Steel moment frames 101

What to consider when creating wide-open spaces

By Dylan Richard, P.E.

A building's stability is a critical design element that structural engineers must understand. Structures dating back thousands of years have typically relied upon one of, or a combination of, three system types for stability: shearwall, braced frame, and moment frame. This article provides an introduction to the "wide-open spaces-friendly" moment-frame system in steel-framed structures.

Moment frames

A moment frame consists of a system of columns and beams that are connected to one another with fully or partially restrained moment connections. With a moment connection, a column is attached to a beam with no releases at the joint when structurally analyzed. Loads are resisted in moment-frame systems by flexure in the beams and columns that induce shears and moments into the beams, columns, and their moment-connected joints. The three types of moment frames are ordinary moment frame (OMF), intermediate moment frame (IMF), and special moment frame (SMF), defined as follows:

- OMFs are expected to withstand limited inelastic deformations in their members and connections as a result of lateral forces. OMFs are typically used in non/low-seismic regions.
- IMFs are expected to withstand limited inelastic deformations in their members and connections as a result of lateral forces and require the use of pre-qualified connections per the American Institute of Steel Construction (AISC) or connections that have undergone and passed a qualifying cyclic test. IMFs must sustain an inter-story drift angle of up to 0.02 radians, and are typically used in low/mid-seismic regions.
- SMFs are expected to withstand significant inelastic deformation in their members and connections as a result of lateral forces and require the use of pre-qualified connections per AISC or connections that have undergone and passed a qualifying cyclic test. SMFs must sustain an inter-story drift angle of up to 0.04 radians. SMFs are typically used in mid/high-seismic regions.

Considering the pros and cons

Moment frames are generally more expensive than shearwall and braced-frame systems, especially when they are designed to similar stiffness for serviceability. Cost is the main reason that structural engineers tend to use moment frames as a last resort.

Shearwalls and brace frames tend to create barriers within structural floor plans, which are often acceptable for highly partitioned spaces. However, architects and owners want open-space floor plans with minimal obstructions; the beam-to-column connections in moment frames allow for wide-open spaces with no diagonal members or walls, making them worth the higher cost.

Comparing costs — Some key factors that lead to the cost premium for moment frames include the following:

- Moment-frame column and beam sizes can be significantly heavier per linear foot than in braced frames due to their means of transferring forces and resisting lateral drift. Heavier sections lead to higher overall tonnages (material costs), and possibly the need for larger erection equipment.
- Doubler plates may be required in columns at moment connections to strengthen the column web locally. The costly part of doubler plates is primarily due to the fabrication time required to attach them to the column.
- Moment frames can require more field-welding than braced frames, which leads to higher erection costs.
- A greater number of moment frames is often required over braced frames to provide enough stiffness in the building to accommodate drift requirements for serviceability.
- There are a limited number of pre-qualified connections allowed in mid/high-seismic regions, which can be more expensive than braced frame and low-seismic moment-frame connections.

Cost comparison study — Figure 1 shows a typical moment frame and braced frame for a 15-foot-wide by 15-foot-tall, two-dimensional steel frame. The structural sizes shown were designed for strength per AISC LRFD for a ±10 kip lateral load (using a factor of 1.3 to simulate wind) and for serviceability to withstand L/400 (which in this example = 15 feet / 400 = 0.45 inches) lateral drift. Columns in this example were also upsized as required to eliminate the need for doubler plates, and were pinned at their bases. Based on estimates from W&W Steel LLC in Oklahoma City, the installed price (material, shipping, fabrication, and erection) for the sample moment frame would be approximately $8,141, and the braced frame would be approximately $3,185, resulting in an increased cost of approximately 250 percent. The industry range for cost

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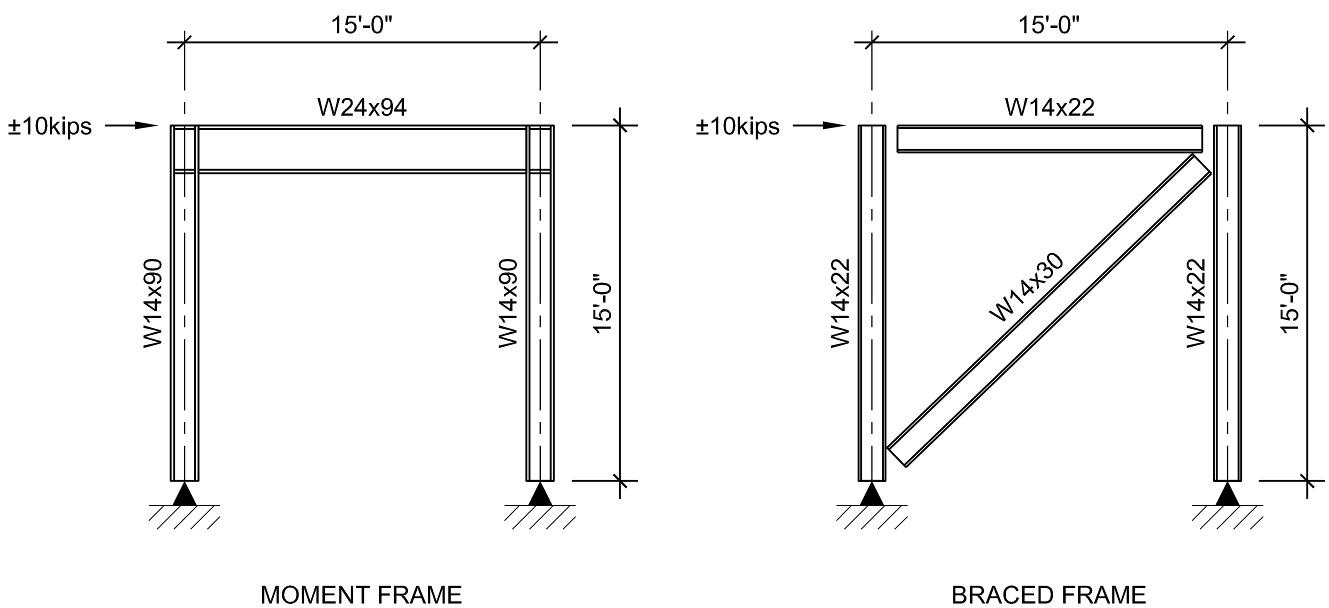

Figure 1: A recent cost study resulted in an increase in installed price of approximately 250 percent for the moment frame as compared with a braced frame.

increase between braced and moment frames can vary, but is typically between 200 percent and 400 percent.

Conclusion

Structural engineers are generally required to identify a design's structural stability system in the project's very early stages. Understanding the owner's and architect's vision for the project and its programmatic needs is critical to establishing which structural stability system(s) will be used and where it (they) will ultimately be placed. Moment frames are the logical choice when large, open spaces are desired, and if limited or no place exists to add shearwalls or braced frames without compromising the space.

If moment frames are selected, costs can be minimized by paying attention to the following rules of thumb:

- Avoid the need for doubler plates by increasing column sizes.
- Provide partial penetration welds in lieu of complete penetration welds at beam-to-column moment connections wherever possible (applies to non/low-seismic projects only).
- Consider fixed-column base connections to reduce moment frame drift. They provide more stiff frames at the first story than do pinned-column base connections, resulting in reduced drift deflections.
- Increasing material tonnage in order to decrease fabrication and erection labor will typically net a lower overall cost for a moment frame.

Reference the following resources for more information on moment frames for steel structures:

- A Policy Guide to Steel Moment-Frame Construction (FEMA 354, November 2000)
- Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications (ANSI/AISC 358-05, Dec. 13, 2005)
- AISC Design Guide 13 – Stiffening of Wide-Flange Columns at Moment Connections: Wind and Seismic Applications (AISC, 1999 Edition with 2003 Revisions)
- AISC Design Guide 12 – Modification of Existing Steel Welded Moment Frame Connections for Seismic Resistance (AISC, 1999 Edition) ▼

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