DAMAGE TO STEEL STORAGE RACKS IN INDUSTRIAL BUILDINGS IN THE DARFIELD EARTHQUAKE

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SUMMARY

On September 8, a team investigated damage to industrial structures in Christchurch due to the Darfield Earthquake. While there was very little damage to structures regardless of age and framing system, damage to steel storage racks varied from no damage to complete collapse. This paper reports on the observations about the damage to steel racks, reviews pertinent design standards, and makes some preliminary conclusions about the performance of steel storage racks in the Darfield earthquake.

INTRODUCTION

On 8 September 2010, a team of four surveyed several buildings in two industrial areas of Christchurch. The team visited 10 sites and was granted access to six.

The structures at these sites were predominately steel frames with tilt-up concrete walls. The structural damage to these structures was limited to small cracks in two of the structures that did not go through the thickness of non-load-bearing tilt-up concrete walls. Thus, the emphasis of this report will be on the damage to storage systems within the buildings, which was quite severe.

GROUND MOTION CHARACTERIZATION

The Riccarton High School strong motion sensor (site RHSC) is very near the industrial sites that we surveyed (the sensor is located at -43.54, 172.57). The sensor is roughly one kilometre north of the sites we visited. Two response spectra (5% of critical damping) for this site compared to the appropriate design spectrum from NZS 1170.5 is shown in **Error! Reference source not found.**. The north/south response (red line) is higher than the east/west response.

The high response for long periods in the north/south direction is typical of many records from this event. This is of particular interest in rocking because as objects tip, their natural frequency diminishes drastically (the period increases significantly).

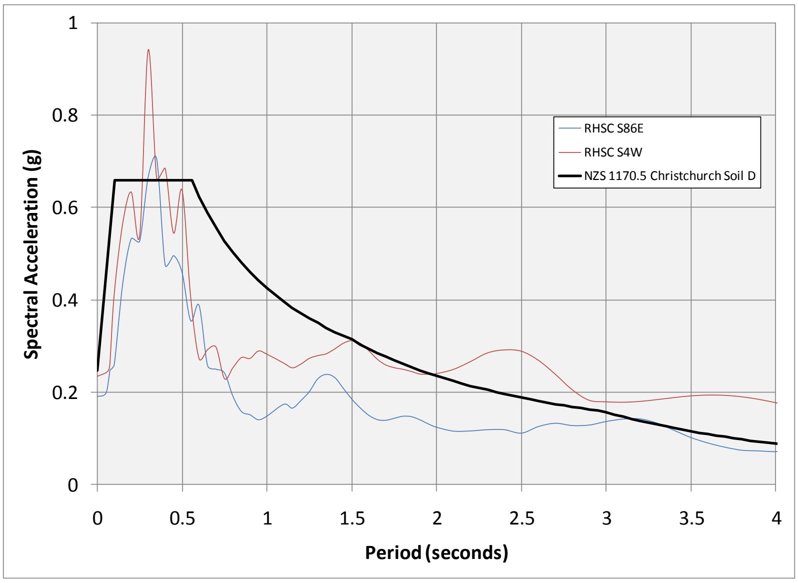

Figure 1: ***Response Spectra for motions recorded at Riccarton High School. Source: GNS, Mukai.***

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OBSERVED DAMAGE TO STORAGE SYSTEMS

A kitchen cabinet manufacturer used commercially available rack systems tied back to walls (Figure 2), to store particle board. The racks and the contents were undamaged. The buildings at this site, 20 to 25 years old, showed no damage.

An engineered wood products manufacturer had one storage rack that had a permanent drift (Figure 4). This rack stored various fasteners and the total load on the top two shelves was 13,400 kg. This system is a commercially available system. Both the building (which exhibited no damage) and the racks were 2.5 years old. Interestingly, this company had their own engineers analyze the storage racks prior to purchase and required the supplier to increase the stiffness of the rack. Using approximate dimensions of cross section and member lengths and the loading of the top two shelves, the first-mode period is estimated to be 0.4 seconds.

Figure 2: ***Undamaged stock and storage rack bolted to wall in Kitchen cabinet manufacture site. Source: D. Mukai.***

A glass workshop with four-year-old buildings stored large sheets of glass in vertical storage units (Figure 3). Some of the storage units were on wheels and others were fixed to the ground. In general, glass sheets stored longitudinally in the east-west direction had less damage than those stored in the north-south direction.

Figure 3: ***Undamaged glass plates stored vertically on racks with wheels at the glass workshop building. Plates stored in the East-West direction. Photo credit: D. Mukai.***

Three other sites fared even worse. A miscellaneous storage provider used light gauge commercially available racks. The heaviest loaded racks (Figure 5) carried pallets of 40 x 25 kg bags of flour (1,000 kg per pallet). These racks completely collapsed (Figure 5). A metal fabricator and supplier had two rows of racks collapse or overturn (Figure 6a). The down-aisle collapse caused the shelf to vertical member connection to fracture (Figure 6b). The buildings at this site, 35, 8, and 5 years old, showed no damage. The racks that collapsed (there were several others that suffered no damage) were heavily loaded with threaded bars, nuts, and bolts. Also, all the racks that failed were anchored. Other non-anchored racks walked, rather than overturned. A final site that was visited with severe rack damage was a milk distribution centre. Because the failed racks were in danger of collapsing into a high-voltage transformer, we were not allowed inside the facility. These racks were commercially available systems complete with cross-bracing and tension wires, both which failed. Complete collapse was only prevented by the racks catching on a low overhead girder. The racks were heavily loaded with cases of ultra-high-temperature pasteurized (UHT) milk.

In addition to these sites, we could see damage in two sites we were denied access to. Also, the media had reports of food distribution centres with extensive damage and losses.

Figure 4: Rack at wood products site with permanent drift. Note relative distances to plugs on wall. Photo credit: D. Mukai.

Figure 5: Damage inside miscellaneous storage provider site. Each pallet contained forty 25kg bags of flour. Photo credit: M. Hannah.

Figure 6: (a) Collapsed racks at metal fabricator and supplier site and (b) fractured connectors from the collapsed racks. Photo credit: N. Crannitch.

DESIGN GUIDELINES

Seismic Design of High Level Storage Racking Systems with Public Access [1], is based on *Design Recommendations* by G.J. Beattie and B.L. Deam. This document points out that Storage racking systems fall within the definition of 'buildings' in the Building Act 2004 (Building Act) and therefore must comply with the NZBC requirements". This document covers racking system loads, strength and deflection criteria, analysis methods for braced frames (cross-aisle) and moment frames (down-aisle), and displacement-based design procedures.

Previous to this document, HERA has published two documents [4, 5] that have been the basis for pallet racking system design from 1996. Because none of the observed racks were Drive-In pallet racks and [5] covers drive-in pallet racks, only [4] is reviewed.

The Design of Selective Pallet Racking Systems [4] is a follow up to articles in Issues 19 and 24 of the Design Bulletin. This article points out that racks in storage warehouses and supermarkets are considered as buildings. However, even racks that are exempt as buildings are still required to meet the same requirements as if they were not exempt. Because storage rack sections are typically less than 3 mm thick, they are not covered by Approved Document B1/VM1 [3] and this article provides verification methods for design to fill this void. The pertinent design standards for racks are *NZS 4203, Loading Standard* and *AS/NZS 4600, Cold Formed Steel Structures Standard*. The article then discusses modifications to NZS 4203 for pallet racks. The article suggests modifications to ψ and loading combinations based on the unique loading conditions for pallet racks. Due to the flexibility of racks, the article also suggests relaxed deflection limits. The article provides suggestions for Risk factor, R, based on the value of the stored goods and risk to occupants. When using an equivalent static method, the article suggests that periods be calculated by a Rayleigh approximation and that the ductility factor, μ, be taken as 1.25. The article also gives guidelines for modal analyses and time history analyses. In terms of analysis, the article recommends including P-Δ effects for $\mu > 1.25$. The article provides effective length factors for columns. In regards to shelves, the article does not allow changing the shelf arrangement unless the new layout is analyzed. The article also suggests that any change in loading conditions (including change in weights or pallet sizes) should require a new building consent.

DISCUSSION AND CONCLUSIONS

The observed damage is not from a random sample, so no broad conclusions may be made about the performance of all storage racks in the industrial area. However, of the industrial sites surveyed, the following observations are made:

- The two sites where damage was minimal were newer: the kitchen cabinet shop had their rack systems reviewed within a year of the earthquake and the wood products shelves were 2.5 years old at the time of the earthquake.
- Anecdotal evidence was that damage was more severe in the north-south direction than the east-west direction. This is consistent with many strong motion records from the region and also with damage to URM buildings within the Christchurch central business district.
- The systems that had severe failure all were heavily loaded: pallets of flour, pallets of milk, and pallets of metal pieces.
- In all cases, business operations were not stopped. Every firm found ways to continue operations in some way.

The following conclusions are made from these observations:

- It seems that newer racks will perform well in an event like the Darfield earthquake.
- There is a lower level of design and performance of racking compared with buildings as evidenced by severely damaged racks observed in buildings of similar age and with no damage.
- Both down-aisle and cross-aisle loads are critical.
- Seismic rack design is crucial when loads on the shelves are high.
- A detailed comparison of failed racks to the BRANZ and HERA documents reviewed here would be invaluable to the advancement to pallet rack design.

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