A Staggered-Column Double-Span Beam Framing System

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Using continuous beam framing to reduce deflection and weight.

FRAMING OF STRUCTURAL STEEL MEMBERS historically has consisted of individual simple span beams connected to multi-story columns via direct shear or bearing connections. However, substituting longer beams that span two bays and are continuous over a midspan column may provide both structural and economic advantages.

The many reasons for the popularity of the traditional simple-span framing system include the following:

1. Fabrication of the steel members is simple. Commonly, the members are cut to precise length, and members are prepped to transfer or accept direct shear forces from other members. The system is conducive to bolt-up applications with little welding either in the shop or the field.
2. The members are easy to analyze. The routine design consists of a multitude of statically determinate members that can be sized rapidly, which was of enormous benefit prior to computerization of the design and construction industry.
3. The erection of the structure is straightforward with cost-effective field connections, especially when bolts can be used to their greatest extent.

While the system serves well in terms of simplicity, there are a number of issues that limit the economic viability of the framing system on some project types, especially when compared to continuous, monolithic structures such as reinforced or post-tensioned concrete framing. Advantages of continuous beam framing systems include the following:

1. Flexural members that span continuously over supports deflect less than the commonly used simple-span steel members of equal stiffness due to the reverse curvature in bending of the members. Continuous flexural members commonly have as much as a fivefold advantage in stiffness over simple-span steel members. In other words, for equal loads, equal span, and equivalent stiffness a continuous beam with fixed ends will deflect only ⅕ as much as the simple-span member.
2. The superior deflection characteristics of continuous beam members normally equate to lighter and thinner structures when compared to simple-span members. Given an acceptable deflection criteria, structural designers can then associate member cross-sectional properties more with strength than controlling deflection, which reduces structural depth and weight. The result is frequently shorter floor-to-floor heights, less skin on the perimeter of the building, reduced costs in vertical utility lines and elevator runs, lower total base forces from lateral loads (though not always), and a lighter structure.

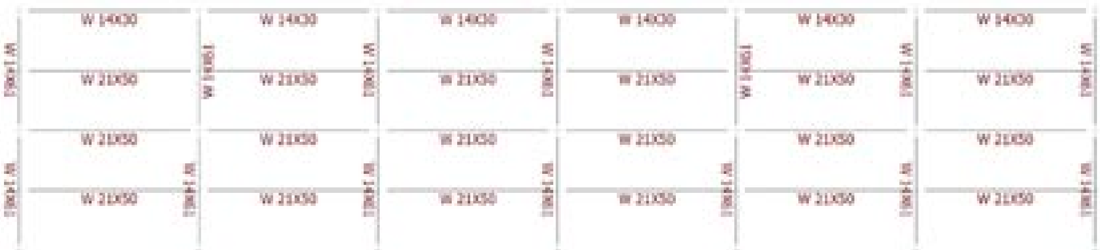
Steel has been modified to act continuously using several methods in the past. Historically, continuous beam behavior with structural steel has been accomplished using moment connections at beam and column intersections. Rigid or semi-rigid connections also provide lateral force resistance to steel frames. The rigid or semi-rigid connections are applied at the interface of the beams and columns, but significantly increase cost and thus are not commonly used to reduce the depth of steel structures.

The staggered-column double-span beam framing system approach to structural steel framing incorporates the advantages of economical fabrication and continuous framing of flexural floor members. The system configuration, incorporates a row of columns that alternate from one story in height to two stories in height (staggering up and down) allowing beams to span continuously over every other column. Use of this framing layout would normally occur along girder lines with conventional simple-span filler beams framing into them.

Advantages of Continuity

Such a system has numerous advantages. Commonly, fewer pieces are encountered, depending upon the framing layout. Fabrication of the steel members remains simple, and the system also is conducive to bolt-up applications with little additional welding, either in the shop or the field, when compared to simple-span framing systems.

Also, the maximum moment in the beam typically shifts to the support over the column that forms the center support under the beam. The magnitude of the moment will vary depending upon beam loading and the length of the spans to both sides of the intermediate support. The beam framing qualifies for redistribution of moment per Appendix 1, Section 1.3 of the 2005 AISC *Specification for Structural Steel Buildings*. Even higher moments at the middle support can be handled by the addition of reinforcing steel in the slab for composite beams, increasing

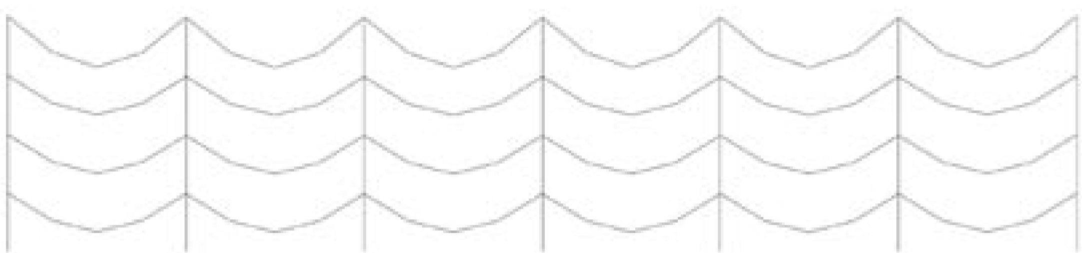


Conventional Floor Framing

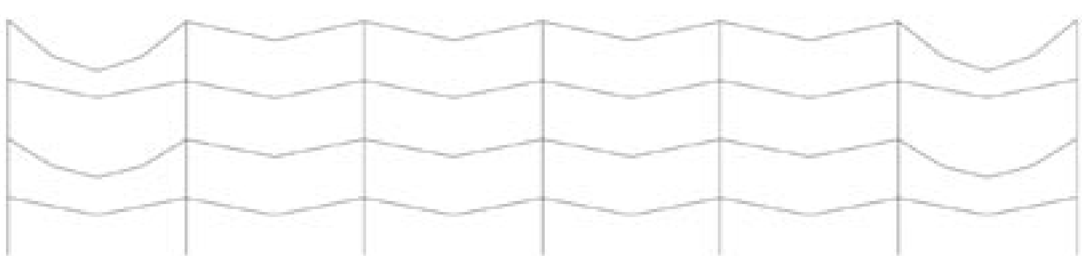
Modified Framing Plan

▲ Alternating the top of column sections enables the use of single W21×44 that are continuous over the middle support and twice as long as the corresponding simple spans using W21×50 beams.

▼ These elevation views show the reduced deflection for the double-span beams that are continuous over a center support, even though they are slightly lighter sections.



Deflection With Conventional Single-Span Framing



Deflection With Staggered Double-Span Framing

the beam stiffness and reducing the depth and weight of the double-span beam. Thus shorter floor-to-floor heights can be achieved more economically than with conventional simple-span beams.

As with simple framing, the erection of the structure is straightforward with cost effective field bolt-up connections and fewer picks of the crane. The result is a steel frame that erects as quickly as conventional steel framing.

The framing is especially well suited for resistance to progressive collapse of steel structures using the Alternate Path Method. Stability is satisfied when any one column is removed from any location within the profile of the frame. In fact, even greater strength, serviceability, and stability can be obtained, if needed, by the addition of

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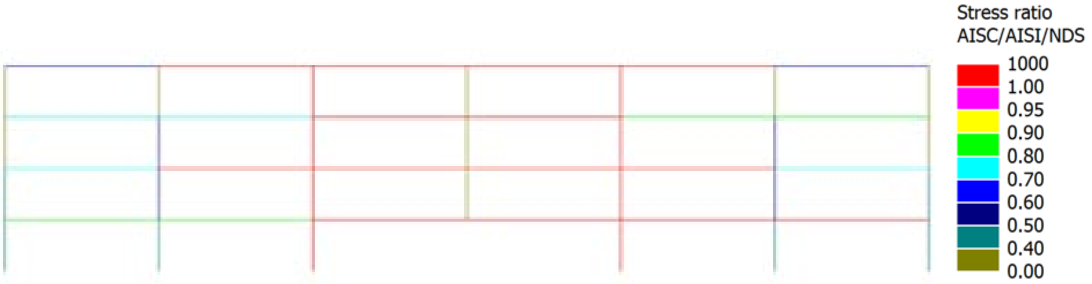

By slightly increasing some member sizes in this staggered-column double-span beam steel framing example, stresses can be kept at or below allowable levels. They are shown here as the percentage of allowable stress resulting from a column blow out (progressive collapse), per one of the required ASCE 41 load combinations.

beam-to-column moment connections at the ends of the pass-through beams.

AISC defines the pass-through beam-to-column connection as a fully rigid (FR) connection. The layout of the framing inherently resists lateral loads, providing greater stability to the frame even during erection.

Nuances of design for the staggered-column double-span beam framing system include the following:

1. The intermediate support locations, where the beam passes through the column, must be designed for the column axial load and all incidental moments, shears, and axial forces in all components. AISC *Specification* Section J10 should be applied to this condition. More specifically, the relative widths of the beam flange and column flanges matter. We recommend that the beam flange width be a minimum of 90% of the column flange width and that the column flanges extend transversely over the beam flanges. Most common connection software can be used to assist in this design endeavor.

2. In composite beam designs, slab reinforcing may be added over the beam at the middle column connection to augment the moment capacity of the beam member, thus preventing a plastic hinge from forming in the beam under normal service load conditions.

3. Skip live loading conditions and unbraced compression flange lengths must be checked as is true for any continuous framing system.

While the design for this type of system requires extra thought and planning, the use of continuous double-span beams with staggered end points can leverage the structural performance of steel framing systems. The results can include increased system ductility using equivalent sections, equivalent performance while reducing sections for some members, or increased ability to resist progressive collapse while requiring less member and connection strengthening than would otherwise be required. However, least weight does not always result in least cost. The designer considering this system should be aware of erector safety issues which include an increased chance of crane hits, potential problems maintaining a working floor and long beam length. These concerns should be discussed with local erectors. MSC