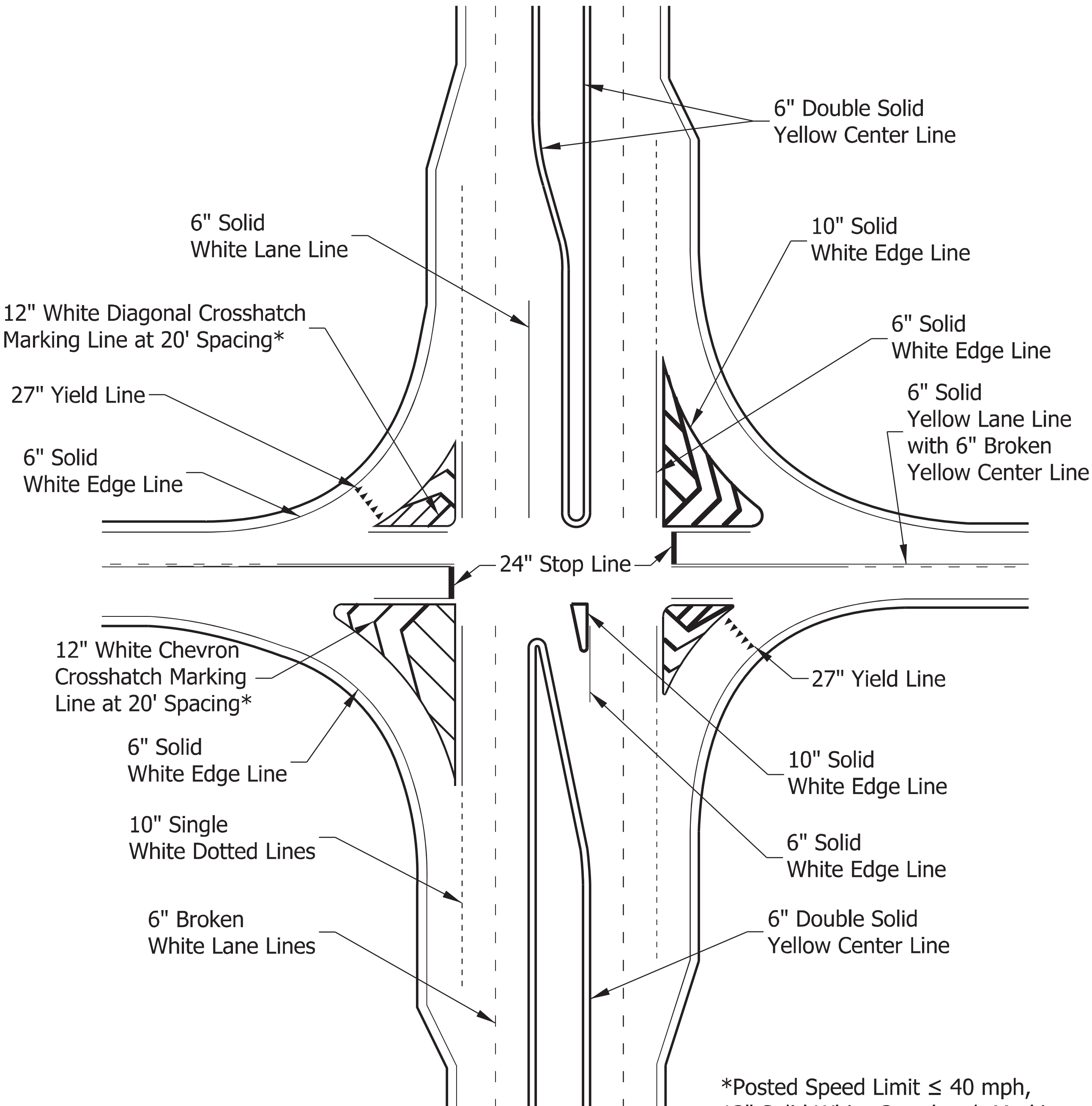
**SIGN PLANS NOTES**

**Figure 502-1CC**

| | |
|---|---|
|  | Box Truss, Tri Cord Truss |
|  | Monotube Span Structure, Cable Span Structure |
|  | Double Mastarm, Single Mastarm Structure |
|  | Center-Mounted Structure (Double Mastarm and Single Mastarm) |
|  | Ground-Mounted Panel Sign |
|  | Ground-Mounted Sheet Sign |
|  | Bridge Bracket Sign Structure |
| IGDO | Interstate Guide Directional Overhead Sign |
| IGD | Interstate Guide Directional Sign |
| IGS | Interstate Guide Service and Rest Area Sign |
| IGI | Interstate Guide Information Sign |
| GDO | Guide Directional Overhead Sign |
| GD | Guide Directional Sign |
| IGDOE | Interstate Guide Directional Overhead Existing Sign |
| IGDE | Interstate Guide Directional Existing Sign |
| IGSE | Interstate Guide Service Existing Sign |
| IGIE | Interstate Guide Information Existing Sign |
| GDOE | Guide Directional Overhead Existing Sign |
| GDE | Guide Directional Existing Sign |

SIGN PLAN LEGEND

Figure 502-1DD




*Posted Speed Limit ≤ 40 mph,
12" Solid White Crosshatch Marking
Line at 20' Spacing

Posted Speed Limit ≥ 45 mph,
24" Solid White Crosshatch Marking
Line at 40' Spacing

TYPICAL INTERSECTION PAVEMENT MARKINGS

Figure 502-2A

| DESCRIPTION | COLOR | WIDTH | APPLICATION |
|---|---|---|---|
| Single Broken Line | White | 6 in | Separation of lanes on which travel is in the same direction, with crossing from one lane to the other permitted (e.g., lane lines on multilane roadways). The broken line is formed by a pattern of segments and gaps. The typical pattern is a 10 ft segment followed by a 30 ft gap for a for a total cycle length of 40 ft. |
| | Yellow | 6 in | Separation of lanes on which travel is in the opposite direction, and where overtaking with care is permitted (e.g. centerline on 2-lane, 2-way roadways). The broken line is formed by a pattern of segments and gaps. The typical pattern is a 10 ft segment followed by a 30 ft gap for a total cycle length of 40 ft. |
| Single Solid Line | White | 6 in | Separation of lanes, or of a lane and shoulder, where lane changing is discouraged (e.g., lane lines at intersection approaches, right-edge lines). |
| | | 6 in | Lane lines separating a motor vehicle lane from a bike lane. |
| | | 10 in | Delineation of locations where crossing is strongly discouraged (e.g., separation of turn lanes from through lanes, gore areas at ramp terminals, paved turnouts, edge lines at lane drops, painted island edges). |
| | Yellow | 6 in | Delineation of left-edge lines on divided highways, 1-way roads and ramps. |
| Double Solid Lines | White | 6-6-6 in* | Separation of lanes on which travel is in the same direction, with crossing from one side to the other prohibited (e.g., channelization in advance of obstructions which may be passed on either side). |
| | Yellow | 6-6-6 in* | Separation of lanes on which travel is in the opposite direction, where overtaking is prohibited in both directions. Left-turn maneuvers across this marking are permitted. Also used in advance of obstructions which may be passed only on the right side. |
| Solid Line Plus Broken Line | Yellow | 6-6-6 in* | Separation of lanes on which travel is in the opposite directions, where overtaking is permitted with care for traffic adjacent to the broken line, but prohibited for traffic adjacent to a solid line. Used on 2-way roadways with 2 or 3 lanes. Also used to delineate edges of a two-way left-turn lane - solid lines on the outside, broken lines on the inside. |
| Double Broken Line | Yellow | 6-6-6 in* | Delineates the edges of reversible lanes. The broken or dashed line is formed by a pattern of segments and gaps. The typical pattern is a 10 ft segment followed by a 30 ft gap for a total cycle length of 40 ft. |

**6-6-6 in indicates typical width of the lines and the 6 in unpainted gap between them*

**Figure 502-2B – Pavement Marking Lines Applications**

(Sheet 1 for INDOT Roadways)

| DESCRIPTION | COLOR | WIDTH | APPLICATION |
|---|---|---|---|
| Single Dotted Line | Either | 6 in | See Section 502-2.02(05). Color same as that of the line being extended. The typical pattern is a 2 ft or 3 ft segment with a 9 ft gap for lane lines and a 2-6 ft gap for extension lines through intersections. |
| | White | 10 in | See Section 502-2.02(05). Separation of through lane and auxiliary lane or dropped lane. The typical pattern is a 3 ft segment followed by a 9 ft gap for a total cycle length of 12 ft. |
| Transverse Lines | White | 6 in* | Crosswalk edge lines (minimum 6 ft apart). |
| | | 24 in | Stop lines. |
| | | 27 in. | Yield lines. |
| Diagonal and Chevron Crosshatch Lines** | White | 12 in | Diagonal crosshatch markings for 1-way traffic, placed at an angle of 45 º, at 20 ft apart, on right-hand shoulders to add emphasis to these roadway features for design speeds less than or equal to 40 mph. |
| | | | Chevron crosshatch markings for 1-way traffic, placed at an angle of 45 º, at 20 ft apart, for channelization islands to add emphasis to these roadway features for design speeds less than or equal to 40 mph. |
| | | 24 in | Diagonal crosshatch markings for 1-way traffic, placed at an angle of 45º, at 40 ft apart, on right-hand shoulders to add emphasis to these roadway features for design speeds of 45 mph or greater. |
| | | | Chevron crosshatch markings for 1-way traffic, placed at an angle of 45 º, at 40 ft part, for channelization islands to add emphasis to these roadway features for design speeds of 45 mph or greater. |
| | Yellow | 12 in | Diagonal crosshatch markings for 1-way traffic, placed at an angle of 45º, at 20 ft apart, on left-hand shoulders for design speeds less than or equal to 40 mph. |
| | | | Diagonal crosshatch markings for 2-way traffic, placed at an angle of 45º, at 20 ft apart, for channelization islands to add emphasis to these roadway features for design speeds less than or equal to 40 mph. |
| | | 24 in | Diagonal crosshatch markings for 2-way traffic, placed at an angle of 45º, at 40 ft apart, on left-hand shoulders for design speeds of 45 mph or greater. |
| | | | Diagonal crosshatch markings for 2-way traffic, placed at an angle of 45º, at 40 ft apart, on shoulders or channelization islands to add emphasis to these roadway features for design speeds of 45 mph or greater. |

* *Transverse lines for crosswalk edge lines are to be a minimum of 6 in*

** *Chevron crosshatch markings are used to separate traffic heading in the same direction while diagonal crosshatch markings are used to separate opposing directions of traffic.*

**Figure 502-2B – Pavement Marking Lines Applications (Cont'd)**

(Sheet 2 for INDOT Roadways)

| DESCRIPTION | COLOR | WIDTH | APPLICATION |
|---|---|---|---|
| Single Broken Line | White | 4 in | Separation of lanes on which travel is in the same direction, with crossing from one lane to the other permitted (e.g., lane lines on multilane roadways). The broken or dashed line is formed by a pattern of segments and gaps. The typical pattern is a 10 ft segment followed by a 30 ft gap for a for a total cycle length of 40 ft. |
| | Yellow | 4 in | Separation of lanes on which travel is in the opposite direction, and where overtaking with care is permitted (e.g. centerline on 2-lane, 2-way roadways). The broken or dashed line is formed by a pattern of segments and gaps. The typical pattern is a 10 ft segment followed by a 30 ft gap for a total cycle length of 40 ft. |
| Single Solid Line | White | 4 in | Separation of lanes, or of a lane and shoulder, where lane changing is discouraged (e.g., lane lines at intersection approaches, right-edge stripes). |
| | | 4 in | Lane lines separating a motor vehicle lane from a bike lane. |
| | | 8in | Delineation of locations where crossing is strongly discouraged (e.g., separation of turn lanes from through lanes, gore areas at ramp terminals, paved turnouts, edge lines at lane drops, painted island edges). |
| | Yellow | 4 in | Delineation of left-edge lines on divided highways, 1-way roads and ramps. |
| Double Solid Lines | White | 4-4-4 in* | Separation of lanes on which travel is in the same direction, with crossing from one side to the other prohibited (e.g., channelization in advance of obstructions which may be passed on either side). |
| | Yellow | 4-4-4 in* | Separation of lanes on which travel is in the opposite direction, where overtaking is prohibited in both directions. Left-turn maneuvers across this marking are permitted. Also used in advance of obstructions which may be passed only on the right side. |
| Solid Line Plus Broken Line | Yellow | 4-4-4 in* | Separation of lanes on which travel is in the opposite directions, where overtaking is permitted with care for traffic adjacent to the broken line, but prohibited for traffic adjacent to a solid line. Used on 2-way roadways with 2 or 3 lanes. Also used to delineate edges of a two-way left-turn lane - solid lines on the outside, broken lines on the inside. |
| Double Broken Line | Yellow | 4-4-4 in* | Delineates the edges of reversible lanes. The broken or dashed line is formed by a pattern of segments and gaps. The typical pattern is a 10 ft segment followed by a 30 ft gap for a total cycle length of 40 ft. |

**4-4-4 in. indicates typical width of the lines and the 4 in. unpainted gap between them*

**Figure 502-2B – Pavement Marking Lines Applications (Cont'd)**
(Sheet 3 for LPA Roadways)

| DESCRIPTION | COLOR | WIDTH | APPLICATION |
|---|---|---|---|
| Single Dotted Line | Either | 4 in | See Section 502-2.02(05). Color same as that of the line being extended. The typical pattern is a 2 ft or 3 ft segment with a 9 ft gap for lane lines and a 2-6 ft gap for extension lines through intersections. |
| | | 4 in | See Section 502-2.02(05). Color same as that of the line being extended. The typical pattern is a 2 ft segment with a 9 ft gap for lane lines and a 2-6 ft gap for extension lines through intersections. |
| | White | 8 in | See Section 502-2.02(05). Separation of through lane and auxiliary lane or dropped lane. The typical pattern is a 3 ft segment followed by a 9 ft gap for a total cycle length of 12 ft. |
| Transverse Lines | White | 6 in* | Crosswalk edge lines (minimum 6 ft apart). |
| | | 24 in | Stop or yield lines. |
| Diagonal and Chevron Crosshatch Lines** | White | 12 in | Diagonal crosshatch markings for 1-way traffic, placed at an angle of 45 º, at 20 ft apart, on right-hand shoulders to add emphasis to these roadway features for design speeds less than or equal to 40 mph. |
| | | | Chevron crosshatch markings for 1-way traffic, placed at an angle of 45 º, at 20 ft apart, for channelization islands to add emphasis to these roadway features for design speeds less than or equal to 40 mph. |
| | | 24 in | Diagonal crosshatch markings for 1-way traffic, placed at an angle of 45º, at 40 ft apart, on right-hand shoulders to add emphasis to these roadway features for design speeds of 45 mph or greater. |
| | | | Chevron crosshatch markings for 1-way traffic, placed at an angle of 45 º, at 40 ft part, for channelization islands to add emphasis to these roadway features for design speeds of 45 mph or greater. |
| | Yellow | 12 in | Diagonal crosshatch markings for 1-way traffic, placed at an angle of 45º, at 20 ft apart, on left-hand shoulders for design speeds less than or equal to 40 mph. |
| | | | Diagonal crosshatch markings for 2-way traffic, placed at an angle of 45º, at 20 ft apart, for channelization islands to add emphasis to these roadway features for design speeds less than or equal to 40 mph. |
| | | 24 in | Diagonal crosshatch markings for 2-way traffic, placed at an angle of 45º, at 40 ft apart, on left-hand shoulders for design speeds of 45 mph or greater. |
| | | | Diagonal crosshatch markings for 2-way traffic, placed at an angle of 45º, at 40 ft apart, on shoulders or channelization islands to add emphasis to these roadway features for design speeds of 45 mph or greater. |

* *Transverse lines for crosswalk edge lines are to be a minimum of 6 in.*

** *Chevron crosshatch markings are used to separate traffic heading in the same direction while diagonal crosshatch markings are used to separate opposing directions of traffic*

**Figure 502-2B – Pavement Marking Line Applications (Cont'd)**
(Sheet 4 for LPA Roadways)

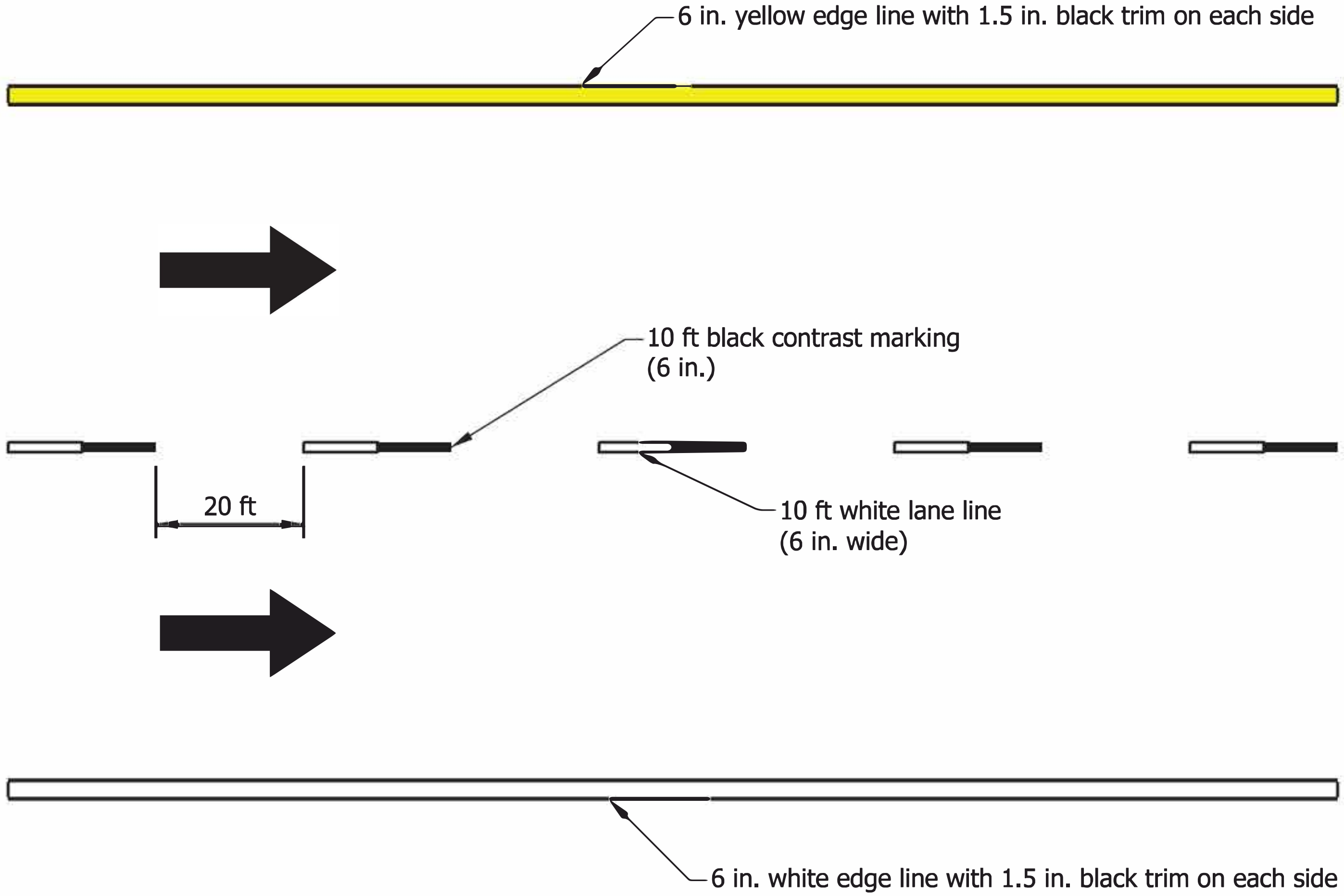
| Application[1] | Material Type | | | | |
|---|---|---|---|---|---|
| | Paint | Thermoplastic[6] | Multi-Component[6] | Preformed Plastic[4] | Raised Pavement Markers[2] |
| AADT / Pavement Surface Life | < 3,000; or < 4 Years | ≥ 3,000; and ≥ 4 Years | ≥ 3,000; and ≥ 4 Years | ≥ 18,000; and ≥ 8 Years | ≥ 3,000; and ≥ 4 Years |
| Edge Lines | X | X | X | X[5] | |
| Center Lines | X | X | X | X[5] | X |
| Lane Lines | X | X | X | X[5] | X[3] |
| Transverse Markings | X | X | | | |
| Concrete Pavement | X | | X | X | X |
| Asphalt Pavement | X | X | X | X | X |
| Pedestrian Crossings | | X | | | |
| Bike Lanes | | X | | | |

Notes:

1. Other applications or restrictions may apply; see Section 502-2.01(04) for additional information.
2. For guidance on the use of milled longitudinal rumble stripes with raised pavement makers (RPM's), see Section 502-2.09 or discuss with the District Traffic Engineer.
3. Snowplowable RPM's should be used to supplement lane lines on roadways with a functional classification of: (1) interstate, (2) freeway or expressway, or (3) other principal arterial.
4. The wet reflective version of preformed plastic markings should be specified.
5. Preformed plastic markings should be used on interstate highway lane lines regardless of AADT. Preformed plastic markings should be used for the edge lines and any centerlines if the AADT is ≥ 80,000.
6. The use of polyurea as a substitute for thermoplastic or multicomponent markings should be considered for contract completion dates between November 15 and March 15 due to its lower minimum application temperature.

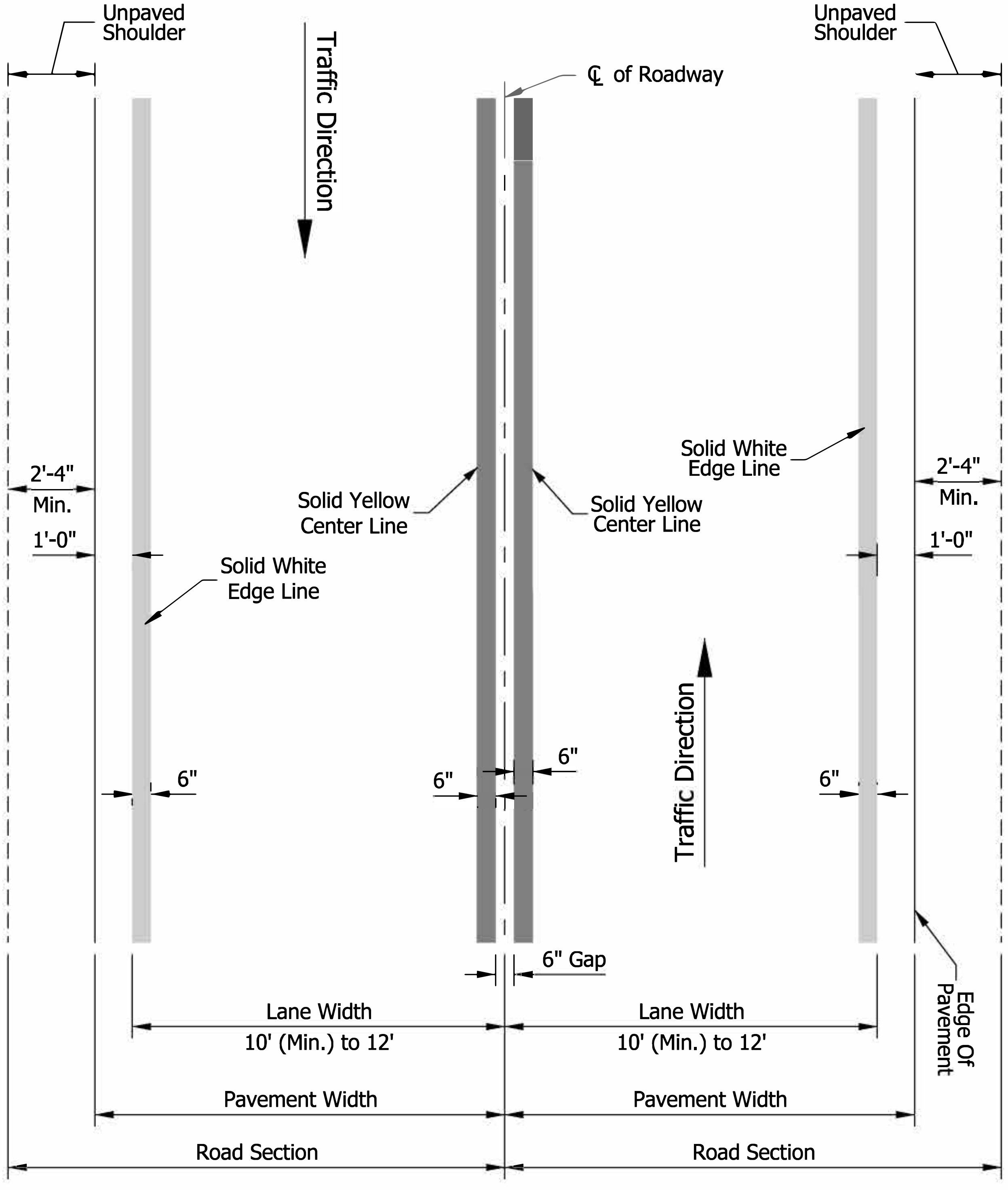
RECOMMENDED PAVEMENT MARKING APPLICATION

Figure 502-2C




CONTRAST MARKINGS FOR CONCRETE PAVEMENT

Figure 502-2D




LOCATIONS OF EDGE AND CENTER LINES
WITH UNPAVED SHOULDERS

Figure 502-2E

| Speed (mph) | Minimum Distance (ft) | |
|---|---|---|
| | Passing Sight Distance [1] | Stopping Sight Distance [2] |
| 25 | 450 | 155 |
| 30 | 500 | 200 |
| 35 | 550 | 250 |
| 40 | 600 | 305 |
| 45 | 700 | 360 |
| 50 | 800 | 425 |
| 55 | 900 | 495 |
| 60 | 1000 | 570 |
| 65 | 1100 | 645 |
| 70 | 1200 | 730 |

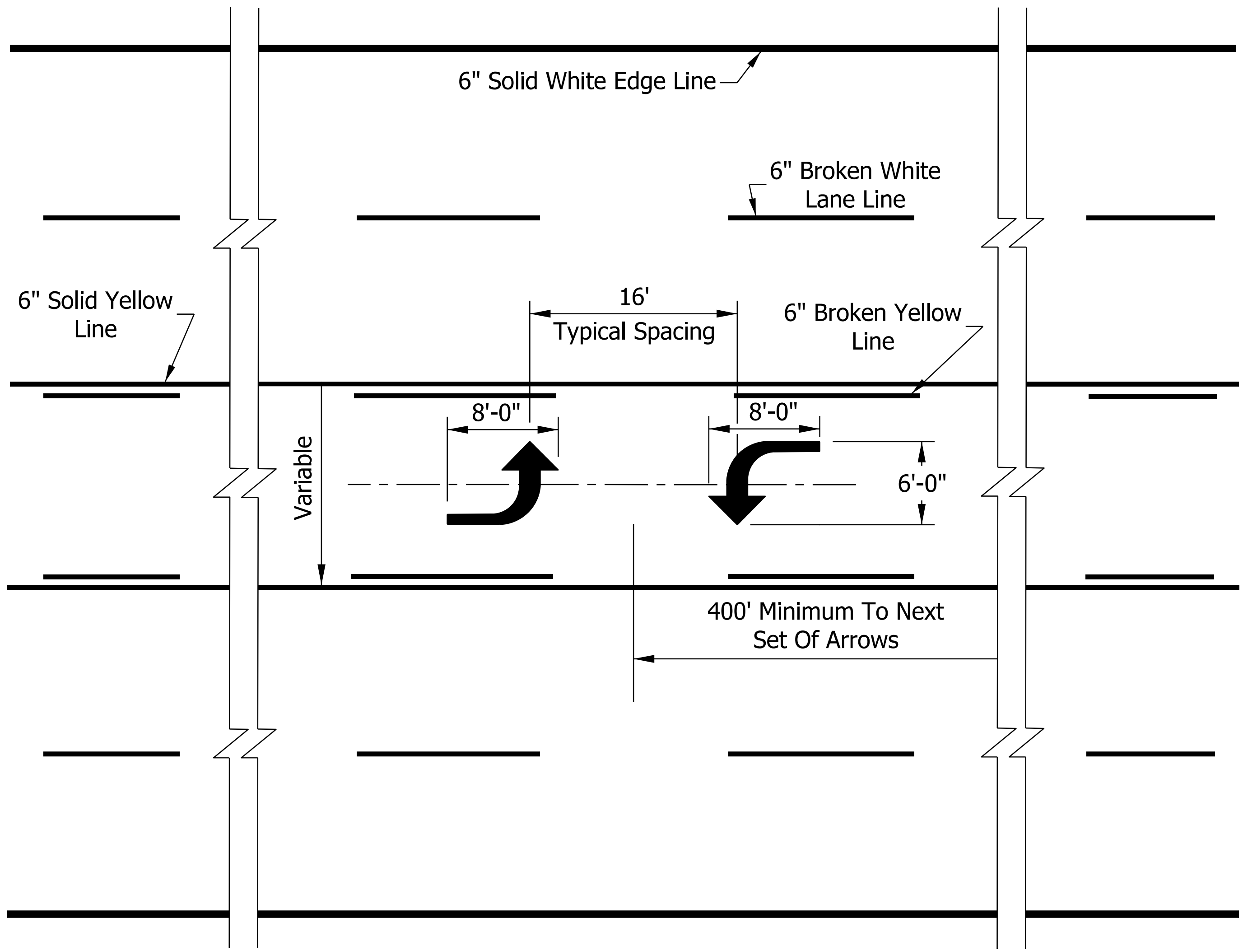
1. AASHTO Passing Sight Distance.
2. AASHTO Stopping Sight Distance.

| FEATURE | MINIMUM CRITERION | MARK NO-PASSING-ZONE THROUGH FEATURE |
|---|---|---|
| Horizontal or Vertical Curve | MUTCD | Yes |
| Major Intersection | SSD | n/a |
| Minor Intersection | 0 | n/a |
| Obstruction, center-of-roadway or median underpass pier, etc. | (3) | Yes |
| Railroad Crossing, Rural | SSD + 75 ft | Yes |
| Railroad Crossing, Urban | Variable | Yes |
| One-Lane Bridge | PSD | No |
| Narrow Bridge | SSD | Yes |
| Stop Intersection where required | SSD | No |

(3) See MUTCD Section 3B-13 for additional information.

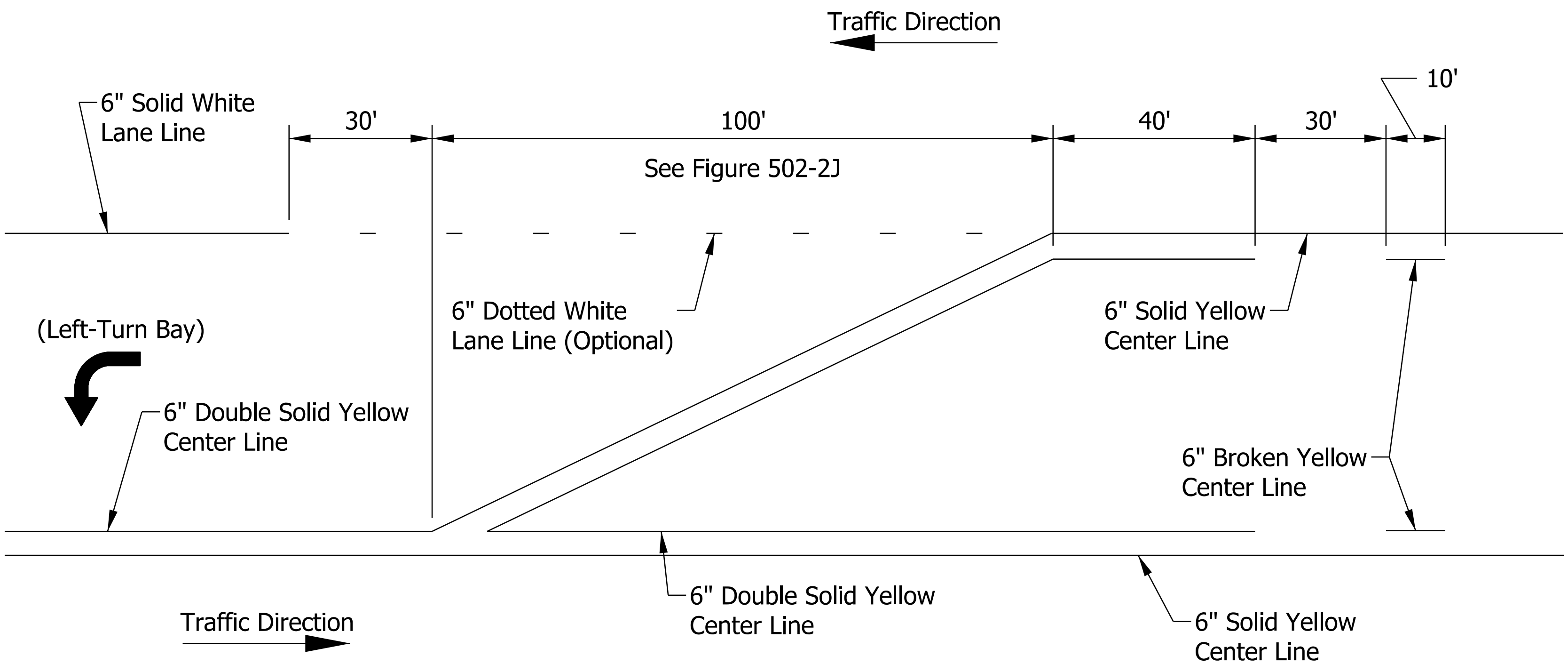
## NO-PASSING-ZONE DISTANCES AND APPLICATIONS

## Figure 502-2F




TWO-WAY LEFT-TURN LANE MARKINGS

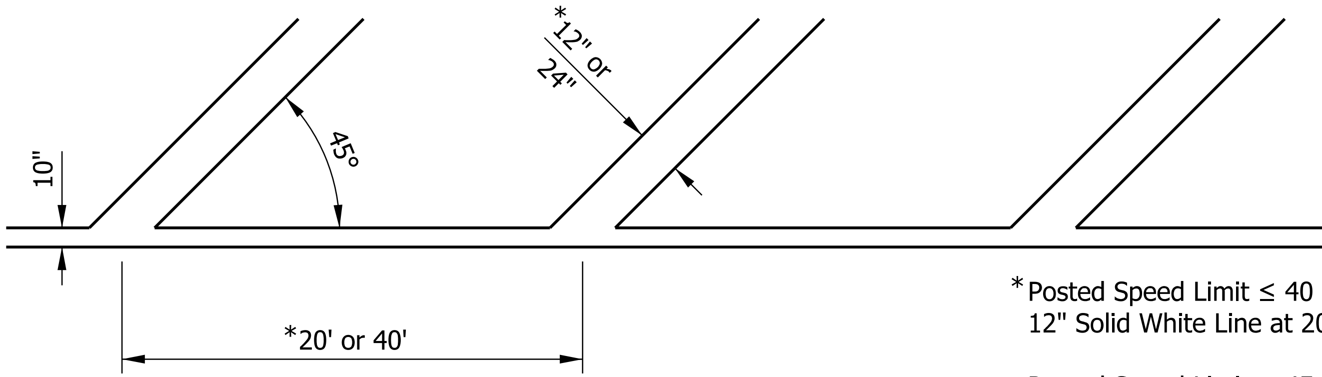
Figure 502-2G




*See Figures 502-2A and 502-2 O for additional intersection marking details.*

TWO-WAY LEFT-TURN LANE TRANSITION MARKINGS
TWLTL to Exclusive Left-Turn Lane

Figure 502-2H




*Posted Speed Limit ≤ 40 mph,
12" Solid White Line at 20' Spacing

Posted Speed Limit ≥ 45 mph,
24" Solid White Line at 40' Spacing

NOTE: Exit gore marking should be per IMUTCD Figure 3B-8 spacing details as shown here.

EXIT GORE MARKINGS

Figure 502-2 I

| Design Speed (mph) | Merging Taper Rate |
|---|---|
| 20 | 10:1 |
| 25 | 10:1 |
| 30 | 15:1 |
| 35 | 20:1 |
| 40 | 30:1 |
| 45 | 45:1 |
| 50 | 50:1 |
| 55 | 55:1 |
| 60 | 60:1 |
| 65 | 65:1 |
| 70 | 70:1 |

| Taper Type | Minimum Taper Length |
|---|---|
| Merging Taper (Lane Drop) | *L* [1] |
| Lane Shift Taper | *L* [1] |
| Two Way Left Turn Lane Transition Taper | 100 ft |
| Downstream Recovery Taper | 50 ft/lane [2] |

[1] Taper Length, L = Merging Taper Rate x Offset Distance

[2] The desirable length is 100 ft/lane.

**LONGITUDINAL TAPER RATE AND LENGTH**

**Figure 502-2J**

| Roadway Type | Application on Tangent Sections | Application on Curves | Spacing (ft) | Placement |
|---|---|---|---|---|
| Interstate or Freeway | Required[1, 2] | Required[2] | 400 | Right side |
| Expressway | Required[1, 2] | Required[2] | 400 | Right side |
| Interchange Ramp | Required | Required | 100 | Outside curve side |
| Multilane Transition to Two-Lane | Required | Required | Varies[3] | Varies[3] |
| Other Highway | Optional | Optional | 500 | Right side[4] |

NOTES:

1. Delineators are not required on tangent sections where raised pavement markers are used.

2. Delineators are not required where continuous highway lighting is used between interchanges.

3. See Figures 502-2L – 502-2P and the INDOT *Standard Drawings* for spacing and placement of delineators within transition areas.

4. Delineators on the left side of a conventional two lane highway shall be white.

5. Color. The delineator color should match the color of the line it is offset from. For example, if the edge line is white, the delineator shall be white. For the left side of divided highways, if used, the delineator shall be yellow. Red delineators may be used on the reverse side of any delineator post for motorists who may be traveling the wrong way on one-way roadways (e.g., ramps).

6. Guardrail. Barrier delineators are required on all concrete median barriers, temporary concrete median barriers, and concrete railings. Delineators may be provided on or adjacent to guardrail.

7. Islands. Delineators may be used to outline raised islands.

8. No-Passing Zones. The end of the no-passing zone is normally indicated on the right side of the roadway with three, horizontally aligned, white delineators.

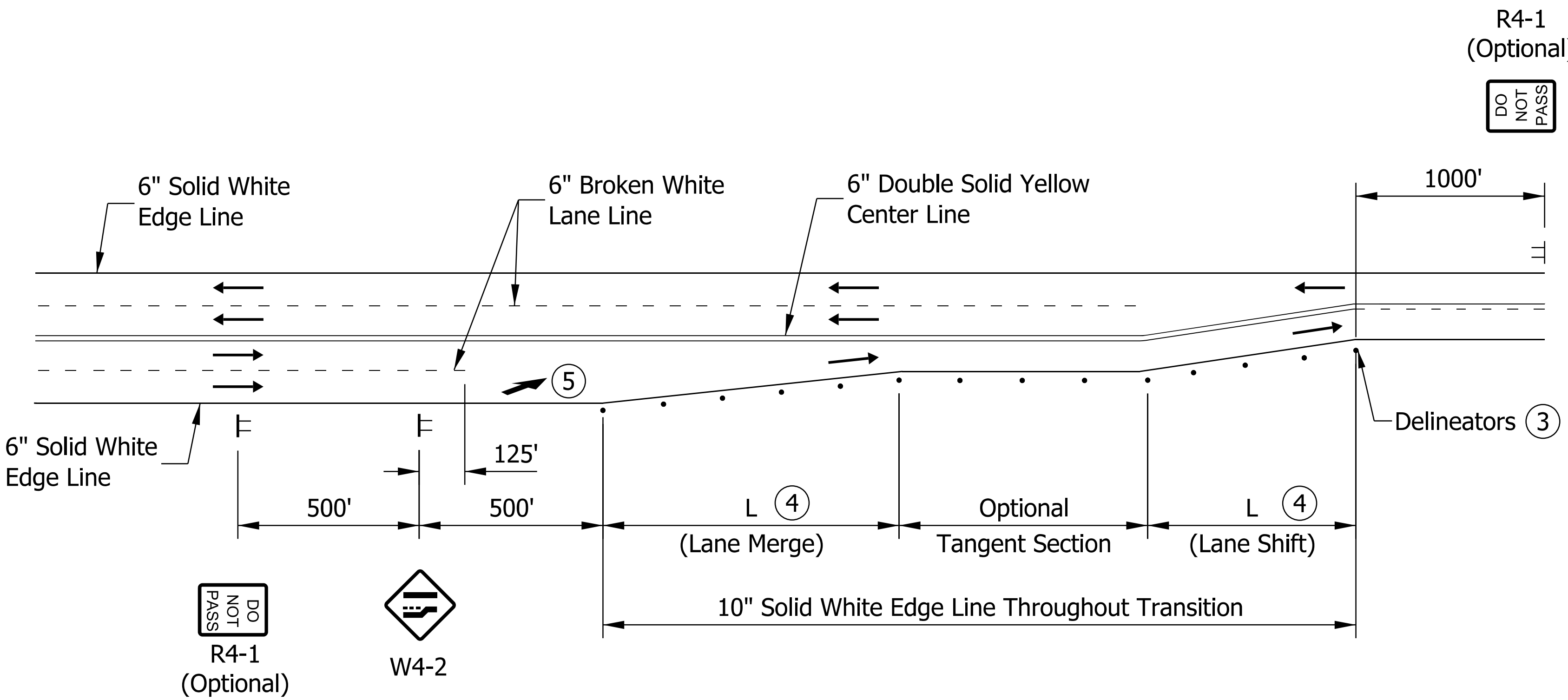
9. Height. The top of the delineator should be placed so that the top of the reflecting head is approximately 4 ft above the surface of the nearest travel lane.

10. Offset. Delineators should be offset a constant distance from the roadway edge unless guardrail or other obstructions intrude into the space between the pavement edge and the extension of the line of delineators. Typically, delineators should not be placed less than 2 ft or more than 8 ft from the outside edge of the shoulder.

11. Spacing Gaps. Where normal uniform spacing is interrupted by driveways, cross roads, etc., the delineator should be moved to either side provided the distance does not exceed one-quarter of the normal spacing. If these criteria are exceeded, the delineator may be deleted.

**DELINEATOR APPLICATION, PLACEMENT, AND SPACING**

**Figure 502-2K**




NOTES:

1. RPM's are desirable along all edge and center lines within the transition area.

2. Adjustments to the signing and pavement marking locations may be required to meet field conditions.

3 See Figure 502-2K for delineator spacing.

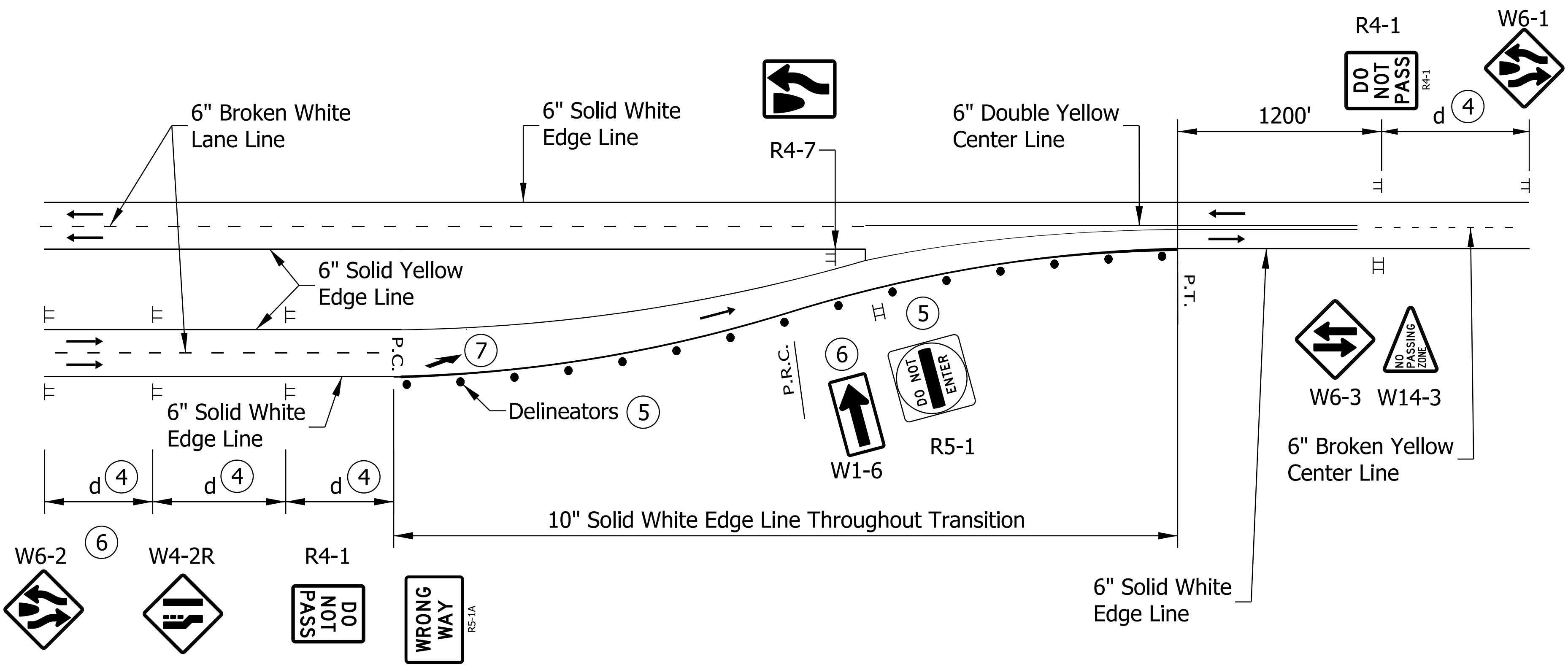
4 See Figure 502-2J for taper lengths.

5 See IMUTCD 3B.20 for lane reduction arrow design and application.

→ Traffic Direction

# TRANSITION MARKINGS
# 4-Lane Undivided to 2-Lane Undivided
# (Right Lane Ends)

Figure 502-2L




NOTES:

1. RPM's are desirable along all edge and center lines within the transition area.

2. Adjustments to the signing and pavement marking locations may be required to meet field conditions.

3. This transition design should only be used for existing conditions.

4 d = Advance Warning Distance, See IMUTCD Table 2C - 4.

5 See Figure 502-2K for delineator spacing.

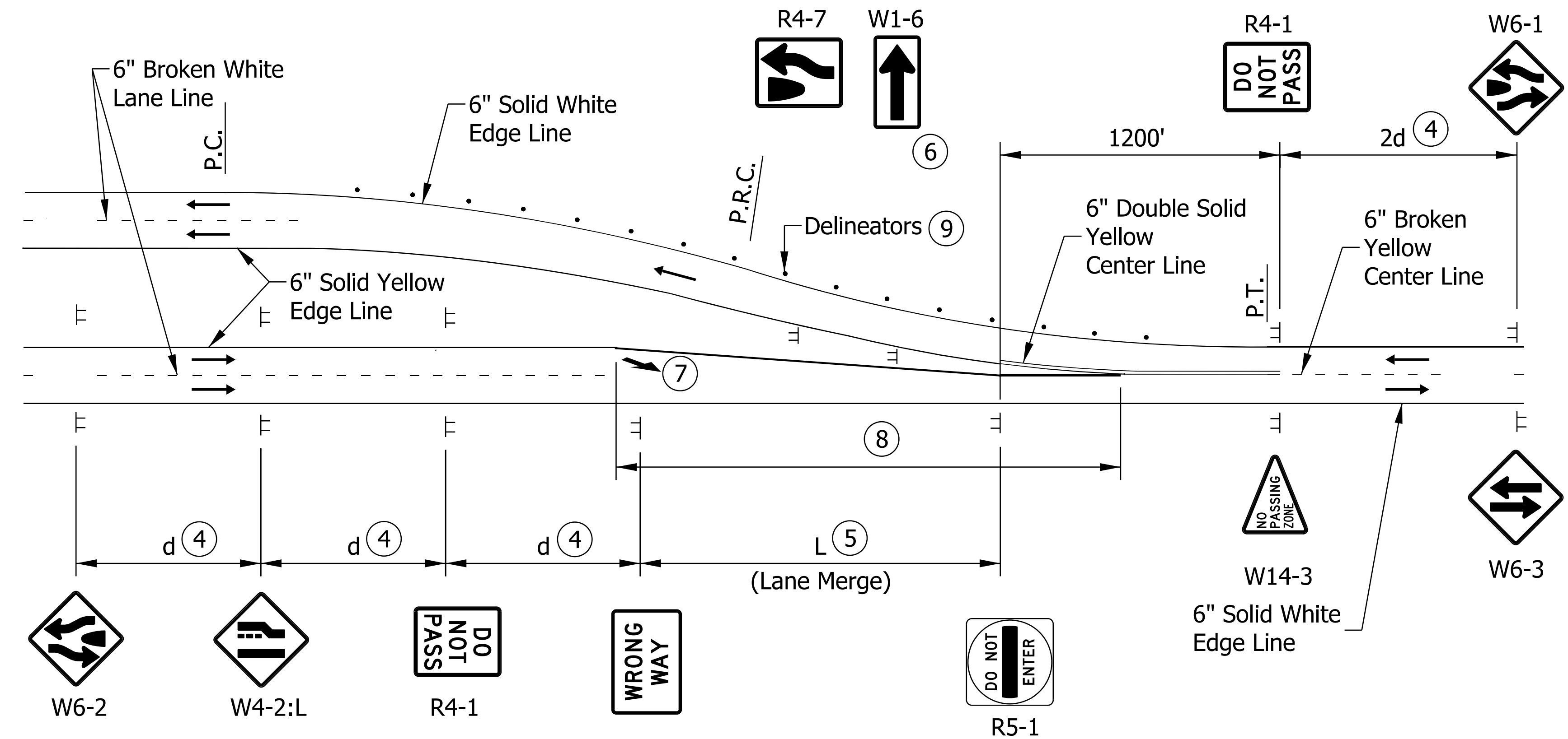
6 Optional

7 See IMUTCD 3B.20 for lane reduction arrow design and application.

→ Traffic Direction

# TRANSITION MARKINGS
# 4-Lane Divided to 2-Lane Undivided
# (Right Lane Ends)

Figure 502-2M




NOTES:

1. RPM's are desirable along all edge and center lines within the transition area.
2. Adjustments to the signing and pavement marking locations may be required to meet field conditions.
3. This transition design should only be used for existing conditions.

→ Traffic Direction

4 d = Advance Warning Distance, See IMUTCD Table 2C - 4.

5 See Figure 502-2J for taper lengths.

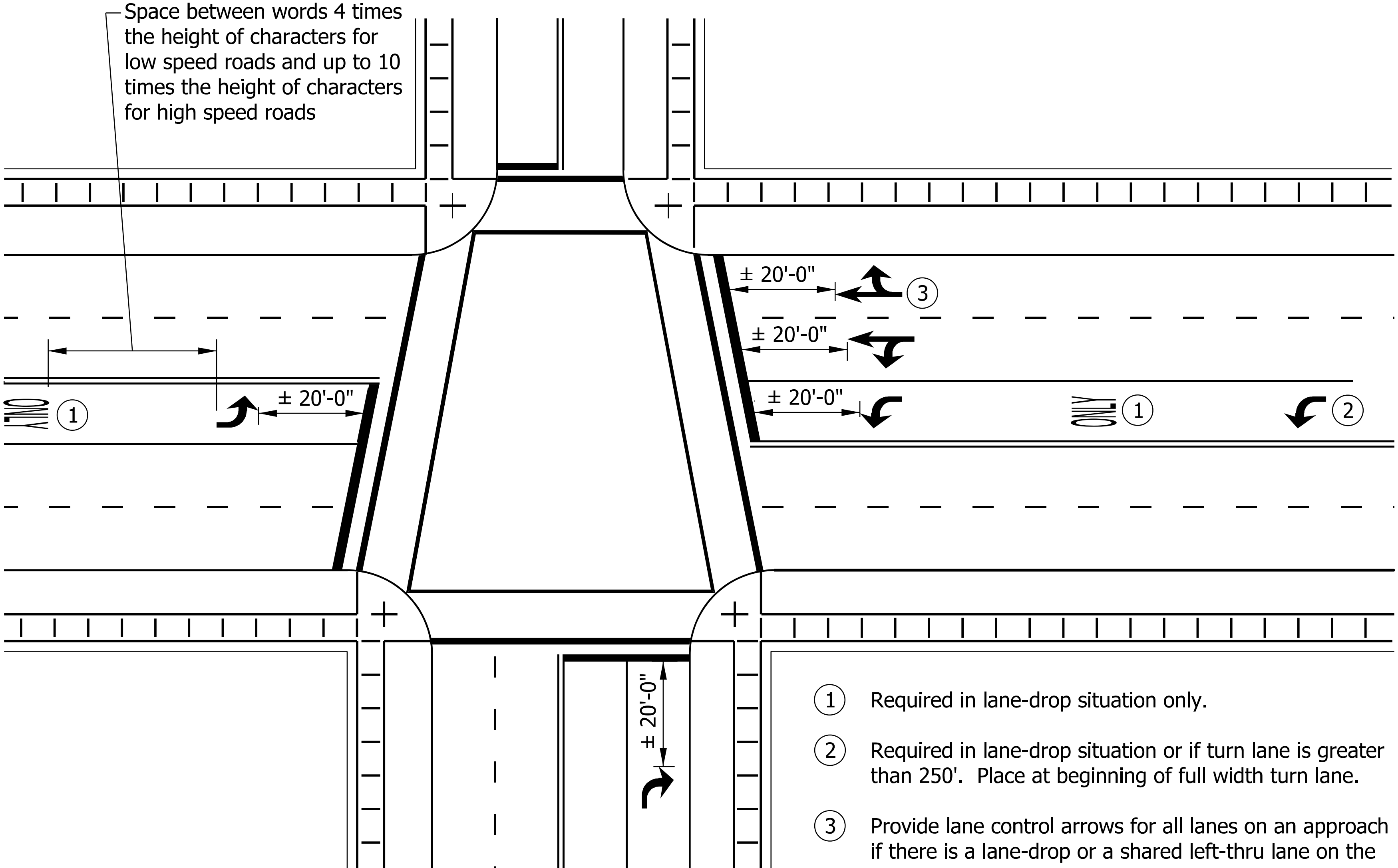
6 Optional.

7 See IMUTCD 3B.20 for lane reduction arrow design and application.

8 10" Solid Yellow Edge Line Throughout Transition.

9 See Figure 502-2K for delineator spacing.

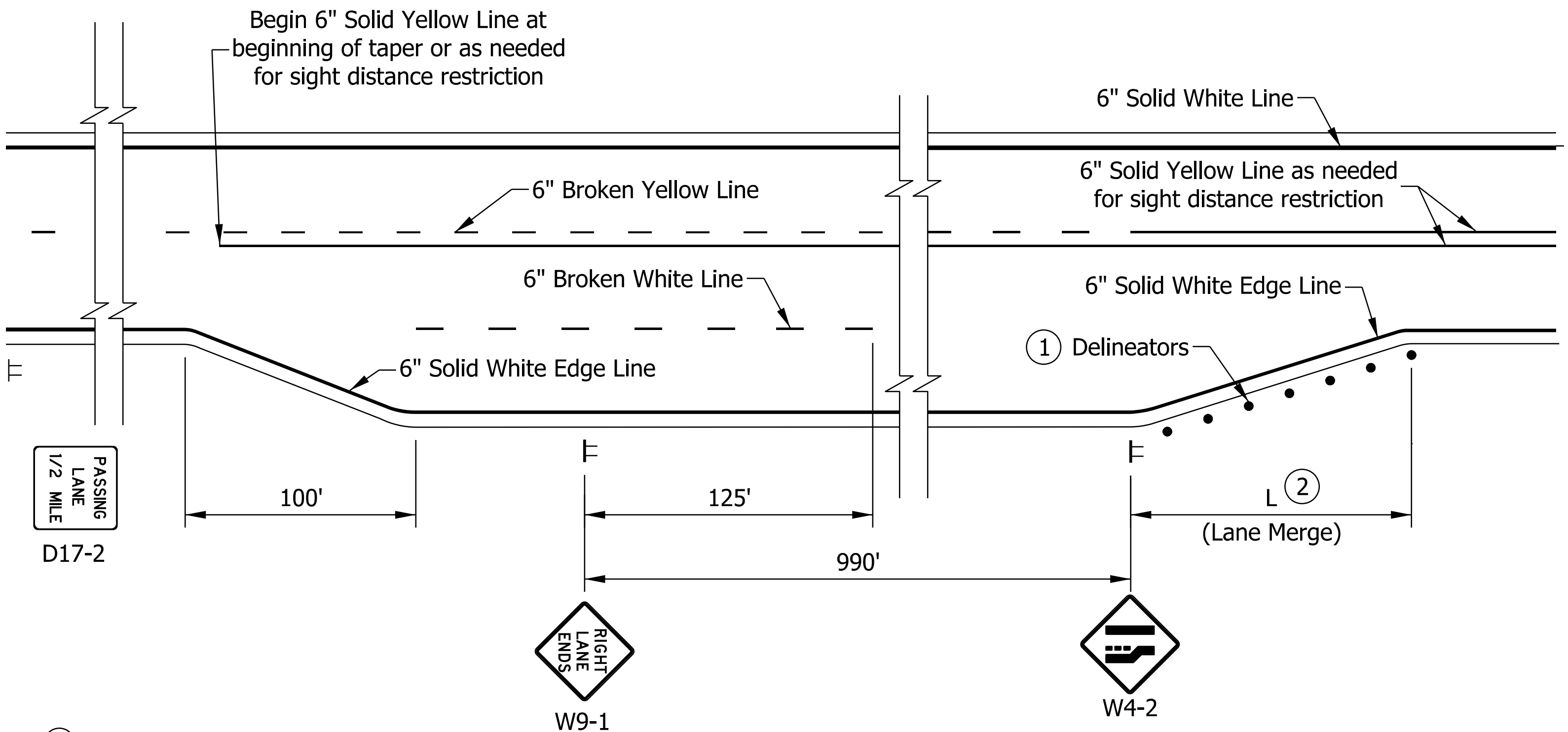
# TRANSITION MARKINGS
# 4-Lane Divided to 2-Lane Undivided
# (Left Lane Ends)
# Figure 502-2N




1. Required in lane-drop situation only.
2. Required in lane-drop situation or if turn lane is greater than 250'. Place at beginning of full width turn lane.
3. Provide lane control arrows for all lanes on an approach if there is a lane-drop or a shared left-thru lane on the major street.

TRAFFIC CONTROL WORD/SYMBOL MARKINGS

Figure 502-2 O



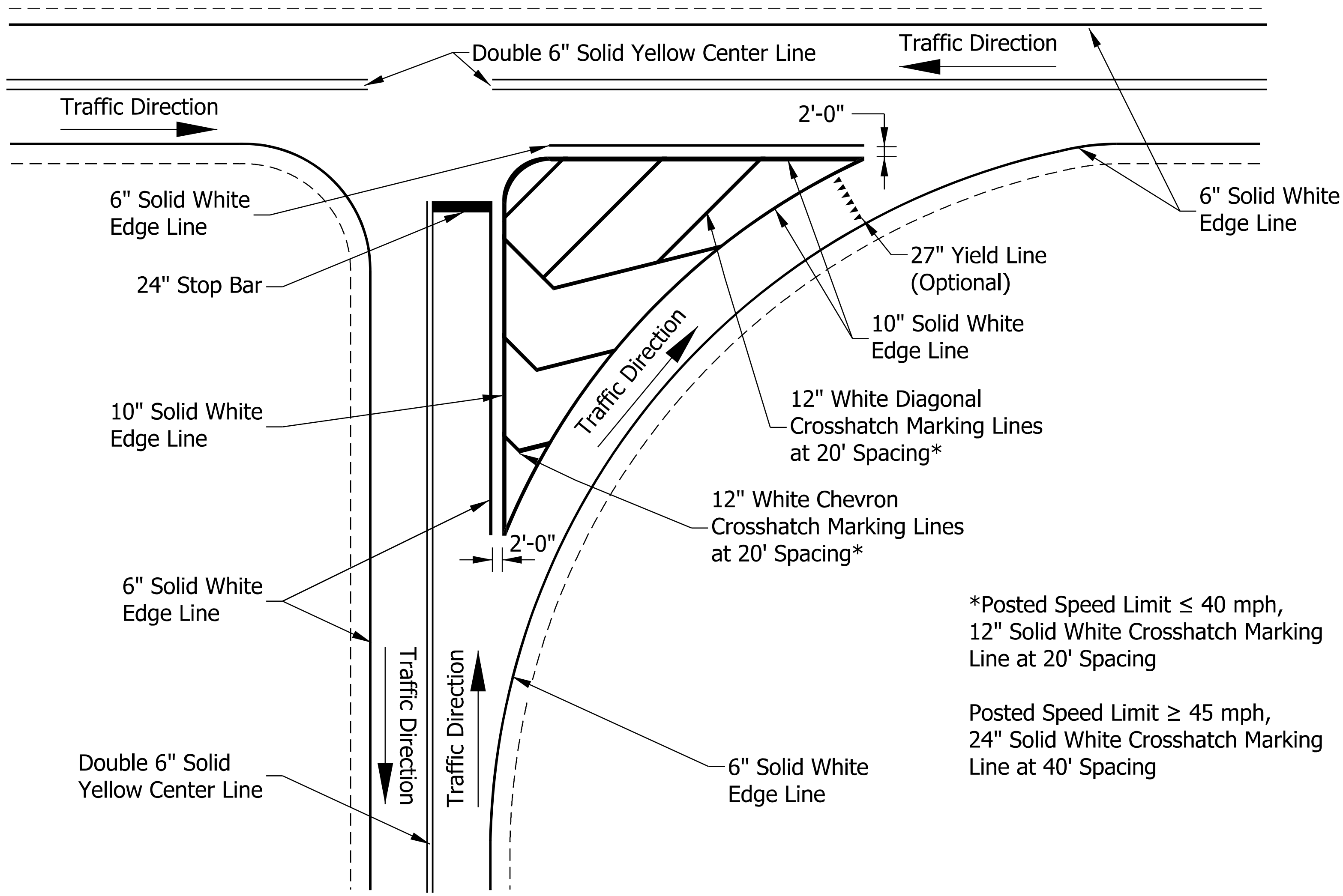

1. See Figure 502-2K for delineator spacing.

2. See Figure 502-2J for taper length.

3. See IMUTCD Figure 2D-21 for alternate message options on the D17-2 sign.

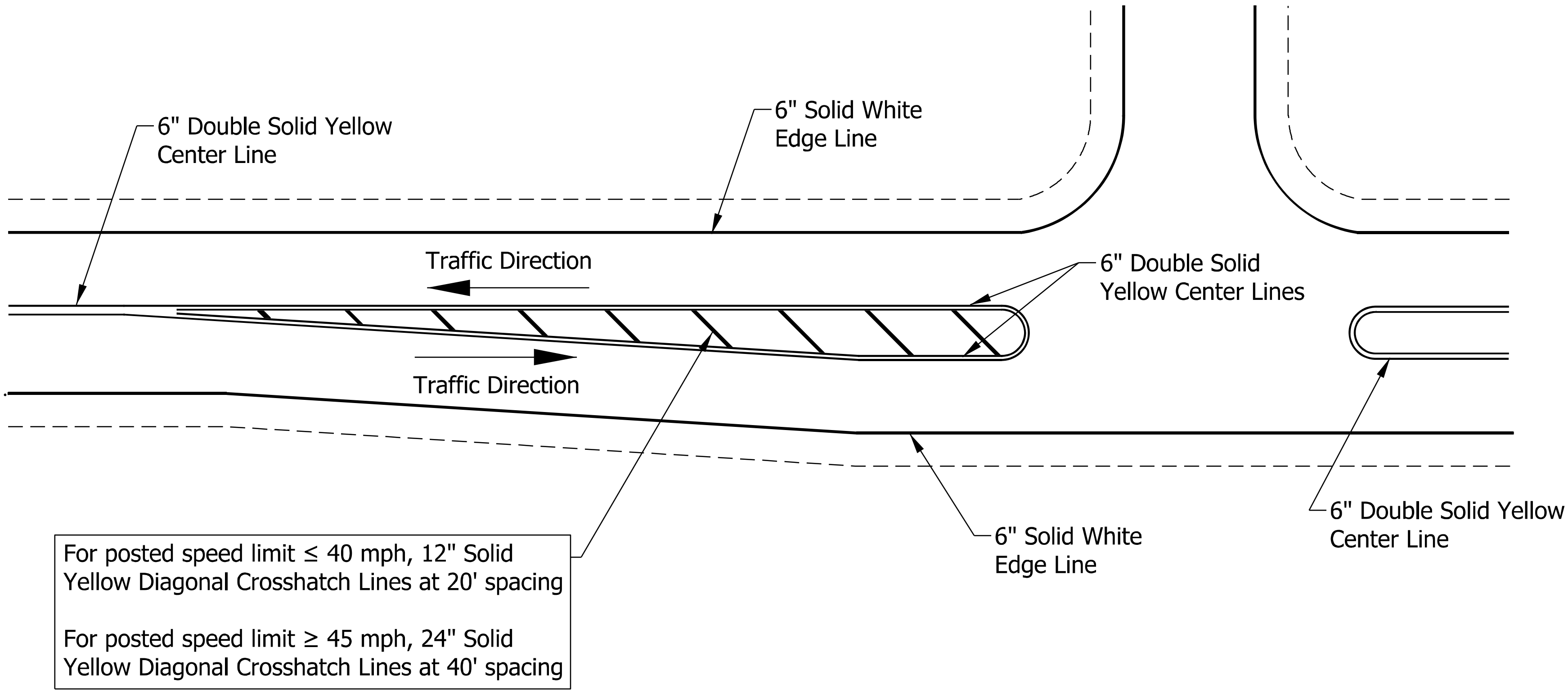
PASSING LANE MARKINGS

Figure 502-2P




CHANNELIZED ISLAND MARKINGS
Triangular Island

Figure 502-2Q




CHANNELIZED ISLAND MARKINGS
Flush or Raised Corrugated Elongated Island

Figure 502-2R

| Roadway Type | Rural Two Lane, Lane Widths ≥ 10’ and < 11’ | | Rural Two Lane, Lane Widths ≥ 11’ and ≤12’, Paved Shoulder Widths ≥2’ and <4’ | | Rural Two Lane, Lane Widths ≥ 11’≤ and ≤12’, Paved Shoulder Width ≥ 4’ | | Rural Multi-lane, Undivided, Paved Shoulder Width ≥ 4’ | | Rural Freeway, Interstate, or Divided Highway, Paved Shoulder Width ≥ 4’ | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Pavement Corrugation Type** | **HMA Pavement** | **PCCP Pavement** | **HMA Pavement** | **PCCP Pavement** | **HMA Pavement** | **PCCP Pavement** | **HMA Pavement** | **PCCP Pavement** | **HMA Pavement** | **PCCP Pavement** |
| Shoulder Corrugations | | | | | | X | | X | X | X |
| Shoulder Rumble Strip (Sinusoidal) | | | | | X | | X | | | |
| Edge line Rumble Stripe (Sinusoidal) | | | X | | | | | | | |
| Centerline Rumble Stripe (Sinusoidal) | X | | X | | X | X | | | | |

Notes:

1. The posted speed limit should be 50 mph or above. Use of pavement corrugations where the posted speed limit is less than 50 mph may be considered where special circumstances justify their use (e.g. crash history).
2. Centerline rumble stripes should not be used on multi-lane facilities.
3. Corrugations may not be installed on chip seal (seal coat) surfaces less than a year old or any pavement surface treatment such as microsurface or ultrathin bonded wearing course (UBWC) that is under an active warranty (i.e. less than 3 years old).
4. See Section 502-2.09(01) for additional selection guidelines.

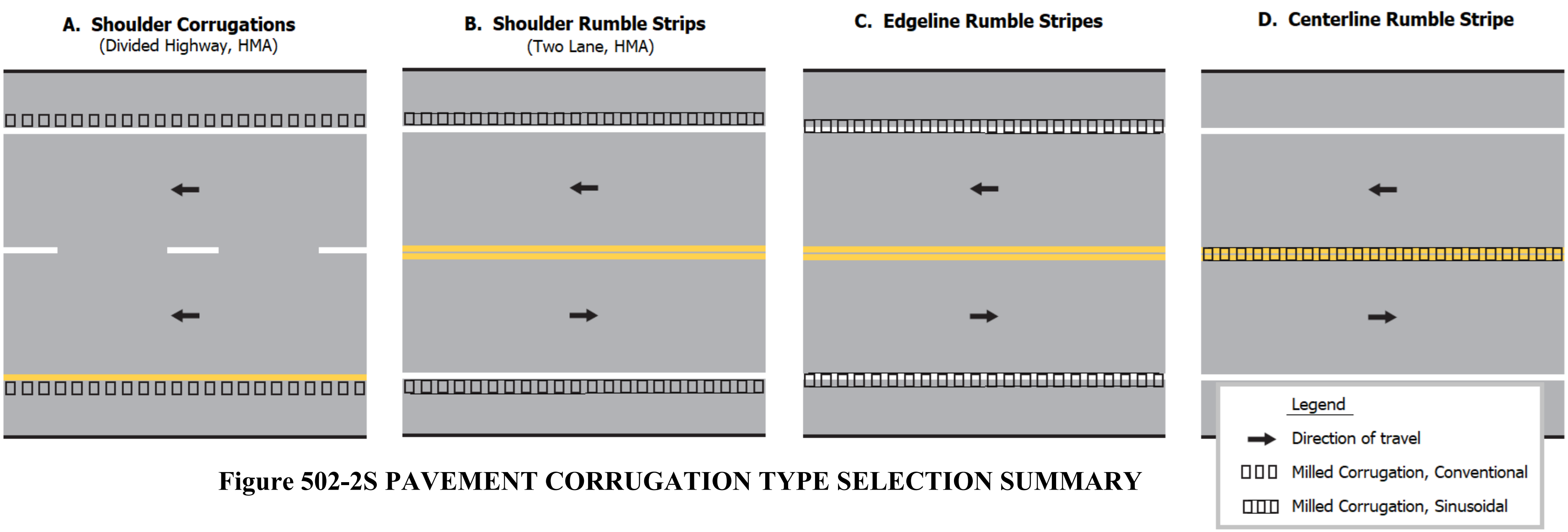
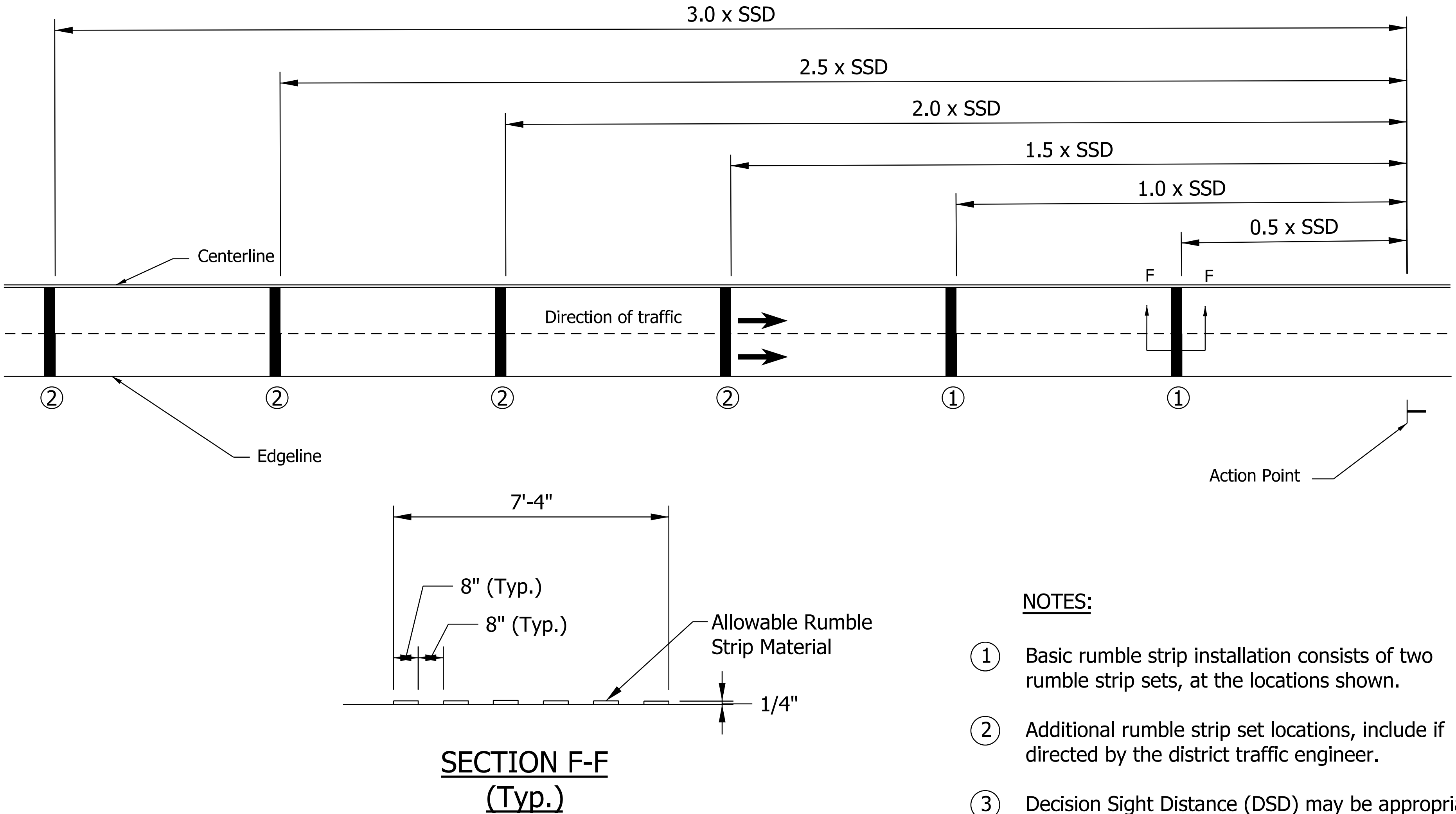



**Figure 502-2S PAVEMENT CORRUGATION TYPE SELECTION SUMMARY**




NOTES:

1. Basic rumble strip installation consists of two rumble strip sets, at the locations shown.

2. Additional rumble strip set locations, include if directed by the district traffic engineer.

3. Decision Sight Distance (DSD) may be appropriate for some locations. For DSD, see IDM Chapter 42, Figure 42-2A.

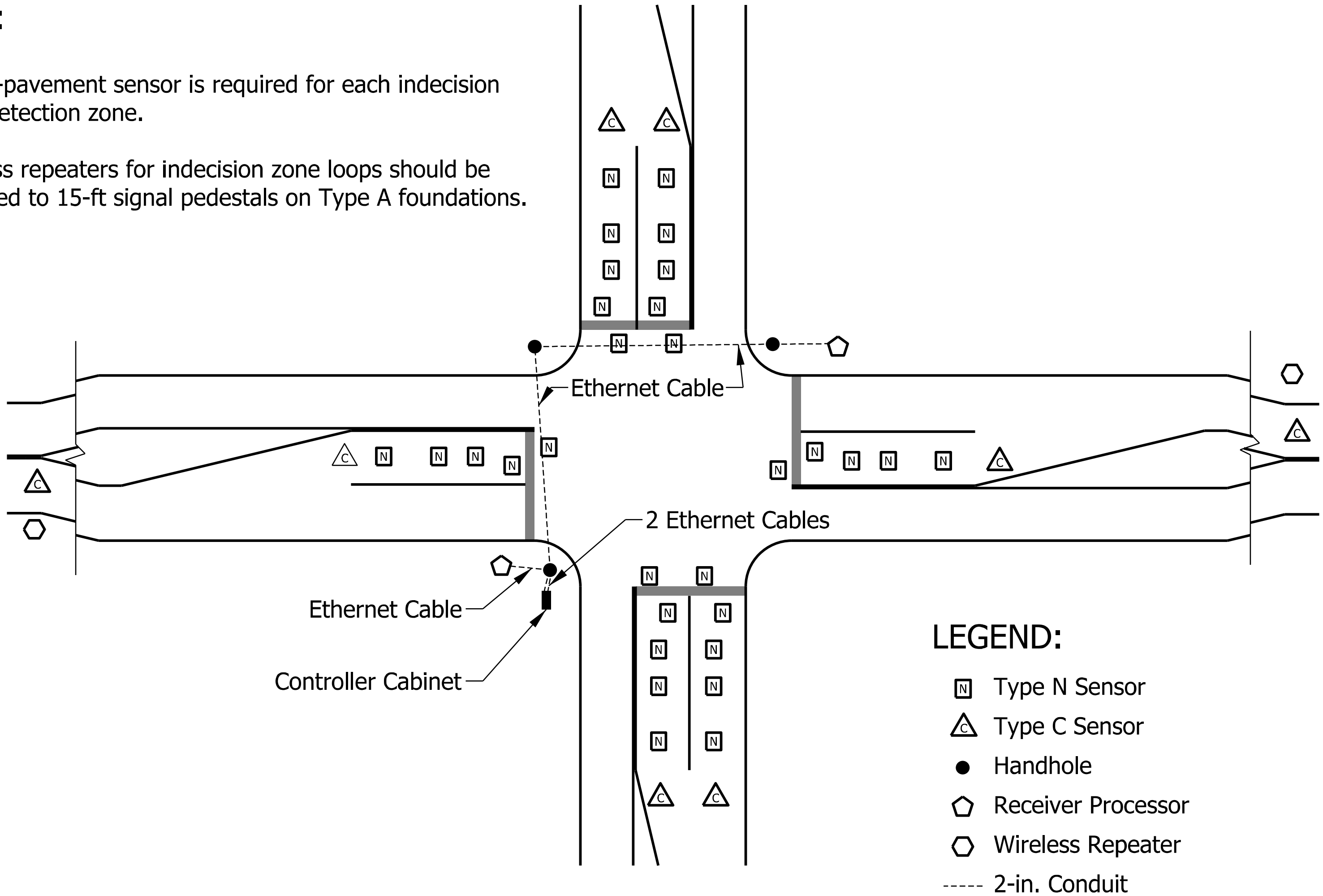
4. For Stopping Sight Distance (SSD) see IDM Chapter 42, Figure 42-1A.

TRANSVERSE RUMBLE STRIPS

Figure 502-2T

## NOTES:

1. One in-pavement sensor is required for each indecision zone detection zone.
2. Wireless repeaters for indecision zone loops should be mounted to 15-ft signal pedestals on Type A foundations.



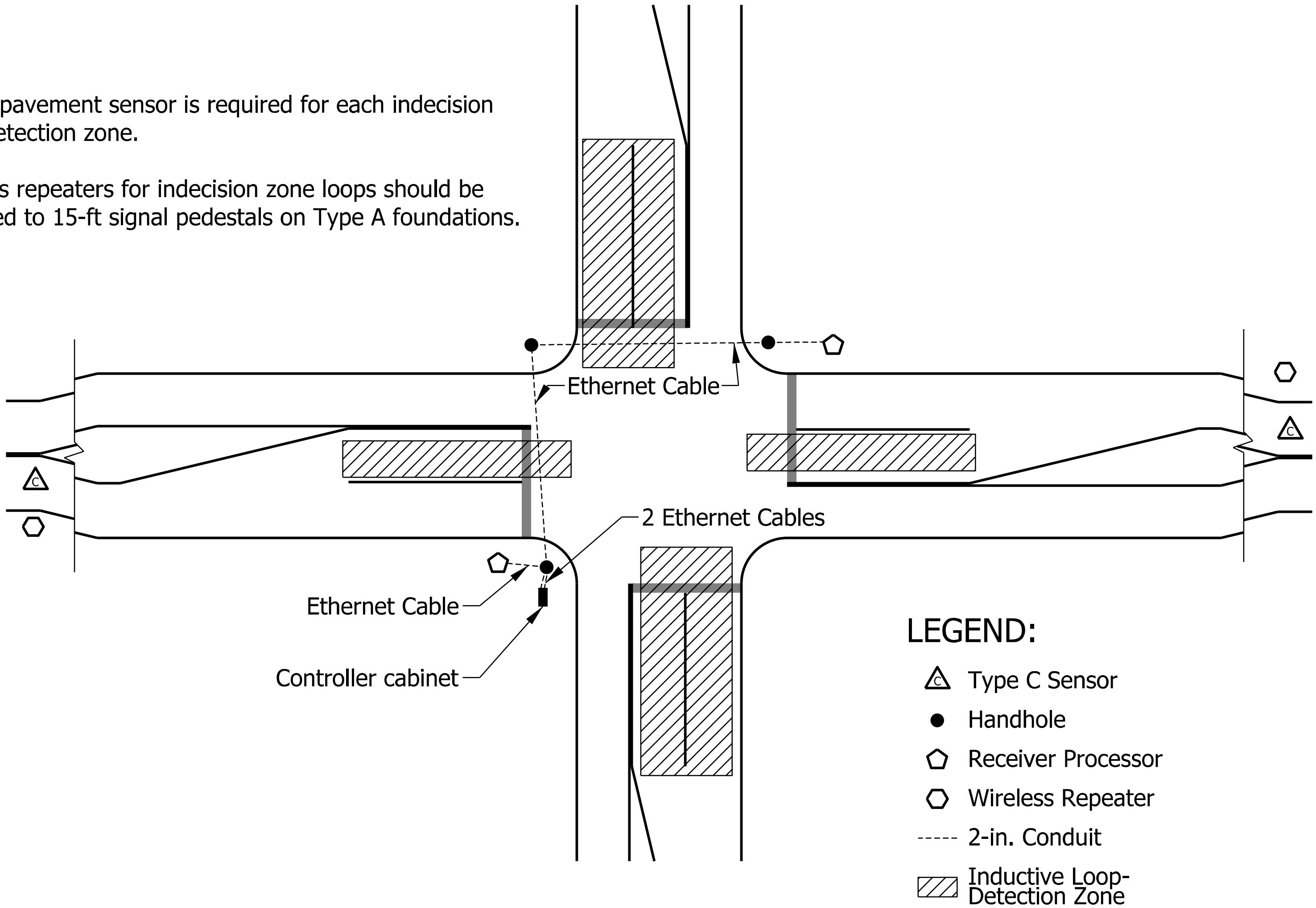

# TYPICAL WIRELESS VEHICLE-DETECTION SYSTEM

Figure 502-3A

## NOTES:

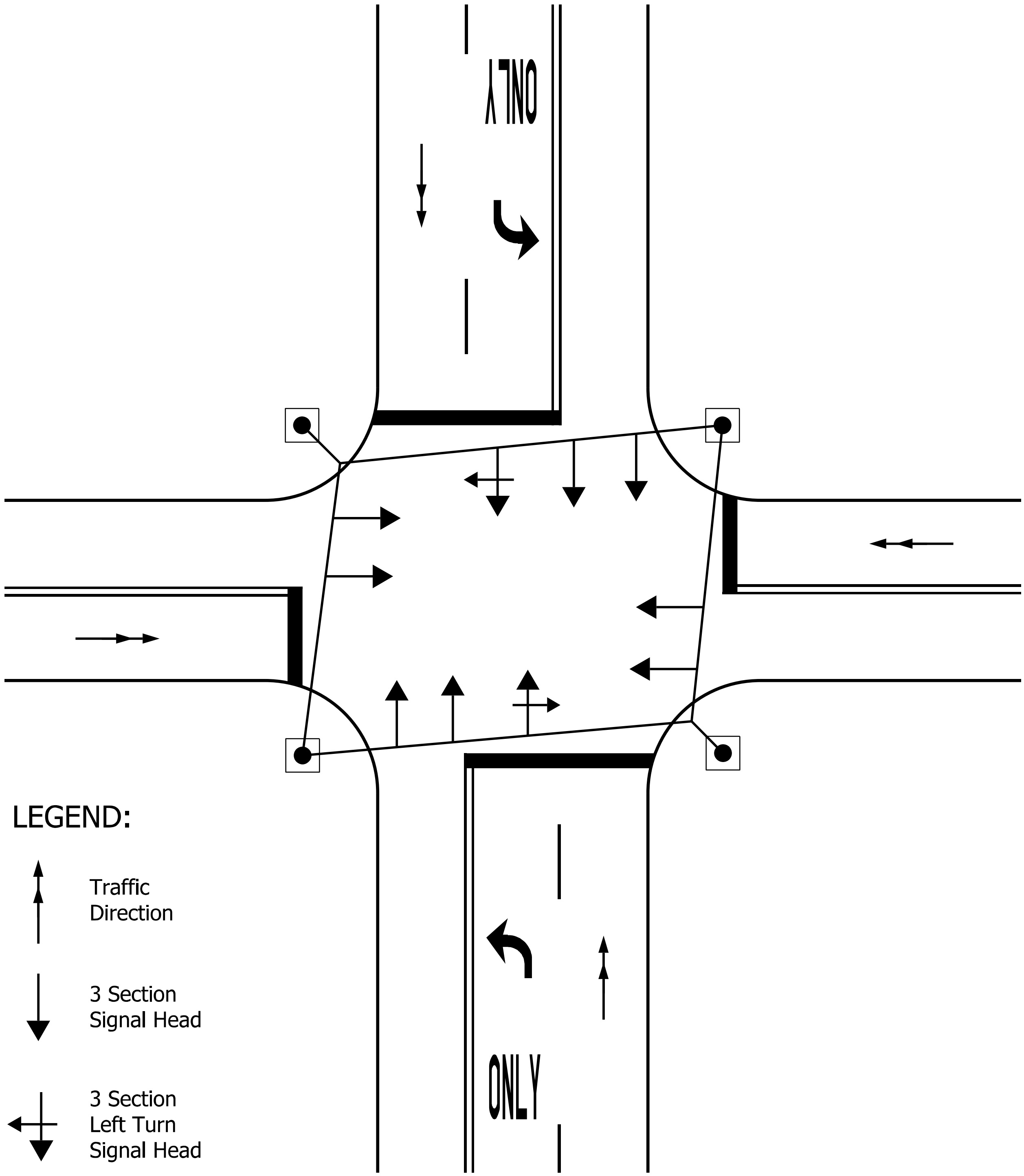
1. One in-pavement sensor is required for each indecision zone detection zone.

2. Wireless repeaters for indecision zone loops should be mounted to 15-ft signal pedestals on Type A foundations.



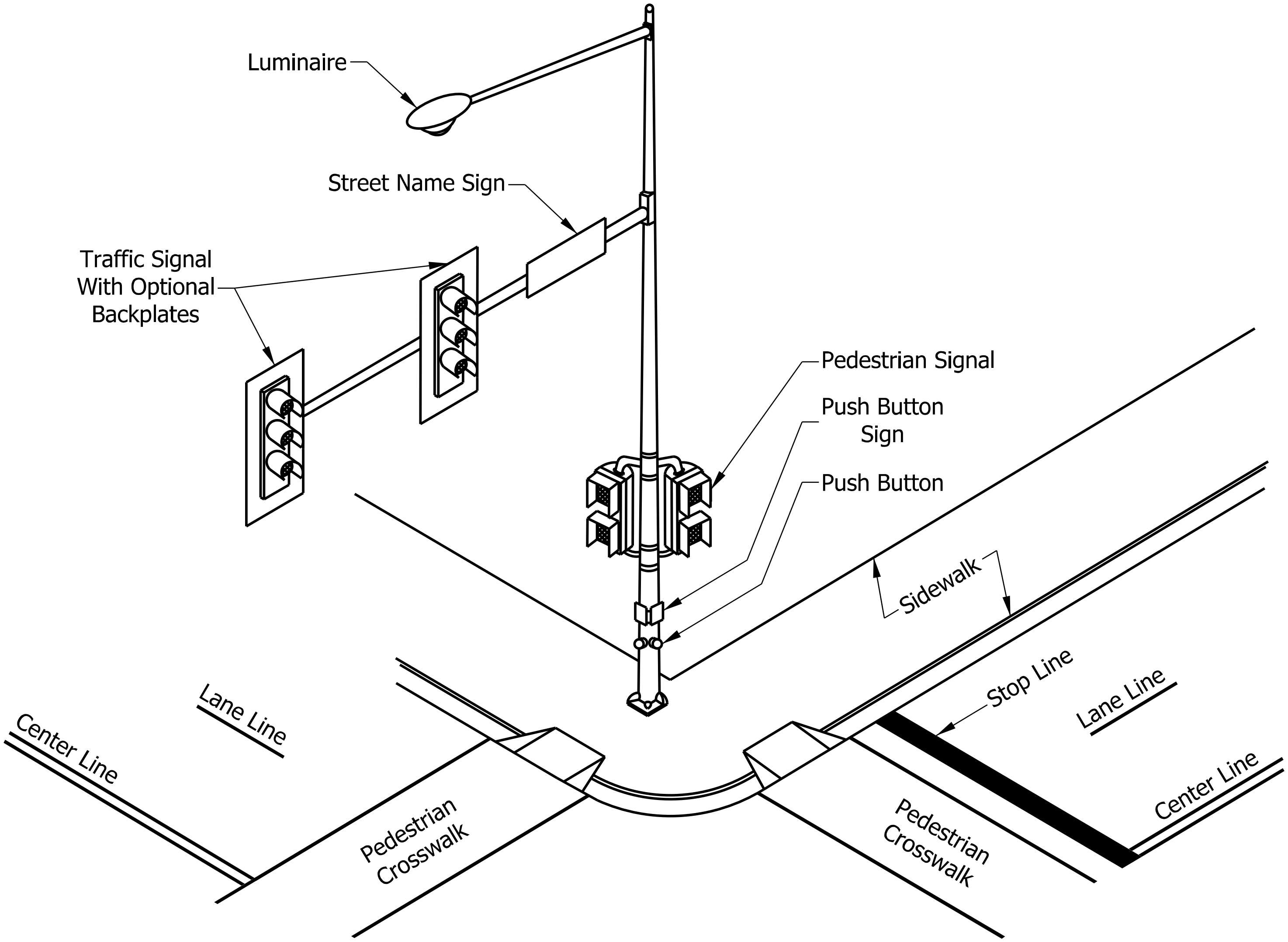

TYPICAL HYBRID WIRELESS VEHICLE-DETECTION SYSTEM

Figure 502-3B



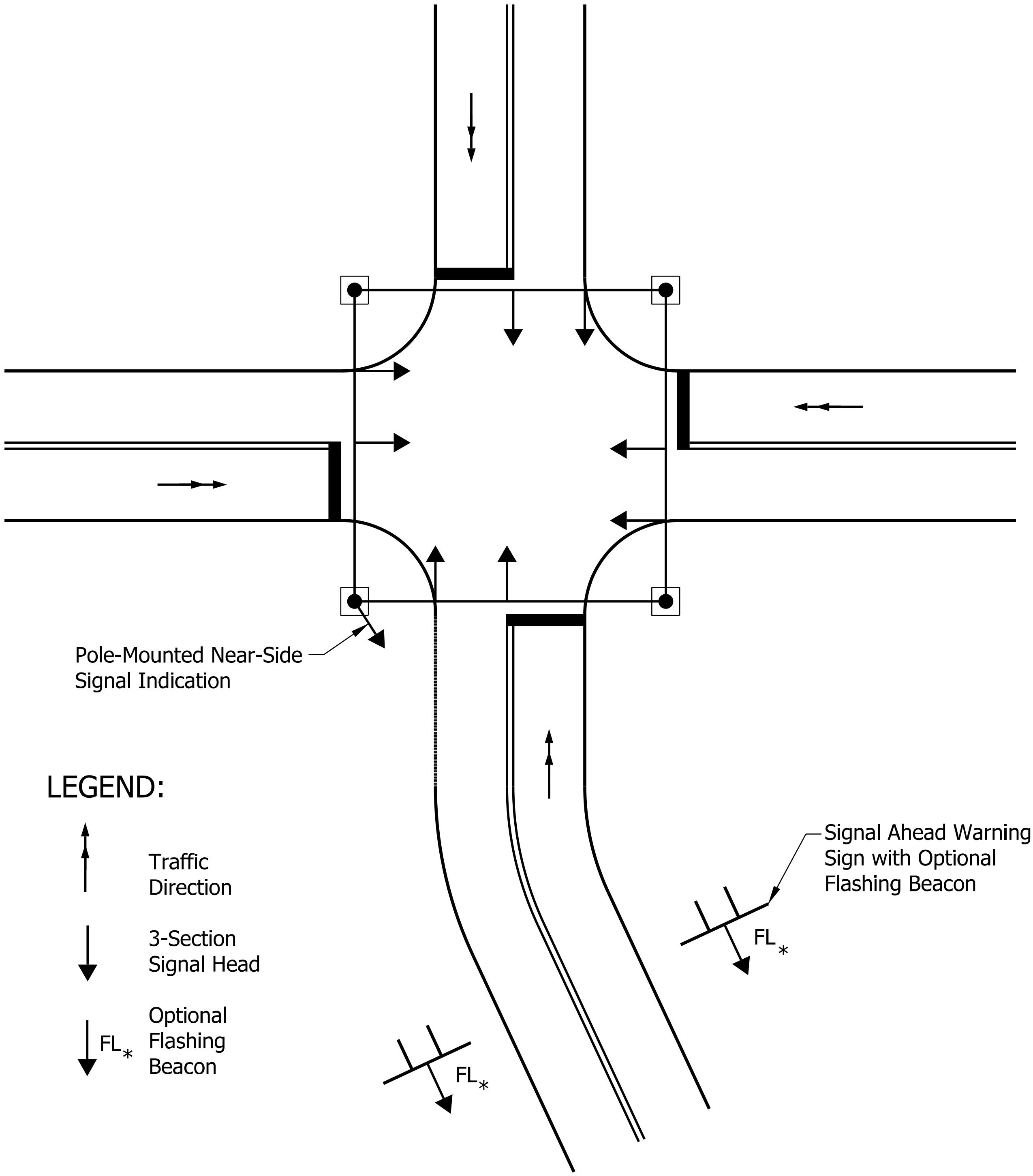

CABLE-SPAN MOUNTED SIGNAL
PARTIAL BRIDLE CONFIGURATION

Figure 502-3C



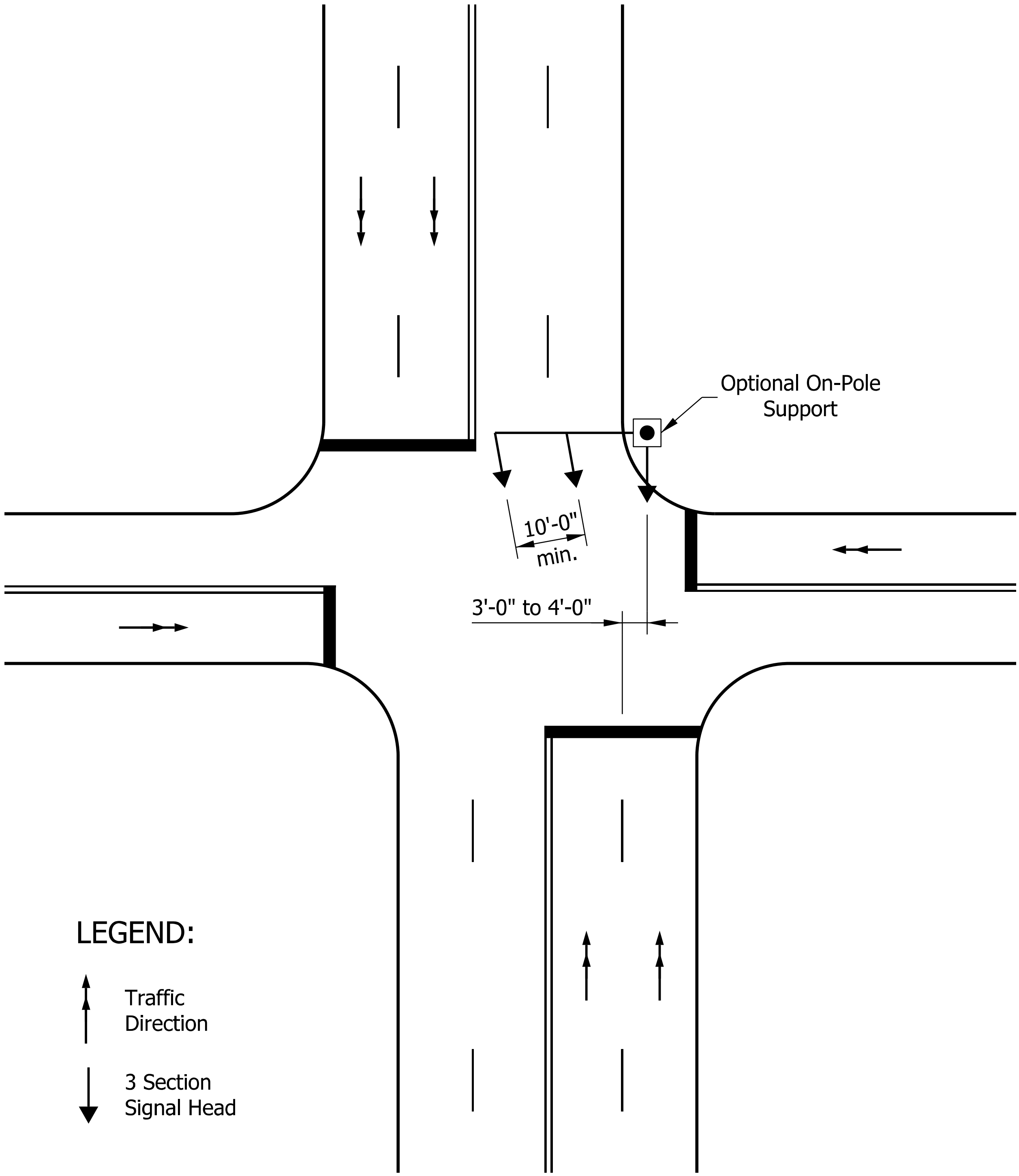

COMBINATION SIGNAL-LUMINAIRE POLE

Figure 502-3D



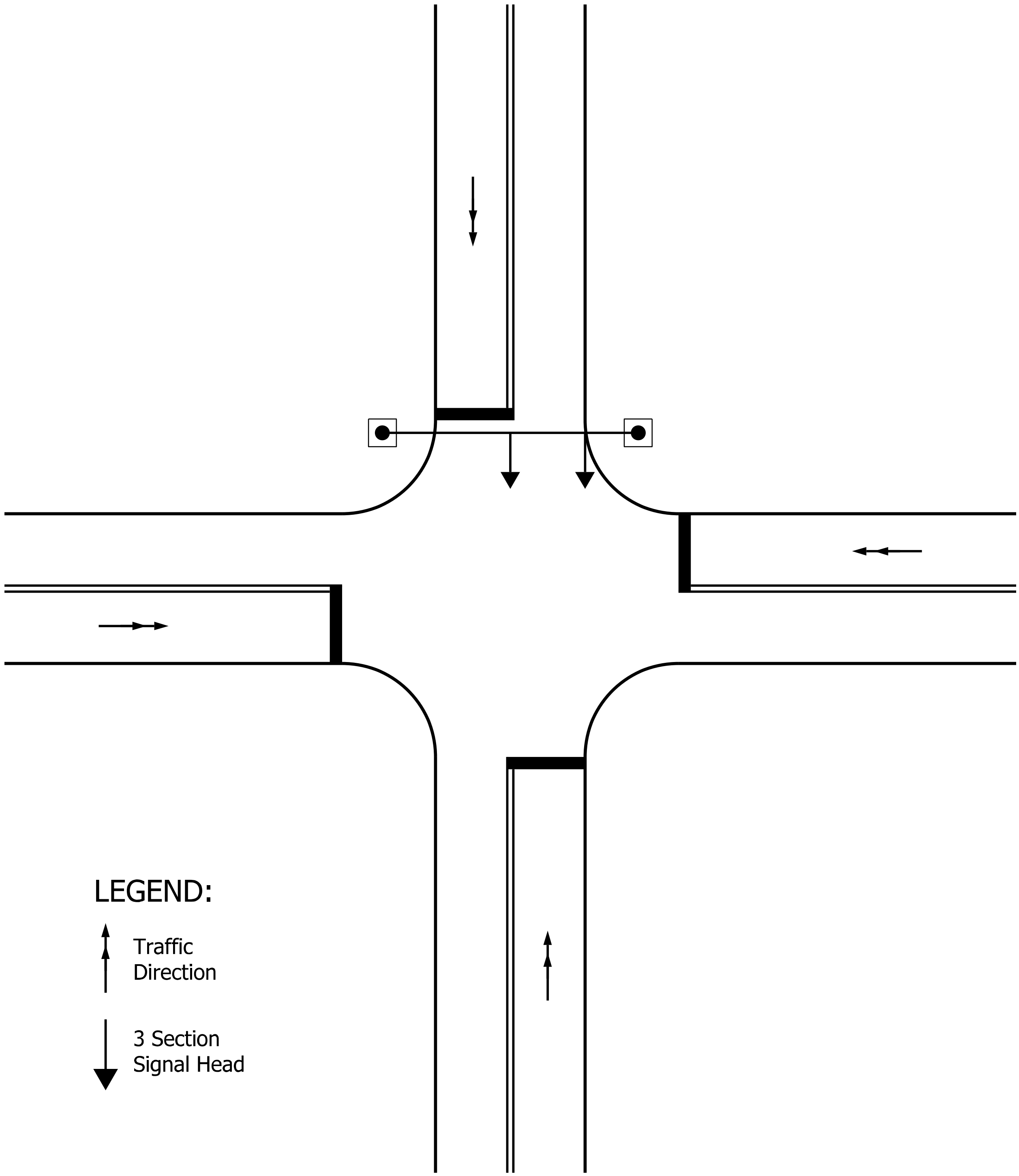

SIGNAL HEAD PLACEMENT
Rural Two-Lane Road with Obstructed Sight Distance

Figure 502-3E



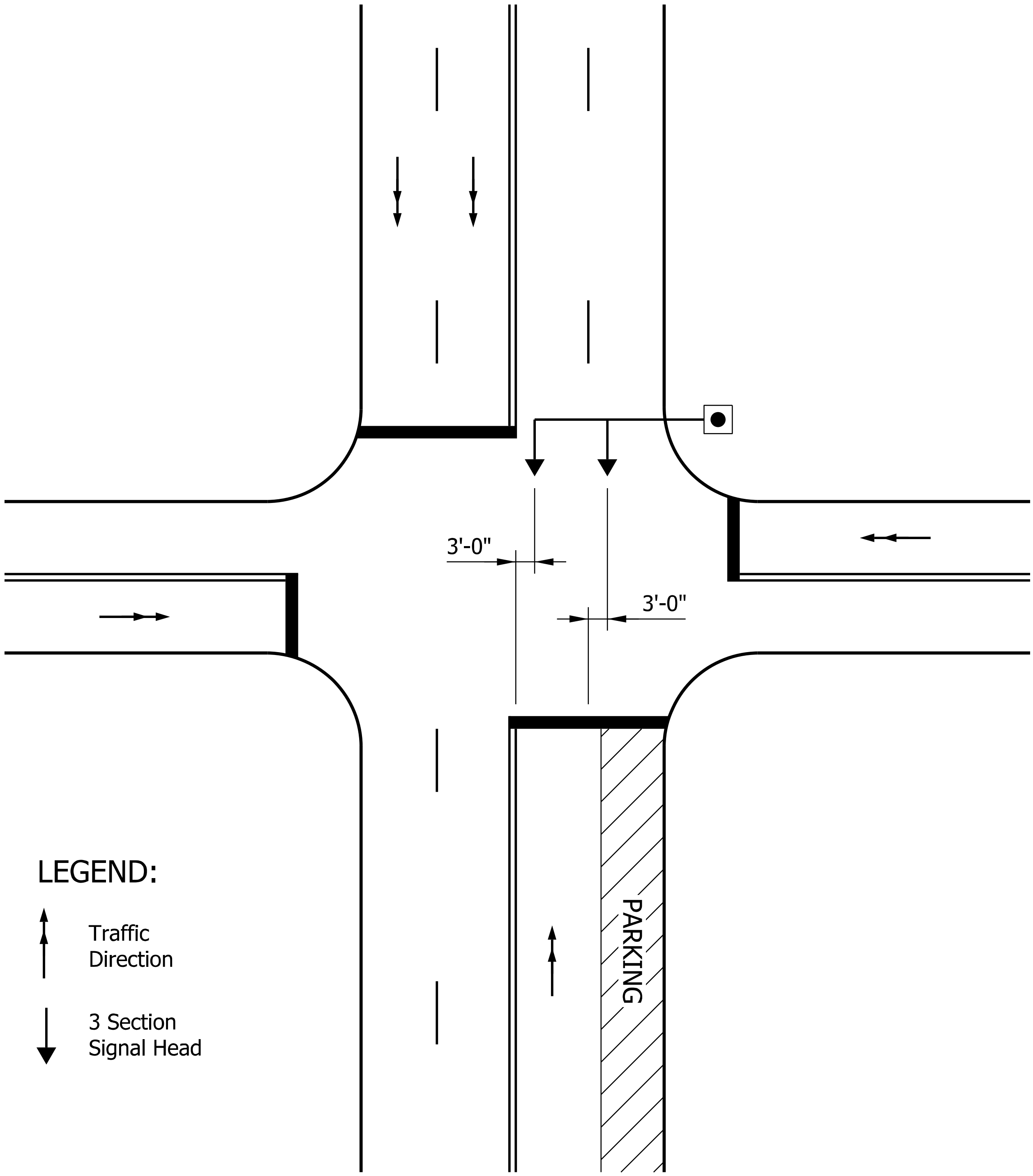

SIGNAL HEAD PLACEMENT
Offsetting Intersection

Figure 502-3F



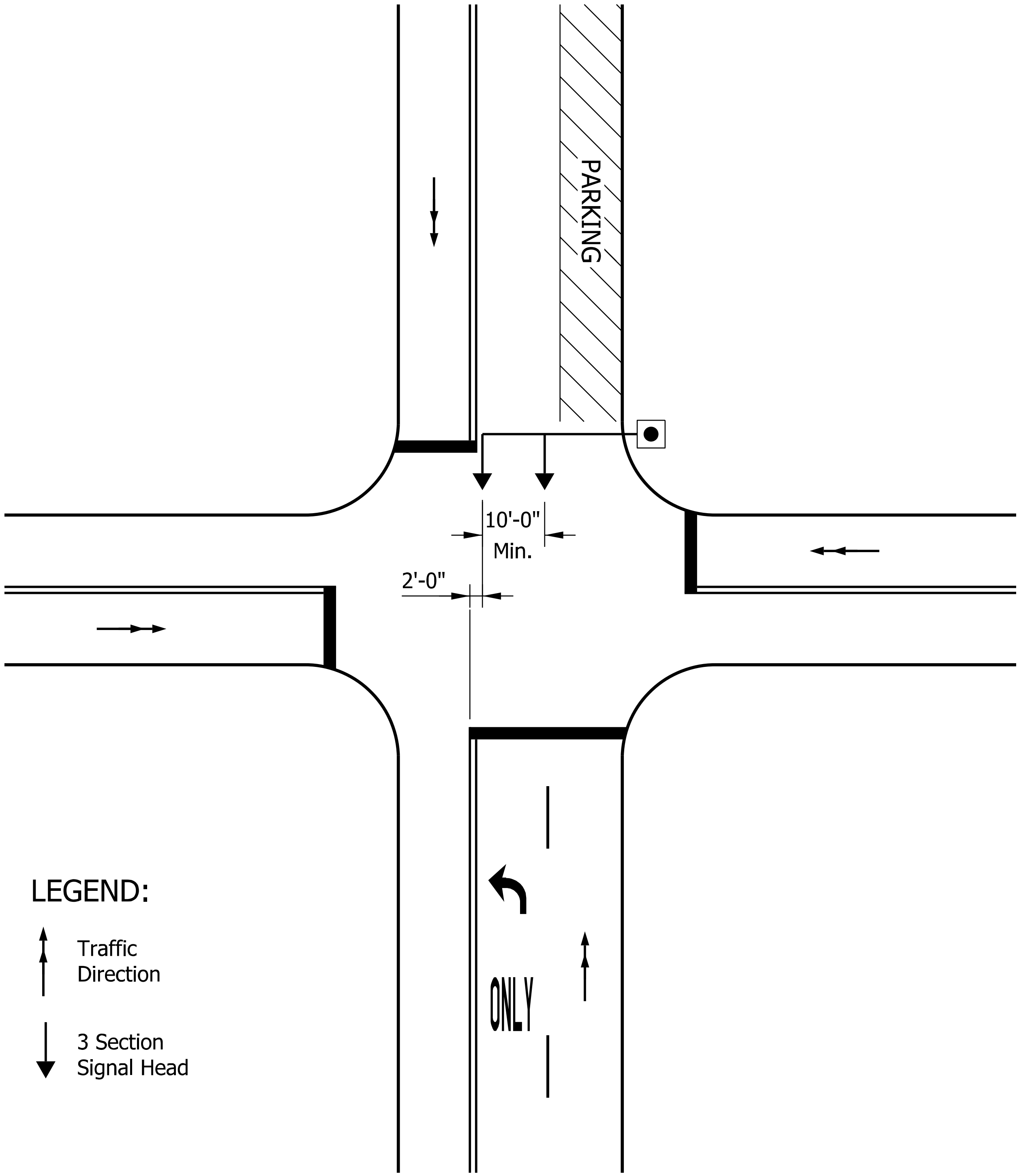

SIGNAL HEAD PLACEMENT
Rural Two-Lane Road with
Truck Blocking View of Signal Heads

Figure 502-3G



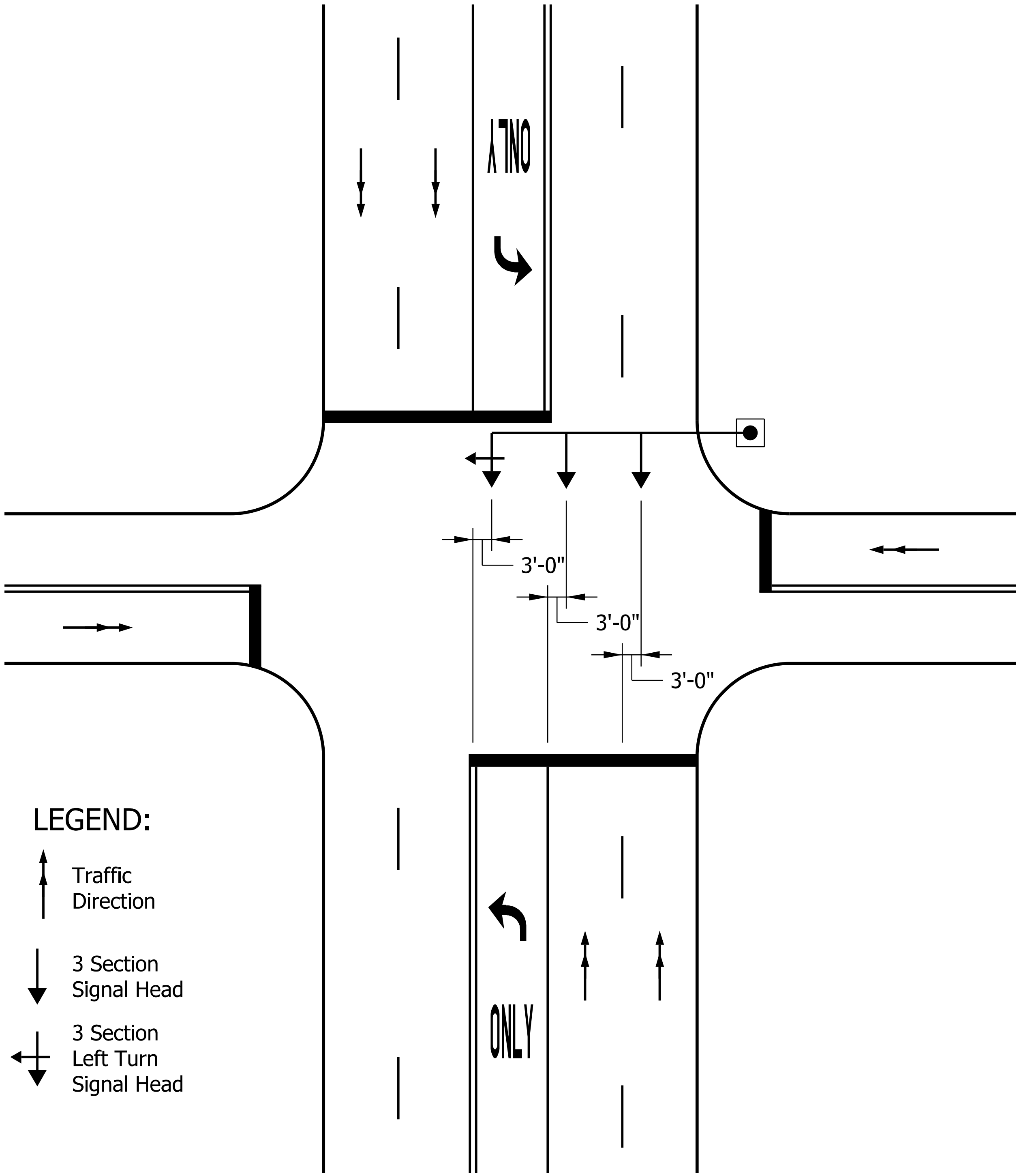

SIGNAL HEAD PLACEMENT
Approaching Lanes with Permissible Phase
and Parking on Near Side

Figure 502-3H



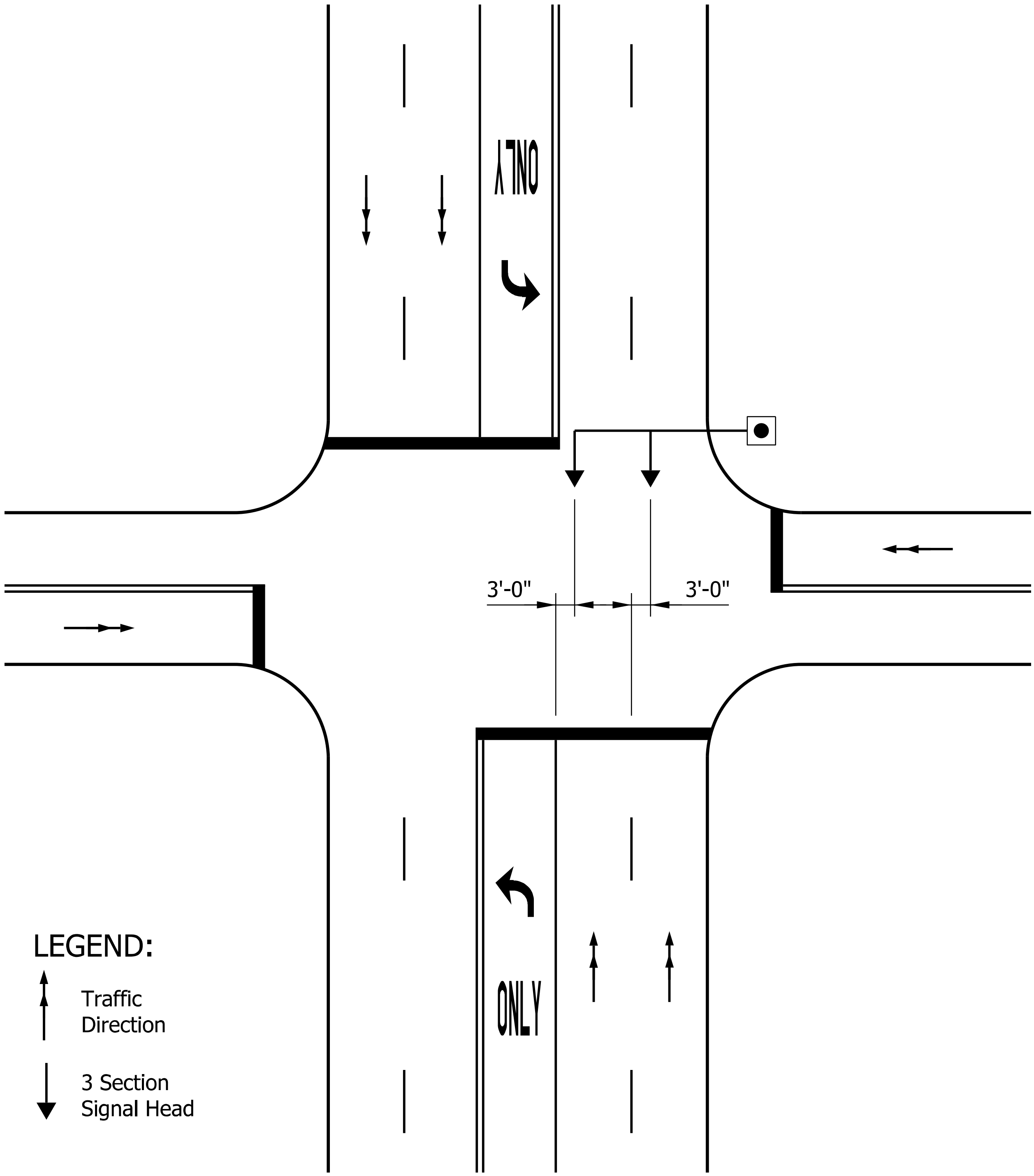

SIGNAL HEAD PLACEMENT
Approaching Lanes with Left-Turn Lane with
Permissible Phase and Parking on Far Side

Figure 502-3 I



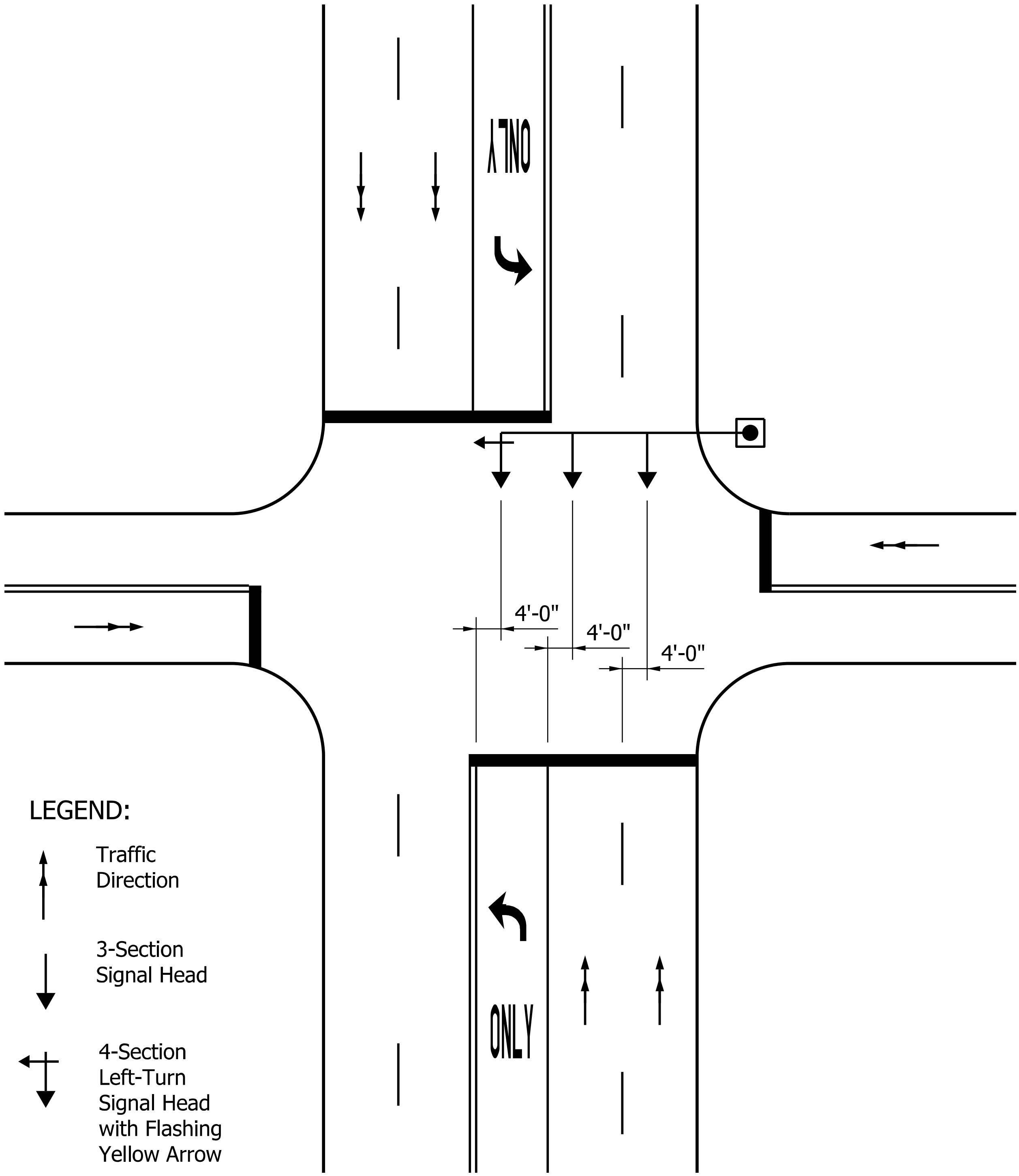

SIGNAL HEAD PLACEMENT
Approaching Lanes with Left-Turn Lane
with Protected Phase

Figure 502-3J



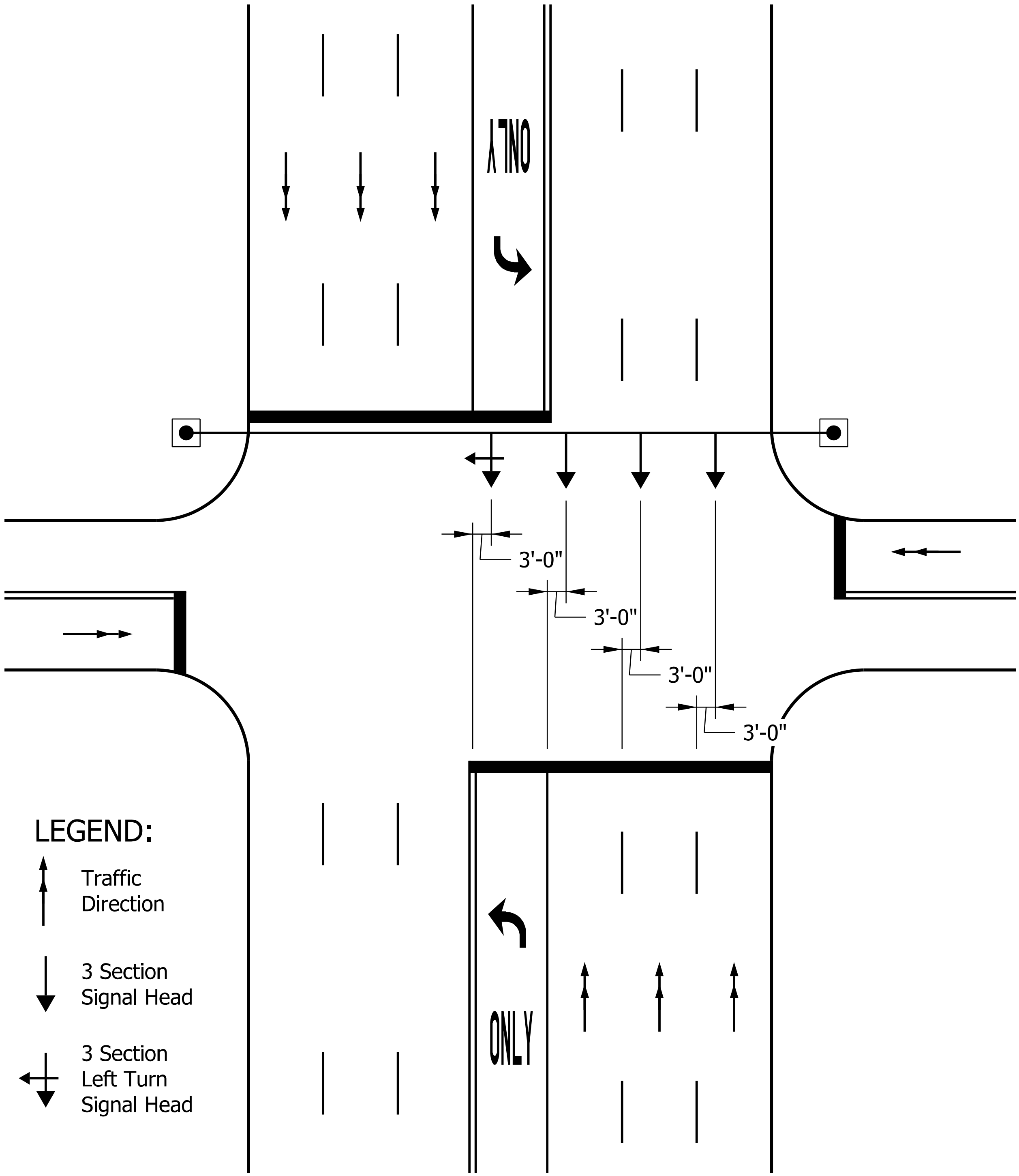

SIGNAL HEAD PLACEMENT
Approaching Lanes with Left-Turn Lane
with Permissible Phase

Figure 502-3K



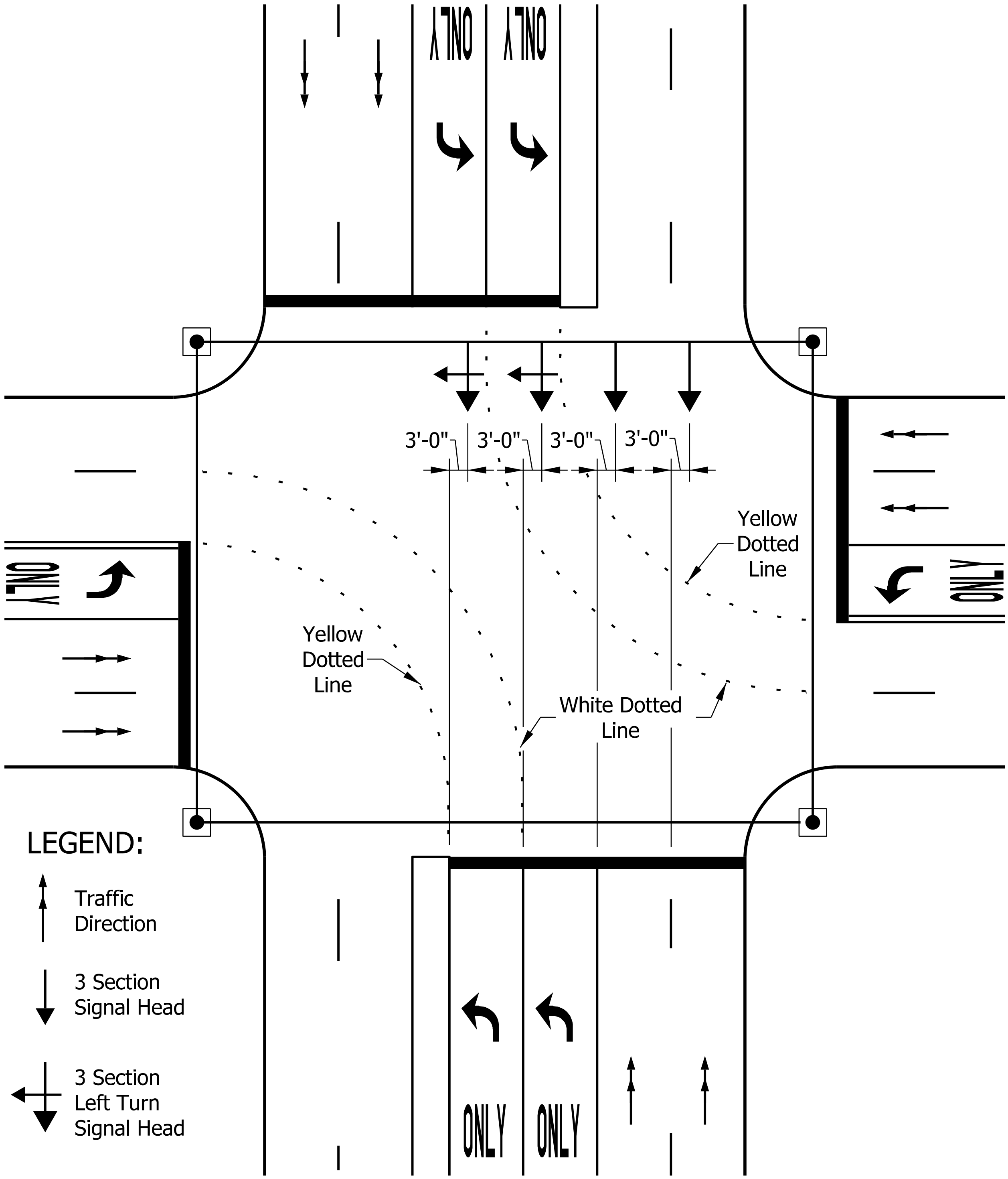

SIGNAL HEAD PLACEMENT
Approaching Lanes with Left-Turn Lane
with Protected/Permissible Phase

Figure 502-3L



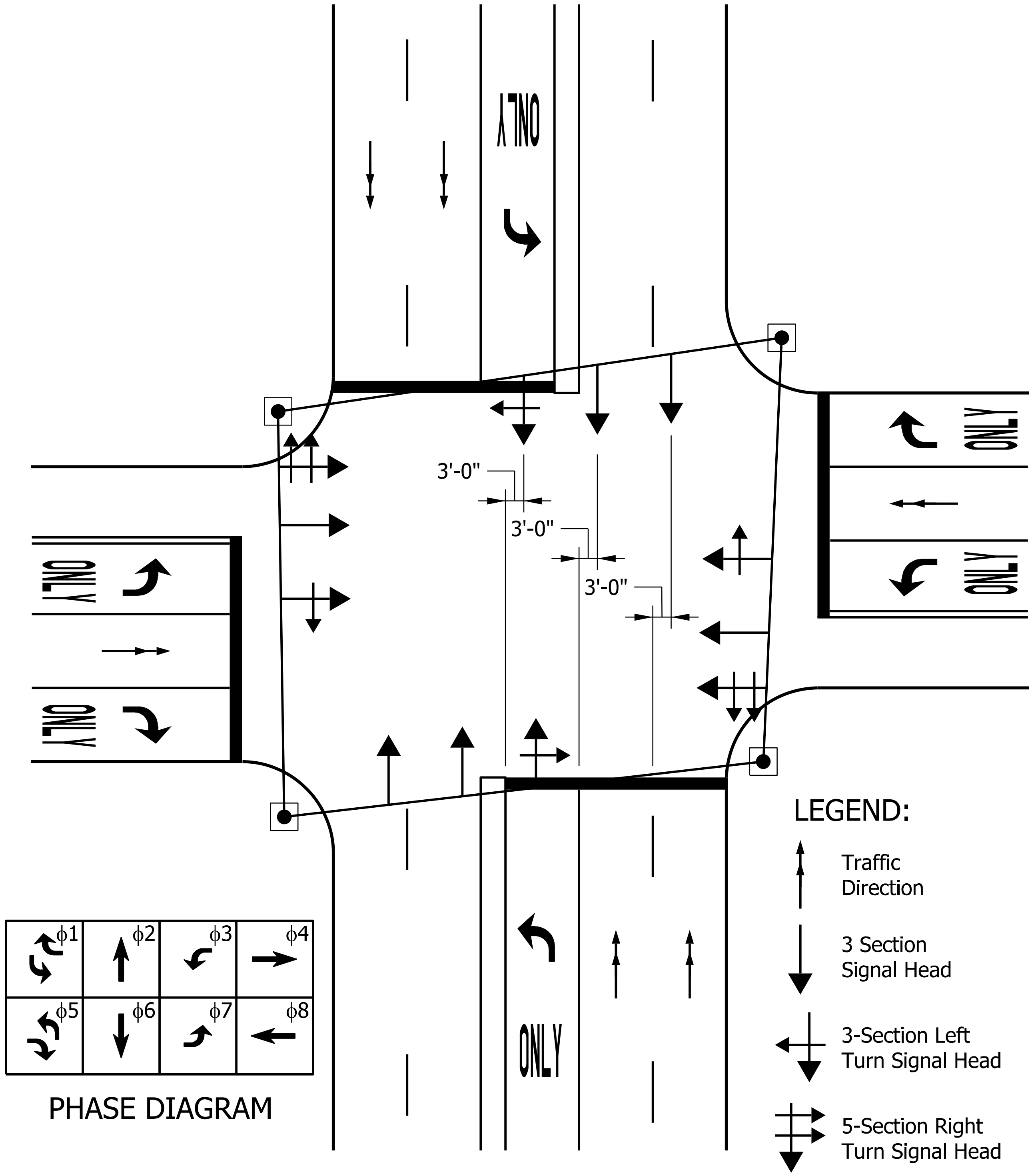

SIGNAL HEAD PLACEMENT
Multi-Lane Roadway Approaching Lanes with
Left-Turn Lane Protected Phase

Figure 502-3M




SIGNAL HEAD PLACEMENT
Approaching Lanes with Two Left-Turn Lanes
with Protected Phase

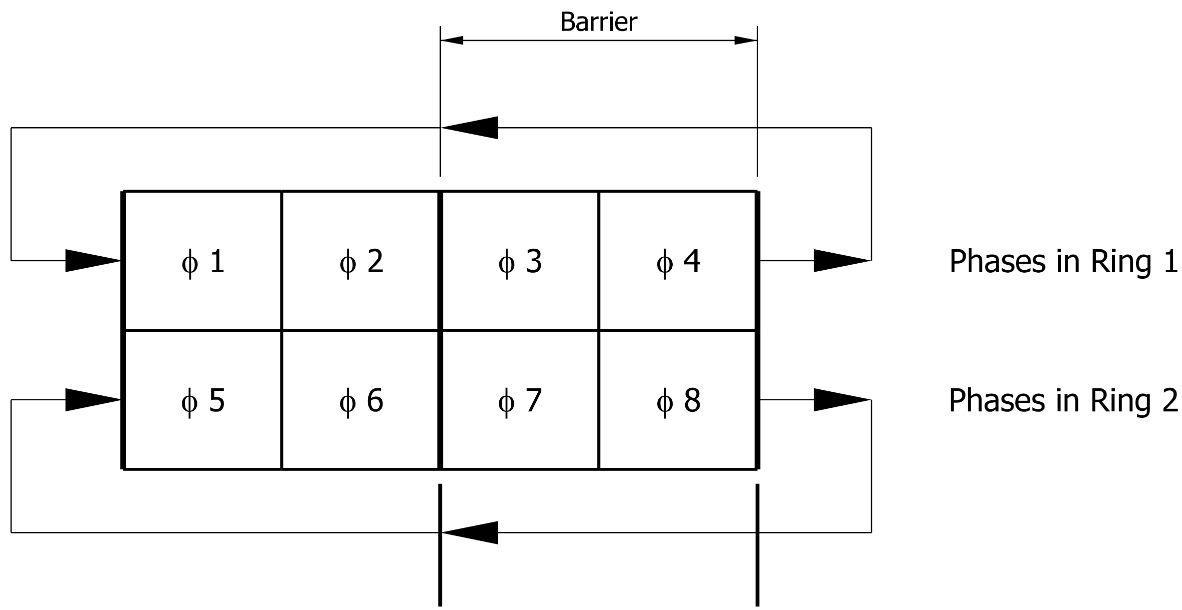
Figure 502-3N




SIGNAL HEAD PLACEMENT

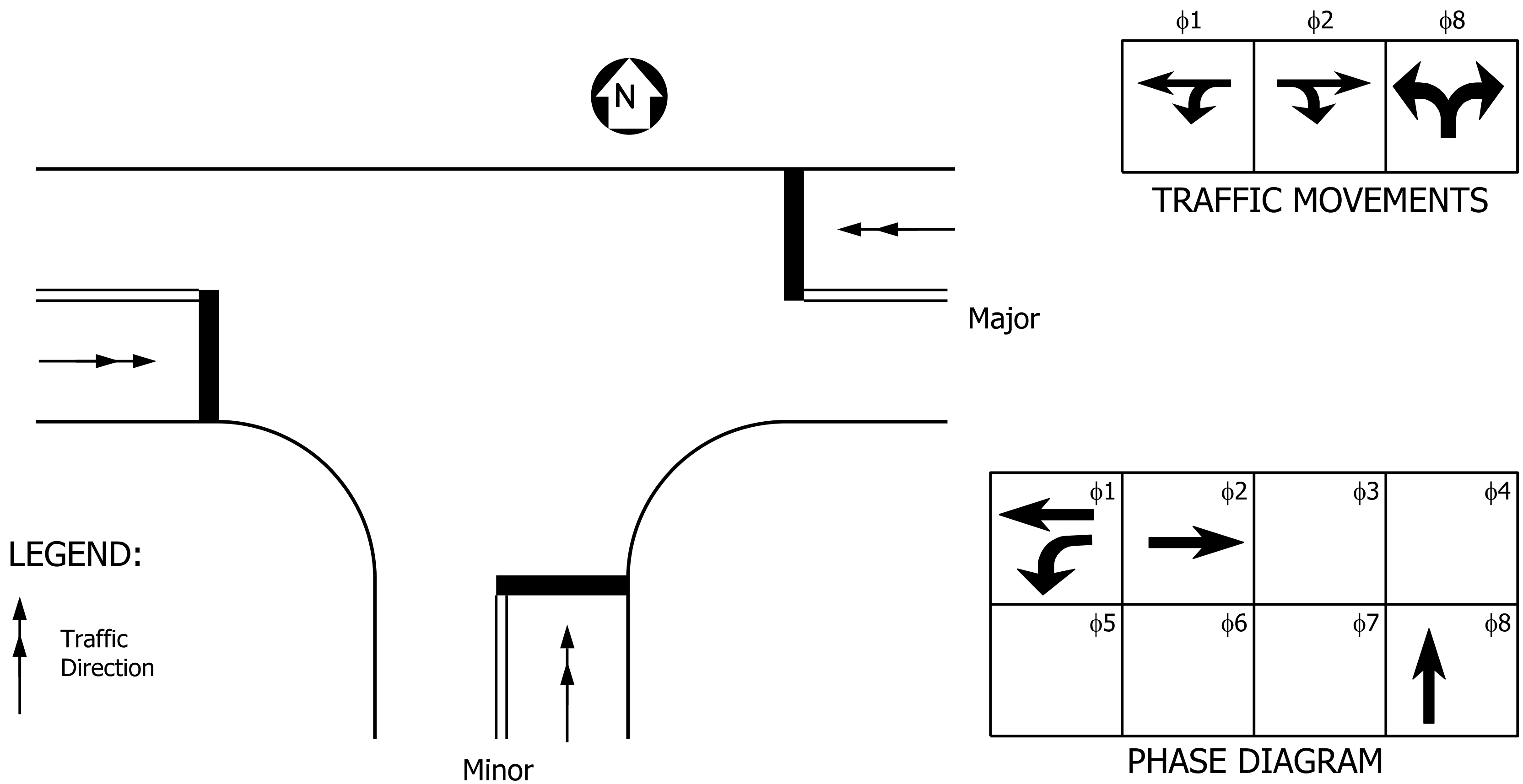
Approaching Lanes with Right-Turn Overlaps

Figure 502-3 O



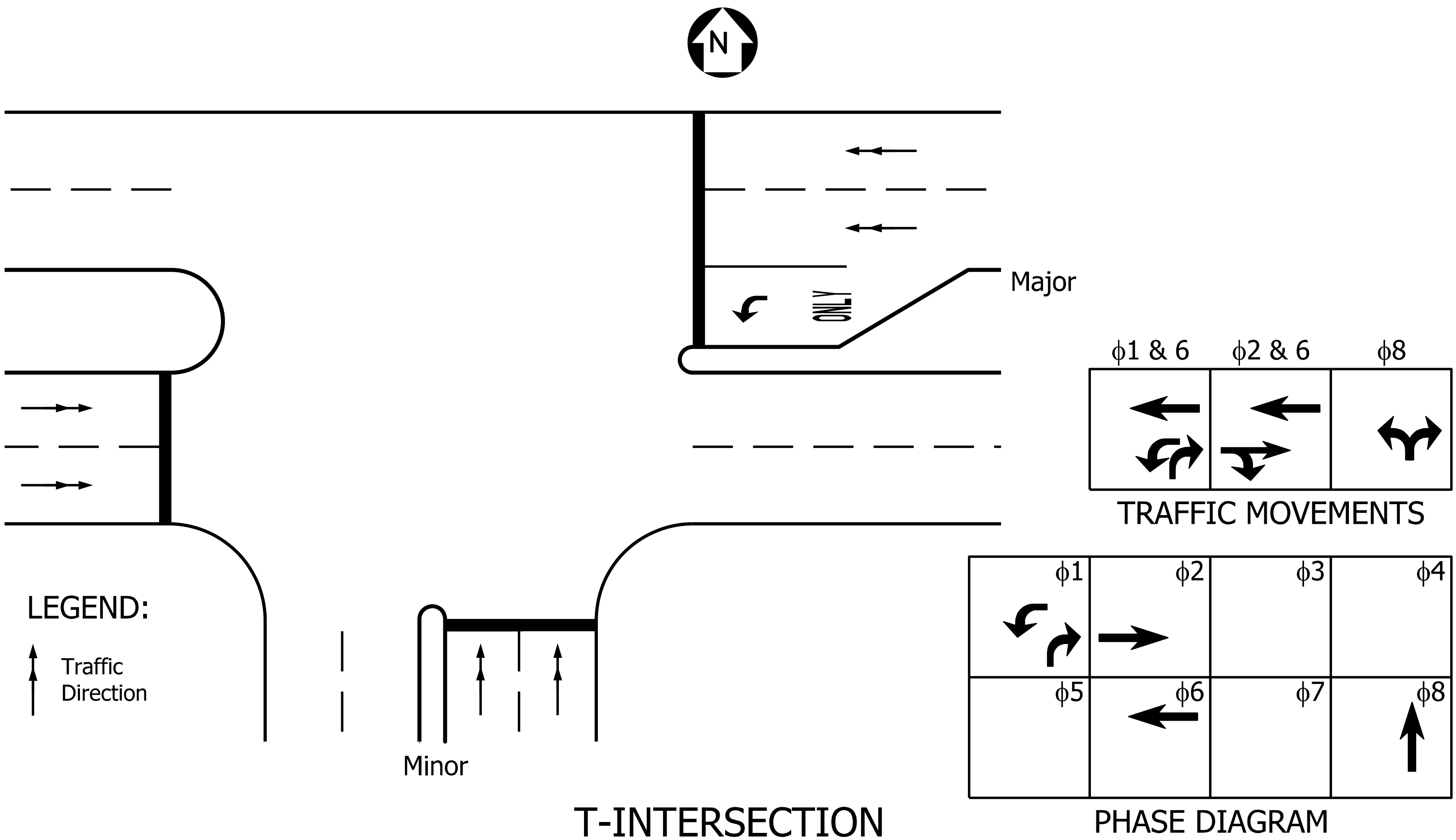

SEQUENCE OF PHASES,
EIGHT-PHASE DUAL-RING CONTROLLER

Figure 502-3P



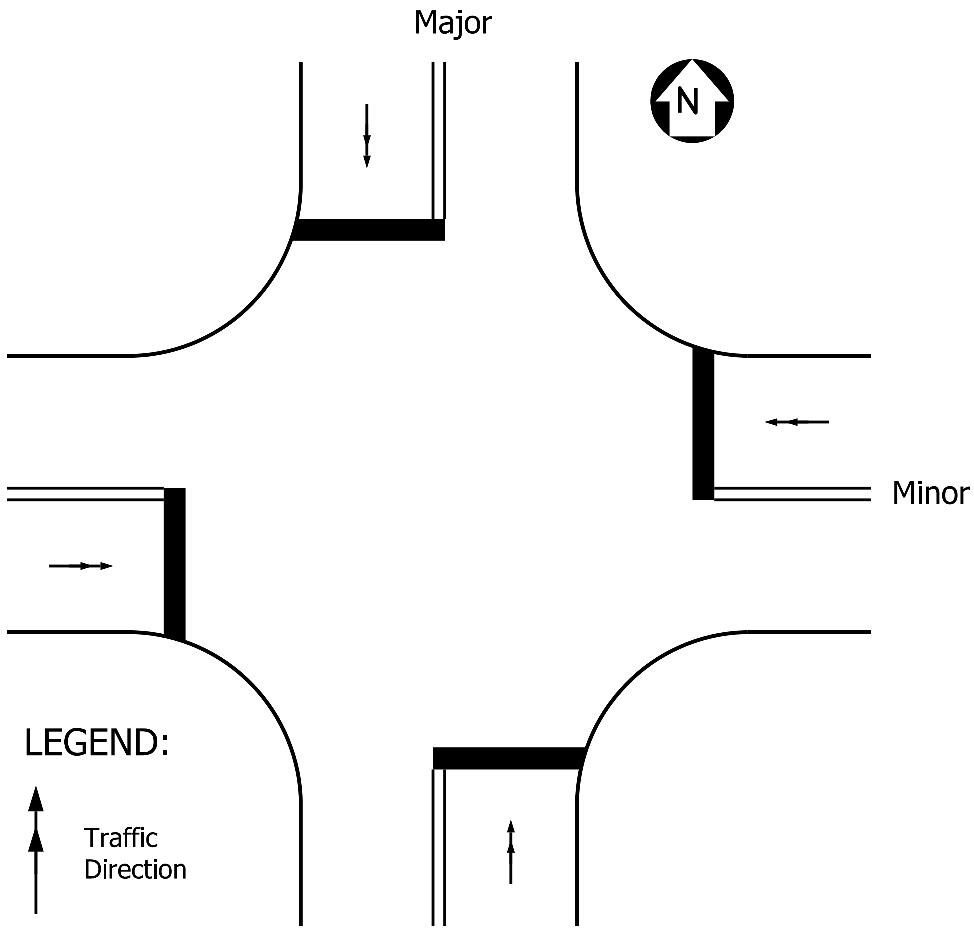

T-INTERSECTION
THREE-PHASE OPERATION

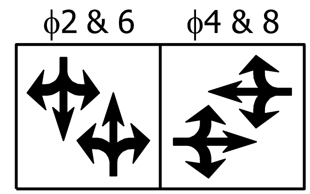
Figure 502-3Q



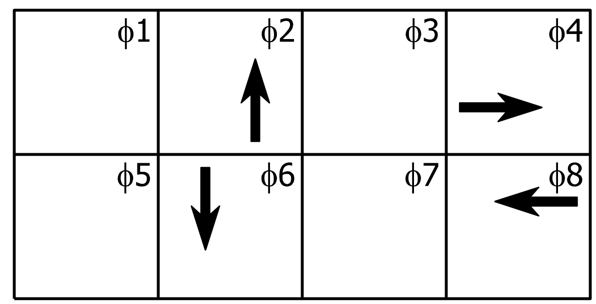

T-INTERSECTION
FOUR-PHASE OPERATION
MULTI-LANES APPROACHES

Figure 502-3R



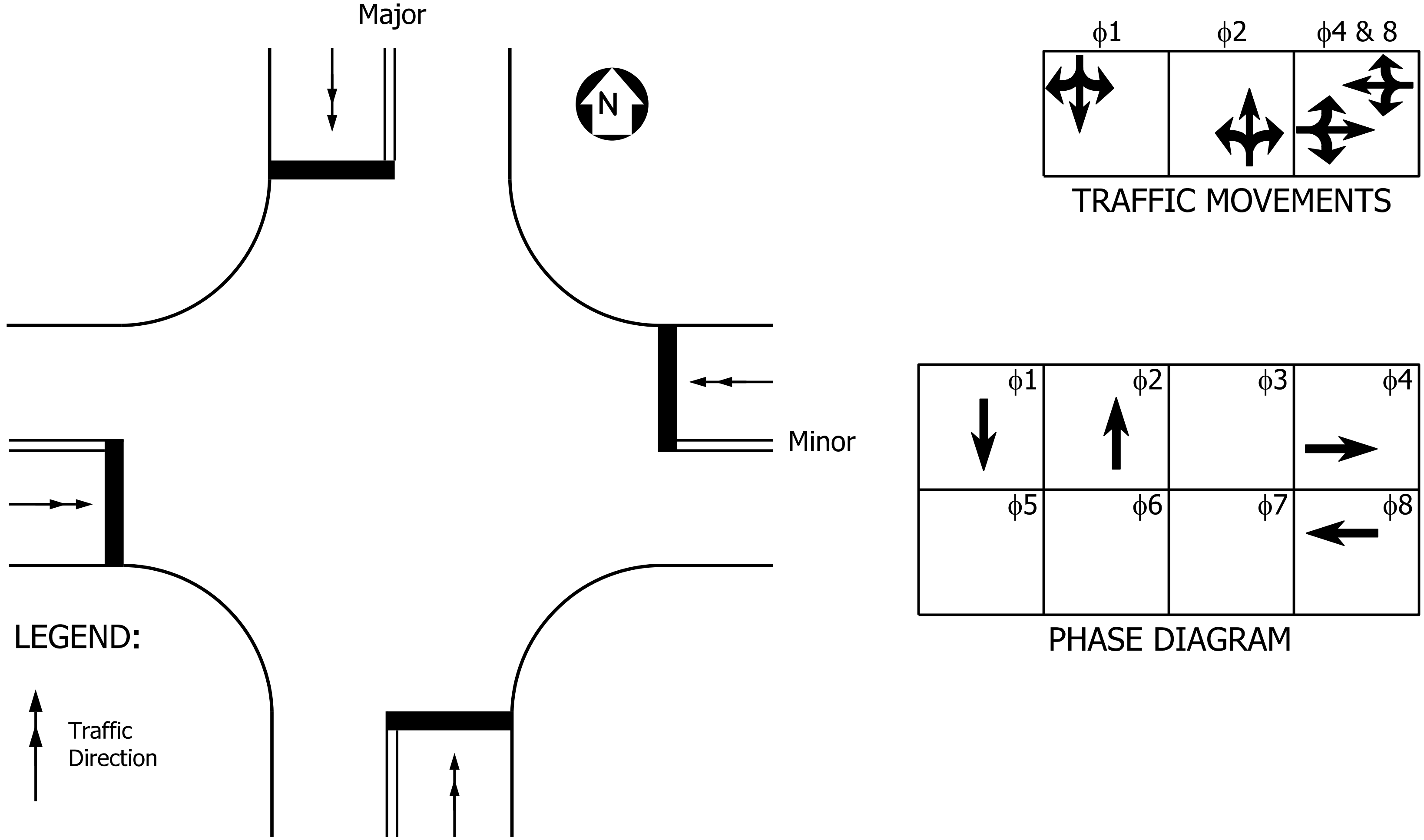

TRAFFIC MOVEMENTS




PHASE DIAGRAM

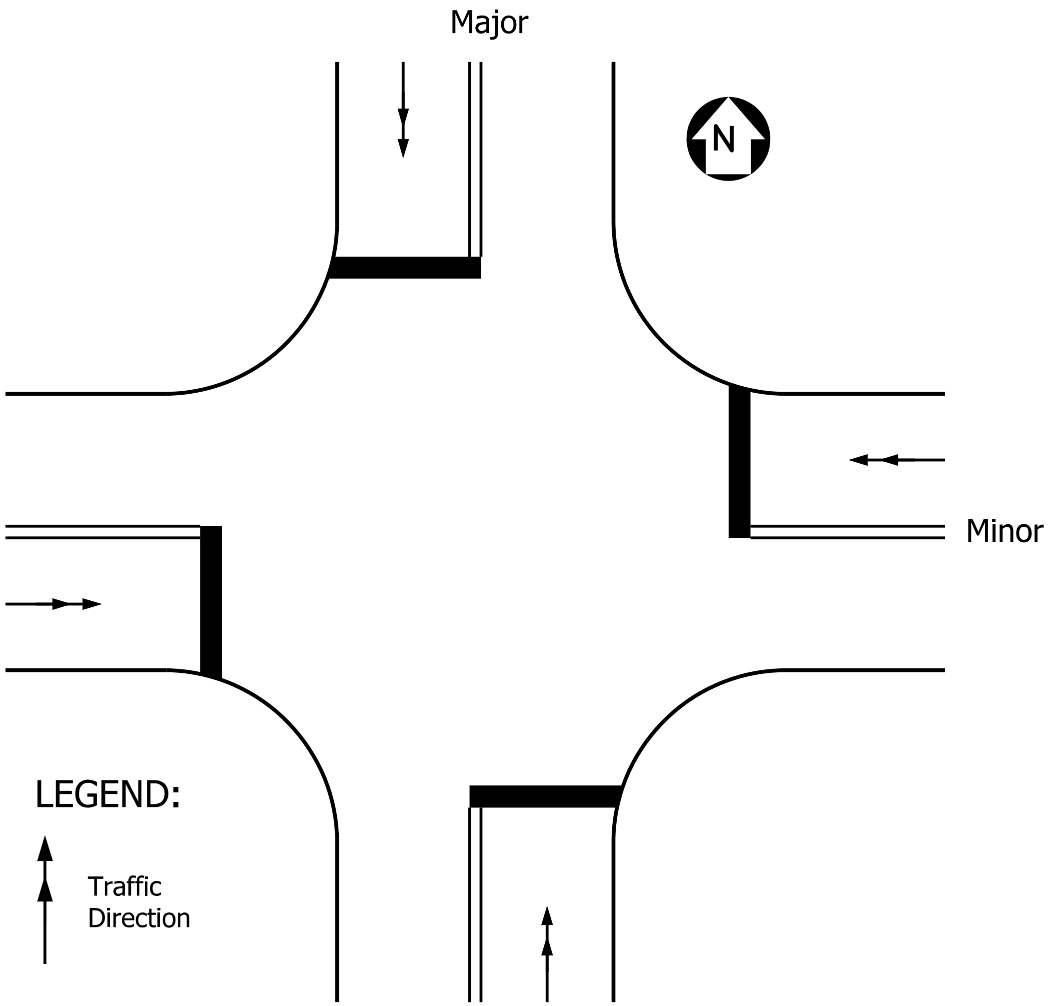
TYPICAL INTERSECTION
FOUR-PHASE OPERATION

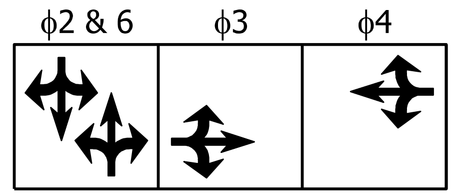
Figure 502-3S



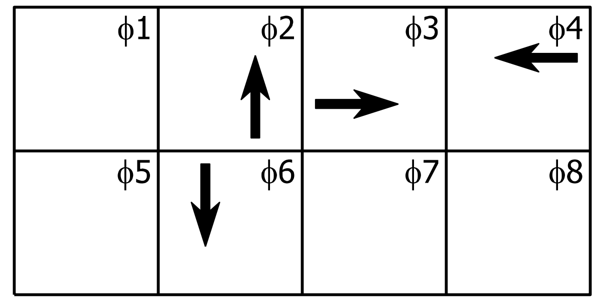

FOUR-PHASE OPERATION
SEPARATE SPLIT PHASES FOR MAJOR STREET

Figure 502-3T



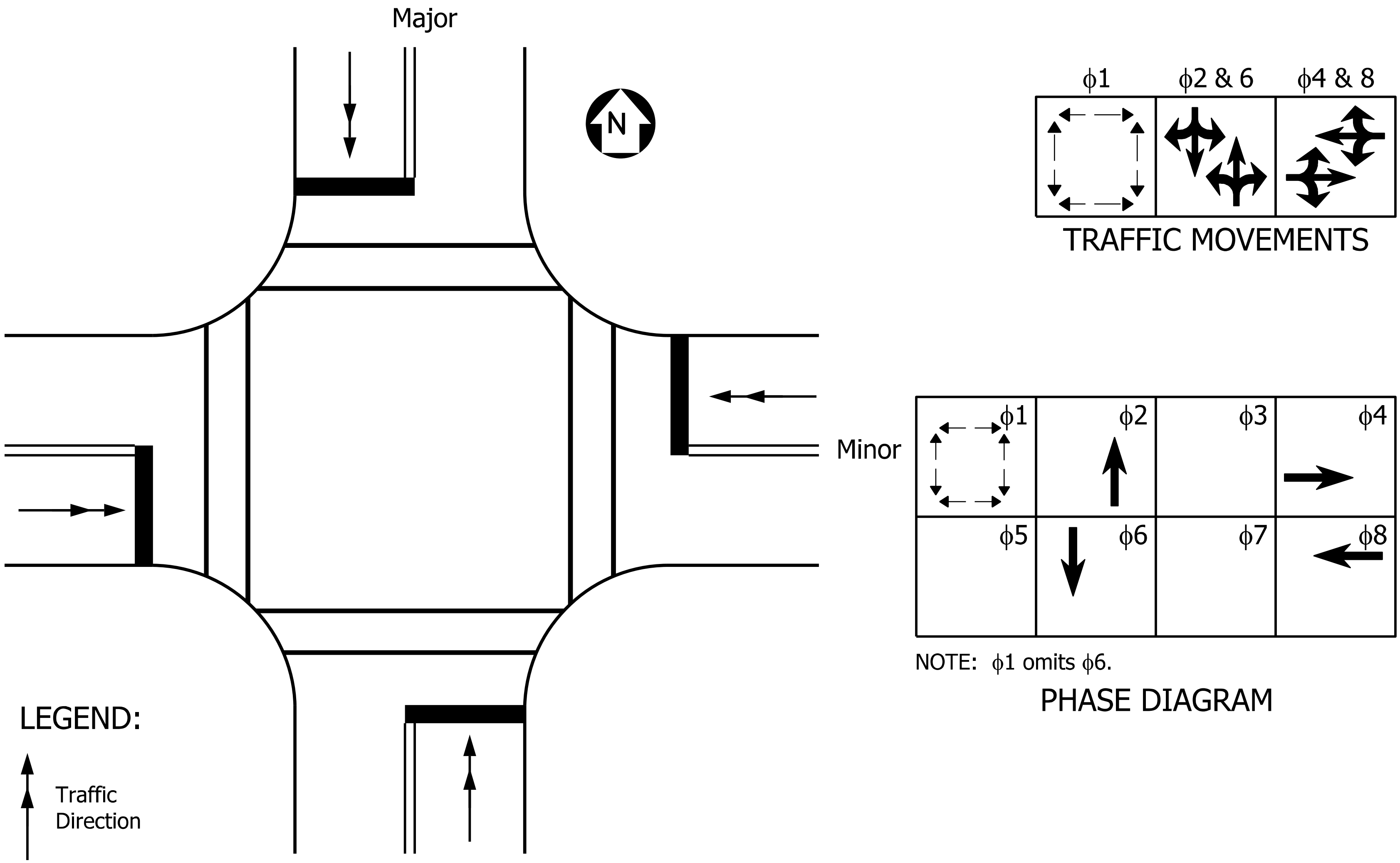

TRAFFIC MOVEMENTS




PHASE DIAGRAM

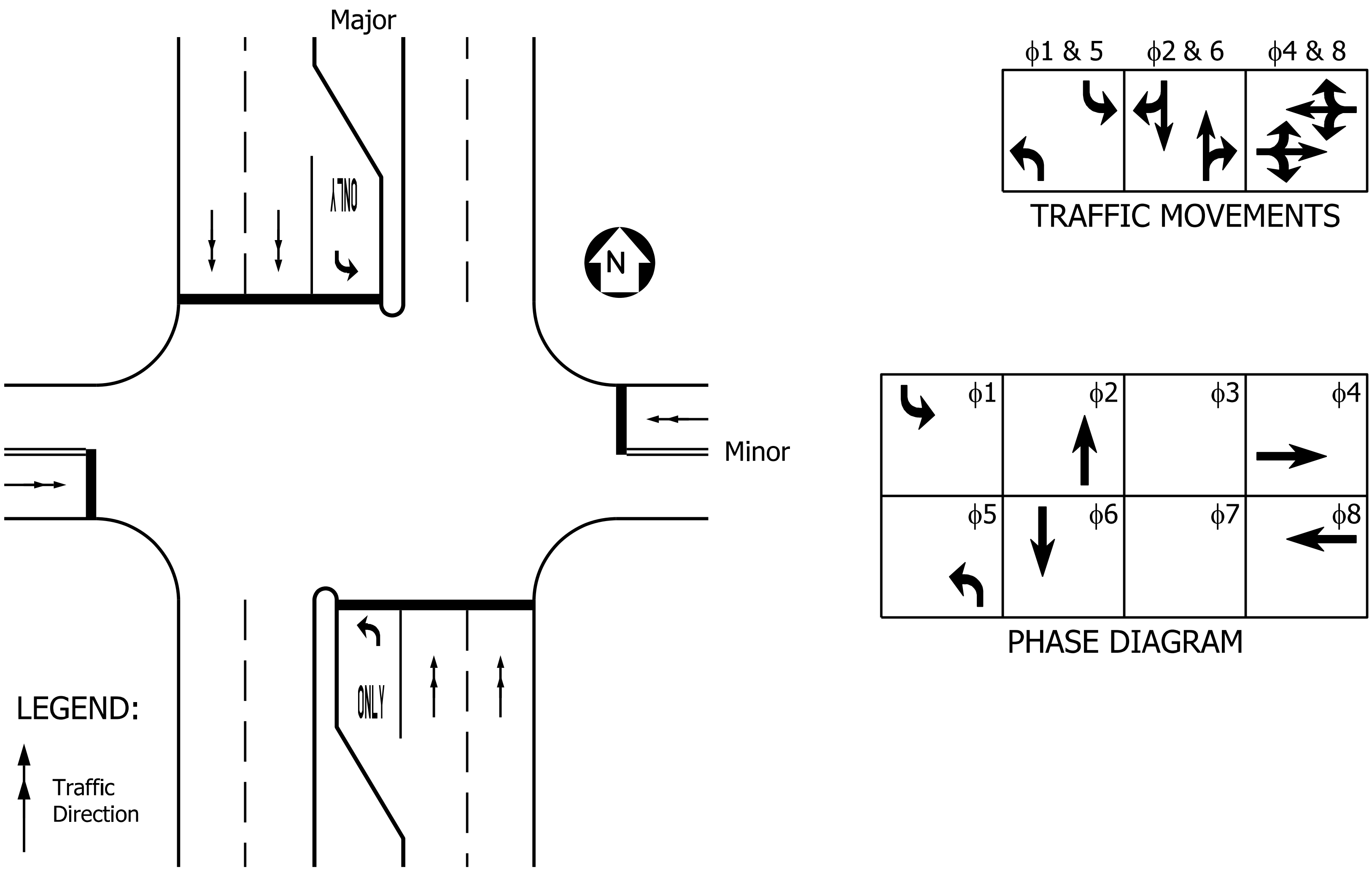
FOUR-PHASE OPERATION
SEPARATE SPLIT PHASE FOR MINOR STREET

Figure 502-3U



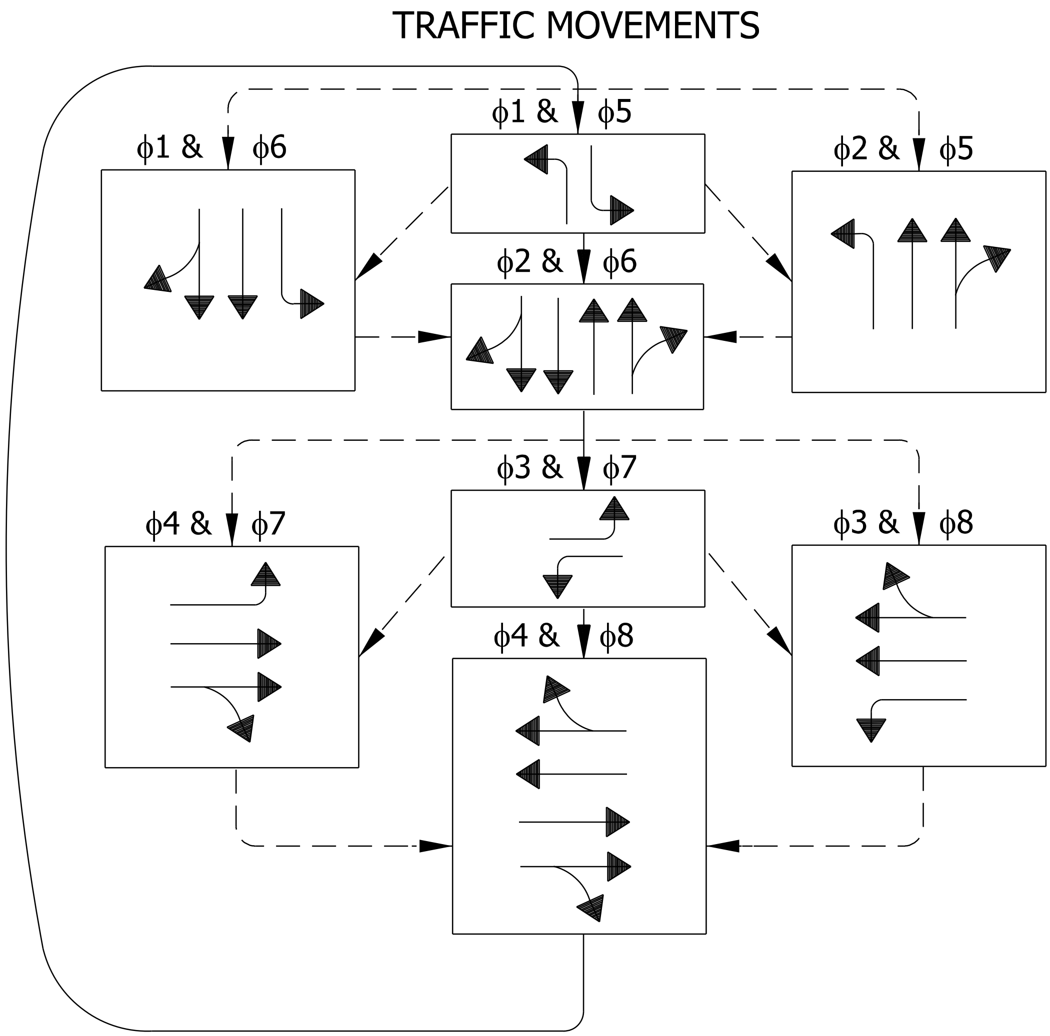

FIVE-PHASE OPERATION
EXCLUSIVE PEDESTRIAN PHASE

Figure 502-3V



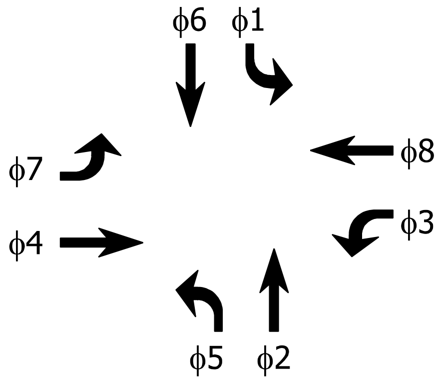

SIX-PHASE OPERATION
SEPARATE LEFT-TURN PHASE FOR MAJOR STREET

Figure 502-3W

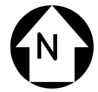


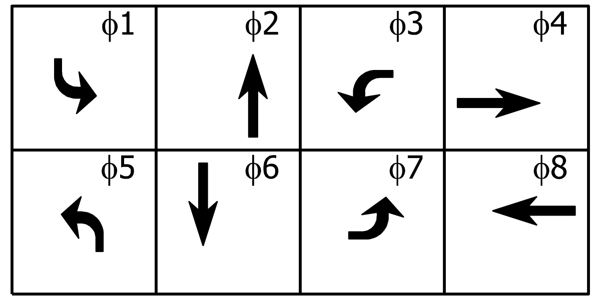

EIGHT-PHASE OPERATION
DUAL RING

Figure 502-3X

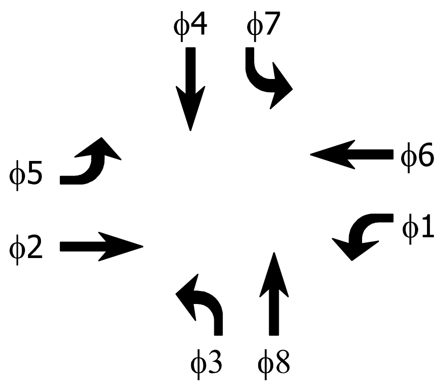



VEHICLE MOVEMENTS
North / South Major

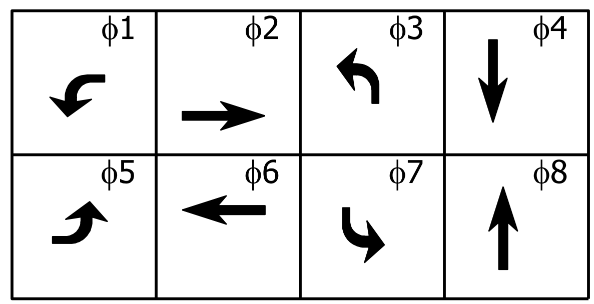



PHASE DIAGRAM
North / South Major




VEHICLE MOVEMENTS
East / West Major




PHASE DIAGRAM
East / West Major

TYPICAL VEHICLE MOVEMENT AND PHASE NUMBERING

Figure 502-3Y

| LEADING-LEFT TURN PHASE | |
|---|---|
| ADVANTAGES | DISADVANTAGES |
| Increases intersection capacity of 1- or 2-lane approach without left-turn lane if compared to 2-phase traffic signal operation.<br><br>Minimizes conflict between left-turn and opposing straight-through vehicles clearing the left-turn vehicles through the intersection first.<br><br>Drivers tend to react quicker than with lagging-left operations. | Left-turning vehicles completing their movement may delay the beginning of the opposing through movement when the green is exhibited to the stopped opposing movement.<br><br>Opposing movements can make a false start in response to the movement of the vehicles with the leading green.<br><br>Where there is no left-turn lane, an obstruction to the left-turn movement is created if a through vehicle is present. |
| LAGGING-LEFT TURN PHASE | |
| ADVANTAGES | DISADVANTAGES |
| Both directions of through traffic start at the same time.<br><br>Approximates the normal driving behavior of vehicle operators.<br><br>Provides for vehicle/pedestrian separation as pedestrians usually cross at the beginning of straight-through green.<br><br>Where pedestrian signals are used, pedestrian signals have cleared the intersection before the beginning of the lag-green interval.<br><br>Cuts off only the platoon stragglers from adjacent interconnected intersections. | Left-turning vehicles can be trapped during the left-turn yellow change interval where used with 5-section heads, as opposing through traffic is not stopping as expected.<br><br>Creates conflicts for opposing left turns at start of lag interval because opposing left-turn drivers expect both movements to stop at the same time.<br><br>Where there is no left-turn lane, an obstruction to the through movement during the initial green interval is created. |

NOTE: The disadvantages inherent in lagging-left operations are such that they are used only for a coordinated signal system, pre-timed operation, or specific situations in actuated control, such as a T intersection.

**COMPARISON OF LEFT-TURN PHASE ALTERNATIVES**

**Figure 502-3Z**

| Approach Posted Speed (mph) | Passage Time in Seconds from Detector to Stop Bar | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5[1] | 6 | 7 |
| 20 | 29 | 53 | 87 | 116 | **145** | **174** | **193** |
| 25 | 36 | 78 | 108 | 144 | **180** | **216** | **252** |
| 30 | 44 | 88 | 132 | 176 | **220** | **264** | **308** |
| 35 | 51 | 102 | 153 | 204 | **255** | **306** | **357** |
| 40 | 59 | 118 | 177 | 236 | **295** | **354** | **413** |
| 45 | 66 | 132 | 198 | 264 | **330** | **396** | **462** |
| 50 | 73 | 146 | 219 | 292 | **365** | **438** | **511** |
| 55 | 81 | 162 | 243 | 324 | **405** | **486** | **567** |
| 60 | 88 | 176 | 264 | 352 | **440** | **528** | **616** |
| 65 | 95 | 190 | 285 | 380 | **475** | **570** | **665** |

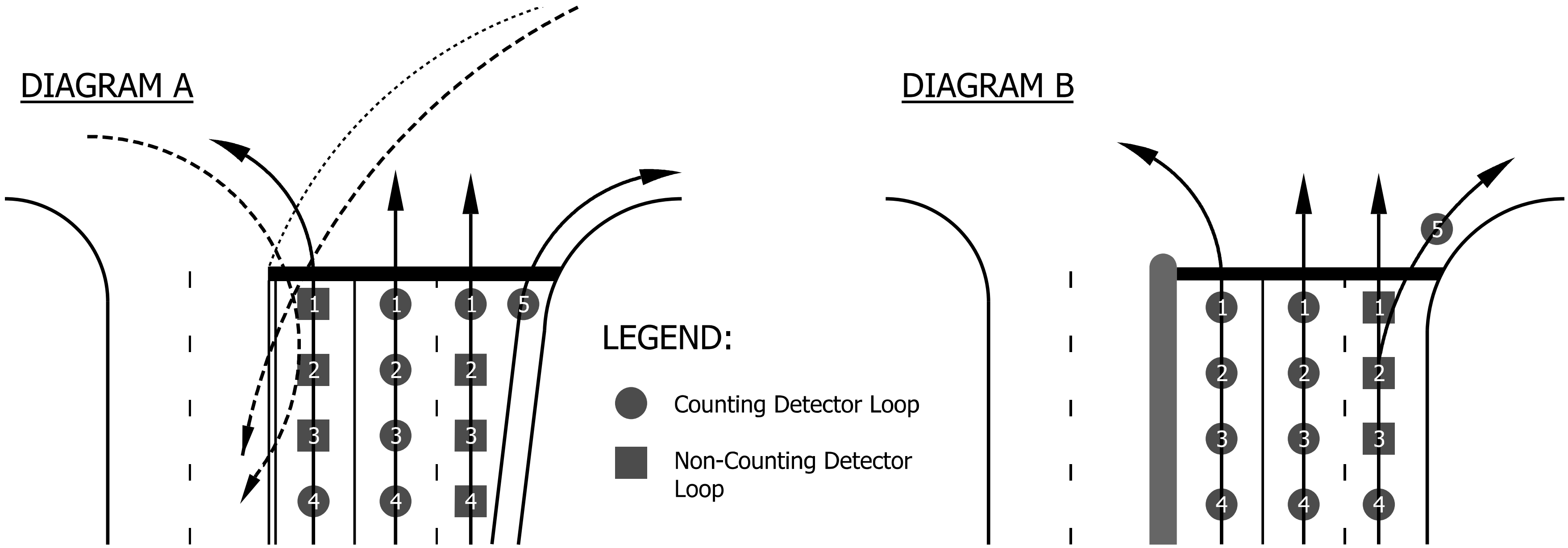
Legend:

| | | | |
|---|---|---|---|
| $\boxed{0}$ | Basic Controllers | 0 | Variable Initial Only |
| **0** | Density | 0 (shaded) | Indecision Zone |

[1] INDOT typically uses Passage Time of 5 sec.

**DETECTION SETBACK DISTANCE**

**Figure 502-3AA**




LEFT-TURN LANES

1. Dotted lines or staggered stop line, as shown in Diagram A, can be used to reduce left-turn encroachment onto the left-turn lanes. Counting with Loop 4 is recommended.

2. A raised median as shown in Diagram B will eliminate such encroachment onto the left-turn lanes. Counting with all loops in the lane is recommended.

THROUGH LANES

The through lanes should not have encroachment or early-departure concerns. If a vehicle squarely enters the loop system and crosses the center of each loop, counting with 4 loops is preferred.

RIGHT-TURN LANES

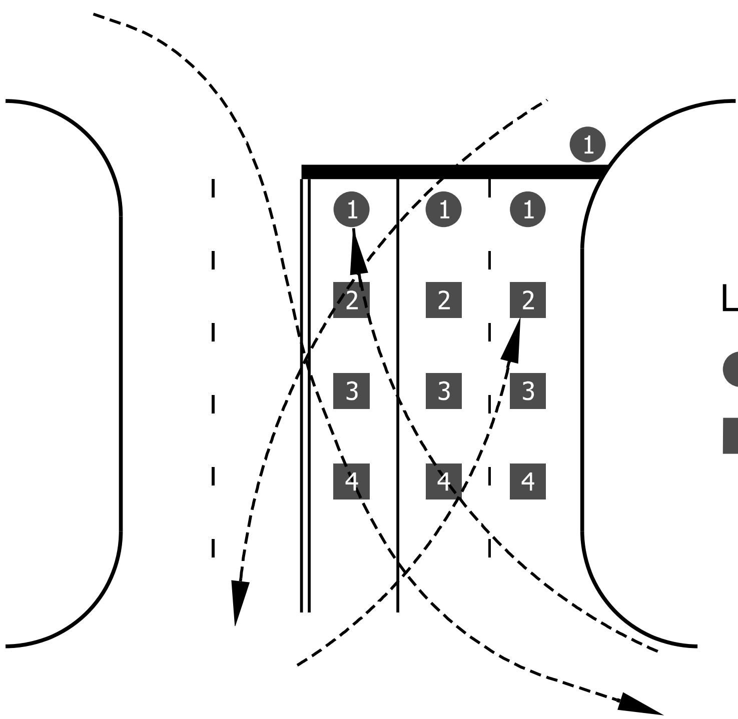
1. If the lane at stop line is wider than 12 ft as shown in Diagram A, a vehicle will depart before crossing Loop 1. Counting with Loops 1 and 5 will provide accurate through-lanes and right-turn-lane counts.

2. If Loop 5 is beyond the stop line, counting with Loops 4 and 5 will provide accurate through-plus-right and right-turn-lane counts.

3. The minimum distance between Loops 1 and 5 should be 6 ft, with 3 ft between the edge of the lane and the edge of loop.

# COUNTING LOOP SELECTION

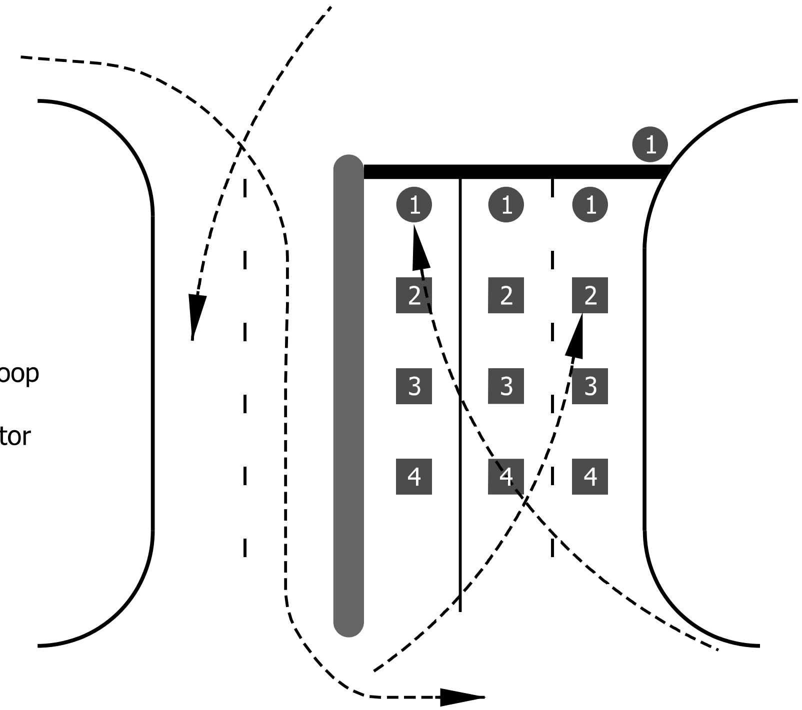
Figure 502-3BB



LEGEND:

Counting Detector Loop

Non-Counting Detector Loop



METHOD A

A vehicle entering the detection zone will often cross loops in one lane to get in desired lane. A vehicle turning off the main road will often cross these loops, causing them to overcount. This makes counting difficult.

Access should be provided for the design vehicle.

METHOD B

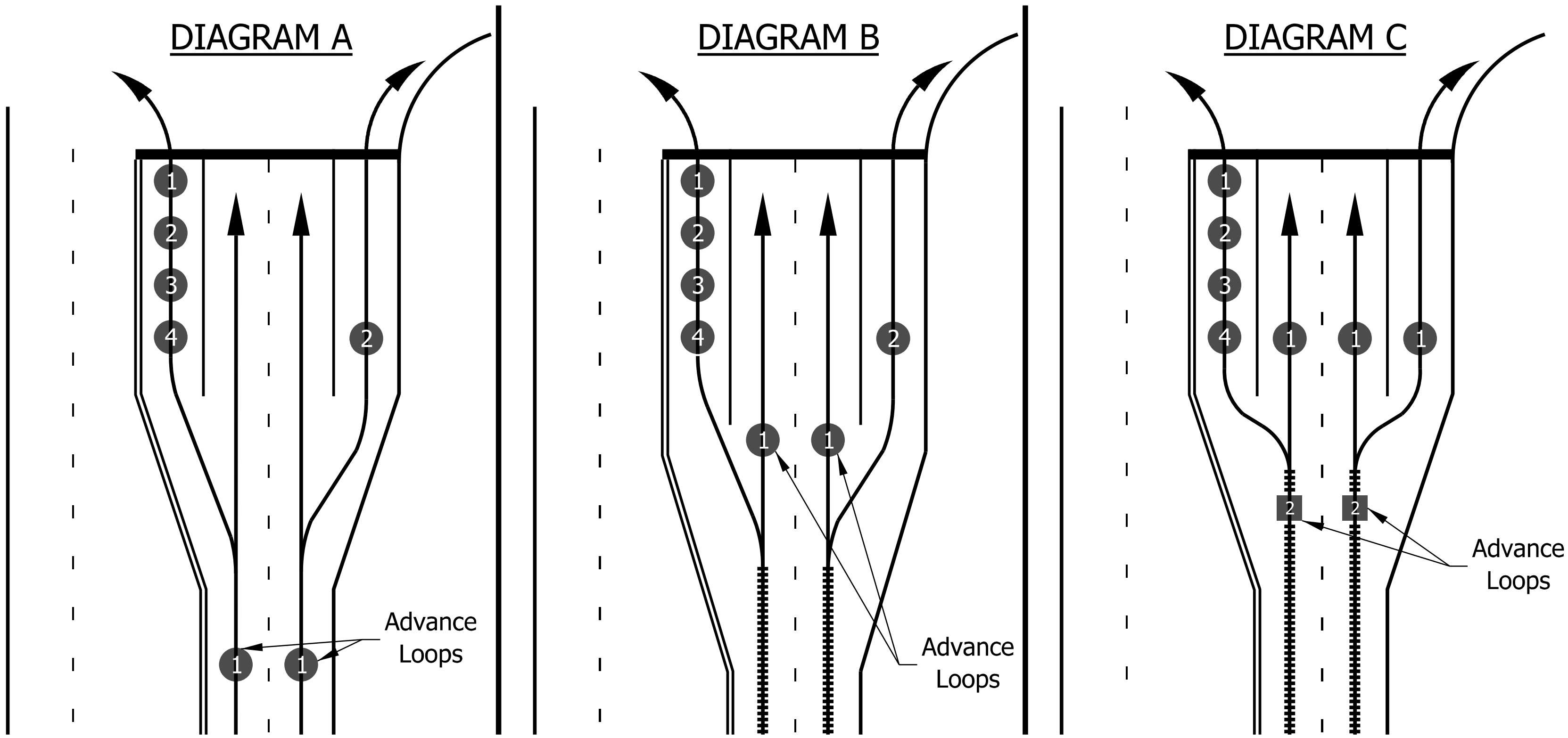
A raised median will channel a vehicle turning off the main road, and will keep it out of the lanes being counted.

A median will eliminate turn encroachment.

Once a vehicle is channeled away from the counting loops into its intended lane, loop 1 can be used to provide accurate counts.

# COUNTING LOOP SELECTION
# FRONTAGE ROADS AND PARKING LOTS

Figure 502-3CC




Counting loop selection is based on the length of the storage lanes and on the placement of the advance loops based on the posted speed limit. Counting can be done with the advance loops if they are located ahead of the storage lanes as shown in Diagram A. or after the beginning of the storage lanes as shown in Diagram B. If the location of the advance loops is where a vehicle is maneuvering to the left or right of the storage lane as shown in Diagram C, the counting loops should be installed close to the left-turn loops to minimize the cost of the installation.

LEGEND:

- ● Counting Detector Loop
- ■ Non-Counting Detector Loop
- Maneuvering Area

# COUNTING LOOP SELECTION
# ADVANCED LOOPS

Figure 502-3DD

| Foundation Type | Soil Properties | Support | Arm Length, $L$ (ft) |
|---|---|---|---|
| A | Cohesive, $S_u$, or $C_u$ = 750 lb/ft; or Sand, Friction Angle = 30 deg Bearing Capacity = 1200 psf, and Coefficient of Friction = 0.3 | Drilled Shaft | $\leq 35$ |
| B | | Drilled Shaft | $35 < L \leq 60$ |
| C | Cohesive, $S_u$, or $C_u$ = 750 lb/ft; or Sand, Friction Angle = 30 deg Bearing Capacity = 1200 psf, and Coefficient of Friction = 0.3 | Spread Footing | $\leq 35$ |
| D | | Spread Footing | $35 < L \leq 60$ |

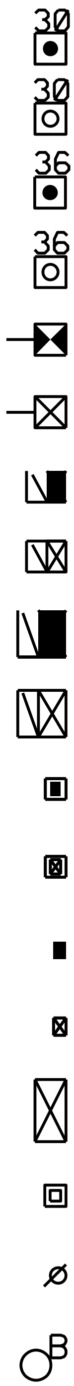
SIGNAL CANTILEVER STRUCTURE
FOUNDATION TYPE DETERMINATION

Figure 502-3EE

| Device | Area, $ft^2$ | Weight, lb |
|---|---|---|
| Signal Head with Backplate, 3 Sec., Lens Dia. 12 in. | 8.7 | 35 |
| Signal Head with Backplate, 5 Sec., Lens Dia. 12 in. | 13.1 | 55 |
| Regulatory Sign, 36 in. x 30 in. | 7.5 | 19 |
| Street-Name Sign, 18 in. x 96 in. | 12 | 30 |
| Street-Name Sign, 18 in. x 132 in. | 16.5 | 41 |
| Mounted Camera | 1 | 20 |
| Top-Pole Luminaire | 2.4 | 53 |

**AREA AND WEIGHT OF DEVICE**
**TO BE MOUNTED ON SIGNAL CANTILEVER**

**Figure 502-3FF**




30' Steel Strain Pole & Foundation

Ex. 30' Steel Strain Pole & Foundation

36' Steel Strain Pole & Foundation

Ex. 36' Steel Strain Pole & Foundation

Signal Cantilever Structure & Foundation

Ex. Signal Cantilever Structure & Foundation

TS2 Controller and "M" or "M Stretch" Cabinet on "M" Foundation

Ex. Controller and "M" Cabinet on "M" Foundation

TS2 Controller and "P-1" or "R" Cabinet on "P-1" Foundation

Ex. Controller and "P-1" Cabinet on "P-1" Foundation

Controller and "G" Cabinet on "A" Foundation

Ex. Controller and "G" Cabinet on "A" Foundation

NEMA 2-Circuit Flasher and Cabinet

Ex. Flasher Controller and Cabinet

Ex. Railroad Signal Controller Cabinet

Ex. Utility Cabinet

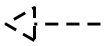
Ex. Utility Pole

Bridle

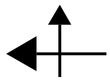
SIGNAL PLAN LEGEND

Figure 502-3GG
(Page 1 of 5)

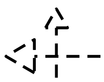
Traffic Signal Head, 3 Face, 12 ":
Red, Amber, Green



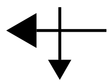
Ex. Traffic Signal Head, 3 Face, 12":
Red, Amber, Green



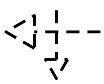
Traffic Signal Head, 3 Face, 12":
Red, Lt. Amber Arrow, Lt. Green Arrow



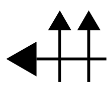
Ex. Traffic Signal Head, 3 Face, 12":
Red, Lt. Amber Arrow, Lt. Green Arrow



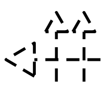
Traffic Signal Head, 3 Face, 12":
Red, Rt. Amber Arrow, Rt. Green Arrow



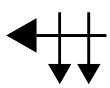
Ex. Traffic Signal Head, 3 Face, 12":
Red, Rt. Amber Arrow, Rt. Green Arrow



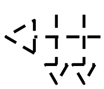
Traffic Signal Head, 5 Face, 12":
Red, Amber, Green, Lt. Amber Arrow, Lt. Green Arrow



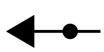
Ex. Traffic Signal Head, 5 Face, 12":
Red, Amber, Green, Lt. Amber Arrow, Lt. Green Arrow



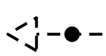
Traffic Signal Head, 5 Face, 12":
Red, Amber, Green, Rt. Amber Arrow, Rt. Green Arrow



Ex. Traffic Signal Head, 5 Face, 12":
Red, Amber, Green, Rt. Amber Arrow, Rt. Green Arrow



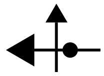
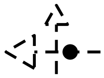
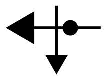
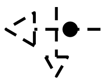
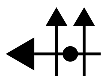
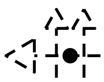
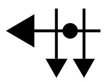
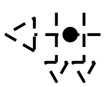
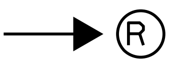
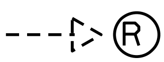
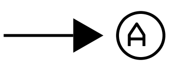
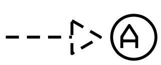
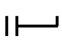
Traffic Signal Head, Optically Programmed, 3 Face, 12":
Red, Amber, Green



Ex. Traffic Signal Head, Optically Programmed, 3 Face, 12":
Red, Amber, Green

## SIGNAL PLAN LEGEND

Figure 502-3GG
(Page 2 of 5)

| | |
|---|---|
|  | Traffic Signal Head, Optically Programmed, 3 Face, 12": Red, Lt. Amber Arrow, Lt. Green Arrow |
|  | Ex. Traffic Signal Head, Optically Programmed, 3 Face, 12": Red, Lt. Amber Arrow, Lt. Green Arrow |
|  | Traffic Signal Head, Optically Programmed, 3 Face, 12": Red, Rt. Amber Arrow, Rt. Green Arrow |
|  | Ex. Traffic Signal Head, Optically Programmed, 3 Face, 12": Red, Rt. Amber Arrow, Lt. Green Arrow |
|  | Traffic Signal Head, Optically Programmed, 5 Face, 12": Red, Amber, Green, Lt. Amber Arrow, Lt. Green Arrow |
|  | Ex. Traffic Signal Head, Optically Programmed, 5 Face, 12": Red, Amber, Green, Lt. Amber Arrow, Lt. Green Arrow |
|  | Traffic Signal Head, Optically Programmed, 5 Face, 12": Red, Amber, Green, Rt. Amber Arrow, Rt. Green Arrow |
|  | Ex. Traffic Signal Head, Optically Programmed, 5 Face, 12": Red, Amber, Green, Rt. Amber Arrow, Rt. Green Arrow |
|  | Traffic Signal Head, 1 Face 12" Red |
|  | Ex. Traffic Signal Head, 1 Face 12" Red |
|  | Traffic Signal Head, 1 Face 12" Amber |
|  | Ex. Traffic Signal Head, 1 Face 12" Amber |
|  | Countdown Pedestrian Signal Head, International Symbols, 18" |
|  | Ex. Pedestrian Signal Head |

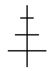
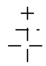
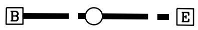
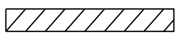
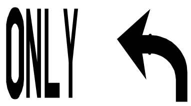
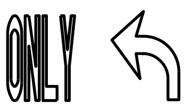
SIGNAL PLAN LEGEND

Figure 502-3GG
(Page 3 of 5)

| | |
|---|---|
| P | Accessible Pedestrian Push Button & Sign |
| EX. P | Ex. Pedestrian Push Button & Sign |
| | Signal Pedestal on "A" Foundation |
| | Ex. Signal Pedestal on "A" Foundation |
| | Disconnect Hanger |
| | Ex. Disconnect Hanger |
| | Signal Handhole |
| | Ex. Signal Handhole |
| | 2" Conduit |
| | Ex. 2" Conduit |
| | Octagonal Loop, 4-Turn Series |
| | Ex. Octagonal Loop, 4-Turn Series |
| | Circular Loop, 4 Turn-Series |
| | Circular Loop, 4-Turn Series |
| P | Preformed Loop |
| P | Ex. Preformed Loop |
| ML1 ML2 | Microloop |
| ML1 ML2 | Ex. Microloop |
| | Signal Detector Housing |
| | Ex. Signal Detector Housing |

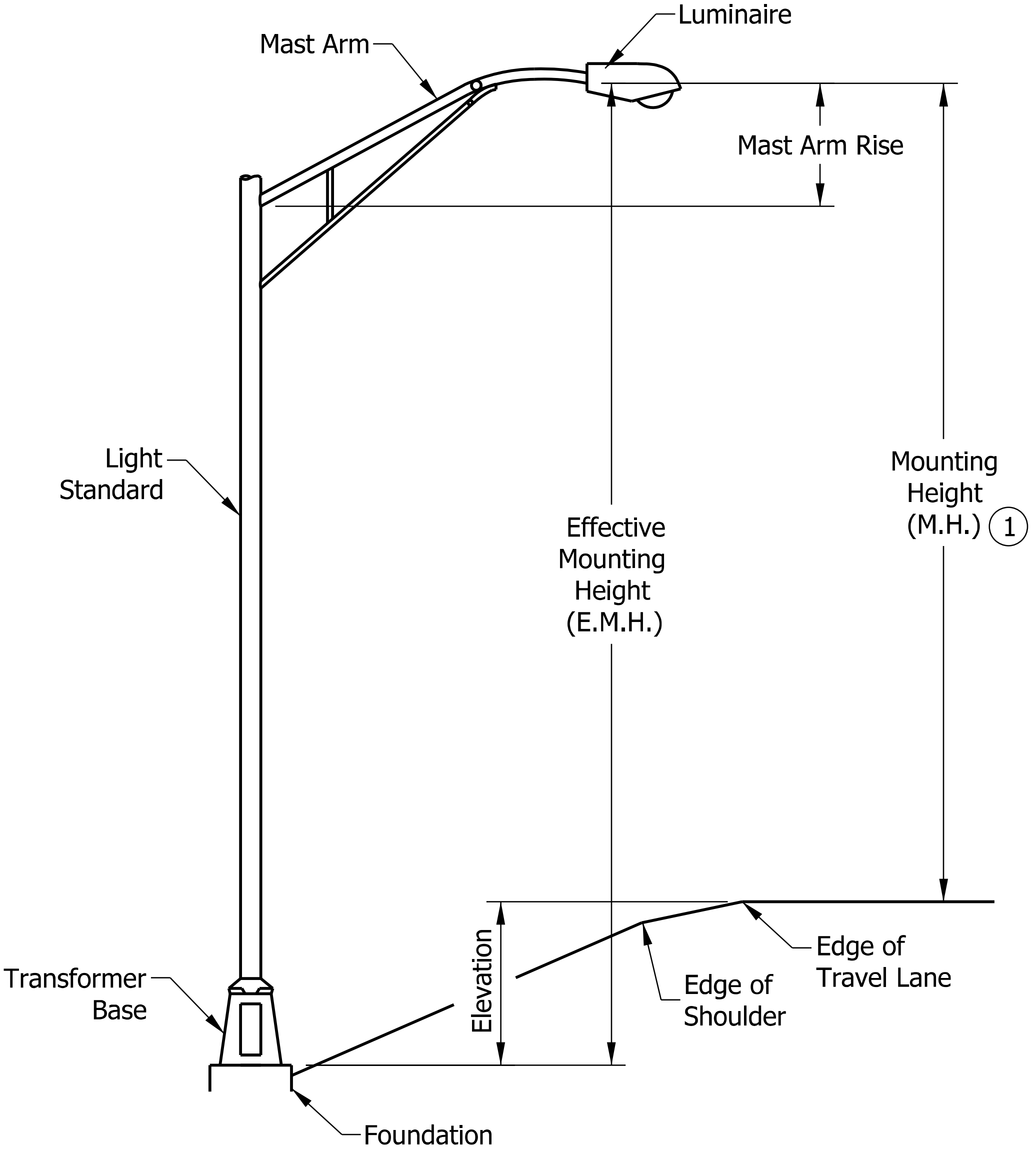
# SIGNAL PLAN LEGEND

Figure 502-3GG
(Page 4 of 5)

| | |
|---|---|
|  | Radio Antennae |
|  | Ex. Radio Antennae |
|  | Existing R/W |
|  | 24" Stop Line |
|  | Ex. 24" Stop Line |
|  | Pavement Message Markings |
|  | Ex. Pavement Message Markings |

SIGNAL PLAN LEGEND

Figure 502-3GG
(Page 5 of 5)




1 INDOT typically uses mounting heights of 40 ft.

TYPICAL LIGHT-POLE INSTALLATION

Figure 502-4A

| Mast-Arm Length (ft) | Maximum Rise (ft) |
| --- | --- |
| 9 or Less | 4 |
| 10 to 14 | 5 |
| 15 to 19 | 5.5 |
| 20 to 25 | 6 |
| 26 to 30 | 8 |

MAST-ARM RISE

Figure 502-4B

| Lamp Wattage (1) | Approx. Ballast Wattage (2) | Total Wattage | Initial Lumens | Mean Lumens | Average Life (h) |
|---|---|---|---|---|---|
| HIGH-PRESSURE SODIUM | | | | | |
| 50 | 19 | 69 | 4000 | 3600 | 24000 |
| 70 | 28 | 98 | 6400 | 5450 | 24000 |
| 100 (4) | 23 | 123 | 9500 | 8550 | 24000 |
| 150 | 25 | 175 | 16000 | 14400 | 24000 |
| 200 | | | 22000 | 19800 | 24000 |
| 250 (5) | 42 | 292 | 28000 | 25200 | 24000 |
| 310 | | | 37000 | 33300 | 24000 |
| 400 (5) | 72 | 472 | 51000 | 45000 | 24000 |
| 1000 (6) | 102 | 1102 | 130000 | 117000 | 24000 |
| LOW-PRESSURE SODIUM | | | | | |
| 18 | 14 | 32 | 1800 | 1720 | 10000 |
| 35 | 25 | 60 | 4800 | 4570 | 18000 |
| 55 | 30 | 85 | 8000 | 7610 | 18000 |
| 90 | 35 | 125 | 13500 | 12850 | 18000 |
| 135 | 40 | 175 | 22500 | 21400 | 18000 |
| 180 | 50 | 230 | 33000 | 31400 | 18000 |
| METAL HALIDE | | | | | |
| 100 | 25 | 125 | 9000 | 6200 | 15000 |
| 175 | 30 | 205 | 11700 (7) | 7400 (7) | 6000 |
| 250 (3) | 45 | 295 | 19100 (7) | 20800 (7) | 6000 |
| 400 | 55 | 455 | 33100 (7) | 22100 (7) | 15000 |
| 750 | 59 | 809 | 82000 | 60000 | 16000 |
| 1000 | 52 | 1052 | 100280 | 79000 | 11000 |

## NOTES:

(1) The common wattages are shown. For others see the IES Lighting Handbook.
(2) Shown as the highest loss known for the commonly-used ballast types.
(3) Used for sign illumination.
(4) Used for a highway underpass.
(5) Used for conventional highway lighting.
(6) Used for high-mast lighting.
(7) Horizontal

# LAMP DATA

# Figure 502-4C

| | |
|---|---|
| Lamp Lumen Depreciation Factor, LLD | 0.90* |
| Luminaire Dirt Depreciation Factor, LDD | 0.87 |
| Percent of Voltage Drop Permitted | 10% |
| Pole Height | 40 ft |
| Lamp Size | 150 W, HPS (Underpass)<br>250 W or 400 W, HPS (Conventional)<br>1000 W, HPS (High-Mast) |

* For High Pressure Sodium Lamps only. For Solid State Light Sources the LLD should be as given by the manufacturer.

LIGHTING DESIGN PARAMETERS

Figure 502-4D

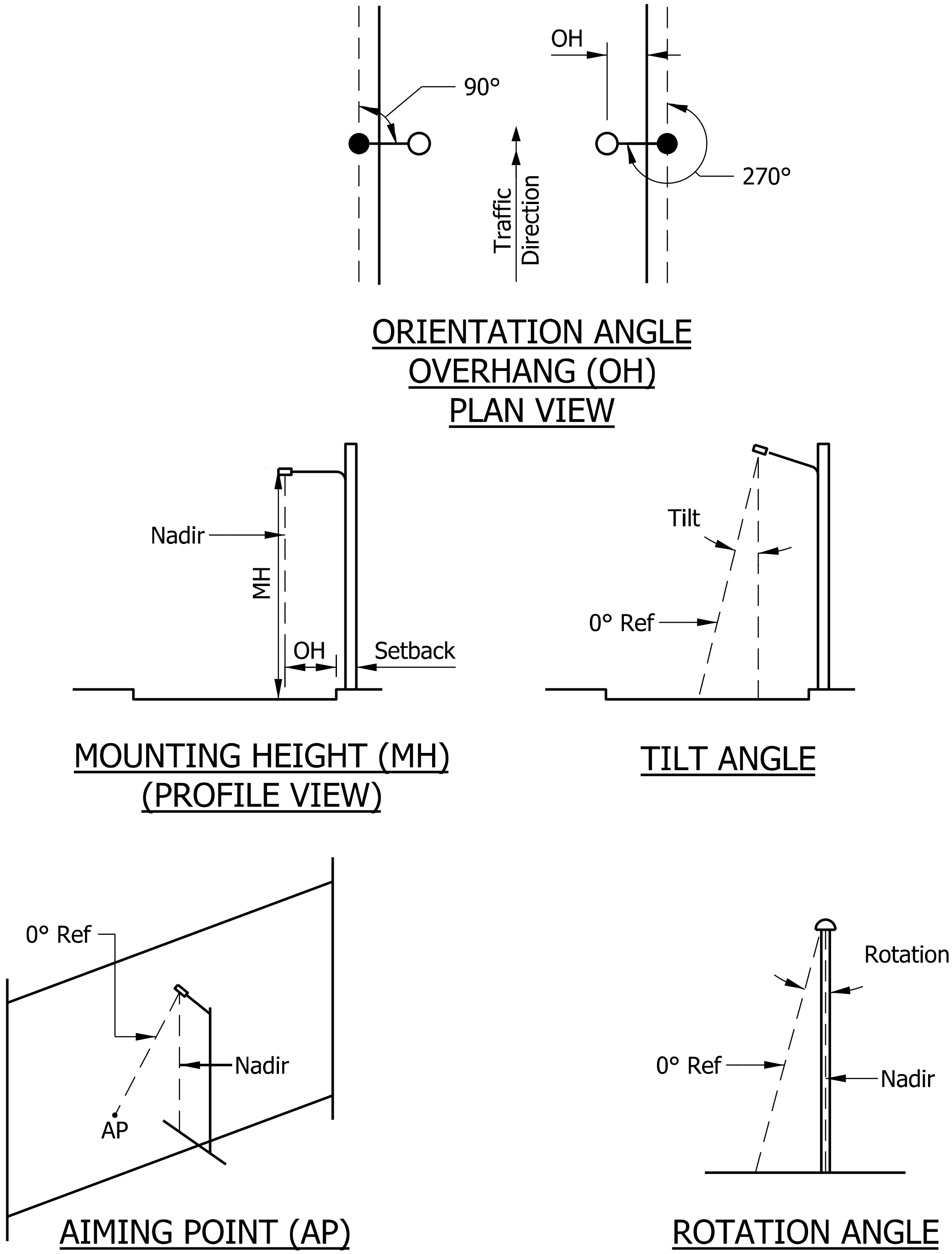
| Roadway Classification | Average Maintained Horizontal Illuminance, $E_h$ (ft-cd) | Uniformity Ratio |
|---|---|---|
| Interstate Route or Other Freeway | 0.8 | 4:1 |
| Expressway | 1.1 to 1.6 | 3:1 |
| Intersection or City Street | 0.8 | 4:1 |
| Weigh Station or Rest Area Ramp | 0.6 | 4:1 |
| Weigh Station or Rest Area Parking Area | 1.0 | 4:1 |

NOTES:

1. See Figure 51-7V for Bikeway or Trail.
2. Where pedestrian trail, bikeway, and shared pathway are adjacent to a roadway, the design criteria for the roadway shall govern.
3. See NCHRP 672 for roundabout lighting levels.

**ILLUMINANCE DESIGN CRITERIA**

**Figure 502-4E**




LUMINAIRE GEOMETRY

Figure 502-4F

| Spacing Classification | Definition | Spacing Distance |
|---|---|---|
| S | Short | 4 times MH or less |
| M | Medium | 5 times MH or less |
| L | Long | More than 5 times MH |
| **Width Classification** | **Pavement Mounting Location** | **Roadway Width Served** |
| Type I | Center | 2 times MH or less |
| Type II | Edge | MH or less for one-side mounting<br>2 times MH or less for both-sides mounting |
| Type III | Edge | 1.5 times MH or less for one-side mounting<br>3 times MH or less for both-sides mounting |
| Type IV | Edge | 2 times MH or less for one-side mounting<br>4 times MH or less for both-sides mounting |
| Type V | Center | 4 times MH or less |
| **Glare-Control Classification** | **Definition** | **Control Requirement** |
| C | Cutoff | Strict control of lighting above 80 deg vertical |
| S | Sim-Cutoff | Medium control of lighting above 80 deg vertical |
| N | Non-Cutoff | No control of lighting above 80 deg vertical |

NOTES:

1. MH = mounting height.
2. The complete luminaire classification consists of the spacing, width type, and glare control, in sequence. Example: M-III-S.
3. There is no assurance that these values will be achieved by a luminaire which satisfies the classification requirements and is used as shown above.
4. INDOT does not use all of the IES classifications listed above. See review section 502-5.06(03) item 1 or contact the Office of Traffic Engineering to determine the luminaire classification used by INDOT.

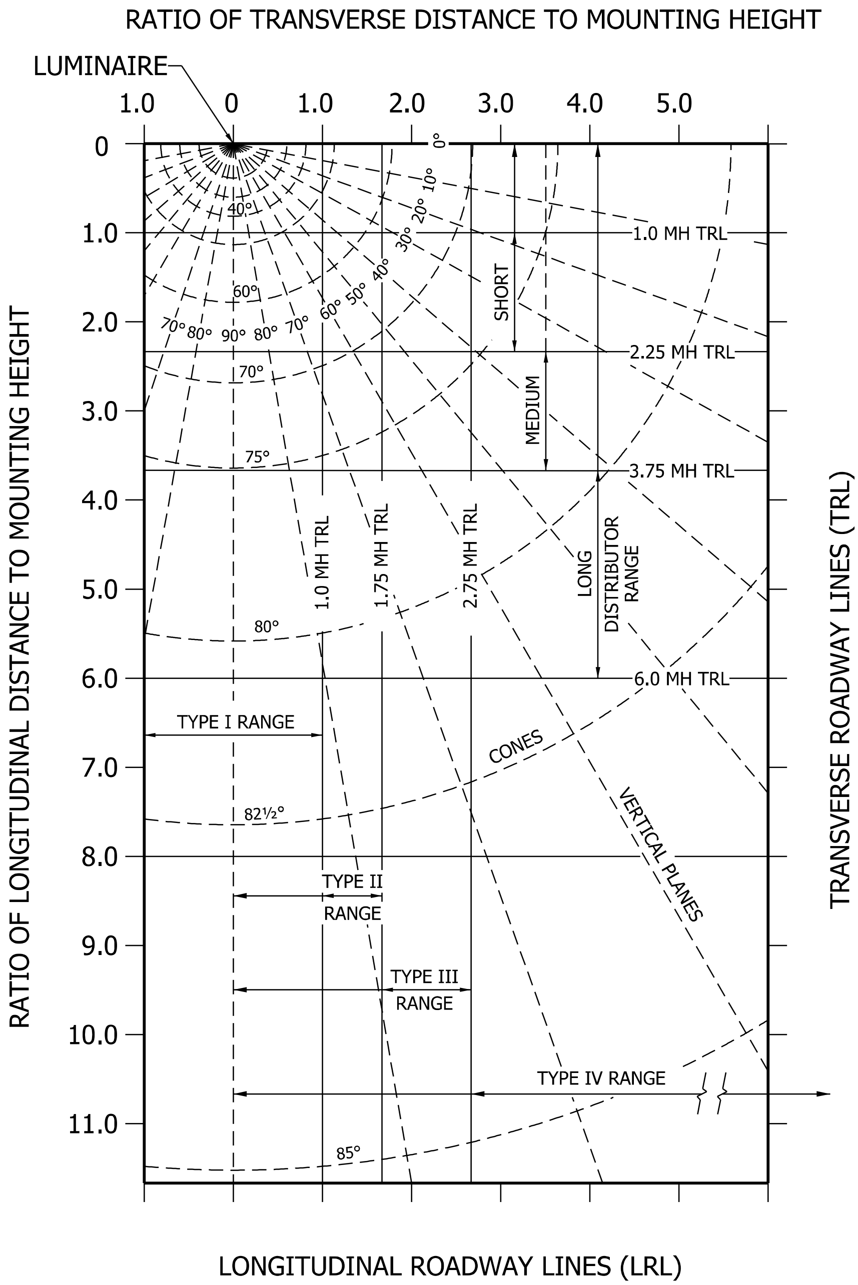
LUMINAIRE CLASSIFICATION SYSTEM

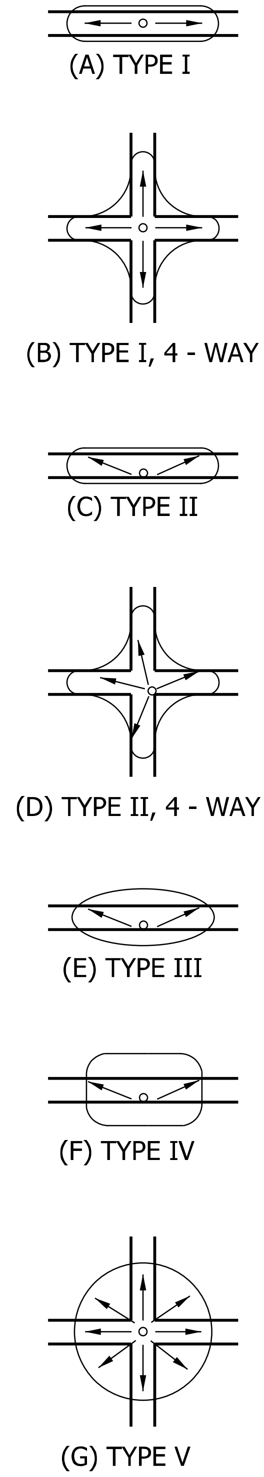
Figure 502-4G

| Arrangement | One Side or Staggered | Staggered or Opposite | Twin Mast Arms (Median Mounting) | At-Grade Intersection or High-Mast |
|---|---|---|---|---|
| Lateral Placement | Pavement Width to 1.5 MH | 1.5 MH plus Pavement Width | Pavement Width to 1.5 MH, Each Pavement | Pavement Width to 2.0 MH |
| Light Type | II, III or IV | III or IV | II or III | IV or V |

LUMINAIRE PLACEMENT AND LIGHT TYPE

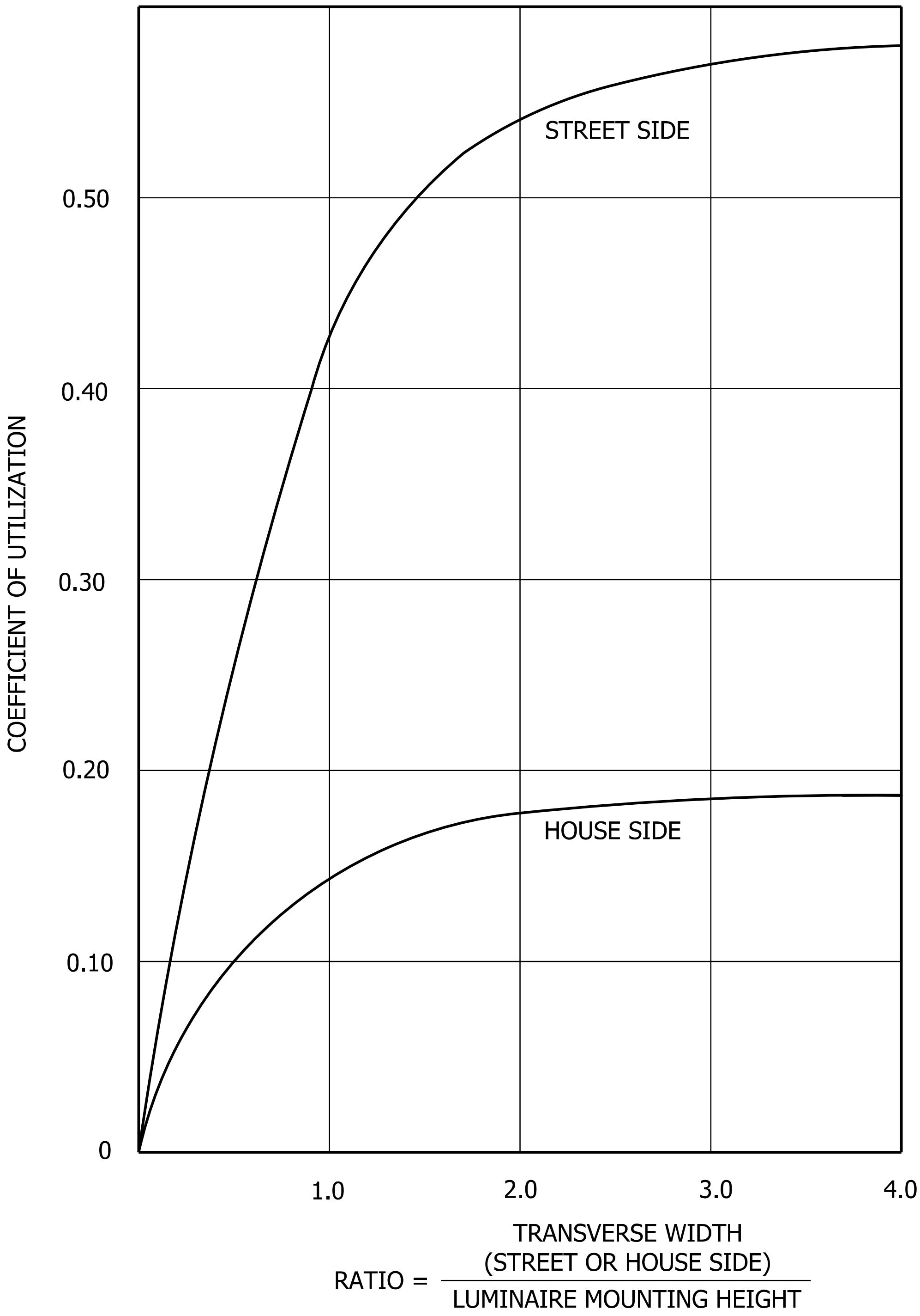
Figure 502-4H






# PLAN VIEW FOR LUMINAIRE COVERAGES

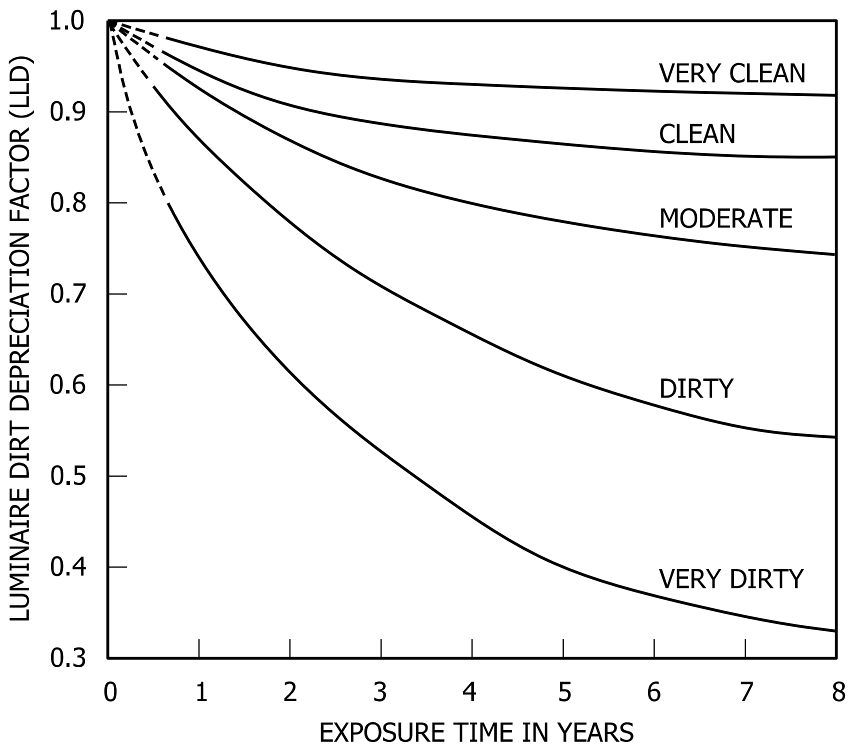
Figure 502-4 I




NOTE: The coefficient-of-utilization curve will vary with various manufacturers and equipment types.

# SAMPLE COEFFICIENT-OF-UTILIZATION CURVE

Figure 502-4J




NOTES:

1. VERY CLEAN - No nearby smoke or dust-generating activities and a low ambient contaminant level. Light traffic. Generally limited to residential or rural areas. The ambient particulate level is not more than 150 micrograms per cubic foot.

2. CLEAN - No nearby smoke or dust-generating activities. Moderate to heavy traffic. The ambient particulate level is not more than 300 micrograms per cubic foot.

3. MODERATE - Moderate smoke or dust-generating activities nearby. The ambient particulate level is not more than 600 micrograms per cubic foot.

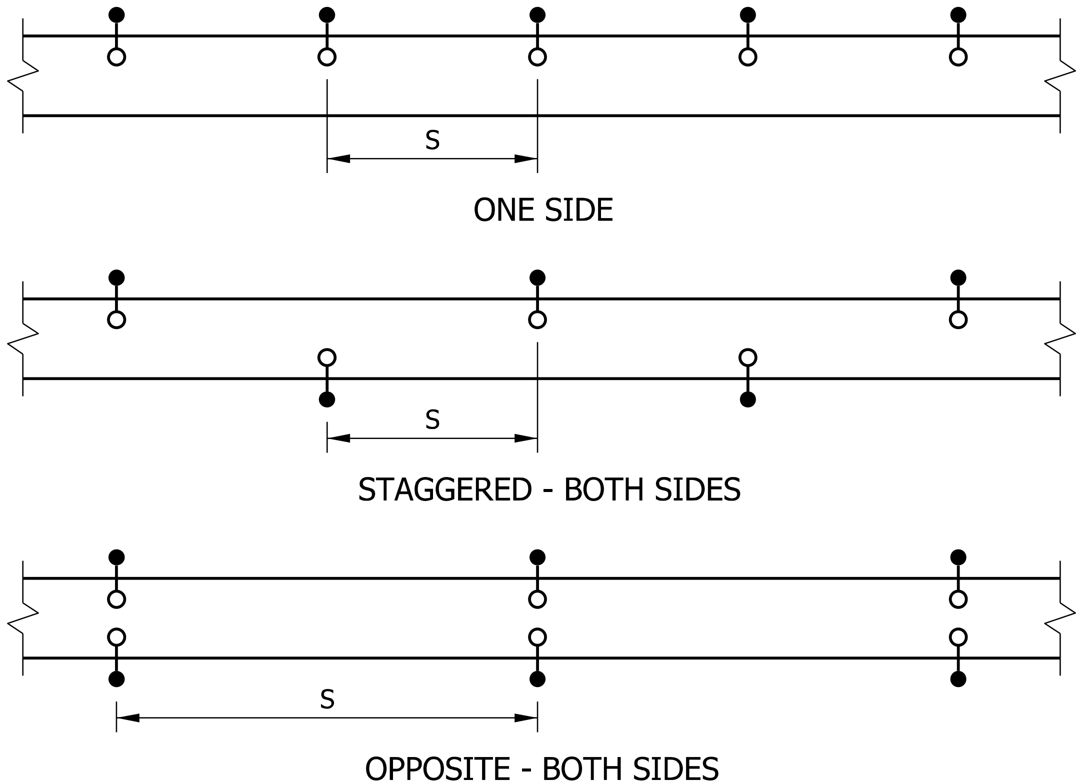
4. DIRTY - Smoke or dust plumes generated by nearby activities may occasionally envelope the luminaries.

5. VERY DIRTY - As above, but the luminaires are commonly enveloped by smoke or dust plumes.

ROADWAY LUMINAIRE DIRT DEPRECIATION FACTORS

Figure 502-4K

## TYPICAL MOUNTING CONFIGURATIONS
(Luminance patterns repeat at spacing boundaries indicated.)

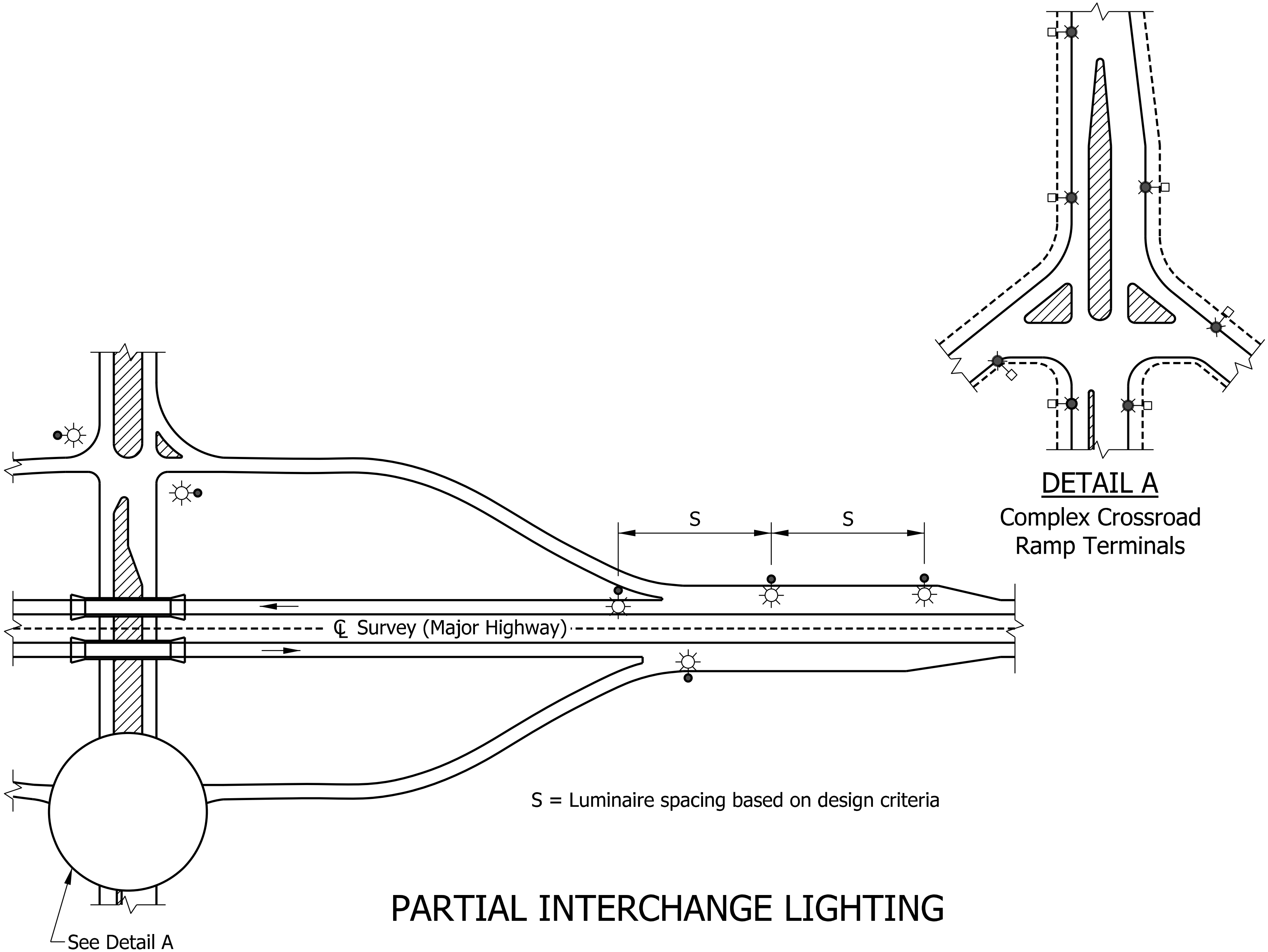



LEGEND:

- ● Light Standard
- ○ Luminaire
- S = Spacing

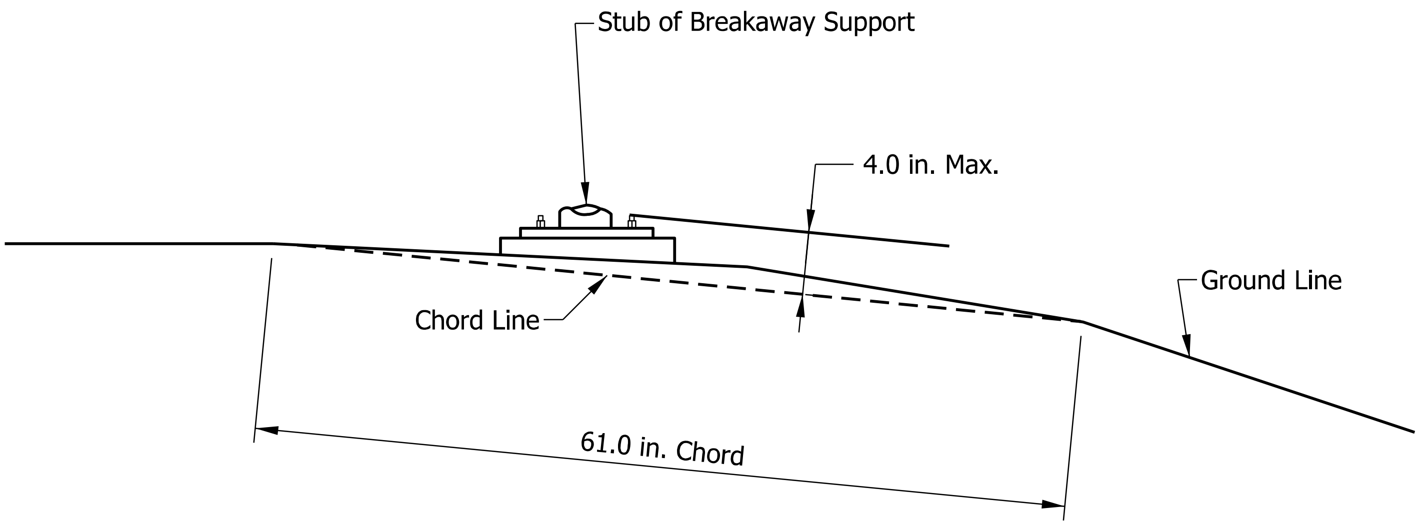
# LIGHTING SYSTEM CONFIGURATIONS

Figure 502-4L



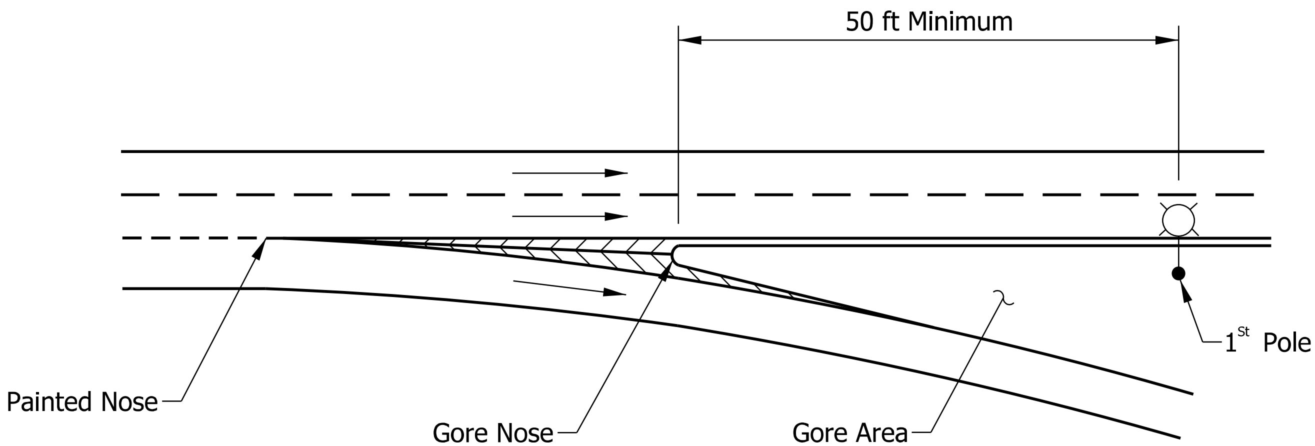

PARTIAL INTERCHANGE LIGHTING

Figure 502-4M




BREAKAWAY SUPPORT STUB CLEARANCE DIAGRAM

Figure 502-4N




POLE CLEARANCE FOR RAMP GORE

Figure 502-4 O

| Lamp Wattage, Type | Line Voltage | | |
|---|---|---|---|
| | 120 | 240 | 480 |
| 250 W, MV | 2.7 | 1.4 | 0.7 |
| 400 W, MV | 4.2 | 2.1 | 1.1 |
| 150 W, HPS | 1.7 | 0.9 | 0.5 |
| 250 W, HPS | 2.9 | 1.4 | 0.7 |
| 400 W, HPS | 3.9 | 2.0 | 1.0 |
| 1000 W, HPS | 9.0 | 5.0 | 2.5 |

MV luminaire information is for information only.

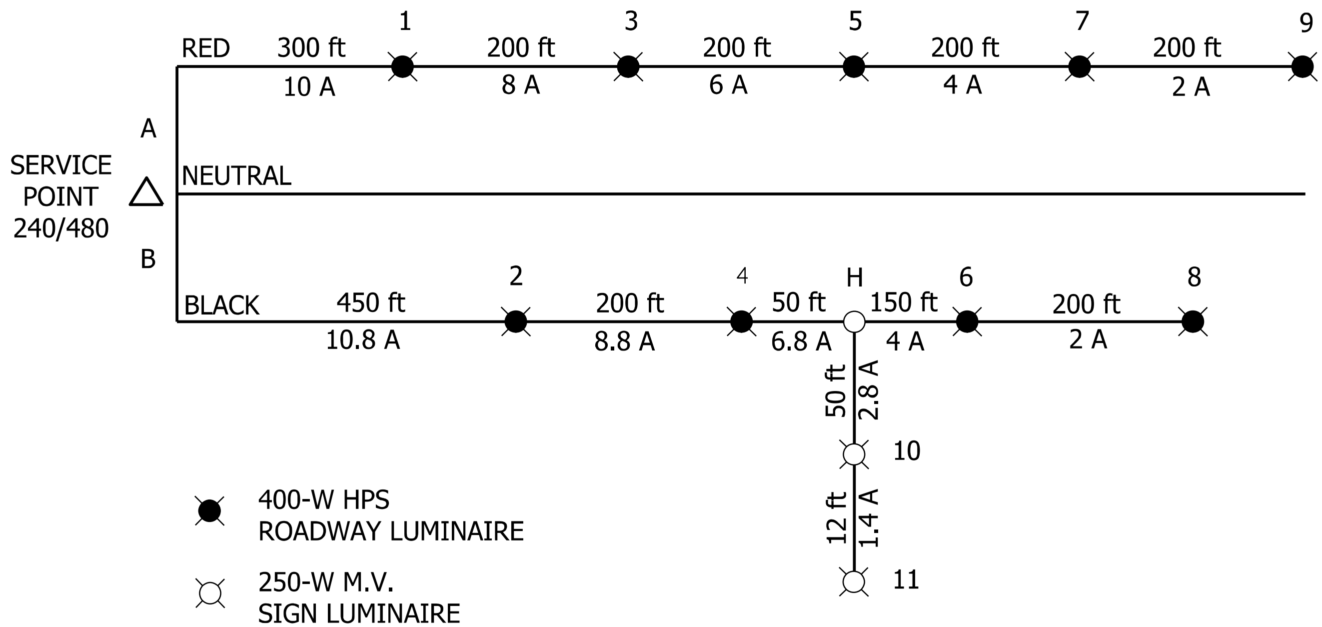
DESIGN AMPERAGES FOR VARIOUS HPS LUMINAIRES

Figure 502-4P

| Wire Size (AWG) | Resistance (Ω/mi) |
|---|---|
| 10 | 6.55 |
| 4 | 1.62 |

**COPPER-WIRE RESISTANCE**

**Figure 502-4Q**




VOLTAGE DROP CALCULATIONS EXAMPLE

Figure 502-4R

| Estimated Mounting Height, EMH (ft) | Lumens (HPS Light Source) | Number of Luminaires |
|---|---|---|
| 100 | 400,000 | 4 |
| 105 ≤ EMH ≤ 120 | 600,000 | 4 or 6 |
| 125 ≤ EMH ≤ 150 | 800,000 | 6 or 8 |
| 155 ≤ EMH ≤ 200 | 1,600,000 | 6, 8, 10, or 12 |

NUMBER OF LUMINAIRES FOR
HIGH-MAST TOWER

Figure 502-4S

| Slope, $S$ : 1 | Height (ft) |
|---|---|
| $2{:}1 \le S \le 3{:}1$ | 3 |
| $3{:}1 < S \le 4{:}1$ | 2 |
| $4{:}1 < S < 5{:}1$ | 1.5 |

**HEIGHT OF RETAINING WALL AT HIGH-MAST-TOWER CONCRETE PAD**

**Figure 502-4T**