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Proof of Concept Tests for Hollowcore Floor Unit Connections

By

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This report has been prepared for Precast NZ Inc.

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EXECUTIVE SUMMARY

The following report was commissioned by Precast NZ. Four sub-assembly tests were conducted at the Department of Civil Engineering, University of Canterbury.

The tests consisted of single hollowcore units topped with cast in-place 30 MPa concrete (three units of 300 series and one of 200 Series, with varying details of connections between the hollowcore unit, topping and support beam). The units were supported on reinforced concrete beams at one end and held by hydraulic actuators at the other. The ends of the units were raised and lowered by the actuators to provide a relative rotation between the units and beams, which were clamped to a strong floor. This rotation mimics the rotation that develops due to inter-storey drift arising from the lateral forces of an earthquake.

The aims of the test programme were:

- To investigate whether or not sub-assembly tests, such as these, produce similar characteristics of damage as the full size Matthews test at the University of Canterbury.
 - HC1 - 300 series hollowcore unit, topped with 30 MPa concrete, reinforced with HRC mesh, seated on a mortar bed, connected to the beam by HD 12 starters at 300 mm centres, plastic dams in each cell to prevent the concrete of the beam pour entering the cells. This was a “control” specimen.
- To test the concepts of two possible details for supporting the topped hollowcore units in buildings subjected to seismic attack
 - HC2 - 300 series hollowcore unit, topped with 30 MPa concrete, reinforced with plain bars (HD 10 @ 300mm centres e.w.), seated on a low friction bearing strip, connected to the beam by HD 12 starters at 300 mm centres, compressible backing board is placed between the unit and the beam.

- HC3 - 300 series hollowcore unit, topped with 30 MPa concrete, reinforced with ductile mesh, seated on a low friction bearing strip, connected to the beam by HD 12 starters at 300 mm centres, and two, two leg HR12 “paperclips”, one in each of two cells. The remaining two cells have plastic dams.
- To determine if 200 series hollowcore had similar performance characteristics to the 300 series hollowcore units, when built with the conventional detail of mortar pad seating and plastic dams in all cells of the units
 - HC4 - 200 series hollowcore unit, topped with 30 MPa concrete, reinforced with HRC mesh, seated on a mortar pad, connected to the beam by HD 12 starters at 300 mm centres, plastic dams in each cell to prevent the concrete of the beam pour entering the cells.

FINDINGS

For the test specimens, in terms the relative rotation between the floor and supporting beams at which flexure-shear cracks formed, running up through the webs, initiating in front of the supporting beam, these rotations are summarised below:

- HC1 0.35%
- HC2 did not occur
- HC3 did not occur
- HC4 0.5%

The use of interstorey drifts as an indication of relative rotation between floor and beam is conservative. Flexibility of the structural elements results in the actual rotation of the floor beam connection being less than that arrived at by simply applying interstorey drift figures.

Full delamination of the topping which incorporates the HD12 starter bars and fracturing of the HRC mesh at the ends of the starter bars occurred in specimens:

- HC1 3.5 - 4%
- HC4 1.6%

Significant vertical displacement (greater than 1 mm) occurred in the specimens:

- HC1 1.9%
- HC2 did not occur
- HC3 did not occur
- HC4 1.8%

For the backing board and low friction bearing strip specimen (HC2) it is apparent the reduction of end fixity means that assessment of the vibration characteristics of this configuration may need to be undertaken.

A number of boundary conditions and strain states are not modelled in this 2-D sub-assembly (discussed in Section 7) as compared to the full 3-D Matthews test. This feature limits the extent of what can be concluded from the results. Even so, the comparable damage in the “control” with that of the Matthews test, does indicate that the sub-assembly approach is good enough to point to potentially successful solutions, permitting focused full 3-D tests in the Matthews rig.

RECOMMENDATIONS

The testing has investigated the performance of the floor connections subjected to high levels of drift. Not all building designs require high levels of drift and details which did not perform well in these tests may still have application where high drifts are not expected.

The backing board and low friction bearing strip (HC2) performed to some extent better than the “paperclips” and low friction bearing strip (HC3). However, both have the potential to be viable solutions for construction of new floors. The authors believe that both configurations should be evaluated in the full 3-D test rig which will account for the second order effects and local deformation features that can not be otherwise modelled in the 2-D sub-assembly tests.

USE OF THE REPORT

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Context of the Report

The research presented in this report was conducted at the Department of Civil Engineering at the University of Canterbury.

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Stresscrete

Pacific Steel

1 Introduction

This report will give the background behind the experimental programme, testing and results from the recently completed testing programme undertaken for Precast NZ Inc. at the Department of Civil Engineering, University of Canterbury.

2 Experimental Background

The Matthews test undertaken at the University of Canterbury [M1, M2] raised issues over the performance of the hollowcore units to frame connection. It was decided that a Technical Advisory Group (TAG) should be formed to discuss the implications these results had on both the design and construction industry in New Zealand. The membership of TAG incorporated the major Structural Engineering companies, Universities and Learned Engineering Societies within the New Zealand design and construction industry.

After discussing the Matthews test results at the first TAG meeting (April 12, 2002), it was decided that other connection details that are used to connect the hollowcore unit to the supporting beam should be tested to determine their likely performance during a significant earthquake. PrecastNZ requested that four connections should be tested.

The four connection details to be tested were as follows:

HC1—Control-300 series hollowcore unit with a hooked starter bar (the same as tested by Matthews et al [M1, M2])

HC2—Compressible backing board solution (Developed by TAG)

HC3—Paperclip detail hybrid, incorporating a low friction bearing strip

HC4—200 series hollowcore unit with the control connection detail (similar problems with this connection detail were expected)

3 Experimental set up

The experimental set up used to test the connection details needed to satisfy several criteria so the applied loading matched the in-situ performance as close as possible. The most important criterion was to simulate the rotation between the hollowcore unit and the supporting beam. This important aspect was evident in the Matthews test but had been overlooked by various other researchers in the past (Mejia-McMaster and Park [M3], Herlihy et al [H1] and Oliver [O1]).

The shear force patterns experienced during the Matthews set up (12m span) are shown in Figure 3-1. Ideally the optimum way to test the various connection details would be to rebuild the Matthews specimen and test them in that manner. It was decided to undertake 2-D testing of most likely solutions to concerns raised by the Matthews et al [M1]. These could be carried out relatively quickly to ensure future full scale testing would be in the most promising direction thereby enabling acceptable and verified answers to be obtained with the least possible delay. This 2-D set up was based on the expected deformations and shear forces found from the Matthews testing programme. Clamping the supporting beam to the strong floor and articulating the hollowcore relative to the beam achieved this. The background to the development of this set up is also shown in Figure 3-1. Once the background to the loading was established it was possible to design the load frame. The completed loading set up is shown Figure 3-2.

3.1 Test dimensions

In order to get a direct comparison between these test results and the Matthews test it was decided that all the dimensions should be based on the Matthews test.

The supporting beam was 750mm deep and nominally 450mm wide. This width did vary slightly depending the seat length used. The beam consisted of six D24 grade 300 longitudinal bars top and bottom. The transverse reinforcement was R12 stirrups at 100mm centres. A basic cross section is shown in Figure 3-3.

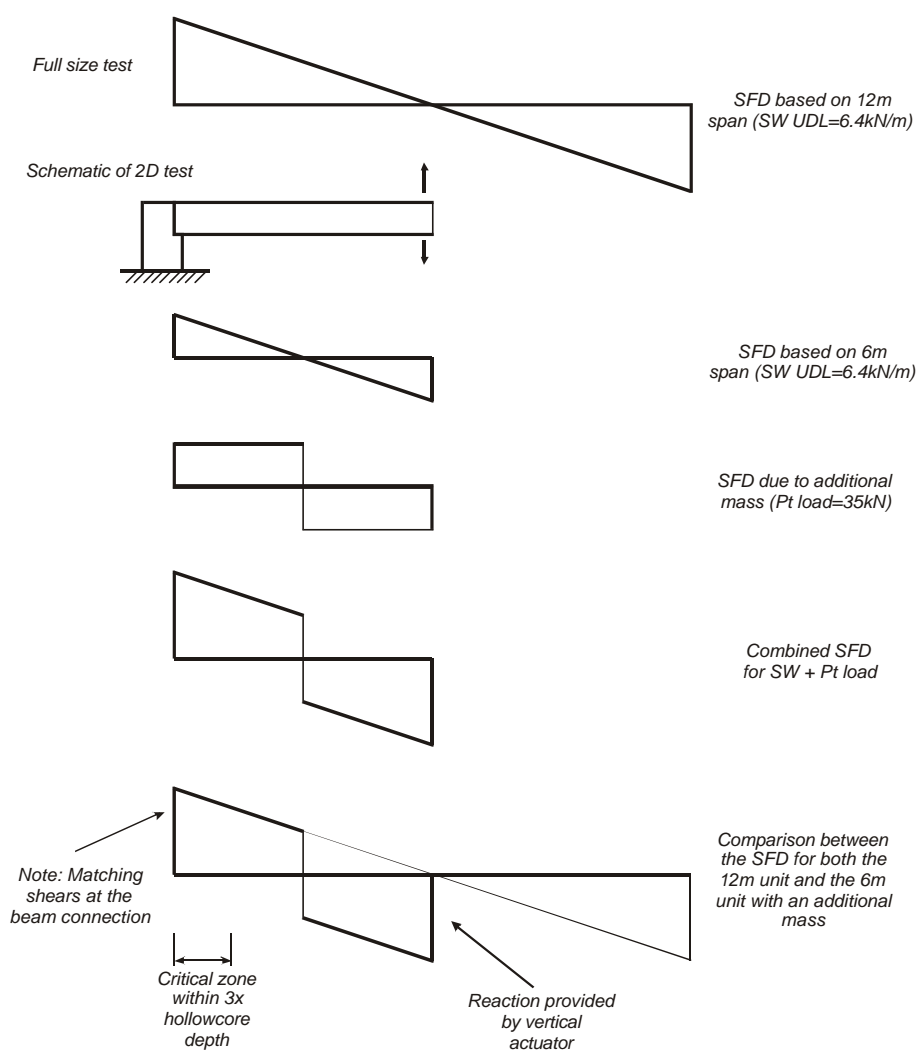


Figure 3-1. Schematic showing the determination of experimental set up.

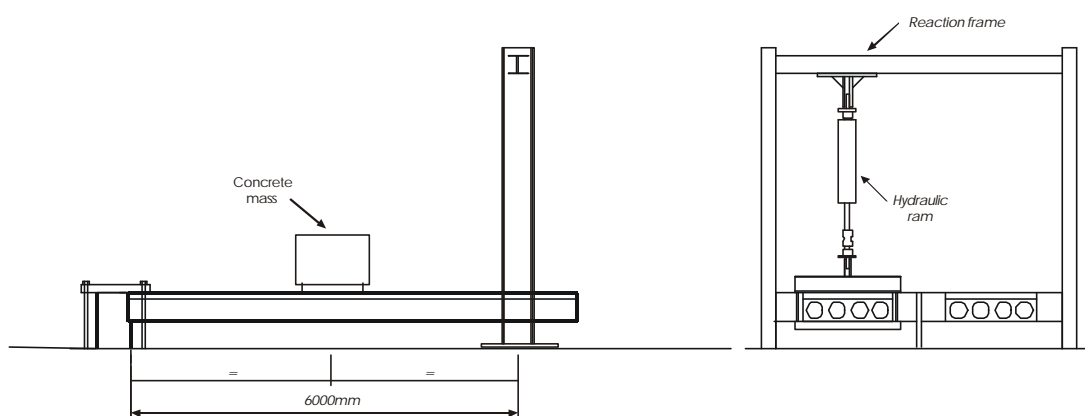


Figure 3-2. The experimental set up.

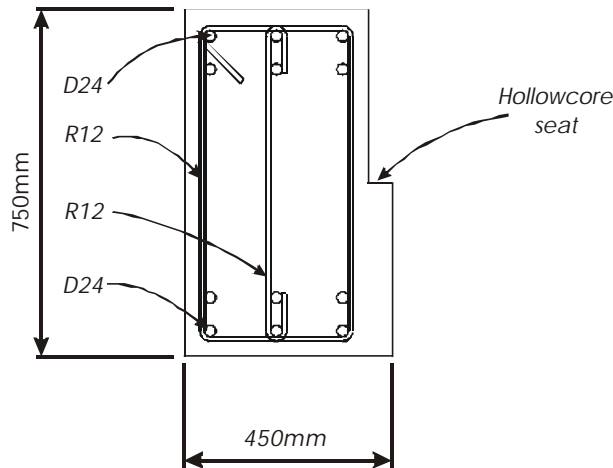


Figure 3-3. Beam dimensions and reinforcement layout.

The dimensions for the length of hollowcore unit to be tested were based on the typical length that the units usually span. For the 300 series this length was 12m while the 200 series design length was approximately 9m.

As stated above, the actual length of unit tested was half the design length, this corresponds to a test length of 5.8m and 4.8m respectively.

3.2 Connection details to be tested

3.2.1 Test HC1

This hollowcore connection detail was the same as used in the Matthews test. This test was considered to be the control. Its main purpose was to check that the experimental set up and loading regime created the same failure mechanism as seen in the Matthews test. Figure 3-4 shows the dimensions of set up.

This set up had the following key points:

- 50mm seat length
- HRC mesh reinforcing within the topping concrete
- HD12 starter bars at 300mm crs
- The hollowcore unit was placed on a mortar bed

- Plastic dams placed in the ends of all cores

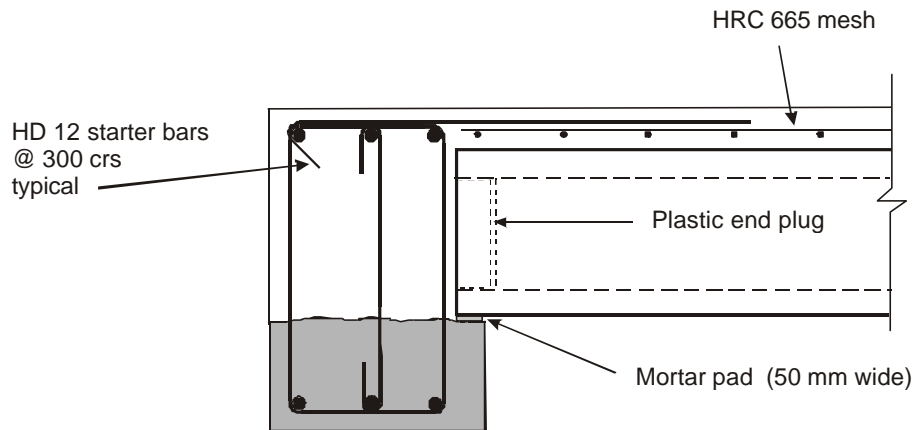


Figure 3-4. HC1 dimensions

3.2.2 Test HC2

This connection detail was the detail recommended by TAG. The basis for the design of this detail was to try to isolate the hollowcore unit from the supporting beam so that the level of damage, caused by the rotation between the beam and the hollowcore unit, could be minimised. A diagram showing the dimensions for this set up is shown in Figure 3-5.

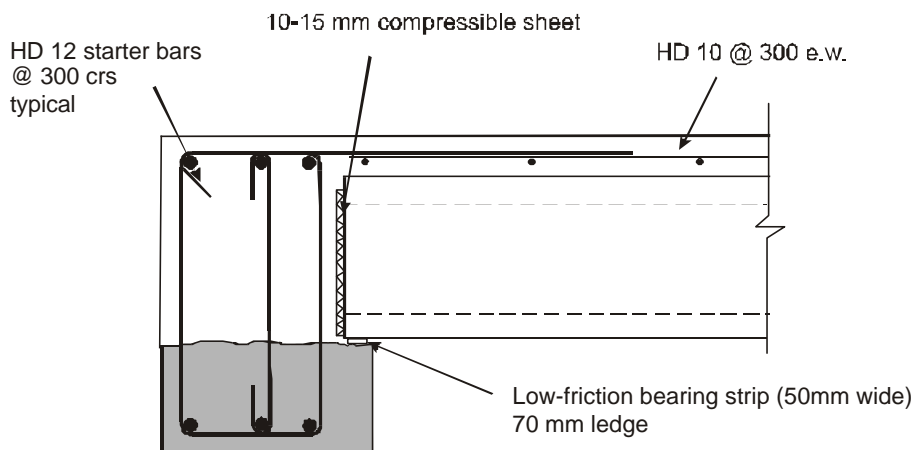


Figure 3-5. HC2 dimensions

This set up had the following key points:

- 70mm seat length (based on the Cl 4.3.6.4 NZS3101: 1995 [S1])

- HD10 (Grade 500E) reinforcing steel at 300mm crs both ways within the topping concrete
- HD12 (Grade 500E) starter bars at 300mm crs
- 14mm compressible plastic placed across the end of the hollowcore unit (Figure 3-6)
- The unit was also placed on a low friction bearing strip (McDowel bearing strip) (see Figure 3-7 for exact positioning of the bearing strip)



Figure 3-6. The compressible backing board placed on the end of the hollowcore unit.

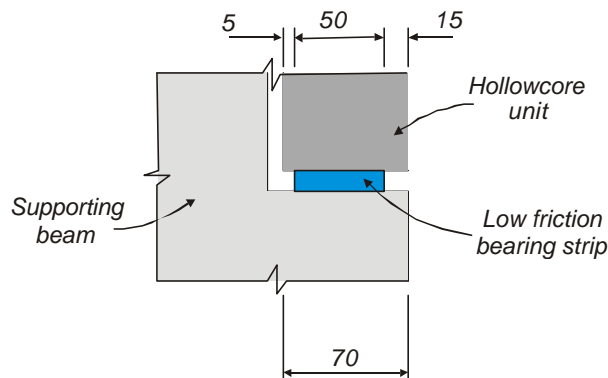


Figure 3-7. Location of the low friction bearing strip.

3.2.3 Test HC3

This connection detail provided extra tie reinforcement to support the unit if the hollowcore unit's seat was lost during an earthquake. This extra tie reinforcement consisted of a HR12 (Grade 500E) paperclips placed in the first and third core of the

hollowcore unit. A diagram showing the dimensions for this set up is shown in Figure 3-8.

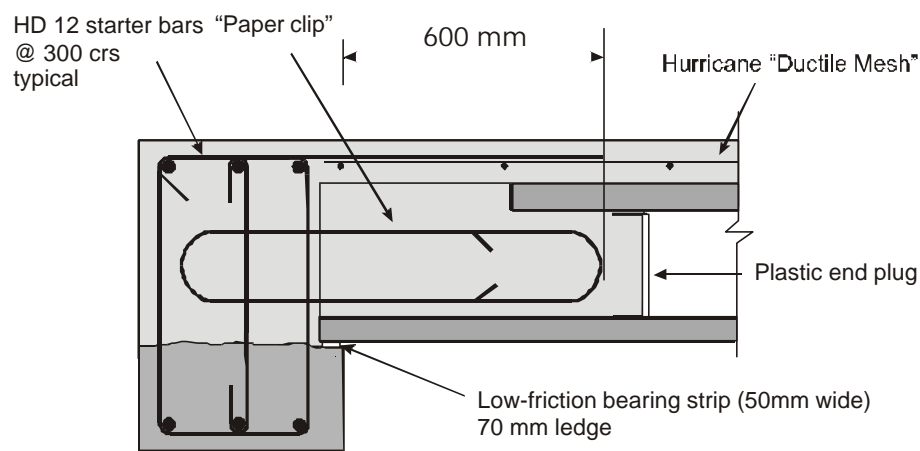


Figure 3-8. HC3 dimensions

This set up had the following key points:

- 50mm seat length
- Hurricane "Ductile Mesh" within the topping concrete
- HD12 (Grade 500E) starter bars at 300mm crs
- Plastic dams in the second and fourth cores
- HR12 (Grade 500E) paperclips placed in the first and third cores. (See Figure 3-9)
- The first and third cores filled with concrete 100mm past the end of the paperclip.
- The hollowcore unit seated on a low friction bearing strip (McDowel bearing strip) (See Figure 3-7 for the exact positioning of the bearing strip).

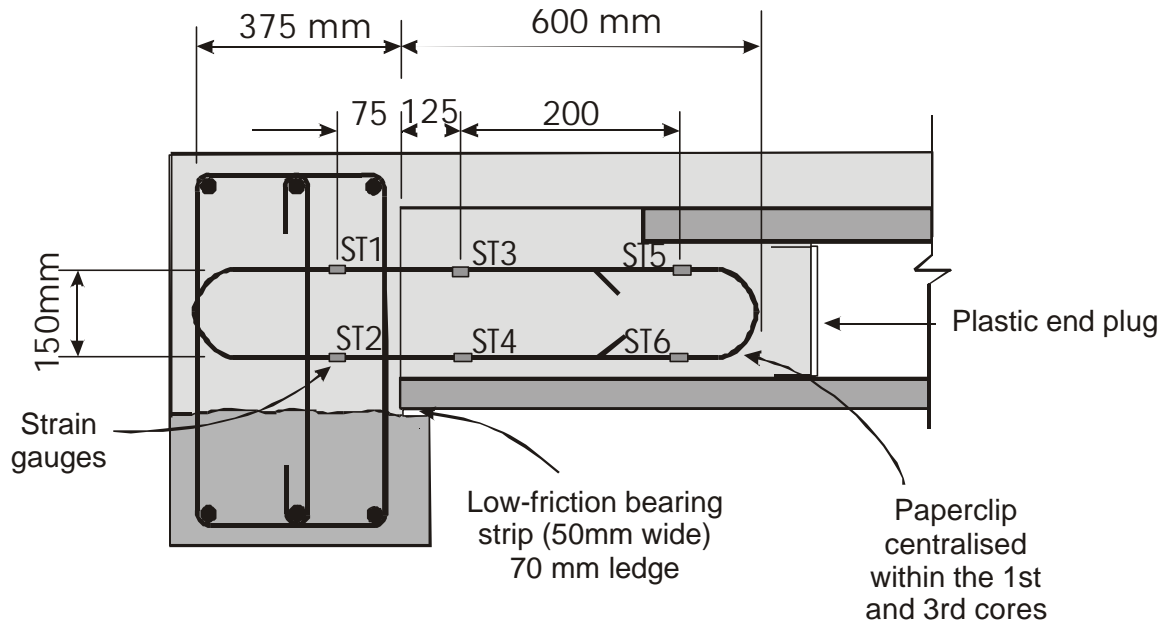


Figure 3-9. Exact positioning of the paperclip within the connection detail.

3.2.4 Test HC4

This connection detail to be tested used the same details as HC1 (control) except a 200 series hollowcore unit was used rather than a 300 series hollowcore unit. A diagram showing the dimensions for this set up is shown in Figure 3-10.

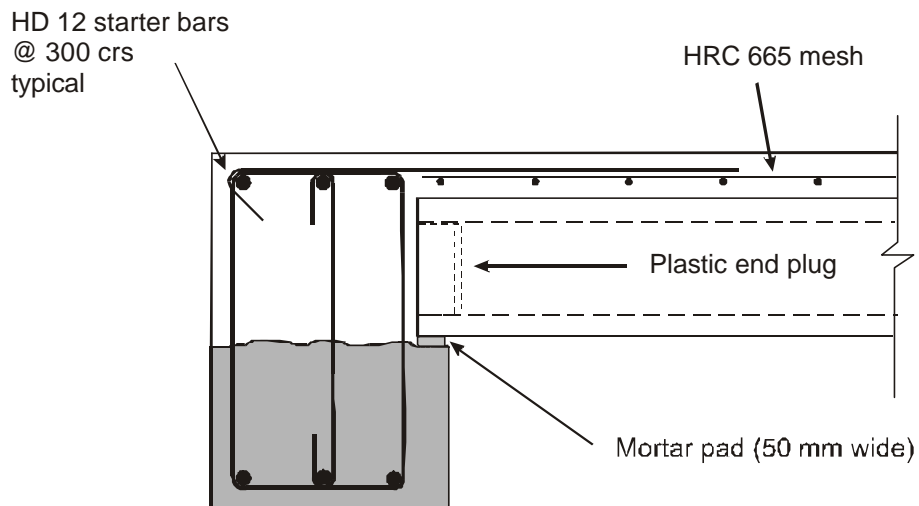


Figure 3-10. HC4 dimensions

This set up had the following key points:

- 50mm seat length
- HRC mesh reinforcing within the topping concrete
- HD12 starter bars at 300mm crs
- The hollowcore unit was placed on a mortar bed
- Plastic dams placed in the ends of all cores

4 Description of the testing programme

4.1 Displacement history

Each of the four test specimens was loaded in the same manner. The tests were displacement controlled, focusing on the relative rotation between the hollowcore unit and the supporting beam. This relative rotation is related directly to the interstorey drift anticipated for the floor under investigation. The displacement history used was based on the traditional loading history as determined by Park [P1]. The history consisted of two completely reversing loading cycles at increasing interstorey drifts. The actual history used is shown in Figure 4-1.

For the purposes of this report the relative rotations between the hollowcore unit and supporting beam are described in terms of interstorey drifts.

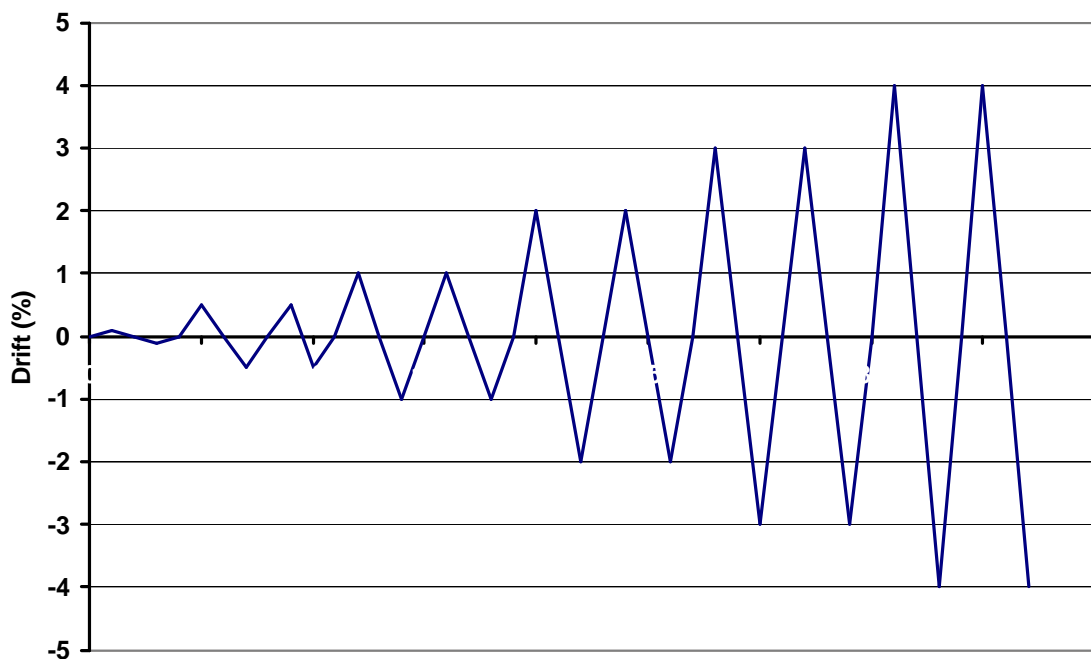


Figure 4-1. Displacement history applied to the test specimen.

A positive drift/rotation results in tension on the bottom of the hollowcore unit. A negative drift/rotation results in tension on the top of the hollowcore unit.

4.2 Instrumentation

A series of linear potentiometers were set up on the topping of the units to measure the starter bars strains and the strain transfer to the concrete topping. Further linear potentiometers were set up to measure the relative movements between the hollowcore unit and the supporting beam as well as the movement of the supporting beam relative to the ground. The location of all the linear potentiometers is shown in Figure 4-2 and 4-3.

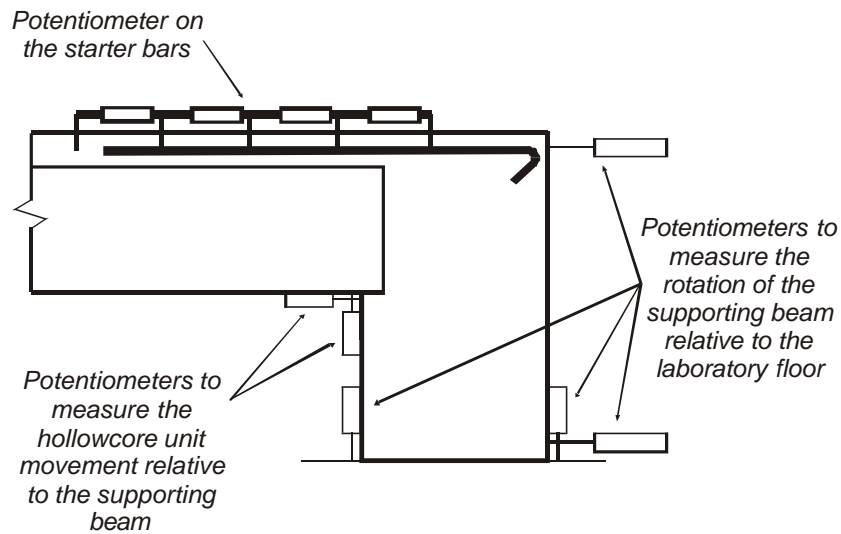


Figure 4-2. Location of all the potentiometers attached on the test specimen.

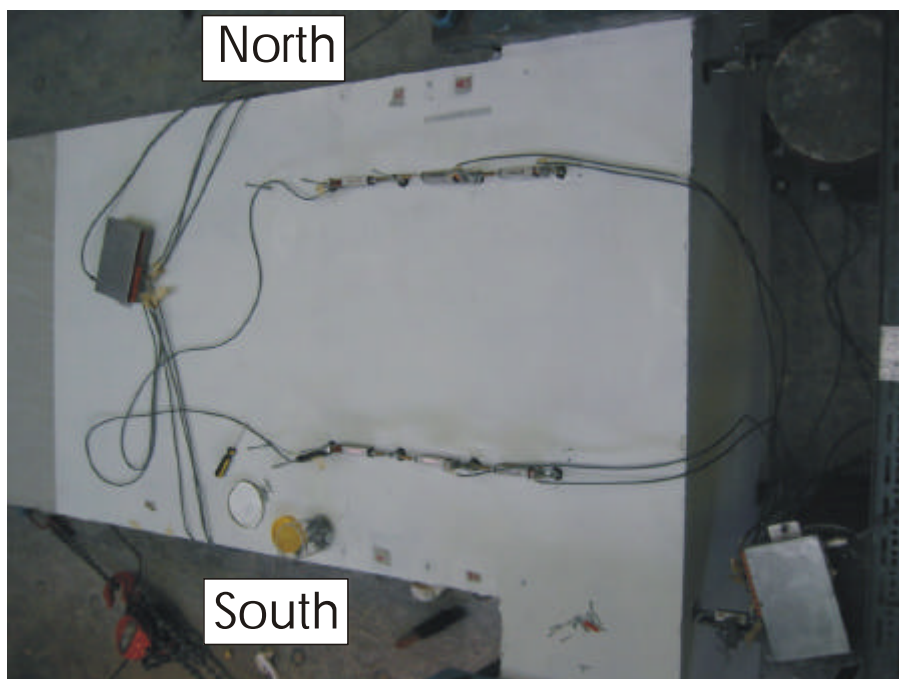


Figure 4-3 Plan view showing the location of the starter bar potentiometers

5 Experimental Observations

It should be noted that the target drifts of $\pm 0.5\%$, $\pm 1.0\%$, $\pm 2.0\%$, $\pm 3.0\%$ and $\pm 4.0\%$ were not always achieved during the testing programme. This was determined upon the completion of the data analysis. The reason why these drifts were not always achieved is due to the correction required in the interstorey drift to remove the rotation of the supporting beam.

Table 1. Target interstorey drift versus actual interstorey drift

Target Drift (%)	HC1	HC2	HC3	HC4
0.5	0.35	0.54	0.43	0.26
-0.5	-0.40	-0.42	-0.40	-0.40
0.5(2)	0.43	0.52	0.35	0.24
-0.5(2)	-0.42	-0.42	-0.41	-0.44
1.0	0.93	1.04	0.58	0.51
-1.0	-0.90	-0.90	-0.82	-0.76
1.0(2)	0.92	1.03	0.67	0.56
-1.0(2)	-0.94	-0.91	-0.82	-0.78
2.0	1.95	2.03	1.62	1.98
-2.0	-1.98	-1.84	-1.71	-1.74
2.0(2)	1.94	2.02	1.72	1.98
-2.0(2)	-1.92	-1.85	-1.70	-1.79
3.0	2.92	3.02	2.69	2.97
-3.0	-2.89	-2.75	-2.68	-2.76
3.0(2)	3.10	3.01	2.93	2.99
-3.0(2)	-2.92	-2.77	-2.46	-2.78
4.0	3.98	4.04	3.87	3.95
-4.0	-3.99	-3.65	-3.47	-3.84
4.0(2)	N/A	4.02	3.88	3.94
-4.0(2)	N/A	-3.63	-3.43	-3.94

Table note: Number in brackets denotes the second cycle for that rotation/drift.

The amount by which the supporting beam rotated varied on the fixity between the hollowcore units and the supporting beam. As a whole, the negative drift was always underestimated. Table 1 gives a summary of the target drifts versus the actual drifts for all the tests undertaken.

It should be noted that the actual values vary quite significantly in places when compared to the target drift.

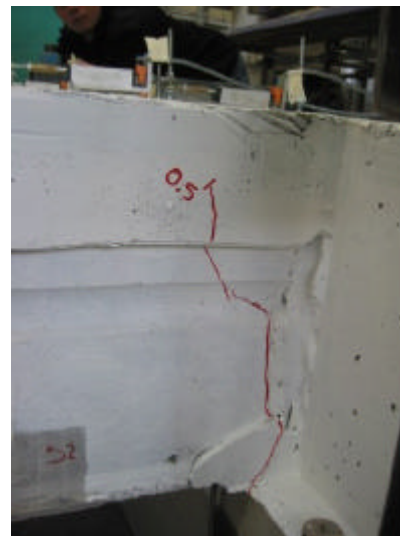
5.1 Test HC1

All the drifts mentioned within this section refer to the target drift. The numbers in brackets is the actual drift at that time.

At 0.5% (0.35%) drift a crack formed at the bottom of the hollowcore unit at the beam face (Figure 5-1). This crack formed in the same location as seen in the Matthews test. Some longitudinal cracks also formed in the bottom of the unit. These cracks were visible externally and internally.



(a) North side



(b) South side

Figure 5-1. Damage at 0.5% (0.35%) drift

At -0.5% (-0.40%) drift a crack formed at the interface between the end of the hollowcore unit and the cast in-situ concrete. This crack will be referred to as the continuity crack. No other cracks formed within the topping.

The second cycle to 0.5% (0.43%) saw a small area of the beam cover concrete spall (Figure 5-2(a)). At zero percentage drift the residual crack width between the end of the hollowcore unit and the supporting beam was 0.3mm.



(a) Spalling of the beam cover at 0.5% (0.43%) drift



(b) Split web at 1.0% (0.93%)

Figure 5-2. Damage photos for both the second cycle to 0.5% (0.43%) and the first cycle to 1.0% (0.93%)

No additional cracks formed during the second cycle to -0.5% (-0.42%).

At 1.0% (0.93%) drift a longitudinal split, 300mm long, formed in the web of the hollowcore unit (Figure 5-2(b)). The crack in the bottom of the hollowcore unit on the beam face was now 3-4mm wide. More of the beam cover concrete had spalled.

At -1.0% (0.90%) additional cracks formed within the topping. The continuity crack at the end of the hollowcore unit was approximately 2.5mm wide. The hollowcore unit has lifted 2mm relative to the beam at this crack interface.

The second cycle to 1.0% (0.92%) drift saw the bottom crack at the beam face open to 4mm. Some of the existing cracks extended slightly and more of the beam cover spalled. At this point the topping delaminated, starting at the continuity crack extending 250mm out along the hollowcore unit.

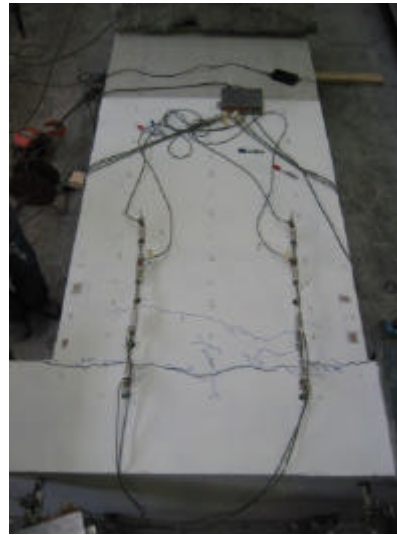
At zero drift, on the way to, the second cycle to -1.0% (-0.94%) the residual crack width between the hollowcore unit and the beam was 2mm. There was no visual

change to the condition of the beam or hollowcore unit after the second cycle to -1.0% (-0.94%) drift when compared to the first cycle.

The crack at the beam face opened to 8mm wide at a drift of 2.0% (1.95%) is shown in Figure 5-3(a). More of the beam cover concrete spalled but no additional cracks within the unit formed.



(a) Damage to the seat connection at 2.0% (1.95%) drift



(b) Topping cracks at -2.0% (-1.98%) drift

Figure 5-3. Photos showing some of the damage in HC1.

At -2.0% (-1.98%) the continuity crack was now 7-8mm wide (Figure 5-3(b)) and the unit had lifted 4mm relative to the top of the beam. At zero drift the residual width of the crack between the hollowcore unit and the beam was 4mm at the top and 3-4 mm at the bottom. A crack had formed in the topping concrete at the termination of the starter bars.

The second cycle to 2.0% (1.95%) saw the topping start to separate from the hollowcore unit on the north edge. At zero drift the hollowcore unit had dropped by 2mm at the floor-beam junction. The residual crack width between the end of the hollowcore unit and the beam was 6mm.

There was no visual change to the connection performance between the first and second loading cycles to -2.0% (-1.92%).

At 3.0% (2.92%) drift it was possible to pass a ruler through the crack in the bottom of the hollowcore unit (Figure 5-4(a)). The end of the prestressing strands could be seen as the strand pulled through the broken section of the hollowcore unit. This can be seen in Figure 5-4(b). When a torch was shown up the end of the core it was possible to see the light coming through the cracks in the bottom of the unit.



(a) The crack was large enough to pass a ruler through the gap between the unit and the beam.
(b) The prestressing strands pulling out of the fractured hollowcore unit.

Figure 5-4. Damage to the hollowcore unit (Drift=3.0%).

At zero drift the hollowcore unit had dropped 4mm at the floor-beam junction.

At -3.0% (-2.89%) drift, numerous cracks had formed within the topping, see Figure 5-5). The length of delamination of the topping from the hollowcore unit varied across the width of the unit between 350-400mm.

The crack at the beam interface was now 9mm at the top and 8mm at the bottom at zero drift. The unit had still dropped 4mm at the floor-beam junction.

During the second cycle to 3.0% (3.10%) drift the unit had now dropped 5mm at the floor-beam junction. Sizeable cracks could be seen in the webs on both sides of the unit and the delamination on the north side had extended out to the end of the starter bars (i.e. 600mm into the floor slab). This damage can be seen in Figure 5-6.

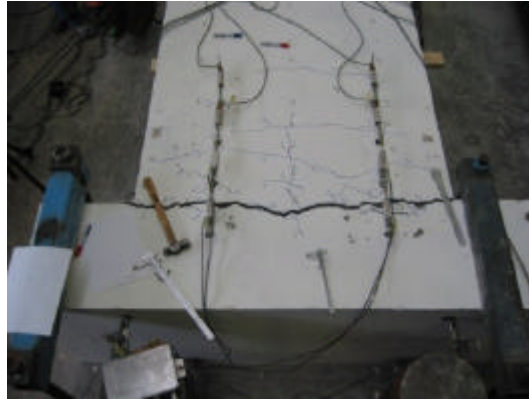


Figure 5-5. Cracks in the topping at -3.0% (-2.89%) drift



(a) A crack had formed between the hollowcore unit and the topping, leading to delamination of the topping



(b) Dropping of the hollowcore unit and damage to its seat.

Figure 5-6. Damage to the hollowcore unit at 3.0% (3.10%) drift.

The second cycle to -3.0% (-2.92%) drift saw slightly more deterioration of the unit. At zero drift the hollowcore unit had dropped 5mm at the floor-beam junction.

At 4.0% (3.98%) drift more cracks formed within the webs of the unit. The light from a torch could easily be seen through both the side and the bottom of the hollowcore unit. It was possible to see the prestressing strands kinking as they were trying to carry the weight of the unit since the seat had been lost. The south side of the unit now had 500mm of delamination while the north side stayed at 600mm.



(a) North side



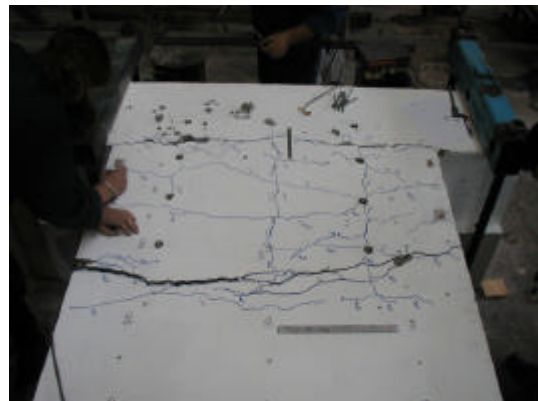
(b) South side

Figure 5-7. Damage at 4.0% (3.98%) drift.

On the way to -4.0% (-3.99%) it was possible to hear the HRC mesh at the end of the starter bars fracturing. The crack width between the end of the hollowcore unit and the supporting beam varied between 3-4mm. The hollowcore unit dropped by 12mm at the floor-beam junction.



(a) The topping peeling away from the hollowcore unit



(b) The large crack that formed at the end of the starters and caused the mesh to fracture.

Figure 5-8. Damage that caused the topping mesh to fracture on the way to -4.0% (-3.99%) drift

On the next cycle to 4.0% the unit failed completely and fell off its seat. Photos of both the failure and removal of the specimen is shown in Figure 5-9.



(a) North side failure



(b) South side failure



(c) Overall failure



(d) A photo showing when the prestressing strands pulled out of the end of the hollowcore unit



(e) The section of hollowcore unit attached to the beam (similar to the failure in the Matthews test)



(f) The end of the hollowcore unit after removal. Note the kinked prestressing strands.

Figure 5-9. Failure plus removal photos of the HC1.

5.2 Test HC2

At 0.5% (0.54%) drift one small crack formed in the underside of the hollowcore unit. It was possible to see a crack forming around the edge of the compressible material (Figure 5-10). At this early stage it appeared that this connection detail was performing considerably better than the previous test.



(a) North side



(b) South side

Figure 5-10. Damage at 0.5% (0.54%) drift

At -0.5% (-0.40%) drift the continuity crack formed at the end of the hollowcore unit. This can be seen in Figure 5-11. No other cracks formed.

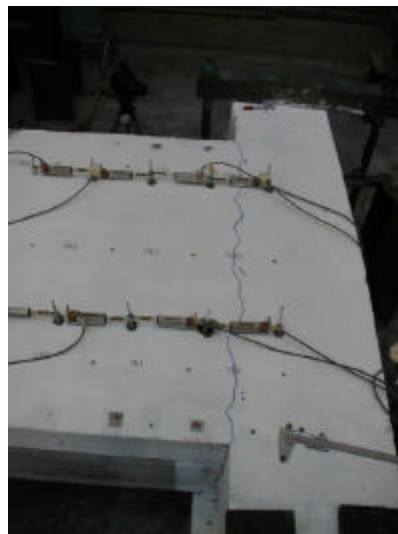


Figure 5-11. Continuity crack at -0.5% (-0.40%) drift.

The second cycle to 0.5% (0.52%) drift saw a small crack form in the web of the hollowcore unit (Figure 5-12). It was also possible to see the movement of the hollowcore unit relative to the beam. This can be seen in Figure 5-12 by the grey unpainted line at the interface of the two components.



(a) Sliding of the hollowcore unit relative to the supporting beam.



(b) Web split in the south face of the hollowcore unit.

Figure 5-12. Damage at 0.5% (0.52%) drift.

There was no visual change to the performance of the connection during the second cycle to -0.5% (-0.42%) drift.

At 1.0% (0.93%) drift no new cracks formed. The unit could be seen to be sliding on the low friction bearing strip (Figure 5-13(a)). The connection was still performing extremely well.

At -1.0% (-0.90%) drift a second crack formed within the topping (Figure 5-13(b)).



(a) The unit sliding on the low friction bearing strip at 1.0% (0.93%) drift



(b) Cracks within the topping at -1.0% (-0.90%) drift

Figure 5-13. Damage at $\pm 1.0\%$ drift

The second cycles to $\pm 1.0\%$ (1.04%, -0.90%) drift saw no real change. A section of the beam cover spalled at 1.0% (250mm long and 20mm deep). This can be seen in Figure 5-14. Two of the cracks already present within the topping extended around 30-50mm.



Figure 5-14. Spalling of the beam cover concrete (Drift=1.0%).

At 2.0% (2.03%) drift there was 200mm of delamination. The unit appears to be performing well by sliding on the low friction bearing strip. The crack at the interface between the unit and the compressible material is 8-9mm at the base of the crack.

At zero drift the residual continuity crack width between the beam and the hollowcore unit was 0.2mm at the top (topping) and 3-4mm at the base of the unit.

At -2.0% (-1.84%) drift, it was possible to see the compressible material being squashed at the bottom of the unit as it slid into the beam. A second crack formed within the topping half way along the starter bars.

At zero drift there was 250-300mm of delamination of the topping from the unit across the width of the unit.

The second cycle to 2.0% (2.02%) drift saw more of the beam cover concrete spall. It appears that the low friction bearing strip works well in terms of allowing the unit to slide but is less successful at removing high spots on the beam. It is these high spots resulting in a concentration of stress that are causing the cover concrete to spall. All the cores were checked internally for web splitting, no cracks were seen.

There was no visual change of the connection detail at the second cycle to -2.0% (-1.85%) drift. At zero drift the top cracks at the interface between the beam and

hollowcore unit had closed while the bottom crack was 2-3mm. It was unclear as to whether the bottom crack width was due to the rotation of the unit or whether the compressible material had remained partially compressed. This residual crack width is shown in Figure 5-15.



Figure 5-15. Photo showing the residual crack width at -2.0% (-1.85%) drift.

At 3.0% (3.02%) drift the south corner of the hollowcore unit broke off. The small longitudinal web crack that formed at 0.5% (0.52%) drift lengthened. Overall the connection detail is performing well.

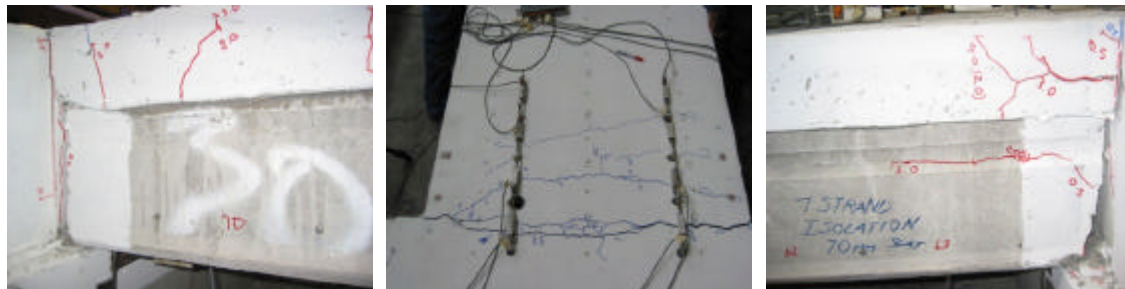
At -3.0% (-2.75%) drift it was possible to see some lifting of the hollowcore unit relative to the supporting beam. The unit had lifted approximately 4mm. Several longitudinal cracks formed on the topping. These cracks coincided with the position of the starter bars. It appeared as if the starters were trying to pop out of the topping. The compressible material was clearly seen to be compressed.

At zero drift the residual crack widths between the hollowcore unit and the beam varied between 0.5-1.5mm across the top of the unit and 3mm at the bottom.

The second cycles to both $\pm 3.0\%$ (3.01%, -2.77%) drifts saw no real change in performance. Another small section of beam cover spalled and a couple of new cracks formed.

The two cycles to $\pm 4.0\%$ (4.02%, -3.65%) saw the connection to continue to perform well. During the positive cycle it was possible to see daylight between the end of the

hollowcore unit and the supporting beam. More cracks formed in the topping. The delamination of the topping at the end of the test varied across the unit between 200mm on the south edge to 500mm on the north edge. Figure 5-16 shows the damage at the end of testing. Note that damage to the bottom edge of the hollowcore unit indicates some bearing contact between the unit and the concrete of the supporting beam.



(a) North side

(b) Plan

(c) South side

Figure 5-16. Damage at the end of the test.

Photographs showing some of the hidden damage were taken upon demolition of the experiment. These are shown in Figure 5-17.



(a) The compressible backing board still attached to the beam.



(b) Compressible backing board removed.
Note indentations when it has been compressed.



(c) Hairline crack showing some delamination of the topping.



(d) The very bottom of the hollowcore unit fractured.

Figure 5-17. Photos of the demolition of HC2.

5.3 Test HC3

At 0.5% (0.43%) drift a small crack formed on the north side of the unit at the interface between the unit and the supporting beam.

At -0.5% (-0.40%) drift two series of cracks formed in the topping. The first coincided with the end of the zone where the slots were cut into the hollowcore unit to allow the paperclips to be placed. The second crack appeared half way between the first crack and the supporting beam. These cracks can be seen in Figure 5-18.



Figure 5-18. Topping cracks at -0.5% (-0.40%) drift.

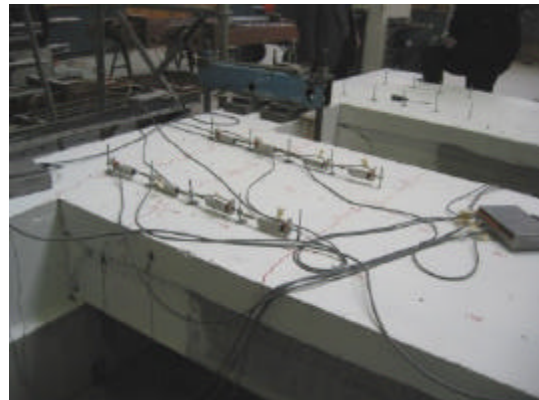
No new cracks were seen during the second cycle to 0.5% (0.35%).

More cracks formed within the topping during the second cycle to -0.5% (-0.41%) drift.

At 1.0% (0.58%) drift two longitudinal cracks formed in the bottom of the hollowcore unit. These cracks were in the soffit of the cores that were not filled with concrete (i.e. the second and fourth cores). The cracks were approximately 300mm long (Figure 5-19). There was no crack at the end of the hollowcore unit next to the supporting beam. It appeared that the low friction bearing strip was allowing the bottom of the unit to slide.



(a) Longitudinal cracks in the bottom of the hollowcore unit (Drift= 1.0% (0.58%))



(b) Topping cracks at -1.0% (-0.82%) drift.

Figure 5-19. Photos showing the damage at the $\pm 1.0\%$ (0.58% , -0.82%) drift level.

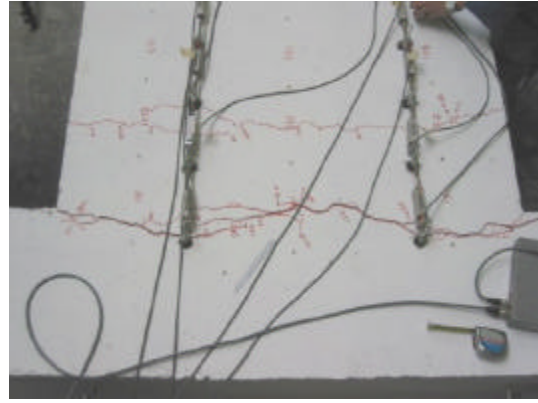
At -1.0% (-0.82%) the continuity crack in the topping formed at the end of the hollowcore unit. This crack was approximately 0.2mm wide. The initial two cracks that had formed at -0.5% had now propagated across the entire width of the unit. Figure 5-19(b) shows the topping cracks.

There was little change in damage during the second cycle to $\pm 1.0\%$ (0.58% , -0.82%) with only a couple of small cracks extensions.

At 2.0% (1.62%) drift the crack at the vertical interface between the hollowcore unit and the beam was 2mm . No other cracks had formed. The damage at this drift can be seen Figure 5-20.



(a) Seat damage at 2.0% (1.62%) drift



(b) Topping cracks at -2.0% (-1.71%) drift

Figure 5-20. Photos showing the damage at $\pm 2.0\%$ drift.

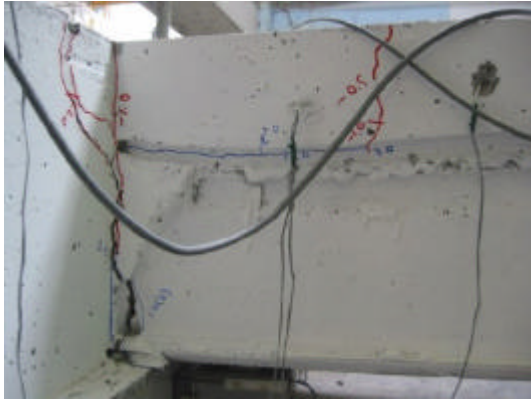
There was 30-50mm of delamination of the topping from the hollowcore unit at zero drift. No web splitting was observed.

At -2.0% (-1.71%) drift the continuity crack has opened to be 3mm wide. Slight lifting of the hollowcore unit relative to the beam was observed. A small section of the beam cover concrete at the top of the beam has been pulled off as the negative rotation was applied. Some rotation of the supporting beam was observed. This appeared to be due to the additional reinforcement within the connection requiring a larger force to be applied to the specimen to impose the correct displacement.

At zero drift the delamination of the topping had extended to 50-75mm across the unit.

The second cycles to $\pm 2.0\%$ (1.72% , -1.70%) drift saw no change in the connection performance. No new cracks formed. The bottom of the hollowcore unit seemed to sliding on the low friction bearing strip.

No major new cracks formed on the way to 3.0% (2.69%) drift. The crack at the interface between the hollowcore unit and the beam was now 8mm wide at the base of the crack. A small hairline crack was observed to have formed between the hollowcore unit and the cast in-situ topping. This can be seen in Figure 5-21.



(a) North side



(b) South side

Figure 5-21. 3.0% (2.69%) drift photos.

At -3.0% (-2.68%) drift the continuity crack now measured 8mm wide. The hollowcore unit had lifted 3mm relative to the beam.

The second cycle to 3.0% (2.93%) drift saw the unit being pried off the beam. It became evident that the edge of the hollowcore unit had been broken off at an earlier stage during the test. This was obscured when it first occurred. The regions where the fracture could be seen corresponded to the unfilled cores. The damage can be seen in Figure 5-22.



(a) The fractured unit



(b) Side elevation of the fracture

Figure 5-22. Photo showing the fractured unit at 3.0% (2.93%) drift, second cycle.

The second cycle to -3.0% (-2.46%) drift saw no change in performance.

At 4.0% (3.87%) drift more damage could be seen at the bottom of the unit. The crack widths showed that the compression crack did not close (the crack width varied between 2-5mm across the unit) and that the bottom crack had opened significantly (15mm on the north edge compared to 20mm on the south edge) at the base of the crack.

The -4.0% (-3.47%) drift cycle saw no significant change in the specimen condition. At zero drift the delamination of the topping was rechecked. It was found that the width of delamination was 150mm.

The second cycle to $\pm 4.0\%$ (3.88% , -3.43%) drift saw the bottom of the hollowcore unit continue to deteriorate. At the completion of the test the residual continuity crack width between the hollowcore unit and the beam was on average 10mm wide.

5.4 Test HC4

At 0.5% (0.26%) drift there were no cracks within the test specimen.

At -0.5% (-0.40%) drift there were several cracks over the topping. The number of cracks seen at this drift level is significantly more than seen in any of the other tests as shown in Figure 5-23.

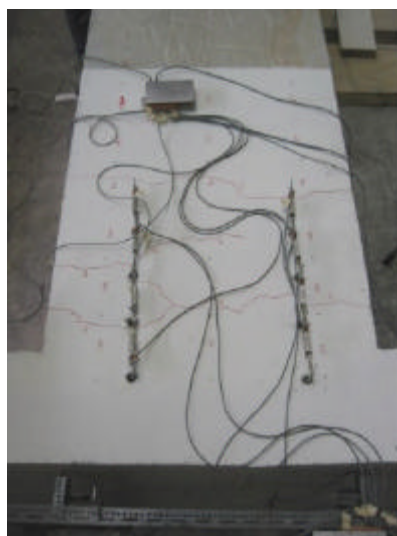
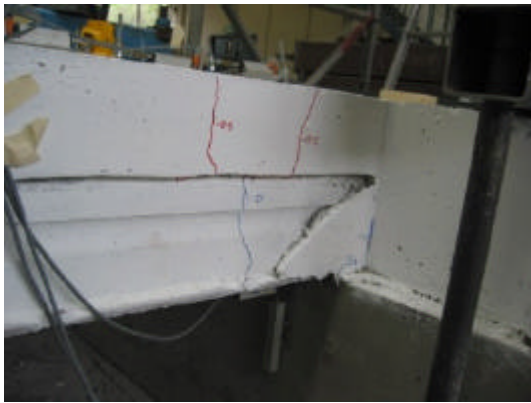


Figure 5-23. Cracks within the topping at -0.5% (-0.40%) drift.

Again during the second cycle to 0.5% (0.24%) drift no cracks formed. While the second cycle to -0.5% (-0.44%) saw some of the existing cracks extend. The cracks that formed on the topping appeared to run along the interface between the topping and the hollowcore unit.

At 1.0% (0.51%) drift a thud was heard (this is associated with some load drop off). Upon inspection it was found that the hollowcore unit had fractured approximately 300mm off the beam face (Figure 5-24). The crack between the topping and the unit had extended. A small crack also formed at the interface between the beam and the hollowcore unit.



(a) South edge



(b) Underside

Figure 5-24. Damage to the unit at 1.0% (0.51%) drift. Note the fracturing of the unit 300mm off the beam face.

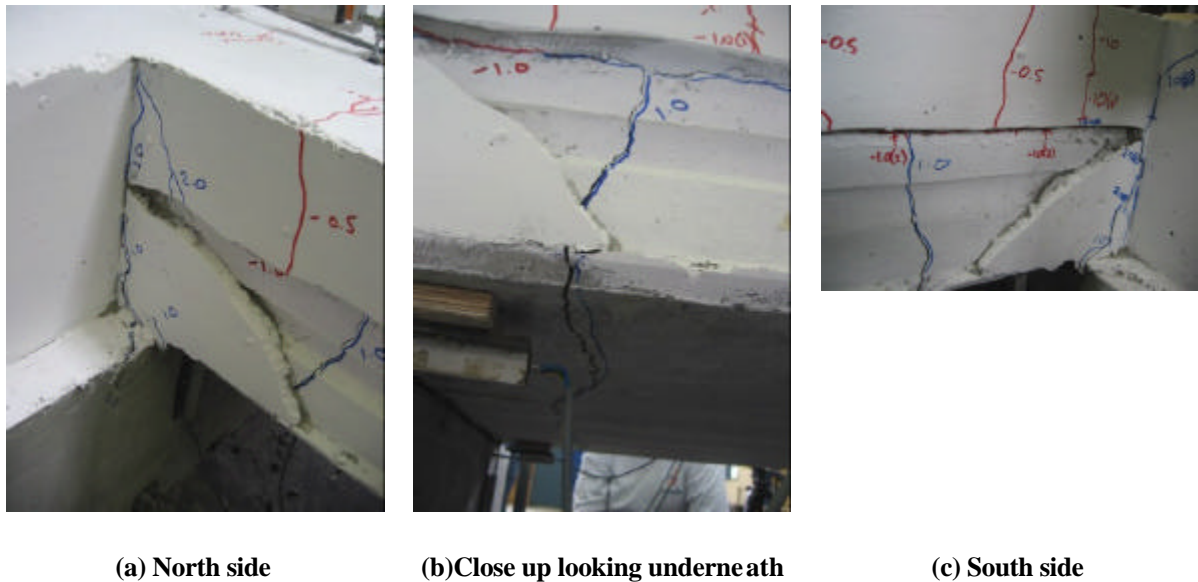
At -1.0% (-0.76%) drift more cracks had formed within the topping as seen in Figure 5-25.

The second cycles to $\pm 1.0\%$ (0.56%, -0.78%) saw no change during the positive cycles and a few more cracks forming in the topping during the negative cycles.

At 2.0% (1.98%) drift there was another thud, another load drop off occurred. Upon inspection it was found that the end of the hollowcore had fractured at the beam face (similar to what occurred in the control, HC1), the crack was 1.5mm wide at both the top and bottom of the crack. The unit had started to drop, a disparity in height could be felt between the two sides of the unit each side of the continuity crack. Figure 5-26 shows the fractured unit.



Figure 5-25. Cracks that had formed within the topping at -1.0% (-0.76%) drift.



(a) North side

(b) Close up looking underneath

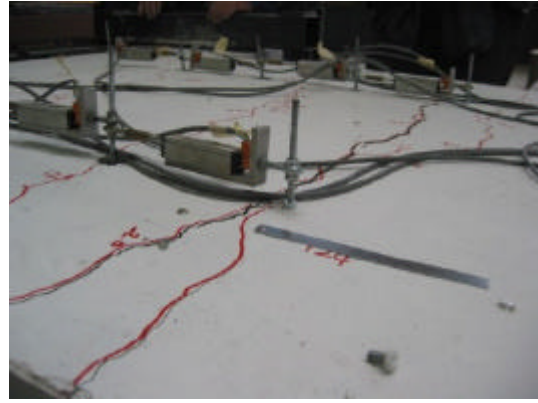
(c) South side

Figure 5-26. Fracturing of the unit at 2.0% (1.98%) drift.

At -1.8% (-1.6%) drift on the way to -2.0% (1.74%) strands of the HRC mesh could be heard to fracture. As the specimen was being loaded it was possible to see the crack open at the end of the starter bars. This is point where the mesh fractured. Once -2.0% drift was reached this crack width was 3-3.5mm. At this point the entire topping up to the end of the starter bars had delaminated. The continuity crack at the end of the hollowcore unit was 1.5mm wide. The hollowcore unit was now 1mm higher than the beam. Figure 5-27 shows the delaminated topping and topping crack.



(a) Delamination of the topping concrete

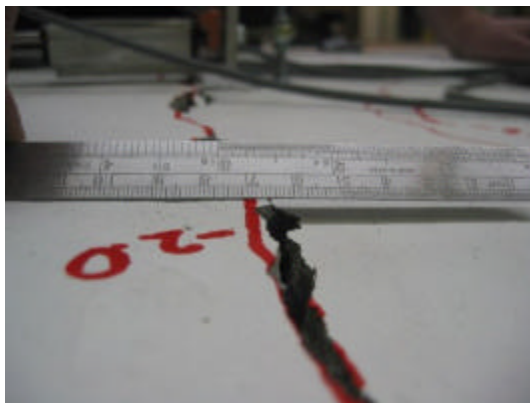


(b) The large crack at the end of the starters that caused the mesh to fracture.

Figure 5-27. Photos showing the damage following the topping mesh fracturing.

The second cycle to 2.0% (1.98%) drift clearly showed the fractured end of the hollowcore unit on the north side. The crack that formed at the bottom of the unit measured 6mm. The large crack that caused the mesh to fracture had not closed during this half load cycle.

More mesh fractured during the loading out to the second cycle to -2.0% (-1.79%). The crack width at the end of the starters was now 7mm wide. There was also a 6mm vertical separation in the topping on either side of that crack. At the end of the hollowcore a 4mm vertical displacement could be measured between the underside of the topping concrete and the top of the hollowcore unit (Figure 5-28(a)).



(a) Difference in height each side of the continuity crack.

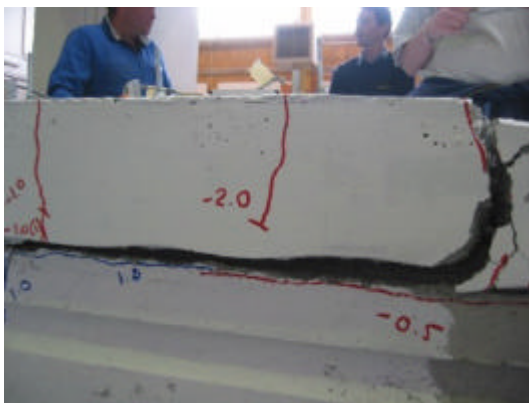


(b) Damage to the underside of the hollowcore unit

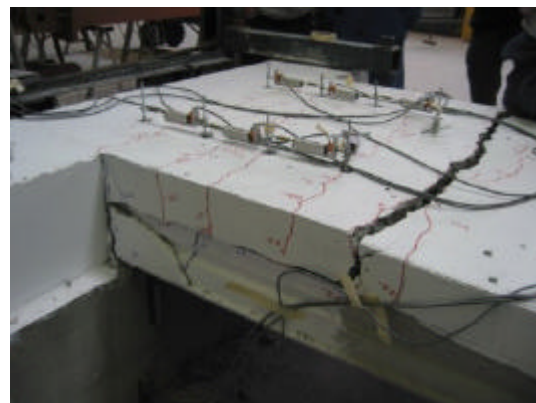
Figure 5-28. Topping damage at -2.0% (-1.79%) drift and seat damage at 3.0 (2.99%) drift.

At 2.2% (2.20%) on the way to 3.0% (2.99%) drift some of the beam cover concrete spalled. At 3.0% a 9mm wide crack had formed at the bottom of the unit, see Figure 5-28 (b). Since a portion of the beam had spalled it was possible to see that a larger section, than first thought, of the hollowcore unit had broken off. The crack at the end of the starter did not close during this half cycle.

At -3.0% (-2.76%) drift there was a 24mm vertical separation across the crack at the end of the starter bars. The width of crack was 20mm. The unit was rotating about the bottom of the hollowcore unit at this crack location (Figure 5-29).



(a) Close up looking at the end of the starter bars



(b) Overall photo of topping failure

Figure 5-29. Photos of the topping after the mesh had failed.

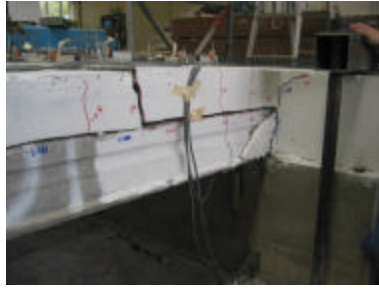
At zero drift the residual crack width between the hollowcore unit and the beam was 10mm.

The second cycle to $\pm 3.0\%$ (2.99%, -2.78%) drift saw no change to the performance. The entire hollowcore unit had separated itself from the supporting beam, see Figure 5-30. It is only the kinked strands that were holding the unit up.

The two cycles to $\pm 4.0\%$ (3.95%, -3.9%) saw a very similar response. The test was left over night to dismantle the next day but upon arrival to dismantle it the unit had collapsed. The kinked strands cannot maintain the self weight of the unit. The end of the test for HC4 can be seen in Figure 5-31 while Figure 5-32 shows HC4 being dismantled.



(a) Overall photo showing performance

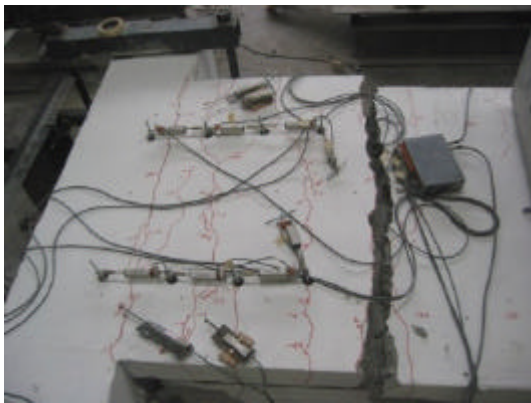


(b) Photo showing separation of topping from hollowcore



(c) Close up showing the topping separation

Figure 5-30. Damage after the $\pm 3.0\%$ (2.99%, -2.78%) drift cycle.

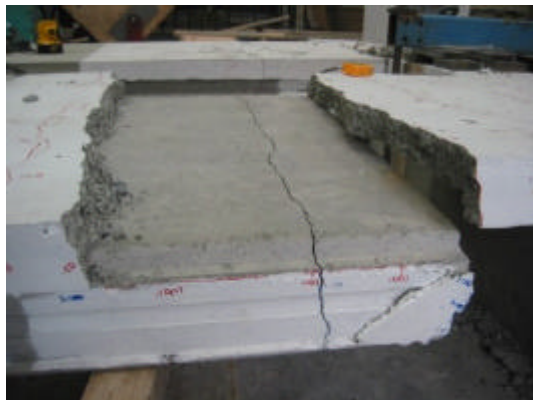


(a) Plan of the HC4 at the end of test.



(b) Elevation of HC4 at the end of test

Figure 5-31. Photos at the end of test.



(a) Crack in the end of the hollowcore unit



(b) Damaged end of hollowcore unit



(c) Damaged seat.



(d) Removed unit.

Figure 5-32. Photos of the demolition of HC4

6 Experimental Results

6.1 HC1

By examining the hysteresis loop for HC1 it clearly shows the point in which the end of the hollowcore unit fractured. It was at the first cycle to 0.5% (0.35%) drift. This point is marked on Figure 6-1. Further cycles in the positive drift direction saw much smaller loads required to reach the target drift levels. This was because the bottom of the unit was no longer fixed to the beam. As the drift increased the required load to reach that drift reduced as the connection between the hollowcore unit and the supporting beam became increasingly damaged.

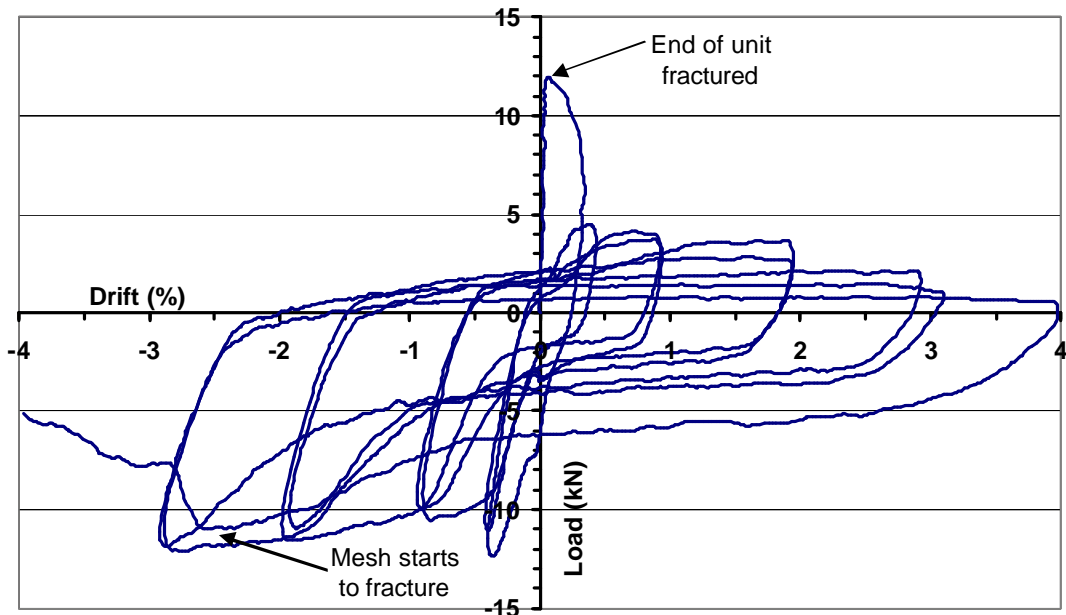


Figure 6-1. Hysteresis plot for HC1.

The complete opposite occurred for the negative drift direction. The reason for this complete reversal, when compared to the positive direction, is because as the drift increases the connection starts to activate the starters bars. More load is required as more of the starter bars are activated. It was not until the topping failed at the termination of the starter bars (and the mesh started to fracture) was there any drop off in applied load. This point is also shown on Figure 6-1.

Most of the load cycles saw very little difference between the first and second cycle to that particular drift level. The only exception to that was the two cycles to 0.5% (0.35%) drift. The reason for that has been explained above.

Figure 6-2 and 6-3 illustrates the distribution of strains along the 12mm diameter deformed starter bars during the test and the region of topping concrete at the end of the bars. The diagram shows values from both the northern and southern starter bars (Figure 4-2). Instrument failure and the preservation of instrumentation prevented a complete set of results to be shown. The results clearly show that a majority of the strain induced in the starter bar is from the crack(s) that formed across the interface between the end of the hollowcore unit and the supporting beam (continuity crack). Smaller strains, but strains that were large enough to yield the starter bar, also occurred in the next section as well.

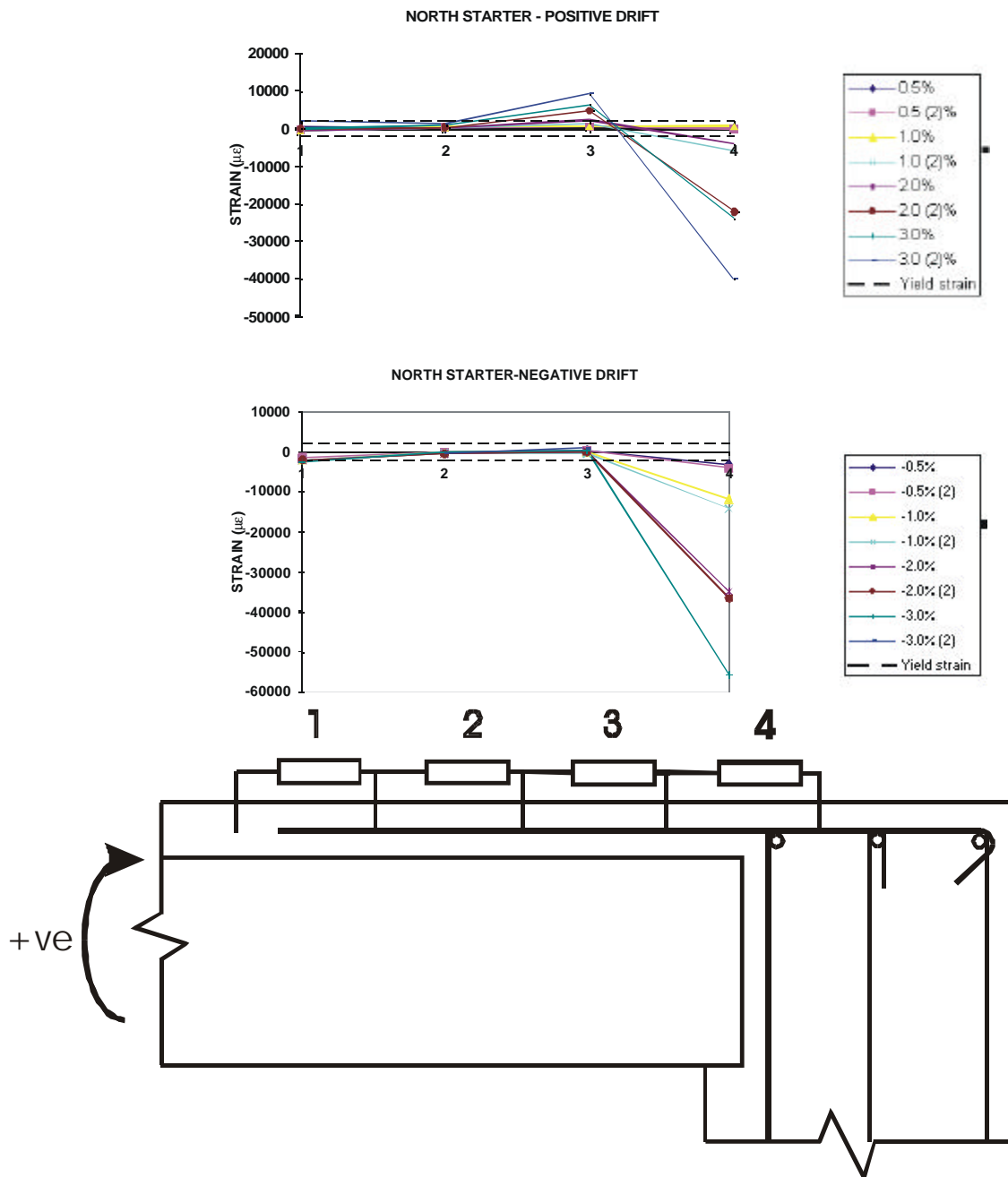


Figure 6-2 Starter bar strains for the north starter—HC1

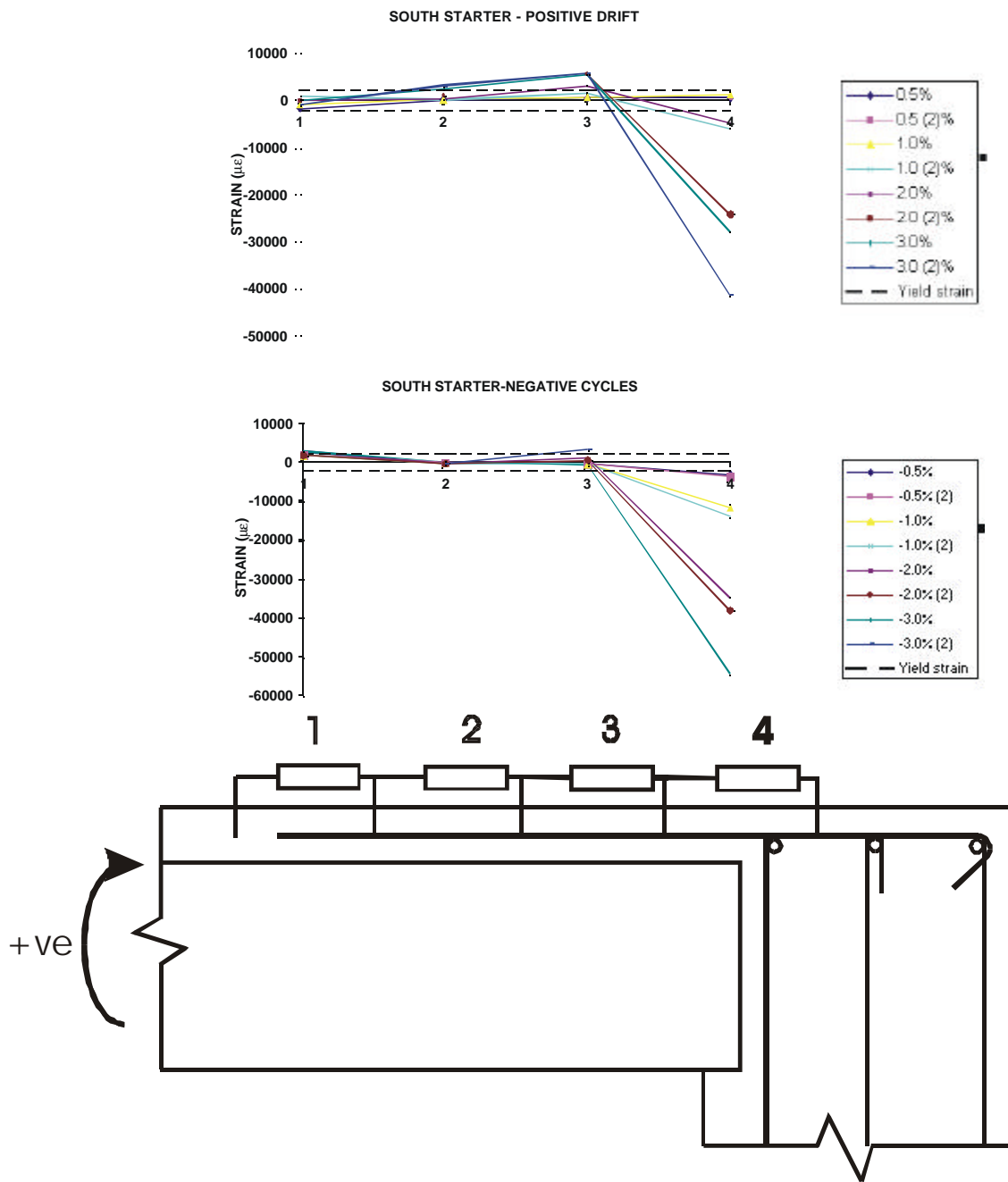


Figure 6-3 Starter bar strains for the south starter—HC1

During the test the vertical displacement of the hollowcore unit at the floor-beam junction was monitored. As can be seen from Figure 6-4 the unit did drop with increasing displacement. The unit had dropped by 5mm, at the floor-beam junction, at the time the potentiometers were removed so they would not get damaged if the unit failed.

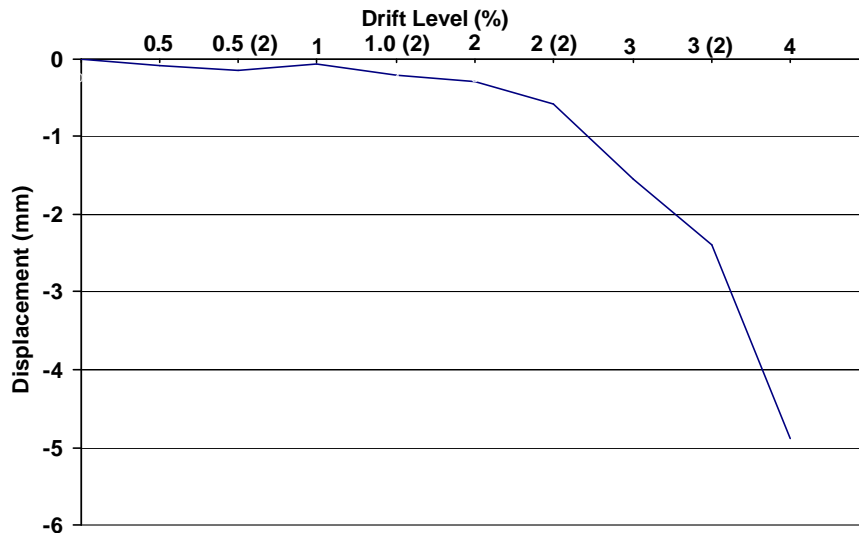


Figure 6-4. The vertical displacement of the hollowcore unit versus drift

6.2 HC2

The hysteresis loops for HC2 (Figure 6-5) were similar to that seen in HC1 for the negative drift cycles. The increasing drift level saw an increase in the applied load, as expected. The magnitude of applied load was very similar to that when compared to HC1, at the -3.0% drift level. At negative drift levels lower than -3.0% the amount of applied load was less. This difference was due to having the compressible material (backer) placed behind the hollowcore unit. As the unit rotated the material compressed so that the unit was unable to form the couple between the tension in the starters at the top of the unit and the compression strut that would have normally formed at the bottom of the unit. This compression strut did form later as the backer material compressed significantly so that some bearing was possible between the concrete of the beam behind the compressible backing material and the bottom edge of the hollowcore unit. The authors' feel using a thicker backing board could reduce this bearing and perhaps increase the performance of the connection.

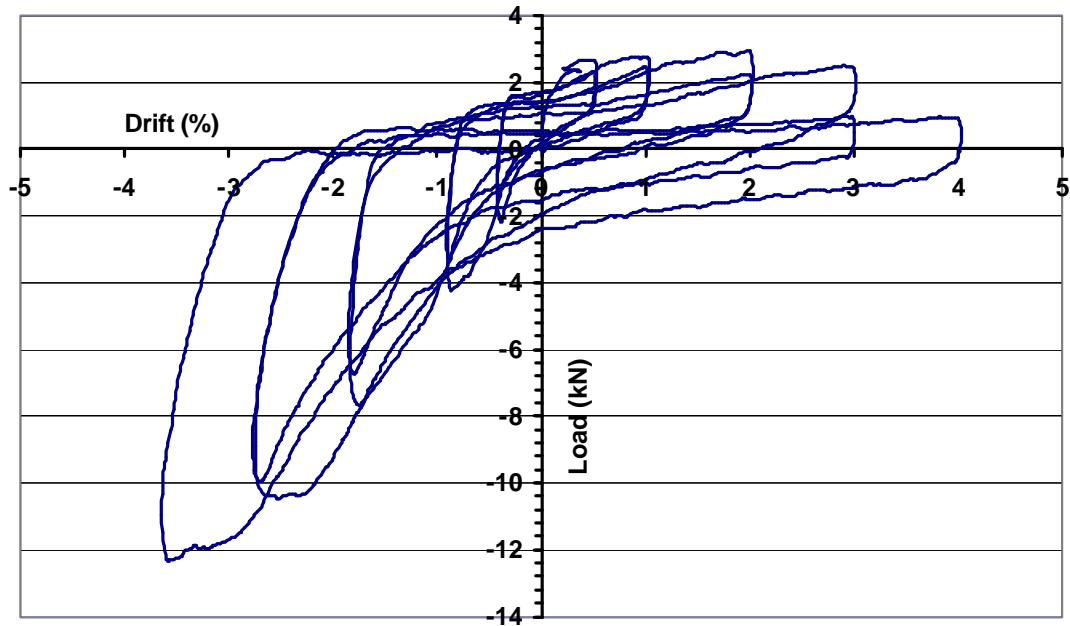


Figure 6-5. Hysteresis plot for HC2.

During the positive drift cycles it is possible to see the benefit of having both the backing board plus the low friction bearing strip. The load required to rotate the unit to a specific drift is virtually constant. The load that is required was due to the friction of the unit sliding against the low friction bearing strip.

The bearing strip also ensured that the end of the unit did not fracture as it did within the control specimen (HC1). This meant that at no stage during the test was the seating lost.

Figure 6-6 and 6-7 illustrates the distribution of strains along the 12mm diameter deformed starter bars during the test and the region of topping concrete at the end of the bars. The diagram shows values from both the northern and southern starter bars. Instrument failure and the preservation of instrumentation prevented a complete set of results to be shown. The results show that a majority of the strain induced in this region occurred in two places. Firstly at the continuity crack(s). The second region was in the concrete between the end of the starter bar and the stub that was placed within the topping concrete. This location was expected as there is a large stress concentration at the end of the starter bars and it is common to find some cracks opening at this location.

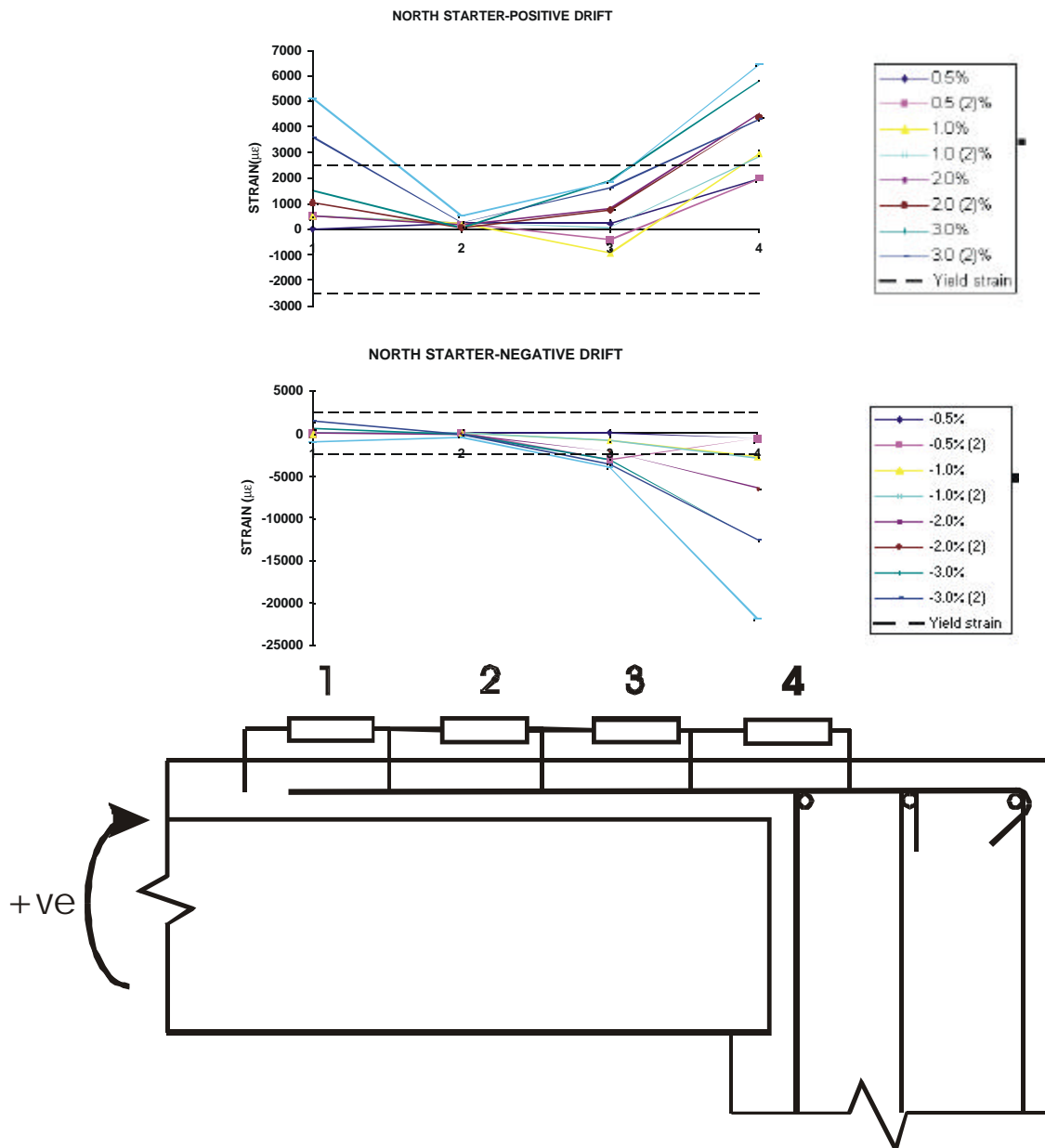


Figure 6-6 Starter bar strains for the north starter—HC2

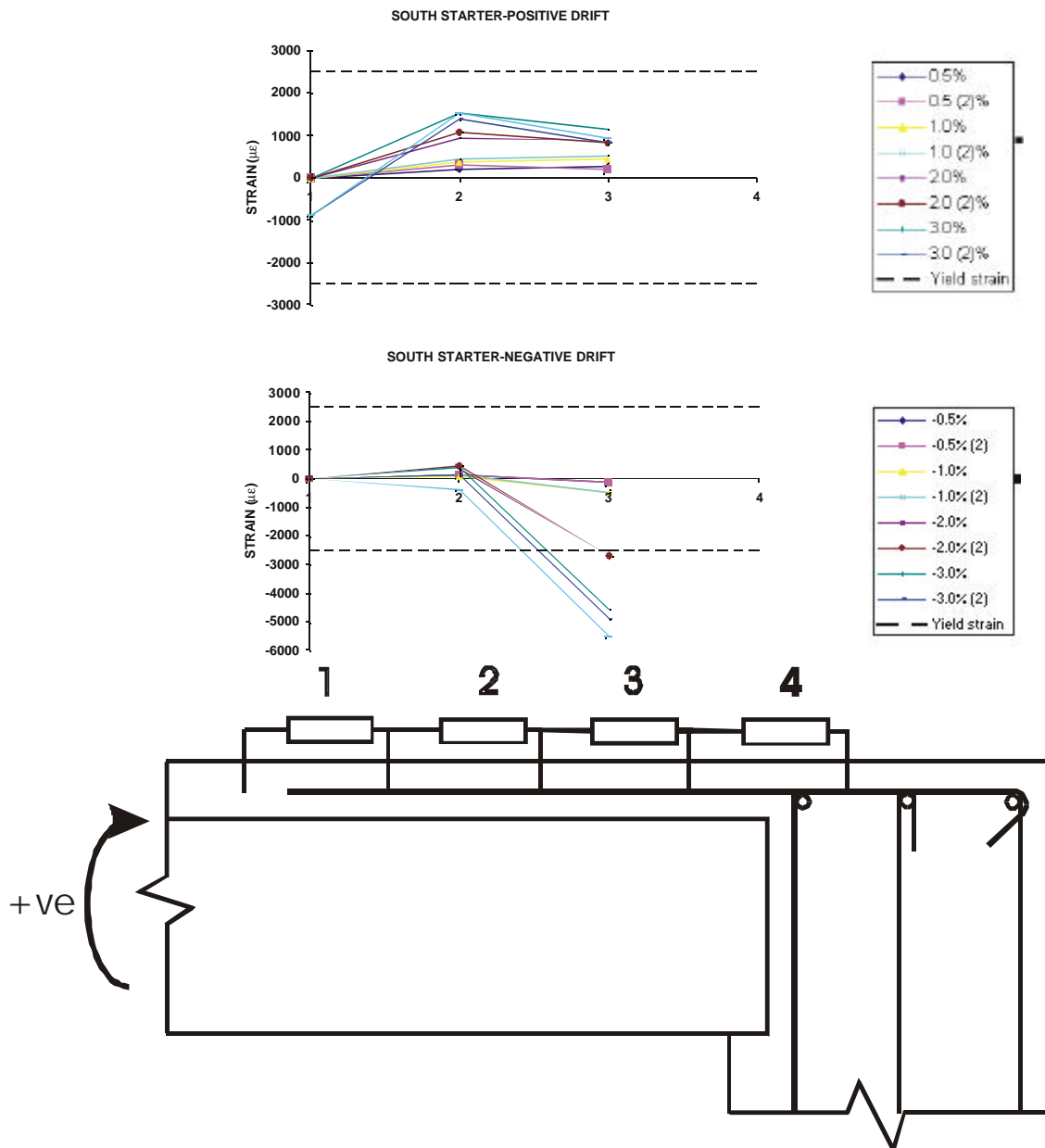


Figure 6-7 Starter bar strains for the south starter—HC2

Overall, when comparing the results with HC1, the strain in the starter bars for HC2 was less. This is due to the reduced applied moment to the system due to the presence of the compressible backing material. Although the reduced flexural strength and continuity effects is good for reducing the amount of strength enhancement to the perimeter beam it may cause other problems as the floor itself is more likely to be livelier, causing vibration issues. This is because the compressible backing board and the low friction bearing strip reduce the fixity at the end of the hollowcore units.

As can be seen in Figure 6-8 the hollowcore unit did not drop with time. This was due to the unit retaining its seat.

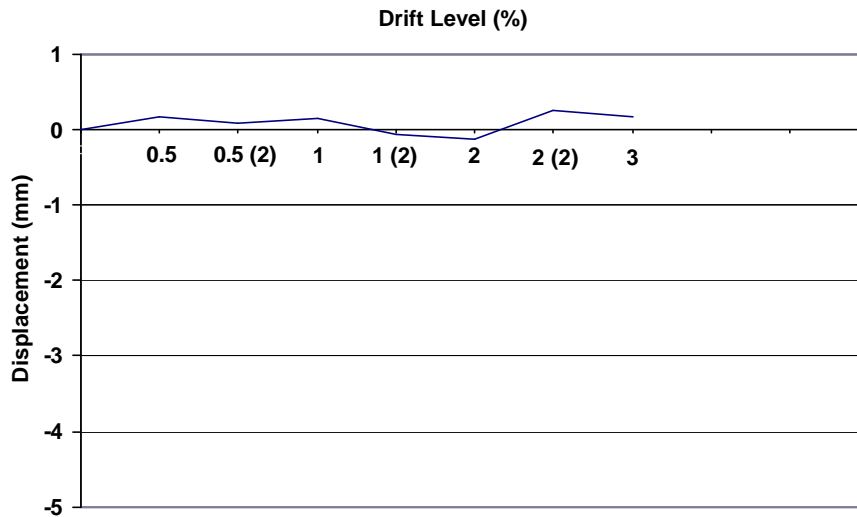


Figure 6-8. The vertical displacement of the hollowcore unit versus drift

One point to note regarding the performance of the compressible backing material is that the void within the material did fill with grout that reduced the compressibility of the material. Further comment on this is given in Section 7.1.2.

Also discussed in Section 7.1.2 is the performance of the McDowel bearing strip used as the low friction bearing material. The strip did not appear to have the ability to remove the high spots on the beam seat that lead to premature spalling of the beam cover concrete.

6.3 HC3

The hysteresis plot from this test (Figure 6-9) was very similar to that for HC1 (refer Figure 6-1). The first cycle to 0.5% (0.43%) saw a larger force than any other of the positive cycles. Since this unit had a low friction bearing strip, the end of the unit did not fracture until later into the test. The level of applied load was greater than the previous two tests in the positive drift direction due to the paperclips that had been placed in the first and third cores. The paperclips significantly increased the positive moment capacity of the units.

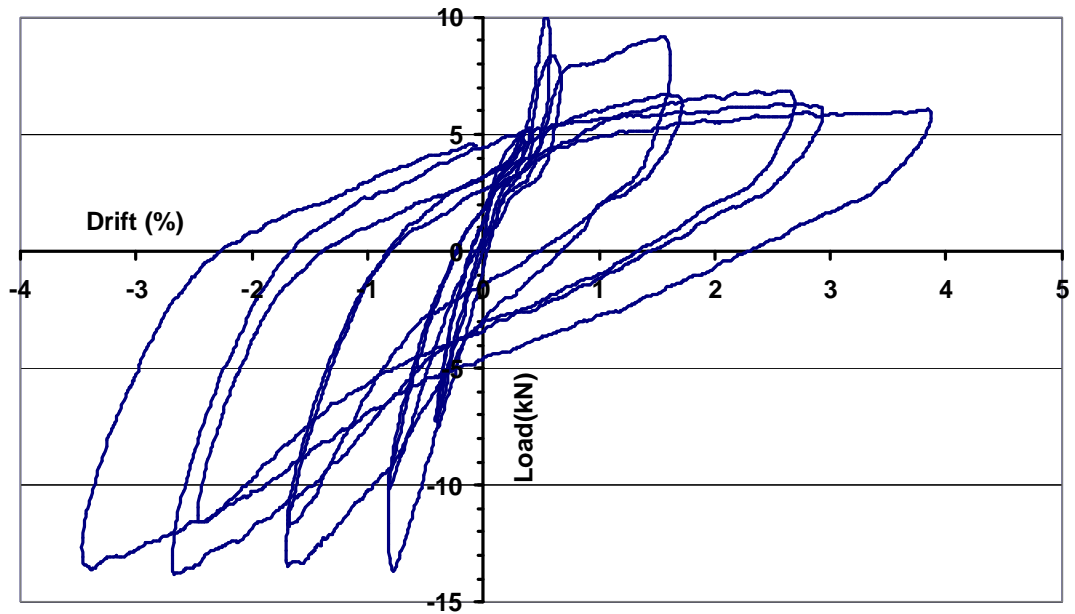


Figure 6-9. Hysteresis plot for HC3

Very little activation of the starter bars occurred during HC3. This can be seen in Figure 6-10 and 6-11. However relatively high strains occurred in the region at the end of the starter bars.

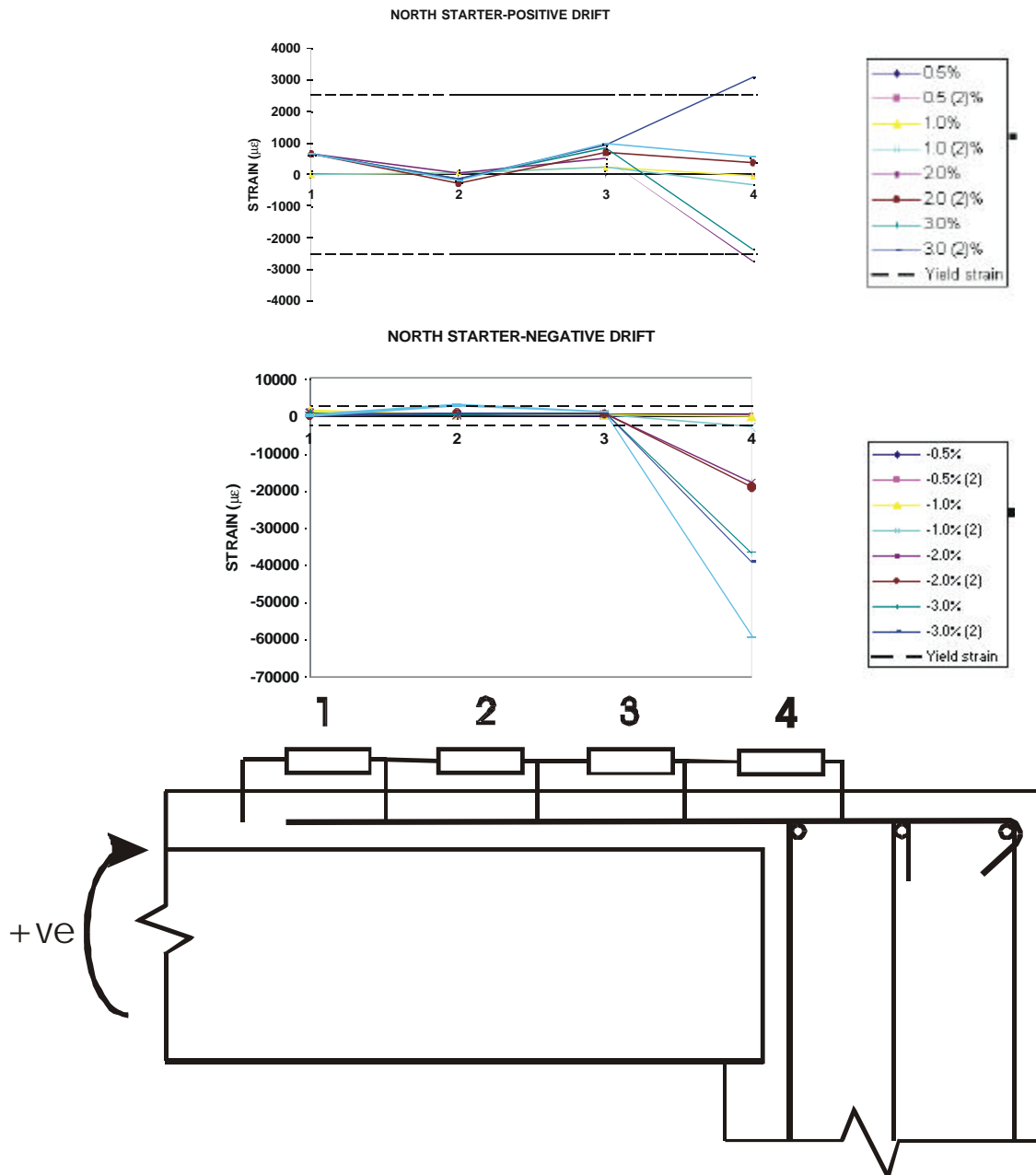


Figure 6-10 Starter bar strains for the north starter—HC3

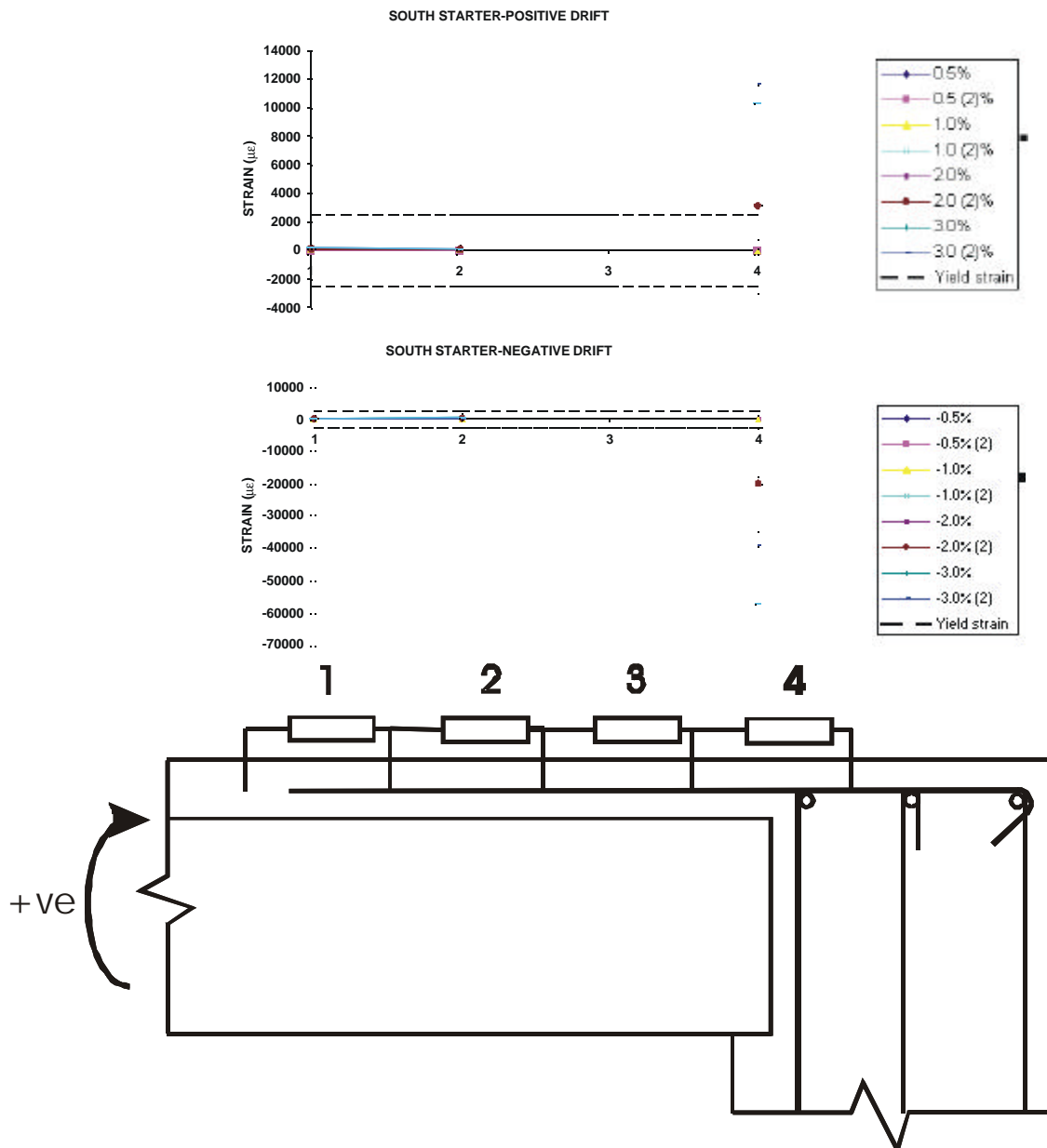


Figure 6-11 Starter bar strains for the south starter—HC3

Figure 6-12 shows the hollowcore only slightly dropped through the duration of the experiment.

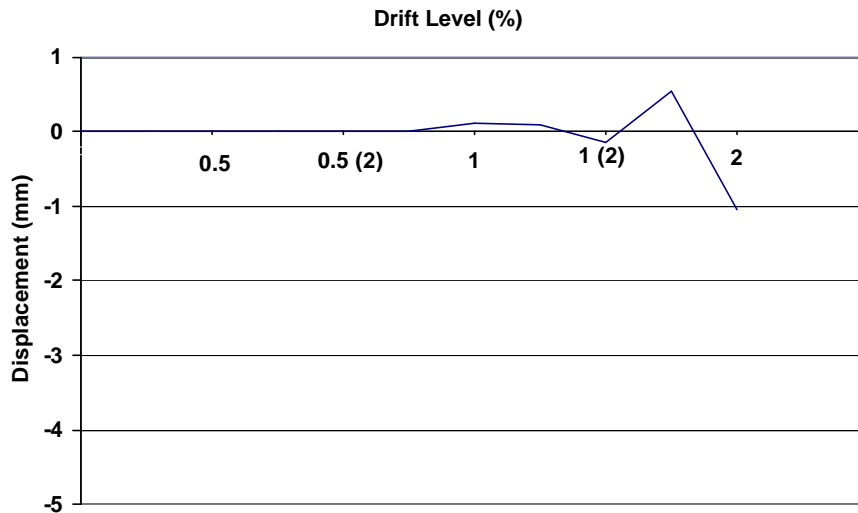


Figure 6-12. The vertical displacement of the hollowcore unit versus drift

As can be seen from Figure 6-13 at no stage during the test did the paperclip appear to yield (see Figure 3-9 for the location of the strain gauges). Two of the strain gauges attached to the paperclip failed during the test, these were ST1 and ST4. There are several possibilities as to why they failed, the most probable is that the starter may have started to slide within the infill concrete and this movement dislodged the strain gauges.

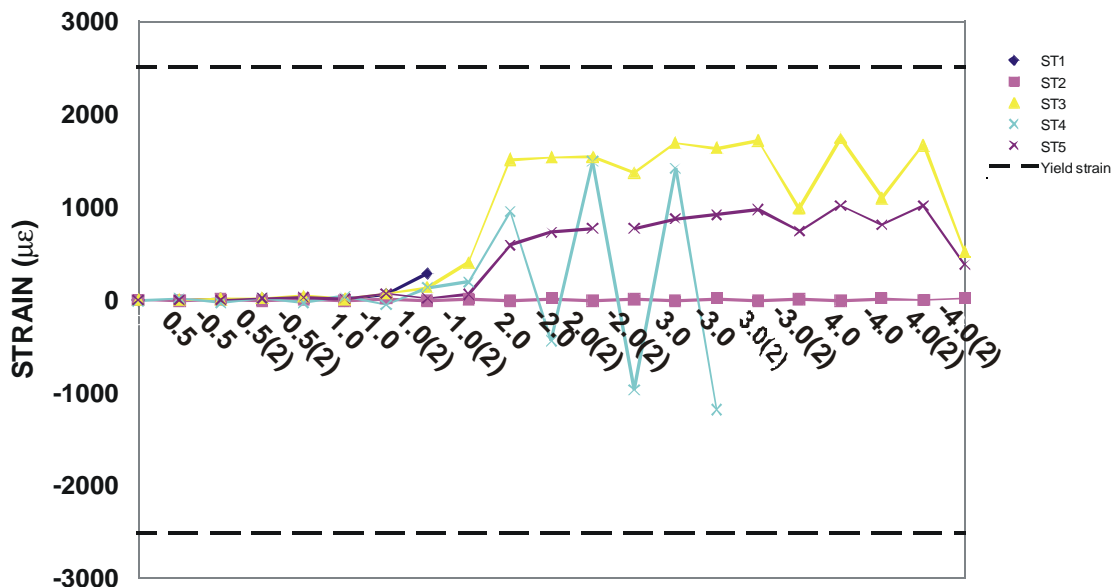


Figure 6-13. Paperclip strains

6.4 HC4

The shape of this hysteresis plot was significantly different to the other three tests. Initially, up to the completion of the $\pm 1.0\%$ (0.56%, -0.76%) cycles the plot looked to be essentially elastic. After that it changed significantly, as shown in Figure 6-14. At -1.8% (-1.60%) drift the reinforcing mesh at the termination of the starter bars fractured and the topping separated from the hollowcore unit. This can be seen by the drop off in load after -1.8% (-1.60%) drift (labelled in Figure 6-14). From this point onward the unit was sitting on the beam ledge alone. Therefore the only load required to articulate the specimen is the load required to overcome the friction of the unit sliding on the beam ledge. As can be seen from the hysteresis plot the force to overcome friction is relatively very small.

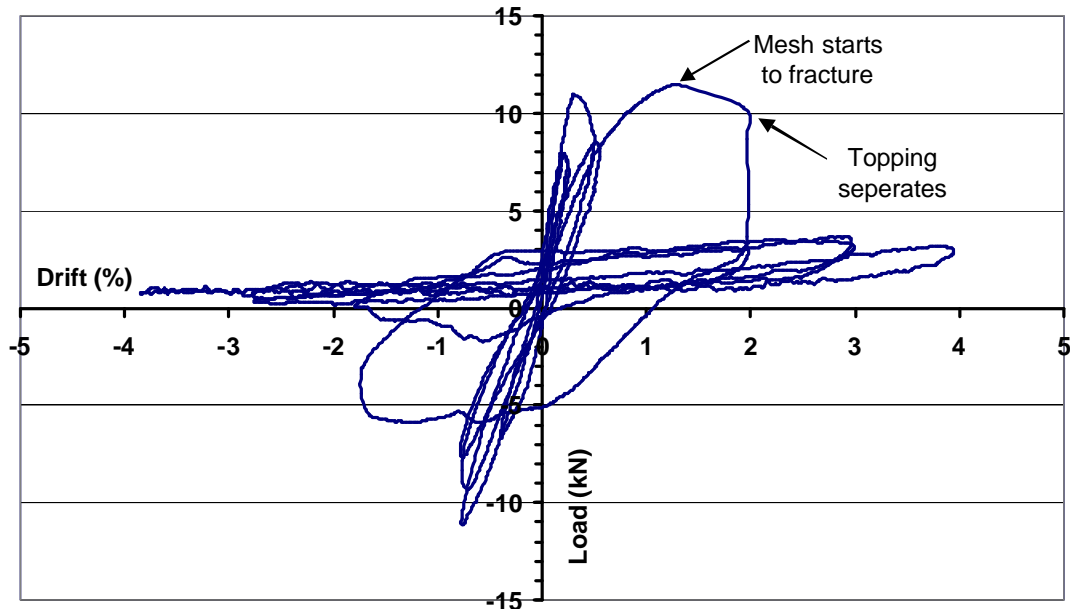


Figure 6-14. Hysteresis plot for HC4

Due to the failure that occurred the apparent strain in the concrete between the termination of the starter bars and the stub cast in the concrete is high. The largest strain in the starter bar was seen at the continuity crack. It was only at this point that the bar yielded. This can be seen in Figure 6-15 and 6-16.

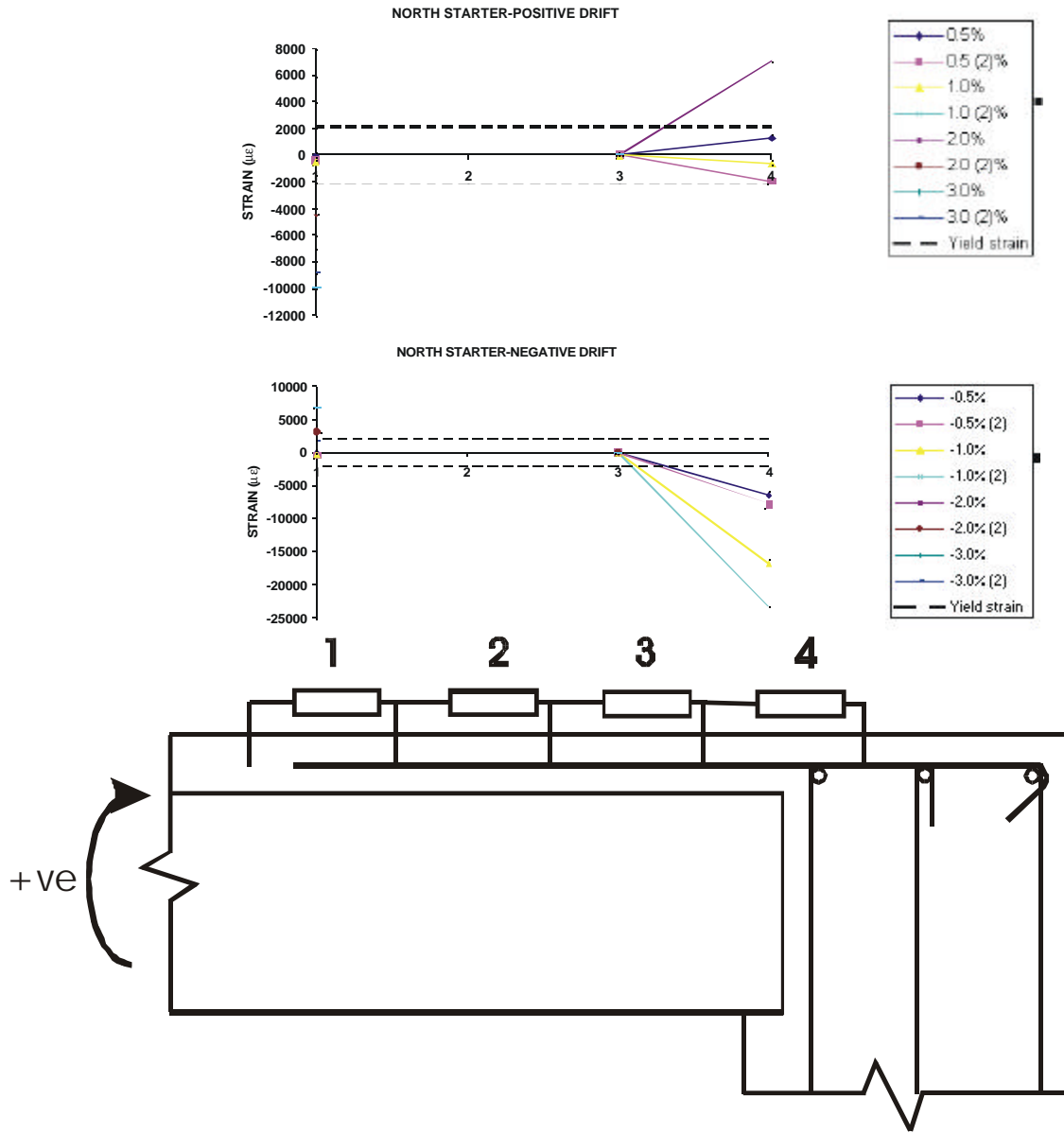


Figure 6-15 Starter bar strains for the north starter—HC4

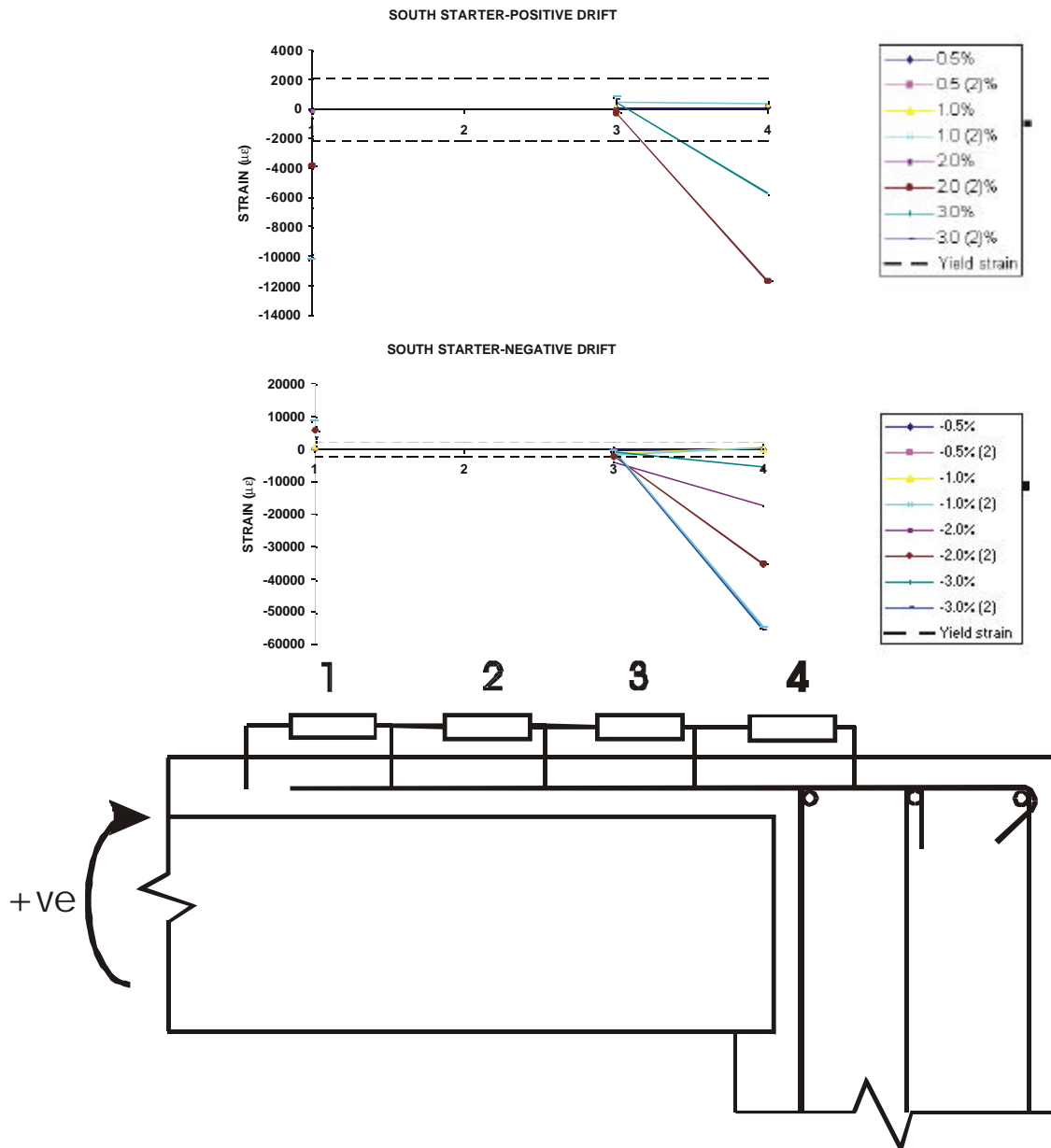


Figure 6-16 Starter bar strains for the south starter—HC4

Unfortunately the instrumentation used to measure the hollowcore unit dropping failed for this test. So the only data available was the visual observations made.

7 Conclusions and Recommendations

As can be seen from both the test observations and results some positive results were obtained. Firstly, by using a simplified test rig, when compared to the Matthews test set up, it was possible to compare the difference in performance between the various connection details proposed. The exact earthquake performance was not possible to be achieved as explained in Section 7.2. The authors feel that the Matthews set up is required to fully verify any connection detail.

7.1 Review of Test Results

7.1.1 HC1

The performance of this connection was very similar to that seen in the Matthews test. This gave the authors the confidence that it would be possible to compare the performance of the various connection details.

7.1.2 HC2

Some very positive results were seen in the performance of this detail. The major concern with the HC1 performance has been the fracturing of the end of the unit causing the seat to be lost. Relatively small amounts of this sort of damage were seen late in the test (around the 4% drift level).

Further work is still required to get a complete solution. The following issues need extra attention:

- The exact width of compressible backing board to be used
- The type of material used for the backing board. (The current material allows grout to seep into the voids, as shown in Figure 7-1. This could be addressed by simply cutting the board in the orthogonal direction)



Figure 7-1. Grout seepage into the compressible backing board.

- The low friction bearing strip used was manufactured by McDowel. It did not have the ability to even out the high spots resulting in beam cover spalling. A thicker bearing strip maybe required.

The reduction in continuity at the ends will require consideration by the designers in the floor selection process in terms of vibration response.

The next step required is further testing of this connection detail in the Matthews test rig.

7.1.3 HC3

The connection also produced a positive result. Its performance was far superior to the control (HC1) but not quite as good as the compressible backing board solution (HC2).

There was still evidence of the end of the unit being fractured. The paperclips appear to be able to hold the floor if the seat was lost, provided a proper design of the paperclip is undertaken. To confirm this, tension should be incorporated in a test along with the maximum likely floor loading applied to the unit or the test should be carried out in the Matthews test rig. The paper clip detail tested used the minimum reinforcement required by current gravity design procedures [Appendix C]. Modification of these design procedures, such as longer paper clips or more filled cores, could lead to improved performance.

The authors are unsure as to what variable caused the better performance; probably it is a combination of the variables:

- Low friction bearing strip
- Paperclips in the first and third cores

One important factor that needs to be addressed with this connection detail is what role does all this additional reinforcing steel play in enhancing the perimeter beams negative moment capacity (one of the original objective/questions of the Matthews test). If it increases the beams capacity then an increase in beam shear reinforcement as well as column reinforcement may be required to ensure a weak beam-strong column mechanism still forms.

7.1.4 HC4

This connection performed similar to that of the control (HC1). The initial failure occurred at a different location to that of the control but the mode of failure was the same. The failure occurred at an earlier stage than seen in the control.

The reason why the initial failure did not occur at the beam face but 300mm off it is described in Section 7.2.5.

It may be concluded that the 200 series unit has similar concerns to that of the 300 series connection.

7.2 Limitations of the experiment

All the connections tested are only one off tests therefore it is unclear as to whether the observed results at conservative, unconservative or mean values. These tests should be considered as “proof of concept” tests. These tests can be used to gauge relative performance up to a point, recognising the limitations of the programme discussed below. Further, these tests can aid in directing the research to what could be, potentially, effective solutions to be verified in the full 3-D Matthews test rig.

Due to the experimental set up used there will be some variables that could not be included. Listed below are possible limitations that were noted within the test programme.

7.2.1 Net Tension

The experimental set up used did not induce any tension into the slab-beam connection. During a real earthquake there is tension induced into the system due to the elongation of the hinging perimeter beams.

Tension was not included because the required magnitude was unknown. If tension was included then it is the feeling of the authors that the units (HC1 and HC4) would have dropped earlier. How much earlier is unknown. HC3, the paperclip detail, may have been detrimentally affected; by how much cannot be determined.

7.2.2 No Live or Superimposed Dead Loads Applied

Live load and superimposed dead load was not included during the loading of the test specimens because it meant that the shear force gradient being applied to the test specimen was not the same as the real Matthews specimen.

The authors feeling is that the results would be unconservative without live or superimposed dead load being applied.

7.2.3 No Plastic Hinge forming in the beam in which the hollowcore unit is seated

The performance of the hollowcore unit could be detrimentally affected if a plastic hinge forms in the beam on which the unit is seated. The rotation caused by the plastic hinge makes the hollowcore unit deform in a manner that was not replicated in these tests. This could lead to the splitting of webs of the hollowcore unit or longitudinal split within the top and bottom soffits of the unit.

7.2.4 Second order effects or a 45⁰ earthquake attack

Since this testing programme is purely a two-dimensional test it is unsure what role some second order effects associated with a three-dimensional set up would play in the performance of the hollowcore units or the supporting beam upon which it is seated.

In the event of a real earthquake the building would be exposed to some form of oblique attack. The affect this would play on the hollowcore unit to beam connection is also unknown.

7.2.5 A mature 200 series unit

Traditionally hollowcore units that are placed into a building are “green”. The definition of “green” is under four weeks old. So when the hollowcore units are placed in a building they are still curing, shrinking and creeping. The 200 series unit used in this test was over 18 months old. It also had both ends trimmed to length, which meant that the hollowcore units strands were adequately anchored before the unit was cut. Traditional units strands are adequately anchored, however the unit has only been poured a number of hours before it is cut.

Some strand pull-in is common on the ends of “green” units, however it was observed that the experimental unit had no strand pull in. This would greatly effect whether the end of the hollowcore would fracture at an early stage of the test.

Also since the unit was old, there is less bond development between the old and green concrete compared to two green pieces of concrete.

7.2.6 The addition of air-conditioning units being hung off the bottom of the hollowcore unit

If an air-conditioning unit was attached to the underside of the hollowcore unit, it could promote web splitting as the webs of the hollowcore unit have to resist additional tensile forces.

7.2.7 Vertical accelerations

As damage started to occur within the hollowcore unit it is unsure as to what role vertical accelerations would play in the test performance. The authors feel it may reduce the performance of some of the units.

7.3 Additional Details

A variation on the paperclip detail (4HR16 paperclips, one in each of the cells) should be reviewed. The increased flexural strength should result in greater stresses within the hollowcore unit and topping.

7.4 Summary and Recommendations

Within the limitations of the testing programme the performance of the 300 and 200 series controls (HC1 and HC4) were similar to that of the Matthews specimen.

Though the backing board and low-friction bearing strip (HC2) out performed the “paperclip” and low-friction bearing strip (HC3) both have the potential to be viable solutions for new floors in buildings subjected to high levels of drift. Use of traditional details HC1 and HC4 may have to be restricted to applications imposing limited amounts of drift.

In all four tests, there were a number of features that could not be included (as described in Section 7.2). The authors believe that these factors may detrimentally affect the observed performance of the four tests and recommend that 3-D, Matthews type tests be considered for validation of the viable solutions.

8 References

- [H1] Herlihy M.D., Park R. and Bull D.K., *Precast Concrete Floor Unit Support and Continuity*, Research Report 93/103, Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand, 1995, 67 pp.
- [M1] Matthews J.G, Bull D.K and Mander J.B, 2002 *Investigating the Loadpaths of floor diaphragm forces following severe damaging earthquakes*, Conference Proceedings for the New Zealand Concrete Society, TR27, Taupo October
- [M2] Matthews J.G, Bull D.K and Mander J.B, 2003 *Preliminary results from the testing of a precast hollowcore floor slab building*, Conference Proceedings 2003 Pacific Conference on Earthquake Engineering, February, Christchurch
- [M3] Mejia-McMaster J.C. and Park R., Tests on Special Reinforcement for the End Support of Hollow-Core Slabs, *PCI Journal*, Vol 39, No. 5, September-October 1994, pp. 90-105.
- [O1] Oliver S.J, *The Performance of Concrete Topped Precast Hollowcore Flooring Systems Reinforced With and Without Dramix Steel Fibres Under Simulated Seismic Loading*, Master of Engineering Thesis, Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand, 1998, 176 pp.
- [P1] Park R., *Evaluation of ductility of structures and structural assemblages from laboratory testing*, Bulletin of the New Zealand National Society for Earthquake Engineering, Vol. 22, No. 3, Sept 1989, pp155-166.
- [S1] Standards New Zealand, 1995, *Concrete Structures Standard, NZS 3101, Parts 1 & 2*, Standards New Zealand

Appendix A: -Construction photos



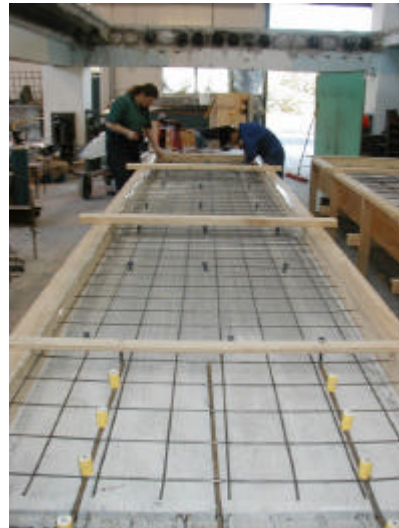
(a) 50mm seat for Control



(b) Unit aligned just before the mortar bed is laid



(c) Starters and mesh in place



(d) Ready to pour

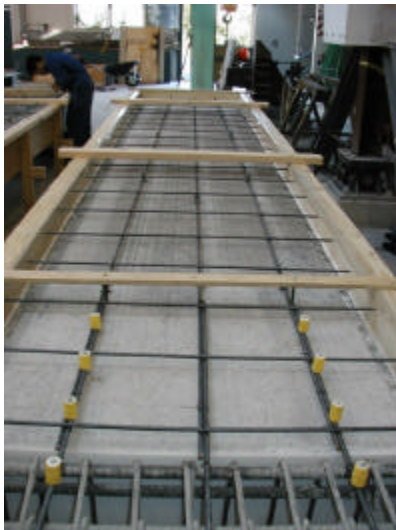
HC1-Construction photos



(a) 70mm seat



(b) Unit in place before starters are attached



(c) Ready to pour

HC2-Construction photos



(a) Looking down a cut core



(b) Bearing strip in place, unit being aligned



(c) Unit in place



(d) Almost ready to pour



(e) Ready to pour



(f) Ready to pour

HC3-Construction photos



(a) 50mm seat

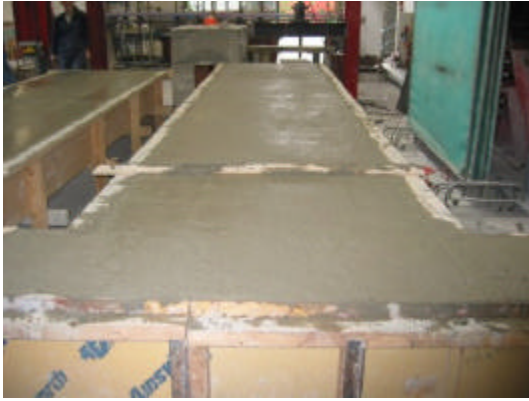


(b) Unit being positioned

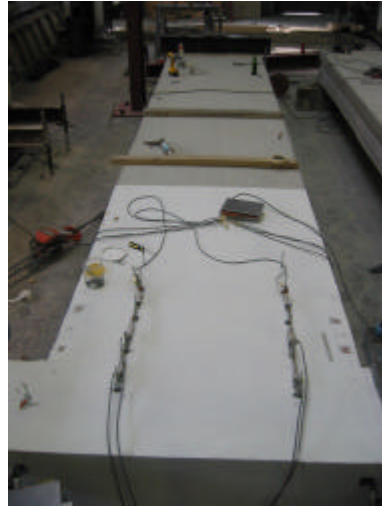


(c) Ready to pour

HC4-Construction photos



(a) Just completed pour

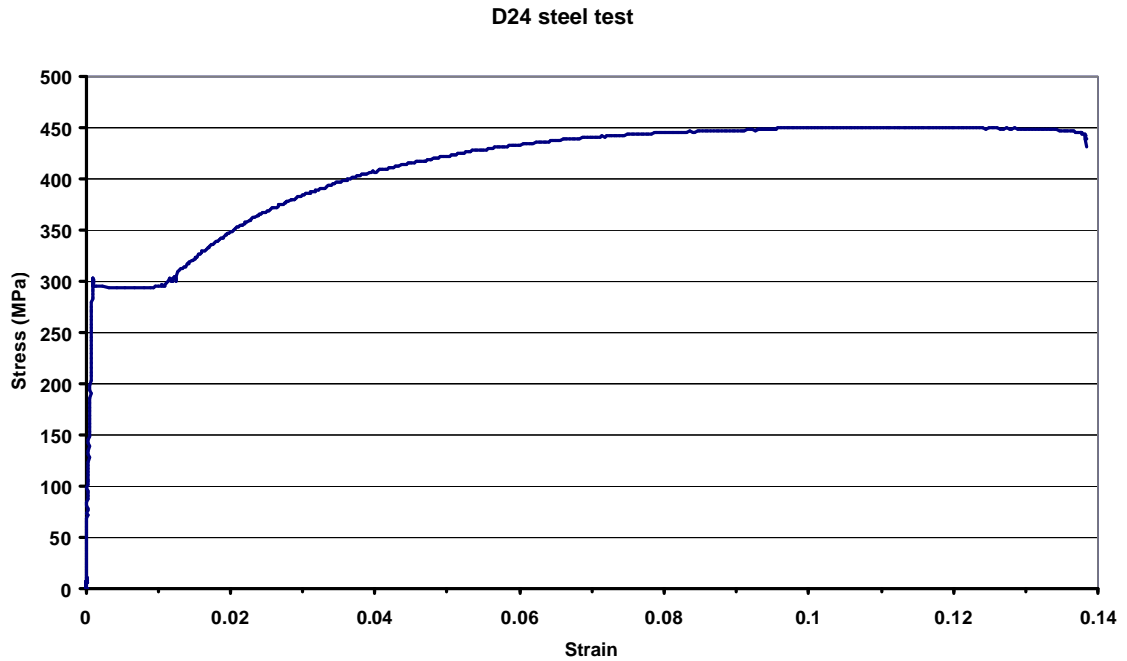


(b) Formwork stripped and ready for testing

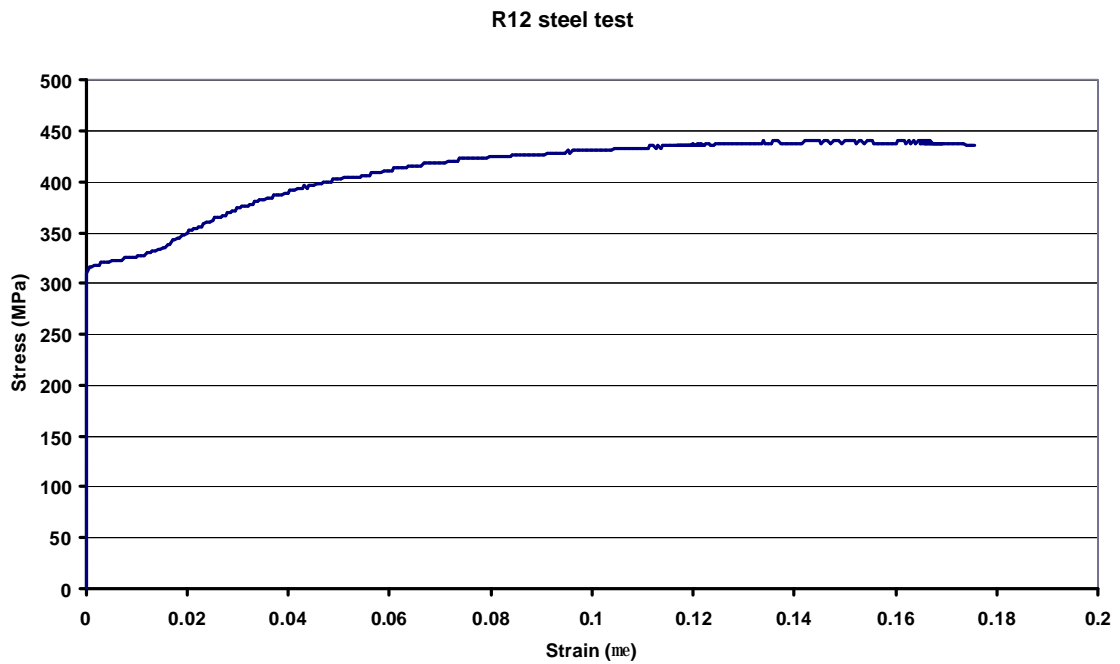
The finished product

Appendix B-Material Properties

Steel Test Results:

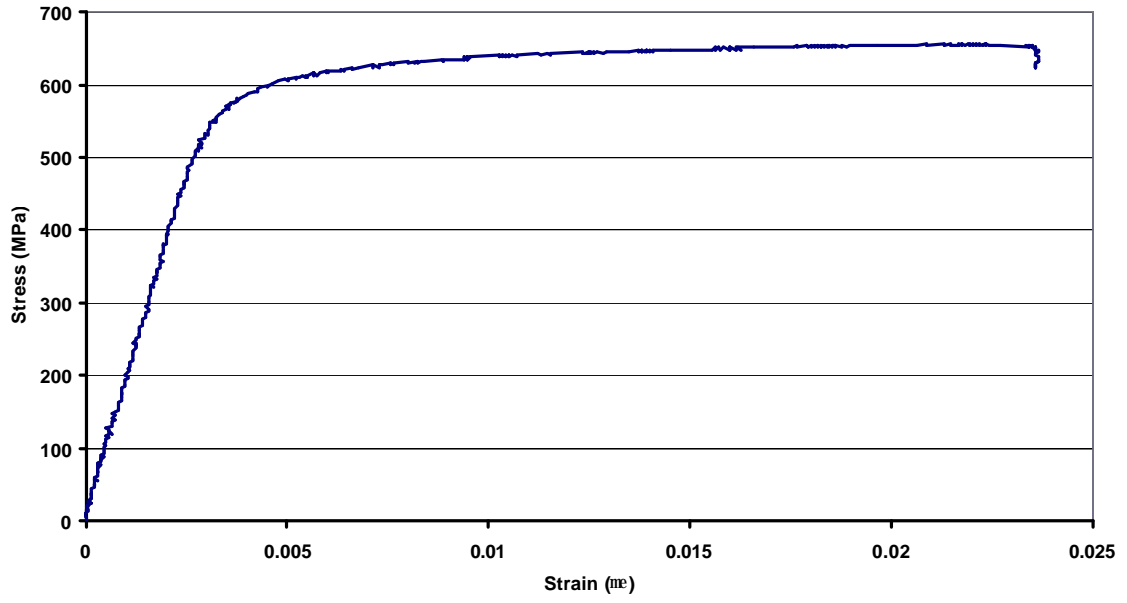


(a) Beam longitudinal reinforcement (D24)



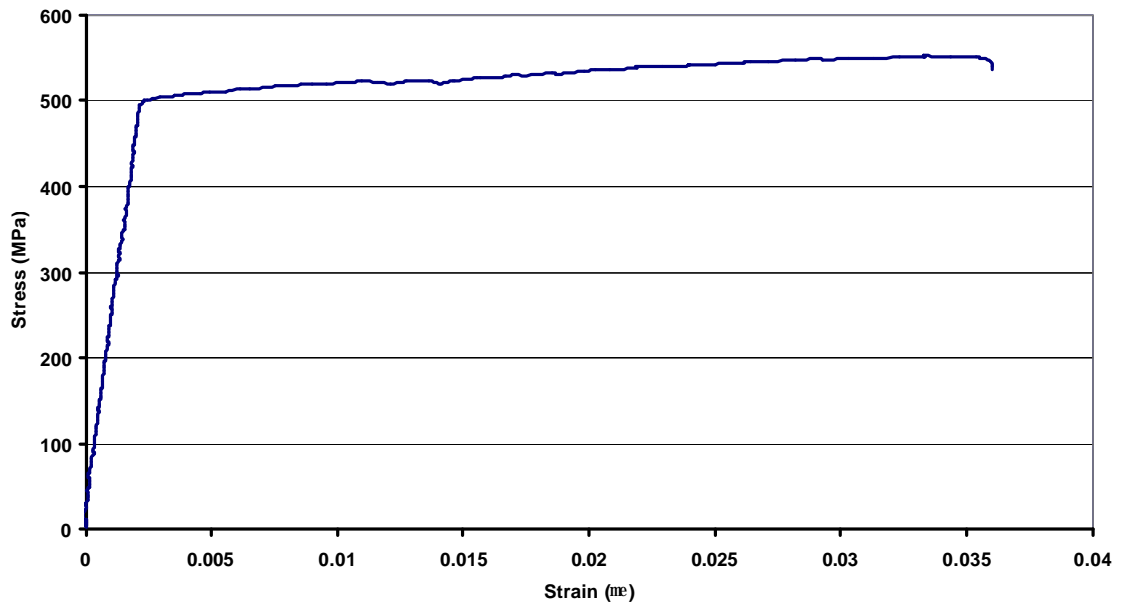
(b) Longitudinal beam transverse reinforcement (R12)

665 mesh steel test



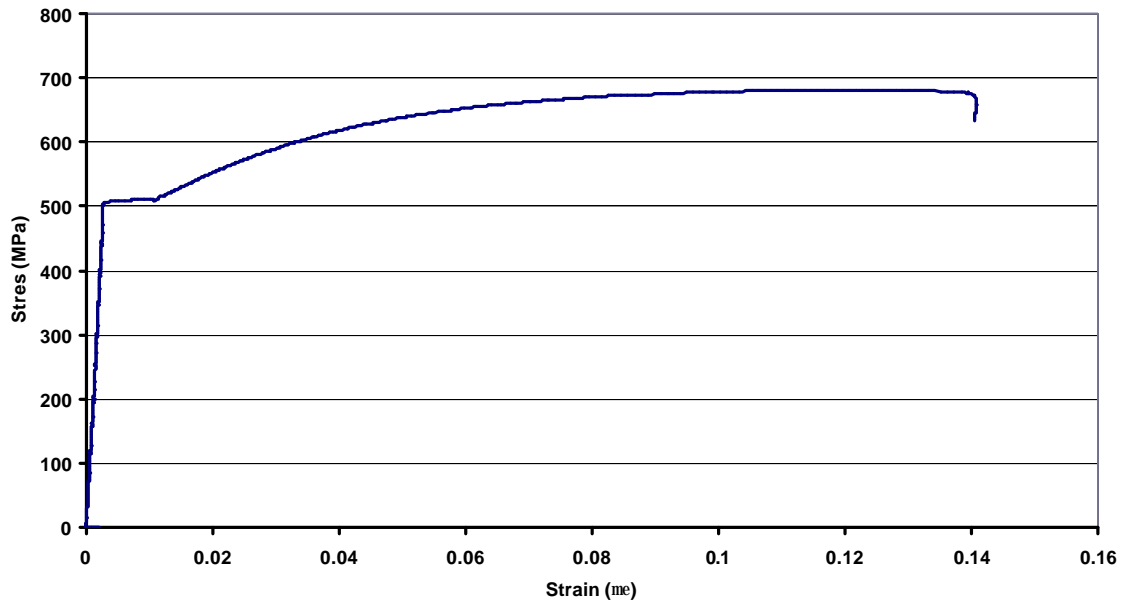
(c) Cold drawn wire mesh (665)

Hurricane Ductile Mesh



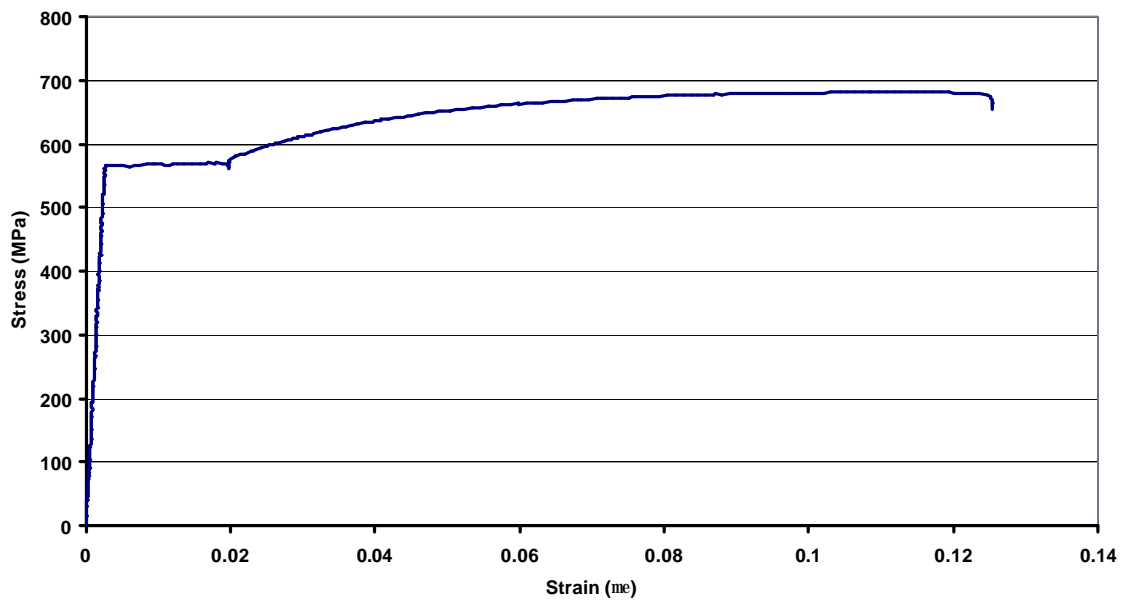
(d) Hurricane ductile mesh

HD12 steel test



(e) Grade 430 starter bar (HD12)

Grade 500E starters



(f) Grade 500E starter bar (HD12)

Concrete Strengths

All the pours used a 30MPa mix with a maximum aggregate size of 19mm (3019AW)

All the concrete strengths stated at their strength on the day of testing.

Test Number	Beam (MPa)	Topping (MPa)
HC1	39.9	41.6
HC2	39.9	41.6
HC3	39.9	33.0
HC4	41.6	33.0

Appendix C-Paperclip Design

The paperclip must be designed so that it has the ability to carry the hollowcore units self weight and any applied load once the seat of the hollowcore unit is lost. The additional loads that should be incorporated are live load and superimposed dead load.

As explained by Oliver [O1, eqn 3.10], the load resisted by each leg of the paperclip is based on the bar kinking 30degrees.

Load to be resisted

Dead Load

Hollowcore unit self weight	3.4kPa	4.08kN/m
Topping weight		2.16kN/m
Super imposed dead load	0.75kPa	0.9kN/m
	Total G	7.14kN/m

Live Load

General office loading (unreduced)	2.5kPa	3.0kN/m
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Factored Loads (1.2G & 1.6Q) 13.37kN/m

$$V^* = \frac{wl}{2} \quad (\text{Span Length}=12\text{m}) \quad 80\text{kN}$$

Design Equation

$$V^* \leq \phi V_n$$

where $V_n = A_s f_s \sin \alpha$

A_s = Area of the paperclips

f_s = yield stress of the paperclip

$$\alpha_{\max} = 30^\circ$$

$$\phi V_n = 0.75 \times 113 \times n \times 500 \times \sin 30 \times 10^{-3} \text{ kN}$$

$$\phi V_n = 21.19n \text{ kN}$$

where n is the number of legs of paper clip required.

Therefore 3.8 legs of R12 Grade 500E paperclips are required, so use 2 paperclips (i.e. 4 legs).

This paperclip design procedure was developed to cover gravity loads [O1] and was applied for the purpose of this test. Design procedures may be developed specifically for interstorey drift.