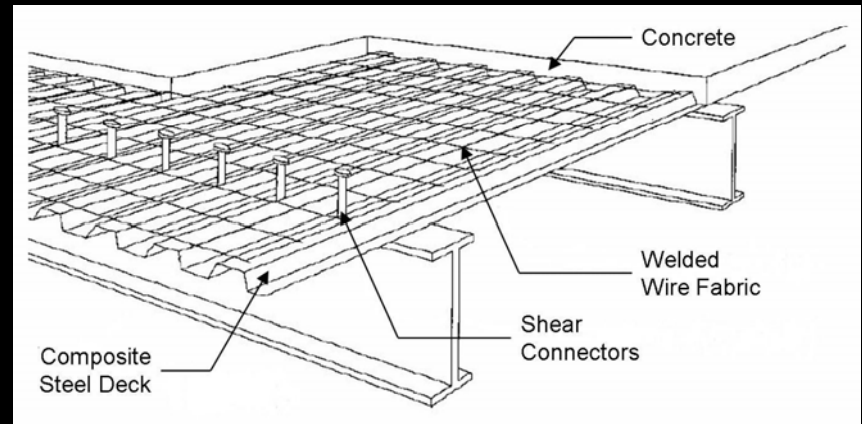


# Composite Construction



## Introduction to Composite Construction



Adapted From (ASCE 2002)

- Composite construction refers to two load-carrying structural members that are integrally connected and deflect as a single unit
- An example of this is composite metal deck with concrete fill, steel filler beams, and girders made composite by using headed stud connectors

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## Introduction to Composite Construction



- A steel beam which is made composite by using shear connectors, composite metal decking and concrete is much stronger and stiffer than the base beam alone
- Composite floor systems are considered by many to be the highest quality type of construction
- This has become a standard type of construction selected by many architects, engineers, and developers (AISC 1991)

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## Advantages of Composite Construction



In a composite floor system the concrete acts together with the steel to create a stiffer, lighter, less expensive structure (Allen 1999)

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## Advantages of Composite Construction



Connecting the concrete to the steel beams can have several advantages:

- It is typical to have a reduced structural steel frame cost
- Weight of the structural steel frame may be decreased which may reduce foundation costs
- Reduced live load deflections
- Shallower beams may be used which might reduce building height
- Increased span lengths are possible
- Stiffer floors

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## Disadvantages of Composite Construction



- The additional subcontractor needed for shear connector installation will increase field costs
- Installation of shear connectors is another operation to be included in the schedule
- A concrete flatwork contractor who has experience with elevated composite slabs should be secured for the job

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## Metal Decking



- Composite decking works together with the concrete fill to make a stiff, light-weight, economical floor system
  - Compare the composite decking (above left), non-composite decking (above center), and the form decking (above right)
- Composite decking is available in various profiles and thicknesses

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## Composite Metal Decking

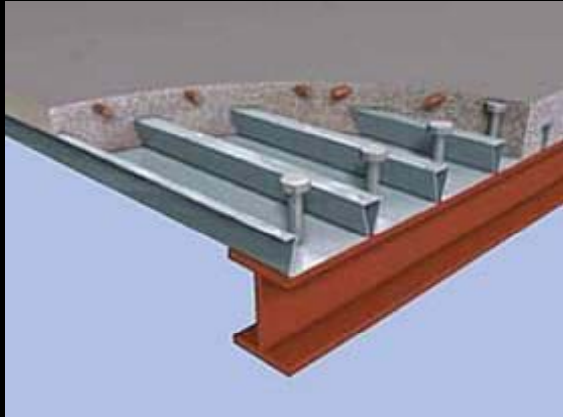


- Decking with deformed ribs (or embossed decking), as shown, is commonly used
  - The deformations on the ribs allow for a stronger bond between the concrete and the decking
- (ASCE 2002)



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## Composite Metal Decking



Less common styles of composite decking include:

- Decking with the ribs formed in a dovetail or fluted pattern (above)
- Decking with welded wire fabric welded to the ribs
- Decking with steel rods welded across the ribs

Image courtesy of Epic Metals Corporation

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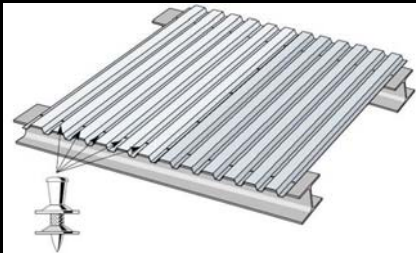
## Installation of Decking



- Metal decking is placed on the structural steel at predetermined points in the erection sequence
- Metal decking may be installed by the steel erection contractor or a separate decking contractor

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## Installation of Decking



- As an alternative to welding, powder actuated tools may be used to attach metal decking to structural steel
- Powder actuated tools use the expanding gases from a powder load, or booster, to drive a fastener
- A nail-like fastener is driven through the metal deck into the steel beam
- The powder actuated tool, powder load, and fastener must be matched to the thickness of the structural steel beam flanges



Images courtesy of Hilti Corporation

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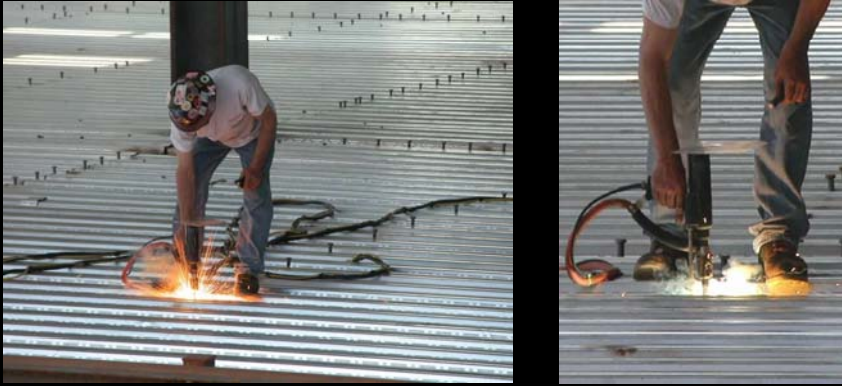
## Shear Connectors



- Depending on the welding process used, the tip of the shear connector may be placed in a ceramic ferrule (arc shield) during welding to retain the weld
- Shear connectors create a strong bond between the steel beam and the concrete floor slab which is poured on top of the metal decking
- This bond allows the concrete slab to work with the steel beams to reduce live load deflection

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## Installation of Shear Connectors



- The electrical arc process is commonly used for stud welding
  - An arc is drawn between the stud and the base metal
  - The stud is plunged into the molten steel which is contained by the ceramic ferrule
  - The metal solidifies and the weld is complete
- The ferrules are removed before the concrete is poured (ASCE 2002, AWS 2004)

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## Installation of Concrete



- Concrete is installed by a concrete contractor on top of the composite metal decking, shear connectors, and welded wire fabric or rebar grid (crack control reinforcing)
- Pumping is a typical installation method for concrete being placed on metal decking
- 10,000 to 15,000 sq. ft. of concrete slab may be installed per day depending on slab thickness and crew size (Ruddy 1986)

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## Quality Control



- The shear connectors used in composite construction require specific inspections and quality control
- Testing procedures are specified in the contract documents or by a local building authority
- AWS D1.1 – Structural Welding Code – Steel, Section 7: Stud Welding (AWS 2004) specifies the tests and inspections for shear studs

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## Cost Impacts of Composite Construction



When used appropriately, typical overall building costs will be less for composite construction than non-composite construction

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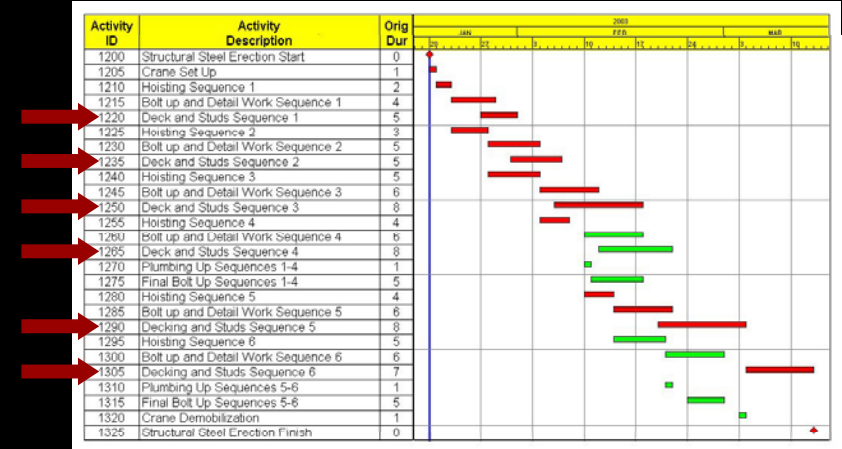
## Cost Impacts of Composite Construction



- The U.S. national average installation cost for shear studs ranges from \$1.15 to \$1.72 per connector (Means 2004)
- A cost comparison should be made between the reduced structural steel cost and the additional shear connector cost when determining whether or not to use composite construction

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## Scheduling of Composite Construction



- The duration for the installation of shear studs is project dependent and should be considered on a project by project basis
- Shear stud installation usually has little or no impact on the overall project schedule

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Image courtesy of CAMBCO Inc.

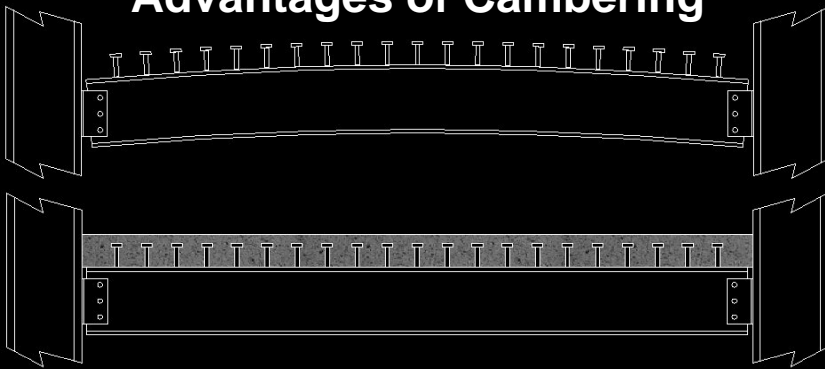
## Introduction to Cambering



- Camber in a beam can be designed to compensate for either:
  - A certain percentage of the dead load deflection
  - The full dead load deflection
  - The full dead load deflection as well as a percentage of the live load deflection (Ricker 1989)
- Camber is usually designed to compensate for deflections caused by pre-composite dead loads

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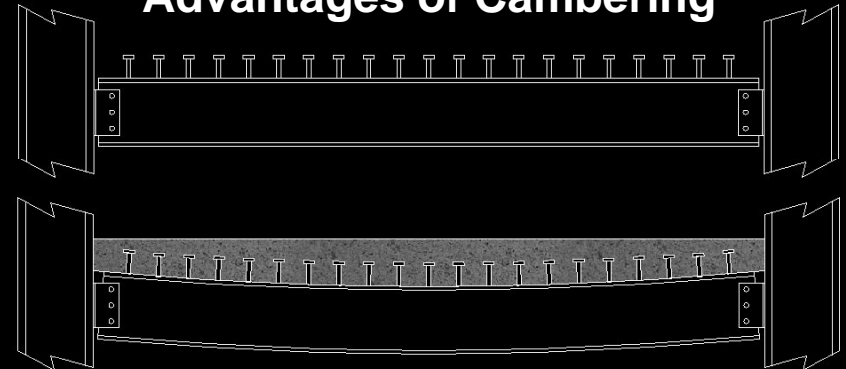
## Advantages of Cambering



- Supporting beams will deflect under the load of concrete being placed
- This deflection can be exaggerated in a composite floor system where the full strength of the system is not achieved until the concrete has cured
- Cambered beams (top diagram above) should deflect to a straight line (bottom diagram above), if load and deflection are predicted accurately and camber equals deflection
  - This allows the floor slab to be flat while maintaining a consistent thickness (Larson and Huzzard 1990)

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## Advantages of Cambering



- If beams are not cambered (top diagram above) the deflection under the load of the wet (plastic) concrete will result in a ponding effect in the concrete (bottom diagram above)
- To create a flat floor in this situation the concrete will need to be thicker at the center of the bay where the deflection is the greatest
- The volume of concrete used will typically be 10-15% more than if the floor is a constant thickness (ASCE 2002)

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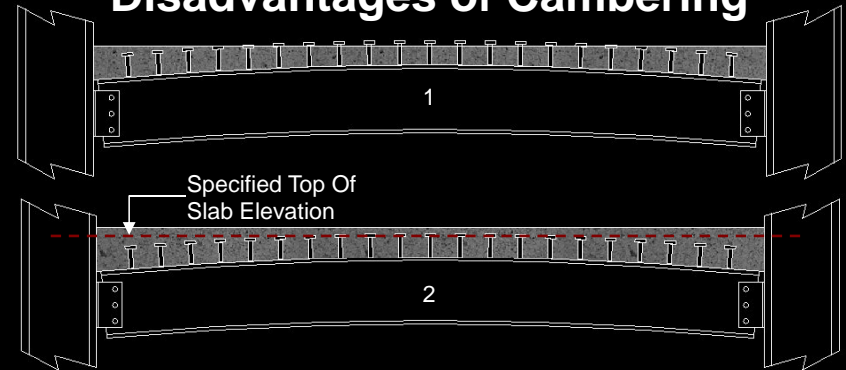
## Disadvantages of Cambering



- The use of cambered beams will, to a certain degree, be limited by other aspects of the design for a structure
- Due to the complexity in detailing, fabrication, and fit-up associated with moment connections (above left), camber should not be used in moment connected beams
- Beams with simple framing connections (above right) may be cambered because the end rotational resistance of a simple connection is small in comparison to that of a moment connection

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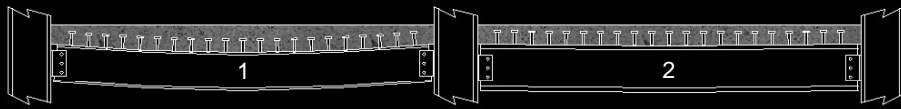
## Disadvantages of Cambering



- The processes used to create camber in beams as well as the actual deflections under load of cambered beams are not exact
- Care needs to be taken in the specification and fabrication of camber to ensure that a beam, once in place and under load, will perform within tolerances
- Levelness and consistent floor thickness can be a problem (ASCE 2002)
- The diagrams above show two possible results of cambered beams not deflecting as predicted under the load of the wet (plastic) concrete
  1. Stud heads are exposed
  2. Top of slab elevation out of tolerance

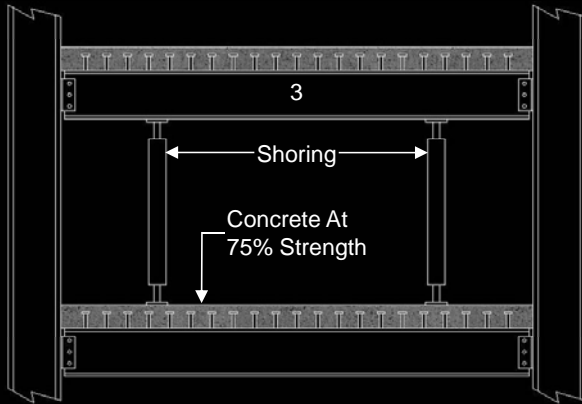
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# Alternatives to Cambering



Alternative methods for achieving a level floor slab without using cambered beams include:

1. Pouring a slab of varying thickness over deflecting beams
2. Using over-sized beams to minimize deflection
3. Shore the beams before placing the concrete



(Larson and Huzzard 1990)

# Shoring



- Shoring may be used in lieu of cambering
- The construction documents must specify the use of shoring
- There are several advantages to using shoring:
  - Lighter floor beams may be used
  - Cambers do not need to be designed or fabricated
  - Less beam deflection allows for better control of the slab thickness
  - Shoring can accommodate a contractor's special loading requirements

# When to Camber



- Girder Beams
- Filler Beams
- Members with uniform cross section
- Composite Floor Beams

(Ricker 1989)

# When Not to Camber



- Cantilevered Beams (above left)
- Crane Beams
- Moment Connected Beams
- Braced Beams (above right)
- Spandrel Beams (above right)

(Ricker 1989)

## When Not to Camber



- Beams with moment connections (above left)
- Beams with non-symmetrical loading
- Beams under 20 feet in length (above right)
- Beams with end plate connections

(Ricker 1989)

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## Heat Cambering



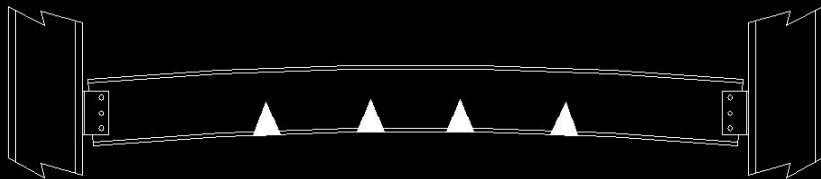
- Beams may be cambered by applying heat to small wedge-shaped areas at specific increments along the beam (Ricker 1989)
- The beam is placed upside down on supports so the "bottom" flange can be heated
- The heated flange expands under the heat and contracts as it cools
- Camber is induced in the opposite side of the beam as the heated flange cools
- Advancing this slide will begin an animation which shows the expansion and contraction that occurs in a heat cambered beam



The animation will repeat after several seconds

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## Installation of Heat Cambered Beams



- A heat cambered beam should be erected with the heat marks on the bottom side of the beam (see top diagram above)
  - This places the beam in a camber up (or concave down) orientation
- Heat marks can be seen on the beams in the bottom picture above

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## Cold Cambering



- Cold cambering methods are more widely used and generally more economical than heat cambering
- The beam is mounted in a frame and force from a ram(s) is used to bend the beam to create camber

(Ricker 1989)

Image courtesy of CAMBCO Inc.

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## Creating Camber



- Cambering is most commonly done at the fabricator's shop after the connections are fabricated (AISC 2000)
- The fabricator may mark cambered beams to ensure proper installation

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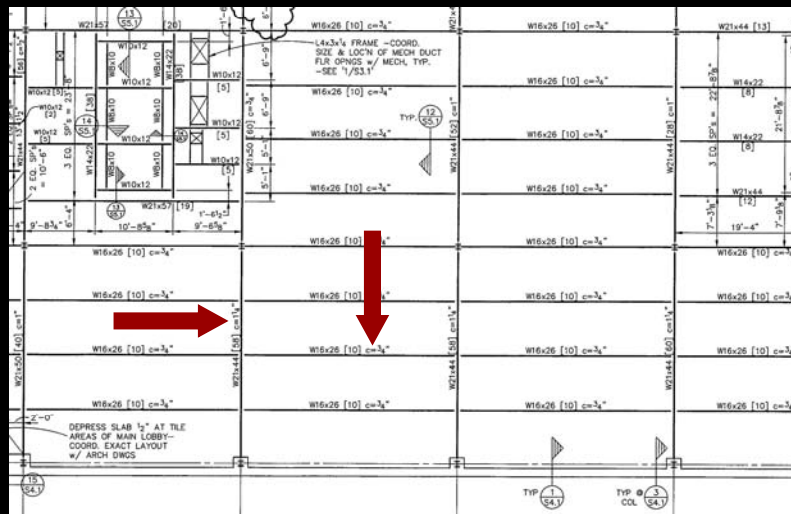
## Natural Mill Camber



- Natural mill camber, which is a slight camber present in a beam when it is received from the mill, will exist in most beams
- If the natural mill camber is at least 75% of the specified camber, no further cambering by the fabricator is required
- If camber is not specified, the beams will be fabricated and erected with any natural mill camber oriented up (or concave down) (AISC 2000)

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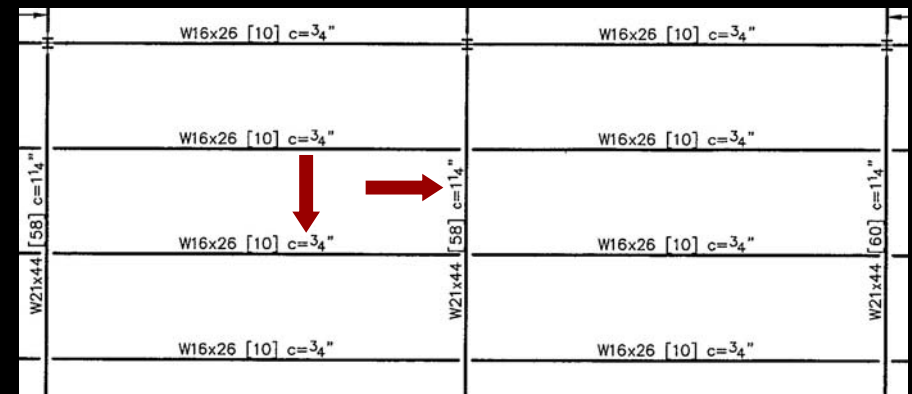
## Cambered Beams on Structural Plans



Cambered beams should be clearly marked on the structural plans (AISC 2000)

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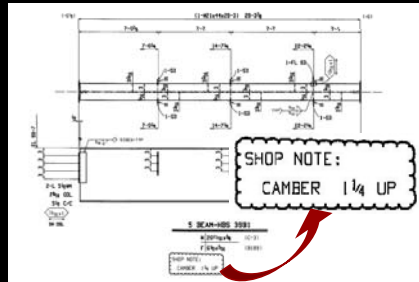
## Cambered Beams on Structural Plans



- The structural plan above shows which beams are cambered
- The amount of camber is indicated for each cambered beam
  - $c=3/4$  indicates that the beams are cambered  $3/4$ " at the center
  - $c=1\ 1/4$  indicates that the girders are cambered  $1\ 1/4$ " at the center

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## Quality Control



- Per the AISC Code of Standard Practice “camber shall be measured in the Fabricator’s shop in the unstressed condition.” (above left)
    - The amount of camber specified on the shop drawing (above right) is for the beam center line in an unstressed or unloaded condition
  - Tolerances for camber are specified in the AISC Code of Standard Practice:
    - Members 50 feet or less in length = minus 0” and plus 1/2”
    - Members over 50 feet the plus tolerance is increased by 1/8” for every 10 feet over 50 feet
- (AISC 2000)

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## Cost of Cambering



- Cambered beams require additional fabrication resources which will make them cost more than non-cambered beams
- The additional cambering cost should be compared with
  - Cost of additional concrete due to “ponding”
  - Cost of using shored construction
  - Cost of using a heavier section that does not need to be cambered

Image courtesy of CAMBCO Inc.

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## Cost Savings from Cambering



- The cost to camber beams may be less than the alternatives
- A cost comparison can reveal the savings associated with the use of cambered beams
- Larson and Huzzard (1990), in their study of cambered beams and uncambered beams found a cost savings of approximately 4%
  - A 30' x 30' bay size was used
  - Filler beams were spaced at 10' o.c.

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## Impacts on the Schedule



- There will be an increase in fabrication duration for structural steel to account for time required to create camber in beams
- The amount of time required to create camber is dependent on a fabricator's internal scheduling and fabrication methods

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