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CHAPTER TWO:
USE AND CARE OF LEVEL

The level is a precision instrument used in surveying to determine and establish elevations of points and differences in elevation between points. There are many types of leveling devices used for this purpose and there are many methods and procedures which may be used to establish elevations.

In highway surveying, leveling is done to provide the necessary vertical control to construct a highway or a bridge. A point of vertical control is known as an elevation. Sometimes in paving or in roadwork an elevation is referred to as a grade.

All elevations are related to some reference. Generally, this reference is sea-level so that a point having an elevation of 722.95 ft means that the particular point is 722.95 ft above sea-level.

Differential leveling is the operation of determining the elevations of points some distance apart. This is the method used in highway surveying to establish the necessary vertical control for construction. Usually this procedure is done by direct leveling. Differential leveling requires a series of set-ups of the instrument along the general route. For each set-up, a rod-reading back to the point of known elevation and then forward to a point of unknown elevation is taken.

DEFINITIONS

BENCHMARK

A benchmark (B.M.) is a definite point on a permanent object which has a known elevation and a known location. Temporary benchmarks, (T.B.M.) are used many times to supplement permanent benchmarks. The elevation of a location of these points is also known but is not intended to be permanent. A benchmark is a point of reference which is convenient for leveling in a given locality. The relation to sea-level is very precise and obtained by running a level circuit such that the elevation of the beginning and the end of the circuit are known and tied together.

TURNING POINT

A turning point (T.P.) is an intermediate point between benchmarks which provides a temporary point of known elevation for a level circuit between two benchmarks a long distance apart. A turning point may be an iron pin which is driven firmly into the ground at a convenient location. Rod readings are taken on the pin before an instrument is advanced and again as the initial rod readings are taken before the instrument has been re-established ahead on the circuit. After the second reading, the pin is pulled and carried ahead. A turning point may be an existing convenient object upon which a rod reading may be taken; however, the object is required to be solid, stable, and not move or change in elevation for the few minutes needed between set-ups. A permanent or temporary benchmark may be used as a turning point.

BACKSIGHT

A backsight (B.S.) is a rod reading taken at a point of known elevation, such as a benchmark or turning point. Another term for backsight is plus sight.

FORESIGHT

A foresight (F.S.) is a rod reading taken on a point for which the elevation is to be established. A foresight is sometimes called a minus sight.

HEIGHT OF INSTRUMENT

The height of instrument (H.I.) is the elevation of the line of sight of the center of the cross-hairs in the telescope when the instrument is properly leveled. The height of instrument is equal to the elevation of the benchmark sighted plus the rod reading taken on the benchmark. In mathematical terms this may be written as follows:

$$\text{H.I.} = \text{elevation B.M.} + \text{B.S.}$$

A level plane of sight is known as the height of the instrument. The important features of the instrument telescope are the optical properties as follows:

1. Illumination -- this refers to how well lighted the image appears

2. Definition -- this refers to the sharpness of detail

3. Width of field of view -- this is expressed as an angle and indicates how much of the object is visible at one time

4. Magnifying power -- this is the ratio of the apparent lineal dimensions of the object and of the image

The level used by INDOT typically is the Dumpy type level with a magnification of 26 to 30 and an erecting eye piece so that the image sighted is seen right side up. The precision of the work done with this type of instrument is excellent to approximately 200 ft.

LEVELING ROD

The second most important piece of equipment needed for differential leveling is the leveling rod. Several types of leveling rods are used in highway construction. The Chicago Rod and the Philadelphia Rod are the two types which are generally preferred. The Chicago Rod is a slip-joint rod which has a total length of 12 ½ ft when all sections are used. The Philadelphia Rod is a sliding joint type of rod that extends to 15 or 16 ft and is a more convenient rod when using a target. Selection of a rod type is a matter of personal preference or availability.

TARGETS

An accessory which may be used with a rod when doing more precise work is a target. The target is fitted with a built-in vernier so that rod readings may be obtained to one-thousandth of a foot. Targets are rarely used for highway surveying, although they may be used when precise readings for certain bridge structures are required. The design of the structure or conditions which exist adjacent to the structure during construction may require these precise readings.

The level and the leveling rod are the only two pieces of equipment that a crew is required to have to run a precise and complete level circuit. Other items of minor equipment are needed for specific types of leveling. A very handy device which is used for checking slopes and setting slope stakes is the hand level. The hand level is simply a small telescope which has a built in level bubble. The bubble is small and therefore poor for precise work. Also, there is very little magnification built into this device. Because the optical properties of illumination, magnification, definition, and width of field of view are not available, the hand level is never used for precise work. The device is used only as a convenience for short sightings or approximate sightings accurate to the nearest one tenth of a foot.

TWO PEG TEST

The two peg test is a very simple test which is used in the field to determine if the line of sight of the telescope is exactly parallel to the bubble tube. This is one of the most important properties of a level and is required to be checked periodically. The steps below are required to be followed to check this adjustment in a level.

1) Set two hubs 300 ft apart

2) Set up the level half way between the two hubs and level the instrument properly. Figure 2-1 illustrates a sketch of the level properly established between the two stakes represented by points A and B. The location is selected so that the tops of the stakes are obviously different in elevation.

3) The rodman sets the rod on stake A and rocks the rod on this point. The instrument operator reads the rod, making sure that the rod is at the center of the cross hairs and that the level bubble is truly centered when the reading is taken. The rodman moves up to point B, sets the rod on the stake, and rocks the rod as the instrument operator turns the instrument to obtain a precise reading of the rod at point B. Once again, the bubble level is centered when the reading is taken. This is the first set-up.

4) The level is then moved to the highest stake, in this case stake B, and set so that the eye piece of the level is just a few inches from the rod when the level rod is plumbed on the stake.

5) The rod reading is taken on stake B by sighting backwards through the telescope.

6) The rodman takes the rod to stake A and a precise reading is taken on stake A.

7) The true difference in elevation between point A and B is computed from the two-readings obtained from the first set-up.

8) The elevation difference of the second set-up is computed. If the plane of sight is truly horizontal, the elevation difference of the second set is equal to the true difference in elevation. If this is not so, the line of sight is not parallel to

the bubble tube on the telescope and adjustments to the instrument are required. Adjustments vary from instrument to instrument and the proper procedure is different for a transit and a level. If an adjustment is necessary, the PE/PS or District is consulted.

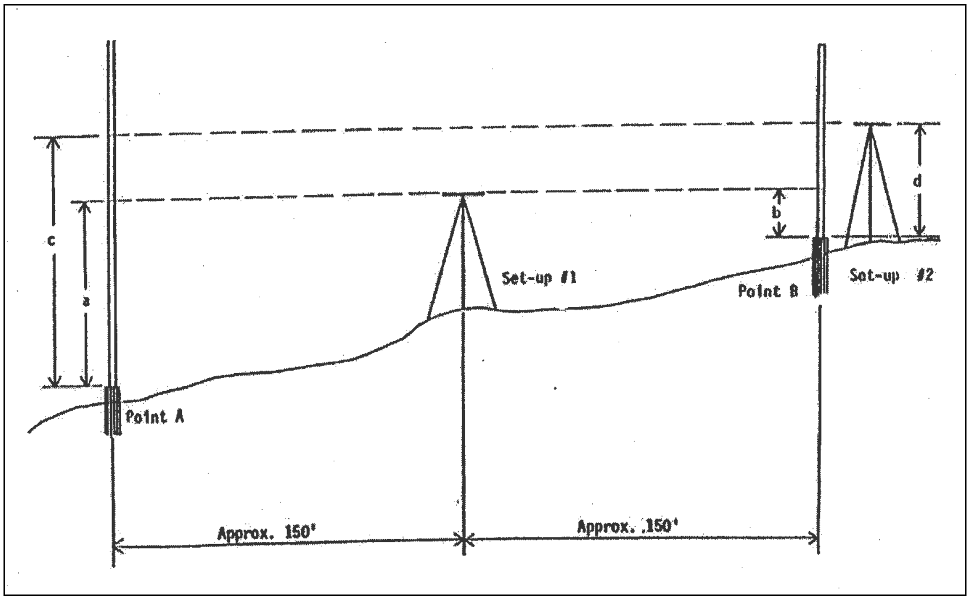


Figure 2-1. Two Peg Test

LEVEL NOTES

There are two forms of field notes commonly used for maintaining level circuit information. These are referred to as the open note form and the closed note form. The open note form is merely an expanded notation. A typical set of open form level notes is indicated in Figure 2-2. Each set-up, noted by H.I., has a corresponding backsight and produces a H.I. Each turning point, noted by T.P., is defined by a foresight and an elevation.

The numbers used in the open note form of Figure 2-2 are indicated in Figure 2-3. This is an example of differential leveling and traces the work done to progress from benchmark A to benchmark K. The elevation of benchmark A is established as 820.00. The level is set up at the location marked I and the rod reading on benchmark A is 8.42. This rod reading is called the backsight or the plus sight, and is abbreviated as B.S. or (+). The backsight is a rod reading taken on the A point known elevation and used to determine the height of instrument. For the example indicated, the H.I. equals the elevation of benchmark A plus the backsight reading.

$$H.I. = 820.00 + 8.42 = 828.42$$

This value is recorded in the H.I. column of the notes as the H.I. of set-up number one. After the rod reading on A has been taken, T.P. #1 (turning point number one) is selected so the distance from benchmark A to the instrument is approximately equal to the distance from benchmark A to T.P. #1. A level rod reading is then taken on the TP #1 and is called a foresight reading, which is noted as F.S. or (-). The turning point is a conveniently located temporary benchmark so that the instrument may be moved ahead and a sight taken back on this point to provide a point of vertical reference. The rodman remains at the first turning point while the level is moved to set-up number two. A backsight reading is taken on the rod held at TP #1. The rod is moved to TP #2 for a foresight reading at another conveniently located point ahead so that the rod reading may be obtained on benchmark K. In the example shown in Figure 2-3, there are four set-ups and three turning points or intermediate temporary benchmarks. Using the same numbers and the same example, a set of closed form level notes may be developed as shown in Figure 2-4. The closed form eliminates the set-up line and doubles the information noted for each turning point.

STATION	B.S. (+)	H.I.	F.S. (-)	Elev.	B.M. Elev.	
B.M. A					820.00	Boat spike in 30" Oak tree, 186 ft. right of Sta. 106 + 43.
1	8.42	828.42				
T.P.1			1.20	827.22		
2	11.56	838.78				
T.P.2			1.35	837.43		
3	6.15	843.58				
T.P.3			10.90	832.68		
4	4.39	837.07				
B.M. K			5.94	831.13	831.15	Bronze Marker on N. end of culvert headwall, 56 ft. right of Sta. 116 + 78.
				Compare		
	30.52		19.39			

Difference of B.S. & F. S. = 11.13

Difference in Elev. of B.M. A & B.M. K = 11.13

Circuit Checks.

Figure 2-2. Level Notes

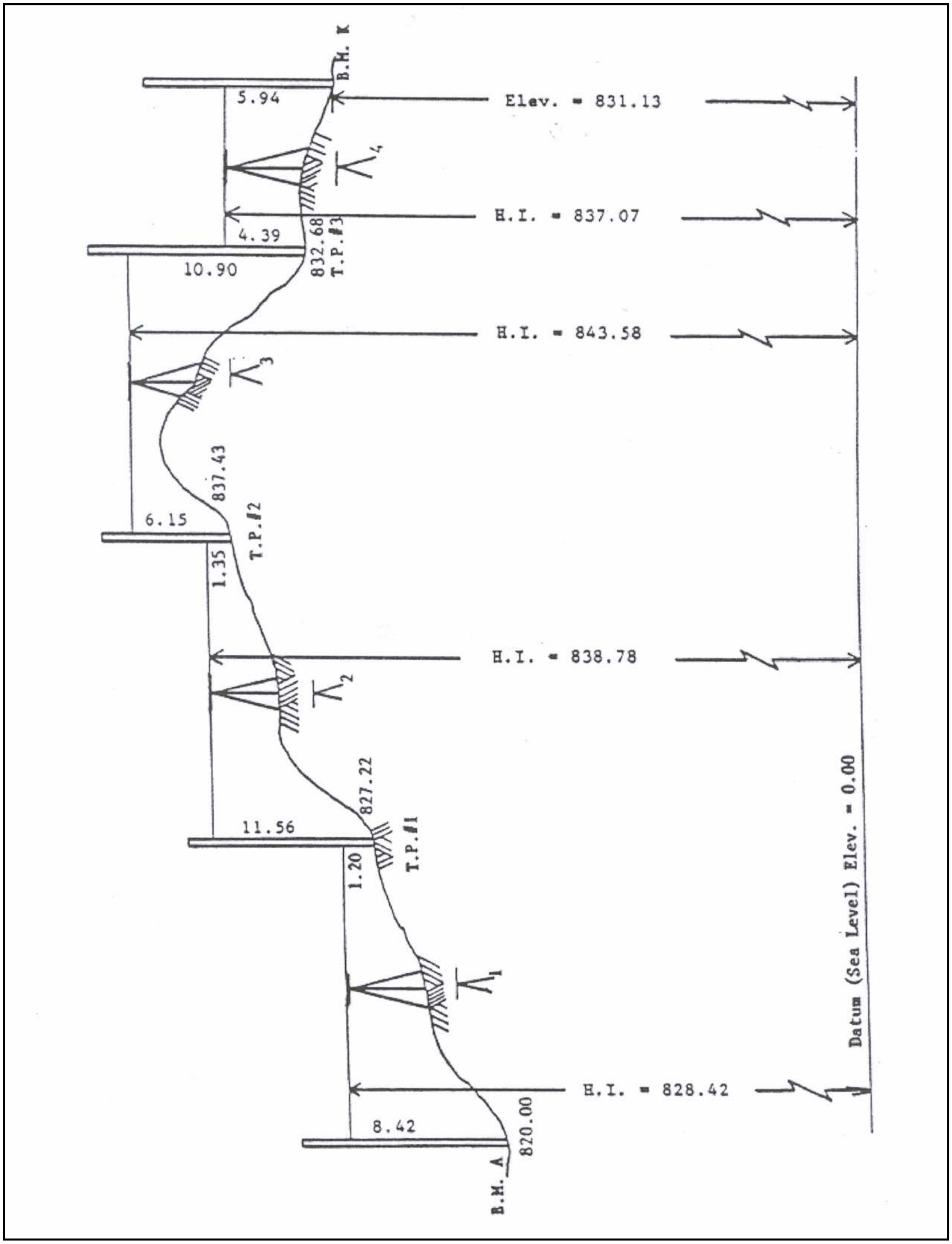


Figure 2-3. Level Set-Up

		LEVEL CIRCUIT				Info Box
STATION	B.S. (+)	H.I.	F.S. (-)	Elev.	B.M. Elev.	
B.M. A	8.42	828.42			820.00	Boat spike in 30" Oak tree, 186 ft. right of Sta. 106 + 43.
T.P. #1	11.56	838.78	1.20	827.22		
T.P. #2	6.15	843.58	1.35	837.43		
T.P. #3	4.39	837.07	10.90	832.68		Bronze Marker on N. end of culvert
B.M. K			5.94	831.13	831.15	headwall, 56 ft. right of Sta. 116 + 78.
				Check		

Figure 2-4. Closed Form Level Notes

LEVEL SET-UP PROCEDURE

The first step in setting up the level is to attach the level itself to the tripod or legs. The level is placed in a location which is fairly open so that a clear rod reading may be obtained on the benchmark. The proper setting of the tripod is very important. The legs of the tripod are required to be spread so that the base plate of the level is approximately horizontal and a stable base is provided. If the ground has a steep slope, two of the legs should be set about the same elevation and lower on the slope than the third leg. The legs are set firmly into the ground and the three wing nuts of the legs just under the head tightened. The tripod is not set on a hard slick surface, such as a hot mix asphalt pavement, concrete pavement, or sidewalk, unless absolutely necessary.

Figure 2-5 illustrates a Dumpy level, which is still used by INDOT. The base plate, which attaches to the tripod, is shown as item #1. Item #2 is the leveling screws. These screws are used in pairs to center the bubble in the tube below the telescope when the telescope or sighting tube is aligned over a pair of leveling screws. To center the bubble, all four leveling screws are loosened uniformly and the telescope turned so that two leveling screws are directly under the telescope and the telescope is in line with the first sight to be taken. With the telescope directly over a pair of leveling screws, the bubble is brought to the center of the tube by loosening one screw while tightening the other with the thumb and first finger of each hand. The bubble moves in the same direction as the left thumb. When the bubble becomes centered in the tube, the pair of leveling screws are tightened. Care is taken to not over tighten the screws. The telescope is then rotated 90° in either direction so that the telescope is directly over the other pair of leveling screws. The process is repeated to bring the bubble to the center of the tube. The telescope is turned back 90° so that the level is over the original pair of leveling screws. The bubble is checked to make sure that the level is centered. If the bubble is no longer centered, then the leveling screws are adjusted to bring the bubble to center and the telescope rotated back over the pair of leveling screws to check the bubble again. If the instrument is in good adjustment, the bubble remains centered.

When the set-up is complete, the instrument operator is now ready to take the initial shot or backsight on the benchmarks or turning point, which is the starting point and point of known elevation for a level circuit. The telescope is rotated so that the benchmark may be sighted directly. Making sure the bottom of the rod is clean, the rodman sets the rod on the benchmark. The rodman is responsible for making sure that the rod is clean, that sections of the rod are set together properly, and that the rod is held right side up. The face of the rod is required to be facing the

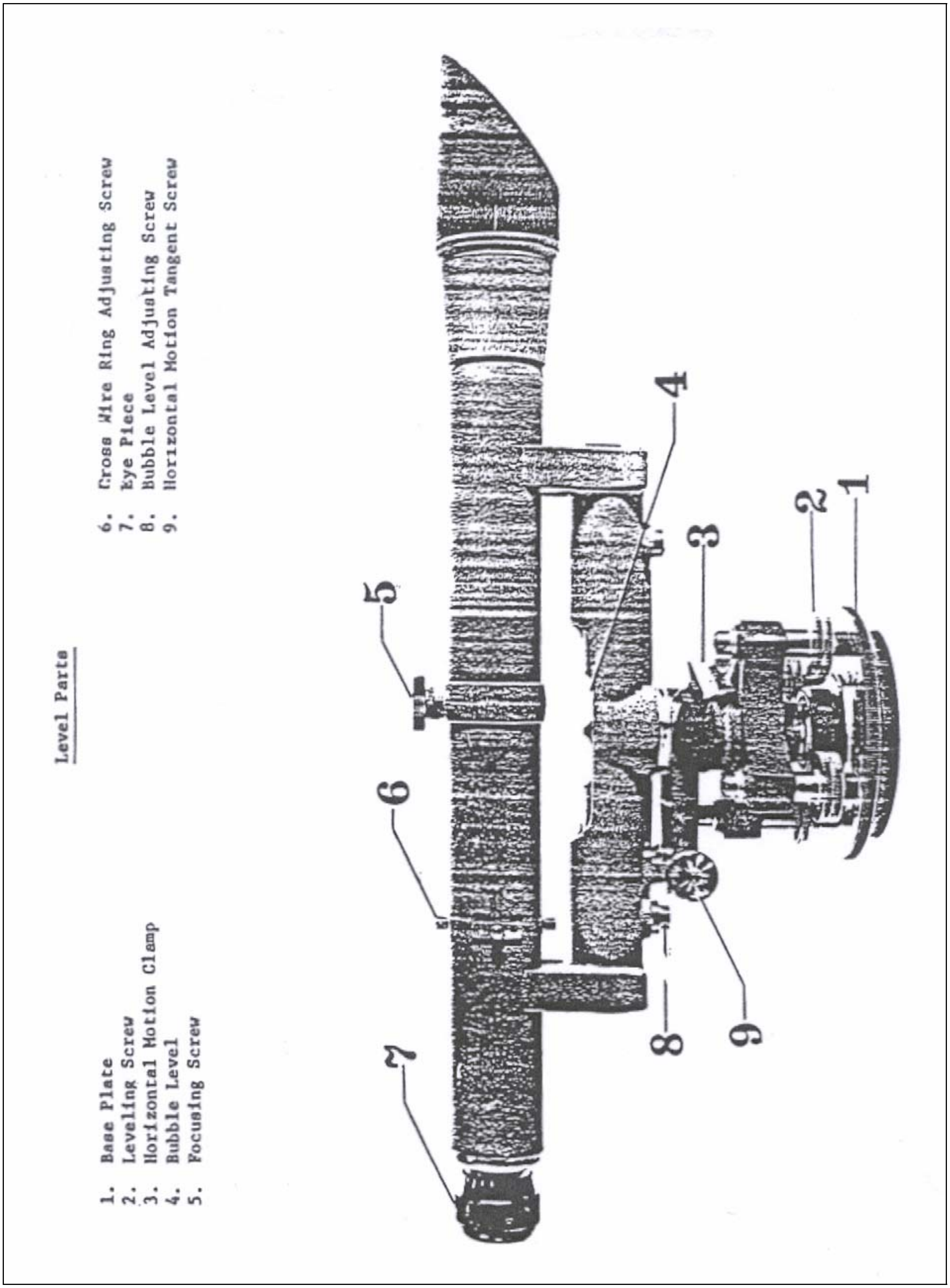


Figure 2-5. Dumpy Level

instrument. The rodman stands directly behind the rod with both hands on the sides of the rod so that no fingers are covering the face of the rod. By standing directly behind the rod, the rodman makes sure that the leveling rod is plumb. As the operator on the level sights through the instrument at the rod, the rodman begins to rock the rod toward the instrument and back to himself so that the rod is moved forward approximately 9 in. and then directly away from the instrument the same amount. A slow, uniform rocking motion is applied by the rodman.

As the instrument operator sights through the level, the cross hairs are seen in his field of view. The level is turned so that the center of the cross-hairs is directly on the rod. The face of the rod appears to move up and down as the rodman rocks the rod. The numbers on the rod increase and then decrease to some minimum number, then increase again. The numbers continue increasing and decreasing as the rodman continues to rock the rod. The minimum number on the rod cut by the horizontal cross hair is the rod reading on the benchmark. The instrument operator takes the reading, keep the number in mind, then looks to check that the bubble is exactly centered. If the bubble is not centered, the appropriate leveling screw is adjusted through the telescope again and another reading taken and recorded as the backsight.

Items #5 and #7 indicated in Figure 2-5 are used to provide two adjustments that bring the rod into sharp focus, bring the cross hairs into sharp focus, and eliminate parallax. Parallax results when the optics are out of adjustment. The presence of parallax may be determined by nodding the head up and down while looking through the telescope. There is no movement of the image relative to the cross hairs. Movement indicates parallax is present and adjustment is needed. Item #3 of Figure 2-5 is the horizontal motion clamp which locks the telescope. Item #9 is the horizontal motion tangent screw which provides the fine adjustment so that the telescope may be turned a degree or so in either direction from the locked position by turning the knurled knob.

The rod reading on the benchmark or turning point is recorded in the notes and when added to the elevation of the benchmark gives the elevation of the height of the instrument, H.I. This reading is the elevation of the plane, the center of the telescope. The rodman moves ahead to the next point to be established, places the rod on the surface whose elevation is required, and begins to rock the rod as was previously done on the benchmark. The instrument operator rotates the telescope so that the rod is sighted with the center of the cross hairs then takes a reading. Since the elevation of the cross hairs is known, the rod reading on this point is subtracted from the H.I. and the elevation of the point is determined.

There are three specific items to keep in mind so that the results of direct differential leveling are accurate, even though the instrument may be out of adjustment.

1. The bubble is centered before the final reading is obtained and recorded

2. The rod is sighted with the center of the cross hairs

3. The backsight is balanced with the foresight. The distance from the rod to the instrument, from the back and foresight, is required to be a maximum of 200 ft.

CARE AND CLEANING OF THE LEVEL

When the level is carried on the shoulder, the clamps are required to be tight enough to prevent wear, but loose enough so the level gives if accidentally bumped.

When the level is carried inside a building, in dense growth, or anywhere there is a chance of being bumped, the level is carried under the arm with the instrument head in front of the carrier.

The level is carefully set down. The cross hairs could be broken or the instrument jarred out of adjustment by harsh treatment. When being transported in a vehicle, the level is packed in the level case and placed in a location to minimize vibration. The leveling screws are not tightened too tight as this could cause warping of the plate. The level is never left unguarded. The tripod legs are spread and pushed into the ground to prevent the level being knocked down. The instrument is protected from rain by a waterproof cover. If a waterproof cover is not available, the dust cap is placed on the objective lens as soon as possible and the instrument taken inside. When brought inside, excess moisture is wiped off the instrument immediately and the instrument allowed to thoroughly dry before being placed in the case. Dust is removed with a camel hair brush, if available. The eye piece may be cleaned with alcohol and wiped with a soft cloth.

PROFILE LEVELING

The purpose of profile leveling is to determine the elevations of the ground surface along some definite line. In INDOT work, the existing ground surface profile is required to be known to provide sufficient and necessary information for both design and construction. Profiles are plotted such that the vertical scale is exaggerated in relation to the horizontal scale so that the differences in the elevation are accentuated.

The line along which the profile is to be taken may be marked prior to the survey. This is normally done in 100 foot stations. A rod reading is taken at each full station and at each major break in the ground slope. This procedure differs from the running of a circuit level in that more foresights are taken from each set-up. The stations of the breaks in slope are taped and referenced from the full stations established along the profile line (Figure 2-6). A sample of a set of profile field notes is indicated in Figure 2-7. The turning points and benchmarks are recorded to hundredths of a foot while the ground rod readings are recorded to tenths of a foot. Obtaining ground rod readings more precise than to tenths of a foot is not required.

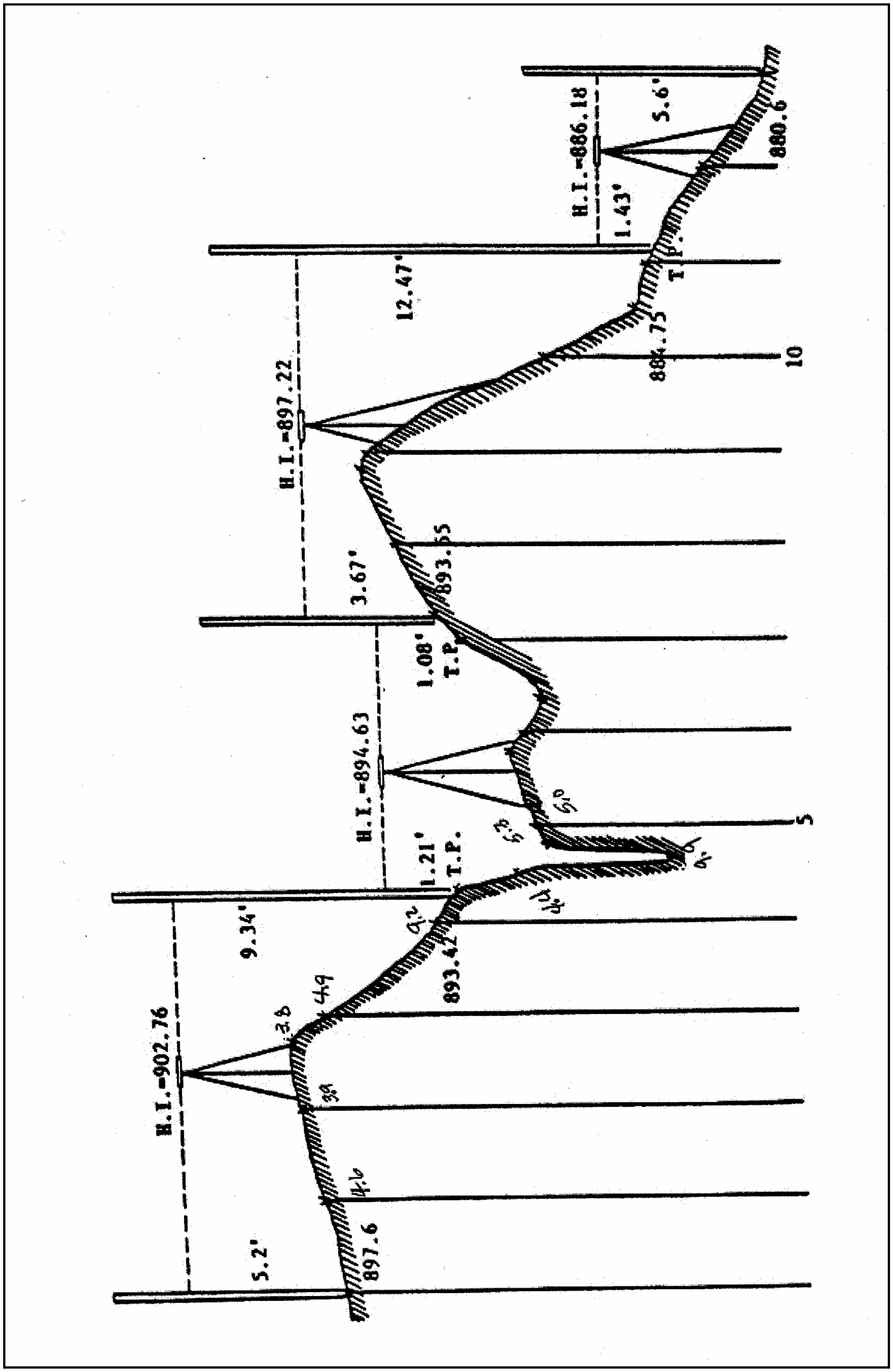


Figure 2-6. Profile Leveling

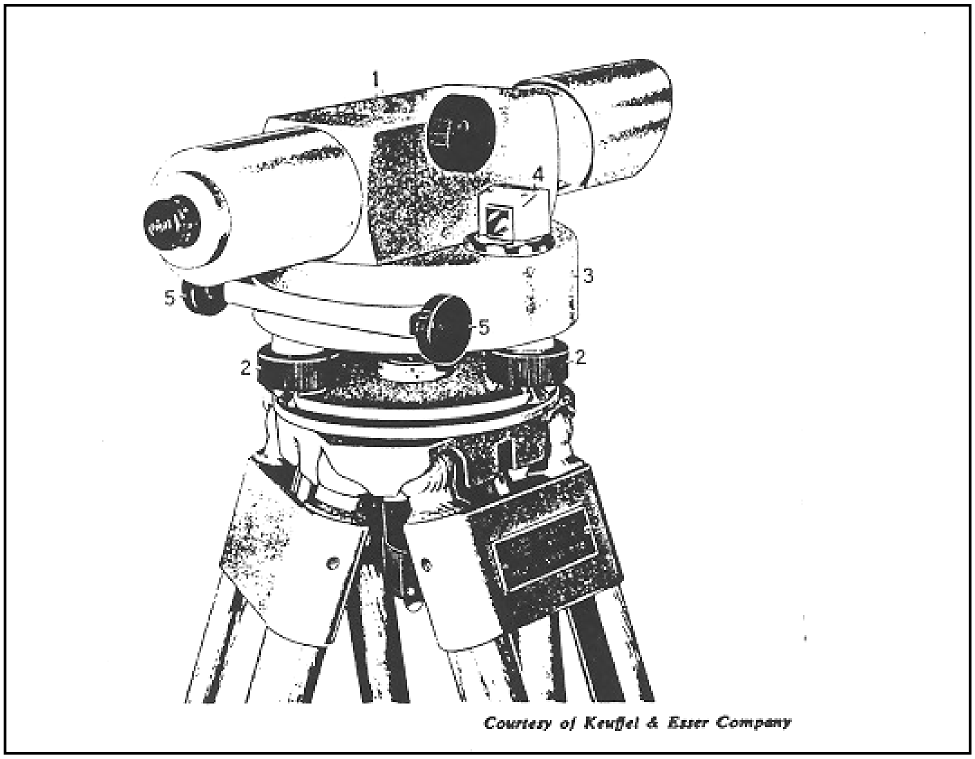
STA.	+ B.S.	H.I.	− F.S.	ELEV.		Remarks
B.M.	4.18	902.76		898.58		Spike in root of white-oak stump, 60' left of Sta. 0
0			5.2	897.6		
1			4.6	898.2		
2			3.9	898.9		
2+65			3.8	899.0		
3			4.9	897.9		
4			9.2	893.6		
T.P.	1.21	894.63	9.34	893.42		Top of stake, near Sta. 4
4+55			4.4	890.2		S. bank Spring Brook
+63			9.9	884.7		Centerline Spring Brook
+75			5.3	889.3		N. bank Spring Brook
5			5.0	889.6		
5+70			3.9	890.7		
6			4.5	890.1		
6+25			5.4	889.2		
7			2.2	892.4		
T.P.	3.67	897.22	1.08	893.55		On rock, near Sta. 7
8			2.4	894.8		
8+75			1.1	896.1		
9			1.9	895.3		
10			8.4	888.8		
10+40			11.3	885.9		
11			12.2	885.0		
T.P.	1.43	886.18	12.47	884.75		Top of stake, near Sta. 11

5-24-82
Cloudy, warm
K T. Jones
T. Smith
A Brown
J. Doe

Figure 2-7. Profile Leveling Notes

SELF- LEVELING LEVEL

The most common type of level used by INDOT is the Zeiss self-leveling level shown in Figure 2-8. The telescope (1) has the usual eyepiece system, objective lens, focusing mechanism, and reticle with cross lines. Also, there are three leveling screws (2), and the instrument is supported on a tripod. The head (3), which encloses the tops of the leveling screws, may be leveled by means of these screws. To enable the operator to determine when the head is level, there is a circular level vial, which may be viewed through the prism (4). With this prism in position, the circular level may be viewed when the operator looks horizontally parallel to the axis of the telescope. The prism may be turned so that the level may be seen when the operator looks horizontally at the sides of the telescope.



1) Telescope
2) Leveling Screws
3) Head
4) Viewing Prism

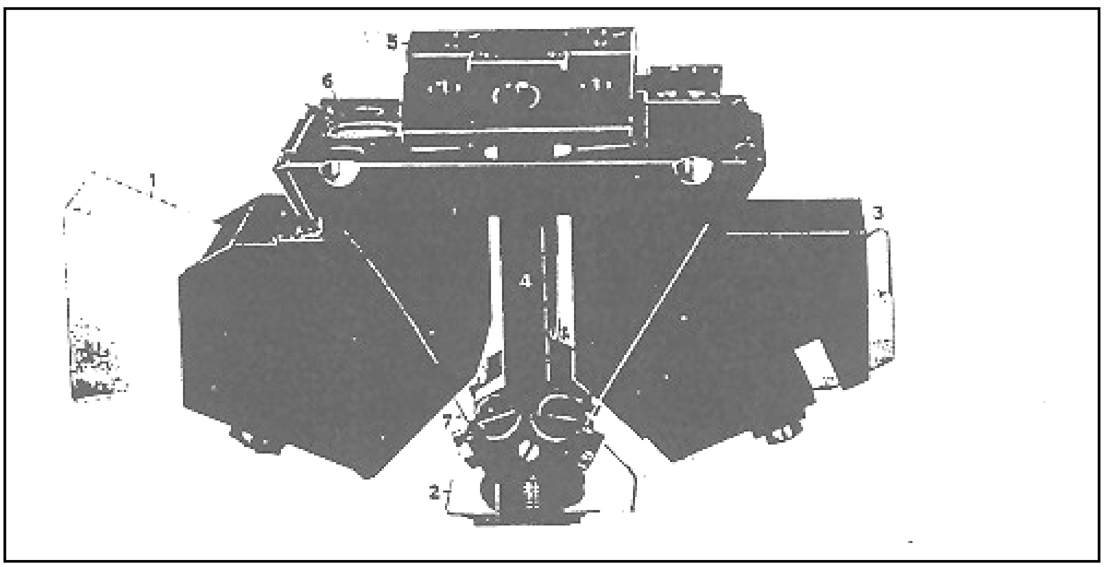
Figure 2-8. Zeis Self Leveling Level

LEVELING

The Zeiss level does not have a longitudinal spirit level to indicate when the telescope is level. None is needed. The head is approximately leveled by means of the leveling screws and the circular level. The line of sight is made exactly horizontal, with the telescope turned in any direction, by an automatic device called a compensator inside the telescope. Also, there is no clamp for preventing rotation of the telescope in a horizontal plane. An automatic coupling is used instead. To sight the telescope toward an object, such as a leveling rod, the telescope is rotated by hand so that the level points are in the proper direction. Then, either tangent screw is turned to make the fine adjustment.

COMPENSATOR

A compensator of the type used in a Zeiss telescope is indicated in Figure 2-9. The main parts are 3 prisms, numbers 1, 2, and 3. The action of these prisms is represented diagrammatically in Figure 2-10. The compensator is inserted in the telescope between the reticle and the focusing system, with prism number 1 toward the objective lens. The prism bends the lines of sight downward from points on the observed object. Then prism number 2 bends the lines of sight so that they pass the reticle and go through the eyepiece system. At the same time this prism turns the image to the true position, so that the image is neither upside down nor reversed right for left.



1), 2), 3) Prisms	5) Weight
4) Vertical Member	6) Support Plate

Figure 2-9. Level Compensator

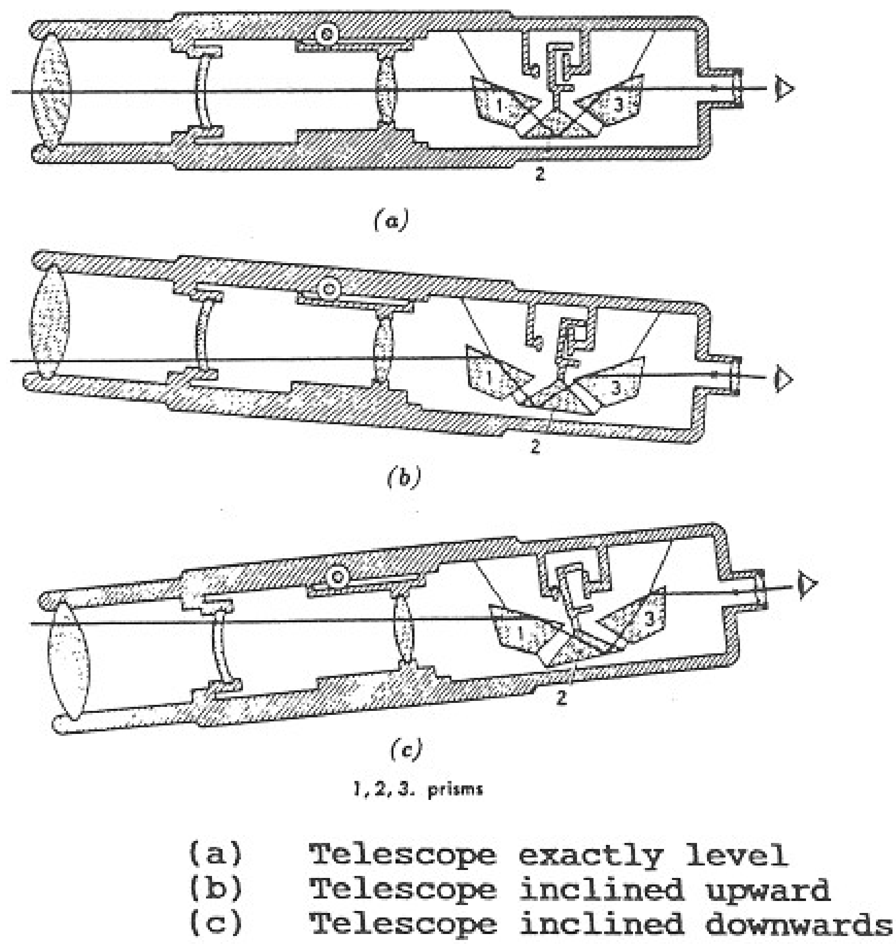


Figure 2-10. Level Prisms

As indicated in Figure 2-9 and Figure 2-10, prism number 2 is carried by a pendulum and is free to swing so that the prism automatically makes the line of sight horizontal. If the telescope is exactly horizontal, as in Figure 2-10 (a), the part of the line of sight at the eyepiece lies in the prolongation of the part passing through the objective lens. If the telescope is tilted slightly, as in Figure 2-10 (b) or (c), the part of the line of sight at the eyepiece is horizontal, but is offset from the other horizontal part.

The pendulum assembly carries prism number 2. At the top of the vertical member (4) is a dome shaped weight (5) which rests on the main support plate (6). This plate has a hole through which the vertical member passes. Inside the vertical member is a damping piston which moves in a damping cylinder. The movement of the pendulum is controlled by the position and four nonmagnetic wires (7) which run from the bottom of the vertical member to the corners of the support plate.