




Results summary

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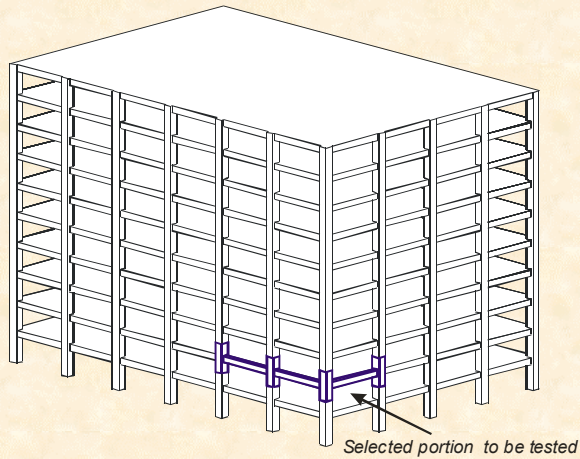
Mr. Des Bull and Prof. John Mander

Supervisors



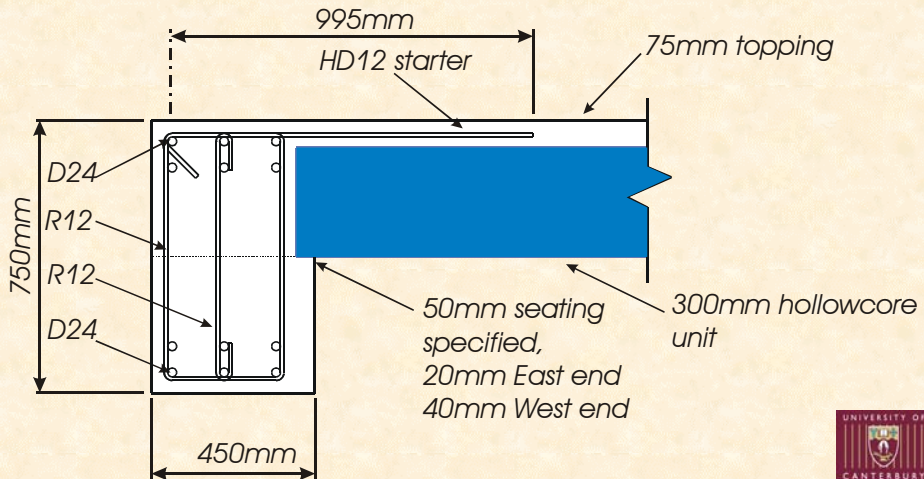
Origin of Test Specimen

Typical 2nd or 3rd storey of a 8-10 storey precast concrete building



Hollowcore Unit Support Detail

Typical construction of the last 10-15 years



A hooked starter bar is lapped with the topping mesh (665)
The hollowcore unit is seated on a dry pack joint

IN-PLANE LOADING

West
End



East
End

The loading is applied in a direction parallel to the hollowcore floor units

The scissor load frames (i.e. Rams A & B plus D & E) apply a shear force to the top and bottom of the columns

The arrow frame ensures that the columns remain parallel at all times

+/-0.25% drift loading cycle



- **First cracks appear in the beams**
- **Crack forms in the bottom of 1st h/c unit**



First crack appear in the beam plastic hinge zone
Hollowcore crack propagates from the corner of the columns where the unit had been cut to fit against the column and perimeter beam

+/-0.5% drift loading cycle ($\mu=1$)



- **Continuity crack forms at end of h/c units**
- **West beam h/c unit starts to crack affecting its seating**



The continuity crack is the crack that opens directly above the edge of the hollowcore unit as the beam rotates relative to the floor
Prying action starts to crack the end of the 1st hollowcore unit on the west beam. (see slide 21 for detail showing prying action)

+/-0.5% drift loading cycle ($\mu=1$)



- **Cracks form on the floor around the central column**
- **Torsion crack form in edge beams**

Shear lag cracks start to appear around the central column

Torsion cracks appear in the edge beams as the starter bars lapped into the floor provide restraint. This only occurs when the starters are in tension (I.e. when a negative moment is applied)



+/-1.0% drift loading cycle ($\mu=2$)

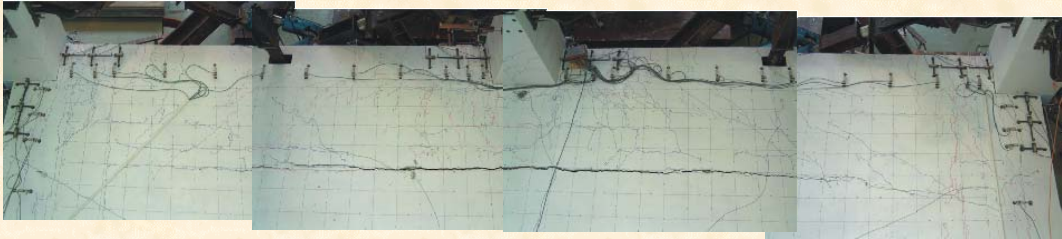
- **Crack along entire length of 1st h/c units soffit**
- **Shear lag cracks appear on topping and on the bottom of 1st h/c unit**
- **Delamination starts to occur**
- **Longitudinal crack in topping starts to propagate**
- **H/C unit starts to be pulled off its support**



First stages of delamination has occurred around the corner columns
A longitudinal crack between the 1st and 2nd hollowcore unit starts to propagate along the length of the specimen

1.9% drift ($\mu=3$)

- Longitudinal “unzipping” of the diaphragm over $\frac{1}{2}$ specimen length
- Majority of mesh fractures



The hairline crack between the 1st and 2nd hollowcore unit has now opened into a 10-20mm wide crack. In doing so all the mesh that passes across that crack has fractured. The diaphragm inertia forces will no longer be able to be transferred over this crack

Note: This occurred at a displacement ductility of 3

If the crack occurred over several floors this could lead to the buckling of a exterior column.

2.5%>-2.0% drift loading cycle ($\mu=4$)

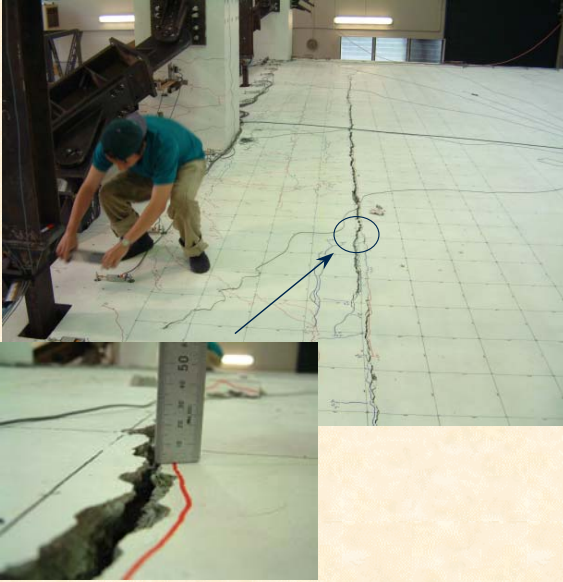


- **Relatively large zones of topping delamination around corner nodes**
- **Entire edge of h/c units damaged**
- **1st h/c unit drops by 5mm**



Delamination propagates along the beams. This is caused by the yielded starter bars popping the topping when the load reverses. The entire seat on both beams is now damaged. Three forms of damage have been noted: H/C units have been pulled off their support (was only observed in a couple of locations); the beam cover concrete has spalled; or the edge of the h/c unit has been broken off (a majority of the seat damage occurred by this mode).

2.5% > -2.0% drift loading cycle ($\mu=4$)



- **20mm offset of central column in orthogonal direction to loading**
- **15-20mm crack in floor, 10mm vertical offset**



At the completion of this cycle the central column had displaced laterally 20mm in the direction orthogonal to the direction of loading.

In-plane conclusion

- **Some h/c units have dropped by 10-12mm**
- **1st h/c unit extensively damaged, web split for first 2-3m**



Major web splitting has occurred in the 1st h/c unit at the west end. This splitting propagates for approximately 2-3m into the floor. All the h/c units have started to drop since their seat has been damaged. The damage is due to the displacement demand imposed on the system.

OUT-OF-PLANE LOADING



Load frames have been changed to load the specimen in a direction orthogonal to the h/c units

Loading cycles up to 2.5% drift

- **Positive direction of loading, crack in soffit of 1st h/c unit opens**
- **Negative direction, 1st h/c unit is lifted. H/C units connection to edge beam is damaged**



During the loading cycles the 1st h/c unit is rotated, up and down, as there is not enough restraint from the floor due to the fracturing of the topping mesh. This causes the unit to start to degrade. The expected performance was for the beam to rotate relative to the floor causing a continuity crack to form between the beam and the floor, the same as was observed during the in-plane loading. This did not occur

2.0% > -2.5% drift loading cycle ($\mu=4$)



- **More mesh fractures during negative cycles**
- **@2.0% parts of h/c unit fell out**



1st h/c unit has degraded more. The first part of the h/c unit drops out. The longitudinal unzipping on the floor has now propagated to the ends of the specimen. This has caused the remainder of the topping mesh to fracture. This crack propagation has led to the damage of the concrete cover on the east beam

Hollowcore damage (internal)



Left: The h/c unit is starting to drop away from the dam since its seating has been lost

Right: Large cracks in the h/c's web and soffit. The web crack width is approx 25mm.

Northridge 1994



When the floor drops the image will look similar to this. Zones of web splitting. Note: the ends of some of the h/c units are still attached to the beam even though the unit has dropped.

University of Canterbury 2002



Observed behaviour of the 1st h/c unit. The entire bottom half of the first unit dropped once the west end let go. This occurred at a interstorey drift of 2.5%

University of Canterbury 2002



The floor was load tested at 2.5% drift. The load applied to the floor represented a 1.0kPa live load and 0.75kPa superimposed dead load. The three units dropped out in one piece leaving the starter bars and its surrounding topping concrete attached.

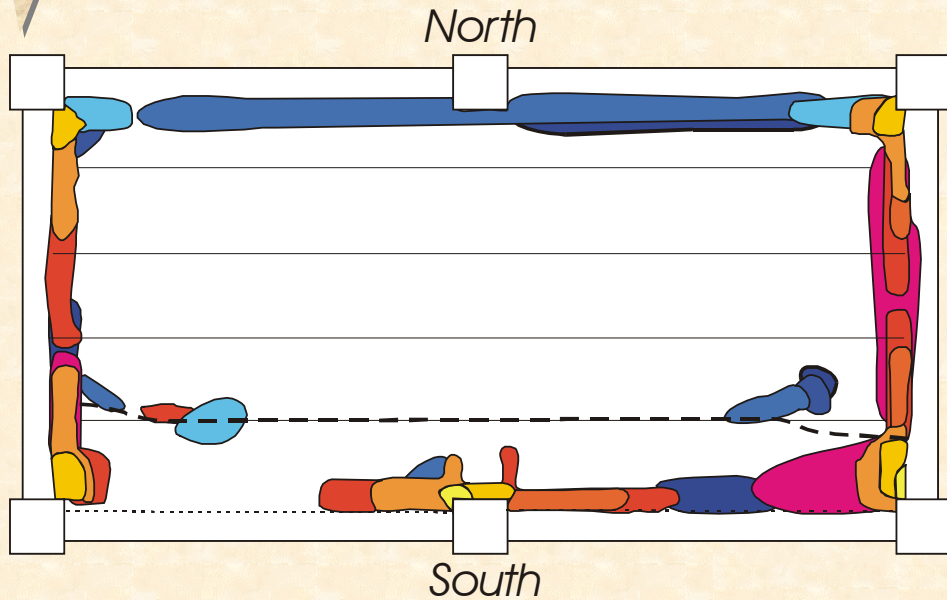
University of Canterbury 2002



Close ups showing the remaining starter bars attached to the beam and the area where the topping has delaminated from the hollowcore units.

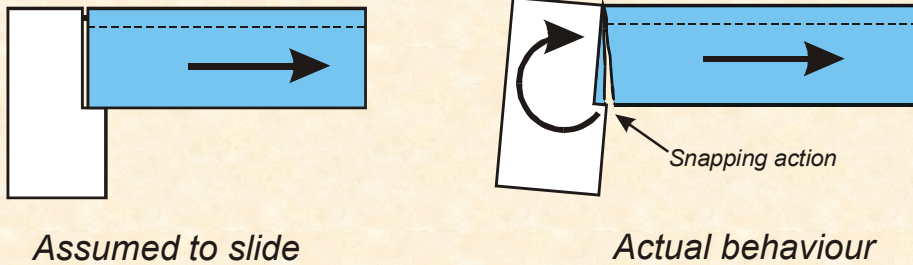
Note: In the left hand image a portion of the h/c unit is still attached to the beam (as was seen in the Northridge photos).

Delamination map



Yellow-Red scale is used for in-plane loading [East-West loading]
Blue scale has been used for the out of plane loading [North-South loading]

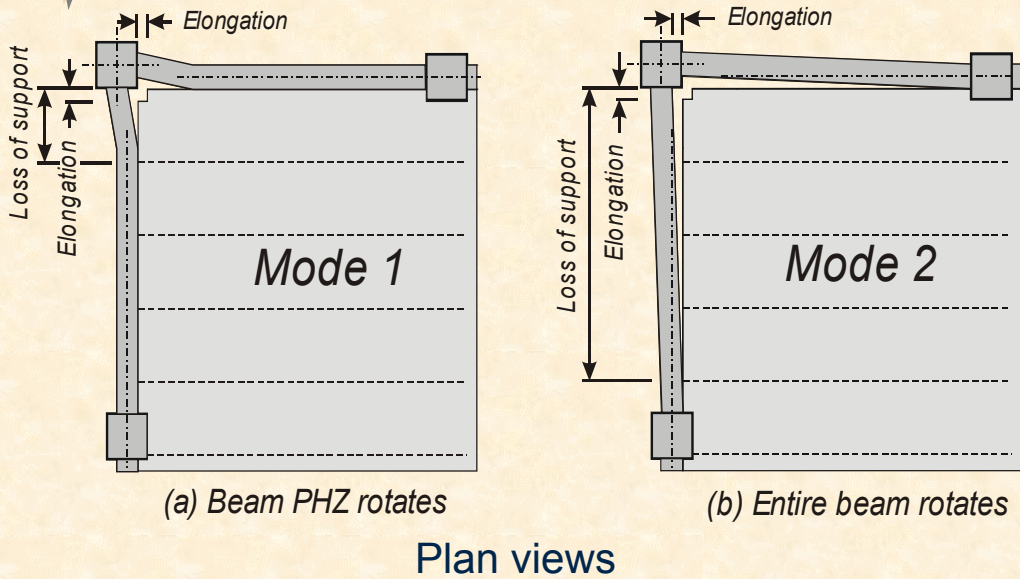
Hollowcore edge support



Left: Assumed performance. This only occurred in some localised regions along the beam. If this did happen then the beam cover spalled.

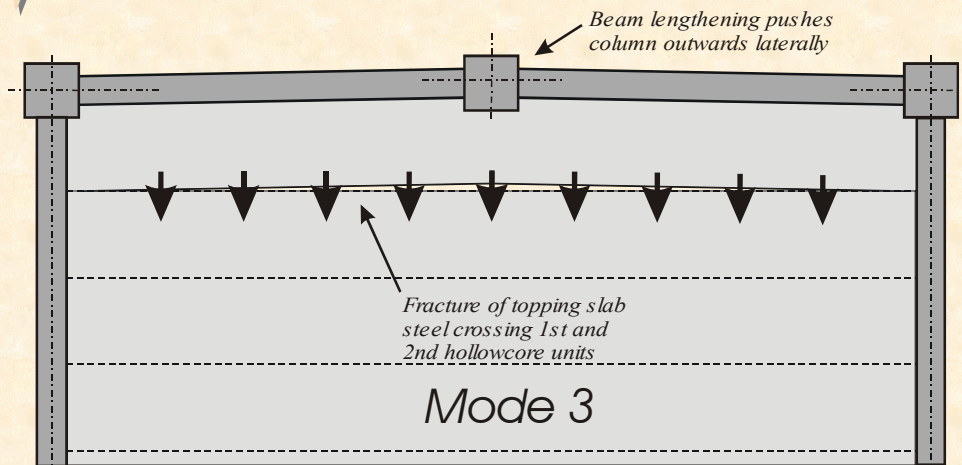
Right: Actual behaviour. The rotation of the beam caused the edge of the h/c unit to be broken off. The damage is due to the rotation imposed on the h/c unit rather than whether the structure is performing elastically or not.

Previous Speculated Deformation modes



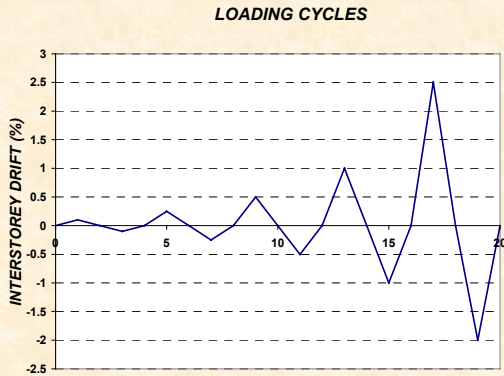
Expected specimen performance

Observed Deformation and failure mode at drift=1.9% ($\mu=3$)

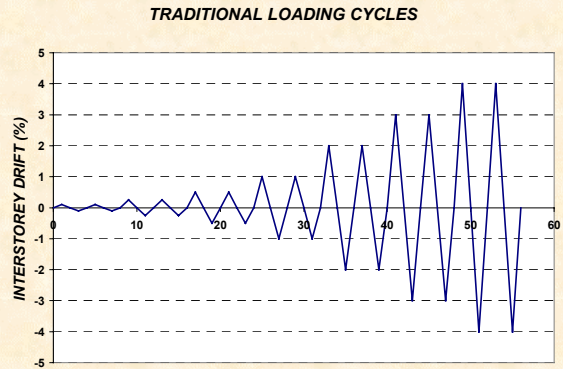


The observed performance is a combination of modes 2 and 3.

Loading Summary



Loading history imposed



Traditional Loading history



The loading history used is not as demanding as the traditional loading history used at the University of Canterbury. The history used is summarised below:

In-plane

+/-0.5%, +/-1.0%, +2.5% & -2.0%

Out-of-plane

+/-0.5%, +/-1.0%, +2.5%, -2.0% & +/-3.5%

Fatigue theory

- **Cycle counting analysis using fatigue theory**

Number of equivalent cycles at design ductility of $\mu=4$

=0.9 cycles for longitudinal direction

=4.0 in transverse direction



The main point from this shows that the frame has not been over worked and still has plenty of capacity. Could the same be said about the floor?

Fatigue theory continued

- **Available fatigue life at max expected amplitude for 2500 yr EQ (drift =3.5%, $\mu=6$)**

=3.9 cycles [+100%, -50%] (=dependable limit of 2 cycles)

- **Fatigue life consumed at 3.5% drift**

Longitudinal = 0.3 cycles

Transverse = 1.3 cycles

- **Loading Plan:**

Transverse – no more loading

Longitudinal - +2.5%, -2.0% & +/-3.5%

