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Collapse of Roof Over Chemical Settling Pond

Figure 1. View of collapse of roof over chemical settling pond, showing a typical condition of the framing. All the light gage steel purlins across the entire width of the roof have rolled over away from the viewer.

In 1985, a chemical manufacturer in Eastern Massachusetts built an artificial pond to settle out solids from a chemical liquid. The pond was excavated into the ground, the ground surface within the pond was covered with a Hyperlon liner, and the pond was covered by a roof of metal building construction. The roof was 250 feet long and 40 feet wide. Figure 2 shows a cross-section through the pond and the roof.

The roof framing consisted of 10 inch deep light gage steel "C" purlins on top of tapered steel roof beams. The beams were spaced at 25 feet on center. The purlins were lapped and bolted back-to-back over their supports, and the bottom flanges of the purlins were bolted to the top flanges of the supporting beams, as shown on Figure 3. The beams were supported at each end by bearing plates on continuous concrete footings.

The roof deck was made up of 26 gauge steel roof panels screwed to the purlins. The vertical sides of the roof construction at the eaves were left open, and there were vent openings along the ridge. The openings at the ridge and at the eaves were covered by bird screen.

In February of 1987, there was a heavy snowstorm in the area, but without heavy winds. As a result a relatively uniform layer of snow of an average depth of 20 inches was deposited on the roof. The entire roof collapsed, but the collapse was arrested by a thick layer of ice that had formed at the top of the pond. Figure 4 shows the collapse before the snow was removed. Figure 1 shows part of the collapse after some of the snow was removed. The collapse was not discovered

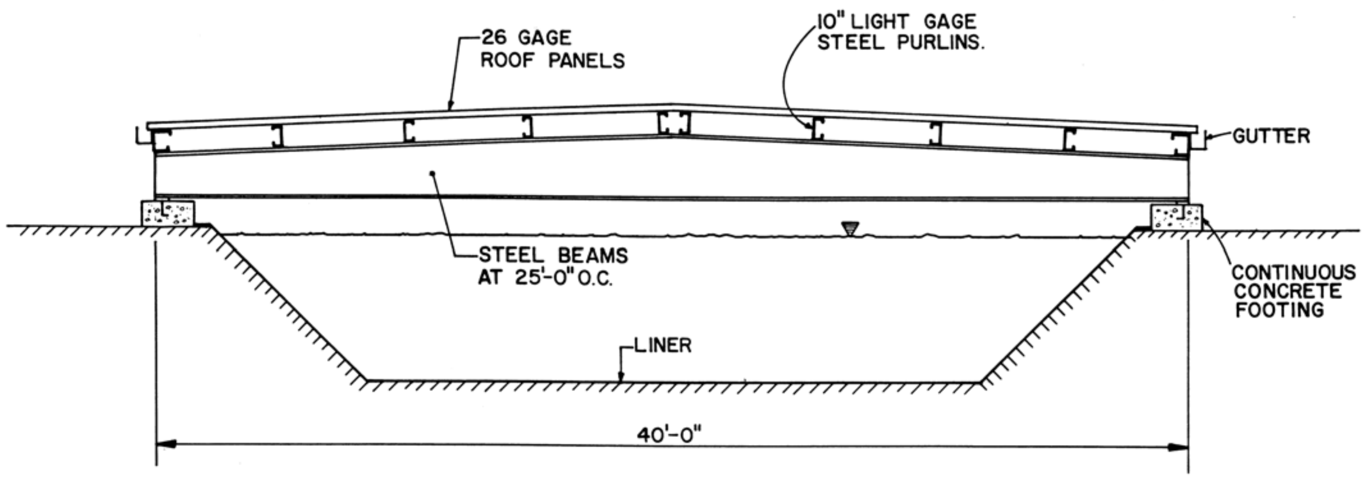

Figure 2. Cross-section through roof and settling pond.

until the next day; thus the depth of snow on the roof when it actually collapsed is not known and could have been less than the measured average depth of 20 inches, since additional snow could have fallen and collected on the roof after the collapse.

Zallen Engineering performed a field investigation of the collapse the day after the collapse. We made test holes into the snow to determine the density of the snow - see Figure 5, and we measured the depth of the snow at various representative points over the whole roof area. In general, the dismantling was done in such a manner that the condition and details of the framing and roof panels could be observed; however some of the details such as the connection of the roof panels across the ridge, were left uncertain. We saved representative framing and roof deck for further examination and measurement.

The average density of the snow was 15.1 pounds per cubic foot, and if the full 20 inches of snow were on the roof when it collapsed, the average resulting uniform snow load at the time of the collapse would have been 25.2 psf. The dead load of the framing and the roof deck was 5 psf. The Massachusetts State Building Code requires a snow load of 35 psf, and this loading was noted on the metal building drawings. The nominal safety factor for steel is 1.67, which applied to the total design load of 40 psf gives a required ultimate strength of 66.8 psf. If the full 20 inches of snow were on the roof when it collapsed, the total load on the roof when it collapsed would have been 30.2 psf, which compared to the required ultimate capacity, shows that the roof had to have failed at 45% or less of the required ultimate capacity.

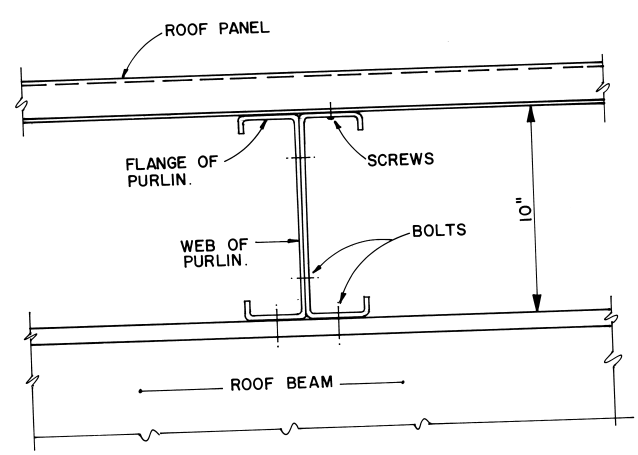

Figure 3. Typical detail of the roof purlins at their supports.

Figure 4. View of the collapsed roof, the day after the collapse. The collapse was arrested by a thick layer of ice at the top of the pond.

Cause of Collapse

The roof collapsed due to lateral-torsional buckling of the roof purlins, as shown in Figure 1. The roof panels and the tops of the purlins on both sides of the roof moved laterally as a unit in one direction (in Figure 1, away from the viewer). Although the tops of the purlins were ostensibly laterally braced by being attached to the roof panels, there was an insufficient mechanism to prevent the roof panels from moving in their own planes transverse to the purlins.

Referring to Figure 3, if the roof panels and the top flanges of the purlins try to move laterally, the only resistance to this movement is transverse bending of a small length of the webs of the purlins close to the supporting beams. These small lengths of the webs of the purlins can be envisioned as a group of cantilever columns with a 10 inch height, fixed against rotation at the bottom. If these "columns" are too flexible as a group, they will buckle as a group, with the tops of the "columns" moving laterally. This is the mechanism that allowed the purlins to roll over as a group and caused the roof to collapse. Generally, the webs of light gage steel purlins or the webs of structural steel purlins will not be sufficiently thick to prevent this mode of failure. Had the purlins been properly laterally braced, they would not have failed and could have resisted the full code ultimate load.

The typical metal building roof design uses "C" or "Z" shaped purlins running over the tops of rigid frames or roof beams, the same as for the subject structure. The lack of proper lateral support for these roof purlins has been a major problem for metal buildings, and it is probable that most roof failures of contemporary

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Figure 5. Test hole in the snow on the roof, to determine the density of the snow.

metal buildings subjected to snow load are due at least in part to this problem. The metal building industry is very adept in the proper and economical design and production of principal framing members such as rigid frames, beams, and columns. However, the rigid frames and roof beams depend on the lateral bracing provided by the roof purlins; if the purlins are unstable and collapse, the rigid frames and roof beams will also collapse. Many of the vendors and some of the manufacturers of metal buildings apparently do not understand the problem of the rolling over of the purlins as a group or how to effectively deal with it.

- Principal Rubin M. Zallen investigated this failure.