Manufactured, Pre-Engineered Moment Resisting Frames Used in Soft-Story Building Retrofits of Light-Framed Construction

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BACKGROUND

Several cities throughout California's high seismic regions have expressed concern over the large number of existing soft-story buildings and the risk they pose. Many city building departments are actively developing guidelines for retrofit of these structures because of their documented risk of collapse during a major seismic event. Officials have the difficult task of enacting mandatory retrofit requirements that will mitigate the risks, while still being flexible enough so building owners can economically implement the requirements.

A common solution to address the potential risk of collapse at the first floor (soft-story level) of an existing building is to add a lateral-force resisting element in the direction(s) where the deficiency exists. The system can vary based on the level of desired performance the owner and designer have agreed upon or the code standard that is being used which will determine strength, stiffness and ductility requirements of the system.

While this added lateral-resisting element could be a shearwall or a braced frame, steel moment resisting frames are a preferred retrofit strategy in light-framed, soft-story structures since they do not impact the open space at the first level. Two common types of open spaces that create a line of deficiency in the building, thus defining the first story as "soft" are tuck-under parking (see Fig. 1 on page 2) and retail space (see Fig. 2 on page 2). These types of soft-story structures often have residential occupancies in the stories above. The moment frame solution allows the building owner to maintain the open space for which the use is intended while providing the necessary lateral-force resistance to mitigate the soft-story problem.

Given that many of these structures are composed of light-framed construction, a traditional shop-fabricated, field-welded steel moment frame can present some challenges for the engineer, fabricator and installer.

There are several challenges of a shop-fabricated moment frame, including the time required for an engineer to design and detail the frame, the attachment of wood nailers to the frame for ease of tying into the existing light-framed structure, field

welding a frame around existing building elements and the potential fire hazard this creates, the need for additional contractor trades during field erection or installation, more specialized inspection for field welds, coordination between the various trades regarding layout and dimensional constraints, inconsistent quality of fabrication shops from project to project, and wide variance in material and installation costs.

Figure 1. Tuck-under parking.

Figure 2. Retail space.

AN ALTERNATE SOLUTION

Manufacturers of various building products have observed these challenges regarding the design, manufacturing and installation of traditional moment frames and have taken steps to address and improve many of the aforementioned issues by developing pre-engineered, manufactured moment frames (see Fig. 3 on page 7 for conceptual soft-story retrofit with manufactured moment frame).

Benefits of the pre-engineered frames vary between manufacturers; however many of them have several attributes in common to help lower design time and installation costs. These include:

Pre-Engineered Solutions

Once lateral load and gravity load demands are determined by the engineer, selecting a frame is similar in nature between manufacturers when utilizing their respective capacity tables. The primary benefit for the engineer choosing a pre-engineered frame is to reduce costs during the development of construction documents and allow more focus on creating an adequate lateral load path, without needing to spend additional time designing and detailing a frame.

The following (Table 1) represents a common example of capacity information that manufacturers publish for a pre-engineered frame:

Model No.	Clear Opening Width, W1	Outside Frame Width, W2	Allowable ASD Shear Load V (lbs)[1]		Maximum Total Gravity Load, W_{Max}[3] (lbs)	Drift at Allow Shear Load V (in.)
			Maximum Shear[2]	Minimum Shear[3]		
OMF99-8x9	8'-2"	10'-2"	7625	7410	31500	0.60

Table 1. Example of manufacturer's design information.

The basic concept of the tables is to provide a lateral load capacity for any load combination based on results generated from analytical design software and/or testing. Loads often are converted to allowable stress design to accommodate the method that wood structures are commonly designed. The results from the software output or testing are converted to an enveloped solution which defines limiting magnitudes of lateral loads, gravity loads and drift. Connections utilized in pre-engineered moment frame solutions are typically no different than those designers are accustomed to using when designing their own frame. If the manufacturer offers IMF or SMF solutions, the connections may be prequalified per AISC 358-05 or they can be proprietary connections tested in accordance with AISC 341-05 requirements. It should be noted that testing of beam-to-column connections is only required if a manufacturer desires to gain an IMF or SMF classification. Even if connection testing is performed, most frame designs and published information are derived from design software and calculations.

For soft-story retrofit projects, the seismic lateral demand to the moment frame is highly dependent on the response modification factor (R-value) and will likely be determined by the most conservative of the following three limitations:

1. The R-value prescribed by the manufacturer which is based on the frame's rating for ductility;
2. The minimum R-value recommended by the code or standard that is used for the retrofit of the soft-story (i.e. 2009 IEBC Chapter A4, ASCE/SEI Standard 41-06, etc);
3. The minimum recommended R-value permitted by the governing building jurisdiction.

The capacity of pre-engineered moment frames are often controlled by drift based on model building code requirements, therefore when using a manufacturer's frame for a soft-story retrofit, a higher R-value may not provide much added benefit for the design of the frame itself.

Custom Frame Design

In addition to pre-engineered/manufactured frames, manufacturers also offer custom loading and custom sizes. The engineer needs to provide the specific loads, drift limits, frame dimensions and any other relevant existing conditions. Frames in series that share common columns or stacked frames for projects where the engineer chooses to retrofit stories above the first level soft-story, are options that the manufacturer may provide as a solution. When retrofitting existing structures, customization becomes more critical since the geometry of the building is already set. Since the reputation of the manufacturer is at stake, providing consistent, high-quality products is imperative in order to maintain confidence with the specifying community. Through repetitive production and internal quality control procedures, these manufacturers have an advantage over traditional steel fabricators in producing a consistent finished good that satisfies the intent of the soft-story retrofit.

Proprietary Steel Sections

Custom-sized steel sections for beams and columns also may be utilized. The manufacturer welds bar and/or plate together to form the desired section. Two key advantages using this practice include maximizing the efficiency of the steel and ensuring frames fit within standard light-framed wall thicknesses. The flange widths vary between current manufacturers but most frames fit within 6-inch nominal walls without the need for furring or wider framing. The smaller widths, however, may limit the manufacturer's offering of larger heights and spans of frames.

Compatibility with Light-Framed Structures

Pre-attached wood nailers can be supplied with the columns and beams to accommodate framing into the existing building. When shipping frames to the project with the wood nailers already attached, significant field labor costs are saved and the designer is assured of getting the proper attachment of wood to steel. In the case of tuck-under parking retrofits, the nailer on the top of the beam may be the only pre-attached wood needed by the engineer for shear transfer purposes, whereas the retrofit of a retail soft-story wall line may require that all flanges of columns and beams are supplied with wood nailers to ease the "tie-in" to adjacent framing or architectural features. If the designer does not want any pre-attached wood, frames may be ordered as such.

Field Bolted Assembly

Some manufacturers provide frames that are assembled in the field utilizing bolted connections between the columns and beam. This becomes very advantageous when retrofitting an existing structure as field welding creates a fire hazard, and additional specialized contractor trades and inspections are no longer required for the job. A bolted connection gives the builder two installation options: 1. Bolt the frame together with as many bolts that are accessible on the ground and "roll" the assembled frame onto the anchor bolts. 2. Install the columns onto the anchor bolts, then lift the beam up into place and bolt together. The second option may be the most preferred method when retrofitting inside of a building because the confined working space may prohibit handling a fully pre-assembled frame. The frames are designed so that

the beam connects between the columns (not bearing on top of columns) which allows the beam to be lifted directly under existing framing. The beam-to-column bolts supplied by the manufacturer are commonly a high-strength grade and will require pre-tensioning. The engineer should refer to the manufacturer's recommendations regarding the manner in which proper pre-tensioning is achieved.

Engineered Anchorage Design

Manufacturers may provide engineered anchorage solutions that provide the required anchor bolt size and grade needed to resist the design forces. Manufacturers also provide various levels of fixity at the column base plate anchorage to the foundation. Pinned, partially-fixed and fully-fixed options are available, and the offerings vary between manufacturers. The designer will need to evaluate the foundation used to ensure that they are suitable to resist the design forces. In some cases, post-installed anchor solutions may be sufficient to resist the loads as long as the existing foundation is determined to be suitable. Anchorage assemblies also may be supplied by the manufacturer along with layout templates.

ADDITONAL OPTIONS

Manufacturers provide moment frames with varying degrees of ductility (SMF, IMF or OMF) and the offerings vary between manufacturers. The level of ductility is based on the design of the frame in accordance with AISC 358-05 and/or testing per AISC 341-05. The engineer may choose the frame that meets their project's design objective while ensuring that all assumptions of loading and behavior meet the manufacturer's intent. When a SMF or IMF is selected, the designer also must consider detailing the frame to meet the intended ductility rating (i.e. lateral beam bracing) as prescribed by AISC and the manufacturer.

LIMITATIONS

There can be some drawbacks with pre-engineered frames such as limitations in sizes offered and capacity limitations due to proprietary sections being used. However, to accommodate existing structures such as soft-story retrofits, manufacturers will offer custom design services to accommodate existing rigid conditions as discussed above. While pre-engineered frames are intended to eliminate much of the design time for the frame itself, designers still need to detail a complete load path for the building system. This may include beam bracing, strengthening the diaphragms so they are capable of delivering the load into the moment frame and adding new foundations that are capable of resisting all forces from the frame.

CONCLUSION

The large inventory of soft-story buildings in California poses a substantial threat of injury and loss of life, economic loss and the displacement of residents following a major seismic event. Steel moment frames often are used to retrofit soft-story structures, and manufactured, pre-engineered moment frames offer an alternate solution in lieu of traditional shop-fabricated, field-welded moment frames. Based on the aforementioned benefits, manufactured frames offer a simplified design process

for engineers, ease of installation for builders, a high level of quality control that promotes specifier and builder confidence, and reduced installed cost for the owner. Manufactured, pre-engineered moment frames are another example of innovative lateral systems from building product manufacturers who continue to provide solutions that are cost effective during all project phases, from design to installation.

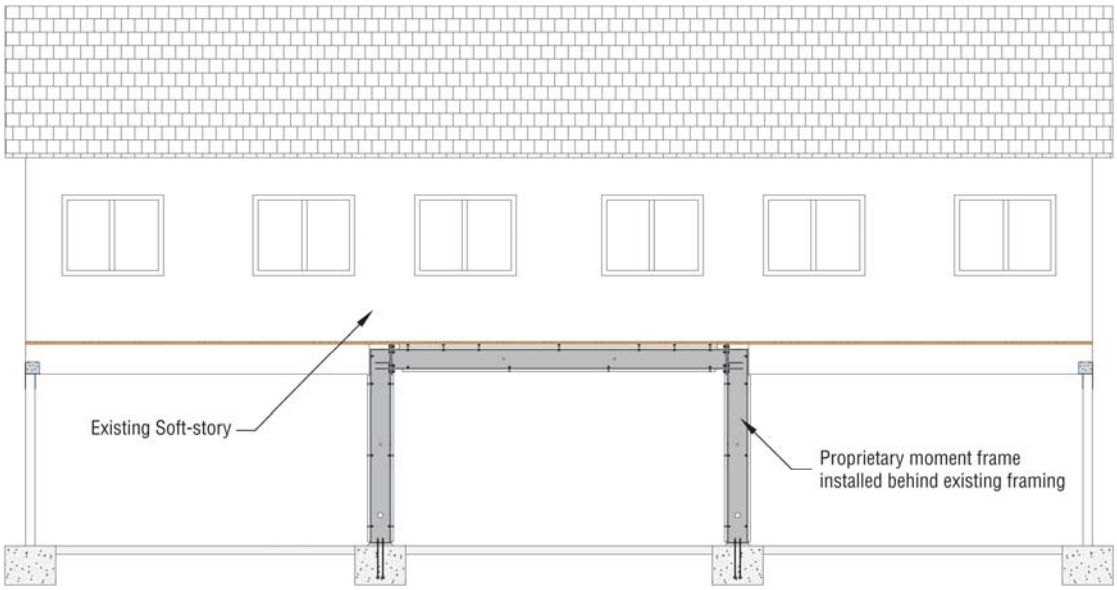
REFERENCES

AISC (American Institute of Steel Construction, Inc.) (2006). ANSI/AISC 358-05, *Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications*. AISC, Chicago, IL.

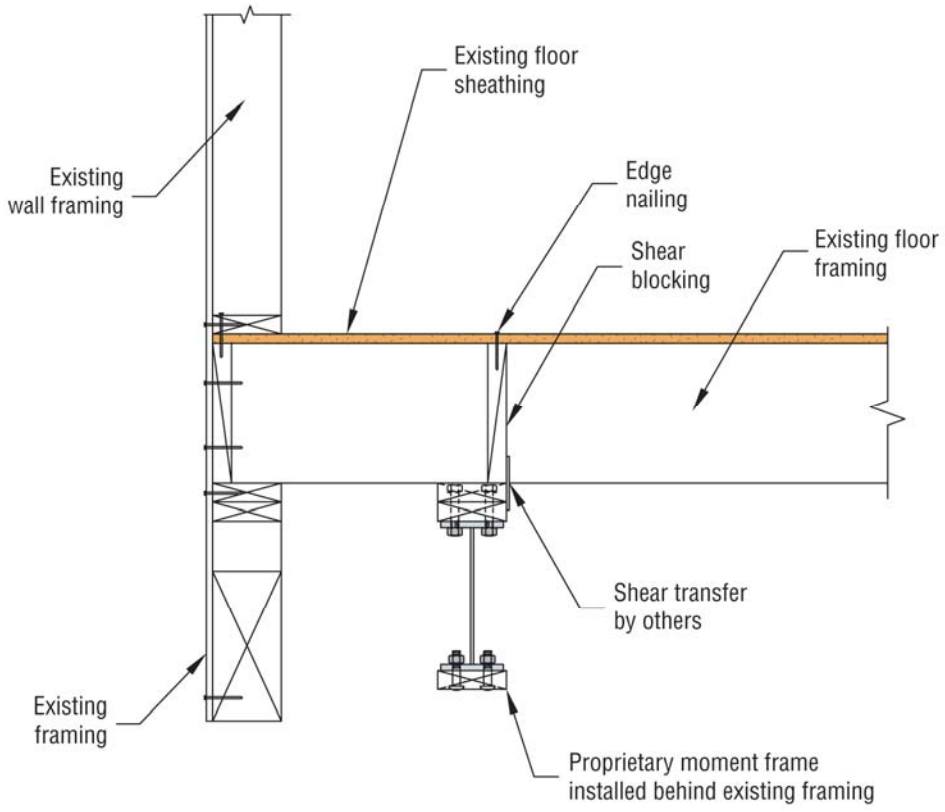
AISC (American Institute of Steel Construction, Inc.) (2005). ANSI/AISC 341-05, *Seismic Provisions for Structural Steel Buildings*. AISC, Chicago, IL.

ASCE/SEI (American Society of Civil Engineers/Structural Engineering Institute) (2007). ASCE/SEI Standard 41-06, *Seismic Rehabilitation of Existing Buildings.* ASCE, Reston, VA.

ICC (International Code Council, Inc.) (2009). 2009 International Existing Building Code, Chapter A4, *Earthquake Hazard Reduction in Existing Wood-Frame Residential Buildings with Soft, Weak or Open-Front Walls.* ICC, Whittier, CA.



Elevation



Section

Figure 3. Two-story, "soft-story" with moment frame retrofit.