



# Producing Level Slab on Metal Deck Floors

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THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

 **CONCRETE  
CONVENTION**



## Construction of elevated concrete slabs

Understanding the effect of structural systems

By Bruce A. Saperman

No one can design and build an elevated concrete slab that is flat, level, of uniform thickness, and at the specified elevation. That's why American Concrete Institute (ACI) tolerance documents spell out permissible variations in flatness, levelness, slab thickness, and elevation. Even with these tolerances, however, holding an acceptable level of slab can be tricky. Many elevated slabs are cast and some may deflect over time. And because of newly developed measurement methods, tolerances are increasingly enforced than ever before. When tolerances aren't met, the result is often a feud among the owner, engineer and contractor.

To avoid getting blamed in a dispute over slab tolerances, engineers and contractors need to know how design and construction decisions affect variations in slab dimensions and location.

### Flat versus level

Flat refers to smoothness of the floor's top surface. A concrete slab's flatness is mainly affected by the finishing operations that occur after the initial strikeoff. Controlling bleeding, straightening and troweling is the key to improving flatness.

Level refers to how close the floor surface is to being horizontal. Forming, shoring, beam number, screed position, concrete placing, and

strikeoff operations determine the floor's levelness.

Figure 1 shows the differences among flatness, levelness, and elevation control. A floor can be flat

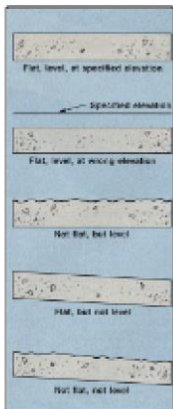


Figure 1. Differences among flatness, levelness, and elevation control.

and level or flat but not level, or level but not flat, or level and flat but not at the specified elevation.

This article discusses effects of design and construction methods on slab levelness and elevation control during and after construction. Effects of concrete placing and finishing operations on floor flatness will be discussed in a subsequent article.

### Contractor and engineer responsibilities

An out-of-level elevated slab may be caused by:

- Deflection of formwork and shoring during concrete placement
- Deflection of unshored structural members during concrete placement
- Deflection of the hardened concrete when supporting formwork is removed and the structure begins to carry its own weight

The contractor is usually responsible for controlling deflections of formwork and shoring that occur during concrete placement.

For unshored construction, such as some composite slabs, the responsibility for controlling deflection is always clear. If a slab is out of level, the condition might be traced to structural design of the

## Construction of elevated concrete slabs

Measuring and evaluating quality

By Eldon Topping and Bruce Saperman

Most contractors and engineers agree that elevated slabs don't always deliver as intended. As a result, even a carefully placed and finished floor slab may be out of tolerance, especially with regard to elevation control, levelness, and slab thickness. That's why the first elevated slab pour on a project is only the beginning of a trial-and-error process. The most important work, that of measuring and evaluating behavior of the existing slab, lies ahead.

Measurements are necessary to identify the areas in which practice departs from theory and to determine what adjustments are needed to improve the quality of the next concrete slab placement. It's this continuous cycle of placement, assessment, evaluation, and adjustment that produces high-quality elevated concrete slabs and satisfied owners.

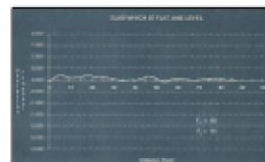
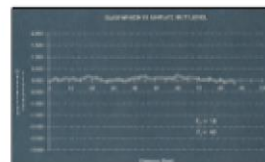
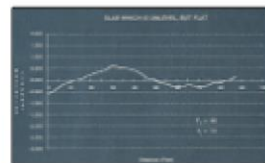
### Defining quality

Specifications define the quality of work that owners expect for their money. The contractor's job is to provide that quality within the time and cost constraints defined by the owner. The American Concrete Institute's tolerance specifications (ACI 117, Ref. 1) address five factors that affect quality for elevated concrete slabs:

- Floor flatness
- Floor levelness
- Elevation control
- Form and surface tolerances
- Form and surface to levelness

Measuring floor flatness and levelness. The Form-shoring system is the approach now recommended by ACI 302 (Ref. 2) for evaluating floor str-

uctures. Besides providing formwork, slab profiles provide an intuitive awareness of how construction practices affect flatness and levelness. Don't just use slab profiles for formwork. Use slab profiles to educate your finishers about their techniques. Also, if the starting elevation of the measurement line is known, the slab can be used to verify that floor elevations are within tolerance.



## Construction of elevated concrete slabs

Practice and procedures

By Eldon Topping and Bruce Saperman

The successful construction of an elevated concrete slab presents unique challenges. To produce a surface that is essentially flat and level when completed, the design/construction team must first produce a surface with profiles which match the drawing requirements and then properly anticipate deflection that will occur when supports are removed. The team can successfully meet those challenges with good planning and a willingness to adjust construction procedures, where necessary. Achieving a quality slab that is level, strong and durable—requires planning, attention to detail, and a good finishing program.

### Flexibility to adjust is critical

Although contractors seldom have the opportunity to change the structural system, they do have the opportunity to introduce flexibility in the construction process to accommodate adjustments required by the behavior of the floor system. Rarely do structural systems deflect exactly as predicted by the engineer; in most cases, there will be isolated areas that don't behave properly. The key for the contractor is to identify those areas and to remain flexible in its approach when responding to the challenges they present. Contractors who can't modify their construction process can expect poor quality. Experienced elevated concrete slab contractors incorporate flexibility when planning construction operations.

### Use preconstruction planning

Many potential problem areas can be avoided by incorporating an effective planning program. This program should anticipate all the situations that develop during construction and provide a response to each situation. In general, planning should provide for consistent concrete at the point of deposit, appropriate placing and finishing procedures, and the flexibility to adjust in areas that don't match expectations.

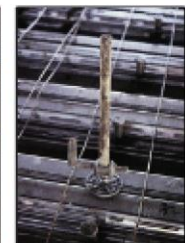
### Concrete consistency is a must

Every contractor has experienced the difficulties in finishing a wet load. Unseasonably, concrete slump variation adversely affects concrete

finishing quality. A good quality finish requires good-quality materials. When the slump in a placement varies, the crew has to work to the next, the finishers have a difficult task; most of the slab might be setting properly while some spots are still fresh and soft. At these soft spots, the finishers often will find their power float sinking into the surface of the concrete. This placement also is more expensive since the finishers must wait for the fresh, soft locations to stiffen before they can complete their work. For some jobs, it's not uncommon to spend an extra hour finishing these spots.

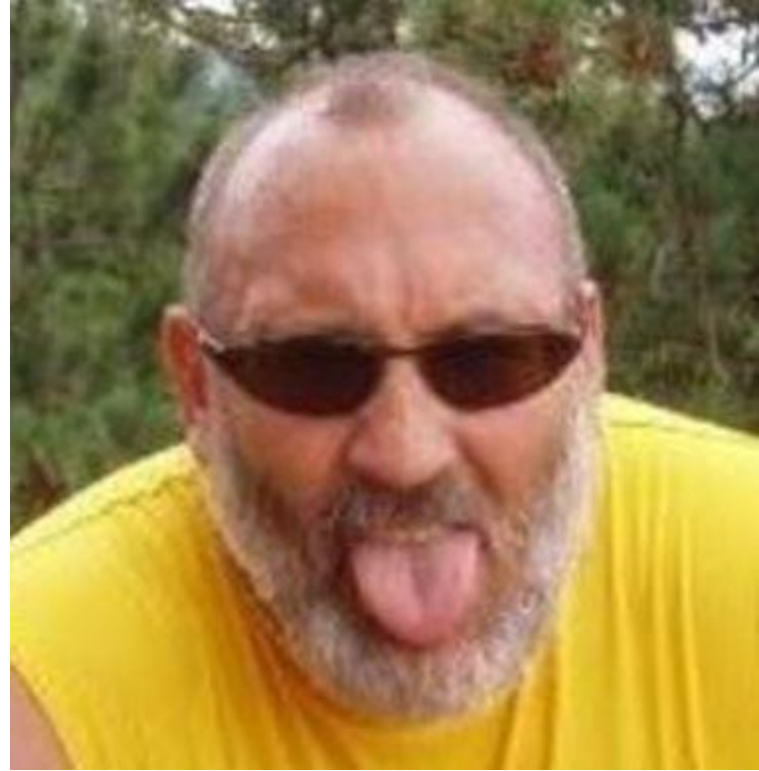
### Emphasize concrete control

Concrete variations can be reduced by using a pre-con-



Vertical rebar is an available tool to maintain consistent screed elevation. Precast elevation control decreases floor levelness.

# Fast Forward to 2009



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# LEARNING OBJECTIVES

- **Discuss fabrication and erection tolerances for floor construction.**
- **Compare design options to mitigate the impact of deflection of composite concrete on metal deck floor slabs.**
- **Describe construction problems for constructing a level floor.**
- **Summarize effective specification requirements for an un-shored composite slab on metal deck.**
- **Describe tools and techniques that allow the contractor to respond to deflection behavior of the slab.**



# OVERVIEW: Segment 1

- Elements Impacting Levelness of Deflected Floor
  - Fabrication/Erection of columns & beams
  - Deflection of erected floor frame
  - Concrete placing/finishing techniques

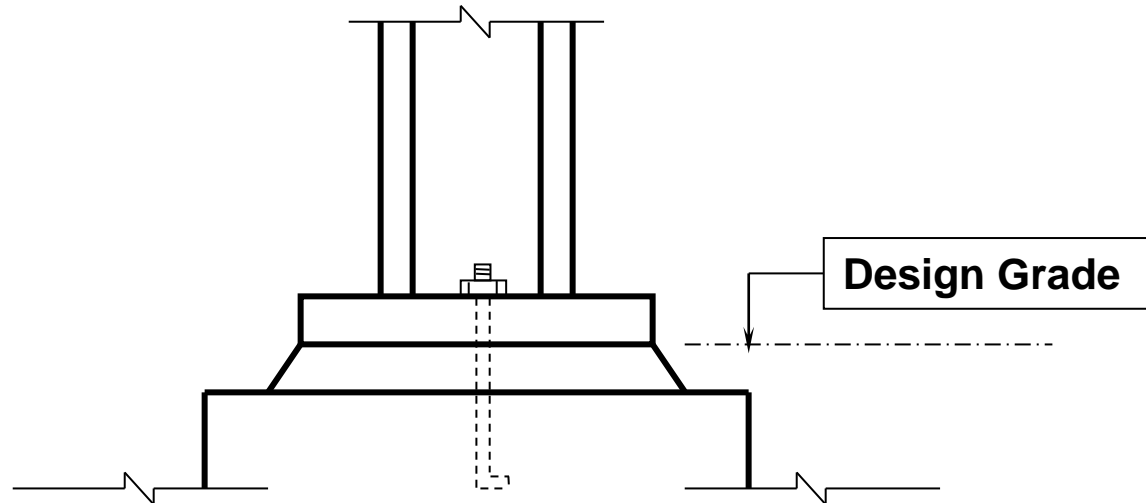




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# Structural Steel Tolerances

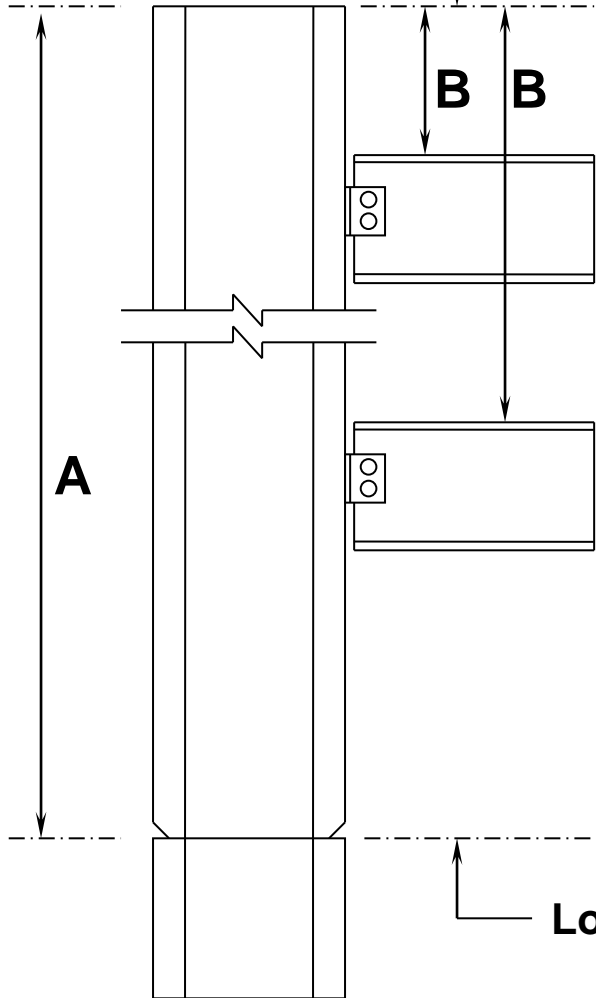


## AISC CODE OF STANDARD PRACTICE – Paragraph 7.6

Elevation tolerance relative to established grade is  $\pm 1/8''$



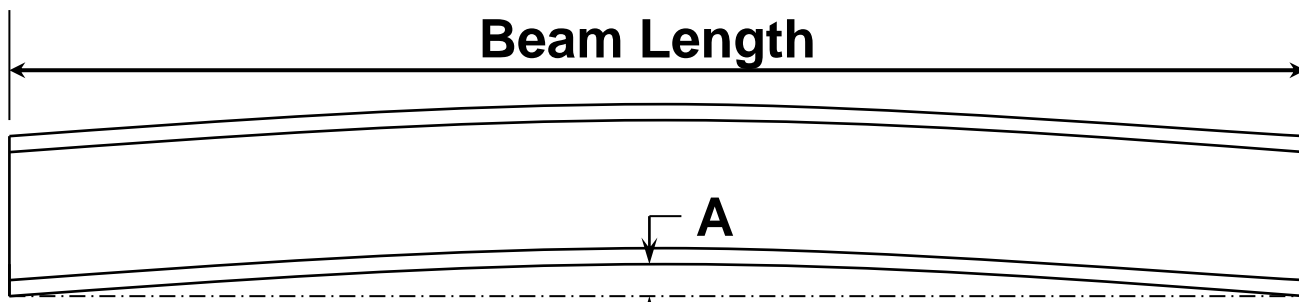
Upper Milled Splice Line



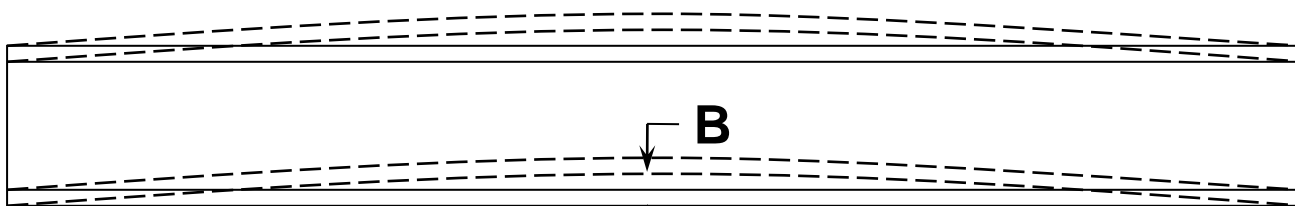
### AISC STANDARD MILL PRACTICE

Item	+/- Tolerance	Paragraph
A	+/- 1/32"	6.4.1
B	+ 3/16" - 5/16"	7.13.1.2(b)

Lower Milled Splice Line



**Beams With Specified Camber**

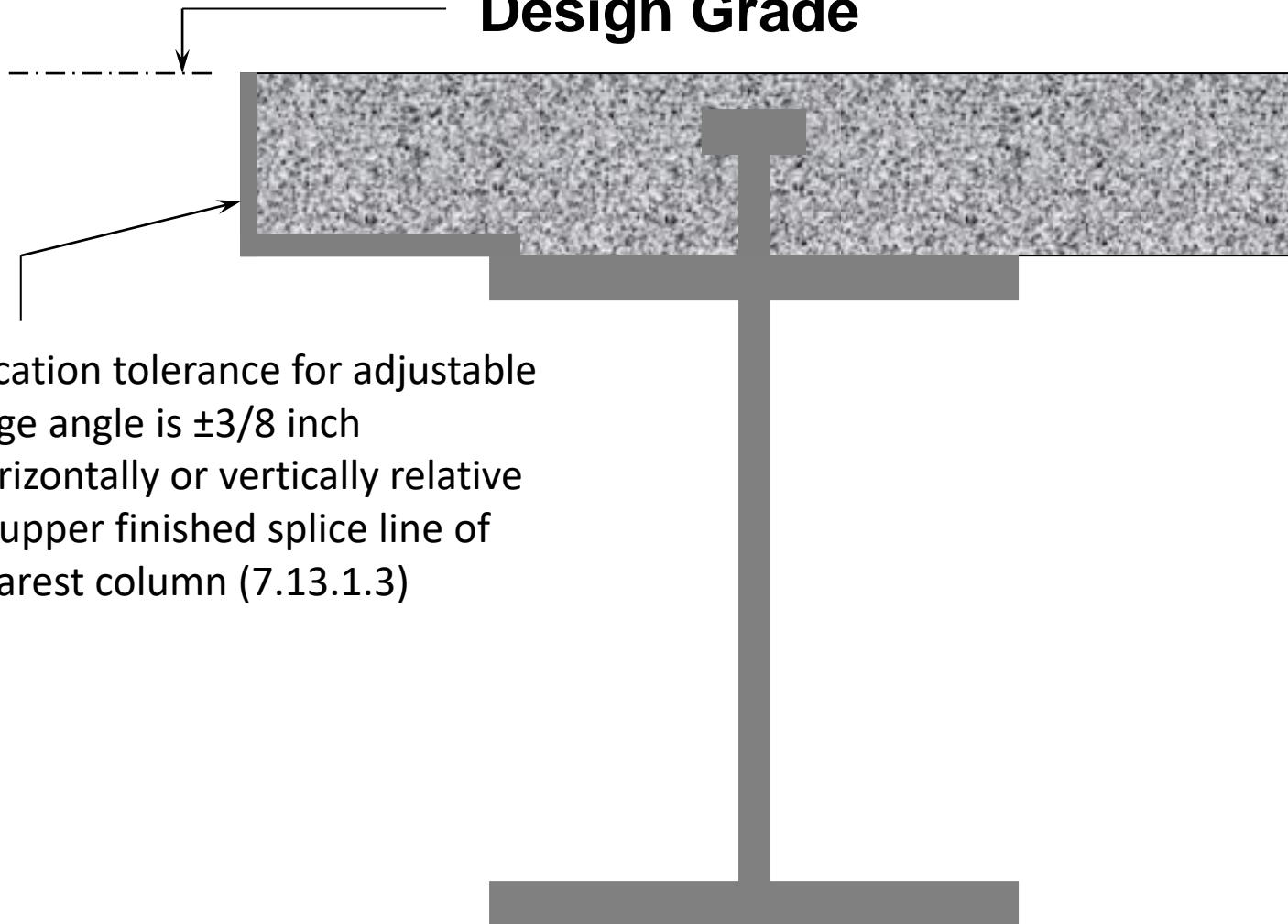


**Beams With No Specified Camber**

## AISC STANDARD MILL PRACTICE

Item	Beam Length	Plus Tolerance	Minus Tolerance
A	50' or Less	$+ \frac{1}{2}''$	- 0.0''
A	Over 50'	$+ \frac{1}{2}'' + \frac{1}{8}'' / 10'$	- 0.0''
B	All	$+ \frac{1}{8}'' \times .2 L$	- 0.0''

## Design Grade

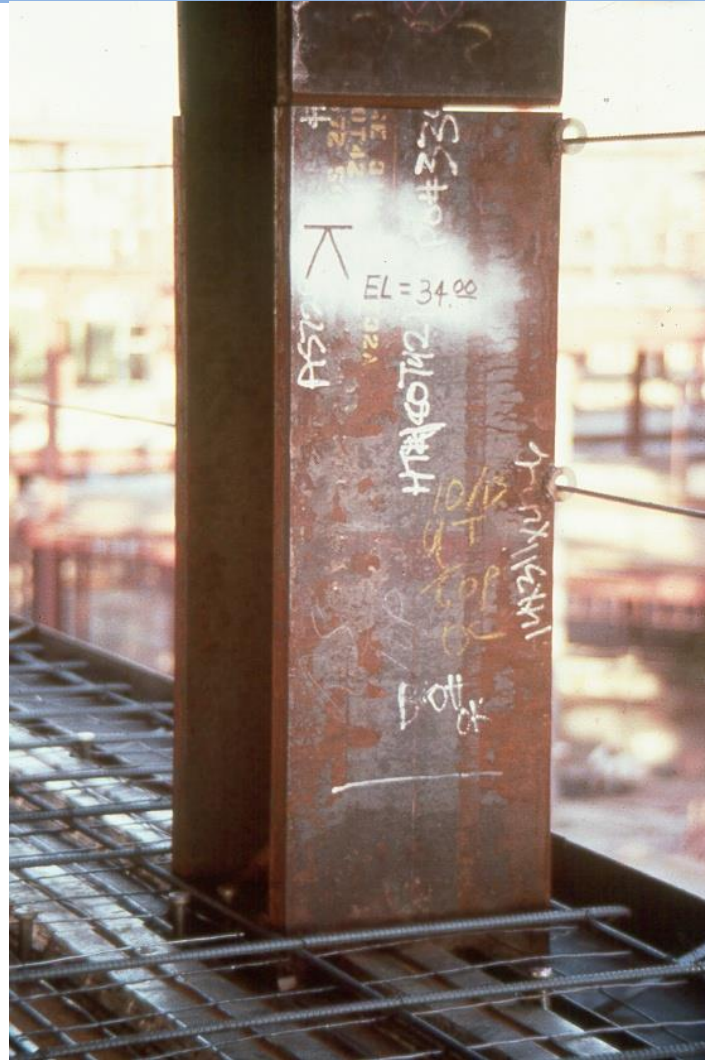


Location tolerance for adjustable edge angle is  $\pm 3/8$  inch horizontally or vertically relative to upper finished splice line of nearest column (7.13.1.3)



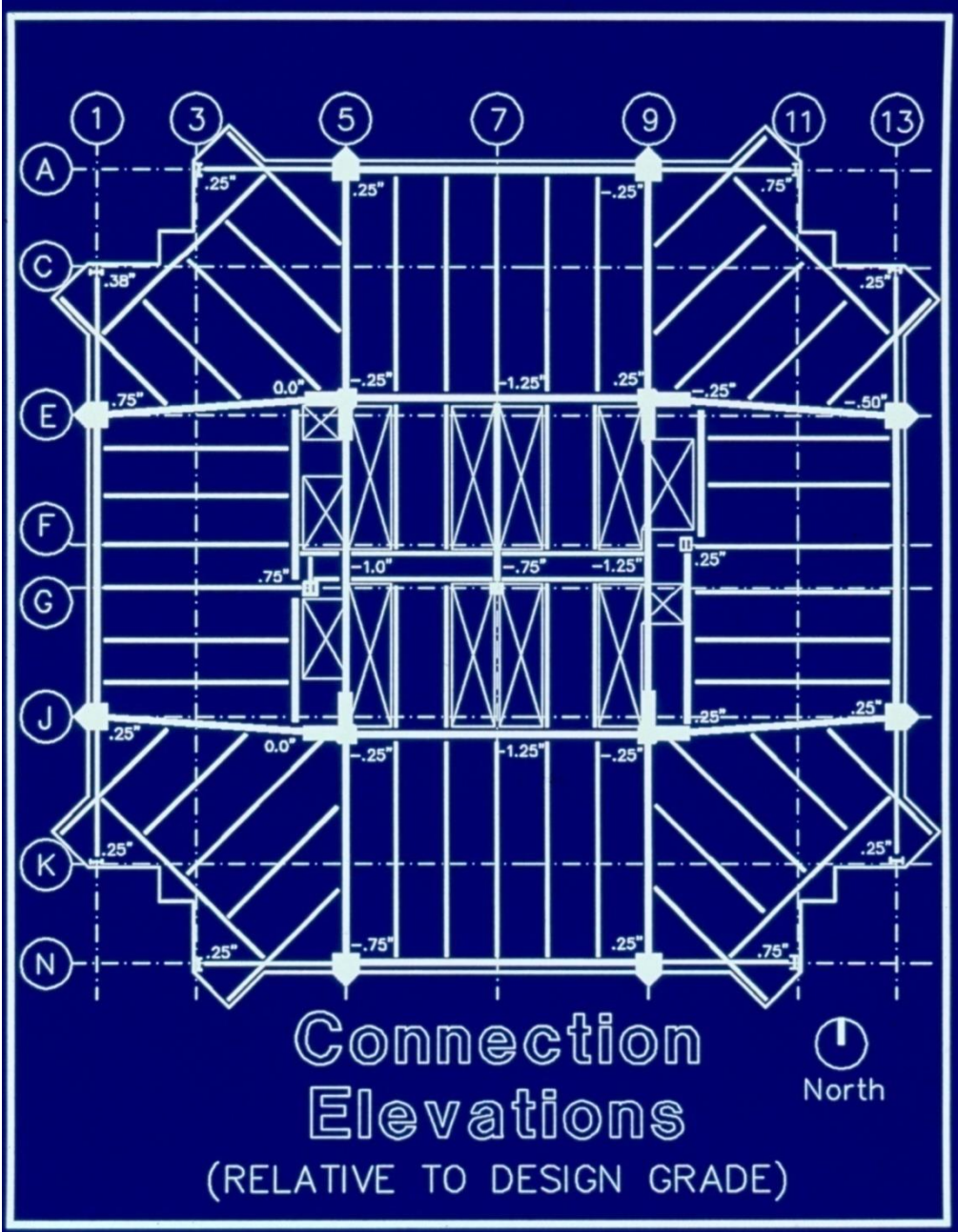
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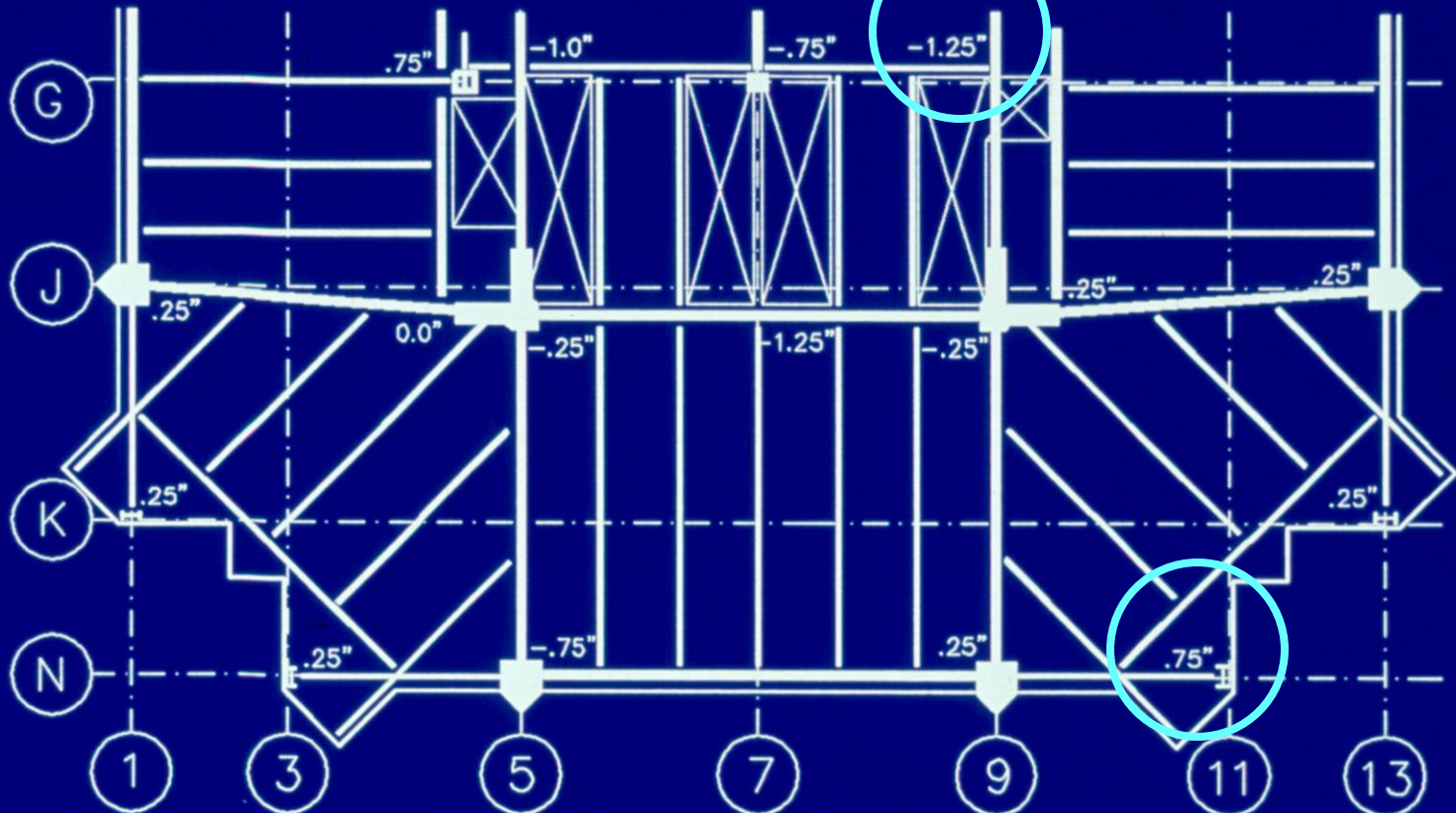




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# Connection Elevations

(RELATIVE TO DESIGN GRADE)



## **COLLECT DATA TO IDENTIFY PRE-PLACEMENT LEVELNESS OF STRUCTURAL STEEL**



# LEVELNESS

The levelness of suspended slabs depends on the accuracy of **formwork** and **strike-off**, but is further influenced, especially in the case of slabs-on-steel decking, by the **behavior** of the structural frame during and after completion of construction.

ACI 302-15 (5.3.2)



# DEFLECTION

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# STEEL DESIGN CHOICES

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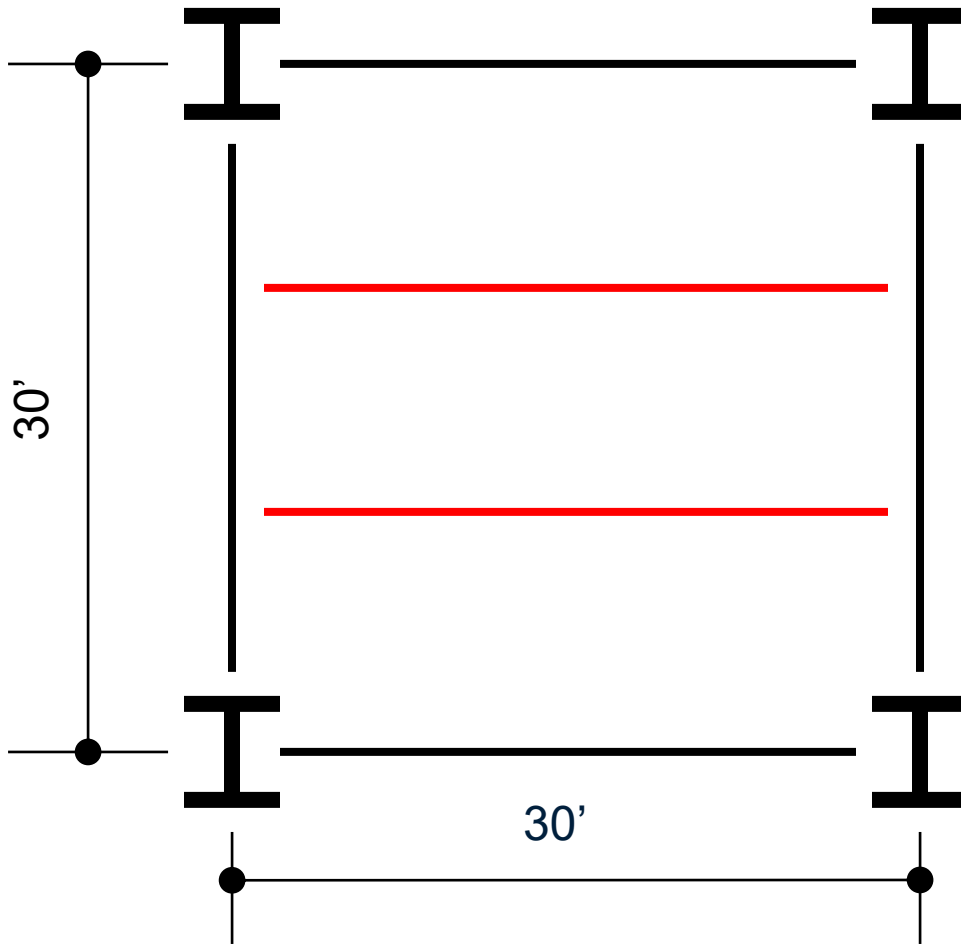
# Structural Steel Design Decisions

- **Steel Code**
  - Allowable Strength Design  
13th Edition (Working Stress)
  - Load & Resistance Factor Design  
13<sup>th</sup> Edition (Ultimate Strength)
- **Steel Strength**
  - ~~$F_y = 36$  ksi~~
  - $F_y = 50$  ksi



# Allowable Strength Design

## 13th Edition

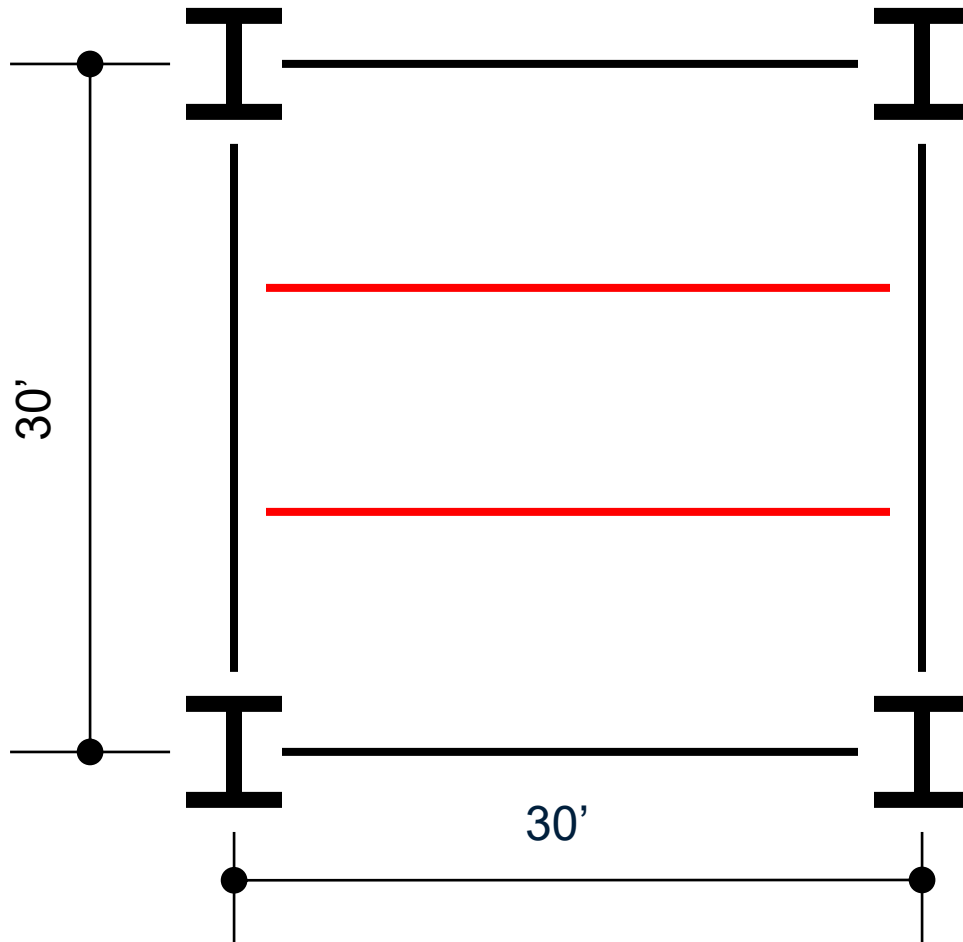


$F_y = 50 \text{ ksi}$   
W14x22

$$\delta = -1.58''$$



# Load & Resistance Factor Design



$F_y = 50 \text{ ksi}$   
W12x19

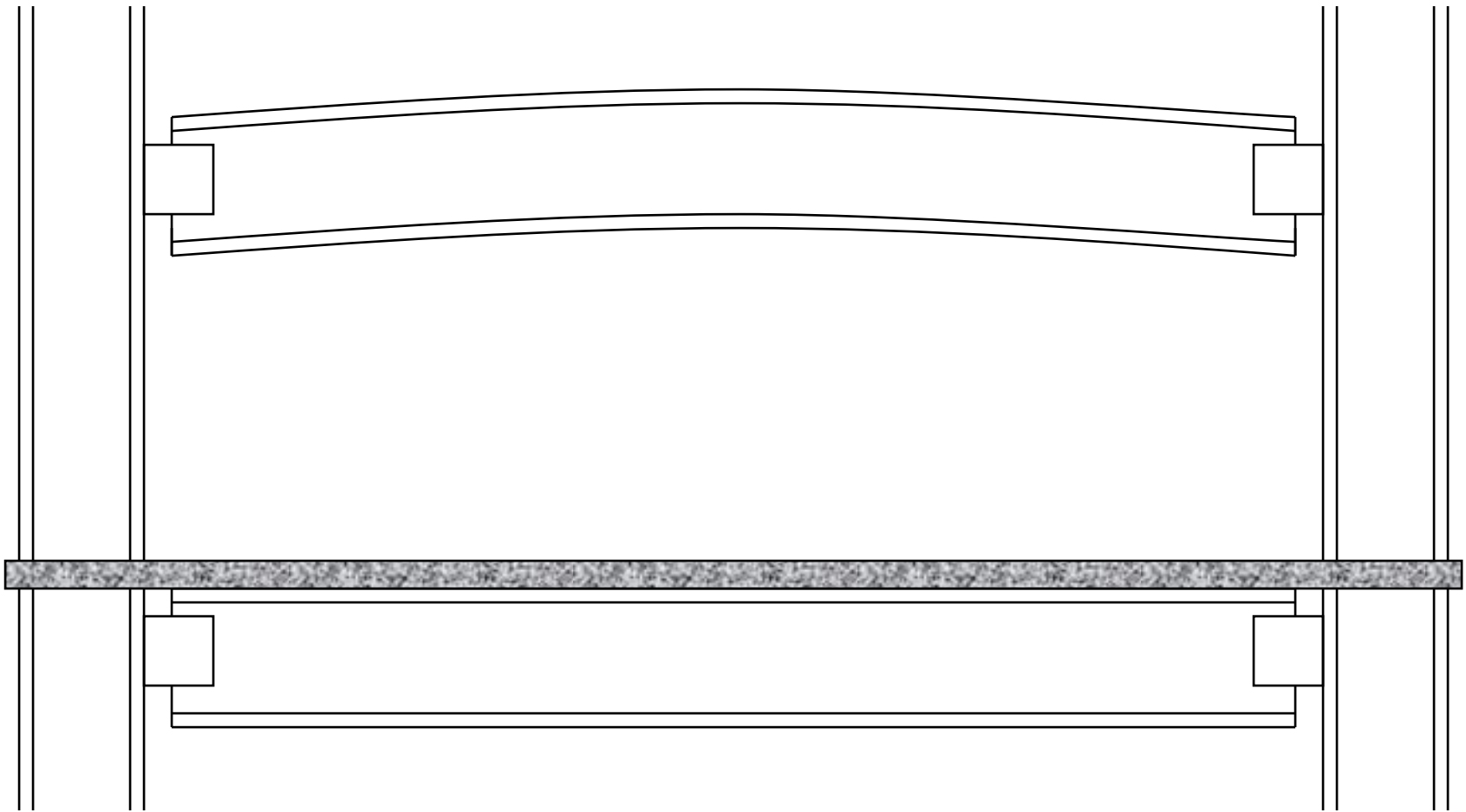
$$\delta = -2.42''$$



**AVOID DESIGNS THAT TAKE  
MAXIMUM ADVANTAGE OF  
LRFD/GRADE 50 SOLUTIONS**

# Cambered Member Deflection

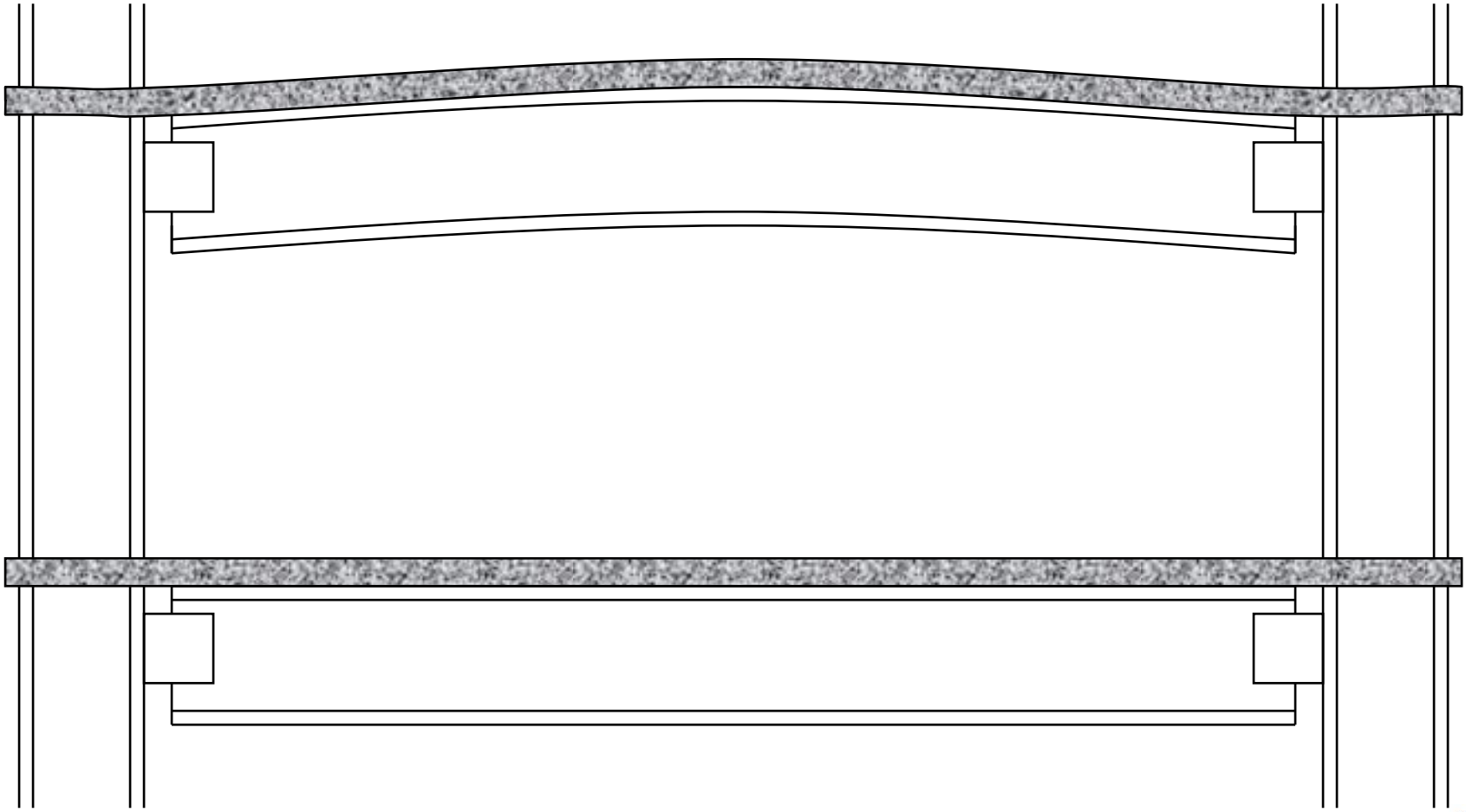




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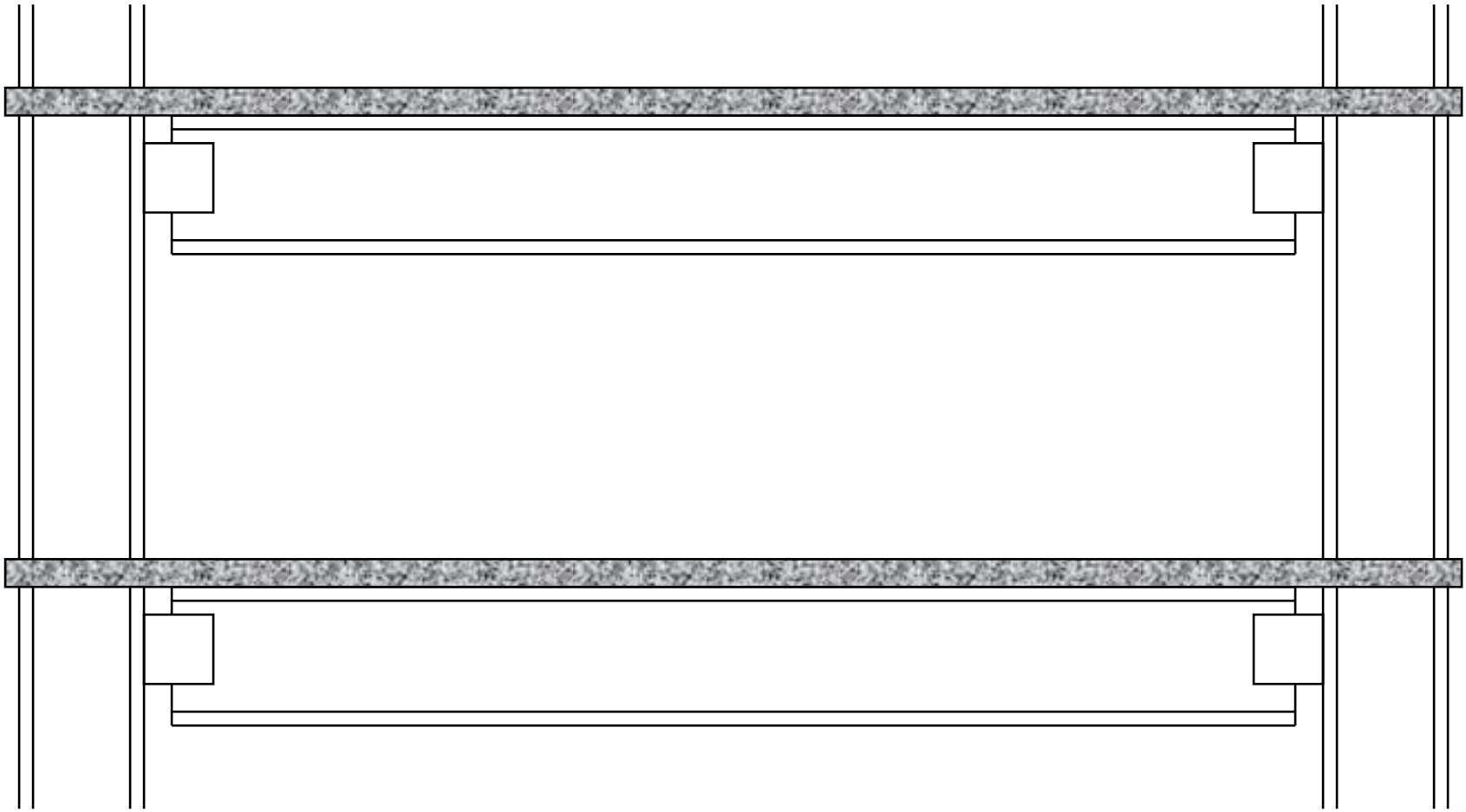




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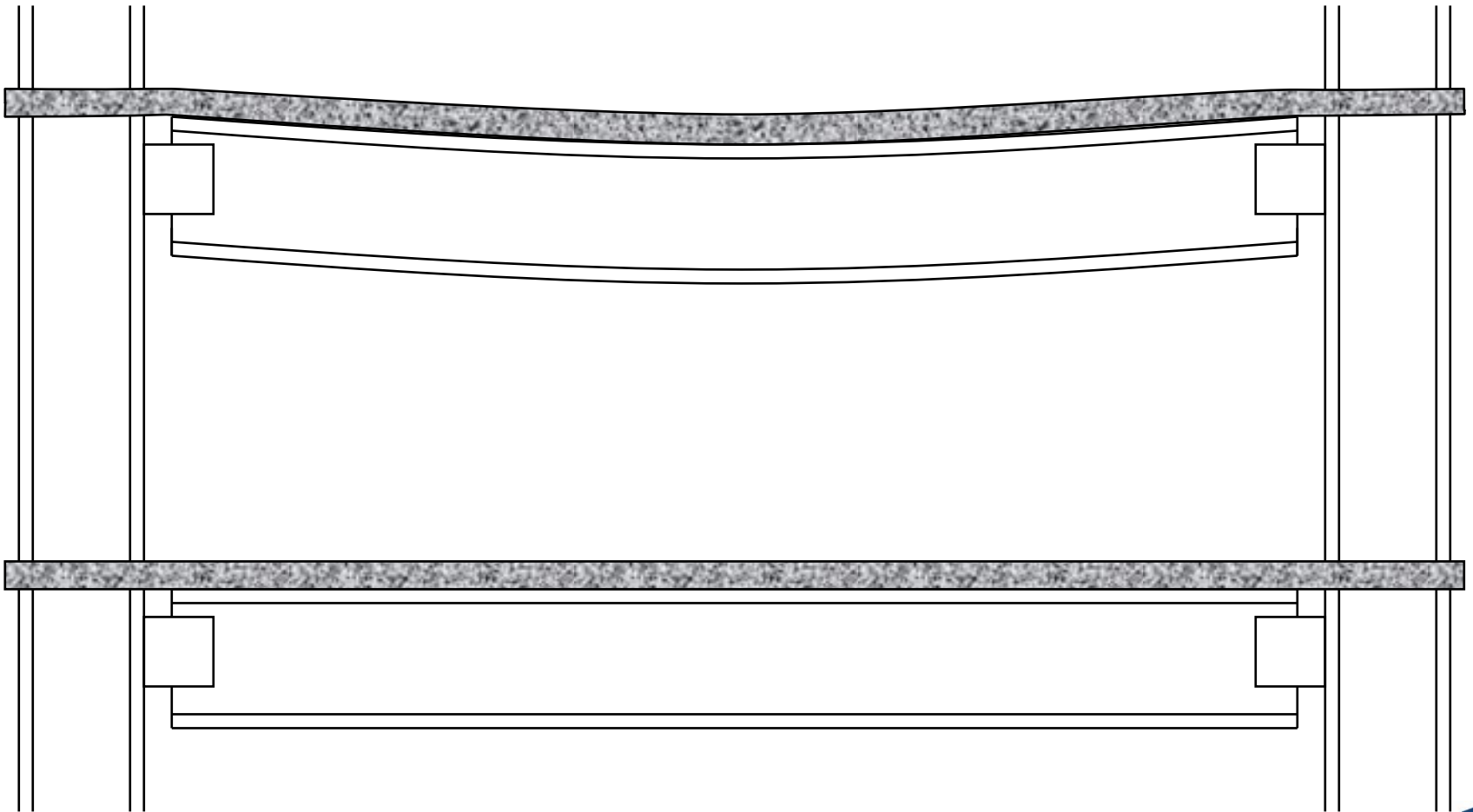




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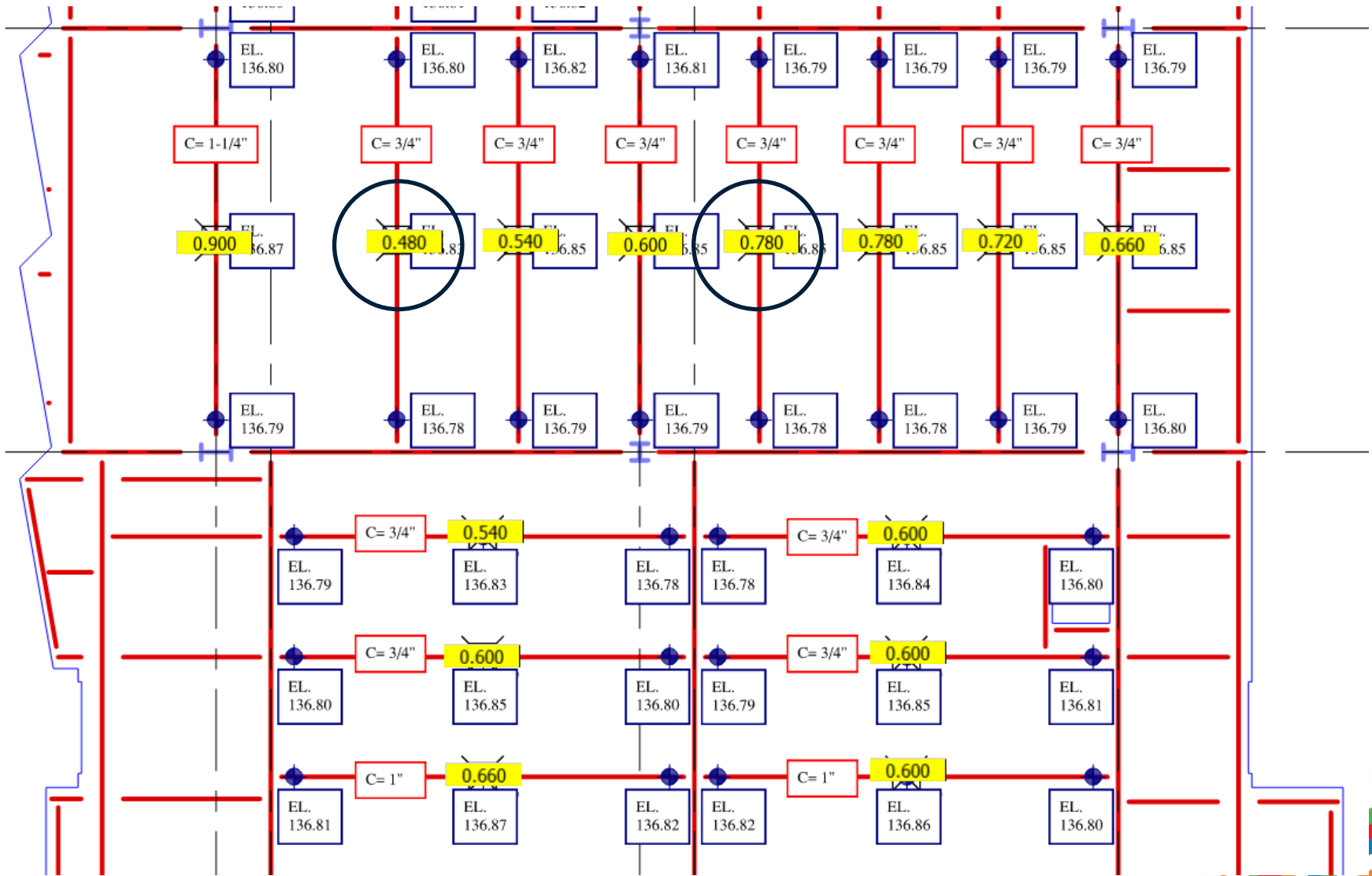
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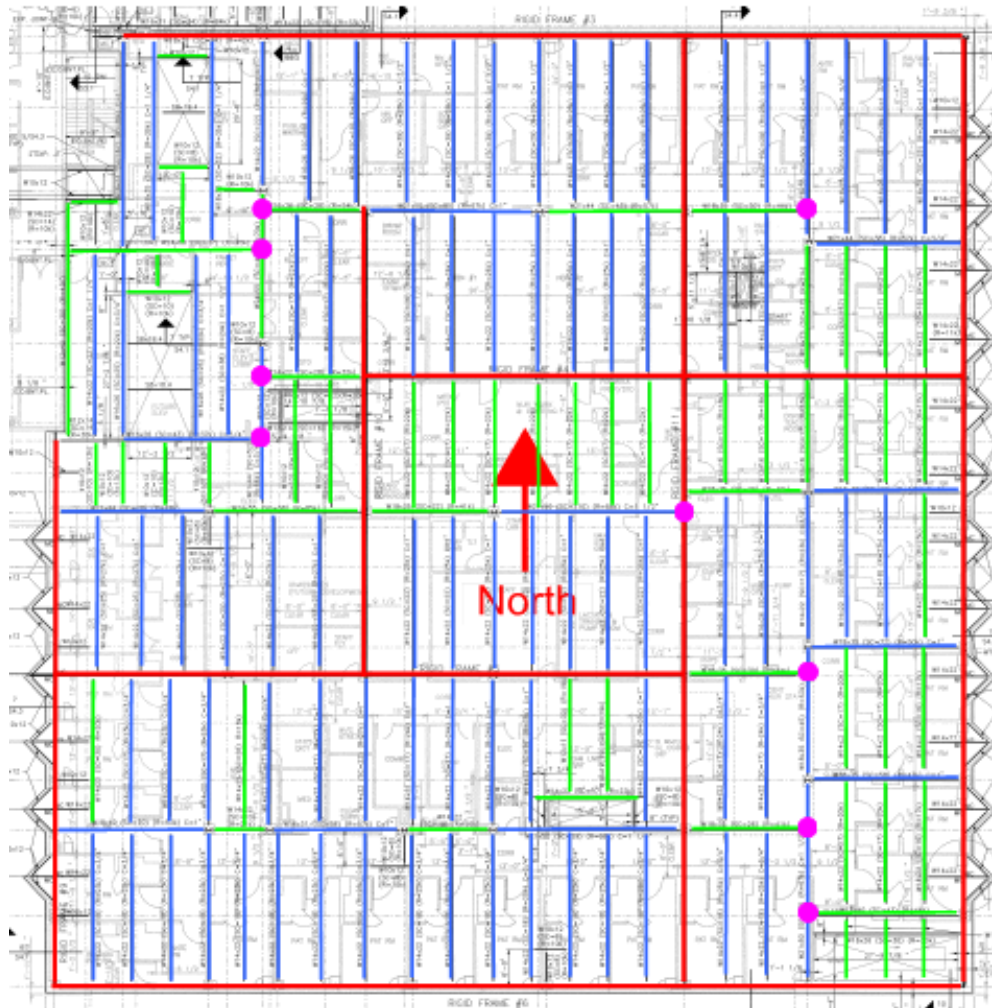




# Cambering Strategy







**LEGEND**

- Girder-supported Girder
- Rigid Frame
- Cambered Beam/Girder
- Un-cambered Beam/Girder

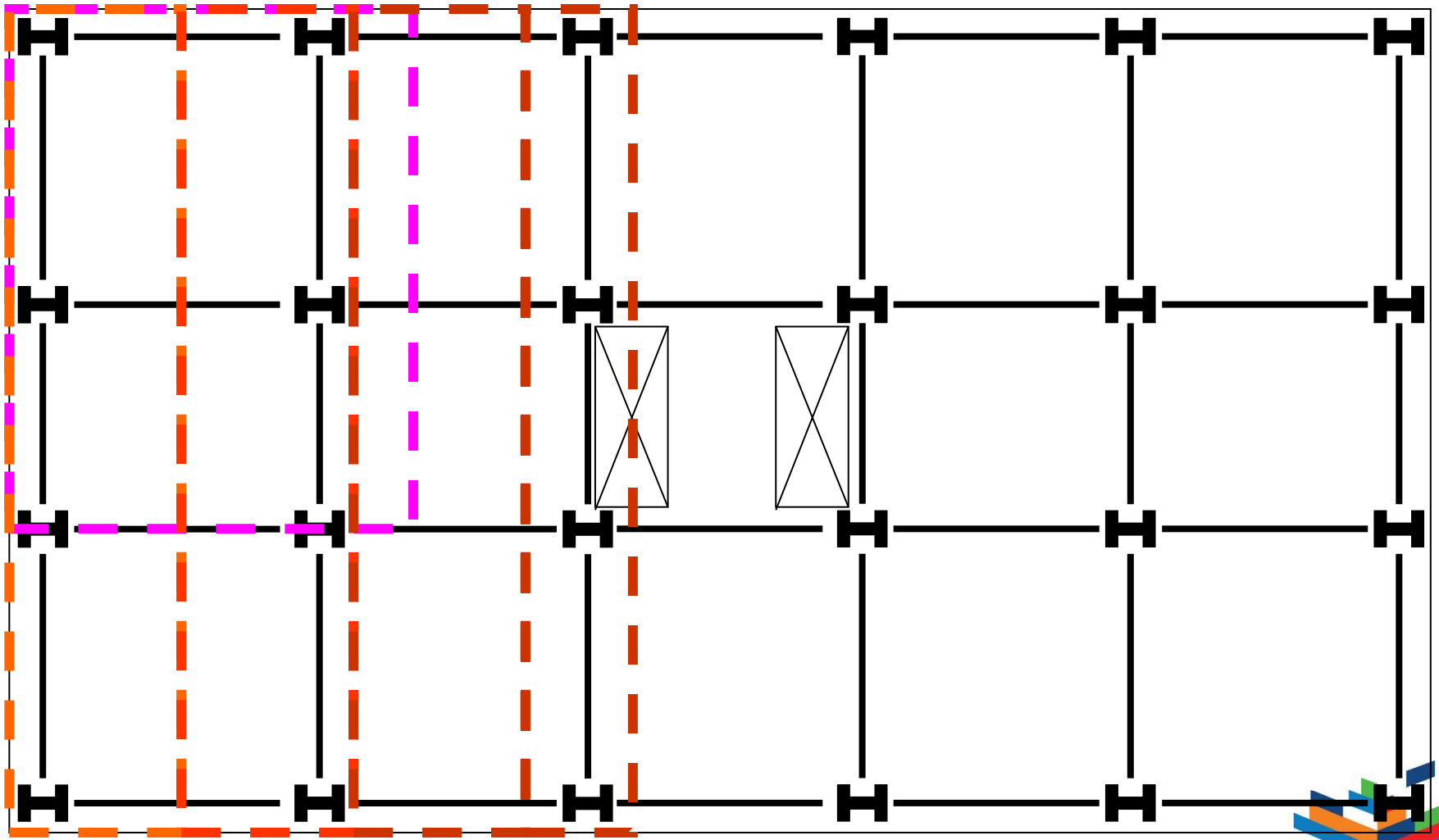


# Effective Cambering Strategy

- One size does NOT fit all
- Look at deflection of the system rather than just individual members
- Recognize that members with no camber still deflect
- Recognize that members framing into columns don't deflect like same members framing into girders

## USE CAMBERING STRATEGY THAT LOOKS AT COMBINED MOVEMENTS OF GIRDERS AND BEAMS

# TYPICAL CONCRETE PLACEMENT SEQUENCE



# Placing & Finishing Techniques

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How do you achieve an unshored structural steel monolithic floor that is level?

**Place concrete to an elevation by using a rod and level...**

**Or...**

**Place concrete by gauging up off the structural steel.**

Keep in mind that for un-shored construction the frame is moving the entire time concrete is being placed.











**RECOGNIZE THAT USING A ROD AND  
LEVEL ON A STEEL FRAME WILL  
NOT PRODUCE LEVEL FLOORS**

**COLLECT DATA THAT ALLOWS  
EARLY IDENTIFICATION OF  
STRUCTURAL BEHAVIOR**

# OVERVIEW: Segment 2

- Ineffective or Incorrect Specification requirements
- Ineffective or unrealistic drawing requirements/  
details

# Ineffective/Incorrect Specifications

## REFERENCE DOCUMENTS

### ACI 302.1R-15 Guide to Concrete Floor and Slab

#### Construction

- Guide-level documents are not written in mandatory language
- If specifier wishes to make content from a guide required, that content must be stated in the project specifications in mandatory language.

# Guide-Level Documents

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the information it contains. ACI disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising there from.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/ Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.



# Ineffective/Incorrect Specifications

## FLOOR FINISHING TOLERANCES

Flatwork Finishing Tolerances per ACI 117 and the following:

Suspended Slabs:

Overall:  $F_F$  35 /  $F_L$  25

Minimum Local:  $F_F$  25 /  $F_L$  17

Grade Tolerance:  $\pm 1/2$  in.



# Ineffective/Incorrect Drawings

Concrete thickness shown on metal decks is nominal and minimal. Average un-shored mid-bay deflection (steel framing plus metal decking), due to the weight of wet concrete, is estimated at 1 inch. Camber of steel members has been documented as indicated to account for a portion of this deflection. Provide additional concrete as required to make up for actual Project deflection. Finished top surfaces shall be level and flat within tolerances specified.

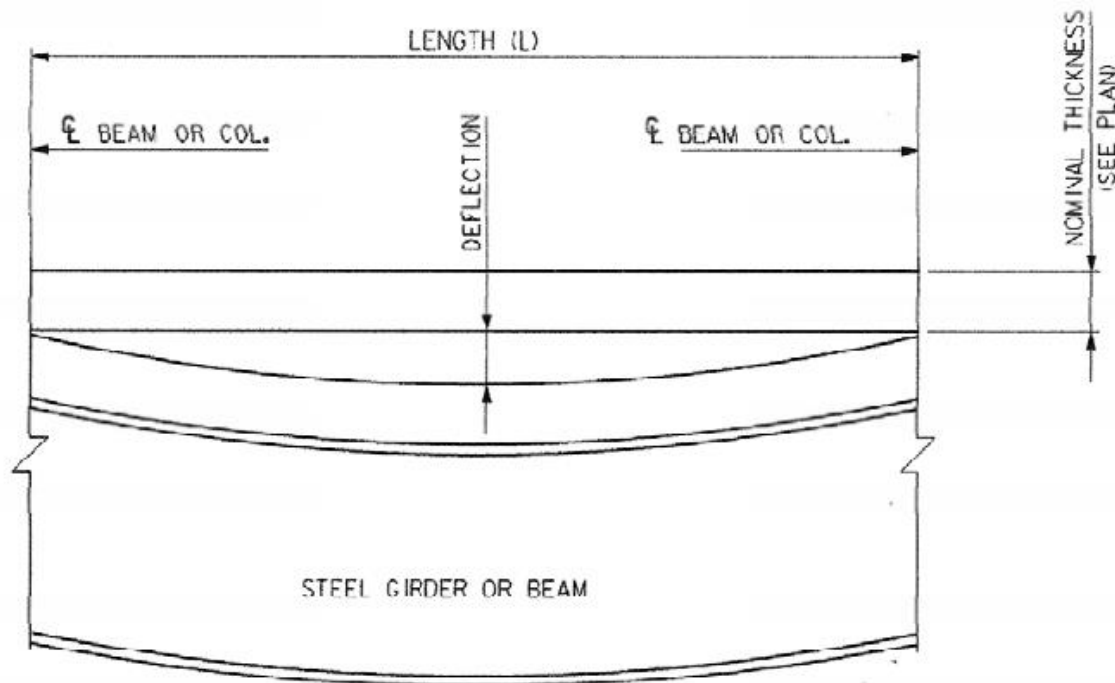
# Ineffective/Incorrect Drawings

## Structural Drawings – Concrete Notes

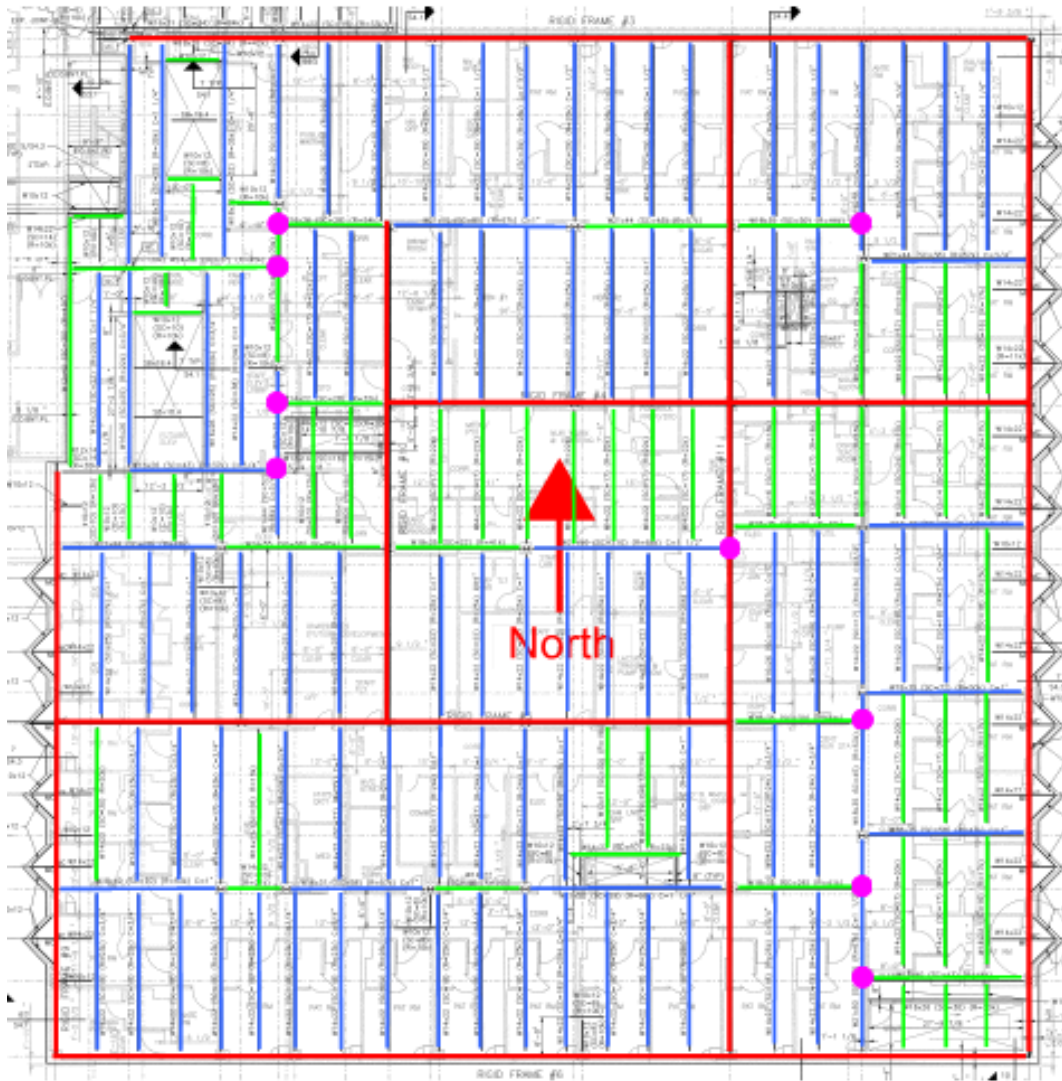
Composite deck shall be capable of supporting the loads described in the specifications and notes.

- Composite members are designed as unshored, unless noted otherwise.
- Composite floor slabs are to be finished level. The overrun of the wet concrete is to be anticipated and included in the contractors base bid.

# Ineffective/Incorrect Drawings



NOTE: GIRDERS, BEAMS, AND METAL DECK WILL DEFLECT UNDER WEIGHT OF WET CONCRETE. PROVIDE ADDITIONAL CONCRETE AS REQUIRED TO COMPENSATE FOR THESE DEFLECTIONS, AND PRODUCE A LEVEL/FLAT FLOOR AS SPECIFIED AT THE CORRECT ELEVATIONS.



**LEGEND**

- Girder-supported Girder
- Rigid Frame
- Cambered Beam/Girder
- Un-cambered Beam/Girder

# What are Unanswered Questions?

- What is the elevation of supporting steel?
- Does fabricated camber match that required?
- How much deflection will occur in key members?
- How much of estimated mid-bay deflection accounted for by cambering?
- What does contractor do if cambered steel members do not deflect to level after loading?
- What does contractor do if additional thickness required is significantly more than anticipated?

# ACI 117-10 (15)

## Specification for Tolerances for Concrete Construction and Materials

### 4.4—Deviation from elevation

#### 4.4.1 *Top surface of slabs*

Slabs-on-ground.....  $\pm 3/4$  in.

Formed suspended slabs, before removal of supporting shores.....  $\pm 3/4$  in.

Slabs on structural steel or precast concrete  
..... no requirement

**4.8.5.4** The  $SOF_L$  and  $MLF_L$  levelness tolerances shall apply only to level slabs-on-ground, or to level suspended slabs that are shored when tested.

# OVERVIEW: Segment 3

- Specification provisions to improve levelness erected frame
  - Pre-and post-placement surveys
- Design options to mitigate impact of deflection
  - Cambering Strategy
- Utilize controlled method of strike-off
- Use survey data to respond to unanticipated behavior

# Specification Provisions

- Measure fabricated camber in the shop and attach report to members when shipped
- Survey, survey, survey



# Survey, Survey, Survey!

- Survey prior to concreting to establish relative levelness of beam-to-column connections and camber of beams
- Survey following concreting to establish movement of members when loaded

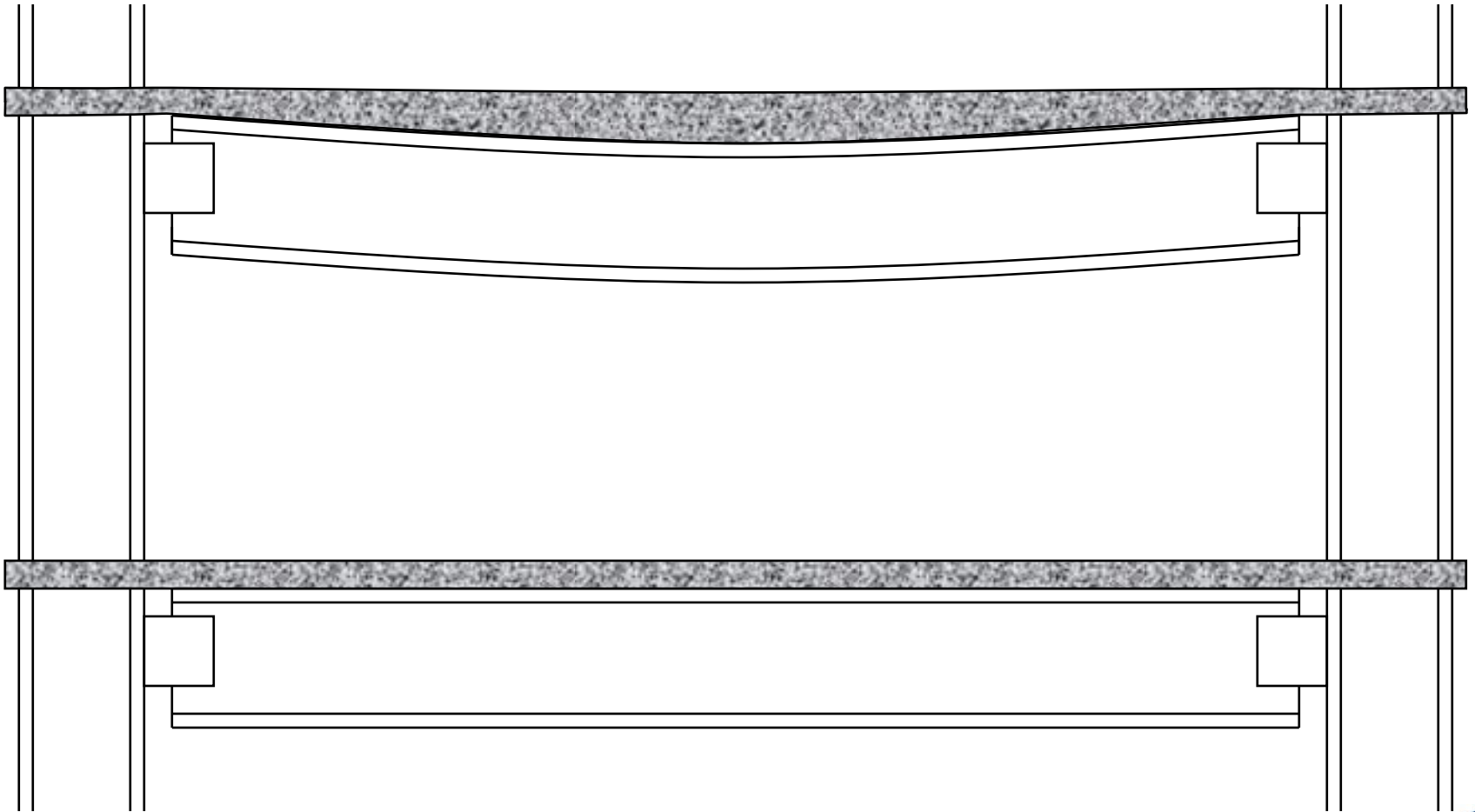
# Respond to Deflection Behavior

# When deflection past level is small ( $<3/4''$ )...



Maintain design thickness at ends of beam

Increase thickness slightly at mid-span of beam

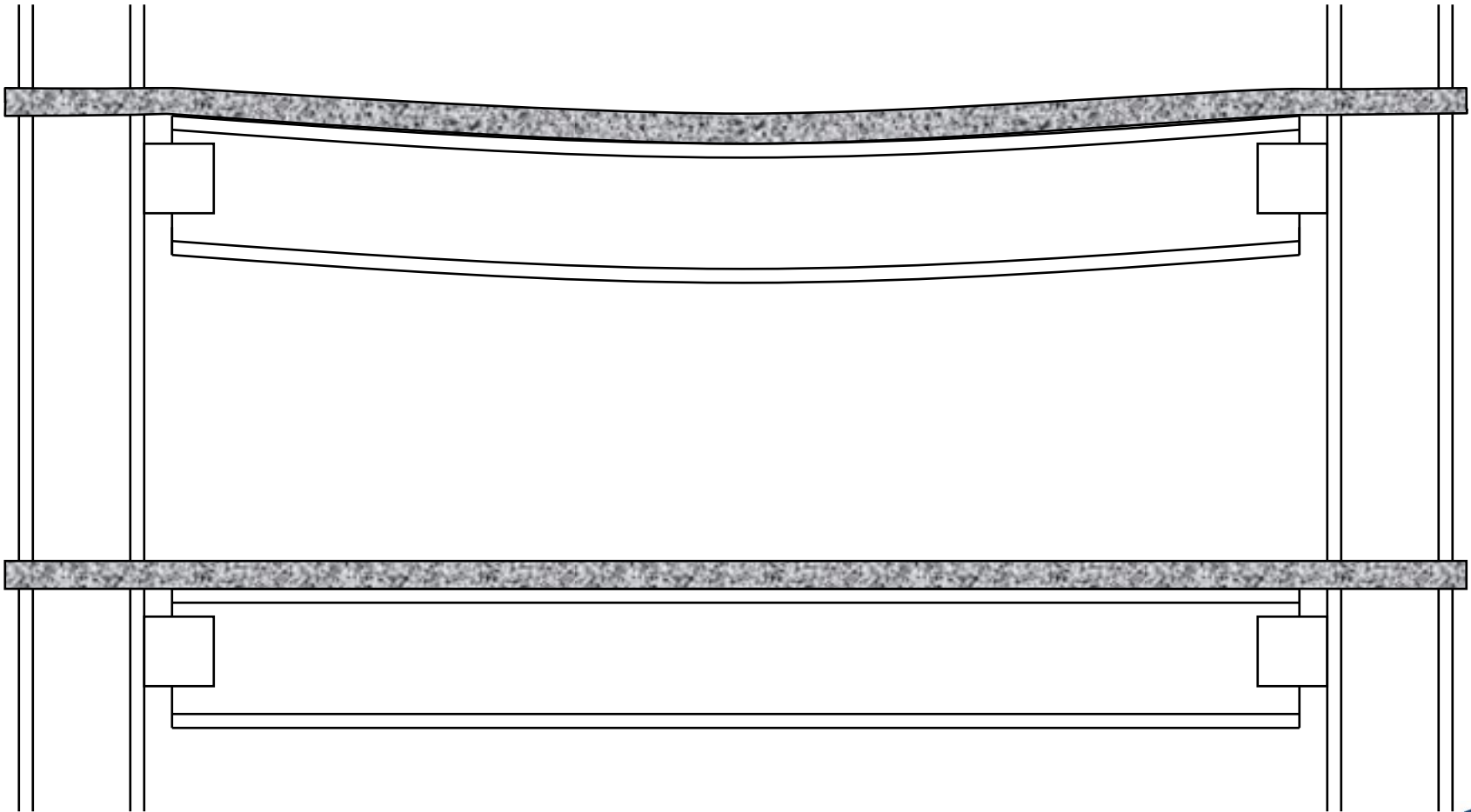


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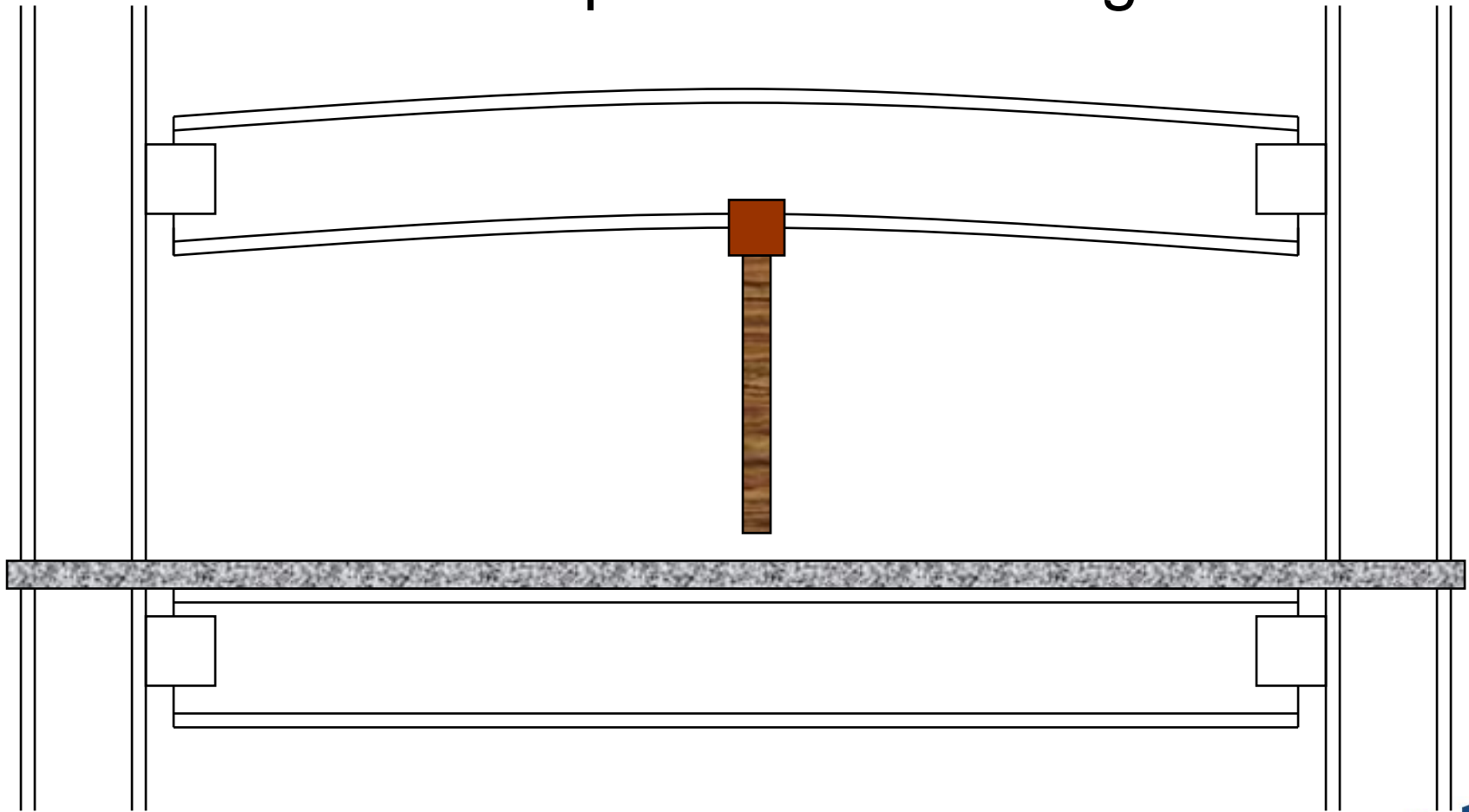


# When deflection past level is large or member is cambered...

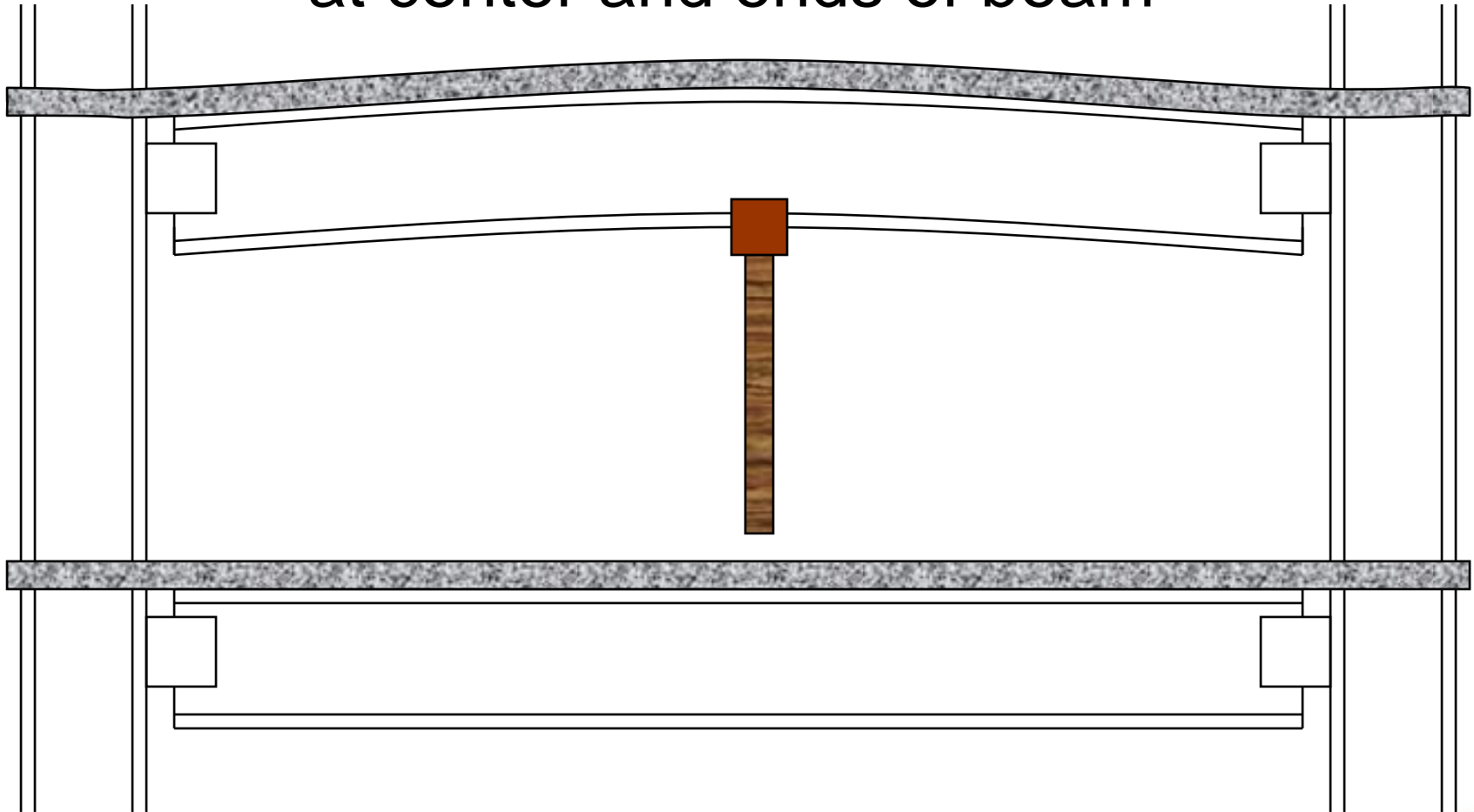




# Attach loose shore to center of beam prior to concreting

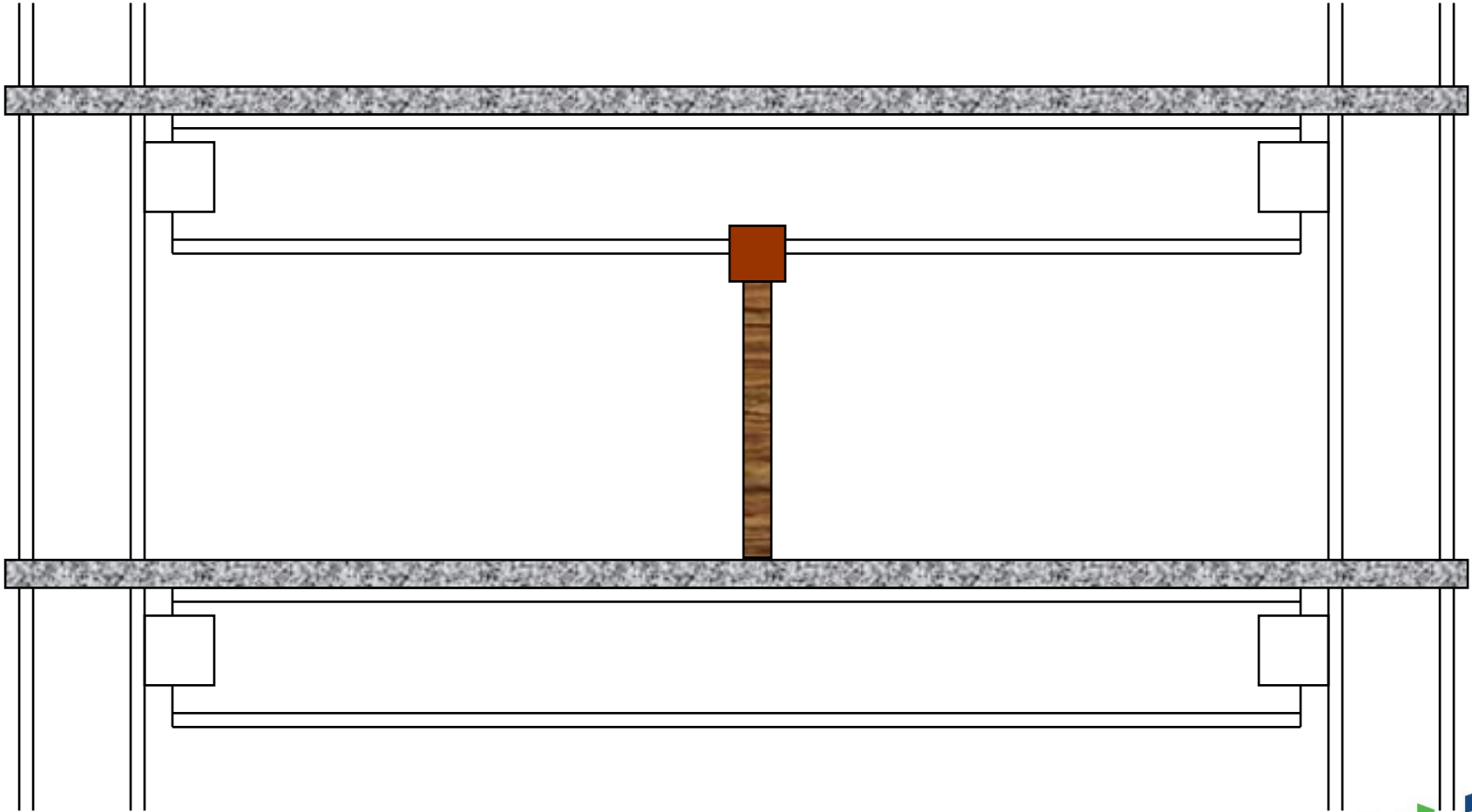


# Maintain design thickness at center and ends of beam





When desired deflection has taken place, shore will stop further movement



# Why does the loose shore approach work??

The composite section, once the concrete has hardened, is 3-to-5 times as stiff as the steel beam alone. Deflection is the inverse of stiffness.



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# Time-Related Composite Beam Deflection

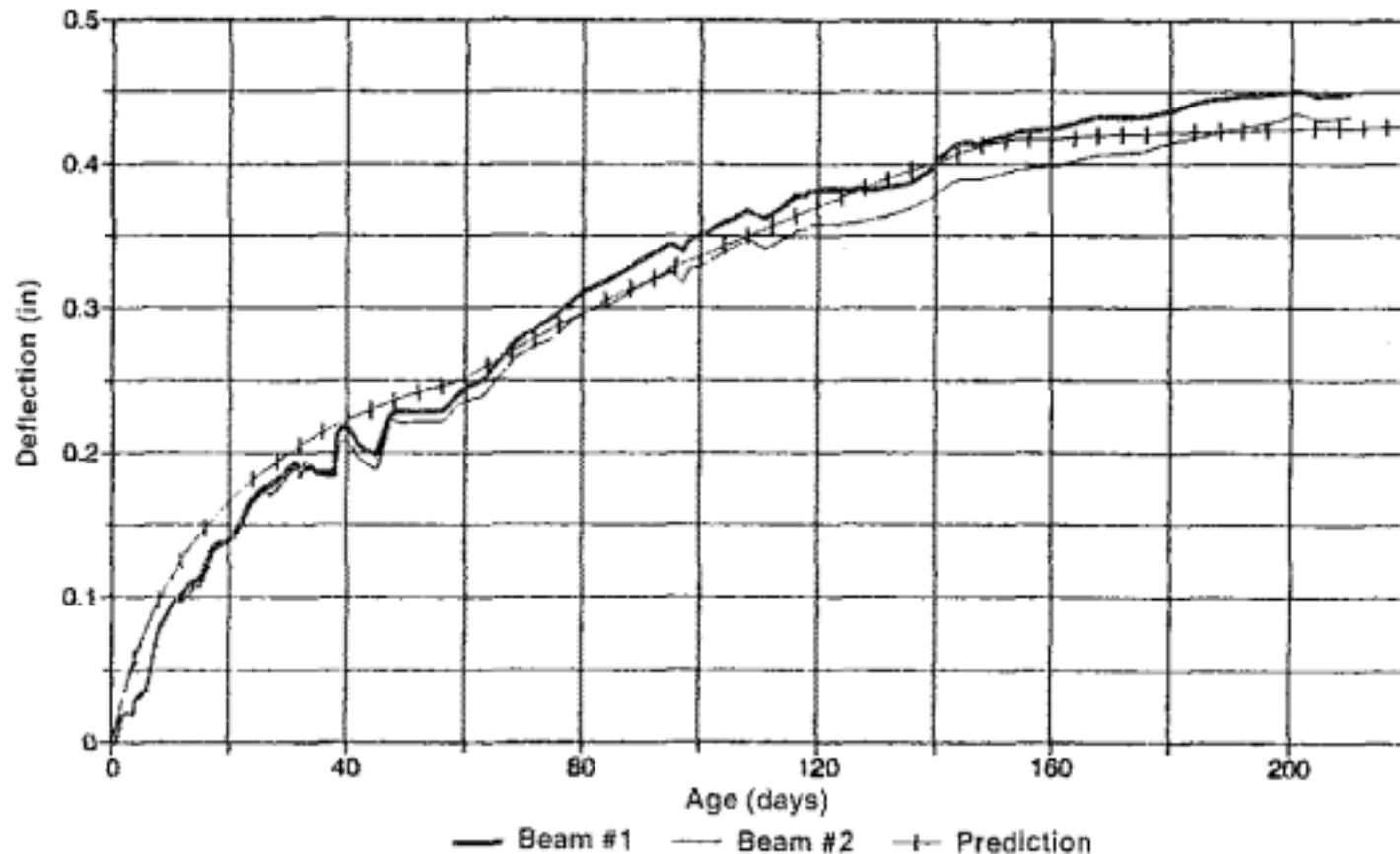


Figure 3.20 Predicted vs. measured shrinkage deflections adjusted for humidity.<sup>1073</sup>

Composite Construction – Design for Buildings, Viest, Colaco, Furlong, Griffis, Leon, and Wylie, Chapter 3, page 3.34

