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Rehabilitation of Reinforced Concrete Slab Bridges

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Edge Beam Replacement Overview

- Project Examples
  - *Old Removal Methods*
  - *New Removal Methods*
  - *Problem Details*
- Design Process

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Coping Problems not Covered

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Coping Problems Covered

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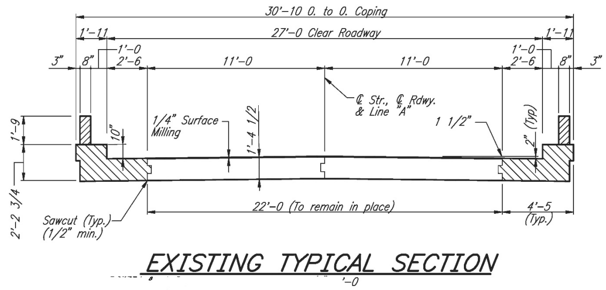
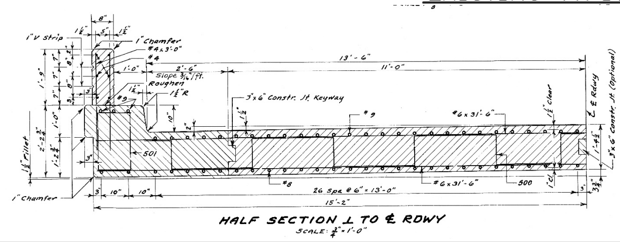
Adams County Bridge 41

Removal Limits





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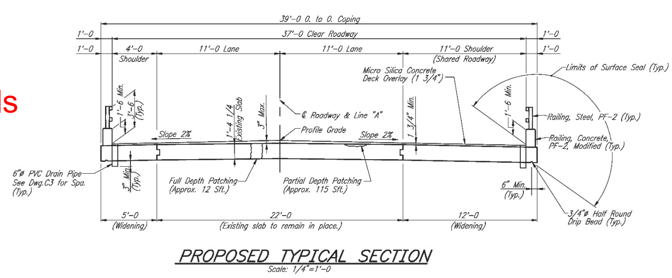
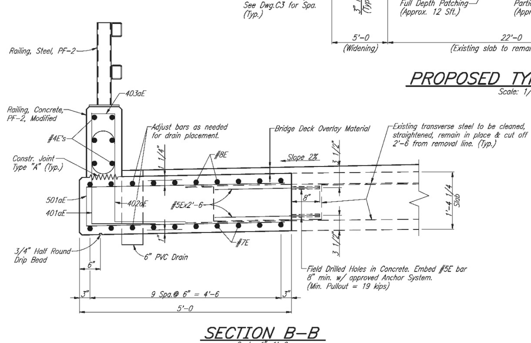
Adams County Bridge 41

Proposed Details





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Construction

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Adams County Bridge 41

Construction

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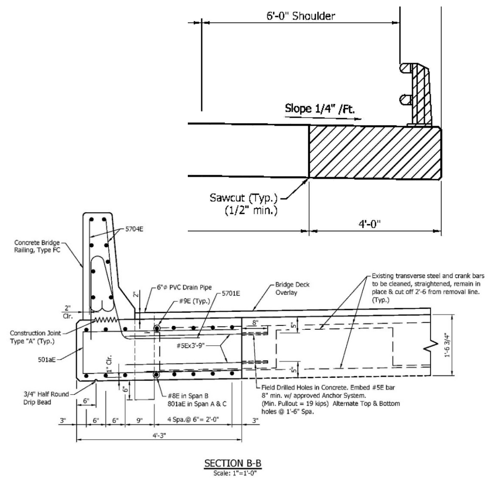
SR 243 over Rocky Fork Creek



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SR 243 over Rocky Fork Creek

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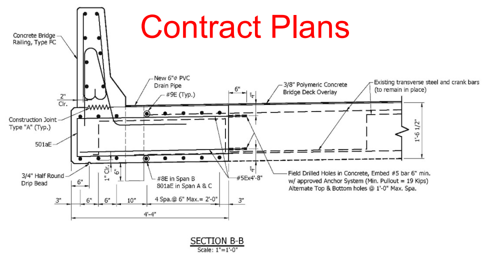
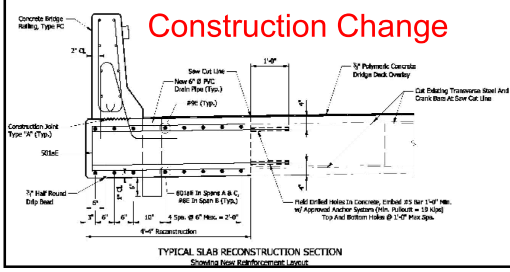
SR 75 over Branch Big Walnut Creek

Contract Plans



Construction Change



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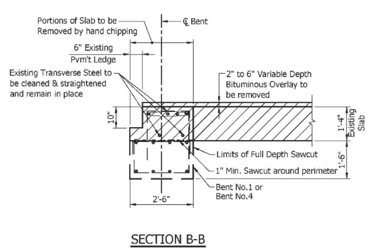
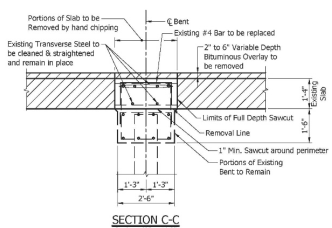
SR 39 over Branch Pond Creek





Removal Limits

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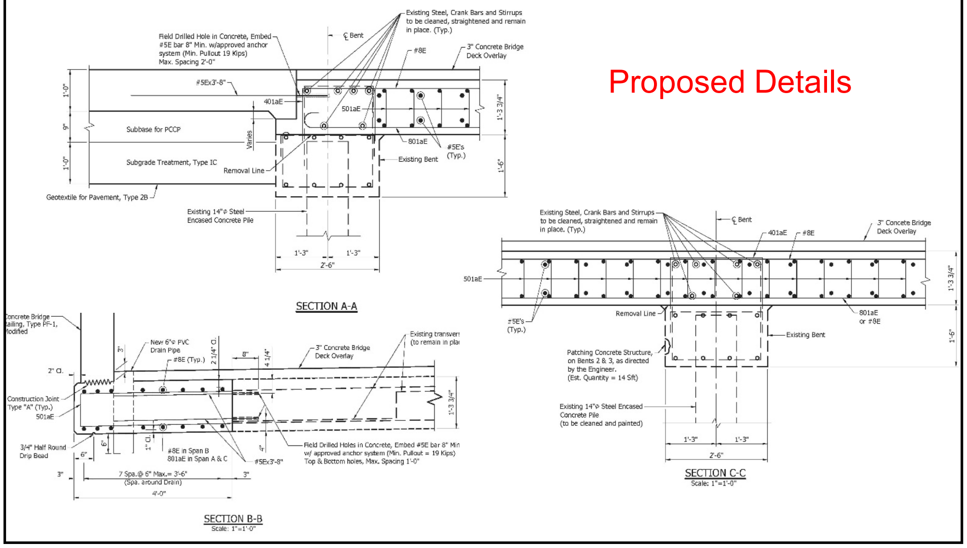
SR 39 over Branch Pond Creek

Proposed Details



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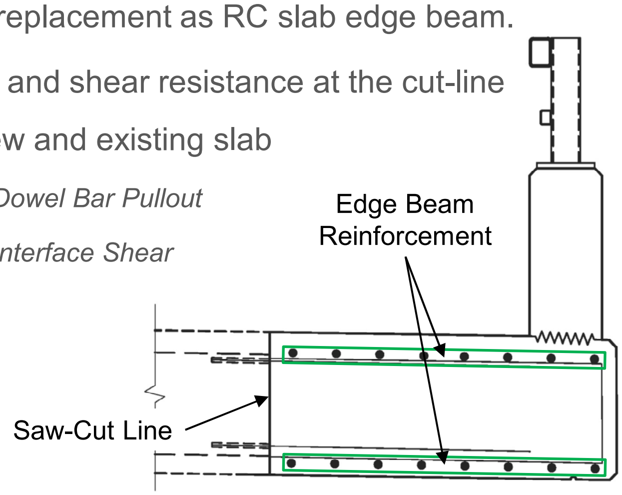
Design Procedure

- Design coping replacement as RC slab edge beam.
- Check moment and shear resistance at the cut-line between the new and existing slab
  - *Load Case 1: Dowel Bar Pullout*
  - *Load Case 2: Interface Shear*



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RC Slab Edge Beam Design

- Assume edge beam width is equal to width of coping replacement (not to exceed 6 ft - AASHTO 4.6.2.1.4b).
  - *For replacement widths > 6 ft, design edge beam as required and remaining slab as interior RC slab strip.*
- Edge beam designed to support dead load and the live load applied within the edge beam width.

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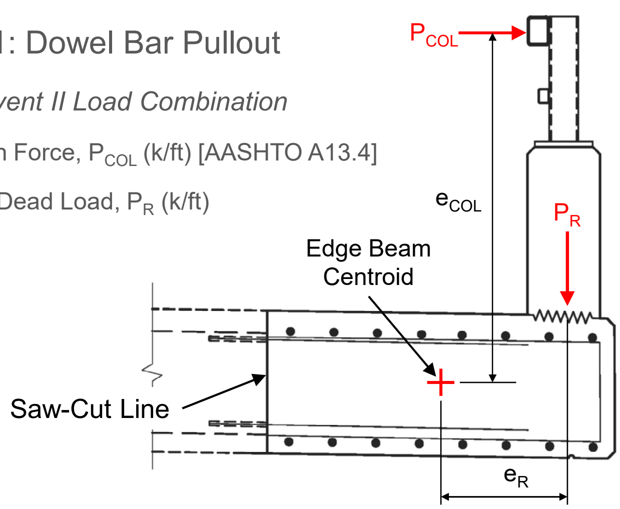
Dowel Bar Design

- Load Case 1: Dowel Bar Pullout
  - *Extreme Event II Load Combination*
    - Collision Force, P_{COL} (k/ft) [AASHTO A13.4]
    - Railing Dead Load, P_R (k/ft)



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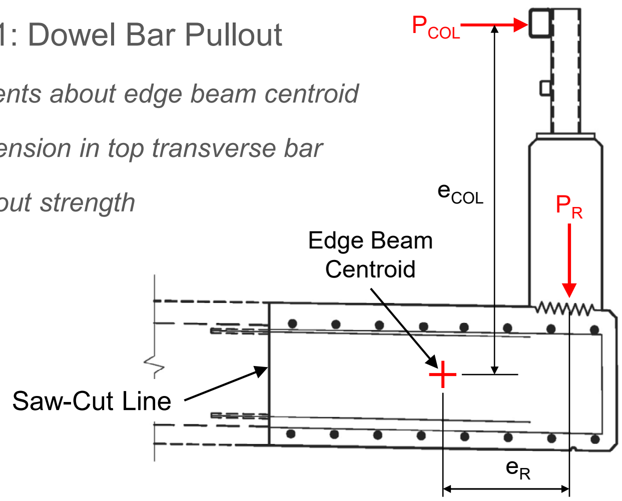
Dowel Bar Design

- Load Case 1: Dowel Bar Pullout
  - *Sum moments about edge beam centroid*
  - *Compute tension in top transverse bar*
  - *Check pullout strength*



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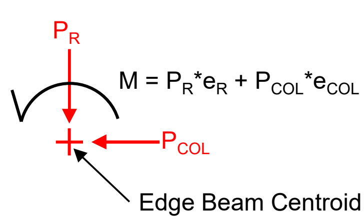
Resolution of Forces

- Determine pullout force in top transverse bar due to collision force and resultant moment.



- Collision force should be distributed longitudinally based on AASHTO A13.3.1-2.

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Determine Tension Force

$$T_u = \frac{P_{COL}}{2} + \frac{M}{d_f}$$

Where;

T_u	=	Top dowel bar pullout force
P_{COL}	=	Collision force
M	=	Resultant moment
d_f	=	Distance between tension force and centroid of compression block

Note: For extreme load combination, all load factors are 1.0

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Pullout Resistance

- AASHTO 5.13.2.3 refers to ACI 318-14 Chapter 17 for pullout strength equations for reinforced concrete.
- Limit States:
  - *Steel Strength in Tension* [ACI 17.4.1]
  - *Concrete Breakout Strength in Tension* [ACI 17.4.2]
  - *Bond Strength of Adhesive Anchor in Tension* [ACI 17.4.5]

    (Specify minimum pullout strength on plans)

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Steel Strength in Tension

$$\varphi N_{sa} = \varphi(A_{se,N} f_{uta}) \qquad \text{(ACI 17.4.1.2)}$$

Where;

N_{sa}	=	Nominal strength of anchor in tension
f	=	0.75 (ductile steel element in tension)
$A_{se,N}$	=	Effective Cross-Sectional Area of Steel Anchor
f_{uta}	=	Ultimate Tensile Strength (Conservatively use f_y)

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Concrete Breakout Strength

$$\varphi N_{cb} = \varphi\left(\frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b\right) \qquad \text{(ACI 17.4.2.1a)}$$

Where;

N_{cb}	=	Nominal Concrete Breakout Strength in tension
f	=	Determine by anchor condition and category [ACI 17.3.3]
A_{Nc}	=	Projected concrete failure area [ACI 17.4.2.1]
A_{Nco}	=	Ideal projected concrete failure area (ACI 17.4.2.1c)
y	=	Strength modification factors [ACI 17.4.2.5 thru 7]
N_b	=	Basic concrete breakout strength [ACI 17.4.2.2]

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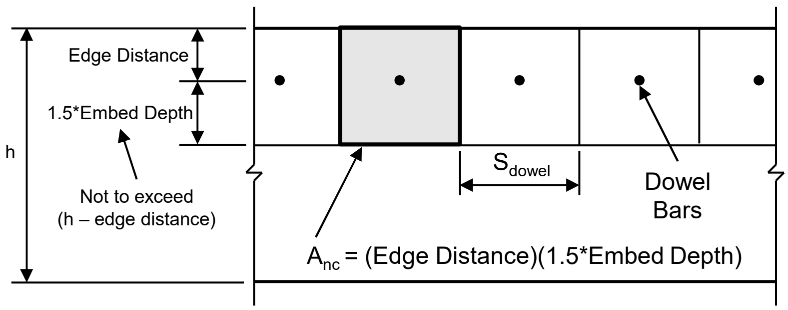
Concrete Breakout Strength

- Projected Failure Area, A_{nc} [ACI 17.4.2.1]
  - *A_{nc} approximates the breakout cone area as a rectangular area.*



Section Along Saw-Cut Line

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Pullout Resistance

- Determine steel and concrete resistances per foot for comparison to top dowel bar tension.

$$T_u \leq \varphi N_{sa} \frac{12\ in.}{Bar\ Spacing}$$

$$T_u \leq \varphi N_{cb} \frac{12\ in.}{Bar\ Spacing}$$

T_u = Top dowel bar pullout force

N_{sa} = Nominal Steel Strength of Single Anchor

N_{cb} = Nominal Concrete Breakout Strength

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Pullout Resistance

- Check Shear and Tension interaction [ACI 17.6]

$$\frac{N_{ua}}{\varphi N_n} + \frac{V_{ua}}{\varphi V_n} \leq 1.2 \qquad \text{(ACI 17.6.3)}$$

- Where;

f	=	Strength reduction factor [ACI 17.3.3]
N_{ua}	=	Maximum tension on dowel bar
N_n	=	Controlling tensile capacity [ACI 17.4.2]
V_{ua}	=	Maximum coincident shear on dowel bar
V_n	=	Controlling shear capacity [ACI 17.5]

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Dowel Bar Design

- Load Case 2: Interface Shear
  - *Strength I Load Combination*
  - *Design Force*
    - Wheel Load (1/2 axle load) [AASHTO 3.6.1.2.2]
    - Distribute load over tire area (10 in.) and project to mid-depth of slab [AASHTO 3.6.1.2.5]
  - *Place Wheel Load at saw-cut line for worst case loading*
  - *Design Shear = Factored Wheel Load*
  - *Check Interface Shear Resistance* [AASHTO 5.7.4]
  - *Check Anchor Shear* [ACI 17.5]

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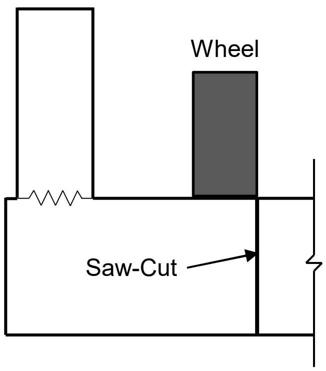
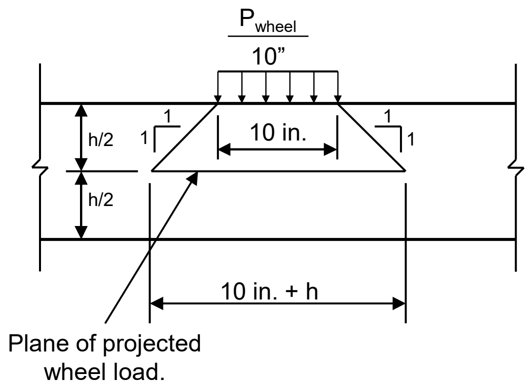
Loading Diagram



Section Through Edge Beam



Section Along Saw-Cut Line

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Interface Shear Resistance

$$\varphi V_{ni} = \varphi\left(cA_{cv} + \mu\left(A_{vf} f_y + P_c\right)\right)$$ (AASHTO 5.7.4.3-3)

Where;

- f = [AASHTO 5.5.4.2]
- c = Cohesion factor [AASHTO 5.7.4.4]
- A_{cv} = Area of concrete interface (AASHTO 5.7.4.3-6)
- m = Friction factor [AASHTO 5.7.4.4]
- A_{vf} = Area of inface shear reinforcement [AASHTO 5.7.4.2]
- f_y = Yield stress of reinforcement [AASHTO 5.7.4.2]
- P_c = Permanent compressive force normal to saw-cut [AASHTO 5.7.4.3]

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Anchor Resistance – Steel

$$\varphi V_{sa} = \varphi\left(0.6A_{se,V}f_{uta}\right) \quad \text{(ACI 17.5.1.2b)}$$

Where;

V_{sa} = Nominal strength of an anchor in shear

f = 0.65 (ductile steel element in shear)

$A_{se,V}$ = Effective Cross-Sectional Area of Steel Anchor

f_{uta} = Ultimate Tensile Strength (Conservatively use f_y)

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Anchor Resistance – Concrete

$$\varphi V_{cb} = \varphi\left(\frac{A_{Vc}}{A_{Vco}}\psi_{ed,V}\psi_{c,V}\psi_{h,V}V_b\right) \quad \text{(ACI 17.5.2.1a)}$$

Where;

V_{cb} = Nominal Concrete Breakout Strength in shear

f = Determine by anchor condition and category [ACI 17.3.3]

A_{Vc} = Projected concrete failure area [ACI 17.5.2.1]

A_{Vco} = Ideal projected concrete failure area [ACI 17.5.2.1]

y = Strength modification factors [ACI 17.5.2.6 thru 8]

V_b = Basic concrete breakout strength [ACI 17.5.2.2]

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Anchor Resistance – Pryout

$$\varphi V_{cp} = \varphi(k_{cp} N_{cp})$$ (ACI 17.5.3.1a)

Where;

V_{cp} = Nominal pryout strength

f = Determine by anchor condition and category [ACI 17.3.3]

k_{cp} = Strength modification factor [ACI 17.5.3.1]

N_{cp} = Controlling basic tension capacity [ACI 17.4.2.1 & 17.4.5.1]

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Summary of Design Considerations

- Sandblast saw-cut surface to promote concrete adhesion to existing concrete.
  - *Sandblasting does not change surface roughness condition.*
- For additional pullout capacity, can consider impact load spreading along the bridge rail.
- Specify minimum pullout strength of anchor on plans for adhesive anchor selection

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Summary of Design Considerations

- Bond strength of Adhesive Anchor Systems is manufacturer specific which is unknown to engineer.
- INDOT's Qualified Products Lists for Chemical Anchor Systems:

  (https://www.in.gov/indot/div/mt/appmat/appmat.htm)
- Designer should verify that required bond strength is attainable from QPL or the min. values provided in ACI Table 17.4.5.2 are used.

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Summary of Design Considerations

- Structures Committee is currently investigating Anchor System Design Data.
- Figure 412-3B to be removed.
- IDM 412-3.01(08) Anchor Systems for Reinforcement is being revised.

Bar Size	Hole Diameter (in.)	Embedment (in.)	Tension Ultimate Bond Strength (kip)		Shear Strength (kip)
			100% f_y	125% f_y	
#4	5/8	4½	12.0	15.0	2.6
#5	3/4	5¾	18.6	23.2	4.8
#6	1	6¾	26.4	33.0	7.4
#7	1 1/8	8	36.0	45.0	10.6
#8	1 1/4	9	47.4	59.2	14.4
#9	1 3/8	10½	60.0	75.0	18.7

Notes:
1. Values are based on the use of 60-ksi reinforcement.
2. Hole diameter and embedment depth shall be per the manufacturer's requirements. The values shown are general guidelines.
3. Anchors are considered 100% effective if the edge distance is equivalent to, or greater than, the standard embedment depth. The edge distance may be reduced to half the standard embedment depth if the strength is reduced linearly to 70%.
4. Anchors are considered 100% effective if the spacing is equivalent to, or greater than, the standard embedment depth. Spacing may be reduced to half the standard embedment depth if the strength is reduced linearly to 50%.

DESIGN DATA FOR ANCHOR SYSTEMS

Figure 412-3B

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