# Implementing Precast, Prestressed Concrete Bridge Girder Design for Lateral Stability

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# Introduction

- Motivations for lateral stability design
- AASHTO LRFD BDS updated stability requirements (9th Edition, 2020)
- WSDOT stability design practices
- PCI Stability Subcommittee Update

# This is highly undesirable

# Motivation

- Stability concerns are strongly emphasized by industry
  - PCI has published "*Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders*"

- Updates to the AASHTO LRFD BDS, 9th Edition emphasize stability concerns

- Current trends
  - Girder lengths are increasing (220+ feet)
  - Stability is problematic at modest span lengths for I-Beams (AASHTO Type I-IV)
  - Issues
    - SAFETY
    - stability failure has occurred
    - re-design after bidding because girders can't be lifted or transported
    - contractors and fabricators don't want to be EOR for the girders
    - change orders, additional reviews, increased cost, schedule implications

# Engineering Roles

- Design Engineering for Service
  - Engineering performed by the engineer-of-record to ensure the in-service structure is safe, durable, and meets all design requirements (AASHTO, BDM, etc.)

- Design Engineering for Constructability
  - Built-in allowances provided in the design (explicitly or implicitly) to ensure a precast girder is able to be constructed with available means and methods at a reasonable cost. Typically performed by the engineer-of-record as needed to minimize changes under contract

- Construction Engineering
  - Engineering performed by the contractor to ensure actual construction means and methods do not damage the bridge or otherwise prevent the bridge from functioning as intended

# Current LRFD Specifications (8th Edition)

Specified since 1st Edition 1994

**1.3.1—General**

Bridges shall be designed for specified limit states to achieve the objectives of constructibility, safety, and serviceability, with due regard to issues of inspectability, economy, and aesthetics, as specified in Article 2.5.

**2.5.1—Safety**

The primary responsibility of the Engineer shall be providing for the safety of the public. The Owner may require a design objective other than structural survival for an extreme event.

**2.5.3—Constructibility**

Constructability issues should include, but not be limited to, consideration of deflection, strength of steel and concrete, and stability during critical stages of construction.

**5.5.1.1—Limit-State Applicability**

Structural components shall be proportioned to satisfy the requirements at all appropriate service, fatigue, strength, and extreme event limit states at all stages during the life of the structure. Unless specified otherwise by the Owner, the load combinations and load factors specified in Section 3 and elsewhere in this section shall be used.

Prestressed concrete structural components shall be proportioned for stresses and deformations for each stage that may be critical during construction, stressing, handling, transportation, and erection as well as during the service life of the structure of which they are part.

**5.5.4.3—Stability**

The structure as a whole and its components shall be designed to resist sliding, overturning, uplift and buckling. Effects of eccentricity of loads shall be considered in the analysis and design.

Buckling of precast members during handling, transportation, and erection shall be investigated.

# Updated LRFD Specifications (9th Edition)

**5.5.4.3—Stability**

The structure as a whole and its components shall be designed to resist sliding, overturning, uplift and buckling. Effects of eccentricity of loads shall be considered in the analysis and design.

Buckling and stability of precast members during handling, transportation, and erection shall be investigated.

**5.9.4.5** Temporary Strands

Temporary top strands may be used to alleviate tensile stresses in precast prestressed girders during handling and transportation. These strands may be pretensioned or post-tensioned prior to lifting the girder from the casting bed or post-tensioned immediately prior to transportation of the girder. Detensioning of temporary strands shall be shown in the construction sequence and typically occurs after the girders are securely braced and immediately before construction of intermediate diaphragms, if applicable.

C5.9.4.5 Temporary Strands

The stability of slender precast girders is improved when lifting and transportation support points are moved away from the ends of the girder. The consequence of having a shorter span between support points is reduced dead load stresses to balance the stresses due to pretensioning and thus excessive tensile stresses in the top flange and compressive stresses in the bottom flange may develop. Temporary strands placed in the top flange of the girder alleviate these excessive stresses and reduce the required strength at prestress transfer. Temporary strands in the top flange balance a portion of the primary prestressing and reduce camber and camber growth due to creep.

# Updated LRFD Specifications (9th Edition)

**5.12.3.2—Precast Beams**

*5.12.3.2.1—Preservice Conditions*

The preservice conditions of prestressed girders for shipping and erection shall be the responsibility of the contractor.

Stability during handling, transportation, and erection can govern the design of precast, prestressed girders. Precast members should be designed such that safe storage, handling, and erection can be accomplished by the contractor using reasonable means and methods.

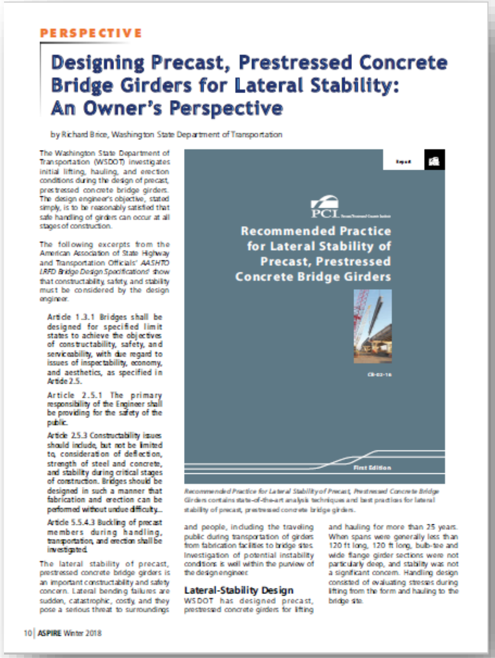
C5.12.3.2.1

AASHTO LRFD Bridge Construction Specifications place the responsibility on the Contractor to provide adequate devices and methods for the safe storage, handling, erection, and temporary bracing of precast members.

Lateral bending stability analysis may be based on the "Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders", Precast Concrete Institute, Publication CB-02-16-E. A detailed design example is presented in Seguirant, Brice, and Khaleghi, (2009).

# Stability design at WSDOT

- WSDOT design practices have adapted to changes in the precast industry
- See ASPIRE Magazine, Winter 2018 (Owner's Perspective)



PERSPECTIVE

## Designing Precast, Prestressed Concrete Bridge Girders for Lateral Stability: An Owner's Perspective

by Richard Brice, Washington State Department of Transportation

The Washington State Department of Transportation (WSDOT) investigates initial lifting, hauling, and erection conditions during the design of precast, prestressed concrete bridge girders. The design engineer's objective, stated simply, is to be reasonably satisfied that safe handling of girders can occur at all stages of construction.

The following excerpts from the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*¹ show that constructability, safety, and stability must be considered by the design engineer.

> Article 1.3.1 Bridges shall be designed for specified limit states to achieve the objectives of constructability, safety, and serviceability, with due regard to issues of inspectability, economy, and aesthetics, as specified in Article 2.5.
>
> Article 2.5.1 The primary responsibility of the Engineer shall be providing for the safety of the public.
>
> Article 2.5.3 Constructability issues should include, but not be limited to, consideration of deflection, strength of steel and concrete, and stability during critical stages of construction. Bridges should be designed in such a manner that fabrication and erection can be performed without undue difficulty...
>
> Article 5.5.4.3 Buckling of precast members during handling, transportation, and erection shall be investigated.

The lateral stability of precast, prestressed concrete bridge girders is an important constructability and safety concern. Lateral bending failures are sudden, catastrophic, costly, and they pose a serious threat to surroundings and people, including the traveling public during transportation of girders from fabrication facilities to bridge sites. Investigation of potential instability conditions is well within the purview of the design engineer.

PCI
Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders
First Edition

*Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders* contains state-of-the-art analysis techniques and best practices for lateral stability of precast, prestressed concrete bridge girders.

### Lateral-Stability Design

WSDOT has designed precast, prestressed concrete girders for lifting and hauling for more than 25 years. When spans were generally less than 120 ft long, 120 ft long, bulb-tee and wide flange girder sections were not particularly deep, and stability was not a significant concern. Handling design consisted of evaluating stresses during lifting from the form and hauling to the bridge site.

10 | ASPIRE Winter 2018

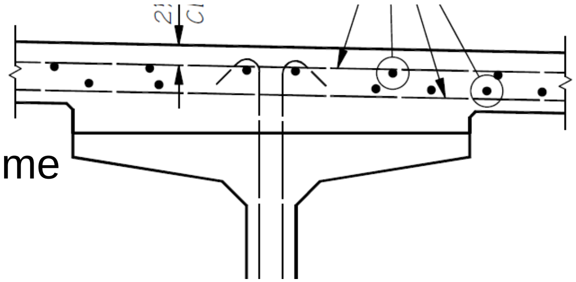
## Goals

Engineer-of-record must be satisfied that girders can be safely fabricated, lifted, transported, and erected by available means and methods.

Avoid post-bid design modifications.

# Post-bid design modifications

- **Design modifications after bidding are undesirable**
- Re-design required if capabilities of manufacturing facility are exceeded
- Changing prestressing arrangement (re-stranding and/or adding temporary top strands) effects initial concrete strength and camber
- Increased initial strength means longer curing time and can negatively impact production rate



- Changes to camber effects haunch depth and concrete volume
  - This can be a significant quantity of material
  - Can the girders carry the extra dead load?
  - Who pays for the extra material?
  - What happens to bearing seat elevations and profile grade?

# Optimized fabrication design

- WSDOT worked with local fabricators to develop a design methodology which includes flexibility for optimizing fabrication and addresses stability concerns

- Goal is to determine least $f'_{ci}$ while simultaneously placing the least possible demand on the stressing bed – while achieving adequate stability

- “Design optimization for fabrication of pretensioned concrete bridge girders: An example problem”, Brice, et. al. PCI Journal Fall 2009

# Design Procedure

Temporary Top Strands (TTS) can be:

- pretensioned
- post-tensioned before lifting from bed
- post-tensioned after lifting from bed
- post-tensioned before hauling

- Caution: TTS can change camber

1) Design for final service conditions
Number of permanent strands

2) Design for lifting w/o Temp Strands
Lifting embedment locations
Arrangement of permanent strands
Greatest strength at lifting ($f'_{ci}$)

3) Design for hauling
Truck support locations
Temporary strand requirements
Strength at hauling ($f'_{c}$)

Temp Strands Required?

Yes

4) Design for lifting w/ Temp Strands
Lifting embedment locations
Least strength at lifting ($f'_{ci}$)

No

5) Check design for final strength and service conditions

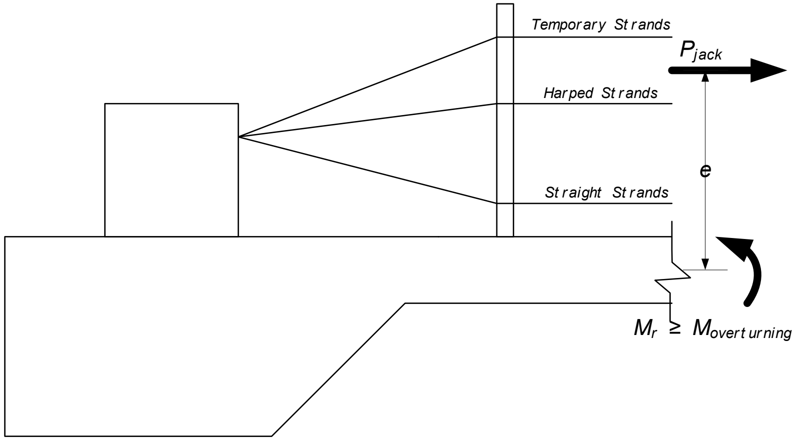
# Standard Design Conditions

- Initial lifting from casting bed
  - No wind
- Storage
  - Assume rigid dunnage and seating outboard of lift points
  - Not explicitly considered
- Hauling
  - Case 1 – Normal crown slope – check stresses
    - 2% crown slope
    - ±20% vertical impact
  - Case 2 – Max superelevation – check stresses and stability
    - 6% superelevation
    - No impact
- Erection
  - Assume same lift conditions as initial lift
  - No wind
  - Not explicitly considered

# Temporary top strands

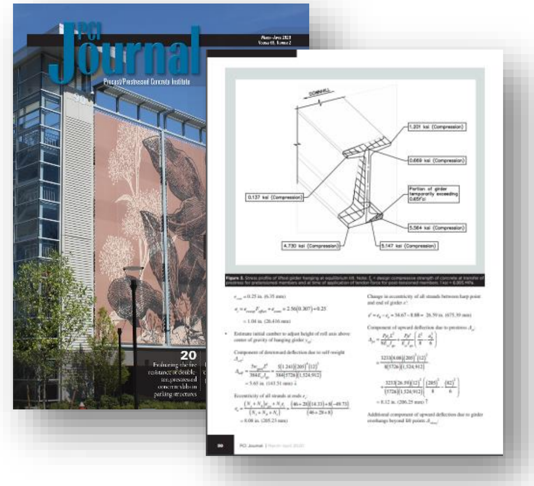
- (6) 0.6”ϕ strands are common (0.7”ϕ can be used)
- Significant force at a high eccentricity above the stressing bed floor
- Tall girders, high prestressing, and TTS create fabrication challenges
- Girders need to be fabricated in existing facilities

- Post-tension option reduces demand on casting system
- PT TTS can be installed at different times depending on need and fabrication demands

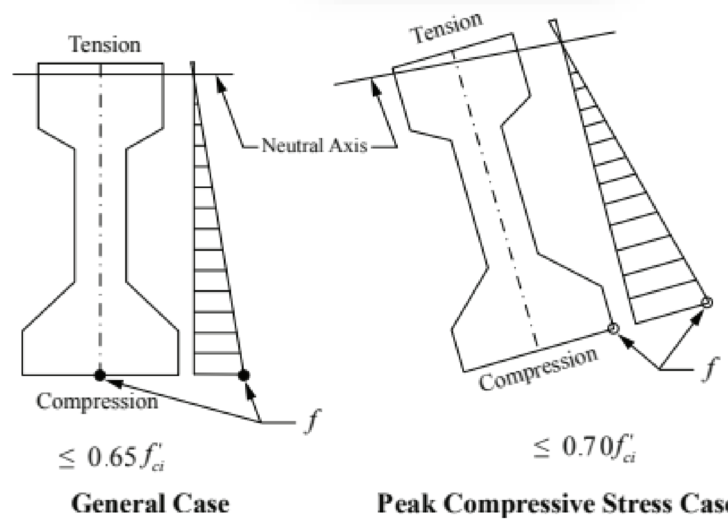



TTS raise eccentricity and increase overturning moment on stressing bed

# Compression Stress Limit



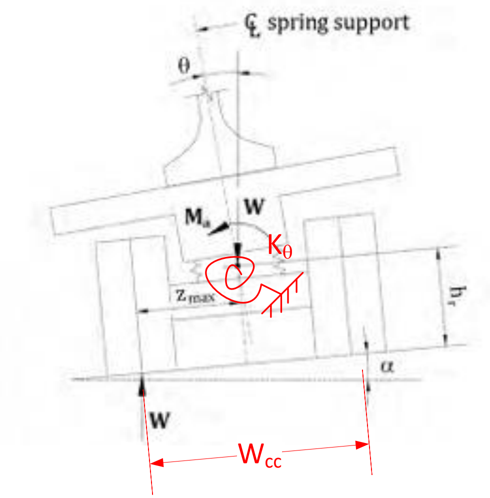

- PCI Recommended Practice had unintended consequence of increasing concrete strength requirement
- WSDOT and fabricators developed rational approach to provide relief
  - See PCI Journal, March-April 2020, Seguirant, et. al.
- General case (no tilt or lateral loads)
  - $0.65f_c$
- Peak Compressive Stress Case (tilt/lateral loads)
  - $0.70f_c$
- Passed T-10, adopted for LRFD 10th Edition – 2023



# Haul truck characteristics

- WSDOT approach - Design to least capable haul truck
- Gives the fabricator/hauler maximum flexibility
- Use least value of $K_\theta$ from the table below along with the corresponding $W_{cc}$ that provides adequate stability

| $K_\theta$ (k-in/rad) | $W_{cc}$ (in) |
|---|---|
| 40,000 | 72 |
| 50,000 | 72 |
| 60,000 | 72 |
| 60,000 | 96 |
| 70,000 | 96 |
| 80,000 | 96 |




- For Step 3 in design procedure, use parameters from row 1, then row 2, and so on, until stress and stability requirements are satisfied

# Haul truck characteristics

- Where did the WSDOT haul truck parameters come from?

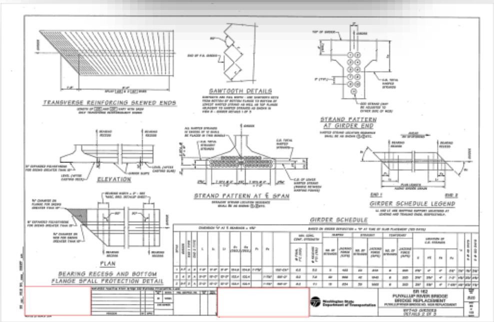
- Local fabricator worked with their preferred hauler and measured equipment
- $K_\theta$ was determined using the methods described by Mast
  - Rounded down to conservative values
- Geometric parameters were determined from direct measurement

- National guidance for haul truck characteristics are not available
  - Reported values are from one fabricator and one hauler in Washington State
  - PCI Stability Subcommittee has initiated research project to develop national guidance
  - PCI is currently soliciting RFPs

# Communicating assumptions

- WSDOT Standard Specifications provide
  - stress limits and stability requirements
  - assumed conditions and general parameters
  - tolerances

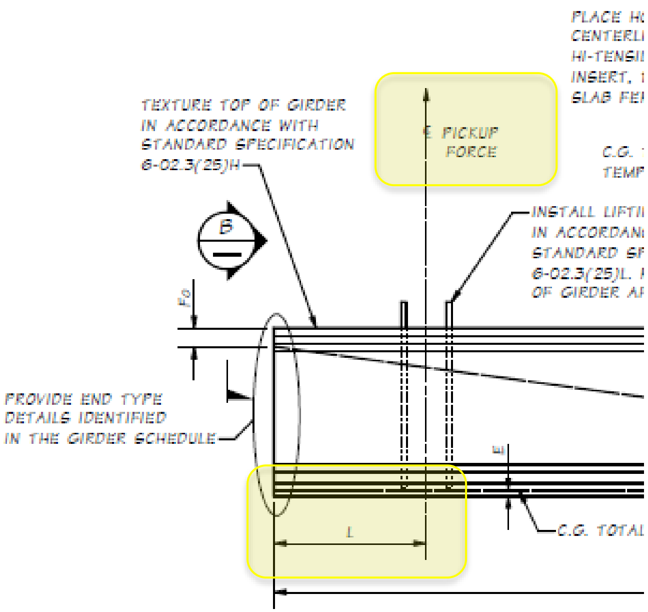

- Contract girder schedule lists job specific information
  - Lift/Bunk points
  - Camber
  - Assumed haul truck characteristics

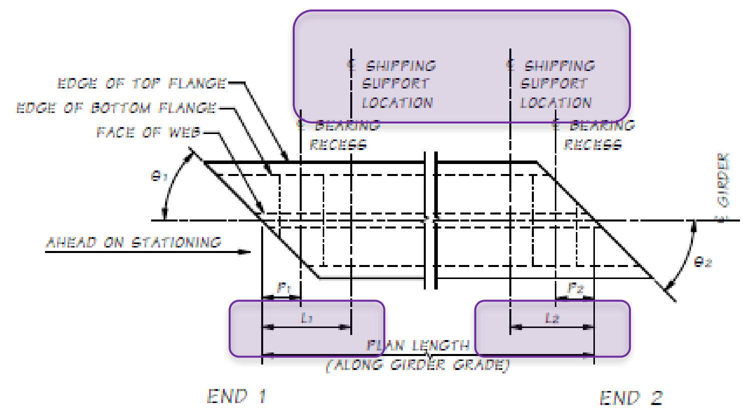



- Contractor must submit PE stamped handling plans when deviating from the contract
  - Calculations must follow PCI recommendations and WSDOT policy

# Job specific information

| SHIPPING AND HANDLING DETAILS | | | | | |
|---|---|---|---|---|---|
| MAXIMUM MIDSPAN VERTICAL DEFLECTION AT SHIPPING | L | $L_1$ | $L_2$ | $K_\theta$ MINIMUM SHIPPING SUPPORT ROTATIONAL SPRING CONSTANT | $W_{cc}$ MINIMUM SHIPPING SUPPORT CNTR.-TO-CNTR. WHEEL SPACING |
| . | . | . | . | . | . |



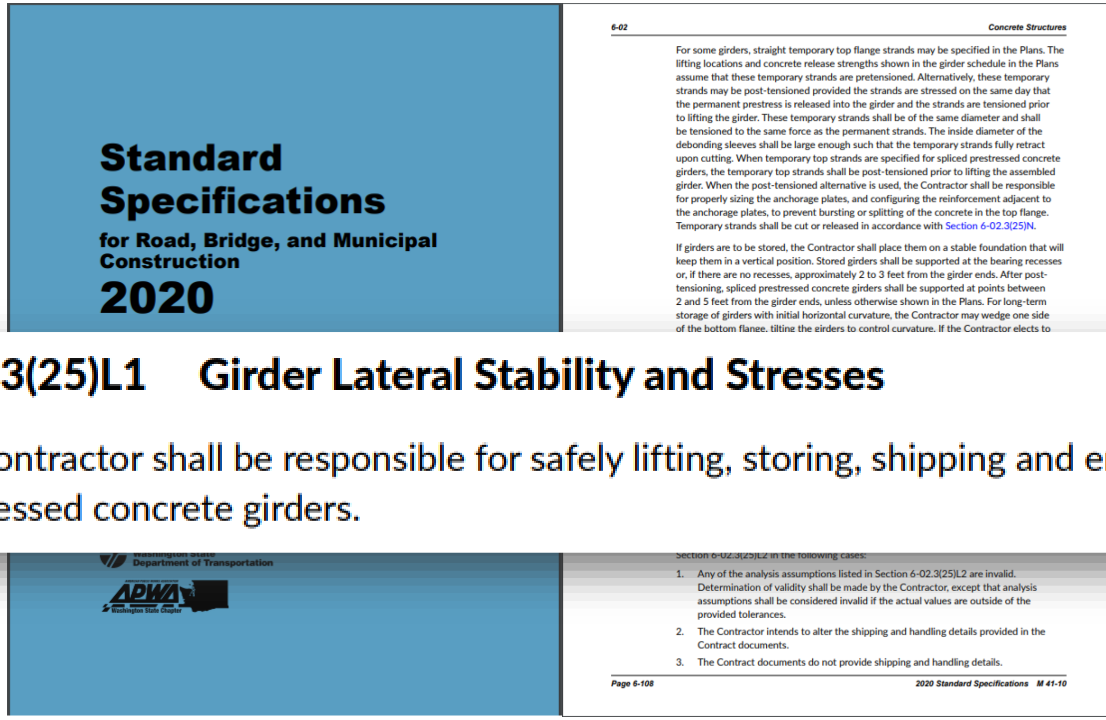

GIRDER PLAN

# Does the owner/agency take on risk by listing assumptions?

- I'm not a lawyer so, maybe…
- WSDOT has a long history of providing handling information in plan sets and is comfortable with our system

- Some owner/agencies don't want to share assumptions – That's Fine!
  - The primary objective is to design girders for stability so that they are constructable
  - LADOT designs for stability, but does not provide lifting/bunking information.

# Responsibility




## 6-02.3(25)L1 Girder Lateral Stability and Stresses

The Contractor shall be responsible for safely lifting, storing, shipping and erecting prestressed concrete girders.

# Designing for stability


- Designing for stability and optimized fabrication utilizes complex iterative analytical procedures
- Software can be used to quickly arrive at acceptable design solutions

- WSDOT design tools – part of the BridgeLink suite
  - PGSuper – precast/prestressed girder design with integrated stability analysis
  - PGSplice – precast spliced girder design with integrated stability analysis
  - PGStable – stand-alone girder stability analysis
  - www.wsdot.wa.gov/eesc/bridge/software

- BridgeSight Inc. – BridgeLink Professional
  - FIB, PCEF, and other DOT girder shapes
  - Customized configurations for your DOT’s standards
  - Support and Training
  - www.bridgesight.com

# PCI Stability RP2

- Theory
  - Clarify frequently mis-understood details
  - Replace iterative methods with closed form equations
- Update to current standards
  - LRFD compression limits
  - Designing for stability
- Lateral Loads
  - Sensitivity to wind and centrifugal forces
  - Guidance
- Lateral Bracing
  - Need for external bracing systems
  - Types of bracing systems (beams, stiffening truss, king-post)
  - Design Guidance
- Haul Truck Parameters – Research Project
  - National guidance for establishing parameters (rotational stiffness)
  - Specifying and verifying haul truck meets requirements under contract

# Questions?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