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Structural Steel Design
Composite Beams
Composite Construction and Cambering
In many buildings and bridges, it is common to have a concrete slab supported by steel beams. If the steel beams are connected to the concrete slab in such a way that the two act as one unit, the beam is called as composite beam.

Composite beams are similar to concrete T-beams where the flange of the T-beam is made of concrete slab and the web of the T-beam is made of the steel section.

Composite beam has the advantage that the concrete in the slab takes all or most of the compression (for which it is best suited), while the steel beam takes all the tension in the overall system.
Introduction to Composite Construction

- 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.

Adapted From (ASCE 2002)
Multi-Storey Building

Figure 1 Typical structure
Composite Slab
Composite Slab

Figure 2 Concrete floor on steel decking
Composite beam

Non-Composite Section

Composite Section

Comp.

Ten.

N.A
Composite beam
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)
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)
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
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
• 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
• 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)
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
Metal decking
Metal Decking
Composite slab with OWSJ
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.
Installation of Decking

- Per the Occupational Safety & Health Administration Standard 1926.760(c) the decking crew may work in a controlled decking zone while placing and attaching the decking.

- A controlled decking zone is an area in which initial installation and placement of metal decking may take place without the use of guardrail systems, personal fall arrest systems, fall restraint systems, or safety net systems and where access to the zone is controlled.
Installation of Decking

- Puddle welds (above right) are commonly used to attach the decking to the structural steel below.
- Daily output for a four person decking crew ranges from 2700 S.F. to 3860 S.F. per day depending on the depth and gauge of the decking (Means 2004).
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.
Shear connectors are commonly referred to as “studs” or “shear studs” in the trade.

They are available in a range of sizes, materials, and grades.

Headed studs (as shown) are most commonly used.

Other, less common options for shear connectors include hooked studs or pieces of C-channel.
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.
Shear studs

Metal decking or single span
Shear studs

- Shear studs without a deck
Shear connectors are installed after the decking is in place.

Shear connectors may be installed by the steel erection contractor or a specialty shear connector installer.

The welding equipment required for installation is provided by the shear connector installer.

Daily output for shear connector installation averages about 1000 per day depending on the size of the connectors (Means 2004)
The bracketed numbers on the drawing above give the number of shear studs to be installed at an even spacing on the respective beam

- When spacing is not uniform it will be indicated on the plan

- Specified spacing of the shear connectors is an important part of the composite design and must be adhered to

- Minimum spacings keep concentrations of compressive forces from occurring at the stud locations

- Maximum spacings help avoid separation of the slab from the beam and guarantee the uniform transfer of shear force (RLSD 2002)
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)
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)
There is an art to the placement of concrete on metal deck and structural steel.

The work, unless shoring is used, must be executed on a deflecting surface.

An experienced concrete contractor should be employed for this work.

- Concrete should be deposited over supporting members first, then spread toward the deck midspans.
- The accumulation of a deep pile of concrete must be avoided.

(AISC 2003, ASCE 2002)
Installation of Concrete

- Concrete construction joints should be located over the beam or girder webs.
- Sometimes this is not possible and the joint is located near the decking midspan.
  - Shoring should be placed beneath the construction joints until the concrete on both sides of the construction joint has reached 75% strength.
    - This avoids a bond failure between the hardened concrete and the metal deck when the adjoining concrete is placed.
  (ASCE 2002)
- Placement of construction joints must be reviewed by the Engineer of Record.

ASCE.org
The contractor must be aware of camber in the beams and the expected deflections.

Consultation with the structural engineer may be necessary.

As the concrete cures it forms a connection with the composite metal decking and shear studs.

The composite floor system is now complete.

(AISC 2003)
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.
• As described in the AWS code (AWS 2004), jobsite conditions may exist that prohibit or delay the stud welding operation.

• The primary issues affecting the installation of the shear connectors are:
  ▪ Moisture on the decking or ferrules
  ▪ Moisture between the decking and the steel beam below
  ▪ A steel temperature below 0° F

• In the pictures above, a torch is being used to remove snow (left) from the areas where shear studs are to be installed (right).
Quality Control

• Required quality control procedures for shear connectors include pre-production tests and fabrication inspections

  ▪ Pre-production testing is performed by the shear stud installer at the beginning of each work shift and includes the following steps:
    1. Weld two sample studs
    2. Inspect for flash
    3. Perform bending test
    4. Equipment settings are recorded

  ▪ The stud installer performs visual fabrication inspections as studs are installed

  ▪ Other testing may be specified or may be necessary if all visual inspections are not passed (SIN 1998)
When used appropriately, typical overall building costs will be less for composite construction than non-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
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.
Scheduling of Composite Construction

- It may be possible, depending on the size of the structure and the sequencing of erection and decking, to install the shear studs as erection proceeds.
- It may also be possible to have a majority of the shear connectors in place and begin placing concrete for the floor slabs while structural steel is being erected in another area of the building.
- On the structure shown above part of the composite first floor slab was placed while erection of the structural steel for the third floor proceeded.
Composite beams - Dr. Seshu Adluri
Image courtesy of CAMBCO Inc.
Introduction to Cambering

Cambering is the process of creating an intentional slight curvature in a beam

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
- 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).
• 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)
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.
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
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 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
- Members with uniform cross section
- Filler Beams
- 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)
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.
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
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.
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
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).
Cambered beams should be clearly marked on the structural plans (AISC 2000)
The structural plan above shows which beams are cambered.

The amount of camber is indicated for each cambered beam:

- $c=\frac{3}{4}''$ indicates that the beams are cambered $\frac{3}{4}''$ at the center
- $c=1\frac{1}{4}''$ indicates that the girders are cambered $1\frac{1}{4}''$ at the center
Installation of Cambered Beams

- The installation of cambered beams is similar to that of other structural steel members
- No additional tooling, equipment, or hardware should be required
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)
• It is possible for all or part of the induced camber to come out of a beam during shipment to a jobsite

• This is acceptable under the AISC Code of Standard Practice (2000), but the fabricator’s quality control procedure should provide verification that the specified camber was measured in the shop
• 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
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.
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.
Impacts on the Schedule

Delivery, shakeout, and erection durations should not be impacted by the use of cambered beams.
Structural Steel: The Material of Choice
Composite beam with prefab concrete slab

(a) Prefabricated concrete slab

Joint

(b) Reinforcement strap

Stud shear connector

In situ concrete

Concrete planks

Stud shear connector

I-section

Reinforcement
Composite Hollow-core Slabs

Figure 4. 'Slim floor' system
Figure 5b  Integrated steel beams for 'slim floor' systems
Composite construction for fire resistance

(a) Column

(b) Beams

Figure 6 Typical solutions for fire protection
References


**AISC Digital Library (2008)**


References Cont.

ESDEP—the European Steel Design Education Programme - lectures


