CROSS Safety Report

Design issues with modifications to existing structure

This month's report concerns modifications to an existing industrial building that had been extended and modified numerous times over the years. Investigations identified several design issues with some of these previous modifications, including a previously replaced roof beam that did not comply with Australian Standards.

Reporter's submission

A reporter explains they were involved in the design of temporary propping for the replacement of a roof, and the design of a new internal floor in an industrial building which had been extended and modified numerous times in the past.

The reporter ultimately identified the following issues:

- Each new part of the building had been built against the existing structure, and it was unclear how lateral support was being provided.
- No bracing was provided adjacent to the roof being removed, due to previous modifications to allow installation of equipment.
- Previous modifications and poor records made it impossible to trace load paths satisfactorily to ground level within the budget agreed at the start of the design. A recommendation was made to implement a project to complete this work as part of their ongoing risk management processes.
- Another consulting engineer had been recently engaged to design the temporary works required for removal of an adjacent section of roof. This engineer had approved the removal of the only vertical bracing remaining in that part of the building and had seemingly designed an undersized replacement roof beam.

The reporter is unsure why the removal of the remaining vertical bracing in the building was allowed previously. They speculate that it may possibly have been thought that, as there was still vertical bracing in other parts of the building, there was no need to maintain the bracing in the part of the building in question. However, the reporter believes it is unclear whether the roof had the necessary diaphragm strength to transfer the load to these vertical braces.

The reporter found that, although the structure had adequate capacity for dead load, any significant wind, earthquake or other lateral load (e.g. from equipment upset or heavy vehicle collision) could have potentially resulted in significant collapse. In the reporter's opinion, there were several potential contributing factors to this situation as apparently:

- The previous roof beam was identified from a 3D scan that only showed the bottom flange of the beam and a part of its depth. The width of the flange matched that of a 410UB section, which the previous engineer then specified as a replacement section. However, further investigation by the reporter revealed the original beam had a tapered bottom flange, unlike that of a 410UB section. When the original roof was constructed, the only sections available were rolled steel joists (RSJs); and the only RSJ which matched the bottom flange width was a 24 × 7.5-inch RSJ, roughly equivalent to a 610UB.
- The replacement 410UB had been strengthened with a large flat plate on the top flange, so that the combined section properties matched the 24 × 7.5 RSJ that had been replaced. It is possible this strengthening was added during construction, when the original roof beam was removed and its true size was evident. However, the member properties in flexural torsional buckling were significantly undersized.
- In a linear elastic analysis, the replacement combined 410UB and plate was found to be acceptable at ultimate wind loads for section capacity only, and not member capacity. The roof was steeply pitched and constructed of trusses made of slender angle sections supported by the beam in question, with purlins and plan bracing in the other direction. It was found that the roof was able to span in the perpendicular direction to supports along its other ends. It was acting as a very deep truss, with the purlins as 'chords' and the plan bracing in its pitched faces. No load was transferred to the supporting beam. However, a non-linear analysis found that the purlins and plan bracing could buckle, or suffer significantly reduced capacities, transferring most of the roof load to the undersized support beam.

The reporter believes the combination of these issues meant that, if both member capacity and non-linear effects were considered, the beam was utilised at almost 100% under dead load only. While a computer model showed some issues with the structure, it took only a single page

Key learning outcomes

For structural engineers and designers:

- When working with existing buildings, it is essential to have a good understanding of its structural behaviour and to identify clear load paths for all vertical and lateral loads
- Confirm adequate bracing is present
- Confirm types and size of older sections by detailed checks of dimensions and shape
- Recognise the importance of flexural-torsional buckling
- Consider performing non-linear analysis to estimate second-order effects (as required by AS 4100 S4.4)
- Use hand calculations to confirm validity of assumptions and solutions used in computer analyses

of manual calculations to confirm that the beam did not comply with Australian Standards. The reporter explains that this seems to be what persuaded the client to investigate further and led to the full investigation that identified the issues outlined above.

Furthermore, the reporter adds, the previous engineer appeared to have terminated the strengthening plate at the point where utilisation became 100%, possibly not recognising the need to develop force in the plate or that it should be extended some distance beyond the point where it was required.

To identify and manage potential issues like those described above, the reporter considers it is vital, when modifying existing structures, to have a good understanding of the load paths through the building and into the ground.

They acknowledge it may not be possible to achieve this for large industrial structures with limited records, but consider it necessary to at least follow the load path to where any modifications will no longer have any significant effect and to where it might be assumed that the structure has performed acceptably over time.

For historic structures, the reporter regards it also necessary to consider the materials and methods of construction available at the time of construction (e.g. size of steel sections, strength of steel).

When designing repairs, replacements or extensions to existing buildings, the reporter believes designers should consider whether it is possible to 'leave it better than you found it'.

In the example described, it seems some of the function of the bracing that had been removed was reinstated by strengthening columns to allow them to act as portals. The new floor structure was also used to provide additional plan bracing for diaphragm action to transfer load to remaining vertical bracing.

Much of this strengthening was required anyway, the reporter explains, and the cost of leaving it better than they found it was not significant in the overall scheme of the project. The client did not apparently consider addition of new vertical bracing at that point in time, but the global stability issues with the structure were entered into their risk management system for consideration at a future time.

The full CROSS Safety Report, including links to guidance mentioned, is available on the CROSS website (report ID: 1355) at **www.cross-safety.org/uk/safety-information/cross-safety-report/design-issues-modifications-existing-structure-1355**.

Expert Panel comments

When working on existing buildings, it is important that all reasonable efforts are made to locate and acquire the existing original drawings, and drawings of all modifications made to the original structure.

It will generally be much easier to determine the original designer's intent and work out lateral stability systems from these drawings than from site inspections or 3D scans. It can also save the client considerable investigation fees and reduce the risks of oversights.

If scope or fees preclude a designer from fully understanding the whole building and how it behaves, then it is strongly suggested that any changes add no additional vertical or lateral load to the existing structure.

Some modern approaches to surveying existing structures using photographic and Light Detection and Ranging (LIDAR) scanning are proving very useful, but it is important to view them in the historic context of the building. For example, imperial-sized hot- or cold-rolled steel sections can be of different shapes and strengths when compared with more modern sections.

It is important to reference the original design charts or undertake analysis from first principles when old members are being analysed. Where there is any doubt, physical site inspections remain invaluable especially when consideration needs to be given to the physical condition of structural members.

It is questionable whether buildings constructed prior to 2019 will be fully compliant with current seismic codes so some consideration needs to be given to whether the existing structure should be made compliant.

Some useful references on this topic are:

→| International Organization for Standardization (2010) *ISO 13822:2010 Bases for design of structures – Assessment of existing structures* (2nd edn), Geneva: ISO

→| Institution of Structural Engineers (2010) *Appraisal of existing structures* (3rd edn), London: IStructE Ltd

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