NEW ZEALAND SOCIETY FOR EARTHQUAKE ENGINEERING

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Wellington City Council

Targeted Building Assessment Programme

Engineering Guidelines for Targeted Damage Evaluation following the November 2016 Kaikoura Earthquakes

Version 1.1 - 25 January 2017

Document Status and Amendments

Version	Date	Purpose/ Amendment Description
Version 1.0	19 December 2016	Release to accompany Wellington City Council owner notifications
Version 1.1	25 January 2017	Incorporating Additional Guidance released 17 January Principal changes summarised below (new text denoted by lines in the margin): • Adjustment to Figure 2: Damage Evaluation processes (page 6) • Outlining and emphasising the principle of 'progressive inquiry' (page 9) • Clarifying the interpretation and application of Critical Damage States (page 9 and Appendix A) • Additional information about planning and undertaking investigations of precast concrete floor systems (Appendix C) and cladding panels (Appendix D)

Disclaimer

These guidelines are to assist in the assessment of existing buildings that have been identified as potentially damaged by the 14 November 2016 Kaikoura Earthquake and subsequent aftershocks. The guidelines are based on the current state of knowledge and are provided to assist Chartered Professional Engineers undertaking the structural assessment of existing multi-storey buildings within the profile of buildings requiring Targeted Damage Evaluation. The guidance is neither specific nor comprehensive, and is not intended for use by any other persons or parties, or for any other purposes.

As changes to the information contained in these Guidelines are likely as further knowledge becomes available subsequent to the expiry of the emergency powers, users should maintain awareness of such developments and adjust assessments accordingly. Users should exercise professional judgement in the application of the guidance to a particular building, and are encouraged to seek other professional inputs and/or reviews when applying the guidance to addressing aspects of damage that the user has had no previous experience in assessing.

1. Context

The 14 November 2016 Kaikoura earthquake, although centred approximately 240 km from Wellington, resulted in long duration shaking in excess of the code demand for selective period ranges in some parts of the city. This was principally due to a combination of soft soils and the underlying geology which produced basin and other effects in some parts of the city.

This draft guideline outlines an appropriate damage evaluation and reporting regime that recognises the following key points:

1. The damage was highly selective, due to a number of factors including the rupture progression, epicentral distance and local basin and edge effects. Some building types were more affected than others.
2. Where significant structural damage has occurred to any structure, a Detailed Damage Evaluation should be undertaken.
3. GNS have advised that we are in a period of increased probability of a local earthquake. This document is targeted at those buildings that have been previously damaged and/or had their capacity reduced. While not in the scope of this document, it is important that the public understand that a local earthquake is likely to produce shaking that is likely to affect earthquake-prone buildings, particularly unreinforced masonry buildings –and the risk these buildings pose.

Wellington City Council is undertaking a Targeted Building Assessment Programme to address public safety issues and to provide confidence that appropriate engineering investigations of buildings most affected by this earthquake have been carried out, and that where found necessary, repairs and remediation are being implemented.

The process outlined in this document seeks to address:

1. Concerns that some owners of at-risk buildings may not have obtained adequate building structure reviews
2. The need to ensure that engineers are completing appropriate investigations
3. The need to focus on the most at-risk buildings in the aftermath of this earthquake to make the most efficient use of engineering resources
4. The establishment of an Affected Building Profile – buildings with key characteristics that may make them at risk in future aftershocks
5. The need to assemble data for research in a consistent format.

This document has been prepared by a group of experienced engineers closely involved in the response to this event, drawing upon guidance previously developed by the Ministry of Business, Innovation and Employment following the Canterbury Earthquake Sequence.

2. Framework for Targeted Damage Evaluations

The following broad framework assumes that Wellington City Council will be requesting that owners of potentially affected buildings have Targeted Damage Evaluations undertaken, and that these evaluations will be subject to review.

It is also assumed that most potentially affected buildings have had some form of Rapid Building Assessment already as a response measure, but this is not a given. Given what we now know about damage to certain types of buildings, Rapid Building Assessment for certain types of buildings may not have identified all potentially critical issues and some form of intrusive investigation may be required.

This overall assessment framework provides the following:

1. Profiles buildings and damage according to the characteristics of the Kaikoura earthquake and observed shaking and damage patterns.
2. Sets a regime of targeted investigations that must be included for Targeted Damage Evaluations of buildings within specifically identified categories of buildings. The investigations must be specific to the building type.
3. Sets the requirements for the reporting of the Targeted Damage Evaluations, whether required for the targeted categories of buildings or provided by engineers for other purposes.

The targeted damage evaluation process is illustrated in general terms in Figure 1 below:

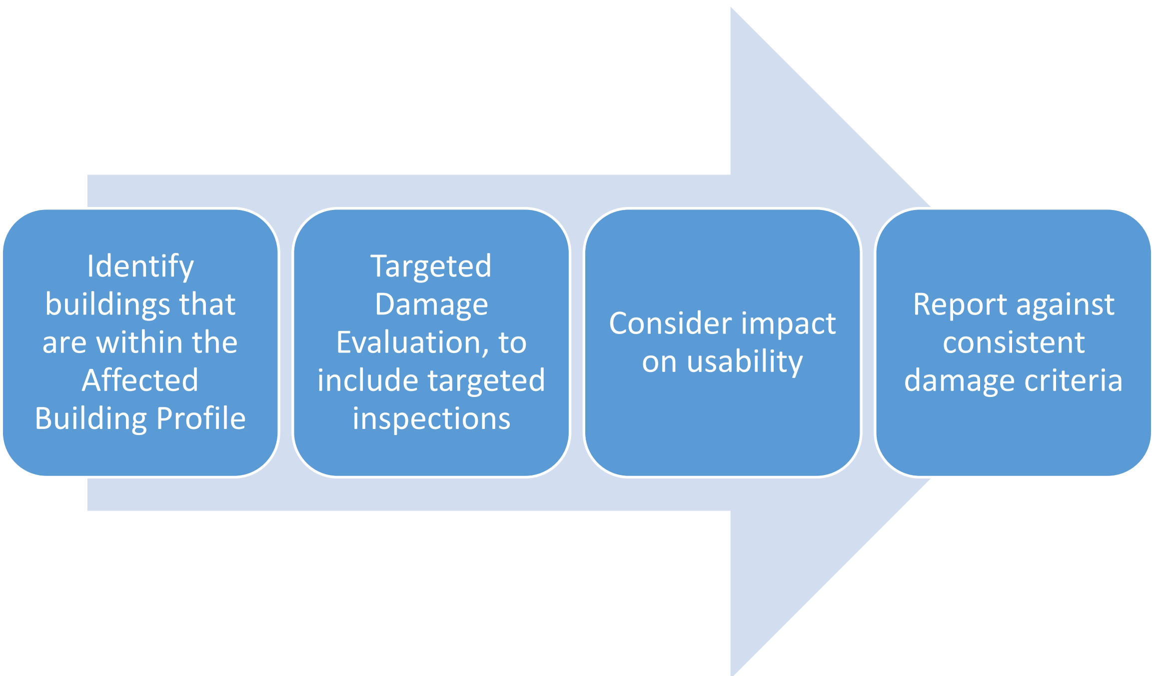


Figure 1: Targeted Damage Evaluation Framework

3. Affected Building Profile

Through observations of the performance of buildings in this earthquake, buildings with the following combination of structural form, size and siting are considered to represent the profile of buildings requiring Targeted Damage Evaluation:

- Building characteristics:
    - Principal lateral load resistance through concrete moment frames, coupled with precast flooring systems (noting that the most vulnerable to loss of support for precast units are those where there are multiple frame bays in parallel with a single span of flooring);
    - A natural period range of 1-2 seconds (typically 8-15 storeys, but note that this occurs in some flexible frames as low as 5 storeys); or
    - Sites where the shaking in the period range has been amplified. This amplification may be due to basin effects and/or soft soils.

- Building damage:
    - Significant loss of contents and/or non-structural damage (partitions, ceiling tiles etc)
    - Signs of frame 'stretch', for example in carpet tiles; or
    - Signs of significant inter-storey drift; or
    - Signs of cracking to precast floor units when visible, particularly transverse to the direction of the span of the unit.

These characteristics are specific to building damage observed in the Wellington CBD as a result of the Kaikoura earthquake. Different earthquakes and/or different areas may require reassessment of a different set of affected building types and elements.

These criteria are also not exclusive to buildings with concrete moment frames. In particular, assessing engineers should consider the possibility of compatibility actions induced in gravity or torsion frames of buildings where the principal lateral load resistance is provided by structural walls.

4. Targeted Damage Evaluation Process

The Targeted Damage Evaluation (TDE) process has been developed to allow efficient identification of critical damage in potentially affected buildings. The targeted inspections that are recommended in Section 5 take into account the direct observations of building performance around Wellington following the Kaikoura earthquake. They are not exhaustive - that is, other forms of damage may have been suffered by buildings. However, they represent the most significant concerns that have been identified in the stock of potentially affected buildings. Different earthquakes may result in different forms of damage in the same buildings, and engineers should be alert to this when completing their evaluations.

The TDE is primarily a qualitative assessment under which engineers must be satisfied that they can understand the primary load-resisting systems of a building (both gravity and seismic), and can view all critical elements in the load paths. Where there is no damage to either the primary load-resisting systems or secondary structure and non-structural elements that would impair its continued function or lead to a public safety risk, the building may be considered suitable for continued use on the same basis as prior to the earthquake, but reflecting the increased risk of aftershocks. Where uncertainty remains, or damage affecting the primary load paths is observed, then a Detailed Damage Evaluation (DDE) should be undertaken. A Detailed Damage Evaluation may include both qualitative and quantitative components. Although not described here, a DDE should generally follow the processes developed following the Canterbury earthquakes (available from the SESOC website at www.sesoc.org.nz).

The relationship between the TDE and DDE for differing damage conditions and rapid assessment outcomes is outlined in Figure 2 below, including for buildings outside the Affected Building Profile.

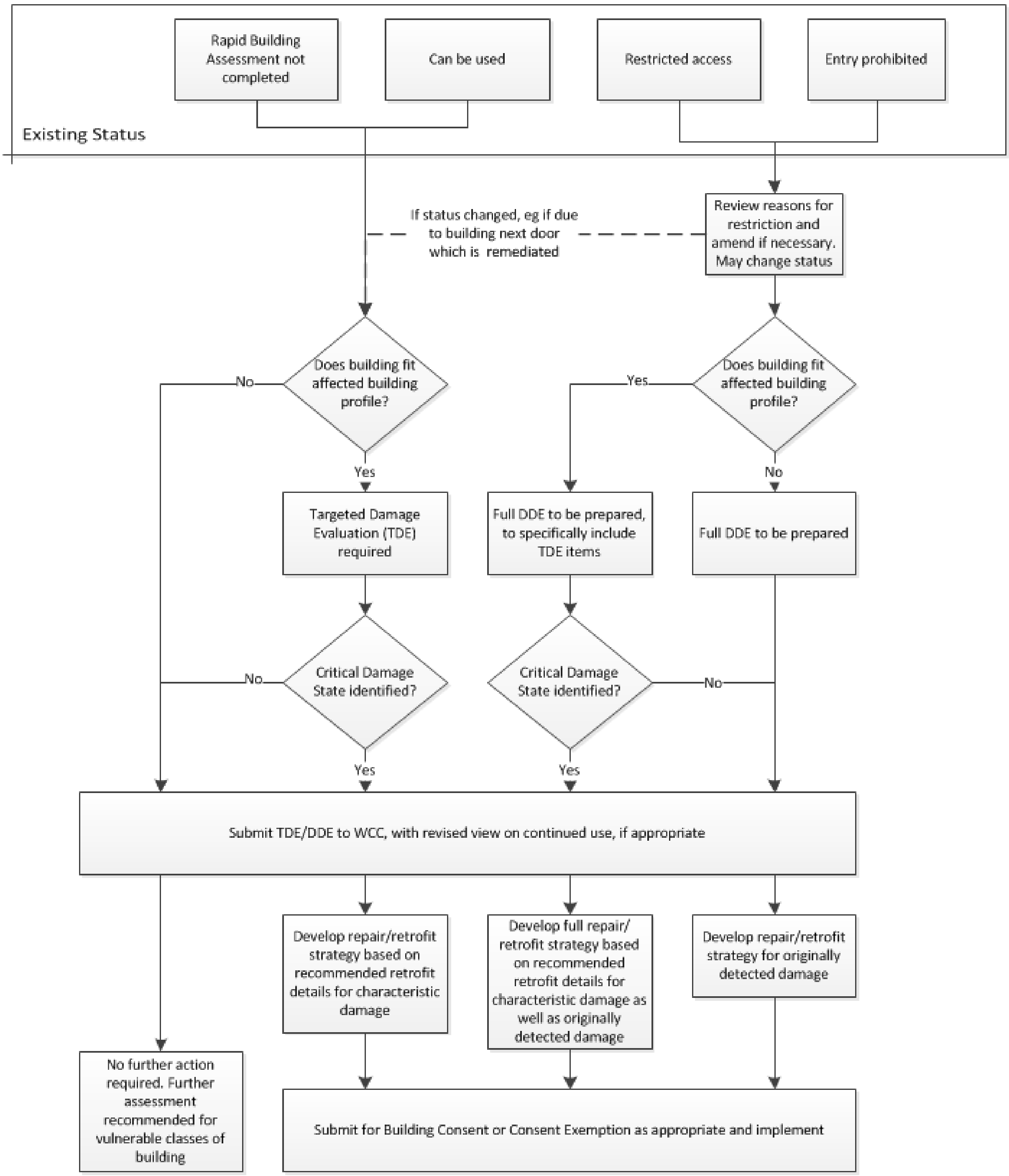


Figure 2: Damage Evaluation Process as determined by initial damage and Rapid Building Assessment status

WCC has identified a number of buildings that potentially fit the affected building profile and has sent letters to all the owners, requesting TDE reports. Regardless of whether or not a building owner has received a letter requiring submission of a report, engineers should consider whether the characteristics and damage of a building may fit the profile and apply this guidance accordingly.

The TDE follows on from a Level 2 Rapid Building Assessment (RBA). Observations from the RBA should inform the TDE, but it should be noted that the RBA may have been completed before the critical damage states had been identified for buildings within the Affected Building Profile. Also, that not all potentially affected buildings have had an RBA.

The fundamental objective of the TDE is that it requires the identification and review of the primary vertical and lateral load paths, and assessment of the significance of damage, if any, to those systems.

For buildings that fit the Affected Building Profile, the TDE procedure should follow the steps below:

1. The inspecting engineer should firstly complete a review of the building structure; sufficient to identify both the vertical (gravity) and lateral (seismic) load resisting elements. This should include a desktop review making use of existing documentation where available, including any structural alterations that have taken place. The desktop review should be undertaken before visiting the building as it will inform where the critical damage is most likely to be located.
2. Once the structural load paths are identified, the engineer needs to ensure that the critical elements of each can be seen and inspected for critical damage. 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. Note that this will usually involve some form of intrusive inspection such as wall linings, carpet lifting and ceiling opening etc.
3. Once the status of any significant damage to the primary structure has been determined, the engineer may complete a review of the balance of the building for life safety hazards. Elements for consideration include:
   a) exterior toppling or falling hazards such as parapets or cladding panels, particularly over public spaces, access points and egress paths;
   b) neighbouring buildings, where global failure or failure of elements may result in a life safety hazard, or otherwise may threaten egress paths etc in the building;
   c) internal egress paths where critical elements such as stairs may fail, trapping people in the building; and
   d) particularly heavy suspended ceilings or other elements that may fall causing life safety hazard.
4. Where there is impaired capacity or life safety hazard from secondary elements such as those noted in 3 above, the engineer should recommend that the building is not used until works are carried out to make it safe. If the hazard is limited to an area that may be effectively isolated, limited use may be recommended if:
   a) the areas to be occupied are protected from risk of collapse from other areas of the building, and
   b) fire egress is not compromised by loss of the inaccessible area, and

c) the safe use of the building is not otherwise compromised by the collapse of the affected area.

5. "Make safe works" may be completed to remove or mitigate the hazards in the short term. It is important to note that all building work needs to comply with the Building Code and will generally require a building consent, or will need to have a Certificate of Acceptance once the work is completed. The consenting requirements for make safe works should be checked with Wellington City Council.

6. The engineer must complete a report for the client and Wellington City Council (refer Section 6).

Critical Damage States refer to component damage. Some component damage may compromise local capacity only (e.g. damage to precast floor units or panels). In such cases, local propping and/ or isolation may be sufficient to temporarily address the situation and enable continued occupancy. Once repairs are made to the affected areas, the building may be restored to full use on the same basis as before the earthquake.

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 as a whole not be occupied. Where subsequent failure (with or without an aftershock) could precipitate a wider building collapse, more comprehensive assessment and repair 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 – Appendix B):

- 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 and neighbouring building owners should also be notified if there may be a potential impact on their building's occupancy.

5. Targeted Inspections

The required inspections for Targeted Damage Evaluations are outlined in the following subsections by affected building type. Note that this representation is not exhaustive, and assessing engineers should be approaching every building with fresh eyes for damage that may not yet have been detected.

Damage should be assessed against the Critical Damage States criteria, as summarised below. These are for the purposes of guiding assessments. These are not mutually exclusive and therefore buildings may exhibit any or all of the Critical Damage States. Even if a single Critical Damage State is identified, unless the building is then considered an immediate collapse hazard and should be evacuated immediately, assessing engineers should continue to consider all remaining potentially applicable categories.

For all Critical Damage States, the approach to be taken 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.

Critical Damage State A – Damage posing local collapse risk (possibly <u>without</u> aftershock)

- A1 Transverse cracking at ends of hollow core floor units or diagonal cracking at the ends of ribs within 400mm of the supporting beam, <u>plus</u> either associated vertical dislocation or diagonal crack in web (in direction of gravity shear)
- A2 Significant damage to support for flange-hung double tee floor units

Critical Damage State B – Damage posing local or global collapse risk in the case of aftershock (to include non-ductile columns)

- B1 Transverse cracking at ends of hollow core floor units or diagonal cracking at the ends of ribs within 400mm of the supporting beam *that is not classified as A1*
- B2 Reduced precast floor unit support
- B3 Loss of lateral support for columns over multiple stories
- B4 Shear damage to corner columns (due to beam elongation and shear demands)

Critical Damage State C – Damage to primary structure posing lower risk

- C1 Plastic hinge damage
- C2 Web cracking in hollow core floor units (without transverse cracking)
- C3 Longitudinal cracking of hollow core floor units
- C4 Mesh fracture in floor toppings

Critical Damage State D – Damage to secondary structural and non-structural elements that may cause increased life safety risk

D1 Stairs

D2 Heavy cladding elements effecting external spaces, especially public spaces.

D3 Heavy overhead non-structural elements

Additional detail on each of these Critical Damage States is provided in Appendix A. This information was compiled by QuakeCoRE from a range of research and practitioner input.

The further processes to be followed for identifying and classifying damage to precast concrete floor systems and cladding elements are summarised in Appendices C and D respectively. These appendices expand upon the general process framework outlined on the following pages.

5.1 Concrete Moment Resisting Frames with Precast Floors

Potential Issues

- Shear failure in ends of precast floor elements (Critical Damage State A1 when there is associated vertical dislocation; otherwise Critical Damage State B)
- Damage to support for flange-hung double tee floor units (Critical Damage State A2)
- Elongation of frames and seating damage leading to loss of support of precast flooring systems (Critical Damage State B1) and shear damage to corner columns (Critical Damage State B3)
- Disconnection of gravity load system from diaphragms, particularly in frames running parallel to floor span where there are no or only nominal ties from the columns to the diaphragm (Critical Damage State B2)
- Excessive damage to plastic hinge regions leading to significant reduction of capacity to resist future earthquakes (Critical Damage State C1)
- Identification of critical damage to stairs (Critical Damage State D1)
- Identification of critical damage to support points for heavy cladding systems (Critical Damage State D2)

Inspections required:

1. From above the floor, under floor coverings – for splitting. Note corner columns or end columns of lateral load resisting frames will generally be critical, but be aware of re-entrant corners or other locations where actions may be concentrated (refer Figure 3).
    a. Measure crack widths to estimate floor seating reduction.
    b. Verify whether floor reinforcement still intact
2. From above, adjacent to columns or supporting beams (refer Figure 3).
    a. Check for vertical offset in flooring and at ends of starter bars
3. From below, in potential plastic hinge regions (refer Figure 3).

a. Check crack widths, spacings and locations against Critical Damage States criteria
b. Look for spalling of floor supports or ends of precast flooring
c. Check residual seating, if possible
d. Look for transverse cracking of flooring systems up to twice the depth of the floor system out from the support

4. Exterior frame columns, particularly in frames running parallel to floor span (refer Figure 3).
   a. Check for horizontal offset
   b. Check residual connection of column to diaphragm
   c. If disconnected, verify over how many floors.
5. Exterior frame columns, particularly corner columns (refer Figure 4).
   a. At ground floor, check for flexural and shear cracking, in addition to checking the drawings for transverse reinforcement details and spacing
   b. Check verticality of column – indicators of residual lean and possible frame elongation
   c. Measure residual gap/compression of surrounding soil/pavement
6. Stairs - where high displacements are estimated to have occurred
   a. At flight to landing junctions of integral precast units – check splitting of the stair
   b. At supports – check loss of seating
7. Heavy cladding - where high displacements are estimated to have occurred
   a. Check sample of fixing points for tolerance and potential brittle failure

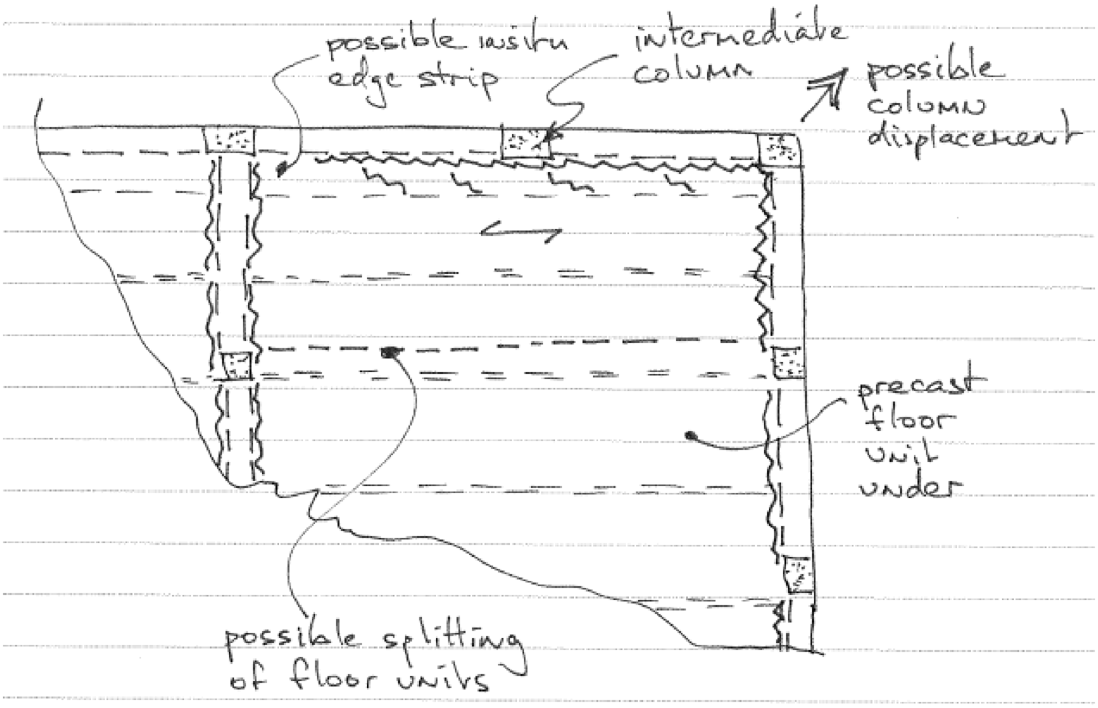


Figure 3: Ductile Concrete Moment Frame with Precast Floors

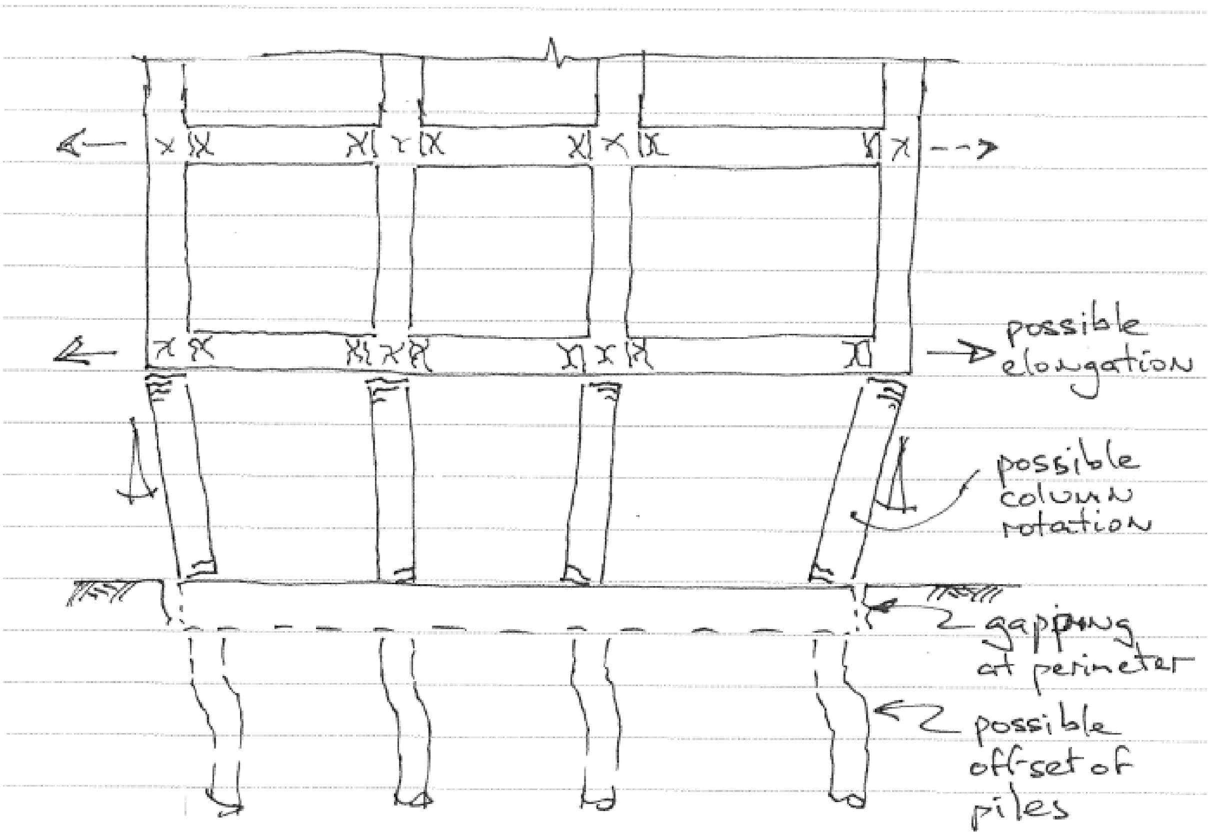


Figure 4: Ductile Concrete Moment Frame – Elongation

5.2 Concrete Shear Walls with precast floors

Potential Issues

- Shear failure in ends of precast floor elements (Critical Damage State A1 when there is associated vertical dislocation; otherwise Critical Damage State B)
- Damage to collector elements connecting diaphragms to shear walls, leading to potential separation in future earthquakes, particularly in locations of high deformation demand
- Compatibility drifts in gravity frames leading to elongation of frames with potential loss of support of precast flooring systems (Critical Damage State A2/B1)
- Excessive strain demands on reinforcement at joints or splices leading to potential failure of flexural steel
- Disconnection of gravity load system from diaphragms, particularly in frames running parallel to floor span (Critical Damage State B2)
- Identification of critical damage to stairs (Critical Damage State D1)
- Identification of critical damage to support points for heavy cladding systems (Critical Damage State D2)

Inspections required:

1. From above, under floor coverings – for floor splitting. Note corner columns or end columns of frames will generally be critical, but be aware of re-entrant corners or other locations where actions may be concentrated (refer Figure 5).
    a. Measure crack widths to estimate floor seating reduction.
    b. Verify whether floor reinforcement still intact
2. From above, adjacent to wall junctions (refer Figure 5).
    a. Check for horizontal stretch of collector and/or vertical offset
    b. Check condition of steel if accessible
3. From above, at coupling beams (if applicable) (refer Figure 5).
    a. Check for vertical offset
    b. Check for cracking and stretch of floor units adjacent
4. From below at wall junctions (refer Figure 5).
    a. Check for horizontal stretch of collector
    b. Check for support of flooring at face of wall
5. From below, at coupling beams (refer Figure 5).
    a. Check for spalling, deformation of coupling beam
    b. Measure crack widths
6. Exterior columns. (refer Figure 5).
    a. Check for horizontal offset
    b. Check residual connection of column to diaphragm
    c. If disconnected, verify over how many floors.
7. Ground floor level/base level of wall system (Figure 6).
    a. At ground floor, check for excessive inelastic demand in lightly reinforced walls
    b. Check for sliding of base of wall
    c. Measure residual gap/compression of surrounding soil/pavement (similar to Figure 4)
8. Stairs - where high displacements are estimated to have occurred
    a. At flight to landing junctions of integral precast units – check splitting of the stair
    b. At supports – check loss of seating
9. Heavy cladding - where high displacements are estimated to have occurred
    a. Check sample of fixing points for tolerance and potential brittle failure

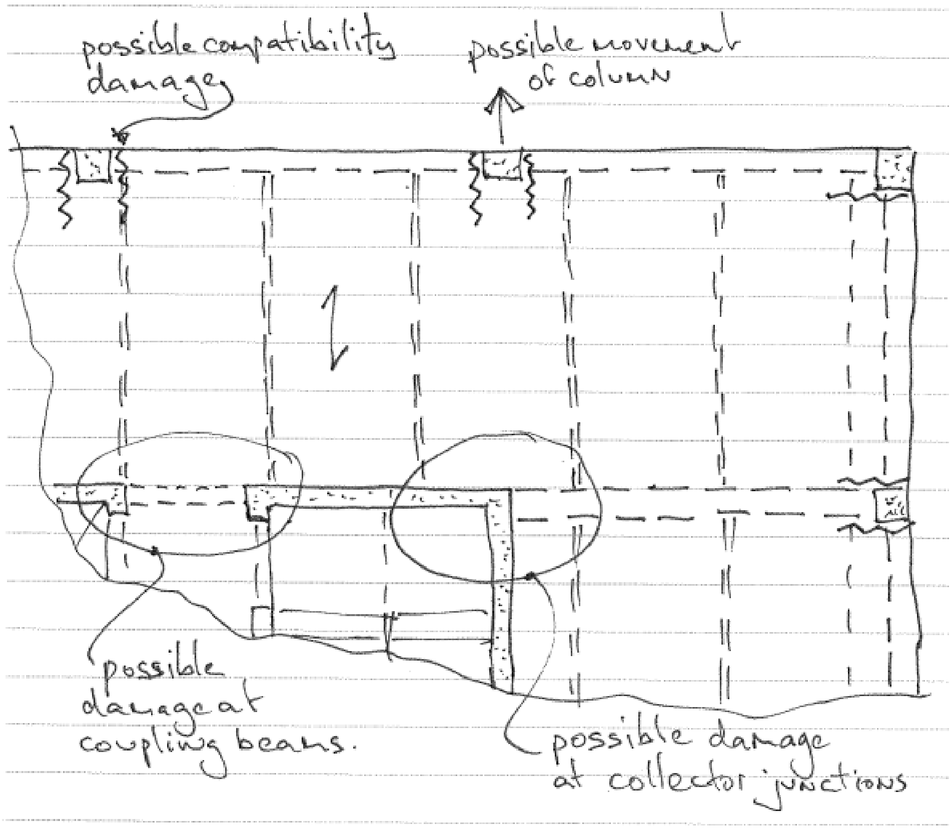


Figure 5: RC Shear Wall with Precast Floors

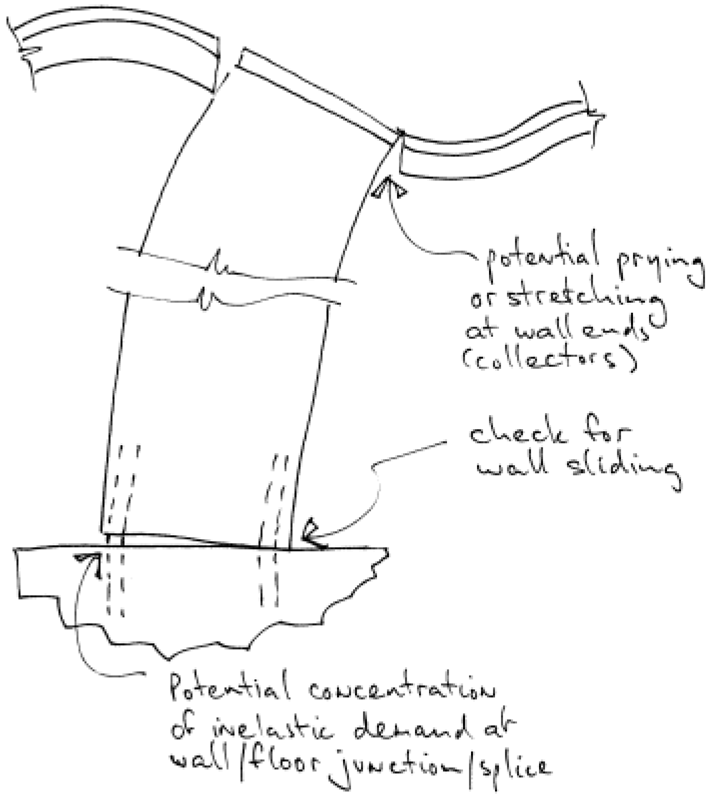


Figure 6: RC shear wall concerns

6. Reporting

The reporting of Targeted Damage Evaluations should follow the structure set out below:

1. **Description of Structure**
    - specifically the relationship with the Affected Building Profile in Section 3
2. **Inspections and Assessments Undertaken**
    - the dates and scope of inspections and assessments, including the engineers involved
    - details of any intrusive investigations undertaken (with locations annotated on floor plans, etc)
    - any additional assessments undertaken
    - results of pre-earthquake seismic assessments, where known
3. **Information Sources**
    - versions/ dates of plans accessed and reviewed (including source)
4. **Damage Observed**
    - overview of damage observed
    - the location and nature of any critical damage states observed (with locations annotated on floor plans, etc)
5. **Occupancy Recommendations**
6. **Further Actions Proposed**
    - further investigations recommended to be undertaken
    - repairs and strengthened proposed

Appendix A – Rapid Building Assessment Forms

Appendix B – Standardised Summary Table

- Refer Appendix B, noting that this is also supplied separately in electronic form (Excel spreadsheet) – available from www.sesoc.org.nz

Appendix A - Critical Damage States

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Critical Damage States

Ken Elwood
Des Bull
Rick Henry
Alistair Cattanach
Nic Brooke
Peter Smith

Critical Damage States

A. Damage posing local collapse risk (potentially without aftershock)
B. Damage posing local and global collapse risk (in case of aftershock)
C. Damage to primary structure posing lower risk
D. Damage to secondary structural and non-structural elements that may cause increased risk to life safety

Key Reference

Fenwick, Bull, Gardiner (2010)

Critical damage states – primary structure

Very critical ↑ … ↓ Less critical

A. Collapse risk (potentially without aftershock)
   1. Transverse crack at end of hollow core or ribs within 400mm of the supporting beam <u>with</u> either vertical dislocation OR diagonal crack in web.
   2. Significant damage to support for flange hung double tee
B. Collapse risk (in case of aftershock)
   1. Transverse crack at end of hollow core or ribs within 400mm of the supporting beam *that is not classified as A1.*
   2. Reduced precast unit support
   3. Loss of lateral support for columns over multiple stories (GLOBAL)
   4. Shear damage to corner columns (due to beam elongation and shear demands) (GLOBAL)
C. Damage to primary structure posing lower risk
   1. Plastic hinge damage
   2. Web cracking of hollow core – unless combined with transverse cracking.
   3. Longitudinal cracking of hollow core
   4. Mesh fracture

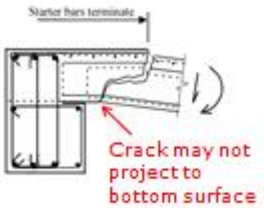
A. Damage posing <u>local</u> collapse risk (potentially without aftershock)

1. Transverse crack at end of hollow core or diagonal cracking at the ends of ribs within 400mm of the supporting beam <u>with</u> either vertical dislocation OR diagonal cracking of hollow core
   - Vertical offset cracks are highest concern – use level across crack to test for offset.
   - Crack on top <u>and</u> bottom (near support) – **very dangerous**
   - Need immediate shoring for damaged hollow core.
2. Significant damage to support for flange hung double tee
   - Do not rely on support on "pig-tail" after crushing of concrete at support of flange hung double tee.
   - If reduced seating below that required for bearing stresses (on unconfined concrete), gravity support likely compromised.

B. Damage posing collapse risk (in case of aftershock)

1. Reduced precast unit support
   - Further drift demands (with or without beam elongation) may lead to unseating.
   - see Fenwick et al 2010 report for assessment procedure.
2. Loss of lateral support for columns over multiple stories
   - Further aftershocks may lead to more eccentricity and/or axial load on column leading to buckling.
   - Assess carefully if securing is necessary if support lost over two or more stories.
3. Shear damage to corner columns (due to beam elongation and shear demands)
   - Further aftershocks may increase axial load and shear demand, leading to gravity failure.
   - Consider shoring beams if shear cracking in column is visible.

Transverse crack at end of hollow core

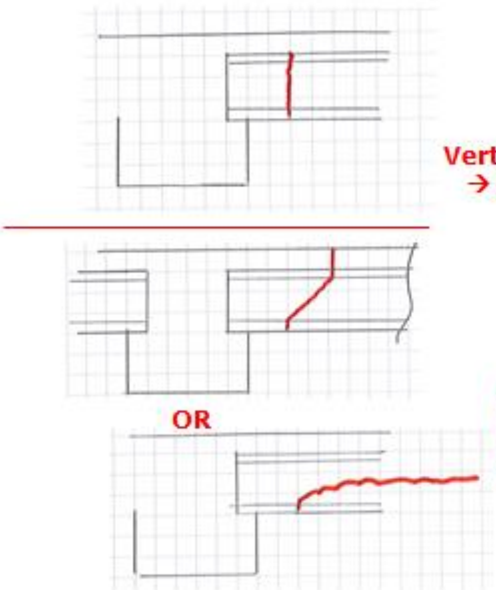


Lift the carpet at end of starter bars.
Start in the corners.
Use level to check for vertical offset.

With vertical offset OR diagonal crack in web → CDS A

Transverse crack at end of hollow core

But if



Vertical crack → CDS B

Diagonal crack (in direction of gravity shear) → CDS A

Transverse crack at end of hollow core

Example damage from the field:

→ **At least CDS B**

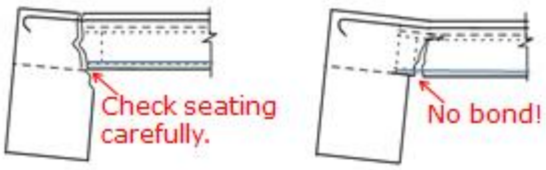
Transverse crack at end of hollow core

Example damage from the field (corner of hollow core):

→ **At least CDS B**

Need to inspect webs of hollow core for diagonal cracks.

Transverse crack at end of hollow core



(a) Loss of support with critical section at back face of precast unit

(b) Positive moment flexural failure with critical section near front face of support (see Section A4)

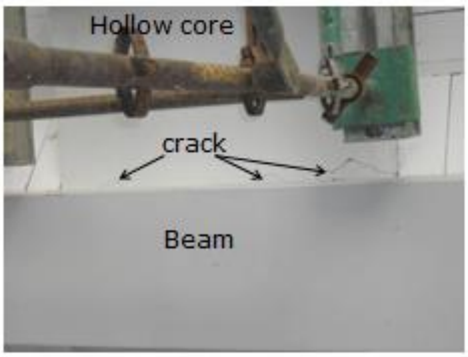
Figure A-4: Loss of support and positive moment flexural failure

With vertical offset → CDS A

Figure 5-9: Positive moment failure of hollow-core unit (Photo from reference 7)

Transverse crack at end of hollow core

Example damage from the field (Hollow Core):



Transverse crack at end of ribs

Example damage from the field (Ribs):

If vertical offset → CDS A

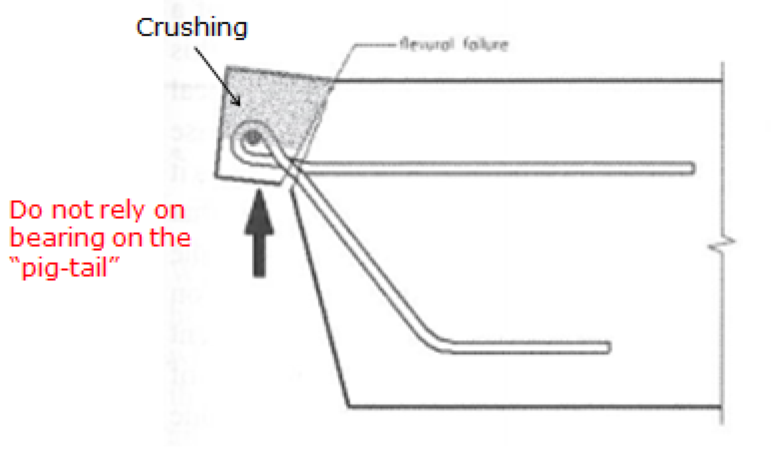
- **If crack width at level of lowest strand < 0.4 mm → not CDS B (or A)**

A2 – Significant damage to support for flange hung double tee

Example damage from the field:

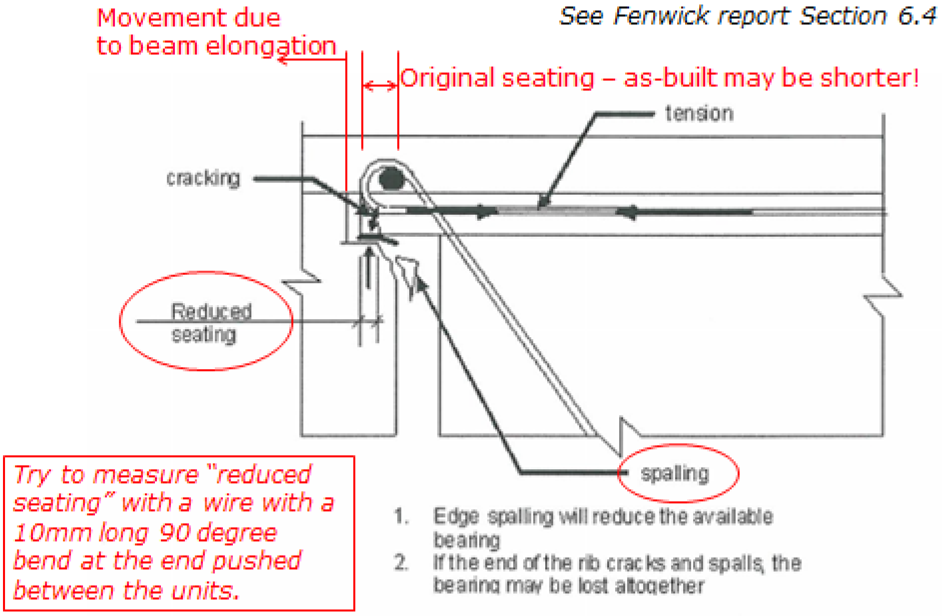
→ CDS A

A2 – Significant damage to support for flange hung double tee



B2 – Reduced precast unit support

(applies to all precast units – example of double tee shown)



B2 – Reduced precast unit support

Example damage from the field (applies to all precast units):

B2 – Reduced precast unit support

Check expected dilation according to Fenwick et al (2010):

- Beam dilation at peak drift demand =
  - Up to 3% beam depth for unrestrained hinge (corner)
  - Up to 1.5% for restrained.
- Add up the maximum dilation tributary to a floor unit.
  - 80% to each end for cases with starter bars
  - 100% to one end if no starter bars

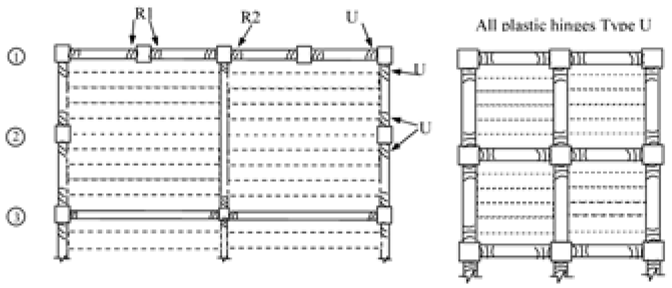
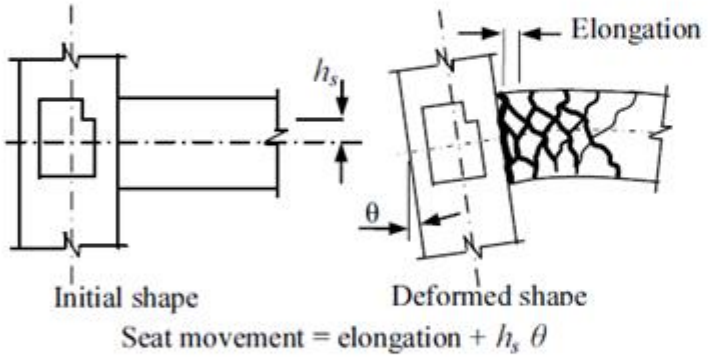


Figure 3-6: Part plan on floors showing plastic hinge elongation types, U, R1 and R2

B2 – Reduced precast unit support

- Note: seat movement due to elongation and drift!



B3 - Loss of lateral support for columns over multiple stories

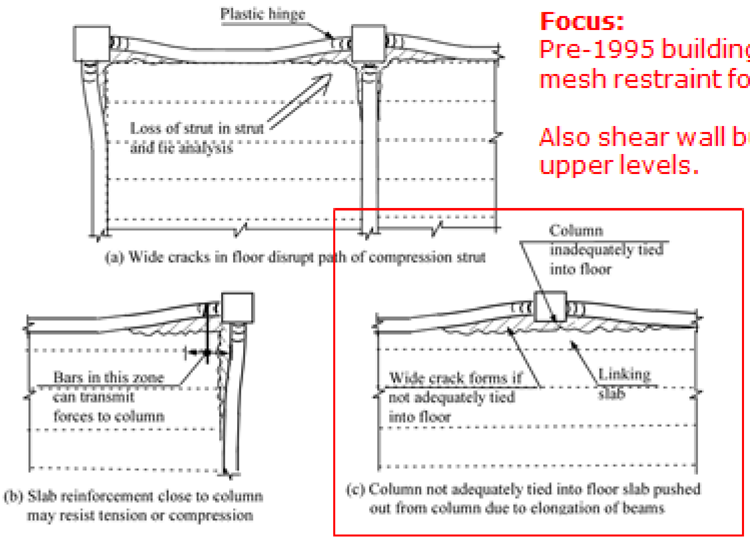
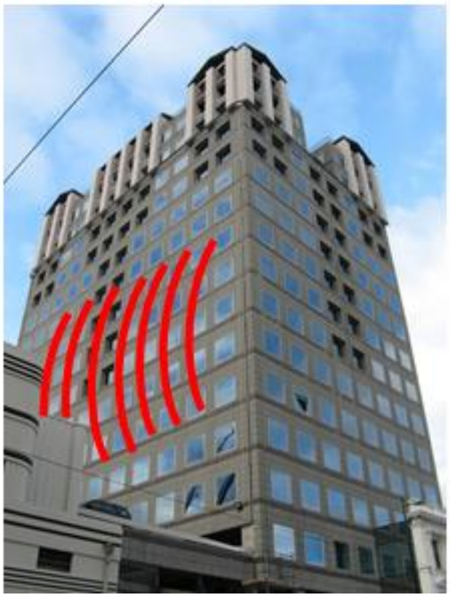


Figure 5-15: Influence of potential cracks on diaphragm action of floor

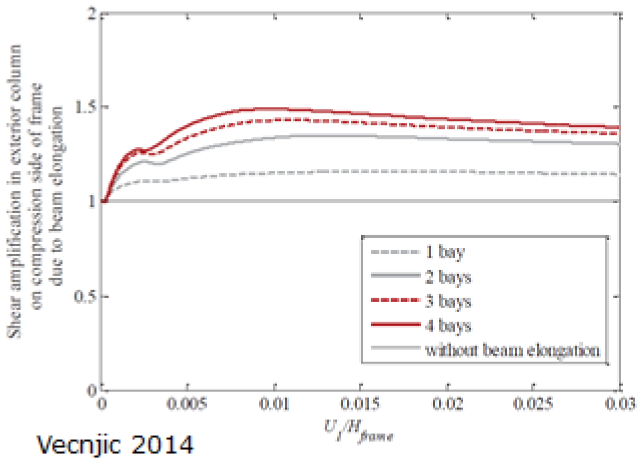
Focus:
Pre-1995 buildings with only mesh restraint for columns.

Also shear wall buildings at upper levels.

B3 - Loss of lateral support for columns over multiple stories



B4 – Shear damage to corner columns



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Focus:
Pre-2005 buildings where column shear not based on plastic hinges on both ends.

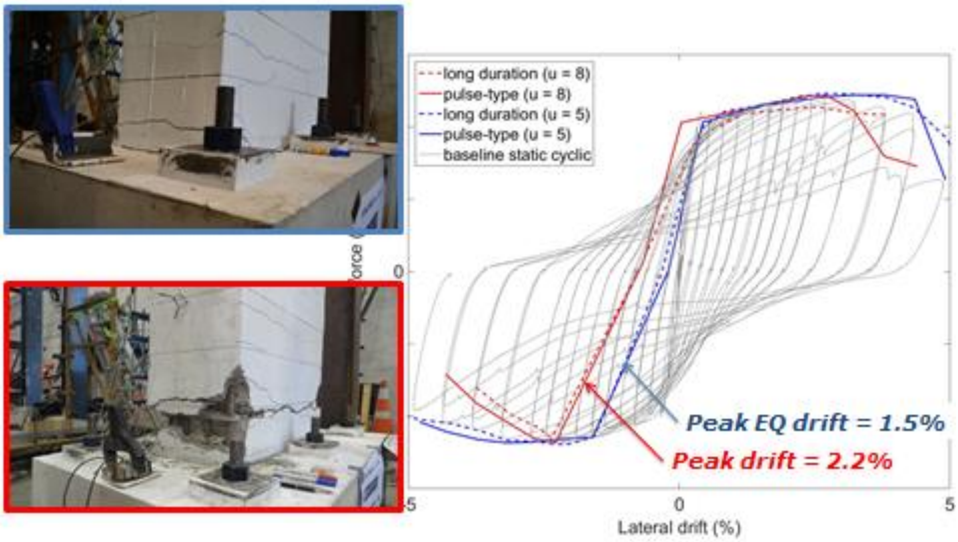
B4 – Shear damage to corner columns

Shoring for gravity load support in case of failure in aftershock:

C. Damage states posing lower risk

1. Plastic hinge damage
   - Aftershocks may lead to degradation of plastic hinge
   - Unlikely to lead to collapse on its own, but will lead to larger drift demands which could impact other drift sensitive components (eg seating of precast units).
   - Recommended limits provided, below which degradation is not a concern.
2. Web cracking of hollow core
   - 0.25% drift → splitting webs of hollow cores
   - Very hard (impossible) to identify – be cautious if floor is extra flexible
3. Longitudinal cracking of hollow core
   - Not a gravity support concern on its own.
     Not to be confused with transverse cracking of hollow core.
4. Mesh fracture
   - Failure of mesh does not mean diaphragm function is lost
   - Concern is support for columns (Damage State B3)

C1 – Plastic Hinge Damage



C1 – Plastic Hinge Damage

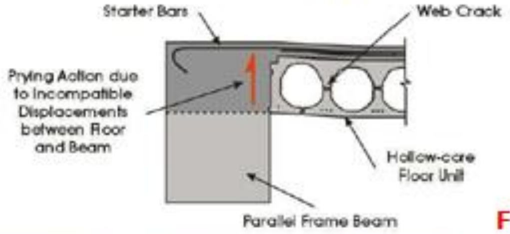
If ANY of the following apply, ***plastic hinge*** residual capacity may have been reduced by earthquake:
(all indications of large peak drift during EQ.)

1. Total crack width in plastic hinge > 0.005d
2. Sliding has occurred on a crack
3. Wide (>0.5mm) diagonal cracks
4. Concrete degradation, indicated by significant spalling (concrete cover can be removed by hand)

If none apply:
Do not expect degradation in strength, deformation capacity, or energy dissipation; but expect degradation in stiffness leading to larger displacement demands in next event.

→ caution if there are other displacement sensitive components (eg precast seating)

C2 – Horizontal web cracking in hollow core



Focus:
Many hollow core unit adjacent to beams may have horizontal web cracks. Caution if floor appears flexible.

Becomes immediate concern if accompanied by transverse crack and vertical dislocation (Damage State A1)

C3 - Longitudinal cracking of hollow core

Example damage from the field:

Not a collapse concern, but impacts diaphragm performance → CDS C

C4 – Mesh fracture

- 1-2mm cracks
  → 665 mesh fracture
- Mesh fracture on its own is not a immediate concern.
  - Reduces inertial loads from diaphragm into frame.
  - Can still develop compression strut.

Concern:
- loss of support for columns (Damage State B3)
- Reduced seating for precast units (Damage State B2)

D. Damage States to non-structural and secondary structural elements that may cause increased life safety risk

1. Stairs
   - Damage to supports leading to potential loss of support
   - Damage to the stair itself leading to splitting/compression failure at top landing
2. Heavy cladding elements
   - Inadequate movement allowance for connections with no redundancy
   - Brittle failure of connections eg. weld failures
3. Heavy overhead non-structural elements

Some History…

Retrofit: Tie back columns

Retrofit: Support for hollow core or ribs

- 1980s
  - Poor quality hollow core
- Pre-1995
  - Only mesh holding back columns
- 1995
  - Highlight to tie in columns – typically diagonal
- 2004
  - Amendment to stop use of nonductile mesh
- 2006
  - Straight bar tie back

Appendix B - Standardised Summary Table
(refer separate Excel file)

Appendix C - Precast Concrete Floor Systems

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 not 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 are 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.

Appendix D - Precast Concrete Cladding Panels

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.