Considerations for Steel Framed Floors

SEAC/RMSCA Steel Liaison Committee

September 2008
Revised: September 2021

DISCLAIMER

This paper was prepared by the Steel Liaison Committee of the Structural Engineers Association of Colorado (SEAC) and the Rocky Mountain Steel Construction Association (RMSCA); a coalition of Structural Engineers, Front Range Fabricators, Detailers and Erectors dedicated to improving the steel construction industry.

SEAC, RMSCA, their committees, writers, editors and individuals who have contributed to this publication do not make any warranty, expressed or implied, or assume any legal liability or responsibility for the use, application of, and/or reference to opinions, findings, conclusions, or recommendations included in this document.

This document has not been submitted for approval by either the SEAC Board of Directors or the SEAC General Membership. The opinions, conclusions, and recommendations expressed herein are solely those of the document's authors.

This document does not replace and is not to be used as an adjunct to the current edition of AISC 303-16 *Code of Standard Practice for Steel Buildings and Bridges* or CASE Document 962D.

Original Participating Members of the Committee

Mike Allen, *Saunders Construction, Inc*
Paul Doak, *P.E., S.E., Martin/Martin, Inc.*
Dave Henley, *P.E., Vulcraft*
Tom Hickish, *P.E., Jirsa Hedrick & Associates, Inc.*
Rob Leberer, *P.E., S.E., Anderson & Hastings Consultants, Inc*
Curtis Mayes, *P.E., LPR Construction Co.*
Rodd Merchant, *P.E., J.E. Dunn Construction*
Tom Skinner, *P.E., JVA Consulting Engineers*
Bryan Starr, *P.E., S.E., S. A. Miro, Inc.*
Tad Toler, *Cobalt of Colorado*
Maynard Trostel, *P.E., Puma Steel*
Jules Van de Pas, *P.E., S.E., Computerized Structural Design*
Bruce Wolfe, *P.E., Structural Consultants, Inc.*
Bill Zimmerman, *P.E., Zimkor, LLC*

Members of Revision Team

Jim Foreman, *P.E., S.E., Martin/Martin Consulting Engineers*
Scott Luckiesh, *P.E., S.E. BKBM Engineers*

STATEMENT OF INTENT

Over the last 12 years, many changes have occurred in the steel construction industry. Years ago, the steel mills provided most of the cambering while today the Fabricator typically does the cambering in his shop. In the past, the Fabricator had to straighten the steel before fabrication to remove mill sweep. Today mills have eliminated the need for the straightening process. Material costs have increased in relation to labor costs, and that relationship usually is a moving target. Lower structural steel weights are common when compared to years past due to the widespread availability 50 ksi material and use of LRFD design methodology as opposed to ASD design. However, weight savings in the steel frame does not always reflect a cost savings to the steel frame or the project.

In light of the changing industry, it is the intent of this paper to discuss design and construction issues that are typically expressed today by Owners, Architects, Structural Engineers (EOR), General Contractors, Fabricators, Detailers and Erectors. If these issues are sufficiently addressed by the design and construction team, then a successful steel framed floor system can be realized by the project.

Each participant on the design / construction team has responsibilities that affect cost, schedule, quality and constructability. Often, the participants carry unique perspectives that may not be obvious to other members of the team. If the issues are addressed and coordinated early with the team, an economical and successful steel framed floor can be constructed.

This paper was prepared by the SEAC/ RMSCA Steel Liaison Committee, a coalition of Front Range Fabricators, Detailers, Erectors, General Contractors and Structural Engineers dedicated to improving the steel construction industry.

The following discussion topics are offered to help you achieve a successful project using steel framed floors.

DESIGN CONSIDERATIONS

Steel is an economical system for supporting floors. The framing is an integral part of the building system. As such, its design needs to be integrated into the overall architectural design of the building. In order to have a successful design, the EOR needs to achieve the following goals:

- Conformance with the governing code for design loads, deflection limits, and fire ratings. These are minimum requirements based on the intended building use and are not negotiable.
- Serviceability including deflection, vibration limitations, acoustic separation, floor flatness/levelness.
- Constructability with considerations such as steel and deck erection.
- An economical solution by finding a balance between material costs, fabrication costs, erection complexity, and schedule.

These goals are not mutually exclusive. However, designing a steel framed floor that meets the requirements for serviceability and constructability may increase the cost of the framing beyond that required for the minimum building code requirements. Therefore, the EOR, Architect, and Owner need to make a series of timely informed choices as part of the design process.

LAYOUT AND GEOMETRY

Typically, the column locations and bay spacings are determined by the Architect with input from the EOR. Numerous studies have shown that bay sizes in the range of 25 feet to 35 feet provide an economical framing system. Additionally, rectangular bays are more economically framed with longer beams and shorter girders, with a plan ratio in the range of 1.25 to 1.50.

Another important decision is the selection of the column size and orientation. Column size can have a significant effect on fabrication costs. Selecting the most efficient, lightest section may require additional stiffeners and web-doubler plates to meet the demands of localized forces from connections. This can drive up the shop fabrication costs well in excess of the increase in material costs of selecting a heavier column section. If the steel fabricator is known early in the design process the EOR should discuss options and costs. Orientation. Normally, a column is oriented so that the girders connect into the column flanges. This provides a number of benefits. It eliminates the need to trim the girder flanges, as they will typically be wider than the clear width between column flanges. It also aligns the girder in the strong-axis direction of the column to facilitate efficient moment connections for lateral frames or cantilever conditions.

COMPONENT SELECTION

After the loads, fire rating requirements, and framing system have been determined, the next step is to select the slab and deck system. Usually, the minimum slab thickness is selected based on the fire rating requirements for the project.

If a fire rating is not required, then a minimum slab thickness on top of the deck flutes of 3" to 3-1/2" is suggested. Many design offices use these minimums to help provide the floor system stiffness needed for serviceability and allows for some routing of electrical conduits. If vibration considerations are critical, a thicker slab may be needed to increase the mass of the system.

The selection of the deck type, depth and gage can determine the spacing and layout of the beams. It is recommended to use a minimum of 22 gage deck to provide sufficient capacity during construction to accommodate concentrated loads and storage of materials. Selecting the deck that has the greatest spanning capacity consistent with the given bay sizes and framing depth limitations will result in a design with the minimum number of beams. Typically, this configuration will reduce beam fabrication and erection costs and improve vibration performance. It is recommended that the greatest beam spacing be limited to the maximum available deck length available for a three-span condition while the deck selection should be based upon a two-span condition. There may be some single deck span conditions due to floor openings for stairs, elevators, mechanical shafts, atriums, etc. Some shoring may be required in these areas if the deck selection exceeds the single span section of the 'SDI Maximum Un-shored Clear Span' portion of the steel deck tables.

Due to safety concerns during erection, the distance between three beams should not exceed the maximum deck sheet length.

The beams in the floor system can consist of either; non-composite or composite steel joists, non-composite beams (cambered or un-cambered), or composite beams (cambered or un-cambered). The composite beams may either be shored or un-shored. Shored construction is generally considered to be uneconomical and is not recommended. However, framing around large floor openings such as elevators may warrant shoring due to the accumulated deflections that can occur in column-free framing. Also, surveys during construction may determine that shoring may be necessary if beams have less camber than specified. Shored systems are not considered in the following discussion.

For composite members, 3/4" diameter Headed Anchor Studs (HAS) should be used, with the same length for similar types of deck. When sizing beams and girders, be sure to check the flange thickness is at least 2.5 times the stud diameter. Normally the most economical use of HAS is in partially composite construction. 25% minimum is recommended, with efficient designs being between 50% and 75% composite. Be sure to coordinate the deck flute spacing with stud layout. Avoid arbitrarily specifying a center-to-center spacing; this will increase construction costs for the Erector and Fabricator. Rule of thumb, the installed cost of a single stud is about the same as 10 lbs of steel, $10 as of September 2021. Adding beam weight to reduce studs may be more economical. Consider keeping studs spaced far enough apart to allow ironworkers to walk on beam during erection. You may want multiple rows with greater spacing. Normally, short secondary beams do not need to be designed as composite, nor should HAS be added for the sake of having studs on all beams.

CAMBERING

The intent of this section of the paper is not to provide limits and requirements for cambering, but rather to give general guidelines that have produced successful projects. There are excellent resources available with more in-depth discussions of these topics, including the following articles from Modern Steel Construction: "Specifying Camber," July 2006; "Tolerating Tolerances," June 2005; and "Elevated Slab Tolerances," August 2007; as well as "Cambering of Steel Beams", Lawrence A. Kloiber, Steel Structures Proceedings Steel Congress '89, ASCE/San Francisco, CA May 1-5, 1989.

The question of whether or not to camber, and how much, involves a number of factors, fabrication costs, detailing, and erection considerations to name a few. The following suggestions are offered to assist the designer with these decisions.

Consider reducing camber if pouring a "level" floor as opposed to a constant thickness floor. Mill tolerances, fabrication techniques, and cambering methods result in uncertain erected cambers and will make it difficult to place a level floor in field. You need to make sure camber does not make slab too thin, especially in composite construction.

The process of cambering may not be necessary if the material weight is increased a small amount. This could result in savings to the project and should be considered in the design process. Cost to camber is about $0.04 to $0.05 per pound, plus an extra month lead-time. A general guide is a beam weight savings of 3 to 4 lbs per lineal foot will offset the cost of mechanically cambering typical floor beams.

Consideration could also be given to not cambering girders since they usually do not deflect as much as the filler beams. Selecting a deeper and/or heavier section will cost more but can help prevent erection issues with in-framing members. Cambers will change during shipping and erection and may make connections difficult if not properly detailed to account for fit-up tolerance.

Cambering in the fabrication shop is accomplished by either, laying the beam on its side and cold-bending the beam until it yields, or by applying heat to the beam at regular intervals to cause expansion and contraction of the beam to the required camber. The heating process is not used frequently because it is much more expensive than the cold-bending process. The cold-bending process is usually accomplished with hydraulic rams pushing the beam into position

AISC camber tolerances require the camber to be equal to or greater than that specified. However, end restraint of the beam end connections may result in less deflection than calculated. Therefore, engineers should consider specifying camber that is less than the calculated non-composite dead load deflection. Standard engineering practice varies on the percent of non-composite dead load deflection to use for camber, ranging from 60% to 100%. Once the target camber has been selected, it is recommended that the EOR increase the size of the beam to satisfy the selected camber limit. In a partially composite system, the cost of the increased beam size can generally be offset by reducing the number of HAS required.

Members that should not be cambered include

- Beams with bracing or moment connections.
- Edge beams.
- Short beams framing openings
- Beams with cantilevers.

Cambered spandrel beams supporting curtain wall systems can present problems in the curtain wall connections. It is recommended that stiffer, un-cambered spandrel beams be designed so that minimal deflection will occur as the curtain wall is constructed.

Fabricators have found the following practices will produce the most predictable and cost-effective results:

- Specify camber in 1/4 inch intervals.
- Specify camber in the range of 3/4 inch to 1-1/2 inches. 1-1/2 inches is the practical limit to camber a beam in a single operation.
- Beams 14 inches and greater in depth.
- Beams with web and flange thicknesses 1/4 inch and greater.
- Beams with a length of at least 24 feet.
- Beams with meeting compact section criteria defined by AISC.
- Camber should not exceed approximately L/360.

When cambering beams greater than 1-1/2", consideration must be given to end rotation and web and flange crippling during the cambering process. Since most beam lines punch the holes for bolted connections before the cambering operation, large cambers will cause excessive rotations at the beam ends and consequent fit-up problems for bolted connections in the field. We recommend contacting a local Fabricator to verify what is common in your area.

Special considerations are required when cambering beams over 40 feet in length. Multiple "pushes" are required, and it is difficult to achieve consistent results.

Non-composite steel joists, as opposed to steel beams, are manufactured to a common radius producing a camber based upon the length. Composite steel joists are cambered specifically to compensate for the non-composite construction loading. Contact a local joist supplier for more information.

CONNECTIONS

A successful steel frame building project requires close coordination of the Design Team, Fabricator, Erector, Detailer, and General Contractor to produce shop and erection drawings which meet the intent of the design. The connections may be designed by either the EOR or the engineer engaged by the Detailer or Fabricator for delegated designs. Check with your General Contractor or Construction Manager to understand the local market. Considerations are:

- The Design Team's requirements for the strength of the connections.
- The Fabricator's shop standards with regard to bolting, welding, coping, etc.
- The Erector's concern for maintaining safety during the erection sequence and their preferences for erectability issues.
- The General Contractor's responsibility for maintaining schedules.

In order for these considerations to be handled in a timely manner, it is essential that the Detailer be brought onboard as early as possible starting with a "Pre-Detailing Meeting." A guideline for this meeting titled "Pre-detailing Meeting Agenda" has been prepared by this committee and provides an excellent resource for preparation of the detailing process.

Listed below are recommendations to improve the success of your project:

- Take advantage of the connection tables in the AISC Steel Construction Manual. The calculations for standard connections are often updated resulting in greater capacities.
- As much as possible, avoid using different bolt diameters. One size throughout is ideal, but if multiple sizes are necessary specify in 1/4" increments. This will help to minimize errors in fabrication and erection.
- Avoid using both A325 and A490 bolts of the same diameter.
- Permit the use of horizontal short slots for steel-to-steel shear connections. Since beam lines normally only punch round holes, the slots should be placed in the connecting material, not the connected member. The short slots will provide construction tolerance and simply the bolt-up of cambered beams.
- Avoid using slots at beam to column connections as a general rule, to avoid the field labor cost of spacing columns in every bay of the structure.

ELEVATION CONTROL

The structural design is based on erected camber while the Code of Standard Practice (COSP) requires camber to be checked in the shop. Thus, we have a conflict between work in the shop and what is required in the field. It is important to recognize that the cambering method as defined by the AISC COSP has worked successfully for many years and should be used as a standard for measuring camber. Should the project require large cambers and/or light beams, cambering measurements may be necessary to be done in the field. The measurement of camber in the field goes beyond the AISC COSP and will add cost to the project. The AISC COSP is a legal document and going outside of it puts all parties at risk. There is also the practical matter of who is responsible if the measurements do not meet the required camber specified in the documents.

One of the floor design goals is to meet the flatness requirements for the project. It should be noted that the camber of the floor beams and the in-place erection tolerances of the steel frame do not directly determine the top of concrete location for a floor. The erected position of the steel framing, including the in-place camber provides a starting point for the concrete contractor to use in meeting the project flatness requirements. Floor flatness is a measurement of finishing tolerances, not a measure of slab performance, and is typically measured 24 to 48 hours after the concrete placement. The slab performance will depend on other factors, such as stiffness and deflection of the floor system under superimposed dead and live loads.

Typically, the only elevations that the Erector has direct control of are the elevations of the first tier steel columns and the elevation of steel beams that connect directly to concrete in some manner. Column elevations are usually established by the setting of shims or leveling nuts under the column base plates. This is a critical beginning point to achieve a reasonably level floor slab. Beyond this, the Erector is largely dependent on the accuracy of the fabricated structural steel, including cambered beams, to establish proper elevations for concrete slab support.

The AISC COSP, Section 6.4.4 and Commentary states “For the purpose of inspection, camber shall be measured in the Fabricator’s shop in the unstressed condition.” However, the desire by the EOR, Architect, General Contractor and Owner is to know the camber of the erected steel. This knowledge will help predict the success of attaining the floor flatness. Some engineering firms specify that all of the steel framing elevations be surveyed and documented prior to and after placement of the concrete. Although these extensive elevation/camber surveys help in identifying problems prior to concrete operations, the benefit to the Owner may not offset the cost of the survey, reporting and review by the EOR. The primary purposes of the survey are to obtain flatness without remedial work, to ensure that the minimum slab thickness has been met for the required U.L. rating, and to avoid an excessive slab thickness that could overload the structure. This can be accomplished by checking beam camber and elevations before and after concrete placement. The goal is to confirm if the camber control system is working, rather than documenting the camber of every erected beam. In lieu of an extensive survey, the following is a cost-effective alternative:

- Require a specified percentage of random field checking of camber as the beams are unloaded off the trucks, placing emphasis on immediate verification of the first several cambered beams delivered to the project.
- Once the frame is erected, check a specified percentage of beams prior to erection of the steel deck. If problems are found, the construction team could decide on an appropriate course of action.
- After the slab is placed, the same beams should be checked for the amount of deflection which occurred during the concrete placement in order to compare with the estimated deflection.

This information will provide feedback to the design and construction team so, if needed, appropriate corrective actions can be considered.

Since the remedial action necessary to correct an out-of-tolerance slab on steel deck to accept floor finishes can often exceed the cost of the survey, this limited survey makes economic sense. The assignment of responsibility and scope for the survey must be clearly specified in the Design Documents. It is recommended the Owner be responsible for the cost of the survey which would be performed under the direction of the Testing Agency and that the General Contractor provide the equipment and labor.

CONCRETE PLACEMENT METHODS AND SEQUENCING

The required slab thickness, levelness requirements, and tolerances should be clearly defined in the Contract Documents. The Owner's expectations for slab performance should be discussed by the Team early in the design process. The resulting design criteria should be clearly stated on the drawings.

There are two placement methods for establishing the top of concrete elevation:

- Level top of concrete - This method will result in a varying slab thickness.
- Uniform thickness - The top of slab will roughly follow the contour of the steel beams.

With both systems, the minimum and maximum slab thicknesses should be stated. The minimum thickness will often be determined by the required fire-rating, and the assumptions for additional concrete weight used in design should be incorporated with a maximum thickness (and/ or average thickness).

Contractors typically prefer a "level" top of slab but check your local market to determine if a particular method is more common. Laser level technology has simplified the task of concrete placement. Owner requirements for floor levelness and flatness may also dictate a "level" floor. If a "level" floor is required, the deck, steel beam/ joist, and girder deflections need to be carefully considered in the design to accommodate ponding effects caused by the concrete placement. Critically, if the additional concrete weight is overlooked in the design, the result could be beam overstress and progressive deflection under the weight of the non-composite concrete. This could result a reduction of the allowable live load under full service loads or require strengthening of the framing to achieve the required capacity. The Contractor should be aware of the potential for the additional concrete required to achieve a "level" slab surface and the topic discussed during the preconstruction meeting. It is also possible for the resulting slab thickness to be less than that specified, particularly if the non-composite concrete load deflection does not fully counter the camber in some beams, resulting in the HAS not having the required minimum cover, or a slab with less than the minimum thickness for the required fire rating. This condition is less likely with a uniform slab thickness placement method described below.

The "uniform" method produces a slab with a uniform thickness, thus controlling the weight of the concrete placed on the structure. The concrete subcontractor must gage the slab thickness at multiple locations along beams to maintain this uniform thickness. This method is more labor intensive than laser level monitoring of the top of the slab and could increase construction costs because the placement method is more complicated and may also require corrective action to achieve levelness appropriate for finishes. Variations in beam camber combined with actual vs. calculated beam deflections can result in unevenness in the slab surface. The successful interaction between the beam camber and the actual deflection that occurs during the concrete placement will dictate the floor levelness.

Placement techniques of concrete for floor slabs such as pumping or dumping from crane buckets can affect the final product. Dumping of concrete in large quantities at one location may cause excessive localized loading and deflection. Pour sequencing can affect dissipation of camber in beams and girders. Hardened concrete on one side of a beam or girder could stiffen the floor enough to resist dead load deflection for fresh concrete placed on the other side of the beam or girder, leaving too much residual camber.

The specified content of fly ash and other concrete admixtures should be carefully considered by the design and construction team. For example, high concentrations of fly ash can significantly affect the concrete set time making finishing more difficult. This can also impact the construction schedule, increasing the overall project cost. Additional considerations beyond the scope of this paper are topics such as the unit weight of lightweight concrete and vapor transmission for seamless flooring applications.

For fire rated concrete floors, U.L. does not allow for a minus (-) tolerance in slab thickness. However, ACI 117, "Specification for Tolerances for Concrete Construction and Materials" does allow a minus (-) tolerance of 1/4 inch. This topic should be discussed by the Design Team early in the process to establish expected design requirements. Some design offices will consider an average slab thickness after concrete placement before requiring the placement of spray applied fireproofing to the underside of the deck to satisfy U.L. Another consideration for accomplishing a flat floor would be to allow for a topping slab or leveling compound to be installed after placement of the structural slab. Once the structural concrete slab has hardened, the floor system will be very stiff and the subsequent deflections due to the placement of the topping slab or leveling compound would be small.

CONCLUSION

The EOR is in a unique position, by coordinating the many design aspects and stakeholder concerns, they can provide significant contributions to the success of the project. If this is to be achieved, open communication via design meetings, pre-detailing meetings, and pre-construction meetings creates a cooperative and collaborative environment between all team members, the Owner, Architect, EOR, General Contractor, Fabricator, Detailer, and Erector.

REFERENCES

Organizations
1. American Institute of Steel Construction (AISC)
2. Steel Deck Institute (SDI)
3. Steel Joist Institute (SJI)
4. American Concrete Institute (ACI)

Reference Materials
1. AISC Code of Standard Practice (COSP)
2. AISC Steel Constriction Manual

Camber Articles
1. Modern Steel Construction, "Specifying Camber," July 2006
2. Modern Steel Construction, "Cambering Steel Beams," September 2004
3. Modem Steel Construction, "Specifying Camber," July 2006
4. ASCE Structures Congress, "Camber of Steel Beams," Lawrence A. Kloiber, May 1989
5. "Economical Use of Cambered Steel Beams," Jay W. Larson & Robert K. Huzzard, circa 1989

Fabrication Articles
1. Modern Steel Construction, "Reducing Fabrication Costs," April 2000
2. Modern Steel Construction, "Rules of Thumb for Steel Design," February 2000
3. SEAT, "Design & Construction Issues for Achieving Floors of Acceptable Flatness and Levelness," April 1994

Serviceability Articles
1. Modern Steel Construction, "The Cost Equation, When Designing for Floor Vibrations," January 2008
2. Modem Steel Construction, "Floor Vibration Serviceability; Tips and Tools for Negotiating a Successful Design," April 2003
3. AISC Engineering Journal, "Preliminary Assessment for Walking-Induced Vibrations in Office Environments," 1St Quarter 2005
4. AISC, "Serviceability Criteria for LRFD Composite Floors," Roberto T. Leon, 2003
5. AISC, "Serviceability Guidelines for Steel Structures," Bruce Ellingwood, 2003
6. Modem Steel Construction, "Save More Money," March 2008

Concrete Finishing Articles
1. Modem Steel Construction, "Tolerating Tolerances," June 2005
2. Modem Steel Construction, "Elevated Slab Tolerances," August 2007
3. Designing Steel for Serviceability Lecture 3, "Control of Floor Elevation and Levelness," date unknown
4. Modern Steel Construction, "Ponding of Concrete Deck Floors," September 2005
5. Concrete Construction, "Building Concrete Slabs Composite with Steel Frames," November 1989
6. AISC Engineering Journal, "Ponding of Concrete Deck Floors," Third Quarter 1986
7. Aberdeen Group, "Controlling Deflection of Composite Deck Slabs," 1997
8. Aberdeen Group, "Constriction of Elevated Concrete Slabs, Practice and Procedures," 1991
9. Aberdeen Group, "Construction of Elevated Concrete Slabs, Understanding the Effect of

Structural Systems," 1990
10. Aberdeen Group, "Concrete Screed Rails Used for Concrete Placed on Metal Deck," 1991
11. SDI, "Metal Deck and Concrete Quantities," 1997

Cost Articles

1. Modern Steel Construction, "Value Engineering for Steel Construction," April 2000
2. Modern Steel Construction, "Economy in Steel," April 2000

Coordination Articles

1. "Pre-Detailing Meeting Agenda" by SEAC/ RMSCA Steel Liaison Committee