PRELIMINARY OBSERVATIONS OF THE DARFIELD (CANTERBURY) EARTHQUAKE: UNIVERITY OF CANTERBURY BUILDINGS

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SUMMARY

The University of Canterbury campus on the west side of Christchurch has a range of building types built since the late 1950s. The building stock is predominantly 3-12 storey concrete construction. About one third of campus buildings had some secondary and non-structural damage during the earthquake, while about three quarters had contents damaged; filing cabinets overturned, books off shelves, shelves overturned, fallen lab equipment, broken glassware. The secondary structural damage was primarily to stairs, finishes at seismic joints, ceilings and elevators. This paper outlines the impacts the earthquake had on the campus buildings, in terms of structural, secondary structural and contents damage. It also outlines the post-earthquake recovery process and downtime.

INTRODUCTION

The University of Canterbury is the 2nd oldest university in New Zealand. The original campus is now the downtown "Art's Centre" and the current campus (with about 13,500 students) was built in the 1950s-1970s on the west side of Christchurch. The campus has two relatively flat sites (Figures 1 and 2), which were independently managed until the smaller Christchurch College of Education became part of the university in 2007.

The earthquake struck at the end of a two-week teaching break. The fourth and final academic term was scheduled to begin on the Monday following the earthquake so, while many undergraduate students were returning to campus that weekend, the on-campus accommodation was not fully occupied at the time of the earthquake.

University staff had developed excellent earthquake preparedness plans and their Emergency Operations Centre (EOC) was activated early on the morning of the earthquake. A building survey carried out by facilities management staff identified two buildings that required a structural safety evaluation. A local structural engineering consultancy firm had carried out seismic evaluations of many campus buildings, so one of their engineers (the third author) was engaged to provide detailed building assessments.

The building evaluations had several stages, beginning with a preliminary structural safety assessment on the day of the earthquake. With only two buildings identified as possibly unsafe to enter, maintenance and emergency management staff began a more detailed damage assessment while the consulting engineer began a systematic survey of structural damage in all of the campus buildings.

On day four, structural engineering faculty were called in to assist with the detailed inspections, after the staff in the campus EOC decided that the survey time could delay reopening the campus. This was reemphasised five days after the earthquake when a significant aftershock disturbed contractors undertaking repairs and was large enough to warrant a second round of building inspections. The structural inspections and green 'safe' placards posted on the campus buildings were required to assure staff that the buildings were safe to enter.

The final stage in the safety assessment process identified two buildings that would need minor work so that they could be safely occupied. This was principally to remove hazards from the stairways required to provide safe fire egress so the buildings could be fully populated once the campus reopened. Only one building was unable to be reopened for student use, the James Hight library (the central library, housed in the tallest campus building), because of severe damage to the shelving.

The university campus was initially closed for one week, but during the assessment and clean up, it was decided to extend the closure for a second week, with a phased return of staff and graduate students during the second week to clean up their offices and make repairs.

The undergraduate classes were originally scheduled to resume two days after the earthquake, so this extended closure also permitted faculty to reduce the teaching term from six weeks to five and rearrange the exam schedule for the end of the semester. In addition, senior management decided that it was important to provide sufficient time to staff who were emotionally distressed by the earthquake, or who might have personal losses, such as housing damage.

IMPACTS TO BUILDINGS

Secondary and non-structural damage contributed the greatest portion of loss within the campus buildings. This was in part due to inadequate detailing of the interior finishing's applied

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Figure 1. The University of Canterbury campus map with featured buildings highlighted

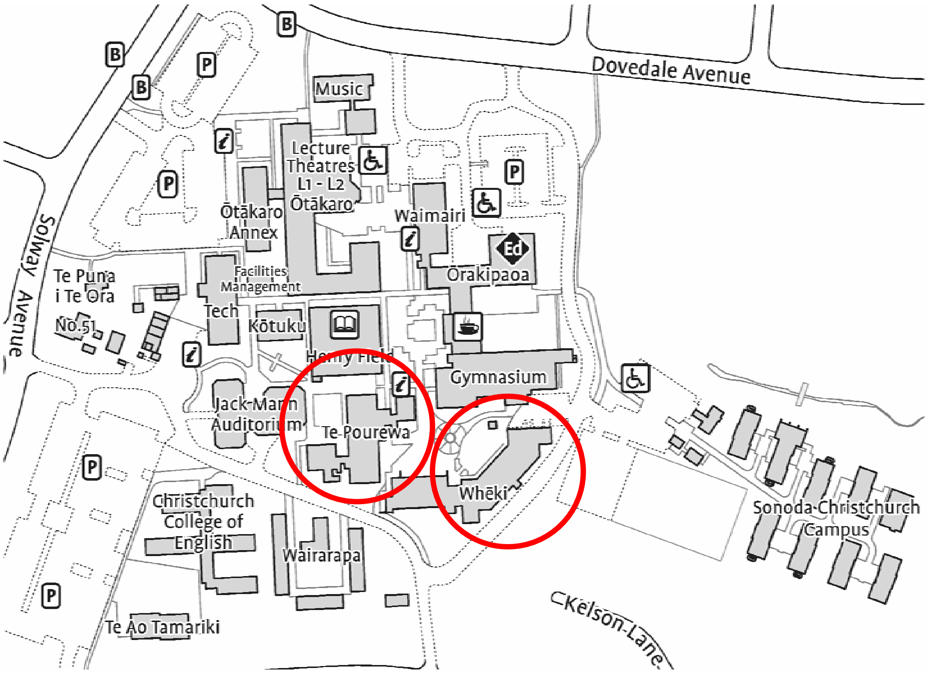

Figure 2. Map of the Dovedale Campus to the west of the main campus

at seismic joints between different structural systems and in part due to inadequate detailing of the secondary systems such as suspended ceiling and shelving systems.

The best example of inadequate interior finishing was in the relatively new six-storey Commerce Building (built 1998). The reinforced concrete moment-frame building has a V-shaped floor plan and lecture theatres in the basement and ground storeys. One leg of the V has a cafeteria at its base, which is slightly above the entry-lobby ground level (Figure 3). There is a two-storey structure closing the V that is laterally braced with structural walls. There were well-detailed sliding joints to accommodate differential movement between the tower frame and both the cafeteria and the two-storey structure, however the finishing tiles were not able to accommodate either the movement or the minor chipping of the edges of the concrete components as they slid over each other (Figure 3).

A second detail in the Commerce Building illustrated the importance of detailing connections to guarantee that they will work the way they are intended to. The wall between the elevator-shaft and stairwell at the base of the V has precast concrete panels attached to the structural frame. Anchors cast into the panels allowed these to be bolted to supports cast into the supporting frame. Slots in upper connection were detailed to accommodate in-plane interstorey drift and the panels have gaps along the top and at each end. Severe concrete damage around the top anchorage points of most of the precast panels (Figure 4) suggests that the bolts were unable to slide through the slots as intended.

While the damage was minor, and temporary connections were easily inserted to retain the panels during aftershocks, the failure of this very small design detail created significant consequences for both fire egress through the stairwell and operation of the elevators.

The History building (Figure 5) provided a second illustration of the need for well detailed connections between frames and walls within a building. This reinforced concrete moment-frame building was originally three storeys high but had another three storeys and an elevator tower added in the 1980s.

Most of the seismic gaps between the elevator tower at the north end of the building and the main building had stretched

Figure 3. Finishing tile damage around sliding seismic joint in the Commerce building

Figure 4. Elevator panel damage around restraint bolts and (later) temporary restraint in the Commerce building

Figure 5. The History building, with an inset showing its decorative beam stubs that provide reinforcing anchorage

Figure 6. Finishing damage at top of masonry infill panel within the Te Pourewa building

Figure 7. Movement of the stairway on its supporting ledge at Level 3 in the History building

Figure 8. Vertical movements of the landing supports between Levels 2 and 3 in the History building

and torn vinyl flooring and dislodged the wall architraves. While access to the elevator was unimpeded, the uneven floor surface was hazardous and needed repairing for safe use.

The 6-storey reinforced concrete moment-frame Te Pourewa building (on the College of Education site to the west of the main campus) had some minor damage due to movement of the frame relative to a concrete block masonry infill panel (Figure 6). There was clear evidence of sliding along the top of the infill panel, but no other visible damage to the panel. Some of the architectural 'spandrel panels' between two structural walls on the north face of the Te Pourewa building were slightly damaged as well.

The stairway in the 6-storey History building was partially damaged by the interstorey drift movements. Each storey has U-shaped stairs seated on ledges at the top and bottom, and mid-flight landings that are bolted to the columns either side of the stairwell. The stairs clearly slid across their ledges during the earthquake (Figure 7), stretching the long bolts holding the stair flights to the ledge beams, tearing the vinyl floor coverings and chipping concrete from the leading edges of the ledges. Like the Commerce building, this damage was not significant structurally, but it compromised fire egress and therefore needed to be repaired before the building could be fully reoccupied.

The gaps between the stair flights and their landings varied with height in the History building, with about 10 mm gap at level 2, the largest gap of about 15 mm gap at level 3 and progressively smaller gaps at the higher levels. This is consistent with the interstorey drift profile for a frame building. However, the building was not noticeably offset after the earthquake, and the permanent gaps appear to have been accommodated by small vertical offsets in the bolted connections at the sides of the mid-flight landings (Figure 8).

There are four other buildings similar to the History building on campus, but none were damaged to the same extent. The most damaged of these, Modern Languages, is aligned parallel to the History building. The remaining three buildings are aligned perpendicular to the History building. Three other taller buildings, the James Hight, Rutherford and Biology buildings had damage that suggested that there were larger movements in the approximately northwest-southeast direction. (The campus has a grid-like layout that most buildings are aligned to.)

The 8-storey Rutherford Building (Chemistry and Physics, circa 1970) had evidence of significant movements within the seismic joints at both floor and ceiling of the 8^{th} floor (Figure 9) and progressively smaller movements at lower levels. One roof frame beam was cracked about 1 m from the column (Figure 10), suggesting a significant gravity load and a unidirectional structural hinge.

Structural Panel Cracking

Many structural panels had minor in-plane cracking after the earthquake. For some, such as < 1 mm diagonal cracks within panels in the Commerce building, these were mostly cosmetic and consequences of the interstorey drifts permitted by the primary lateral load-resisting system.

There were also cracks observed in lateral load-resisting systems, such as those in the 3-storey portion of the Wheki building (College of Education). The plan view of this building is like one quadrant cut from an octagonal building (Figures 11 & 12). It has a steel frame supporting the floors and 3-storey high tilt-up concrete panels at the two ends and around the outer three faces. The three inner faces are glazed and provide minimal lateral load resistance. There was no evidence of cracking in the two structural walls at the ends of the building (these two walls were perpendicular to each other). There were diagonal cracks at some of the corners of the window cut-outs in the bottom storey of the outer faces of

Figure 9. Movement at level 8 between the lift block (left) and southern portion of the Rutherford building

Figure 10. One-way hinging of the roof beam in the Rutherford building (immediately above Figure 9)

Figure 11. The Whiki building, showing a half-octant on the left and the central octant to the right. (Photo: Tony Abu)

Figure 12. Behind the Whiki building. The elevator tower had cracks adjacent to the access door (lower left).

the building. Interestingly, the cracks were almost all on the top-left and bottom-right corners at one end (the face to the right of Figure 10) but at the opposite corners at the other end of the building (the outer face behind the centre of Figure 11), suggesting an impulsive ground motion rather than oscillation.

Diagonal cracks (< 1 mm) were also observed in a structural wall adjacent to the elevator within the 3-storey atrium between the 3 and 4 storey wings of the Wheki building (Figure 12). The stairway within the atrium dropped several millimetres vertically at the intermediate landings, causing the finishing tiles to spall from the central supporting wall. The seismic joint cover plates between the atrium and structural wall at the end of the adjacent 4-storey wing lifted and prevented some of the access (and fire egress) doors opening.

A horizontal crack was observed across the width of a concrete panel in the 1 storey portion of the 1 and 2 storey Otakaro (College of Education) building. The reason for the crack at about two thirds of the panel height is unclear, but it is likely that the roof system contributed to its formation.

Ceiling Damage

Heavy ceiling tiles fell from the suspended ceilings within a significant portion of the larger halls and meeting rooms. In some cases light fixtures also fell and sprinkler pipes were bent but not broken (there was no water leakage or damage).

The 3-storey Engineering and Physical Sciences Library (circa 1970) shed a significant portion of the ceiling tiles at the roof level (Figure 13). The ceiling system only had support rails in one direction. Unbroken ceiling tiles were used to replace tiles fallen from the sloping ceilings of the larger single-storey engineering lecture theatres (E1, E8 and E9), allowing them to be reused for teaching two weeks after the earthquake. The ground floor of the Library reopened 10 days after the earthquake, but the upper levels were closed for student use for another two weeks.

One meeting room ceiling at the top of the 5-storey Civil and Mechanical Engineering building (built 1997) shed many ceiling tiles (Figure 14). This was possibly in part due to the large area of the ceiling as no tiles were shed from smaller office ceilings at the same level or from an identical meeting room one floor below, which had been partitioned into offices a year before the earthquake.

The 12-storey James Hight library tower shed heavy ceiling tiles and light fixings on four floors For this, like all the above cases, it is important to note that there was significant life-safety risk due to heavy tiles falling more than 6 m. Had the earthquake occurred during lecture times, many students could have been injured.

The History building had a lighter weight suspended ceiling comprising support rails with lightweight steel slats clipped on underneath. Many of the slats were dislodged by much heavier lighting equipment (transformers or ballast) that was not well

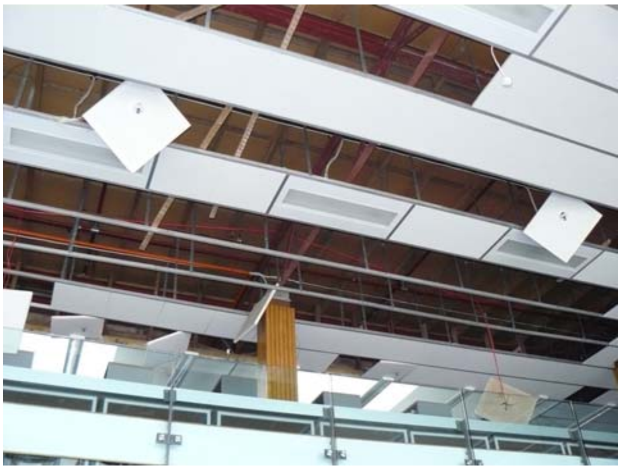

Figure 13. The remaining roof-level suspended ceiling wthin the Engineering and Physical Sciences Library (Photo: Tony Abu)

Figure 14. Tiles shed from a more modern ceiling with support rails in both directions (Photo: Tony Abu)

Figure 15. Collapsed book stacks at Level 3 of the James Hight Library (Photo: Tony Abu)

Figure 16. Gas cylinder restraints and the hand basin damage when chain detached during the earthquake

restrained. Although the slats were considerably lighter than the gypsum ceiling tiles used in other buildings, their falling would alarm and injure occupants evacuating through the corridors that they were used in.

CONTENTS DAMAGE

The James Hight library is the tallest building on the campus and images of its collapsed book stacks (Figure 15) were used extensively by the media to characterise the damage at the University. The library comprises a central 12-storey tower that is surrounded on three sides by 3-storey podium buildings. This configuration partly contributed to the unusual pattern of damage observed in the building. In this case, the most extensive damage was on the second and third floors, with many broken windows and collapsed book stacks. The windows, like many on the campus, have steel frames that are rigidly attached to the reinforced concrete frame and the glass in turn is semi-rigidly sealed into its frame with glazing putty. The final replacement glass was installed six weeks after the earthquake.

Upper floors had books fall from shelves, but no shelf collapse, and some damage to office contents, but it was less severe than the damage on the third floor. The building was closed for the remainder of the semester and the books and services were handled externally.

Books in the Library Warehouse building are stored on mobile stacks, with tracks that prevent the stacks from overturning. There was evidence that the stacks had rolled horizontally in response to the ground motion, crushing a small number of books that had fallen from the central stack units. The stacks at the track ends had shed most of their books and were splayed outwards at the top, probably as a result of dislodged books falling between the stacks. Only one of the approximately 50 stack units had racked in-plane to the point that it was resting against pipe work attached to the building.

Books were dislodged from shelves in many staff offices, particularly offices in the upper levels. Almost all of the bookshelves and slender cabinets are attached to the office walls. Many filing cabinet drawers were opened, some with enough drawers to overturn the entire cabinet. Other filing cabinets were racked in the perpendicular direction, breaking the fasteners providing moment-resistance at the base.

The Chemistry and Physics laboratories at the 8^{th} floor of the 8-storey Rutherford Building had extensive damage to glass beakers and other small lab equipment that fell to the floor. One particular problem was the extensive spillage of silicon oil. This material is used in experiments to keep a constant temperature and it is stored in open glass bowls. The oil bowls fell to the floor, leaving surfaces slick and treacherous, making clean-up significantly more difficult. Some experiments were damaged, particularly those with elaborate glass tubing but by and large the laboratories did not suffer heavy losses. In part, this is because the ground shaking was not severe enough, but in part, the culture of safety in the labs played a part in limiting damage. All shelves had tall lips (approximately 75 mm) which prevented chemical containers from falling. Similarly, other small equipment was restrained by shelf lips. In addition, lab users who were careful to store chemicals and experimental materials had less spills and breakage than others who left materials on the lab benches.

Most tall gas tanks were restrained with chains but in some cases, the shaking loosened the chain from the I-hook and the tank fell (Figure 16). In the future, these will be secured with a closed hook.

Some heavy equipment and machinery stopped functioning when the power was lost. In many cases, faculty would have to wait several weeks for equipment-service providers to re-start and test the equipment, before it can be used in experiments. Only time will tell if any of the scientific equipment was damaged by the shaking or power interruption.

The Rutherford building had a large open water tank on the roof and during the earthquake, water splashed out and caused damage to ceiling and wall finishes in rooms below. In general, the worst non-structural and contents damage was on the top floor, with progressively less damage to lower floors.

All campus building elevators were shut down for inspection and testing. The more important elevators were available from about a week after the earthquake, but it was about 3 weeks before all campus elevators were all inspected and operating again.

IT staff conducted a one day inspection of all computer equipment on campus and found about 15 % was damaged. This figure was used to pre-order new computers, monitors, and other equipment while individual staff members checked the conditions of IT equipment in their buildings.

All campus printers, scanners and copiers have a single supplier who inspected and tagged the equipment with green, orange and red stickers to indicate whether or not they could be used.

The acclaimed James Logie Memorial Collection of Greek and Roman antiquities sustained significant damage during the earthquake[1]. While the display cases contained sand bags in their bases to keep them upright, smaller items in five of the eight cases wiggled and fell, suffering minor damage such as chips and paint scrapes. The larger items were more seriously damaged as they hit the glass in their display cases.

LESSONS LEARNED

The impact of the Canterbury earthquake on the University was significant in terms of non-structural damage to facilities and downtime. University staff were well prepared for the emergency and conducted inspections in a thorough and timely manner, however, the need for time to clean up damage, plan for teaching resumption and assist staff and students in dealing with the distress of the earthquake experience took more time than originally thought. The full dollar value of losses will not be known for some time, but the disruptions to teaching and research were keenly felt and suggest that pre-disaster recovery planning would help to expedite the process in any future emergencies. In addition securing library shelving, and critical research equipment and reviewing safety issues in classrooms (ceiling tiles, ceiling mounted projectors, etc.) would improve nonstructural performance in any future events.

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