ZALLEN ENGINEERING
FORENSIC ENGINEERING IN CONSTRUCTION®
ONLINE EDITION
No. 12 March 2008

Investigation of Fire-Damaged Warehouse

Figure 1. View of south and east sides of moving company warehouse.

A fire occurred in a moving company warehouse in New England in 1998. The owner of the building retained Zallen Engineering to determine the structural safety of the building as a result of the fire and the necessary repairs. The warehouse is 153 feet long by 99 feet wide, was constructed in 1962, and is of metal building construction.

Figure 1 shows a photo of the south end, which is the front of the building, and the east side of the building which contain the overhead loading doors. The front low roof section of the building contains offices and was not damaged by the fire.

Figure 2 (*next* page) is a plan of the roof framing. The principal support system of the building is composed of 7 rigid frames[1] on Lines 2 through 8, spanning the full width of the building. Figures 3 and 4 are photos of part of the rigid frame on Line 8; Figure 5 *(page 3)* shows construction details at the eaves and defines the various structural elements. The end wall supports on Lines 1 and 9 consist of roof beams and columns; see Figure 2. Figure 4 shows part of this framing on Line 9, in the background. The roofing consists of 19 gage cold-formed corrugated steel sheets supported by 8 inch deep, 14 gage cold-formed steel purlins of "Z" shape. The purlins run across the top of and are supported by the rigid frames and end wall roof beams. Figure 4 shows some of the purlins.

The siding consists of 20 gage cold-formed corrugated steel sheets spanning vertically. See Figure 1 for an exterior view. The sheets are supported laterally at the bottom by the top of a low concrete enclosure wall, by 16 gage cold-formed steel intermediate girts, and at the top by either 16 gage cold-formed steel eave struts or the ends of the purlins. Figure 3 shows the low concrete wall and the intermediate girts.

Fire Damage

The fire started at corner A-9 and appears to have been set. At the time of the fire, the warehouse was filled tightly with packing crates up to the eaves, making access for firefighting difficult. Further, although there were sprinklers, they were inoperable. The fire

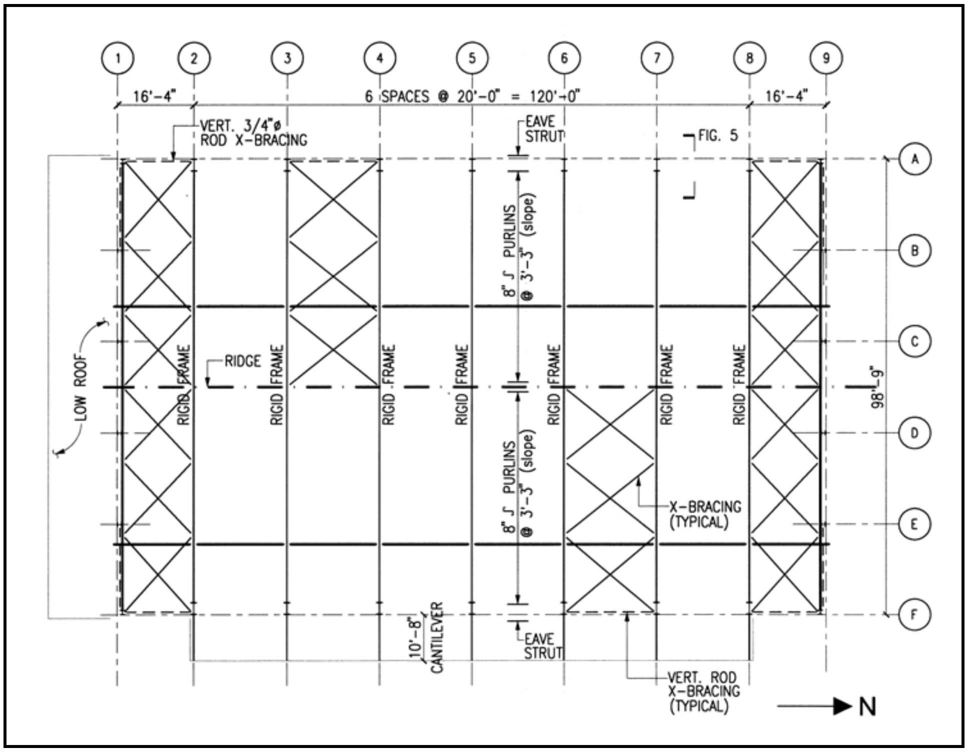

Figure 2. Plan of roof framing.

spread from the A-9 corner across the top of the packing crates southward to beyond Line 6 and eastward to beyond the ridge, causing structural damage of varying degrees to roof framing and wall framing. There was also damage to the metal roofing and siding, the insulation, and extensive smoke damage throughout the building.

There were two types of observable fire damage to the structural framing: 1) where the paint was burned off indicating that the members were subject to significant heat from the fire; and 2) where the members were either twisted and kinked. Figures 3 and 4 show paint burned off of the web of a rigid frame. Figure 6 *(page 3)* shows twisted and kinked roof purlins. Figure 7 *(page 4)* shows corner A-9, the corner where the fire was ignited; the corner column (A-9) is twisted and, although not discernable in the photo, the roof beam on the right (on Line 9) and all the roof purlins and wall girts near the corner are twisted.

Figure 3. View of rigid frame at grid location A-8.

Figure 4. View of rigid frame on Line 8, west of the ridge. In the background is the framing at the end wall on Line 9.

Effects of Fire on Structural Steel Members

When steel is heated, it loses strength and stiffness and expands with the rise in temperature. Above 600 degrees Fahrenheit, its strength and stiffness will drop significantly with further rise in temperature. For a steel member subjected to fire in a building, the expansion is restrained, and the restraint can generate large axial compression forces in the member. The combined effects of loss of strength and stiffness, superimposed load, and forces generated by restraint can cause the member or parts of the member to distort or collapse. If the temperature of the steel rises above 1300 degrees Fahrenheit, there is a metallurgical change in state. After the fire, the member will cool gradually, mainly by air, back down below 1300 degrees Fahrenheit, where, for ordinary low carbon constructional steels, it will revert back to its original metallurgical state.[2]

Therefore, members that were not distorted by the fire have not been damaged structurally by the fire, except superficially, and most members that have been distorted could be reused if bent back into shape. Further, even in the distorted condition, a member still can have considerable strength. Large structural members can be heat bent back into shape. However, it is impractical to heat bend light weight members; it is more economical to simply replace them. Steel items such as high strength bolts that are quenched and tempered in their manufacturing process, which have expanded due to the heat of the fire, should be replaced, since their metallurgical state may have been permanently altered.

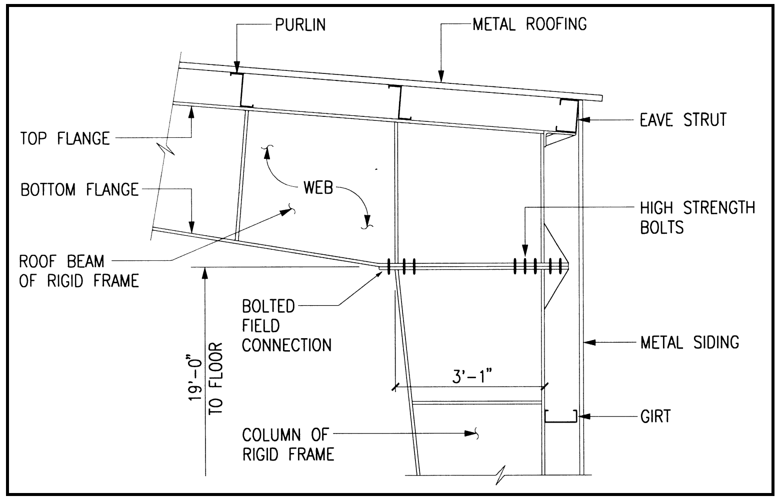

Figure 5. Section through eaves showing construction details. Insulation and bracing are not shown.

Figure 6. Twisted and kinked roof purlins. Insulation has been destroyed by the fire and the metal roofing is exposed.

Structural Evaluation

The various structural members were evaluated for load capacity in the pre-fire condition and in the post-fire condition. The load capacity of the rigid frames were not affected by the fire; however, their pre-fire capacity was deficient because lateral bracing was omitted at the bottom flange of the roof beam portion of the frames. Various portions of the bottom flange will be in compression or tension under snow load and under wind load; if unbraced the flanges will buckle laterally and then not be able to support load. There is a diagonal member on each side of the rigid frame that braces the bottom flange of the frame at the knee, as shown on Figure 3; additional diagonal braces need to be installed at the ridge, and at an intermediate position between the knee and the ridge on each side of the ridge. The cost of installing this bracing is approximately $5,000, which is quite small compared to the cost of repairing the building as a whole.

The snow load capacity of the rigid frames with the additional braces is 25½ psf. By comparison, the current building code requirement is 35 psf.

The pre-fire snow load capacity of the roof purlins is also 25½ psf for the 20 foot spans (bays between Lines 2 and 8 - see Figure 2). Where the purlins were both twisted and kinked (Figure 6), their estimated snow load capacity is 13 psf, which is substantially below the current building code requirement of 35 psf.

The necessary structural repair work consisted of replacing kinked or twisted purlins and girts, and replacing twisted columns and beams on Line 9. This work necessitated the removal and replacement of the metal roofing, metal siding, and insulation under the roofing and siding, in the affected areas. However, due to the soot on the insulation and other damage to the insulation, all the metal roofing, metal siding, and the insulation under the roofing and siding needed to be removed and replaced, the steel framing power washed to remove the soot, and the structural members repainted.

Figure 7. Fire damage at corner A-9. Corner column A-9 is twisted; the roof beam on Line 9, framing to this column, is twisted, and the roof purlins and wall girts near this corner are all twisted. Note the rod cross-bracing in the walls and at the bottom of the roof purlins; these are all loose as a result of the fire.

End Notes

1. The *rigid* in rigid frame refers to the connection between the columns and beams. These connections are such that there is no relative rotation between the end of a column and the end of the beam connected thereto; i.e. the connection is rigid.
2. Ordinary constructional steels are rolled into shape at 1600 degrees Fahrenheit and air cooled to room temperature.

Forensic Engineering in Construction® is published by Zallen Engineering, 1101 Worcester Road, Framingham, MA 01701. 508-875-1360. rmzallen@zallenegineering.com.