Wellington City Council Targeted Building Assessment Programme

Additional Guidance Notes for Targeted Damage Evaluation:

Precast Concrete Floor Systems and Cladding Panels

17 January 2017

Overview

This additional guidance elaborates on the information provided in the *Engineering Guidelines for Targeted Damage Evaluation following the November 2016 Kaikoura Earthquakes* Version 1.0 (the Guidelines). These notes focus on precast concrete floor systems and cladding elements, and should be read in conjunction with Section 5 of those Guidelines. The guidance given herein is in addition to the Guidelines - that is, the overall building evaluation should otherwise follow the Guidelines.

Additional information is provided about planning and undertaking investigations of precast concrete floor systems (Section 1) and precast cladding elements (Section 2), and the extent of inspections and investigations required. The information in these sections relates to establishing the presence of Critical Damage States A (local collapse risk) and B (local and global collapse risk in case of aftershock), and D (secondary structural and non-structural elements) respectively.

Further guidance is given on occupancy status with regard to the observed component damage (Section 3).

This information draws upon observations of buildings of different configurations and damage levels in the early stages of Wellington City Council's Targeted Assessment Programme.

Process and Objectives

The Targeted Assessment Programme is designed to address public safety issues and to provide confidence that appropriate engineering investigations of buildings most affected by the 2016 Kaikoura earthquake have been carried out. The overall objective of a Targeted Damage Evaluation is to identify the presence of critical damage states that could affect either local or global stability, and hence occupancy of part or all of a building. This additional guidance expands upon the overall building assessment process outlined in the Guidelines.

The approach to be taken for both precast concrete floor systems and cladding elements is one of *progressive inquiry* – one that involves consideration of both the configuration of the building as designed and the levels of damage observed from a review of the drawings and an initial investigation. Where only limited or no structural damage is encountered, then no further intrusive investigation is required. However where damage of a certain nature and extent is found, then a second and more comprehensive level of further investigation is to be undertaken.

Section 1 – Precast Concrete Floor Systems

The process to be followed for identifying damage to precast concrete floor systems is summarised as follows:

1. Review available drawings for the building, identifying the load paths, structural system and any configuration issues. From this understanding of the building, the areas where damage is to be expected can be identified - i.e. potential damage 'hotspots'.
2. Undertake an *Initial Investigation* ensuring that the identified hotspots are inspected. If damage (structural or non-structural) is seen that was not predicted from the drawing review, then the load path identification from 1. above should be revisited.
3. If evidence of Critical Damage States A or B is observed in hotspots or other areas, *progressively* extend the investigation to other regions on levels with high drift demands.
4. If evidence of Critical Damage States A or B is <u>not</u> identified in hotspot or other inspected locations and the damage (or lack thereof) confirms the load path/system identification, no further intrusive investigation is required.

These investigations are to be documented, including photographs, locations and measurements of any cracks, in accordance with the framework provided in Section 6 of the Guidelines.

When followed in conjunction with the relevant targeted inspections in Section 5 of the Guidelines, this approach aims to provide a reasonable likelihood of finding Critical Damage States A or B within the building. However it must be noted that it is not possible to guarantee that none exist.

Plan Review - Identifying Building Configuration Issues

From a review of the plans, identify the presence of building 'indicator issues', irrespective of the level of apparent damage.

Indicator issues include:

- Moment-resisting frames with multiple frame bays in parallel with a single span of flooring
- Irregular floor layout (including L-shaped or curved floor plans and irregular layout of lateral force resisting systems)
- Large openings in diaphragms impacting load path to lateral force resisting systems
- Transfer beams
- Nominal (or lack of) structural ties across the floor plate holding the columns of a frame or braced bay into the building.

If these design issues <u>are</u> present, the potential for precast floor unit damage or separation of the floor system from the frame is heightened, and the inspection of the building should focus on whether or not damage has occurred to the floor system (even if only minor or moderate levels of non-structural damage has occurred).

If these design issues are not present, an initial investigation should still be undertaken as required by Section 5 of the Guidelines to be confident that the integrity of the precast floor system has not been affected.

Plan review should also be used to identify likely locations of damage to precast floor units, referred to herein as "hotspots". Generally these hotspots are associated with the building configuration issues noted above, and are located where localised deformation of precast floor units is necessary to accommodate the movement of the supporting seismic and gravity systems. Examples of hotspots include (but are not limited to):

- Corners of the building
- Locations of torsional demand or concentrated deformations on precast units (e.g. between two adjacent walls or adjacent to eccentrically braced steel frames)
- At corners of large diaphragm openings
- Precast units with continuity restraint at gravity beams near gravity columns

Initial Investigation

Undertake *representative inspections* of hotspots identified above. This should, for example, include two opposing corners of the building on three different levels. At least two of these levels should be in the region where the highest building drifts are expected (typically the lower third for moment frames, upper third for shear wall buildings, or middle third for buildings subject to high torsional response), and as evidenced by significant non-structural damage. Use secondary damage as a guide for where inter-storey drifts were likely to have been the greatest.

A focus in the *Initial Investigation* of hotspots in perimeter moment-resisting frame buildings is on looking for diagonal cracking across the corners of the building or towards the ends of the moment frames, and if present, whether the cracking crosses transversely through precast units. It should be noted that precast unit damage can occur with limited or no beam elongation evidence present.

The floor surface at each location should be exposed, along with the precast floor unit soffits from below, and adjacent beam and column surfaces. The flooring from both above and from below should be inspected, and this includes a check of the remaining seating (Critical Damage State B1) – i.e. the presence of spalling or other damage to the faces of supporting beams.

Any of the following damage patterns indicate the floor unit has sustained at least Critical Damage State B:

- transverse cracks across hollow core units (within 400 mm of supporting beam); or
- diagonal cracks at end of ribs (within 400 mm of supporting beam); or
- damage to support for precast floor units; or
- reduced seating.

If a vertical offset is observed at any of the damaged locations, indicating vertical movement of the precast unit, this should be reclassified as Critical Damage State A – i.e. clearly compromised gravity load path. Propping of the affected units should be installed prior to undertaking any further investigation.

If Critical Damage States A or B have been identified, or if the assessor has reason to believe based on the field investigation that damage may extend beyond the previously defined hotspots, investigation of the ends of precast units should be extended to regions beyond the selected hotspots. Inspection locations should be well distributed throughout high drift storeys (as identified by damage to partitions etc) to minimise the possibility of missing further floor unit damage. It is however recognised that it is not practically possible to inspect ends of all floor units and some risk of missing damage must be accepted.

If further critical damage states are identified during this random selection of inspection locations, the scope of additional investigation should be extended.

Local propping of affected units may be sufficient to address the above local situations for the purposes of continued occupancy, but requires a clear understanding of the damage states of floors throughout the building.

If evidence of Critical Damage States A or B is not observed in any of the hotspot areas or from other inspections undertaken, further intrusive investigation of the floor systems is not required – unless the building has significant non-structural damage or other indicators of high drift demands or local damage, in which case appropriate further investigations need to be undertaken.

Intrusive Investigation for Hollowcore

For damaged hollowcore units, further intrusive investigation is necessary to identify any damage to the webs in the proximity of the transverse cracking identified in the initial investigation. In those locations where transverse cracking at the ends of hollowcore floor units is observed, the void cells in the vicinity of the crack should be exposed and the webs of the units closely inspected to understand the nature and extent of cracking for repair specification purposes. The direction and extent of web cracking must be carefully documented. Diagonal web cracking in the direction of gravity shear indicates the gravity support for the floor unit may be compromised. In such cases, damage should be reclassified as Critical Damage State A.

If webs of hollowcore units are not inspected in regions of transverse cracks at the time of completing the report, the webs must be assumed to be cracked, and Critical Damage State A applied as a default classification.

Section 2: Precast Concrete Cladding Panels

The focus of this section is on identifying panel connections that have been compromised such that there is no valid load path restraining the panel from falling in an aftershock or other earthquake event.

While this section primarily deals with precast concrete cladding systems (i.e. the identification of Critical Damage State D2), the general philosophy and methodology is considered valid for stairs and other heavy overhead non-structural elements (Critical Damage States D1 and D3).

In almost all cases, the presence of Critical Damage State D2 will be a result of the inability of the panel connections to accommodate lateral deformation of the primary structure.

The process to be followed is essentially the same as in Section 1 for precast concrete floor systems, and is summarised as follows:

1. Review available drawings for building, identifying the load paths, structural system and any configuration issues. Review the details of the cladding panel connections, looking for the level of movement provided for both horizontally and vertically. From this, identify the areas where critical interactions between the panels and primary structure would be expected - i.e. the cladding panel 'hotspots'.
2. Undertake an *Initial Investigation* to look for signs of building movement externally and internally, and in both non-structural and structural components.
3. If the building is likely to have deformed to a level that approaches the deformation capacity of the connection details, then carry out an *Intrusive Investigation* of the identified 'hotspots'. This initial investigation is part of an *progressive inquiry* – i.e. if damage is found, carry out further *Intrusive Investigations*.
4. If evidence of Critical Damage State D is observed in hotspots or other areas, *progressively* extend the investigation to other regions on levels with high drift demands.
5. If evidence of Critical Damage State D is <u>not</u> identified in hotspot or other inspected locations and the damage (or lack thereof) confirms the load path/system identification, no further intrusive investigation is required.

When followed in conjunction with the relevant targeted inspections in Section 5 of the Guidelines, this approach aims to provide a reasonable likelihood of finding damaged panels within the building. However it must be noted that it is not possible to guarantee that none exist.

Plan Review

Plan review should be completed generally as noted in Section 1. Key indicator issues include the following:

- Fixings embedded into plastic hinge regions of beams
- Rigid connections fixed beyond the critical regions of beams and which may therefore be affected by beam elongation

- Fixings with limited or no clearance to accommodate inter-storey drift (use 2% as a default drift, unless the review of the drawings indicates a lower value is appropriate). Note that if the connection may reliably deform plastically upon reaching its limiting drift, this may not be an issue
- Fixings in panels that have no mechanical interlock with the panel reinforcement
- Fixings that are reliant on shallow embedded or drilled-in anchors
- Panels that are in line with structural elements and that do not have sufficient clearance to accommodate inter-storey drift (use 2% as a default drift, unless the review of the drawings indicates a lower value is appropriate)
- Fixings that have welds at the point of highest stress concentration, particularly in case of site and fillet welds.

Initial Investigation

The Initial Investigation for precast panel connections commences with an external viewing of the façade. The objective is to identify visible exterior evidence of possible panel damage or movement, and/ or if other cladding items such as glazing are showing signs of distress.

Specific external issues to look for include:

- Cracked glass panels
- Loose shims or PE backing rods.
- Torn sealant
- Spalled concrete
- Cracking in panels that may relate to primary fixings

Particular attention should be given to areas above critical egress points on levels where significant panel movement is likely to have occurred.

For some situations where damage is observed or suspected, scaffolding may be warranted to access panels externally or it may be considered necessary for a high rope expert to abseil the façade and record observations.

Investigations to identify precast panel connection hotspots should then continue in the interior, and can be in conjunction with the representative inspection of hotspots undertaken as part of initial investigations for precast flooring systems as outlined on page 3. The focus is on identifying areas where damage relating to deformation incompatibility has occurred in other components such as precast floor systems, and/ or where the internal non-structural damage is indicating that the building has undergone significant deformations.

Intrusive Investigation of the connections of precast concrete panels should then be undertaken in locations where any of the above issues are found.

For situations where the building has clearly been subject to significant deformation but may not be showing apparent signs of panel distress from the exterior, the three levels as determined for the precast floor system hot spots (page 3) and the associated locations (where panels are present) represent a valid basis for undertaking Intrusive Investigations.

Intrusive Investigations for Precast Panel Connections

Intrusive Investigations of precast panel connections will generally require a builder to open up internal linings in locations determined from the above considerations. It is important to see all four connection points of a panel.

Specific issues to look for when investigating panel connections include:

- Sheared, deformed or missing bolts
- Deformed brackets or connections
- Cracked concrete around brackets
- Panel movement as a result of the earthquake that has used up all of the deformation capability, and where the connection has little ductility

If failed connections are found at any of these initially chosen locations, that is obviously a serious matter that will lead to further intrusive investigations at other levels. Those further intrusive investigations don't necessarily need to be completed as part of this Targeted Damage Evaluation report to Council, provided that appropriate isolation measures are taken.

If failed connections are not found at any of these initially chosen levels, it is not intended that further intrusive investigations be undertaken.

Note that the focus of a Targeted Damage Evaluation is looking for change as a result of the earthquake and/ or the identification of currently dangerous situations (for example as may have resulted from advanced corrosion or other deterioration of fixings). It is acknowledged that some of the defects encountered are likely to relate to original design and/or construction issues. This should feed into any subsequent consideration of the seismic rating of the building, which is beyond the immediate focus of the Targeted Damage Evaluation.

Section 3 - Continued Occupancy or Re-occupancy

Critical damage is damage which, in the opinion of the engineer, may be sufficient to significantly impair the building's capacity to resist either gravity or seismic actions (from Section 4 of the Engineering Guidelines - point 2 on page 6).

Critical Damage States refer to component damage. Some components relate to compromised local capacity (e.g. damage to precast floor units or panels), where for example local propping and/ or isolation can be sufficient to temporarily address the situation and enable continued occupancy. Other Critical Damage States relate to the overall stability of the building (e.g. Damage States B2 and B3), and would lead to a recommendation that the building not be occupied.

While it may be possible in some cases to isolate a section of the building, where damage affects the ability to resist lateral loads (e.g. transfer of load from a diaphragm to lateral systems) and failure could precipitate a wider building collapse, in these situations more comprehensive work will be required prior to occupancy.

Recommendations on building occupancy must therefore be based on a holistic assessment of the building and surroundings, and how the building is currently being used.

It is suggested that recommendations with respect to occupancy be expressed under the following categories (as per the updated Standardised Summary Table spreadsheet):

- Continued normal occupancy with no restriction
- Continued occupancy with partial access restriction
- Not to be occupied pending further investigation and/ or repairs.

Similarly, a statement should be made as to the need for external barricading of public or otherwise accessible spaces.