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**Design Philosophies & Associated Details of Steel Box
Girder Bridges -- Relevant Practice and Approaches**
August 17, 2021



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Course Description

Design Philosophies and Associated Details of Steel Box Girder Bridges – Relevant Practice and Approaches
August 17, 2021

This webinar will address the state of practice for designing and detailing straight and curved steel box girder bridges. There will be discussion on analytical approaches, geometry development (span configurations and typical sections), sizing of various elements, and how up-front decisions affect detailing and costs. Transportation and erection considerations and recommendations on how to approach large design-build projects involving numerous structures during the pre-bid stage under tight budgetary constraints will also be covered.



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Learning Objectives

- List the motivating factors for using box girders for a given project.
- Explain what levels of analysis might be used to design box girder bridges and identify any limitations for each type of analysis.
- Identify the primary components of box girder bridges and provide the most prominent design considerations for each.
- Describe some transportation and erection strategies for box girder bridges.



Design Philosophies & Associated Details of Steel Box Girder Bridges *Relevant Practice and Approaches*

August 17, 2021



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Presentation Outline

- ✓ Discuss functionalities
- ✓ Analytical methods
- ✓ Design approach of major elements
- ✓ Discuss some pros and cons
- ✓ Details and their rationale
- ✓ Transportation and handling issues
- ✓ Bid approach on Design-Build mega-projects




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Why tub girders?

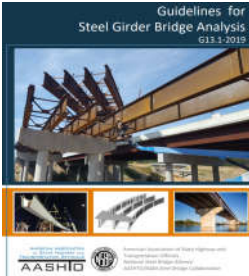
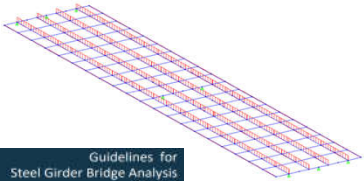
- ✓ **Ideal for curved bridges**
 - Extremely high torsional rigidity
 - Fewer x-frames and less deflection compared to plate girders
 - Higher lateral stiffness compared to I-girders
- ✓ **Aesthetics**
 - Seamless profile suited for urban aesthetics
- ✓ **Durability and maintenance**
 - Fewer exposed 'shelves' for debris to collect – less corrosion
 - Inside is dry – less corrosion – less painting
 - Closed tub - safe passage for easier inspection
- ✓ **Some disadvantages**
 - Extensive design effort
 - Higher fabrication costs



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Level of Analysis

- ✓ **Line girder analysis**
 - Primarily for straight bridges – not recommended for skewed and curved bridges
 - Torsional demands not reflected - M/R method used in the past to supplement the effect of curves
 - Predicted forces and deflections can be off substantially – x-frame fit-up issues
- ✓ **2-D Grid Analysis**
 - Simpler and easier to handle – not recommended for curved bridges
 - Does not adequately address deformations and x-sectional distortions
 - Top flange bracing is not modelled - need additional calcs
 - Distribution factors for LL shown in AASHTO Section 4.6.2.2.2
- ✓ **Plate and Eccentric Beam Analysis**
 - More refined than 2-D grid
 - Handles live load distribution better
 - Not recommended for excessively curved and skewed bridges



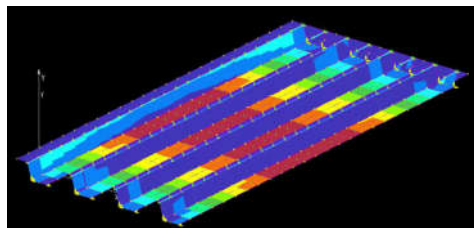
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Level of Analysis – (continued)

✓ 3-D FEM Analysis

- Ideal for major skewed and curved bridges
- Needs experience and engineering judgement
- Modelling is somewhat tedious and complex
- Requires pre- and post-processing
- Results are more reliable - addresses distortional behavior and forces in box



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Before you start....

Things to consider before you start crunching numbers

- Finite budget and time
- Design is complex and tedious and up-front planning is essential
- Start with the typical section – decide on the girder lines, spacing and overhang
- **Invest in the framing plan**
- Consider design and detailing issues
- Consider fabrication issues
- Evaluate transportation and constructability




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Box Shape


Box shape and web inclination considerations

- Longitudinal bending – depth of web
- Transverse stiffness – width of top and bottom flanges
- Torsional capacity – function of area A_o enclosed
- Span length and curvature
- 4:1 slope sets the optimal balance




No slope

- More I_x ; less I_y
- Narrow box width
- More girders / thicker deck



4:1 slope

- Balanced optimal shape
- Fabricator's choice



3:1 slope

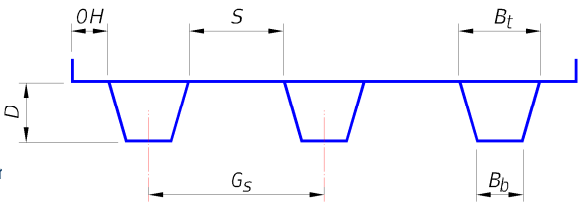
- More I_y ; less I_x
- Require thicker flanges

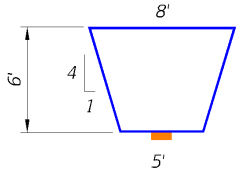
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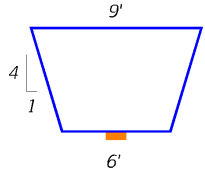
Bridge Typical Section

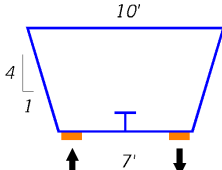
Factors governing bridge typical section

- **Tub Depth – D**
 - AASHTO Span/depth ratio and deflection criteria are for I-girders only. Box girders can be shallower
 - Min. Clear Depth = 6 ft., for access & maintenance
- **Tub Width – B_t**
 - Fewer lines of girders does not necessarily mean cheaper bridge
 - Overall box width B_t and bottom flange width B_b may control typical section







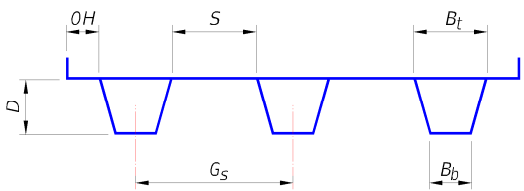



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Bridge Typical Section

Factors governing bridge typical section

- **Tube Spacing – G_s**
 - AASHTO 6.11.2.3 – use tub width to tub spacing ratio only when using AASHTO LL distribution factors - uneconomical
 - Differential deflection - effect on external x-frames and deck
 - Deck thickness and rebars
 - Stay-in-place forms (SIPF) sizing
- **Deck Overhang – OH**
 - Controlled by box width B_t
 - Torsional moment in external girder due to construction loads (Bid-Well deck paver)
 - Controls external cross-frame spacing

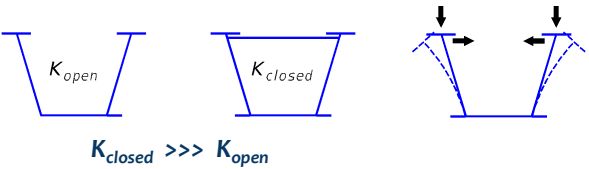



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Top Flange Lateral Bracing

Open and closed sections


- Lateral bracing closes the box
- Closed box offers high torsional stiffness
- For curved box girders use full length lateral bracing



Lateral bracing trusses



Warren Truss



Pratt Truss

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Top Flange Lateral Bracing – continued

Force resolution in trusses

Warren Truss

Pratt Truss

Red = Tension
Green = Compression

$F_s = (F_1 - F_2) \sin \alpha$

$F_s = \text{larger of } F_1 \sin \alpha \text{ OR } F_2 \sin \alpha$

Single-Diagonal

Double-Diagonal

4-Diagonal

Figure C6.7.5.3-1—Warren-type Single-diagonal Top Lateral Bracing System for Tub Section Member: Plan View

Figure C6.7.5.3-2—Pratt-type Single-diagonal Top Lateral Bracing System for Tub Section Member: Plan View

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Top Flange Lateral Bracing – continued

Equivalent Plate Thickness (Kollbrunner and Basler)

t^* = equivalent plate thickness;
 E = Modulus of elasticity (29000 ksi for steel);
 G = Shear modulus (11200 ksi for steel);
 s = panel length (spacing between struts);
 b = strut length (width between flanges);
 L_d = diagonal length = $\sqrt{s^2 + b^2}$;
 A_d = area of diagonal;
 A_s = area of strut;
 A_f = area of girder top flange (one flange).

➤ **Warren Truss**

$$t^* = \frac{E}{G} \frac{sb}{\left[\frac{L_d^3}{A_d} + \frac{s^3}{3} \left(\frac{2}{A_f} \right) \right]}$$

➤ **Pratt Truss**

$$t^* = \frac{E}{G} \frac{sb}{\left[\frac{L_d^3}{A_d} + \frac{b^3}{A_s} + \frac{s^3}{12} \left(\frac{2}{A_f} \right) \right]}$$

ACTUAL – truss bracing

IDEALIZED – fictitious thin plate

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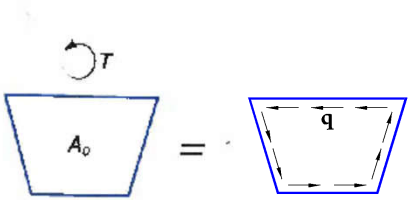
Top Flange Lateral Bracing – continued

Resolution of torsion to shear

Note: Method to calculate top flange lateral forces when using a 2-D analysis is provided by Helwig et. Al. See References.

Torsion → Shear Flow → Shear

Shear flow: $q = T/2A_o$



*Brace design force = $q * B_t$*

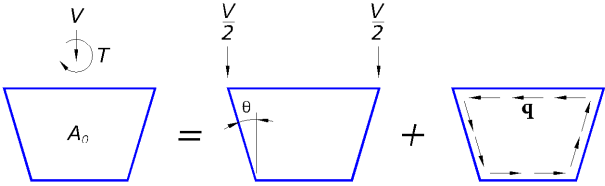
B_t = top width of box

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Sizing Web and Top Flange Plates

Web plates

- Vertical shear (static + elastic effect)
- Torsional shear



*Web design shear = Elastic shear $V/(2\cos\theta)$ +/- Torsional shear ($q*L$)*

(both webs should be designed for the higher value)

L = inclined web length

Top flange plates

- Longitudinal bending stress
- Lateral bending stress
 - Skew and/or curvature
 - Lateral bracing forces
 - Eccentric construction loads
 - Horizontal component of inclined web

Solution: Provide wider flanges

- Higher I_y - more lateral stiffness
- Can directly connect bracing to flange – avoid gussets

Caution: During preliminary analysis leave room for flange lateral stress

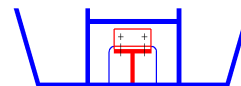
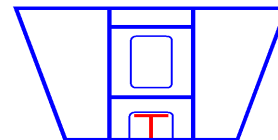
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Sizing Bottom Flange Plates

Bottom flange plates

- Prone to buckling (compression and torsional shear)
- Start with $b/t = 45$ and proceed with AASHTO 6.11.8.2
- Longitudinal stiffeners - Fabrication is labor-intensive and costly
 - Fabricate and weld longitudinal stiffener
 - Provide transverse stabilizing stiffeners and connections
 - Cut-outs in bulk-heads for longitudinal stiffeners to pass thru
 - Provide splice beyond the point of contra-flexure in the tension regions
 - Provide radial coping at termination to improve fatigue characteristics
- Other issues –
 - thin plate distortion and correction, deformed appearance after final coat
 - elaborate testing procedures for stiffener termination
 - long term inspection and maintenance costs – also a tripping hazard

Avoid longitudinal stiffeners if possible. If unavoidable....try to limit it to one...

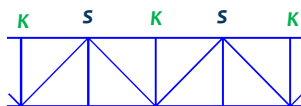


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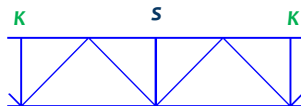
Internal Cross Frames

Internal cross frames - K

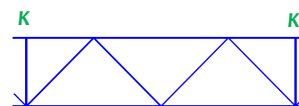
- Prevents box distortion primarily in non-comp stage
- Stiffens top flanges against lateral bracing forces
- Recommend K-frames – allows easier access
- Cross frame spacing
- Place cross frame adjacent to field splice for stability during shipping



(for curved bridges)



(for tangent bridges)



Note: Internal x-frame spacing is limited to 40' (max)

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External Cross Frames

External cross frames

- Controls relative disp. and twist of girders during deck pour
- Prevents uneven deck thickness and bolt fit-up problems
- Typically provided every quarter or third points for curved girders
- External and internal cross frames should line-up

Is it worth removing external cross-frames ?

- Removal of external cross frames may not be cost-effective
- Released forces are transferred to deck



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Plate Diaphragms

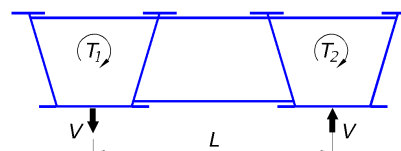
- ✓ Typically provided over piers and end bents
- ✓ Provides torsional equilibrium thru shear stiffness of plates



External Plate Diaphragm



Internal Plate Diaphragm



$$V = (T_1 + T_2) / L$$



- ✓ Provide at least 18" space between back wall and diaphragm at end bents for inspection and maintenance

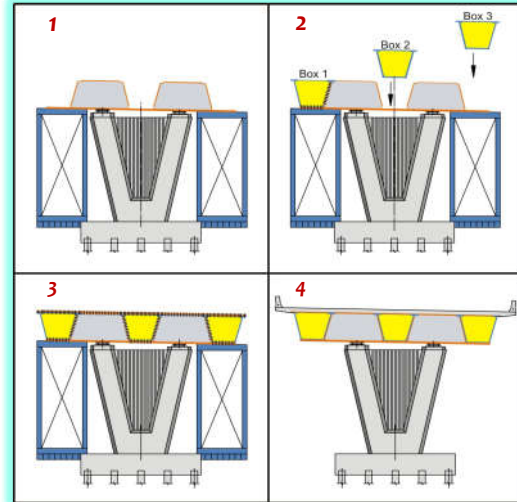
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Integral Diaphragms

Fracture critical : 2 primary configurations

➤ Continuous girders with discontinuous diaphragms

- Lighter splices
- Slows down construction
- Provide access holes at girder ends



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Integral Diaphragms – continued

➤ Continuous diaphragms with discontinuous girders

- Faster construction over traffic – ideal for braided ramps
- High moment connections – heavier splices
- Provide access hole at diaphragm ends



Note: Pictures are shown for plate-girders
but concept is similar for box girders

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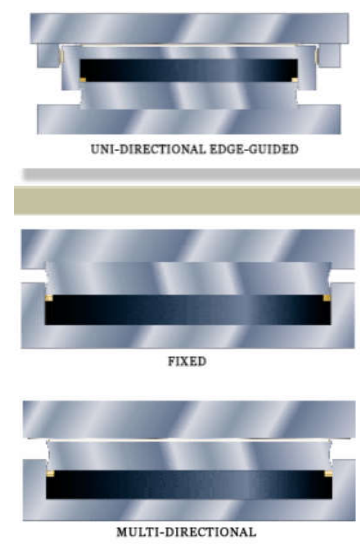
Bearings

Elastomeric or multi-rotational bearings ?

- Consider elastomeric bearings for tangent bridges – check load limits
- Multi-rotational bearings for bridges with excess skew and curve

Single or double bearings per box?

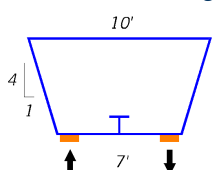
- Single bearing is preferred – if practical
- Bridges with skewed piers – girder may not bear evenly on both bearings
- Bridges on tight curves – one of the two bearings may experience uplift



UNI-DIRECTIONAL EDGE-GUIDED

FIXED

MULTI-DIRECTIONAL




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Choice of Bearings


Choice of Bearing Restraints

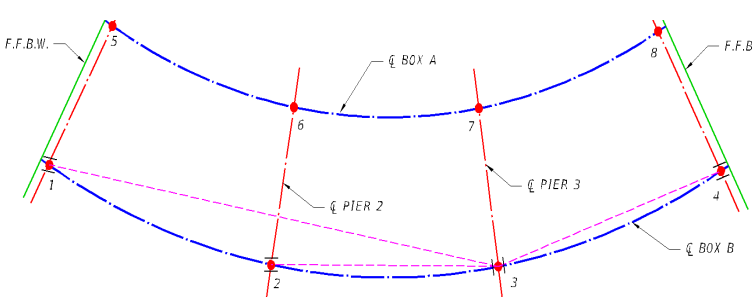
- Fixed, Guided and Non-Guided (free)
- Role of the fixed bearing
- Elimination of fixed bearings may relieve stresses in highly curved bridges
 - Expansion of structure articulated around Bearing # 3 - the pivotal bearing
 - Locked-in stresses in diaphragms reduced
 - Rebound forces from inner line of bearings controlled

Guided



Free





LEGEND

- GUIDED BEARING
- NON-GUIDED BEARING

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Transportation and Erection

Size and weight restrictions (SDG)

- Max. Length = 130 ft. ; Max. Width = 16 ft.; Max. weight = 160,000 lb
- Design-Bid-Build - EOR accommodates restrictions up-front in design
- Design-Build – Restrictions are removed. Responsibility shifts to Contractor who coordinates with Permits Office up-front



Steerable Dollies

Innovative 'means and methods'

- Rear-steerable dollies– negotiates sharp corners
- Air-splicing or splicing on ground – eliminates shoring
- Beam Lifters / Shifters – works in cramped spaces below power lines



Splice on ground and lift with crane



Air-splice



Beam Lifters / Shifters

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Estimating Quantities for Design-Build Mega-Projects

Step-by-step approach for estimating quantities

➤ Geometry

- Separate straight bridges from curved bridges – curved bridges require additional framing
- Separate single span bridges from continuous bridges – single span bridges are not cost-efficient structures
- Identify bridges with disproportionate span balancing – roadway and interchange geometry often controls

➤ Thumb-rules for sizing members Should serve for 80% of the bridges

- Tub width (B_t): Use 9' as starting point. Curved 2-lane ramps are tricky.
- Tub clear spacing S : Use $1.25 B_t$ as a starting point. Try not to exceed 14'. AASHTO guidance is conservative
- Deck overhang OH: Try not to exceed 5'-6"
- Top flanges: Width range = 18" to 36" ; Thickness range = 7/8" to 3 3/4"
- Bottom flanges: Width range = 45" to 100" , Thickness range = 3/4" to 2 3/4"
- Webs: Depth range = 6' to 10' ; Thickness range = 5/8" to 1" (use 8" – 12" less than AASHTO span/depth ratio criteria)

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Estimating Quantities for Design-Build Mega-Projects

Thumb-rules for sizing members (continued)

➤ Steel weight (lbs)

- Calculate total steel weight for girders only
- Add 5% for stiffeners, splice plates and sole plates
- Add 16% to 22% for lateral bracing, x-frames and diaphragms

➤ Steel weight (lbs per sq/ft. of deck area)

- For tangent and slightly curved bridges with spans up to 200 feet : 45 psf to 55 psf
- For tight curves and/or spans up to 275 feet: 55 psf to 65 psf
- For complex bridge geometry with tight curves and skewers or gores: 60 psf to 75 psf

➤ As a final step add 2-3% to account for uncertainties

It is a great idea to get your hands on plan sets for similar bridges (if available) and run quantity checks for validation.

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Hopefully, in the end...you can say....



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References

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- Macdonald, E. R. Analysis of Open Steel Box Sections with Bracing, Masters Thesis, Lehigh University
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- Dey, Gautom : Paper # 02-3302: I-95 & Okeechobee Blvd.: Transportation Research Board A2C02 - Steel Bridges, 2002
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- Chen, B.S., Yura, J.A., Williamson, E.B., and Frank, K.H. Top-Lateral Bracing Systems for Trapezoidal Steel Box Girder Bridges; Report No. FHWA/TX-07/0 -1898-4

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Questions ?



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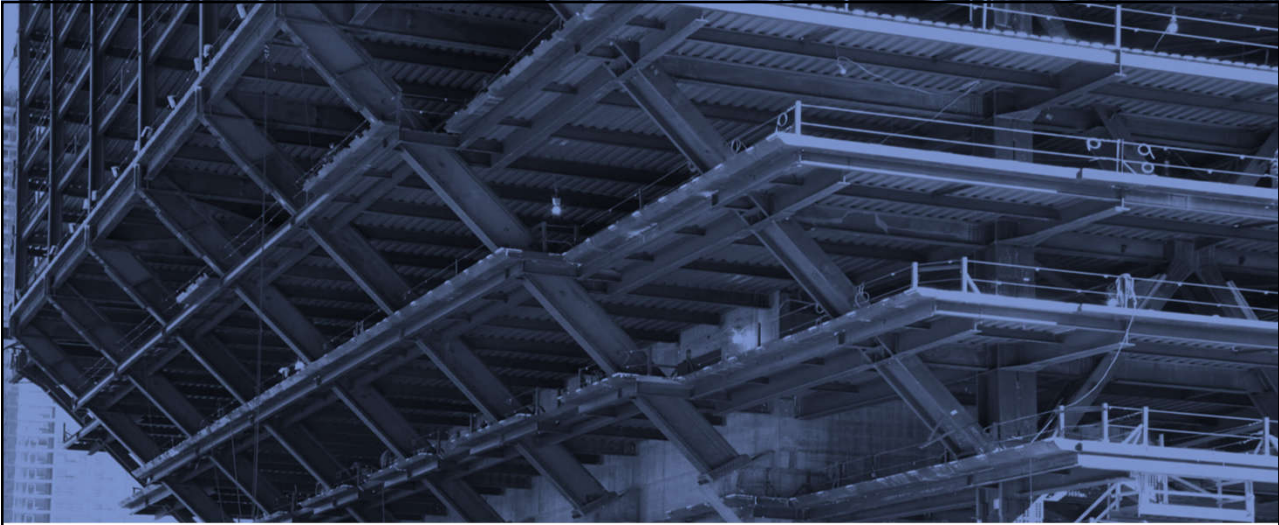
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