Critical Damage States

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Critical Damage States

Damage posing:

1. Collapse risk without aftershock
   - Local and global collapse
2. Collapse risk in case of aftershock
   - Local and global collapse
3. Damage posing lower risk

Key Reference

Fenwick, Bull, Gardiner (2010)

Critical damage states

Very critical

Less critical

A. Collapse risk **without** aftershock
   1. Transverse crack at end of hollow core or ribs (both negative and positive bending)
   2. Damage to support for flange hung double tee
   3. Reduced precast unit support

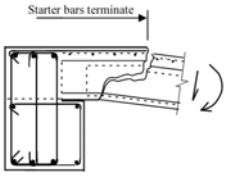
B. Collapse risk in case of aftershock
   1. Reduced precast unit support
   2. Loss of lateral support for columns over multiple stories (GLOBAL)
   3. Shear damage to corner columns (due to beam elongation and shear demands) (GLOBAL)

C. Damage states 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. Collapse risk **without** aftershock

1. Transverse crack at end of hollow core or ribs (both negative and positive bending)
   - Any signs of cracking should be considered to have compromised gravity load path.
   - Vertical offset cracks are highest concern – use level across crack to test for offset.
   - Crack on top and bottom (near support) – **very dangerous**
   - Need immediate shoring for damaged hollow core.
2. 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.
3. Reduced precast unit support
   - If reduced seating below that required for bearing stresses (on unconfined concrete), gravity support likely compromised.

A1 - Transverse crack at end of hollow core or ribs (negative bending)



(a) Negative moment flexural failure

Lift the carpet 1 m out
Starts in the corner.
Use level to check for vertical offset.

Crack at top and bottom
– likely temporarily wedged in place

A1 - Transverse crack at end of hollow core or ribs (negative bending)

Example damage from the field:

A1 - Transverse crack at end of hollow core or ribs (positive bending)

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

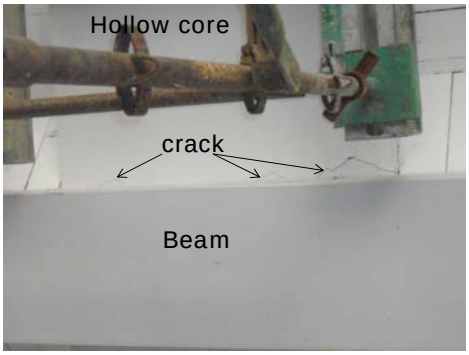
(b) Positive moment flexural failure with critical section near front face of support (see Section A4)

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

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

A1 - Transverse crack at end of hollow core or ribs (positive bending)

Example damage from the field (Hollow Core):

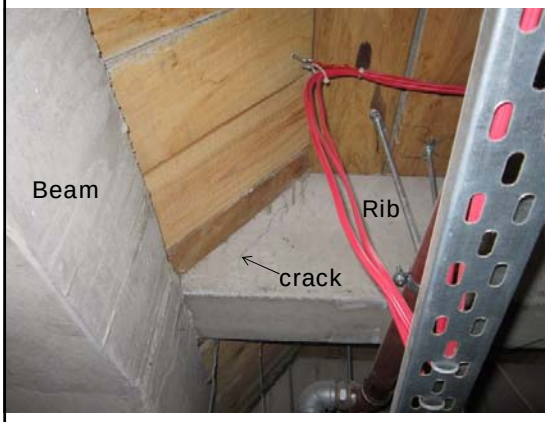


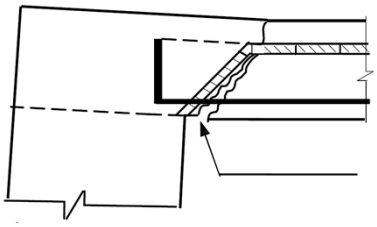
A1 - Transverse crack at end of hollow core or ribs (positive bending)

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

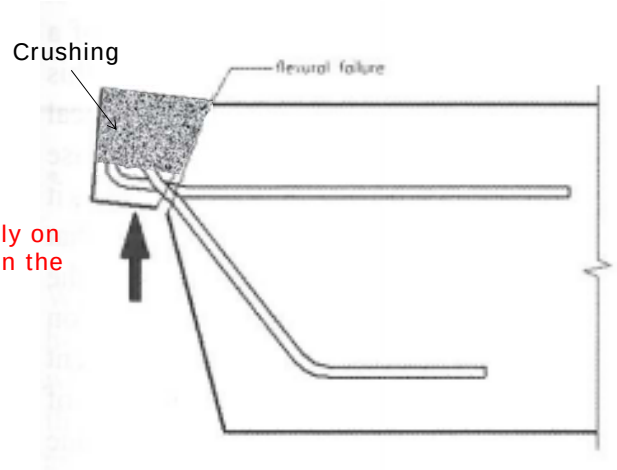
A1 - Transverse crack at end of hollow core or ribs (positive bending)

Example damage from the field (Ribs):





A2 – Damage to support for flange hung double tee



Do not rely on bearing on the "pig-tail"

A2 – Damage to support for flange hung double tee

Example damage from the field:

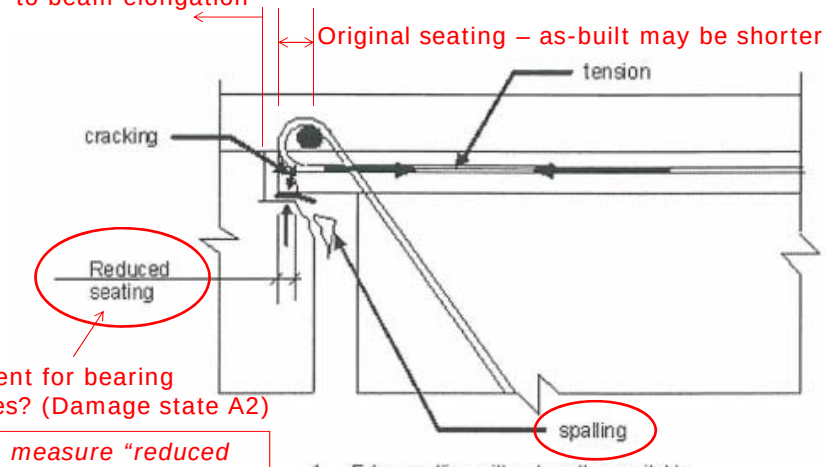
B. Collapse risk in case of aftershock

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.

A2/B1 – Reduced precast unit support

Movement due to beam elongation

See Fenwick report Section 6.4



Sufficient for bearing stresses? (Damage state A2)

Try to measure "reduced seating" with a wire with a 10mm long 90 degree bend at the end pushed between the units.

1. Edge spalling will reduce the available bearing
2. If the end of the rib cracks and spalls, the bearing may be lost altogether

A2/B1 – Reduced precast unit support

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

B1 – 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

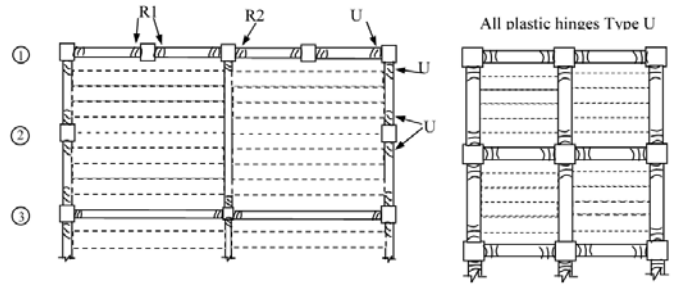
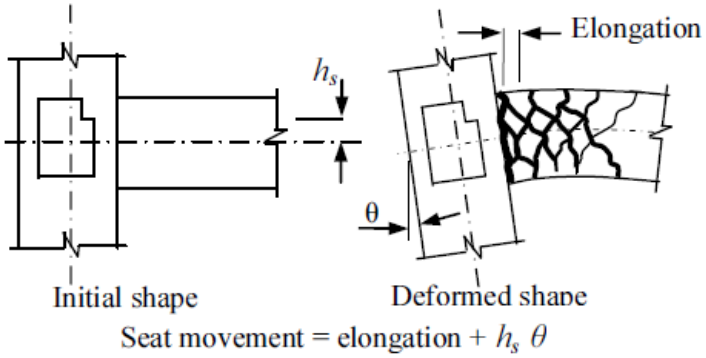


Figure 3-6: Part plan on floors showing plastic hinge elongation types, U, R1 and R2

B1 – Reduced precast unit support

- Note: seat movement due to elongation and drift!



Seat movement = elongation + $h_s\ \theta$

B2 - Loss of lateral support for columns over multiple stories

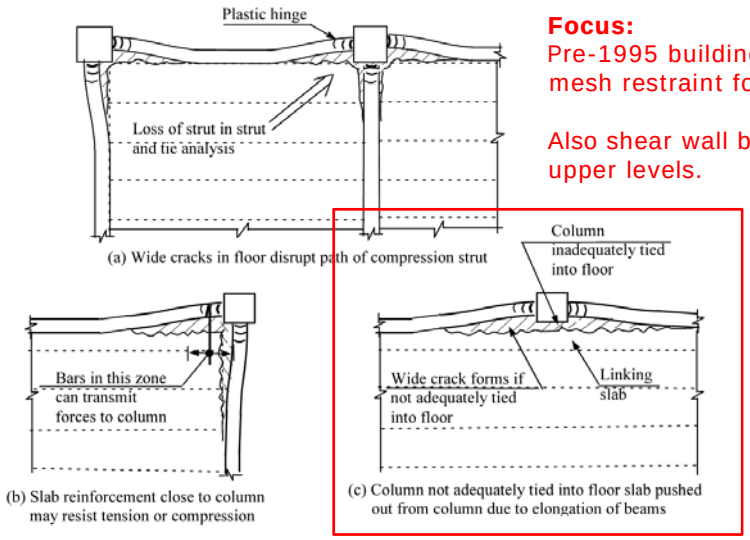
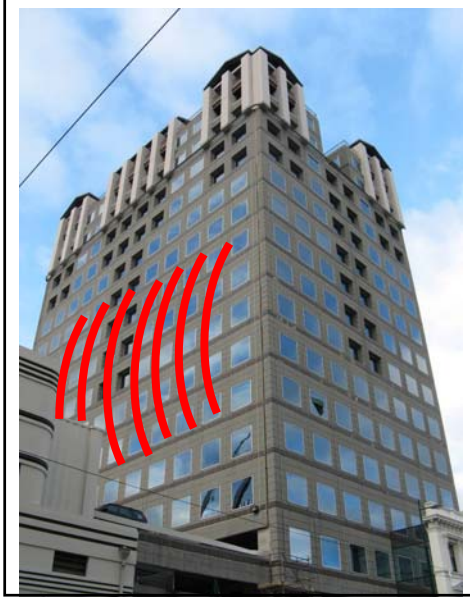


Figure 5-15: Influence of potential cracks on diaphragm action of floor

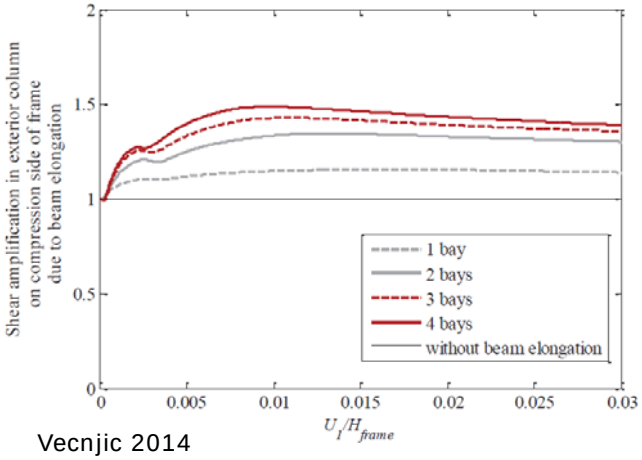
Focus:
Pre-1995 buildings with only mesh restraint for columns.

Also shear wall buildings at upper levels.

B2 - Loss of lateral support for columns over multiple stories



B3 – Shear damage to corner columns



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

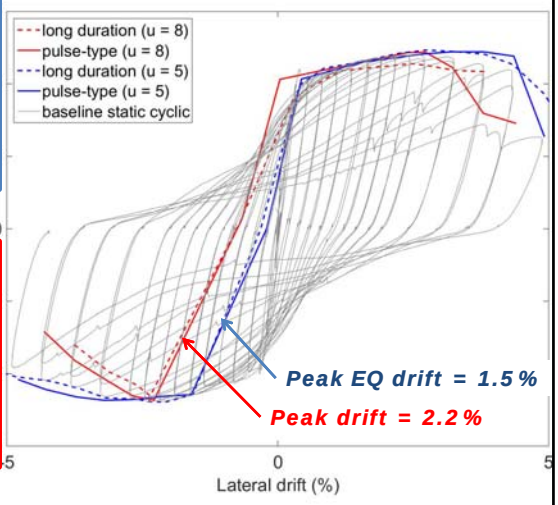
B3 – Shear damage to corner columns

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 B2)

C1 – Plastic Hinge Damage



C1 – Plastic Hinge Damage

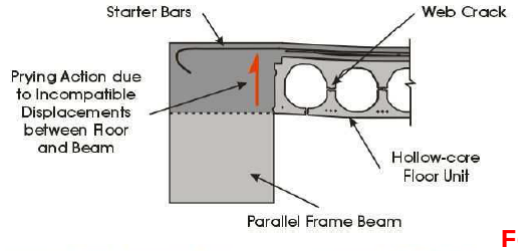
If ANY of the following apply, ***plastic hinge*** residual capacity may have been reduced by earthquake:
(all indications of large peak drift during EQ.)

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 – Web cracking in hollow core



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

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

C3 - Longitudinal cracking of hollow core

Example damage from the field:

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 B2)
- Reduced seating for precast units (Damage State B1)

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