Antiquated Structural Systems Series

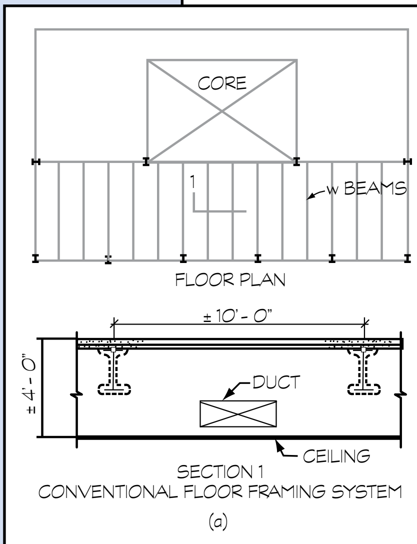
Structural Steel Composite Stub-Girder Construction – Part 6

By D. Matthew Stuart, P.E., S.E., F. ASCE, SECB

For this series of articles, "antiquated" has been defined as meaning outmoded or discarded for reasons of age. In reality, however, most if not all of the systems that have been and will be discussed are no longer in use simply because they have been replaced by more innovative or more economical methods of construction.

Most of the antiquated systems discussed so far have been out of popular use for a considerable number of years, with some dating back to the first part of the last century. However, the subject of this article deals with a system that was still in use less than 20 years ago.

The purpose of this series is to compile and disseminate a resource of information to structural engineers for projects that involve the repair, restoration, or adaptive reuse of older buildings for which no drawings exist. It is hoped that this will enable structural engineers to share their knowledge of existing structural systems that may no longer be in use, but are capable of being adapted or reanalyzed for safe reuse in the marketplace of today and the future.



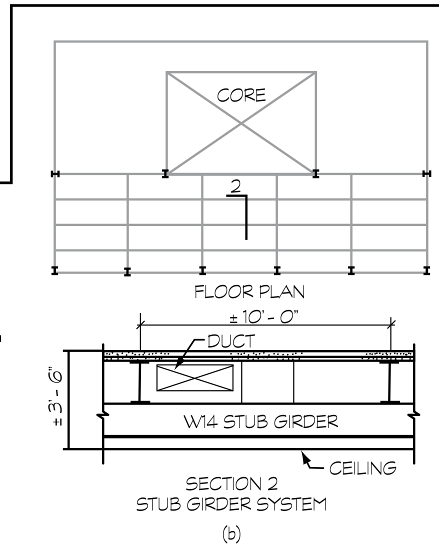


Figure 1: Floor Framing Systems. Courtesy AISC.

The Stub-Girder Composite System

A stub-girder is a composite system constructed with a continuous structural steel beam and a reinforced concrete slab separated by a series of short, typically wide, flange sections called stubs. Stubs are welded to the top of a continuous beam and attached to the concrete slab by shear connectors. Spaces between ends of stubs are used for installation of mechanical ducts and other utility systems and for placement of transverse floor beams that span between stub-girders. Ideally, the depth of stubs and floor beams are identical to allow for transverse framing to support a concrete slab deck, which spans parallel to the stub-girder, and to facilitate composite action between the floor beam and slab (*Figure 1*).

Stub-girder construction was first used in 1971 at the 34-story One Allen Center office building in Houston, Texas. The system was developed by Joseph P. Colaco, Ellisor Engineers, Inc., to facilitate integration of mechanical ducts into steel floor framing of repetitive, multistory high-rise construction. This system went on to be used in a large number of high-rise buildings in North America up through the 1980s. However, the system was eventually abandoned because of increased labor cost associated with both fabrication and the need for shoring until the field-cast concrete slab attained sufficient strength.

Advantages of the stub-girder system that led to its use during the time period in which it was popular included:

1) Reduction in steel tonnage by as much as 25% over conventional composite floor framing due to:
   a) Improved structural efficiency as a result of the greater depth of the stub-girder compared to a conventional system; and
   b) Improved structural efficiency due to the ability of transverse floor framing members to act as continuous beams through openings between stubs.
2) Reduction of overall depth of the structural floor framing system by as much as 6 to 10 inches over a conventionally framed composite floor system, which allowed for a reduced floor-to-floor height and overall height of the building and associated cladding.

Testing

Prior to use of the stub-girder system, a load test was performed at Granco Steel Products Company in St. Louis. The test specimen included a W14x48 continuous bottom beam, W16x26 stubs and floor beams, and a 5-foot-wide, 3¼-inch-deep, lightweight concrete slab over a 2-inch metal deck flange, which was attached to stubs via shear connectors (*Figure 2, page 54*).

The test specimen was loaded beyond calculated design load, with initial failure occurring at the exterior end of the outermost stub at one end of the stub-girder. The method of failure included web crippling and delamination of the web from the flange. Application of additional load resulted in crushing of the slab at the inside edge of the same stub. However, separation between the bottom of the slab and the top of the stubs did not occur, which indicated that composite behavior was maintained up to the point of localized crushing of the concrete slab. Web stiffeners added to the failed stub allowed the system to achieve a final failure load that was 2.2 times greater than the calculated design load.

The methods of design used to determine capacity of the section included a non-prismatic beam analysis, a Vierendeel girder/truss analysis, and a finite element analysis. For the Vierendeel analysis, stubs and transverse floor beams act as verticals and the concrete slab and continuous beam act as chords. See *Figure 3 (page 55)* for a comparison of a typical Vierendeel truss and stub-girder components. All three of these methods of analysis provided a close representation of actual behavior of the stub-girder; however, the Vierendeel and finite element methods more closely identified secondary moment effects on each side of the openings. The Vierendeel method of analysis also provided a more accurate representation of actual steel stress, while the finite element method provided a more accurate representation of stress in the concrete slab, including high stresses that resulted in crushing of concrete at the inside edge of the first exterior stub as observed in the test specimen.

Additional tests of stub-girders were performed in the late 1970s in Canada. The primary purpose of these tests was to determine effects of changes in spacing and depth of stubs, and to establish failure modes of a stub-girder. Results confirmed that behavior of a stub-girder was similar to a Vierendeel girder/truss. Supplementary conclusions of these tests included:

1) The stiffness of the girder increases as the length of the open panel between the stubs decreases.
2) Shear distortions at open panels (as a result of the Vierendeel action) were an important parameter in determining elastic deflection of the stub-girder, but did not influence rotation of solid end sections of the overall girder.
3) Tensile cracking of the concrete slab at the ends of open panels occurred at relatively low loads, but did not have a significant impact on elastic stiffness of the girder.
4) Further extensive cracking of the concrete slab at the ends of open panels occurred in the inelastic range of the girder. It was further determined that ultimate strength and ductility of the girder could be improved through use of internal reinforcement within the slab that was placed to resist the observed cracking.
5) Precision of the Vierendeel method of analysis was dependent on accuracy of distribution of shear forces between the concrete slab and the continuous lower beam across open panels and assumptions made relative to location of points of contraflexure within open panels.
6) Failure of shear connectors resulted as a combination of shearing and prying effects.
7) To prevent premature failure due to web crippling at stubs, stiffeners should be provided.
8) Five different failure mechanisms were identified: buckling of the stub web, concrete failure in the vicinity of shear connectors, diagonal tension failure of the concrete slab, shearing off of headed stud connectors, and combined yielding of the steel beam and crushing of the concrete slab at the ends of open panels due to cumulative effects of primary and secondary (Vierendeel) moments.

Further research in Canada revealed additional insights into behavior, design, and economical construction of stub-girders. This research indicated that only partial end plate stiffeners, rather than traditional fitted stiffeners, were required to reinforce stub webs. Furthermore, web stiffeners were not always required at interior stubs. In addition, a continuous perimeter weld between the base of the stub and the top of the continuous beam was not required. Tests also confirmed that rolled wide flange shapes were more conducive to stub-girder construction than split T (WT) or rectangular hollow tube (HSS) sections.

Additional conclusions of these later Canadian tests revealed that:

1) Deflection computations using the Vierendeel method of analysis were typically conservative for service loads, and unconservative for ultimate loading conditions.
2) The amount of internal slab reinforcement, particularly in the direction transverse to the stub-girder span, was established based on Canadian Standard Association (CSA) criteria available at the time of testing.
3) The conventional method of calculating number of shear studs required and application of standard methods of composite design to analysis of stub-girders appeared to provide satisfactory results; however, caution was recommended when specifying closely spaced studs, particularly at the end stub.

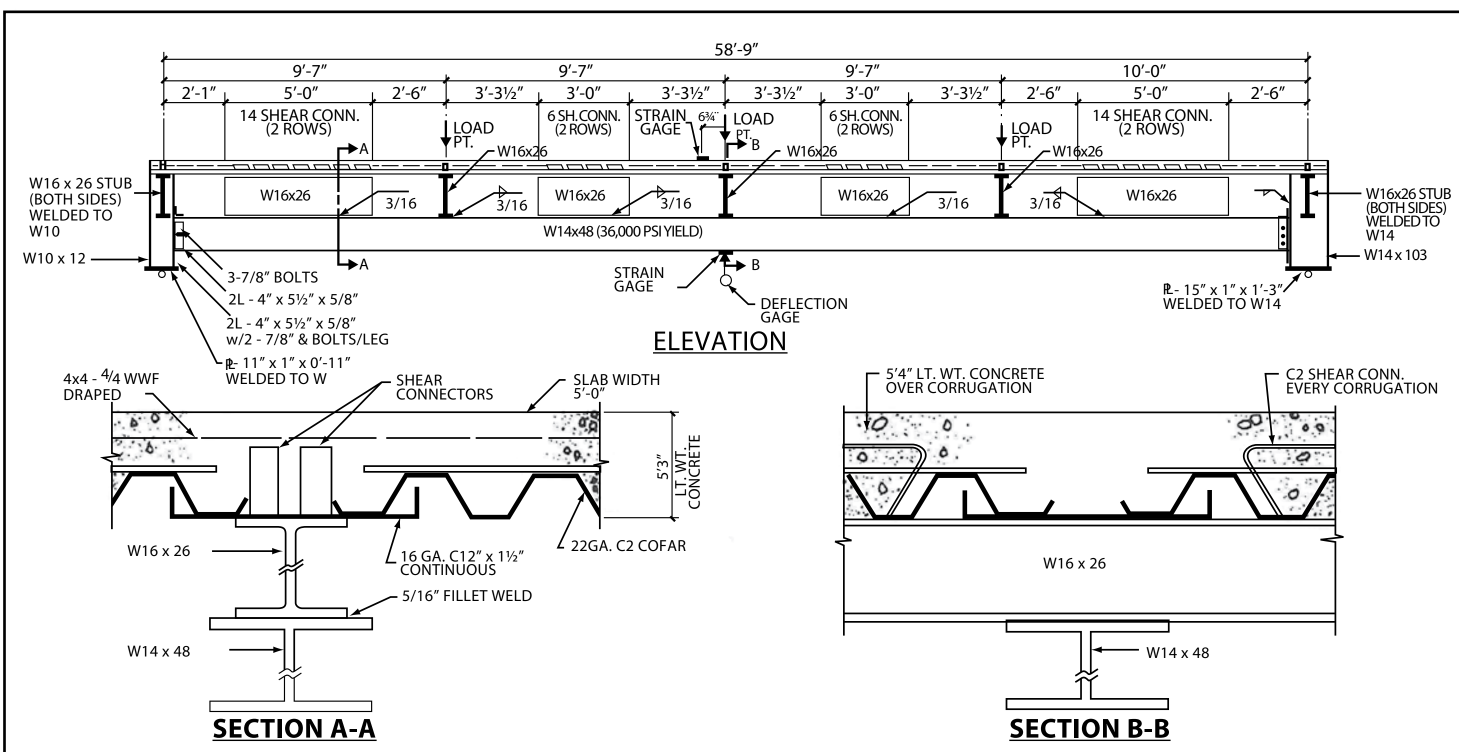


Figure 2: Stub Girder Load Test. Courtesy of AISC.

Design Guidelines

Further recommendations and guidelines emerged throughout the 1980s for the stub-girder system. In fact, the American Institute of Steel Construction (AISC) had plans to develop a design guide for stub-girder construction; however, because deeper wide flange sections became more readily available and guidelines for design of reinforced and unreinforced web openings became more established (see AISC Steel Design Guide Series 2; *Steel and Composite Beams with Web Openings*; 1990), it was never published. In order to document some of the final design guidelines that were established for stub-girder construction, the following list of criteria is provided:

1) Economical spans for stub-girders range from 30 to 50 feet, with the ideal span range being 35 to 45 feet.
2) Transverse floor beams should be spaced at 8 to 12 feet on center.
3) Stubs do not necessarily have to be placed symmetrically about the centerline of the stub-girder span.
4) Use of 3 to 5 stubs per span is the most common arrangement.
5) The stub located nearest the end of the stub-girder (and the surrounding, adjacent truss/girder elements) is the most critical member, as it directly controls behavior of the overall stub-girder. In addition, the end stub may be placed at the very end of the continuous bottom beam, directly adjacent to the support point.
6) Performance of a stub-girder is not particularly sensitive to length of stubs, as long as length of stubs are maintained within the following limits:
   a) Exterior stubs should be 5 to 7 feet long.
   b) Interior stubs should be 3 to 5 feet long.

   However, increasing the length of the open panel between stubs will reduce stiffness of the stub-girder.
7) Stub-girders must be constructed as shored composite construction in order to take full advantage of the concrete slab top chord. Further, because of the additional dead load imposed by shoring from upper floors in multi-story construction, the need for shoring the non-composite section becomes even more critical.
8) Stub-girders should be fabricated or shored to provide a camber that is equal to dead load deflection of the member.
9) Overall strength of a stub-girder is not controlled by compressive strength of the concrete slab, therefore use of high-strength concrete mixes provides no advantage.
10) It is typical for ribs of a metal floor deck to run parallel to the span of a stub-girder. This orientation of ribs therefore increases the area of the top chord slab and also makes it possible to arrange a continuous rib or trough directly above the stubs, which in turn improves composite interaction of the slab with the stub-girder.
11) Welds between the bottom of stubs and the top of the continuous bottom beam should be concentrated at the ends of the stubs where forces between these two elements are greatest.
12) Internal longitudinal slab reinforcement to add strength, ductility and stiffness to the stub-girder should be provided in two layers, one just below and one just above the heads of shear studs.
13) Internal transverse slab reinforcement should be provided to add shear strength and ductility. Placing transverse reinforcement in a herring bone pattern – i.e., diagonal to the direction of the stub-girder span – will also increase the effective width of the concrete flange/top chord.
14) Flexural stiffness of the top chord slab of a stub-girder should be based on the conventional effective width allowed by standard composite beam design criteria, except that the transformed section should include contribution of both the metal deck and internal longitudinal reinforcement.
15) It is not proper to include the top flange of stubs in the calculation of moment of inertia of the top chord slab element.
16) Modeling of stubs as verticals of the Vierendeel truss/girder involves dividing the stubs up into vertical elements equal to one-foot lengths of the section, spaced at one foot on center from one end of the stub to the other. Vertical stub elements should be modeled as fixed at the top and bottom, at the top chord (concrete slab) and bottom chord (continuous beam) of the truss/girder, respectively.
17) Transverse floor beams should be modeled as single vertical web members/elements of the truss/girder. The top and bottom of the member should be modeled as pinned at top and bottom chords.

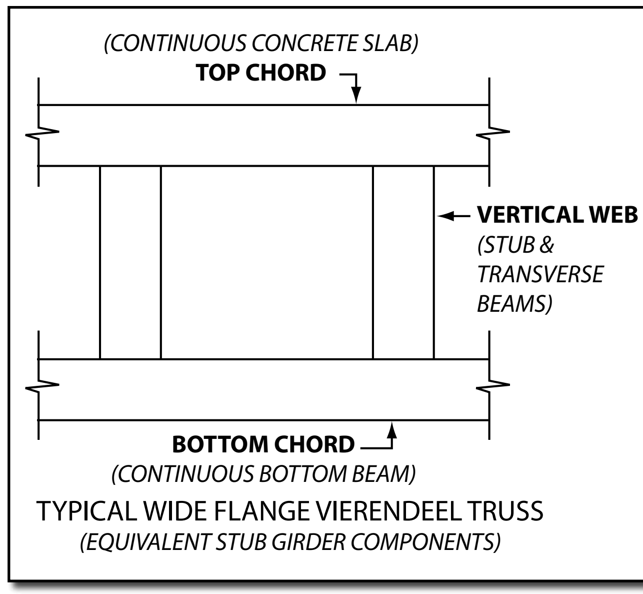


Figure 3.

In conclusion, the stub-girder method of construction was and still is an innovative solution to multi-story, framed steel floor construction. However, as deeper wide flange sections became more available in the marketplace and design engineers became more accustomed to analyzing web holes in wide flange beams, the use of stub-girder construction waned. In addition, because of extra labor costs associated with fabrication of stub-girders and the necessity to construct stub-girders as shored composite construction, the system priced itself out of the industry.▪

D. Matthew Stuart, P.E., S.E., F. ASCE, SECB is licensed in 20 states. Matt currently works as a Senior Project Manager at the main office of CMX located in New Jersey, and also serves as Adjunct Professor for the Masters of Structural Engineering Program at Lehigh University, Bethlehem, PA. Mr. Stuart may be contacted at ***mstuart@CMXEngineering.com****.*

The online version of this article contains references.
Please visit **www.STRUCTUREmag.org**.

References

A Stub-Girder System for High-Rise Buildings
Joseph P. Colaco
AISC National Engineering Conference
New York, NY; May 1972

An Experimental Investigation of Stub-Girders
Y.W. Lam, T. Rezansoff and M.U. Hosain
University of Saskatoon, Canada
Behavior of Building Systems and Building Components Conference
Vanderbilt University
Nashville, TN; March 1979

Some Aspects of Stub-Girder Design
Reidar Bjorhovde and T.J. Zimmerman
University of Alberta and the CISC
Canadian Structural Engineering Conference
Montreal, Quebec; February 1980
Reprinted in the AISC Engineering Journal; Third Quarter 1980

Structural Engineering Handbook
Chapter 18; Stud Girder Floor Systems
Reidar Bjorhovde
University of Pittsburgh
CRC Press LLC 1999