Testing of Light Gauge Steel Strap Braced Walls

By

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ABSTRACT

In North America the use of light gauge steel sections as the main structural members of a building is becoming more common; however, there are situations where little information is available to assist in design. The case of lateral load carrying systems composed of light gauge steel members is one where testing is needed to validate possible design and construction approaches. The ultimate aim of such research is to provide guidelines for the design of light gauge steel systems that resist lateral wind and seismic loads, to be used in conjunction with the 2005 National Building Code of Canada.

The goal of the research documented in this report was to evaluate three typical strap braced wall configurations with respect to their potential in resisting lateral in-plane loads in the inelastic range of behaviour. A total of sixteen 2440 x 2440 mm (8' x 8') wall specimens were tested in 2004 under monotonic and reversed cyclic lateral in-plane loading. Each specimen was composed of light gauge steel studs and tracks as well as flat strap diagonal bracing on both sides of the wall. The three wall configurations can generally be referred to as light, medium and heavy construction, within the light gauge steel spectrum. The wall specimens were evaluated according to a capacity based design approach where gross cross-section yielding of the tension braces alone was the failure mode of choice under lateral loading. Other elements in the lateral load carrying path were expected to remain in the elastic range of behaviour or to have experienced only a minor amount of plastic deformation.

The light walls generally failed by yielding of the strap braces with some damage to the tracks; yet in the medium and the heavy walls other modes of failure were observed. Typically, the bottom tracks were unable to sustain loading over large displacements due to the extensive damage at the holddown area. In addition, the gusset plates and the chord studs in these walls showed permanent damage. The braces for the medium size walls were able to reach their yield capacity for most tests, but could not maintain a yield plateau due to the extensive damage to the track/holddown area. The braces for the large walls did not reach their yield capacity. The detailed results of the research project, including test parameters, failure modes, strength, stiffness, energy dissipation and ductility measurements, are provided in this report.

AKNOWLEDGEMENTS

A special thanks to Professor Colin A. Rogers, for guiding, and supporting me during my studies, for advising and teaching me how to do successful research, your efforts are greatly appreciated.

I would also like to acknowledge the support provided by the Canada Foundation for Innovation and the Canadian Sheet Steel Building Institute. Test specimens were graciously supplied by Genesis by KML Ltd. of Cambridge, Ontario.

To my friends who supported me, Hassan Aoude, Ahmad Bousaleh, and Katherine Hikita.

To my father, mother, my brother, and sisters, your support and help are great.

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1.0 INTRODUCTION

The design of structures to resist the extreme environmental loading caused by an earthquake is of utmost importance to avoid human losses and to preserve properties. In Canada the west coast as well as the Saint Lawrence and Ottawa River valleys are classified as active seismic zones where earthquake loading will often dictate the design of the lateral force resisting system in a building. The 2005 National Building Code of Canada (NBCC) *(NRCC, 2005)* requires that seismic loading also be considered in other areas of the country, where in the past it has not been an issue *(Heidebrecht, 2003; Adams & Halchuk, 2003)*. The new NBCC will also incorporate aspects of capacity based design for seismic loading, where a single fuse element in the seismic force resisting system (SFRS) is selected by the engineer to dissipate earthquake derived energy. This element is expected to enter into the inelastic range of behaviour while the remaining components in the SFRS remain essentially elastic or have minimal plastic damage.

Figure 1: Strap braced walls under construction

The use of cold-formed steel as the main framing element in a structure is becoming more popular for the construction of low to mid-rise buildings across North America, including those found in seismic zones. In order to maintain the integrity of these structures under horizontal forces, the use of diagonal flat steel strap cross bracing may be a practical solution (Figure 1). The straps act as a vertical concentric bracing system, which transfers the lateral forces due to wind or seismic loads from the roof and floor levels to the foundation. The overall lateral strength and stiffness of this bracing system may not be related solely to the steel straps; many other elements in the lateral load carrying path play a role, such as the strap connections, the gusset plates (if needed), the anchorage including holddown and anchor rod, etc. In this type of structure the straps are usually considered to be the fuse element in the SFRS.

1.1 Objective

The aim of this research project is to evaluate the inelastic lateral load carrying performance of typical light gauge steel frame / strap braced wall configurations which are not designed following a strict seismic capacity based design philosophy.

1.2 Scope

This research involves the monotonic and reversed cyclic testing of three wall configurations, for a total of sixteen 2440 x 2440 mm (8' x 8') strap braced specimens. The light walls were composed of 92 mm (3 5/8") studs and tracks with 1.22 x 58.4 mm (0.048" x 2.3") strap braces. The medium and heavy walls were constructed of 152 mm (6") studs and tracks, along with 1.52 x 101 mm (0.060" x 4") and 1.91 x 152 mm (0.075" x 6") straps, respectively. The strap braces were obtained from steel coils having a specified minimum nominal yield stress of 230 MPa. Different holddown anchor systems were required depending on the brace size. A comparison of lateral in-plane resistance, ductility, stiffness and energy absorption ability under monotonic and reversed cyclic loads is to be completed. Moreover, an evaluation of the ability of the flat straps to yield over extended displacements without extensive damage to the other components in the SFRS is to be carried out.

2.0 TEST PROGRAM

During the late summer of 2004, in the Jamieson Structures Laboratory at McGill University, tests of sixteen strap braced wall specimens were carried out using a testing frame designed specifically for in-plane shear loading. The walls were 2440 x 2440 mm (8' x 8') in size with ASTM A653 *(2002)* Grade 33 ksi (230 MPa) diagonal strap braces installed in an X configuration on both sides. Chord studs were welded front-to-front and the remainder of the interior studs were placed at a nominal spacing of 406 mm (16"). Connections between the studs and tracks and between the straps and framing were either by welds or self drilling / self tapping screws depending on the wall size. One row of 1.22 x 38 x 12.7 mm (0.048" x 1-1/2" x 1/2") continuous bridging was welded in place through the web knockouts at the mid-height of the walls. These walls were not designed following a capacity based seismic design approach; rather the elements were selected given typical wind loading levels where all of the components in the lateral load carrying path were expected to remain elastic. The three wall configurations can generally be referred to as light, medium and heavy construction, that is the expected factored lateral in-plane resistance in a wind loading situation is approximately 20, 40 and 75 kN, respectively. A listing of the test specimens with details of all member components is provided in Table 1.

The testing frame is equipped with a 250 kN (55 kip) dynamic actuator with a stroke of ±125 mm (±5"). Displacement controlled monotonic and reversed cyclic protocols were used in testing. The testing frame incorporates external beams to prevent out-of-plane buckling of the wall specimen, such that only lateral in-plane displacement takes place, as shown in Figures 2 to 4. Measurements consisted of wall displacements, strains in the steel straps, acceleration of the loading beam assembly and the shear load at the wall top. The LVDTs, strain gauges, load cell and accelerometer were connected to Vishay Model 5100B scanners which were used to record data using the Vishay System 5000 StrainSmart software.

All top tracks were drilled to accommodate ten shear anchors and two anchor rods, which connected the tracks through an aluminium spacer to the loading beam. Similarly, the bottom tracks contained four shear anchors and two anchor rods, which connected the wall through an aluminium spacer to the testing frame. The function of the top shear anchors was to uniformly transfer the load from the loading beam to the top track; whereas the function of the interior bottom shear anchors was to connect the wall to the testing frame in a more realistic fashion. Additional information on connections and anchorages may be found in Sections 2.1 – 2.3.

Table 1: Matrix of strap braced wall test specimens

Specimen Properties[c]	Test Specimens					
	1A-M, 1B-M, 1C-M[a]	2A-C, 2B-C, 2C-C[b]	3A-M, 3B-M, 3C-M	4A-C, 4B-C, 4C-C	5A-M, 5B-M, 5C-M	6B-C
Strap Bracing						
Thickness (in / mm)	0.048 (1.22)		0.060 (1.52)		0.075 (1.91)	
Width (in / mm)	2.3 (58.4)		4 (101)		6 (152)	
Grade (ksi / MPa)	33 (230)		33 (230)		33 (230)	
Chord Studs						
Thickness (in / mm)	0.048 (1.22)		0.060 (1.52)		0.075 (1.91)	
Dimensions (in / mm)	3-5/8x1-5/8-1/2 (92x41x12.7)		6x1-5/8-1/2 (152x41x12.7)		6x1-5/8-1/2 (152x41x12.7)	
Grade (ksi / MPa)	33 (230)		50 (345)		50 (345)	
Interior Studs						
Thickness (in / mm)	0.048 (1.22)		0.048 (1.22)		0.048 (1.22)	
Dimensions (in / mm)	3-5/8x1-5/8-1/2 (92x41x12.7)		6x1-5/8-1/2 (152x41x12.7)		6x1-5/8-1/2 (152x41x12.7)	
Grade (ksi / MPa)	33 (230)		33 (230)		33 (230)	
Tracks						
Thickness (in / mm)	0.048 (1.22)		0.060 (1.52)		0.075 (1.91)	
Dimensions (in / mm)	3-5/8x1-1/4 (92x31.8)		6x1-1/4 (152x31.8)		6x1-1/4 (152x31.8)	
Grade (ksi / MPa)	33 (230)		50 (345)		50 (345)	
Gusset Plates						
Thickness (in / mm)	NA		0.060 (1.52)		0.075 (1.91)	
Dimensions (in / mm)	NA		10x10 (250x250)		12x12 (300x300)	
Grade (ksi / MPa)	NA		33 (230)		33 (230)	

[a] Monotonic protocol [b] CUREE reversed cyclic protocol [c] Nominal dimensions and material properties

Figure 2: Strap braced wall specimen in test frame

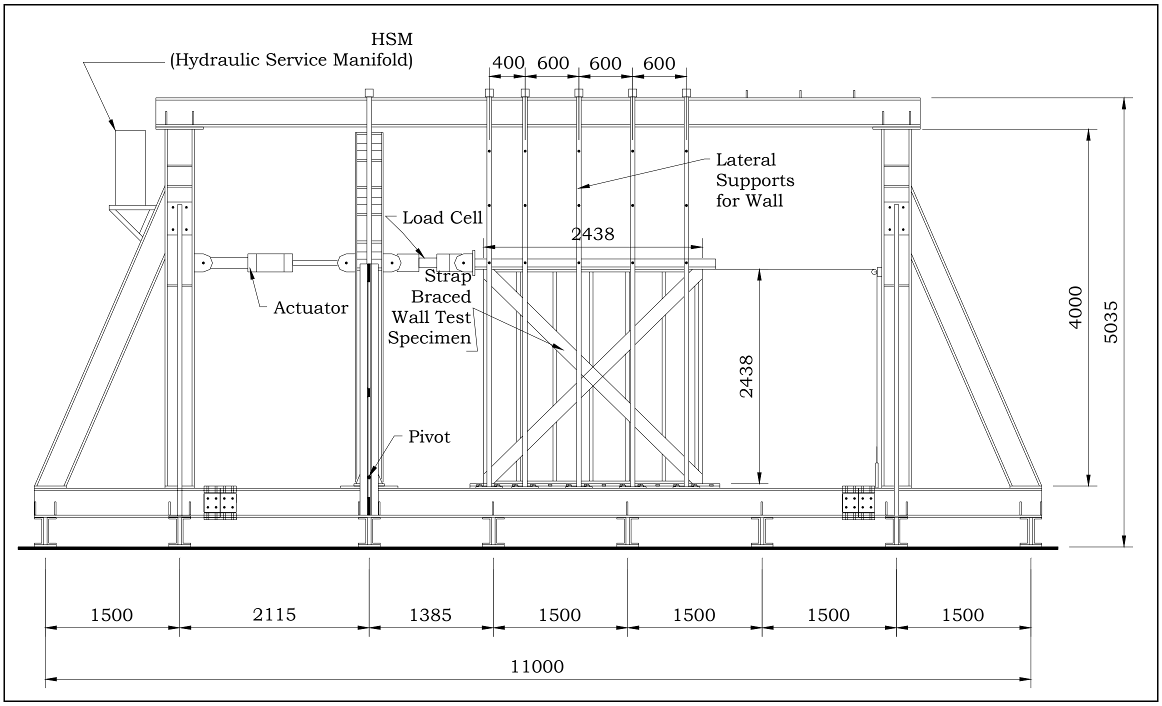

Figure 3: Schematic of strap braced wall specimen in test frame

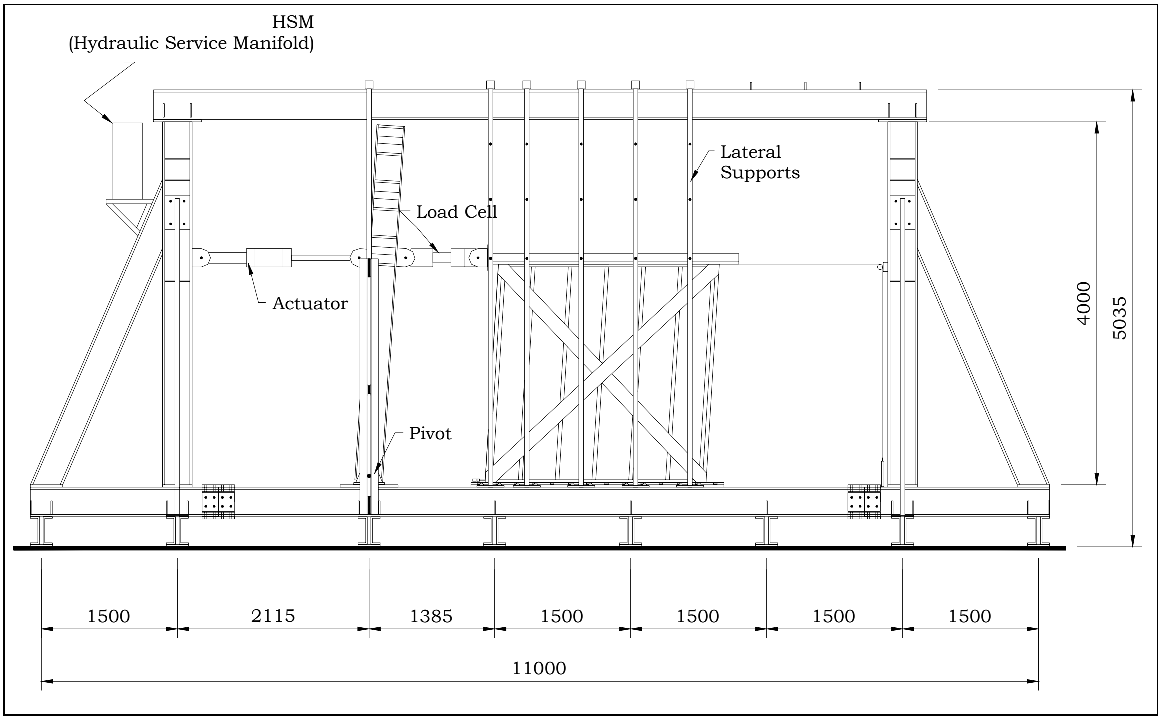

Figure 4: Schematic of displaced strap braced wall specimen in test frame

2.1 Test Walls with 58.4 mm (2.3”) Strap Braces

A representative schematic drawing and photograph of test walls 1A-M, 1B-M, 1C-M, 2A-C, 2B-C and 2C-C, which were braced with 1.22 x 58.4 mm (0.048” x 2.3”) straps on both sides, are shown in Figures 5 & 6. Prefabricated holddowns were welded to the interior-side of the chord studs at the corners of the wall, as is shown in Figures 7 & 8. Each holddown had a factored capacity of 35 kN according to the manufacture’s specifications. The holddowns were installed to transfer the uplift and shear forces from the straps through the anchor rods down to the foundation, or in the case of a multi-storey structure from the wall in the storey above to the lower braced wall segment.

All the interior studs were connected to the top and bottom tracks by No.10-16 wafer-head self drilling screw / self tapping screws. The exterior stud of the chord was connected to the track by two self drilling screws on each side, and the interior stud was connected by one screw on each side. The straps were connected to the top and bottom of the chord studs using six No.10-16 wafer-head self drilling screws / self tapping screw in a non uniform pattern (Fig. 7).

By using one screw on each side to connect the studs to the tracks, no significant stiffness was obtained from the frame itself; hence the straps provided lateral in-plane stiffness to the wall system. The holddown anchor rods were under combined shear and uplift forces, and the chord studs were subjected mainly to axial forces, although some localized shear and bending occurred in the latter stages of the test protocols. Shear anchors consisted of ASTM A325 *(2002)* 3/4” (19 mm) bolts. Test 1B-M, the first to be carried out, was fitted with 1/2" (12.7 mm) diameter ASTM A307 *(2003)* threaded rods at the holddowns. For all other walls of this size 5/8” (15.9 mm) diameter ASTM A307 threaded rods were used.

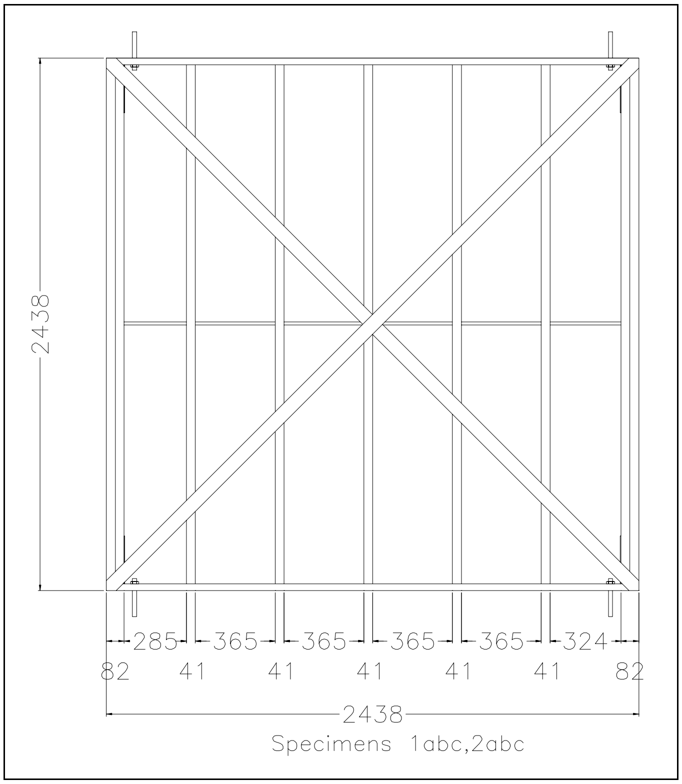

Figure 5: Nominal dimensions of specimens 1A-M, 1B-M, 1C-M, 2A-C, 2B-C and 2C-C

Figure 6: Typical wall with 58.4 mm (2.3”) strap brace prior to testing

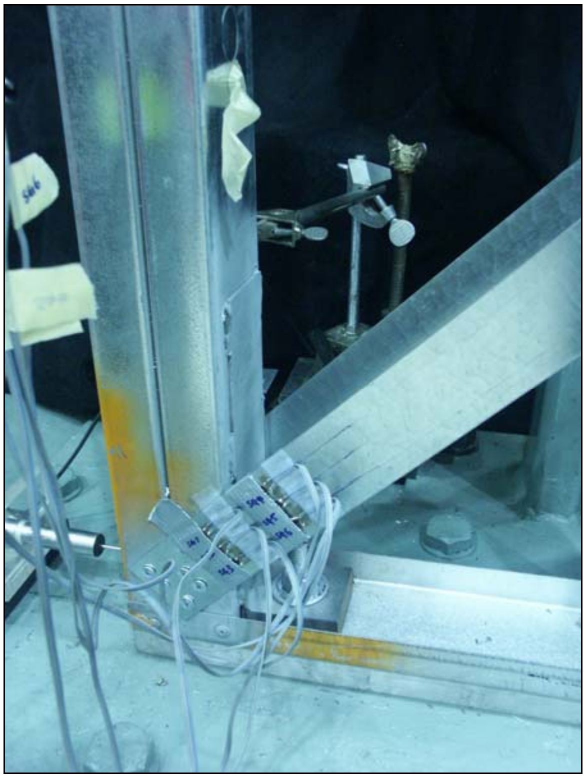

Figure 7: Holddown detail of specimens 1A-M, 1B-M, 1C-M, 2A-C, 2B-C and 2C-C

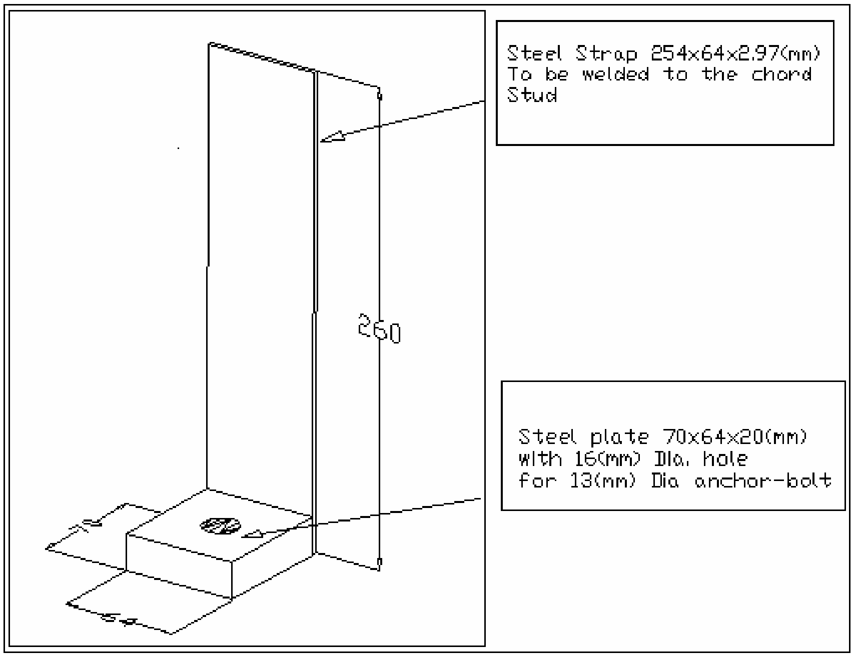

Figure 8: Holddown dimensions of specimens 1A-M, 1B-M, 1C-M, 2A-C, 2B-C and 2C-C

2.2 Test Walls with 101 mm (4”) Strap Braces

Test walls 3A-M, 3B-M, 3C-M, 4A-C, 4B-C and 4C-C were of the nominal dimensions shown in Figure 9. A photograph of a typical wall with 1.52 x 101 mm (0.060” x 4”) straps on both sides is provided in Figure 10. The studs were connected to the top and bottom tracks using one No.10-16 wafer-head self drilling screw/ self tapping screw on each side. Screws were not used to attach the chord studs to the tracks; instead to connect these members 250 x 250 mm (10” x 10”) gusset plates were welded along the two exterior edges with 3 mm fillet welds (Fig. 11). Furthermore, the strap braces were fillet welded (3 mm) to the surface of the gusset plates as shown in Figure 11.

A holddown plate with an anchor rod was used instead of a prefabricated holddown (Fig. 12). For walls 3A-M and 3B-M plates measuring 19 x 90 x 127 mm (0.75” x 3.5” x 5”) were used, whereas for walls 3C-M, 4A-C, 4B-C and 4C-C plates 19 x 127 x 203 mm (0.75” x 5” x 8”) in dimension were installed in the track elements between the gusset plates. The holddown plates were placed at the four corners of each wall, attaching the bottom track through the spacer to the testing frame and the top track through the spacer to the loading beam. Shear anchors consisted of ASTM A325 3/4” (19 mm) bolts. The holddown plates were connected with 3/4” (19 mm) diameter ASTM A307 threaded rods.

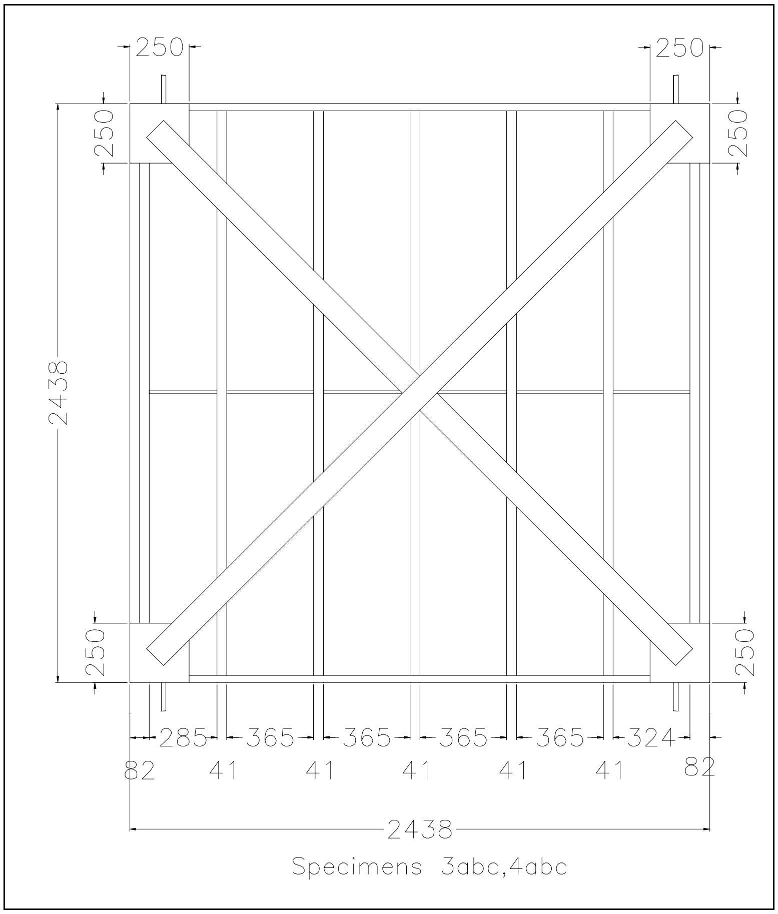

Figure 9: Nominal dimensions of specimens 3A-M, 3B-M, 3C-M, 4A-C, 4B-C and 4C-C

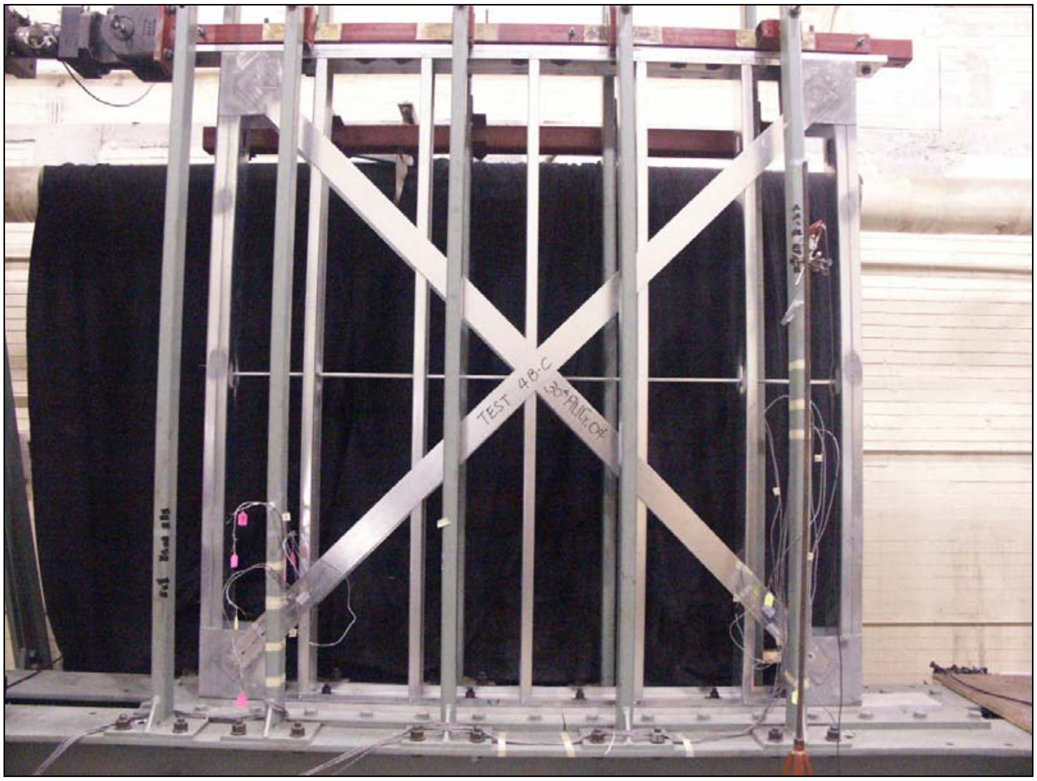

Figure 10: Typical wall with 101 mm (4”) strap brace prior to testing

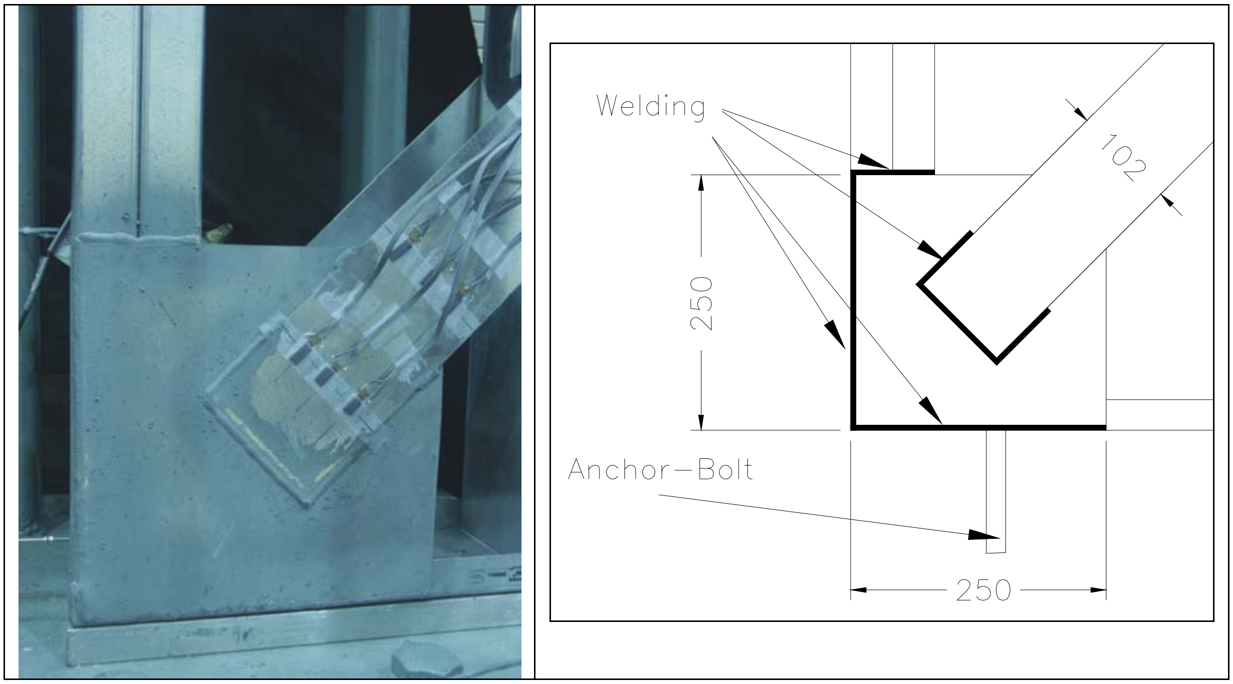

Figure 11: 101 mm (4”) strap brace connection detail prior to testing

Figure 12: 101 mm (4”) strap brace connection and holddown detail prior to testing

2.3 Test Walls with 152 mm (6”) Strap Braces

A representative schematic drawing and photograph of braced walls 5A-M, 5B-M, 5C-M and 6B-C, which were braced with 1.91 x 152 mm (0.075” x 6”) straps placed on both sides, are provided in Figures 13 & 14. All the interior studs were connected to the top and bottom tracks using one No.10-16 wafer-head self drilling screw / self tapping screw on each side. Similar to the walls with 101 mm (4”) strap braces, 300 x 300 mm (12” x 12”) gusset plates were used to connect the chord studs to the bottom tracks by fillet welding (3 mm) along the exterior edges (Fig. 15). The straps were fillet welded (3 mm) to the surface of the gusset plates as shown in Figure 15.

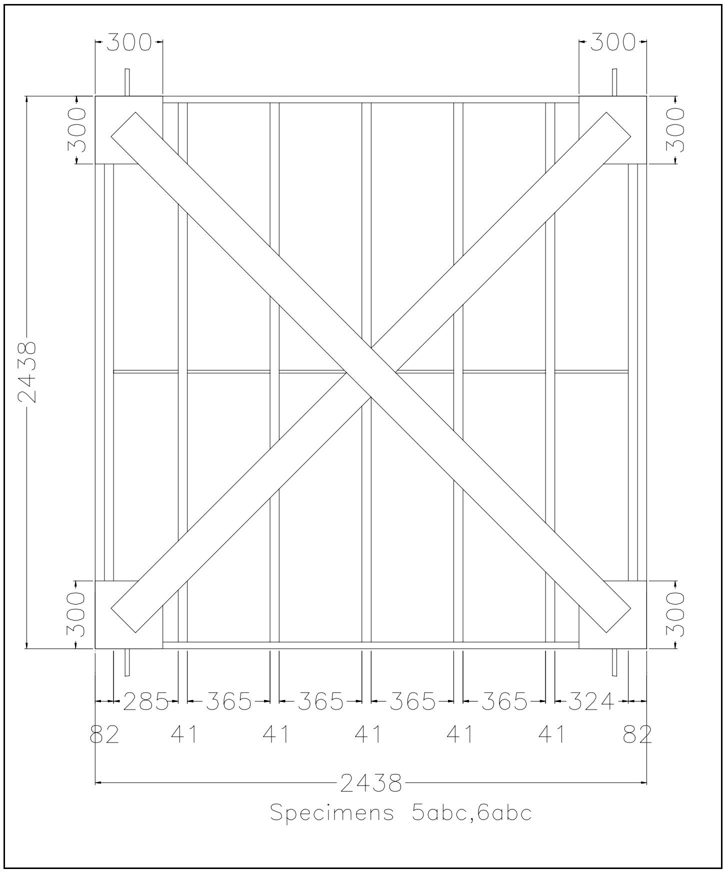

Figure 13: Nominal dimensions of specimens 5A-M, 5B-M, 5C-M and 6B-C

Once again, a holddown plate with an anchor bolt was used instead of a prefabricated holddown, similar to the configuration shown in Figure 12 for the medium size wall. In the case of wall 5B-M 19 x 90 x 127 mm (0.75" x 3.5" x 5") plates were used, while 19 x 127 x 203 mm (0.75" x 5" x 8") plates were installed in walls 5A-M and 6B-C. All the holddown plates were attached to the top and bottom tracks at the four corners of the wall. In an attempt to improve the performance of the plate holddowns, specially fabricated holddowns were installed in wall 5C-M, as shown in Figures 16 & 17. These holddowns were comprised of a C130 x 10 channel section fillet welded to a 19 x 90 x 127 mm (0.75" x 3.5" x 5") plate. A direct connection between the holddown and the webs of the chord studs was made through the installation of six 12.7 mm (1/2") threaded rods. Shear anchors consisted of ASTM A325

3/4” (19 mm) bolts. The holddown plates were connected with 3/4” (19 mm) diameter ASTM A325 threaded rods, except for test 5C-M, for which ASTM A307 rods were installed.

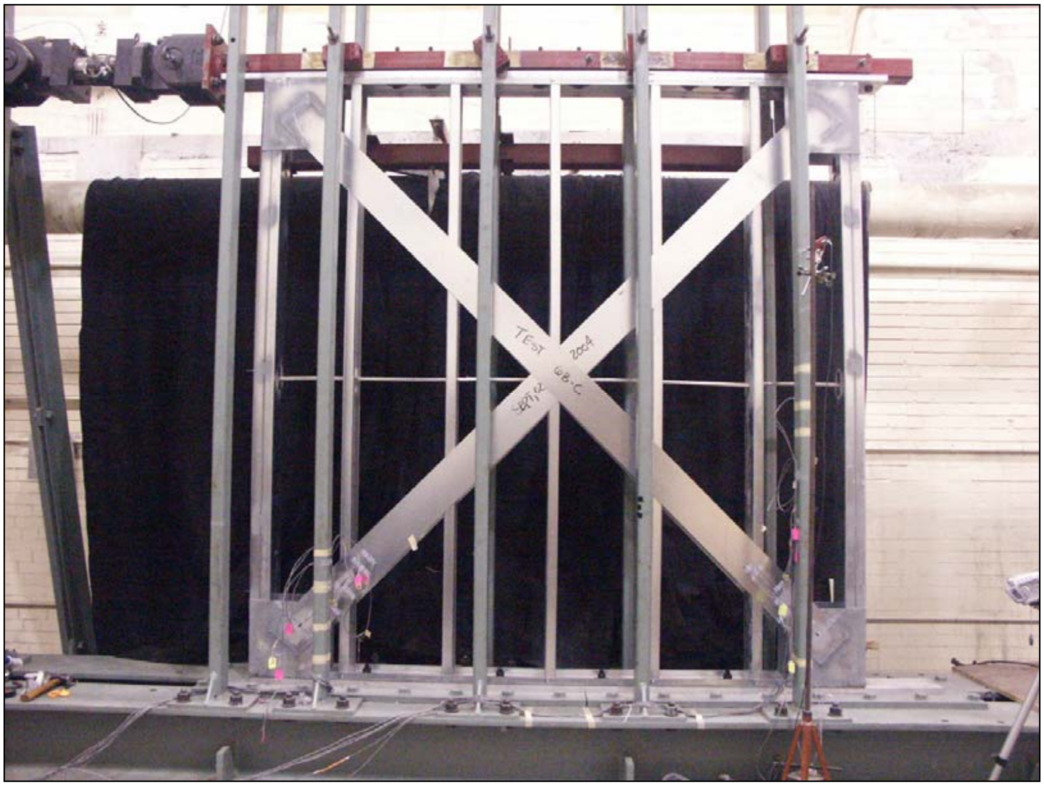

Figure 14: Typical wall with 152 mm (6”) strap brace prior to testing

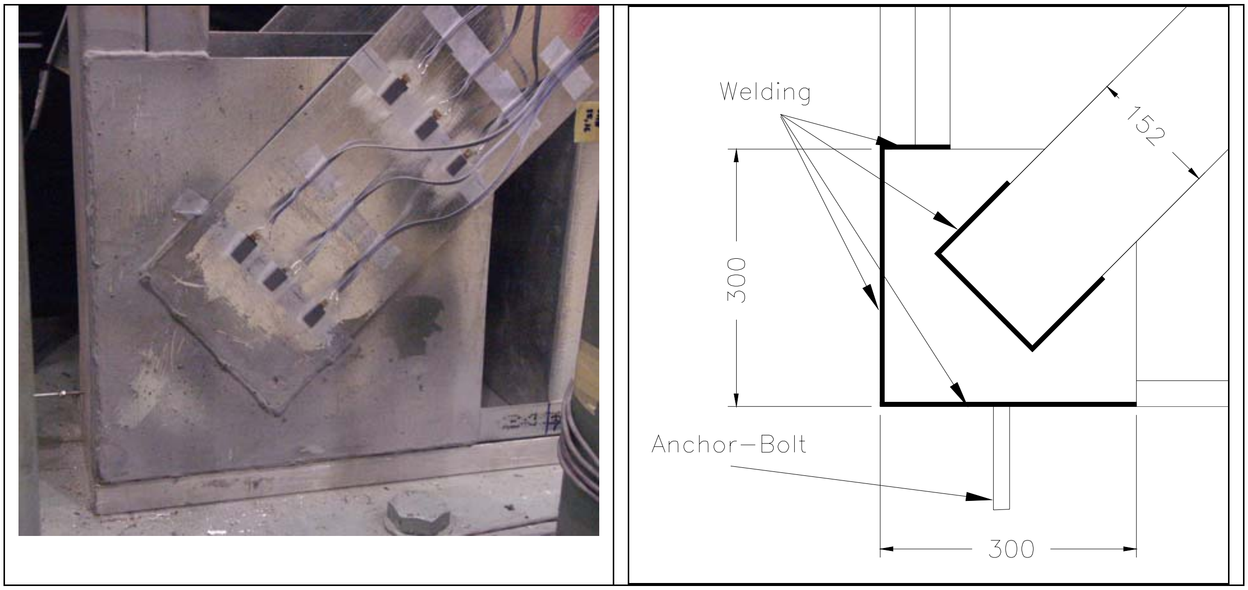

Figure 15: 152 mm (6”) Strap brace connection detail prior to testing

Figure 16: Special holddown for wall specimen 5C-M

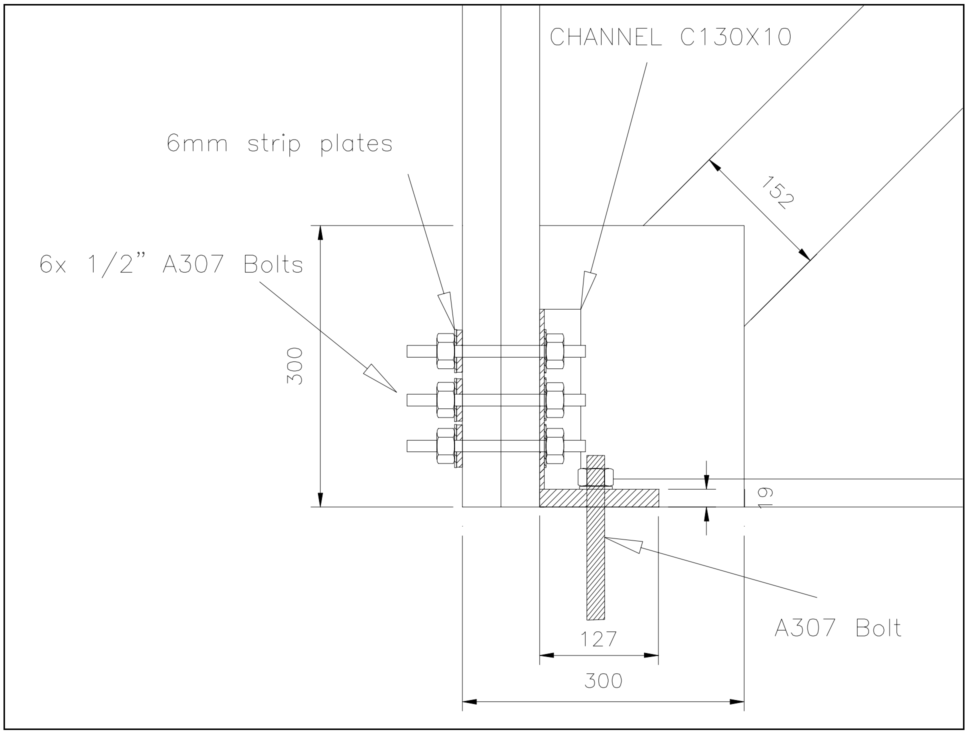

Figure 17: Plane section of the special holddown for wall specimen 5C-M

2.4 Test Assembly and Instrumentation

The walls were fabricated by Genesis by KML Ltd. of Cambridge, Ontario, and shipped to McGill University where they were measured and prepared for testing. Holes were first drilled / punched into the top and bottom tracks; then strain gauges were attached to the braces following the patterns shown in Appendix C. Once placed on the testing machine, the bottom track of the wall was first connected to the frame with an anchor rod at each end, in addition to the four shear bolts over the length of the wall, as shown in Figure 18. The upper track was then connected to the loading beam with an anchor rod at each end, as well as ten shear bolts (Fig. 18). The additional shear bolts along the upper track were installed to ensure that no slip occurred between the wall top and the loading HSS beam (Fig. 19). Five LVDTs were installed in order to measure the slip and uplift at the base of the wall, as well as the in-plane displacement at the top of the wall (Fig. 20).

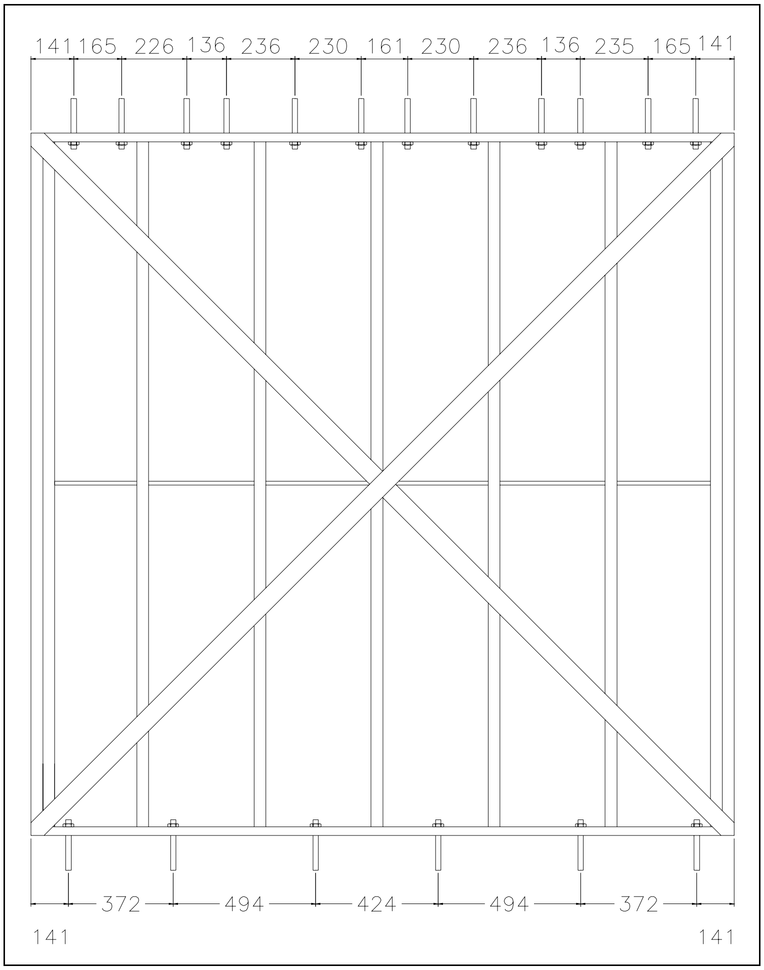

Figure 18: Typical anchorage for walls showing the spacing of all the shear rods and the anchor rods

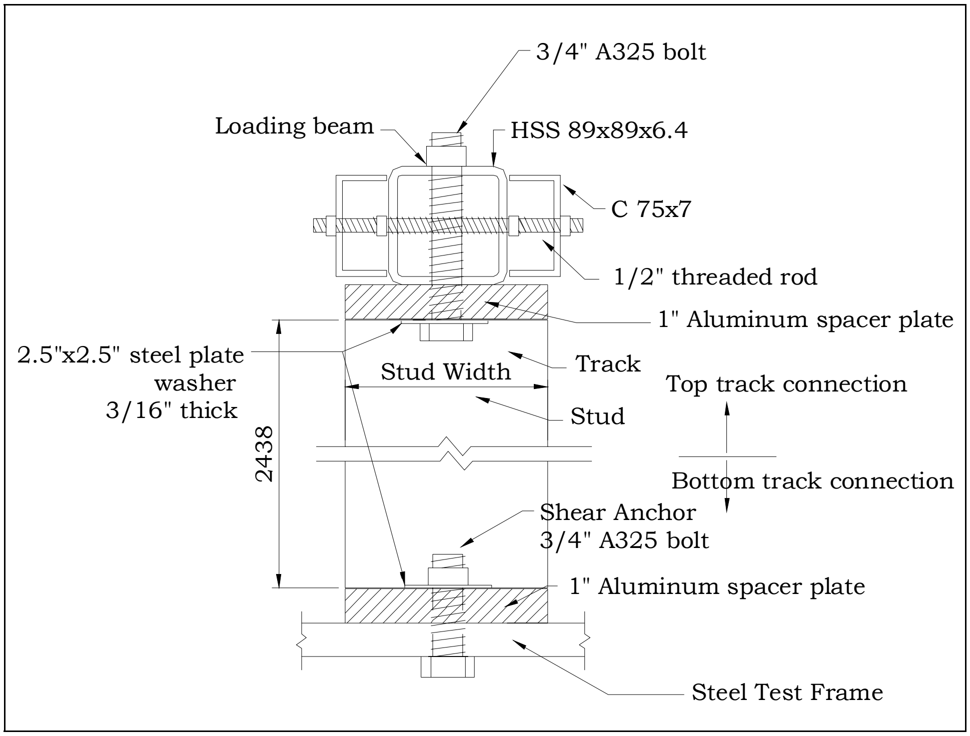

Figure 19 : Detail of loading beam and its components

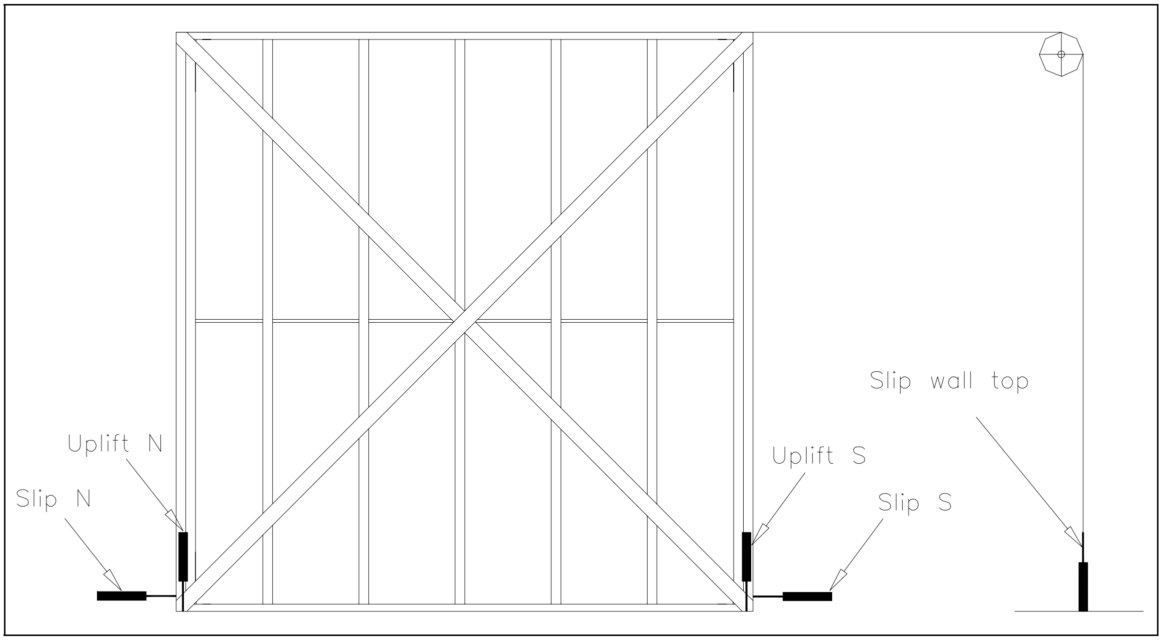

Figure 20 : Positioning of the LVDTs

2.5 Monotonic Loading Protocol

The monotonic load procedure consisted of a steady rate of displacement (2.5 mm / min) starting from the zero load position. In-plane displacement of the top of the wall continued until a sudden drop in the load carrying capacity was observed. A typical resistance vs. displacement graph for the 58.4 mm (2.3") strap braced walls is provided in Figure 21.

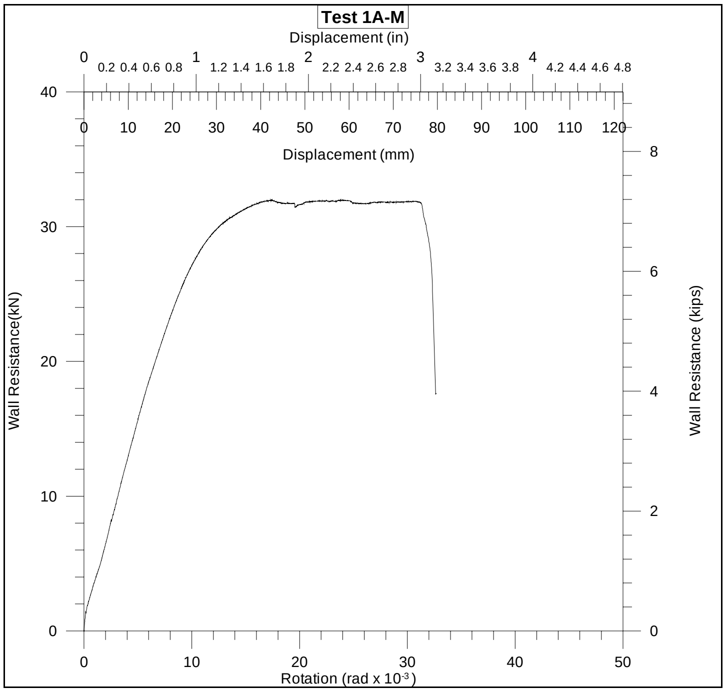

Figure 21 : Typical shear resistance vs. deflection curve for a monotonic test

2.6 Reversed Cyclic Loading Protocol

The CUREE (Consortium of Universities for Research in Earthquake Engineering) ordinary ground motions reversed cyclic loading protocol *(Krawinkler et al., 2000)* was chosen for the testing of the strap braced walls. This protocol is also specified in ASTM E2126 *(2005)* for the testing of walls constructed of metal framing with bracing or solid sheathing. Previous research at McGill University on light gauge steel walls braced with wood sheathing *(Boudreault, 2005; Branston, 2004; Chen, 2004)* also incorporated this loading protocol. It was selected because it was anticipated that the dynamic behaviour of the strap braced wall would resemble in some ways that of the wood sheathed walls. In addition, since a designer would typically be faced with the decision of using wood sheathing or braces for light gauge steel construction, it was felt appropriate to use the same protocol as implemented for the shear wall test program so that a direct comparison of results could be possible.

The CUREE protocol was developed with the philosophy that multiple earthquakes may occur during the lifetime of the structure. It subjects the wall to ordinary ground motions (not near-fault) whose probability of exceedance in 50 years is 10%. The loading history for the CUREE protocol it usually based upon the average ultimate deformation capacity of three monotonic test specimens, where the deformation capacity, Δ_m (maximum inelastic response), is a post-peak deflection defined as the position at which the wall resistance is reduced to 80% of the maximum (peak) resistance. In order to define the maximum deflection that the wall will sustain during a reversed cyclic test, a portion (i.e. $\gamma = 0.60$) of Δ_m is used as a reference deformation Δ. However, in a best case scenario where the braces are able to maintain their yield capacity, and given the range of displacement available from the actuator, no decrease in the wall resistance would be measured. Hence, it was not possible to use this definition of the reference deformation. For this reason, instead of relying on the post-peak deflection to define the deformation capacity, the yield displacement of the wall was incorporated in the calculation of the reference deformation. It was assumed that $\Delta = 2.667\ \Delta_y$, where Δ_y was obtained from the nominally identical monotonic wall tests. The complete cyclic loading history for a particular wall configuration was then based upon multiples of the reference deformation, Δ, which make up the initiation, primary, and trailing cycles of the protocol. A typical reversed cyclic displacement protocol in shown in Figure 22. A complete description of all the protocols used in testing is available in Appendix B. Note: in some cases a drop in load was measured during the monotonic tests due to a non strap brace related failure mechanism of the wall. In these situations the yield displacement of the wall was still used to define the reversed cyclic protocol.

In order to avoid excessive inertial effects due to the mass of the wall and certain components of the test frame, such as the load cell and loading beam, the frequency of the reversed cyclic tests following the CUREE ordinary ground motions protocol was kept at 0.5 Hz, except towards the end of the protocol where 0.25 Hz was used. A sine curve was employed to connect the displacement amplitudes for the reversed cyclic protocol. A typical reversed cyclic test resistance vs. deflection hysteresis for the 58.4 mm (2.3”) strap braced walls is provided in Figure 23.

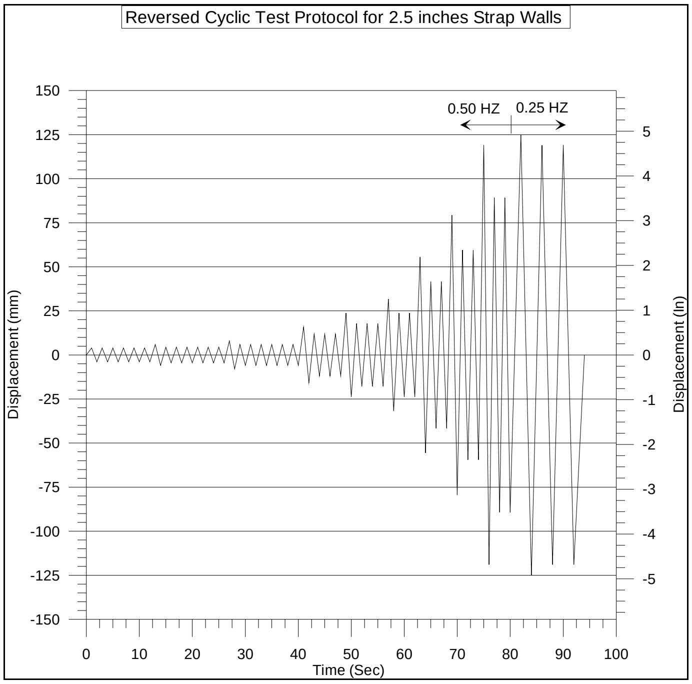

Figure 22: Typical reversed cyclic test protocol

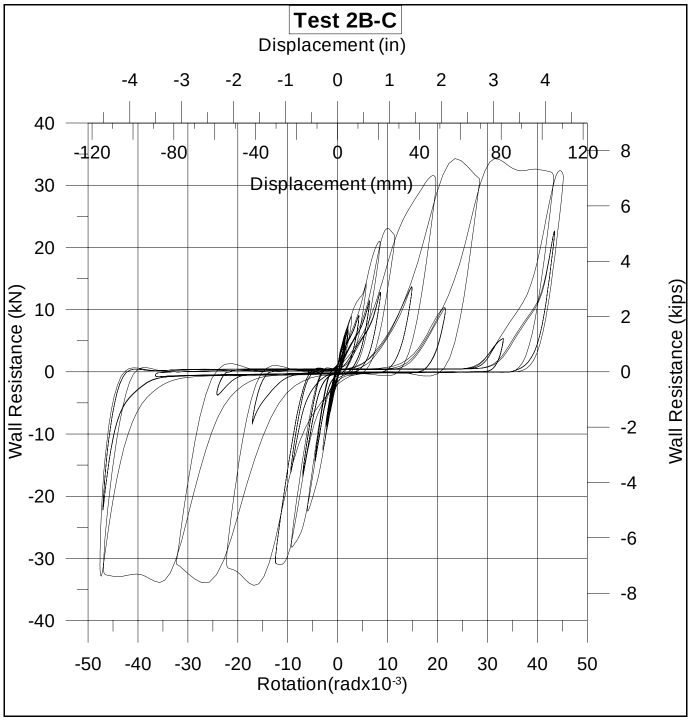

Figure 23: Typical shear resistance vs. deflection response curve for a reversed cyclic test

2.7 Analysis of Measured Test Data

2.7.1 Monotonic Tests

In order to calculate the measured elastic stiffness, K_e, of the strap wall test specimens, the load level at 40% of the maximum wall resistance obtained during the test, $S_{0.4}$, and the corresponding deflection, $\Delta_{S0.40}$, were first determined (Figure 24). At this load level the wall was considered to be in the elastic range of behaviour. The 40% level of ultimate resistance has previously been used by Branston *(2004)* to define the elastic stiffness for light gauge steel frame / wood panel shear walls, was proposed for use by Salenikovich *et al.*, *(2000)* and can be found in ASTM E2126 *(2005)*. The elastic stiffness was then calculated as shown in Equations 1 & 2.

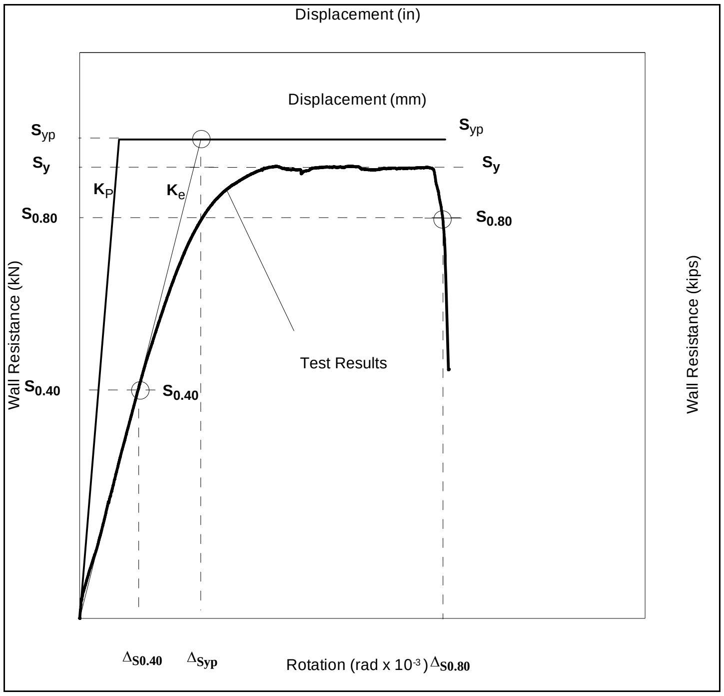

Figure 24: Definition of measured and predicted properties for monotonic tests

S_y: The maximum resistance recorded during testing

$$S_{0.40} = 0.40 \times S_y \qquad (1)$$

$\Delta_{S0.40}$: Measured displacement corresponding to $S_{0.40}$

K_e: Elastic stiffness of the wall system

$$K_e = \frac{S_{0.40}}{\Delta_{0.40}} \tag{2}$$

The predicted stiffness, K_p, and yield strength, S_{yp}, of each test wall were also determined using the measured dimensions of the strap braces and the mean yield stress as obtained from coupon tests (Section 2.8). The predicted elastic stiffness of the system, K_p, was calculated using the axial stiffness of the contributing (tension) straps on both sides of the wall. The predicted yield strength, S_{yp}, was based on the gross cross-section failure mode of the two strap braces. The average measured cross-sectional area of the straps was used in Equations 3 & 4.

K_p: Predicted elastic stiffness of the wall system

$$K_p = \frac{2 \times a \times E}{l} \times (Cos\alpha)^2 \tag{3}$$

S_{yp} = Predicted capacity of wall based on gross cross-section yielding of the strap braces

$$S_{yp} = 2 \times a \times F_y \times (Cos\alpha) \tag{4}$$

a : Measured cross-section area of one strap

E : Modulus of Elasticity (203000 MPa)

l : Length of one strap (exterior wall dimensions used)

α : Angle of straps with respect to horizontal

In order to evaluate the ductility of the tested walls the measured stiffness was used to first determine the ideal elastic deformation at the predicted loading level, Δ_{Syp}. The measured stiffness, K_e, was combined with the predicted yielding load level, S_{yp}, to obtain the deformation, as is shown in Equation 5.

Δ_{Syp}: Ideal elastic yield displacement

$$\Delta_{Syp} = \frac{S_{yp}}{K_e} \tag{5}$$

To calculate the wall ductility, the 80% post-peak load was considered as a reference at which the corresponding wall displacement was obtained, $\Delta_{0.80}$. The wall was considered to have reached the end of its useful capacity after losing more than 20% of its ultimate resistance. In the situation where no decrease in load carrying capacity was observed, the deformation at the end range of the actuator was used to determine a conservative estimate of the wall's ductility. The system ductility was then calculated as is shown in Equation 6.

μ : Ductility of the system

$$\mu = \frac{\Delta_{0.80}}{\Delta_{Syp}} \tag{6}$$

A complete set of graphs for the monotonic tests can be found in Appendix A.

2.7.2 Reversed Cyclic Tests

The resistance *vs.* displacement hysteresis graph was plotted for each wall specimen as illustrated in Figure 25. Each graph was then divided into two sections, one that represents the positive deformation and the other the negative deformation. The outer envelope of the hysteretic curve (backbone curve) was constructed using the most suitable peak points of the graph. In order to obtain a representation of the actual test data that could be used for calculation purposes a polynomial trend-line, which best accommodates the peak loads on the hysteresis graph, was constructed. Assuming that the trend-line (backbone curve) is equivalent to the monotonic curve, the predicted properties were calculated in the same fashion as utilized for the monotonically loaded test specimens (Section 2.7.1).

Prior to carrying out these calculations the wall resistance measured by the load cell, S, was adjusted to take into account the acceleration effects of the mass of the loading beam and the top half of the wall. The resulting resistance, S′, as shown in Equation 7, was then used in all calculations.

$$S' = S \pm \left(\frac{a \times g \times m}{1000} \right) \tag{7}$$

S′ = Corrected shear wall resistance (kN)

S = Measured shear wall resistance (kN)

a = Measured acceleration of the top of the wall, (g) (m/s^2)

g = Acceleration due to gravity (9.81 m/s^2)

m = Mass [250 kg for the loading beam + half the mass of the steel wall (58.5, 96.3, 107.1 kg for the 58.4 mm (2.5"), 101 mm (4") and 152 mm (6") strap walls, respectively)]

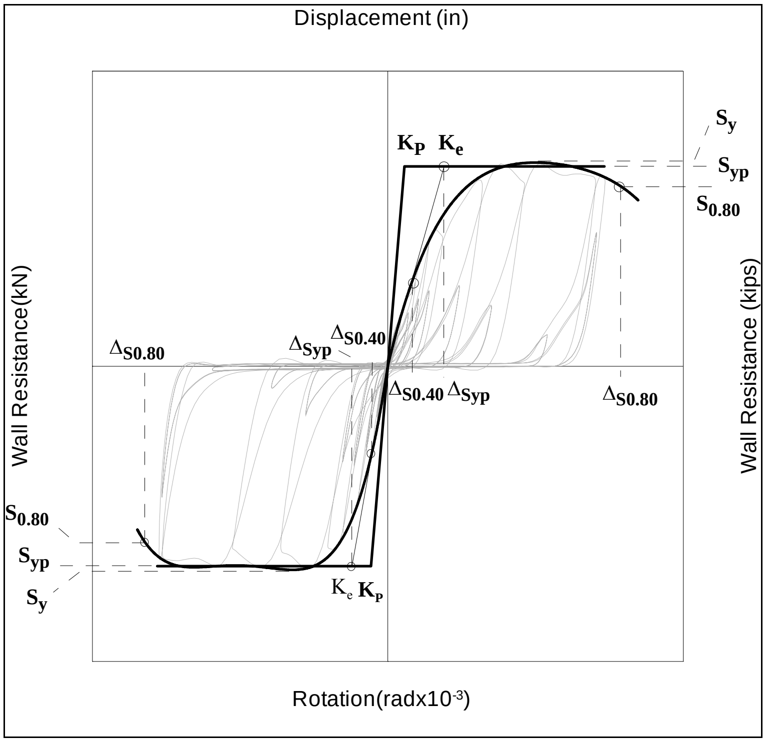

Figure 25: Definition of measured and predicted properties for reversed cyclic tests

A complete set of graphs for the reversed cyclic tests can be found in Appendix A.

2.8 Material Properties

Material tests were carried out for all of the wall components, including: straps, chords and tracks. In total, twenty seven coupons were tested according to ASTM A370 (2002) requirements. All steel coupon tension tests were conducted at a cross-head rate of 0.5 mm per minute in the elastic range, which was increased to a rate of 4 mm per minute beyond the yield point. A 50 mm gauge length extensometer was used to measure the extension of the coupon and to calculate percentage of elongation, yield stress and ultimate stress (Table 2). To determine the base metal thickness of the material, the zinc coating was removed with a 10 % hydrochloric acid (HCL) solution after testing.

All of the steels used in the construction of the test walls met the requirements of the North American Specification for Cold-Formed Steel Members *(CSA, 2001; AISI, 2002)*. That is, the ratio of F_u / F_y was greater than 1.08, and the elongation over a 50 mm gauge length exceeded 10 %, as shown in Table 2. It should be noted that the 1.22 mm (0.048") Grade 230 MPa steel was measured to have a yield stress 54% greater than the minimum nominal specified value (F_y / F_{yn}).

Table 2: Material properties of steel framing members

Member	Nominal Thickness (mm)	Base Metal Thickness (mm)	Yield Stress (F_y) (MPa)	Ultimate Stress (F_u) (MPa)	F_u/F_y	% Elong.	F_y/F_{yn}
Strap	1.91	1.83	262	346	1.32	38	1.14
Strap	1.52	1.48	279	350	1.25	40	1.21
Strap	1.22	1.16	353	440	1.24	33	1.54
Track	1.22	1.22	320	380	1.19	31	1.39
Stud & Chord	1.22	1.23	336	398	1.19	35	1.46
Track	1.52	1.59	330	400	1.21	35	0.96
Chord	1.52	1.56	329	397	1.21	39	0.95
Track	1.91	1.94	348	474	1.36	37	1.01
Chord	1.91	1.91	352	489	1.39	35	1.02

2.9 Modes of Failure

In terms of ductile seismic performance, the desirable mode of failure of a light gauge steel braced wall system is generally that of gross-cross section yielding of the straps. The 2005 NBCC *(NRCC, 2005)* requires the use of a capacity based design philosophy if force reduction factors greater than one are used in the calculation of equivalent static seismic loads. Essentially, the seismic force resisting system (SFRS) is constructed of elements and connections (Figs. 26 & 27) that are all, except for the fuse element, expected to remain in the elastic range of behaviour or exhibit only minor plastic damage. The fuse element, specified as the strap braces in this case, is expected to enter into the inelastic range of behaviour such that ground motion induced energy can be dissipated. Ideally, the braces would be able to maintain their yield capacity over extended lateral displacement of the wall without failure of the connections, gusset plates, tracks, chord studs and holddowns. The aim of this test program was to observe the failure mechanism of the walls under lateral loading and to comment on whether the performance met the capacity based design requirements.

In general, the overall performance of the walls under lateral loading was not governed by the yielding of the straps. Rather failure of or extensive damage to the tracks, chord studs, gusset plates, holddown threaded rods and straps (due to net section fracture) was often observed depending on the wall type being tested. These unfavourable modes of failure prevented the straps from maintaining their yield load, or from yielding altogether. Thus the ductility and energy absorption ability of the SRFS was reduced in comparison to what could theoretically be expected given the material properties of the strap braces. A description of the failure modes for each wall configuration is provided in Sections 2.9.1 to 2.9.3. Additional photographs of the failure modes are available in Appendix E.

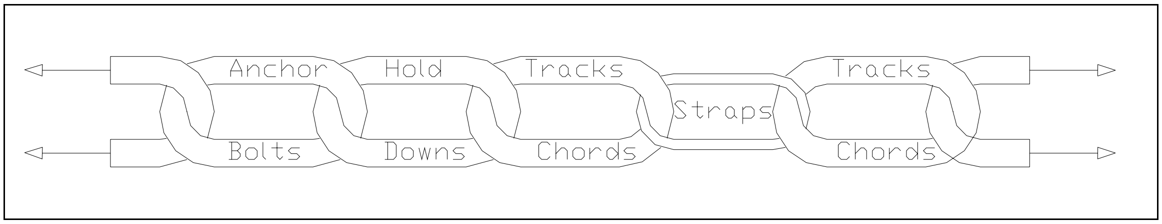

Figure 26: SFRS elements for walls with 58.4 mm (2.3") strap braces

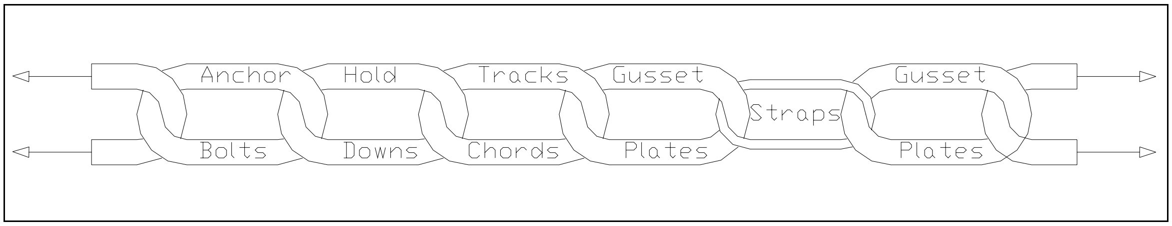

Figure 27: SFRS elements for walls with 101 mm (4") and 152 mm (6") strap braces

2.9.1 Modes of Failure for Test Walls with 58.4 mm (2.3") Strap Braces

Yielding of the straps occurred in all the walls, as can be seen in Figures 28 & 29 and from the strain gauge graphs in Appendix A. However, this was always combined with the failure, mostly concentrated around the holddown area, of other elements in the SFRS. Only in one wall did fracture of a brace take place (Test 1A-M) after approximately 30 x 10^{-3} rad of rotational displacement (Fig. 30). Buckling of the chord stud members caused either by compression or bending did not occur. A listing of the additional failure modes that were observed is as follows:

- Fracture of the straps at the net cross section in specimen 1A-M (Fig. 30).
- Failure of the anchor rod in tension in specimen 1B-M (Fig. 32).
- Connection failure due to pull out of the screws at the track-to-chord connection in specimens 2A-C and 2C-C (Fig. 33).
- Bending in the bottom track due to a holddown rotation in specimen 1A-M & 1B-M (Figs. 31 & 32).
- Compression failure of the track in specimens 2A-C, 2C-C and 2B-C (Figs. 33 & 34).

Figure 28: Typical wall with yielded 58.4 mm (2.3”) strap braces after reversed cyclic testing

Figure 29: Magnified view of yielded 58.4 mm (2.3”) strap braces after reversed cyclic testing

Figure 30: Net cross-section fracture of strap brace in specimen 1A-M

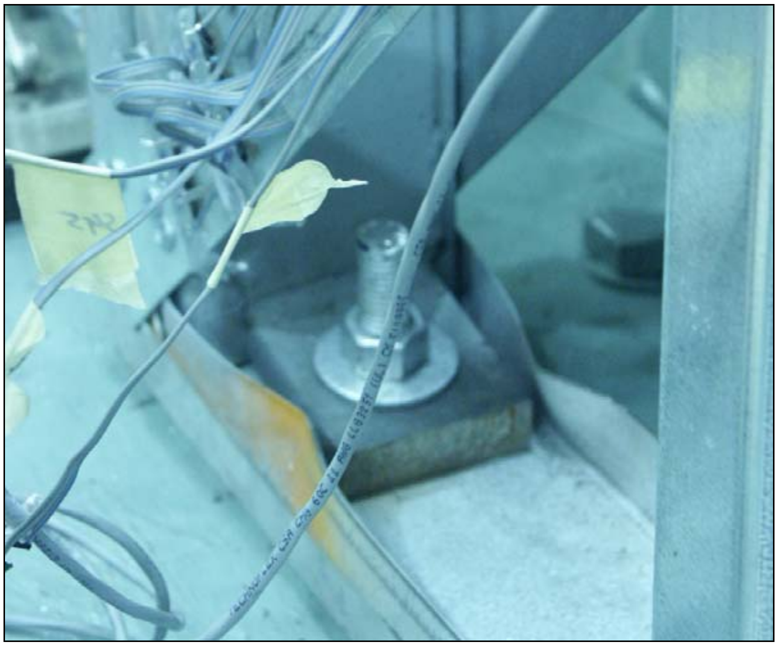

Figure 31: Bending in the bottom track of specimen 1A-M

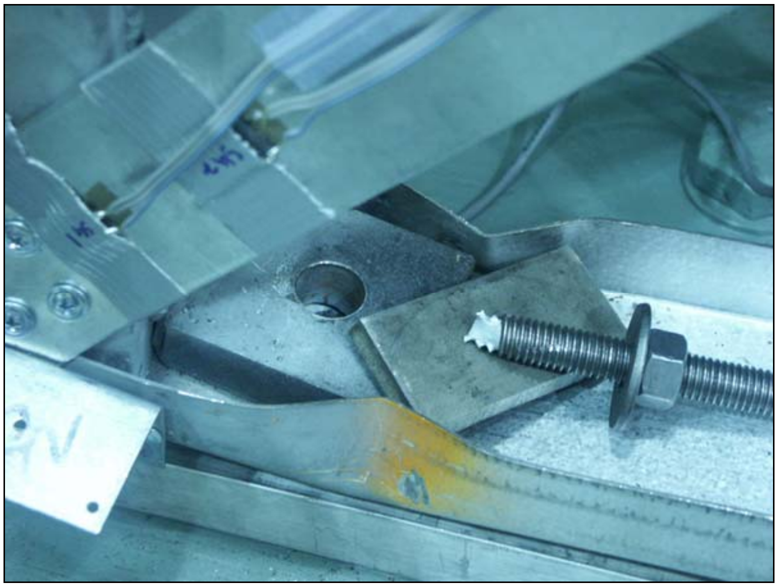

Figure 32: Tension failure of anchor rod in specimen 1B-M

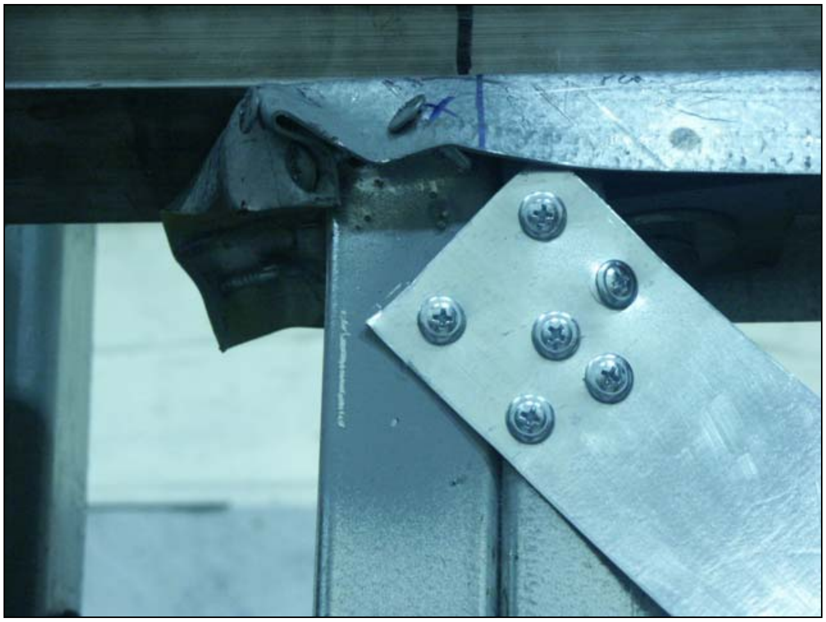

Figure 33: Chord to track connection failure in specimen 2A-C

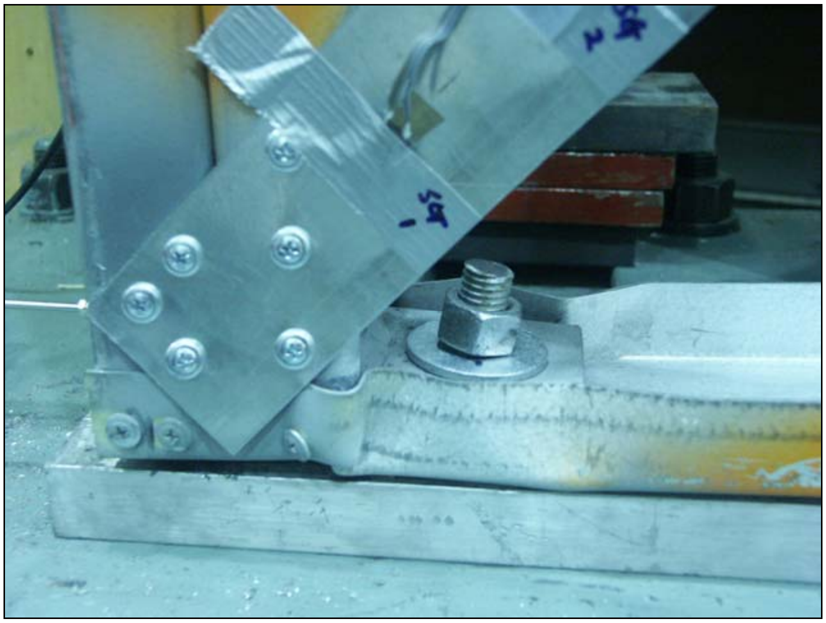

Figure 34: Compression failure of bottom track in specimen 2B-C

Note: the first test to be carried out was on Specimen 1B-M, for which failure of the threaded rod at the holddown occurred after yielding of the braces. A 1/2" (12.7 mm) diameter ASTM A307 threaded rod capable of carrying the expected factored load of 20 kN in a wind loading design situation had been installed. However, the gross cross-section yielding load of 30.4 kN, which can be linked to the high measured yield stress of the steel strap (Table 2), exceeded the capacity of the rod. For this reason a 5/8" (15.9 mm) diameter ASTM A307 threaded rod was installed in all other shear walls of this size such that anchor rod failure would not occur. Although the walls with 58.4 mm (2.3”) wide braces were able to reach their yield capacity, in a number of cases they were not able to maintain this load level because of compression failure in the track, which was usually combined with the pull-out of screws between the track and chord studs.

2.9.2 Modes of Failure for Test Walls with 101 mm (4”) Strap Braces

Yielding of the straps occurred in the medium size walls, as shown in Figure 35, only if adequate holddowns were installed. Even so, the straps were not able to maintain their yield force level due to extensive damage to the area adjacent to the holddown, specifically in the track and gusset plates. The main difference in configuration between these walls and the walls with 58.4 mm (2.3”) wide strap braces was that additional gusset plates were welded to the track, chord and strap. The gusset plate transferred the load from the strap through the welds to the track and the chord studs simultaneously. On the uplift side of the wall the track was then required to transfer the applied load to the 19 mm thick steel holddown plate, which in turn transferred the load to the threaded rod. Specimens 3A-M and 3B-M, which were the first of this series to be tested, were outfitted with 19 x 90 x 127 mm (0.75” x 3.5” x 5”) holddown plates. The punching shear capacity of the tracks around these plates was not adequate, and hence the failure mode shown in Figure 36 took place. For the remainder of the 101 mm (4”) strap braced wall specimens a larger holddown plate was installed in an attempt to alleviate the punching shear failure mode. This was successful to some degree, however permanent deformations / failure of the tracks, gusset plates and chord studs were observed as can be seen in Figures 37 to 40.

The gusset plates, located on both side of the wall, created a stiff corner that would rotate (Fig. 37) in a similar manner to a moment connection due to the weakness and lack of stiffness in the holddown / track area and the anchor rod. This rotation caused a moment to be applied to the chord studs, and hence local buckling would take place (Fig. 39). In one case (test 3C-M) the rotation of the bottom corner caused extensive tensile stresses on one side of the strap brace (Figs. 37 & 38), which ultimately resulted in its fracture. Punching shear failure of the track was also observed for the walls that were constructed with the larger holddown plates. Compression damage to the gusset plates was also observed in some cases when the punching shear failure of the track became excessive (Fig. 40). A listing of these failure modes, which could occur in combination, is as follows:

- Local buckling of the chord studs in specimens 3B-M, 3C-M, 4A-C and 4B-C (Fig. 39).
- Fracture of a strap due to corner rotation and excessive tensile stresses in specimen 3C-M (Figs. 37 & 38).
- Punching shear failure of the track in all specimens (Figs. 36, 38 & 40).
- Punching shear failure of the track with compression failure of the gusset plate in specimen 4B-C (Fig. 40).

Figure 35: Typical wall with 101 mm (4”) strap braces after reversed cyclic testing

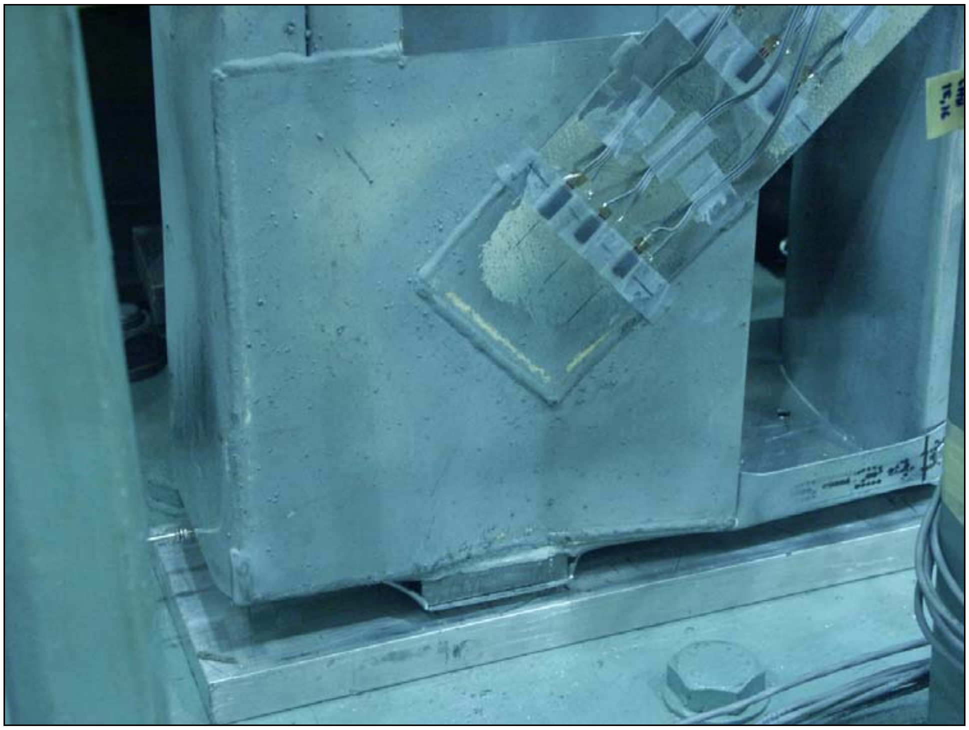

Figure 36: Punching shear failure of the track in specimen 3A-M

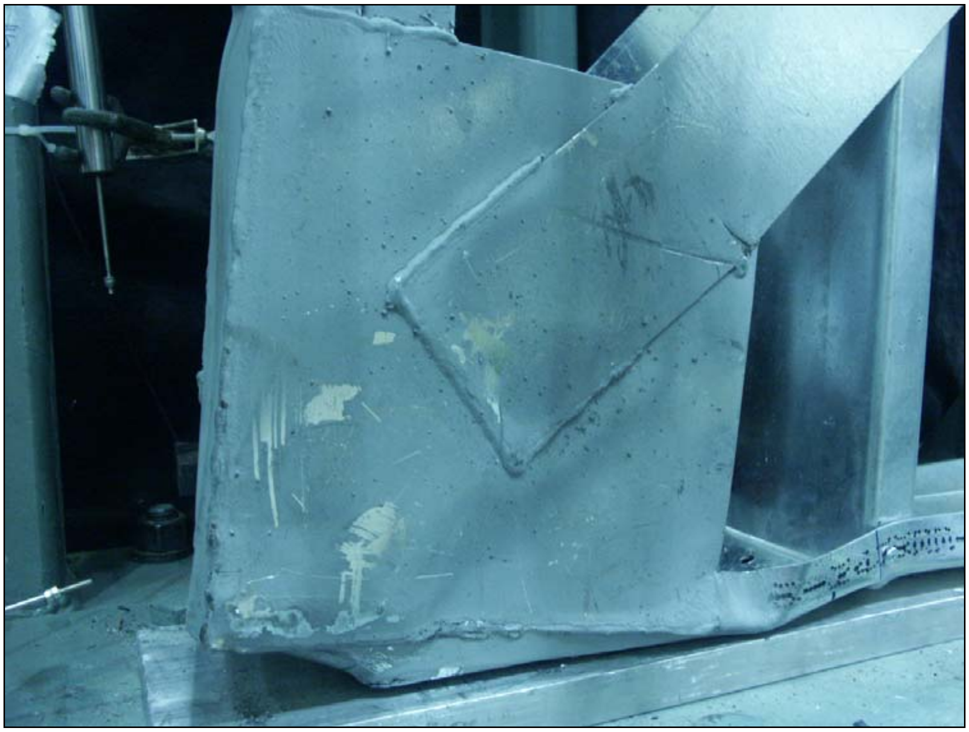

Figure 37: Initiation of tensile fracture in 101 mm (4”) strap brace in specimen 3C-M

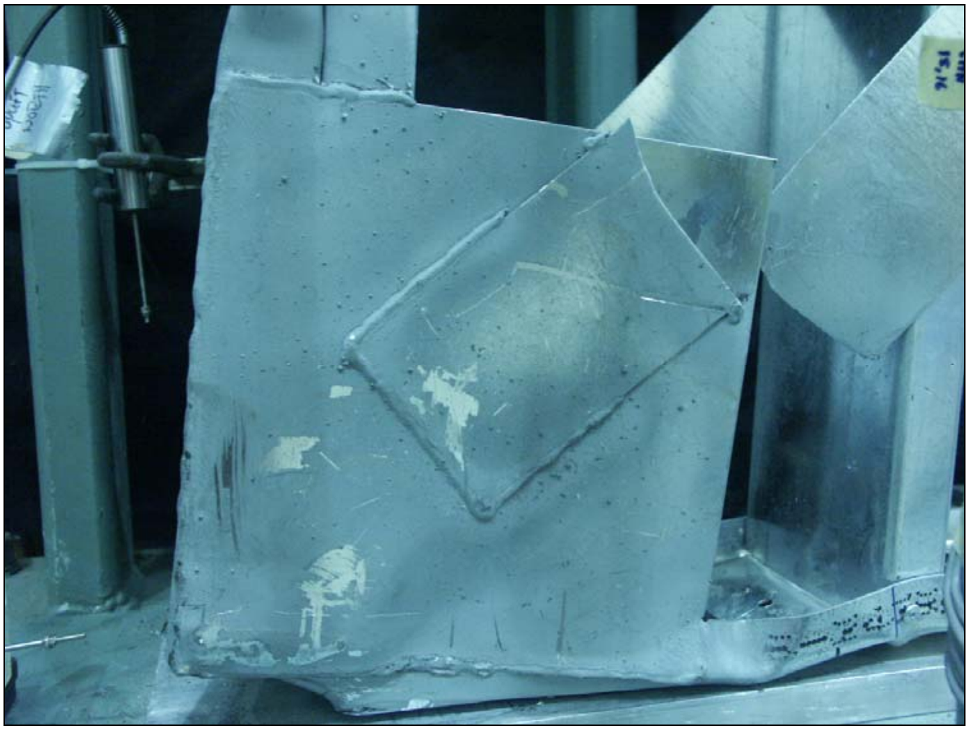

Figure 38: Cross-section failure of a 101 mm (4") strap with punching shear failure in the track of specimen 3C-M

Figure 39: Local buckling of the chord studs due to corner rotation in specimen 4A-C

Figure 40: Punching shear failure of the track with compression failure of the gusset plate in specimen 4B-C

2.9.3 Modes of Failure for Test Walls with 152 mm (6”) Strap Braces

The highest capacity walls in the test study experienced yielding of the strap braces only in some locations; in contrast, extensive damage to the area around the holddown was typically observed, as shown in Figures 41 - 46. Punching shear of the track occurred in all the tests, which did not allow the braces to reach their yield capacity in tension. It was also common to observe the chord studs being pulled in towards the centre of the wall due to the loss of compression resistance in the track and gusset plates after punching shear failure had taken place. Pull out of the screws that connect the interior studs to the bottom tracks was also witnessed (Fig. 46), mainly due to the large deformations experienced by the walls and because in some cases the straps had been screw connected to the interior studs. Similar to the 101 mm (4”) strap braced walls, rotation of the corner connections took place, which lead to moment induced local buckling of the chord studs on the uplift side of the wall (Fig. 44). Test specimen 5C-M was fitted with a modified holddown in an attempt to improve the connection at the chord stud / track / gusset plate location. This holddown was not of adequate design, which resulted in a similar failure mode as observed for the other test walls. In addition, the threaded anchor rod fractured in tension for this test wall (Fig. 45). A listing of these failure modes, which could occur in combination, is as follows:

- Punching shear failure of the bottom track in specimens 5A-M, 5B-M, 5C-M and 6B-C (Fig. 43).
- Moment induced local buckling of the chord studs in specimen 5A-M (Fig.44).
- Failure of the anchor rod in specimen 5C-M (Fig. 45).
- Local buckling in the gusset plate with corner rotation in specimens 5A-M and 6B-C (Fig. 43).
- Pull out of the screws that connect an interior stud to the track in specimen 6B-C (Fig. 46).

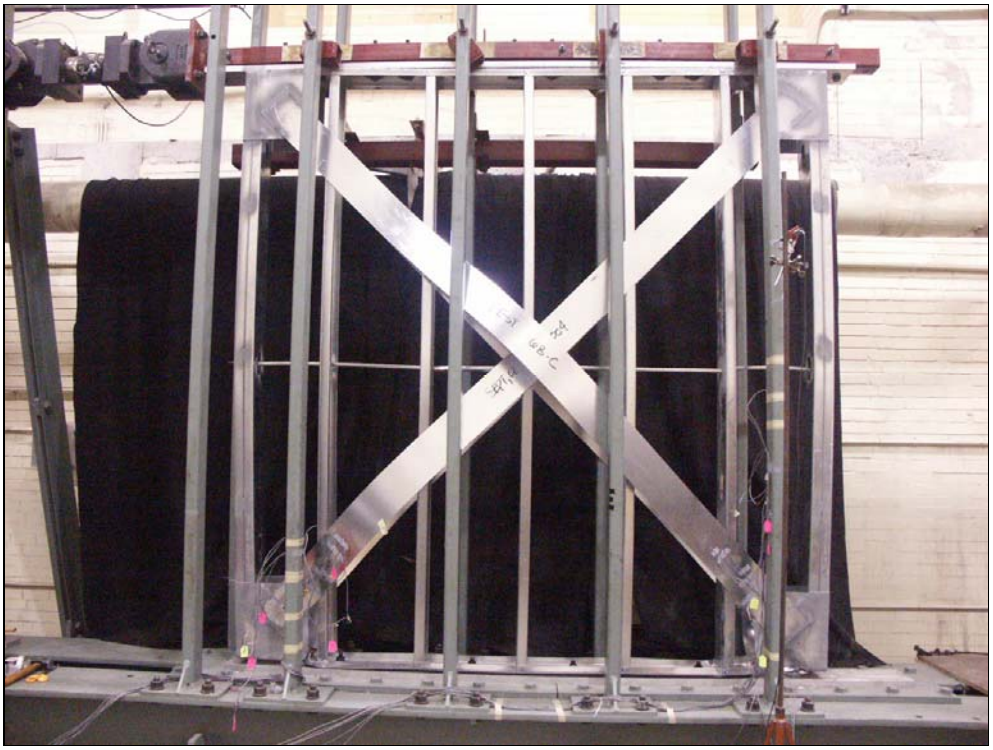

Figure 41: Wall with 152 mm (6”) strap braces after reversed cyclic testing

Figure 42: Magnified view of wall with 152 mm (6”) strap braces after reversed cyclic testing

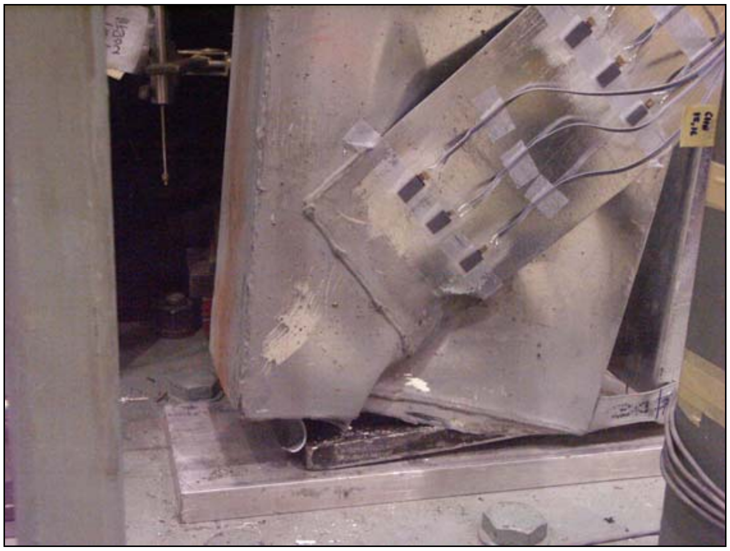

Figure 43: Punching shear failure of the track with compression failure of the gusset plate in specimen 5A-M

Figure 44: Punching shear failure of the track and local buckling in the chord studs of specimen 5A-M

Figure 45: Anchor rod failure of specimen 5C-M

Figure 46: Punching shear failure of the track and screw pull out failure between the interior stud and track in specimen 6B-C

2.10 Summary and Discussion of Test Results

The measured stiffness, K_e, and strength, S_y, of each braced wall was first determined from the test results. As well, the predicted stiffness, K_p, was calculated based on the measured dimensions and properties of the straps and the wall, as explained in Section 2.7 (Figs. 24 & 25). In addition, the predicted nominal stiffness, K_n, was calculated given the nominal dimensions and properties of the straps and the wall. With respect to the resistance of the strap braced walls, two parameters were calculated for comparison purposes; S_{yp} is the predicted yield strength of the wall based on the measured strap dimensions and properties, and S_{yn} is the predicted nominal yield strength of the wall based on nominal dimensions and properties. The ductility, μ, defined as the ability of the strap braced wall system to maintain its yield capacity while attaining significant lateral deformations was also determined (Section 2.7). It is an important factor in describing the performance of a seismic resistance system, i.e. it shows the ability of the system to dissipate energy, E, while maintaining strength. A summary of the test results and the predicted wall design properties are shown in Tables 3 & 4. A discussion of the performance of the three strap wall configurations is contained in Sections 2.10.1 to 2.10.3.

Table 3: Summary of monotonic test results

Specimen	S_y (kN)	K_e (kN/mm)	Ductility (μ) (mm/mm)	Energy (kN-mm)	S_{yp} (kN)	K_p (kN/mm)	S_y/S_{yp}	S_y/S_{yn}	K_e/K_p	K_e/K_n
1A-M	31.97	1.29	3.01	2086	33.93	4.00	94%	126%	32%	28%
1B-M	30.39	1.59	2.32	1123	33.73	3.98	90%	120%	40%	35%
1C-M	31.96	1.48	3.88	2810	34.03	4.01	94%	126%	37%	32%
Avg	31.44	1.45	3.07	2006	33.90	4.00	93%	124%	36%	32%
SD	0.909	0.152	0.782	846	0.153	0.015				
CoV	0.029	0.104	0.255	0.422	0.005	0.004				
3A-M	55.37	2.34	1.57	1478	58.88	9.20	94%	110%	25%	24%
3B-M	48.29	2.99	1.28	1332	58.84	9.20	82%	96%	33%	31%
3C-M	55.12	2.56	3.10	3610	58.77	9.19	94%	109%	28%	27%
Avg	52.93	2.63	1.98	2140	58.83	9.20	90%	105%	29%	27%
SD	4.017	0.331	0.978	1275	0.056	0.006				
CoV	0.076	0.126	0.493	0.596	0.001	0.001				
5A-M	82.93	3.61	2.21	5622	103.4	17.20	80%	88%	21%	20%
5B-M	59.79	5.97	1.78	1943	103.6	17.22	58%	63%	35%	33%
5C-M	81.23	3.85	2.09	3537	103.4	17.18	79%	86%	22%	22%
Avg	74.65	4.48	2.03	3701	103.5	17.20	72%	79%	26%	25%
SD	12.90	1.299	0.222	1845	0.108	0.020				
CoV	0.173	0.290	0.109	0.499	0.001	0.001				

Table 4: Summary of reversed cyclic test results

Specimen	S_y (kN)	K_e (kN/mm)	Ductility (μ) (mm/mm)	Energy (kN-mm)	S_{yp} (kN)	K_p (kN/mm)	S_y/S_{yp}	S_y/S_{yn}	K_e/K_p	K_e/K_n
2A-C (+ve)	35.26	1.27	4.11	10167	34.00	4.01	104%	139%	32%	28%
2A-C (-ve)	35.29	1.08	3.10				104%	139%	27%	23%
2B-C (+ve)	34.50	1.18	3.83	10571	33.83	3.99	102%	136%	30%	26%
2B-C (-ve)	34.47	1.18	3.83				102%	136%	30%	26%
2C-C (+ve)*	38.97	2.26	6.33	5967	33.91	4.00	115%	153%	56%	49%
2C-C (-ve)	35.49	1.22	4.22				105%	140%	31%	27%
Avg	35.00	1.19	3.82	8902	33.91	4.00	103%	138%	30%	26%
SD	0.48	0.07	0.44	2550	0.08	0.01				
CoV	0.014	0.059	0.114	0.286	0.002	0.002				
4A-C (+ve)	59.47	2.36	1.98	19006	58.98	9.22	101%	118%	26%	25%
4A-C (-ve)	60.07	2.09	1.89				102%	119%	23%	22%
4B-C (+ve)	62.31	2.27	2.23	18663	60.64	9.48	103%	124%	24%	24%
4B-C (-ve)	60.59	2.05	1.87				100%	120%	22%	21%
4C-C (+ve)	55.69	2.21	2.00	18513	59.80	9.35	93%	110%	24%	23%
4C-C (-ve)	56.40	2.43	2.26				94%	112%	26%	25%
Avg	59.09	2.24	2.04	18727	59.81	9.35	99%	117%	24%	23%
SD	2.55	0.15	0.17	253	0.74	0.12				
CoV	0.043	0.067	0.082	0.013	0.012	0.012				
6B-C (+ve)	87.13	3.79	2.01	26051	103.5	17.2	84%	92%	22%	21%
6B-C (-ve)	83.56	3.48	1.88				81%	88%	20%	19%
Avg	85.35	3.64	1.95	26051	103.5	17.2	83%	90%	21%	20%

*2C-C (+ve) not included in calculation of statistical parameters.

2.10.1 Test Walls with 58.4 mm (2.3") Strap Braces

Yielding of the 58.4 mm (2.3") wide straps occurred in all of the monotonic tests, even for specimen 1A-M which eventually failed by net-section fracture (Fig. 30). Wall 1C-M was able to maintain its yield capacity up to the full range of the actuator (approx. 40×10^{-3} rad), whereas wall 1A-M suffered from the fracture of a single strap at approximately 32×10^{-3} rad (Fig. 47). Wall 1B-M did reach the yield capacity, but failed soon after due to the undersized anchor rod. An average wall resistance of 31.44 kN, equal to 93% of the predicted value based on measured properties was attained. The full predicted capacity was not reached most likely because of the increase in F_y due to the strain rate effect that would have occurred during testing of the coupons. That is, the yield stress of the coupon was higher than the yield stress of the strap brace due to the lower speed of testing used for the full walls. The estimated strain rate for the coupons was 0.0667 mm/mm/min, which is 92 times greater than the approximate strain rate determined for the strap walls (0.000725 mm/mm/min). When the nominal strap size and material properties were used to calculate the predicted resistance a 124% strength level was reached during testing. The test walls attained a higher load level than predicted mainly because the measured yield stress of the braces was significantly higher than the minimum specified (nominal) 230 MPA. This was offset slightly by the measured base metal thickness, which was less than the assumed nominal 1.22 mm (Table 2) and the strain rate effects.

In terms of predicted stiffness levels none of the monotonically tested walls were able to reach the expected 4.00 kN/mm. As is illustrated in Figure 47, K_e was substantially lower than K_p. This can also be seen in the K_e / K_p and K_e / K_n ratios provided in Table 3. These predicted stiffness values were based solely on the dimensions and material properties of the straps. From observations of the large deformations and damage at the holddown locations, as well as the measured stiffness values, it is apparent that in this case the configuration / flexibility of the holddowns have caused a decrease in the stiffness of the test walls. The predicted stiffness of the braced wall cannot be based solely on the axial stiffness of the strap braces.

An average ductility of 3.07 was obtained for the three monotonic test walls, which is an indication that the straps were able to yield over their length even as the holddown locations were damaged. This includes specimen 1B-M, in which the final failure was caused by fracture of the anchor rod in tension. An average energy dissipation value of 2006 kN mm was determined for the three walls. This could have been higher if wall 1B-M had been detailed with a larger anchor rod to avoid tension fracture.

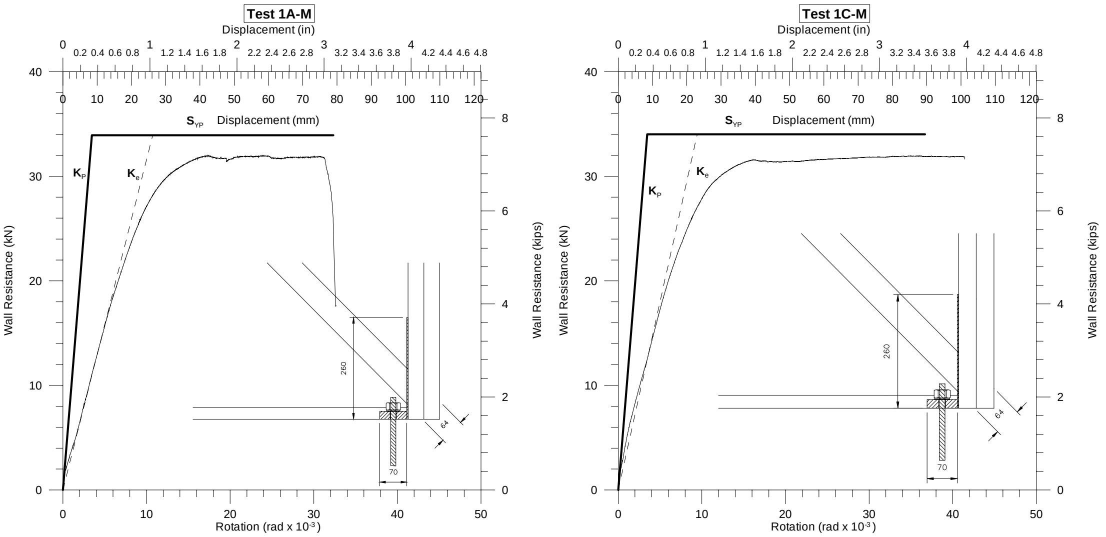

Figure 47: Comparison of resistance vs. displacement curves of 58.4 mm (2.3”) strap braced walls

The cyclic tests, 2A-C, 2B-C and 3C-C, had an average measured resistance of 35.00 kN, which is 3% higher than the predicted S_{yp} value (Table 4). A higher yield capacity was reached compared with the monotonically loaded walls due again to strain rate effects. In this case, the walls which were tested at a frequency of 0.5 Hz would have reached a much higher strain rate than experienced by the monotonic tests. This would likely have elevated the yield stress of the strap braces, and hence increased the overall lateral capacity of the braced wall. Similar to the result obtained for the monotonic tests, the ratio of measured to nominal predicted yield capacity, S_y / S_{yn}, was 138%, mainly due to the yield stress which was significantly higher than the nominal value. In all walls the braces were able to yield without any net section fracture or anchor rod failure. However, as discussed in Section 2.9.1 damage to the holddown / track-to-chord stud connection location was observed.

The measured stiffness, K_e, was substantially lower than that predicted (Table 4) for the same reason presented for the monotonic tests. The walls were able to perform in a ductile manner; that is they were able reach and maintain their yield capacity throughout most of the reversed cyclic loading protocols. An average ductility of 3.82 was determined. Upon closer examination it can be shown that the measured behaviour did not match that expected in an optimal tension only inelastic bracing system (Fig. 48). The walls did reach their yield capacity during most cycles, however often the resistance decreased in the latter stages of each cycle. This drop in load was caused by the damage occurring at the holddown / track-to-chord stud connection locations. In some instances, when the damage at these locations became extreme (Fig. 33), the strap walls were unable to maintain their yield capacity. An example of this can be seen in Figure 49, where for the negative load /displacement region of test 2A-C there is a significant decrease in load above the 30×10^{-3} rad displacement level compared with test 2B-C.

In test 2C-C only the latter stages of the reversed cyclic protocol were run due to a malfunction in the control system (Fig. 60 Appendix A). The wall resistance and stiffness in the negative range was similar to the other cyclic walls; however, the dissipated energy was less because fewer displacement cycles were completed. Furthermore, in the positive range of load and displacement, both the stiffness and strength were higher mainly due to the lack of initiation displacement cycles and the sudden extreme strain rate that was experienced by the wall.

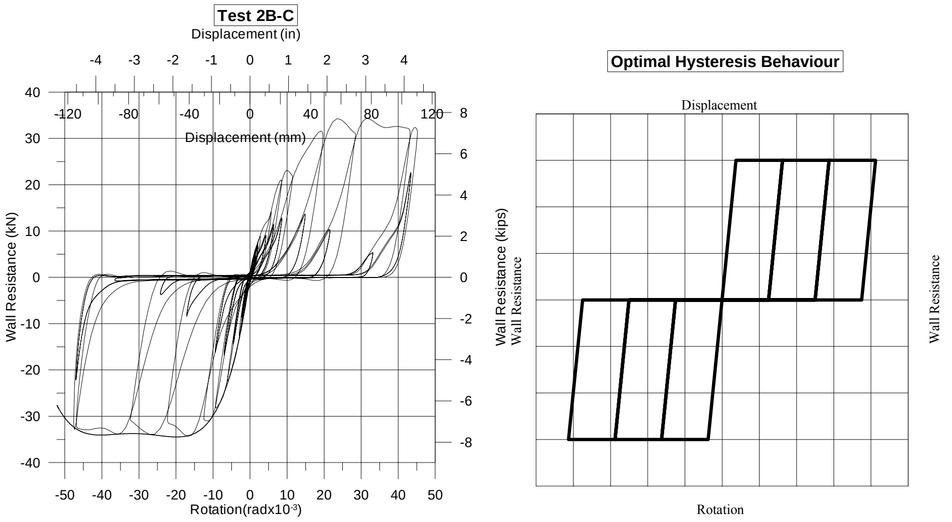

Figure 48: Optimal hysteretic behaviour (right), hysteretic behaviour of wall 2B-C (left)

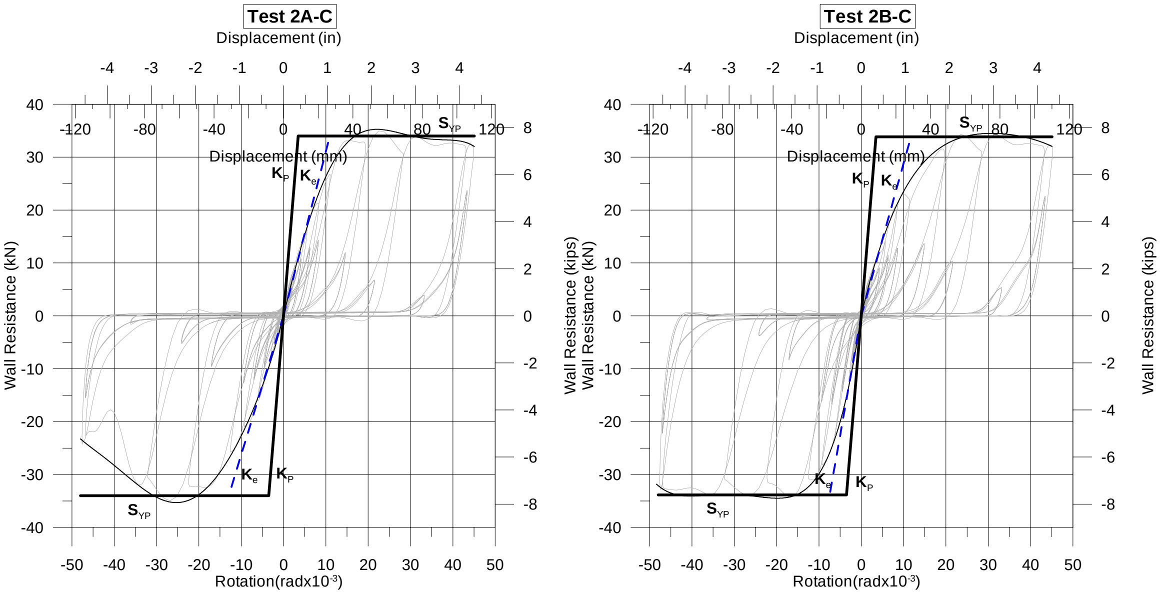

Figure 49: Comparison of resistance vs. displacement hystereses of 58.4 mm (2.3") strap braced walls

2.10.2 Test Walls with 101 mm (4") Strap Braces

It was observed for the monotonic tests 3A-M, 3B-M and 3C-M that the onset of yielding took place (Fig. 50), however due to punching shear failure of the track (Section 2.9.2) it was not possible for the straps to maintain their yield load. The holddown plate / anchor rod / track detail at the track to chord stud connection location was inadequate to allow for the wall to maintain its yield capacity. An average wall resistance of 52.93 kN was measured (Table 3), which corresponds to a performance ratio of S_y / S_{yp} = 90% and a nominal performance ratio of S_y / S_{yn} =105%. The 10% shortcoming in the ratio of S_y / S_{yp} is probably due to the strain rate used for the wall testing compared with that used for the coupons. The early onset of punching shear failure in the tracks may also have limited the capacity of the wall.

The welded gusset plates likely increased the wall stiffness compared with what would be obtained from the strap braces alone. However the average K_e of 2.63 kN/mm for the monotonic tests was well below the expected stiffness, K_p = 9.20 kN/mm, due to the flexibility of the holddown plate / anchor rod / track detail, as well as the extreme damage that occurred. An average ductility value of 1.98 was calculated, an indication of the inability of the walls with 101 mm (4") strap braces to carry loads when subjected to large displacements. After punching shear failure of the track occurred (Figs. 36, 37 & 40) the corner of the wall was able to rotate with little resistance provided for lateral loads. In addition, the fracture of a strap brace in specimen 3C-M was attributed to the extreme rotation of the corner (Fig. 38), which again reduced the ductility of the wall. The energy dissipation results for the three walls were quite variable due to the use of different holddown plate sizes (Section 2.2).

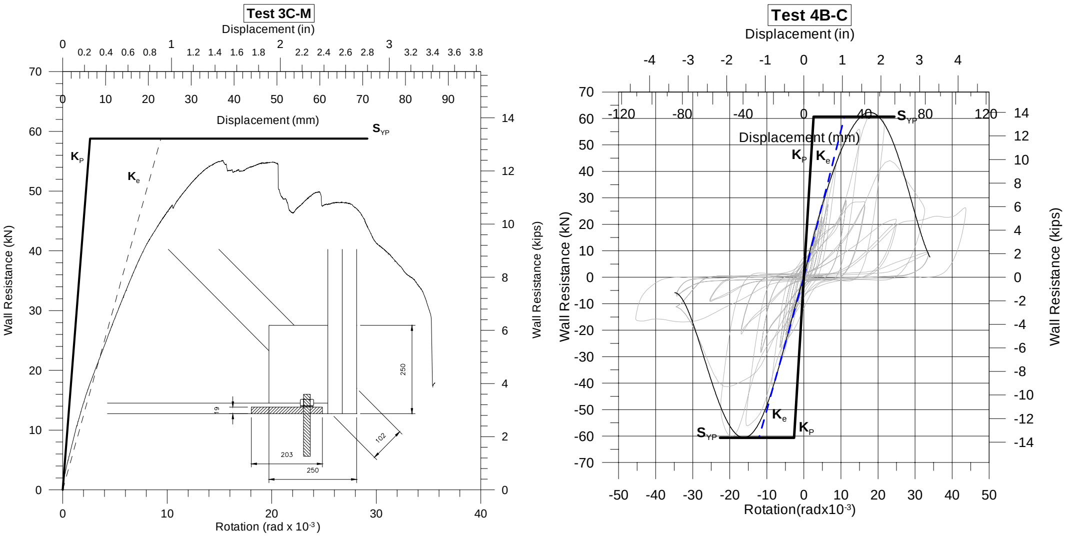

Figure 50: Resistance vs. displacement curves of 101 mm (4") strap braced walls

Similar findings were obtained for the reversed cyclic tests, 4A-C, 4B-C and 4C-C, except that a higher average resistance of 59.09 kN was reached (Table 4). This resulted in a performance ratio of S_y / S_{yp} = 99% and a nominal performance ratio of S_y / S_{yn} = 117%. The increased load levels can be attributed to the strain rate effect experienced by the strap braces. Nonetheless, as is shown in Figure 50, these walls were unable to maintain their load carrying capacity due to punching shear failure of the tracks. No yield plateau was observed, instead a sharp peak resistance was recorded, followed by a sudden degradation in load carrying ability. The stiffness and ductility were affected by the holddown detail in the same fashion as discussed for the monotonic tests.

The fuse element in the seismic force resisting system ultimately was the holddown plate / anchor rod / track connection, instead of the strap braces. The mode of failure did not allow for the yield capacity of the braces to be maintained, and hence this system was not considered to have performed in the ductile fashion that would have been assumed following a capacity based design approach.

2.10.3 Test Walls with 152 mm (6”) Strap Braces

The monotonic tests 5A-M, 5B-M and 5C-M had the lowest performance ratio of all the strap brace walls that were included in the study. An average capacity of 74.65 kN was measured, which corresponds to an S_y / S_{yp} ratio of 72% and a nominal performance ratio of S_y / S_{yn} = 79% (Table 3). Yielding was seen in some areas of the braces, based on strain gauge measurements (Appendix A), however the overall yield capacity of the brace was not reached at any time (Fig. 51). As was observed for the walls with 101 mm (4”) braces, punching shear failure of the track controlled the wall resistance, stiffness and ductility. The measured stiffness K_e was only 26% of the expected value (Table 3).

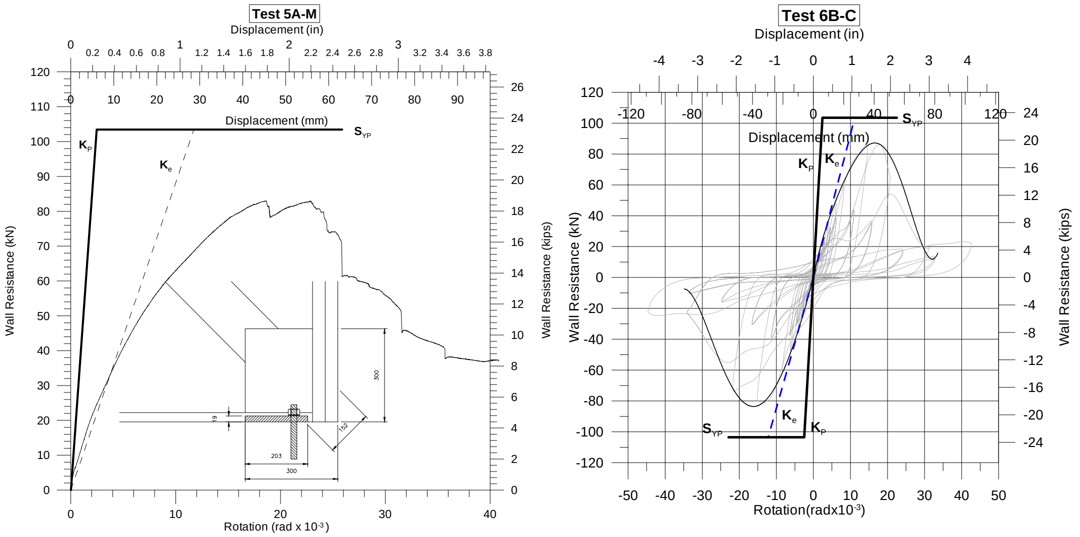

Figure 51: Resistance vs. displacement curves of 152 mm (6”) strap braced walls

Given the poor results of the monotonic tests only one reversed cyclic test was completed (6B-C) (Fig. 51). The average maximum resistance of the negative and positive displacement cycles was 85.34 kN (Table 4). This provided a performance ratio of S_y / S_{yp} = 82% and a nominal performance ratio of S_y / S_{yn} = 90%. Punching shear failure of the bottom track once again controlled the behaviour of the wall. The observed stiffness and ductility were similar to that recorded for the monotonic tests. As found for the 101 mm (4”) strap braced walls, the holddown plate / anchor rod / track detail at the track to chord stud connection location was inadequate to allow for the wall to maintain its yield capacity, and hence to act in a ductile fashion.

3.0 CONCLUSIONS AND RECOMMENDATIONS

A total of 16 light gauge steel frame strap braced walls were tested monotonically and cyclically in order to evaluate their performance in the inelastic range of behaviour. The walls were not designed following a strict capacity based design philosophy. Rather, the test walls, which were cross braced with 58.4 mm (2.3”), 101 mm (4”) and 152 mm (6”) wide straps, were selected given typical wind loading levels where all of the components in the lateral load carrying path were expected to remain elastic. The wall specimens were evaluated according to capacity based design philosophy for which gross cross-section yielding of the tension braces alone was the anticipated failure mode under lateral loading. Other elements in the lateral load carrying path were expected to remain in the elastic range of behaviour or to have experienced only a minor amount of plastic deformation.

The 58.4 mm (2.3”) straps of the light walls were able to yield completely, which provided for the best ductility ratio of 3.07 and 3.82 for the monotonic and cyclic tests, respectively. However, extensive damage was typically observed at the track to chord stud connection location, which in some cases prevented the walls from maintaining their yield capacity. The yield stress obtained from the coupon tests was 54% higher than the minimum specified 230 MPa, which could lead to difficulties in selecting holddowns, anchor rods and brace connections if a capacity based design approach were followed. A comparison of monotonic and reversed cyclic test results indicated that the effect of strain rate needs to be considered because it will cause the brace forces to increase as the rate of displacement increases. The measured lateral in-plane stiffness of the walls was significantly less than that predicted, mainly due to the flexibility of the holddown connections.

The walls with 101 mm (4”) strap braces were able to reach their yield capacity, but could not maintain this load level over extended displacements. This resulted in a lower ductility ratio than the light walls. The inability to carry load as the lateral displacement increased was caused by the extensive punching shear damage at the track location due to the configuration of the holddown plate / anchor rod / track detail. Rotation of the wall corners due to the flexible holddowns also resulted in local buckling of the chord studs due to applied bending moments, and in one case fracture of a brace. Similar to the light walls, the measured stiffness was substantially lower than that predicted, which can also be attributed to the flexibility of the holddowns.

The 152 mm (6”) strap braces were only able to yield in some localized areas. Overall, the large walls were not able to reach their gross-cross section yield capacity, nor were they able to maintain a load carrying capacity as the applied displacement increased. These walls possessed a ductility ratio that was the lowest of all the specimens that were tested. The capacity and ductility of the test walls was limited by the extensive punching shear damage that occurred at the track locations due to the holddown plate / anchor rod / track detail. As found for the other two wall configurations, the measured stiffness was significantly below that predicted from the axial stiffness of the braces.

In general, the strap braced test walls, as designed, were not able to maintain a yield level load carrying capacity over extended displacements, with the exception of the light walls. Moreover, the large walls were not able to reach the load level associated with gross cross-section yielding. The extensive damage to the holddown / chord stud / track location in almost all test walls showed that the inelastic deformations were not limited to the brace elements of the lateral force resisting system. At this stage of the investigation, given the performance of the test walls, it is not possible to assign the light gauge steel strap braced wall configuration a ductility level that could be used to develop force modification factors for seismic design. However, knowing that these test walls were not designed following a capacity based design approach does indicate that the inelastic performance could possibly be improved if additional design steps were taken. It is recommended that supplementary tests of strap braced walls be carried out, for which the elements in the lateral force resisting system of the test specimens are selected based on the probable capacity of the strap braces. An accurate estimate of the yield stress of the brace material is needed, which accounts for both the effects of the higher than minimum nominal yield stress due to the manufacturing processes and the strain rate under seismic loading. Furthermore, the holddown detail needs to be improved, such that the probable brace loads can be carried with minimal rotation and inelastic damage to the track, chord studs, anchor rod and holddown itself.

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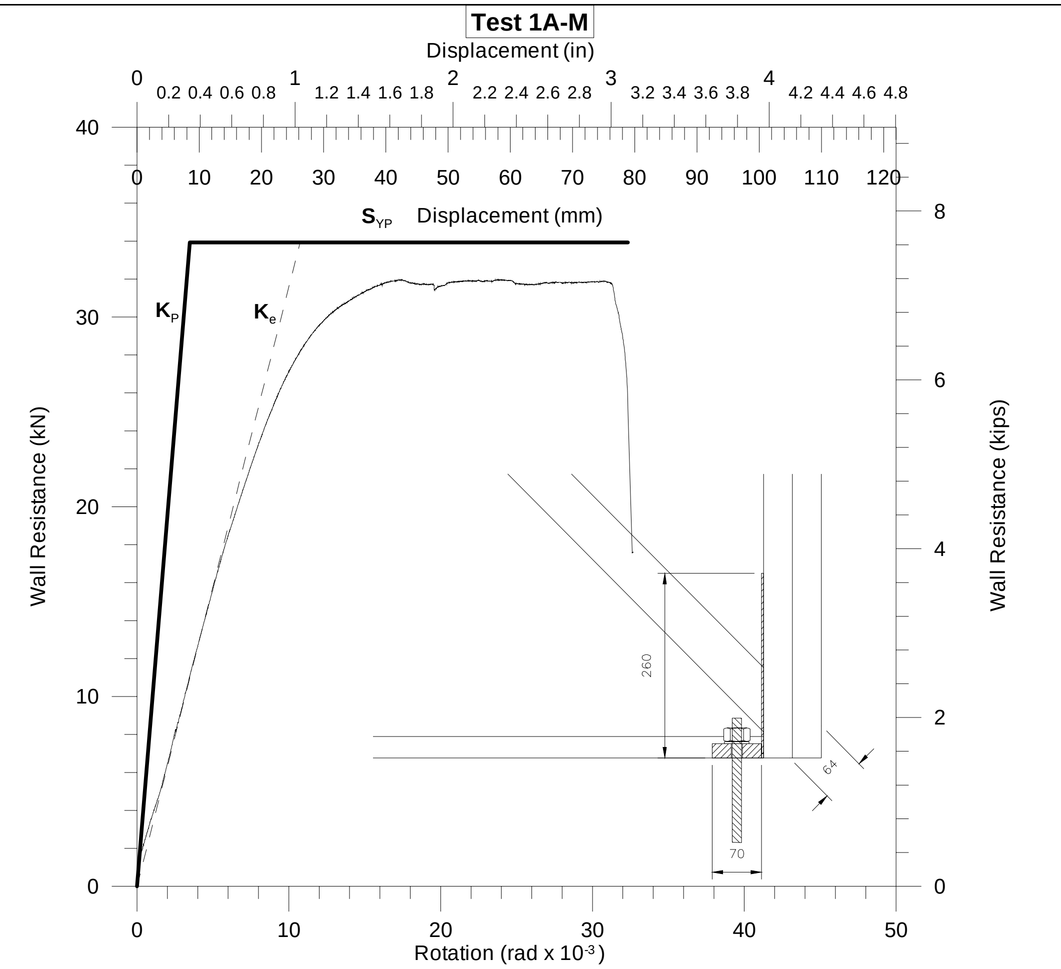
APPENDIX A: TEST RESULTS



		Parameters	Units
Test Result	S_Y	31.97	kN
	$S_{0.8}$	25.58	kN
	$S_{0.4}$	12.79	kN
	K_e	1.29	kN/mm
	Ductility (μ)	3.01	mm/mm
Prediction (Actual Dimensions)	S_{YP}	33.93	kN
	K_P	4.00	kN/mm
Prediction (Nominal Dimensions)	S_{YN}	25.40	kN
	K_N	4.60	kN/mm

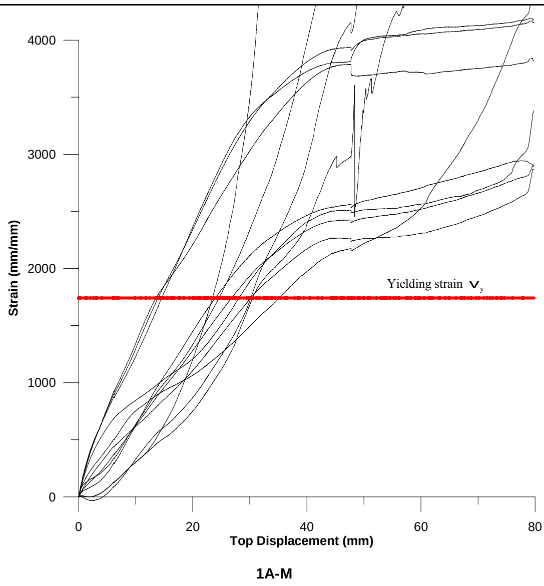
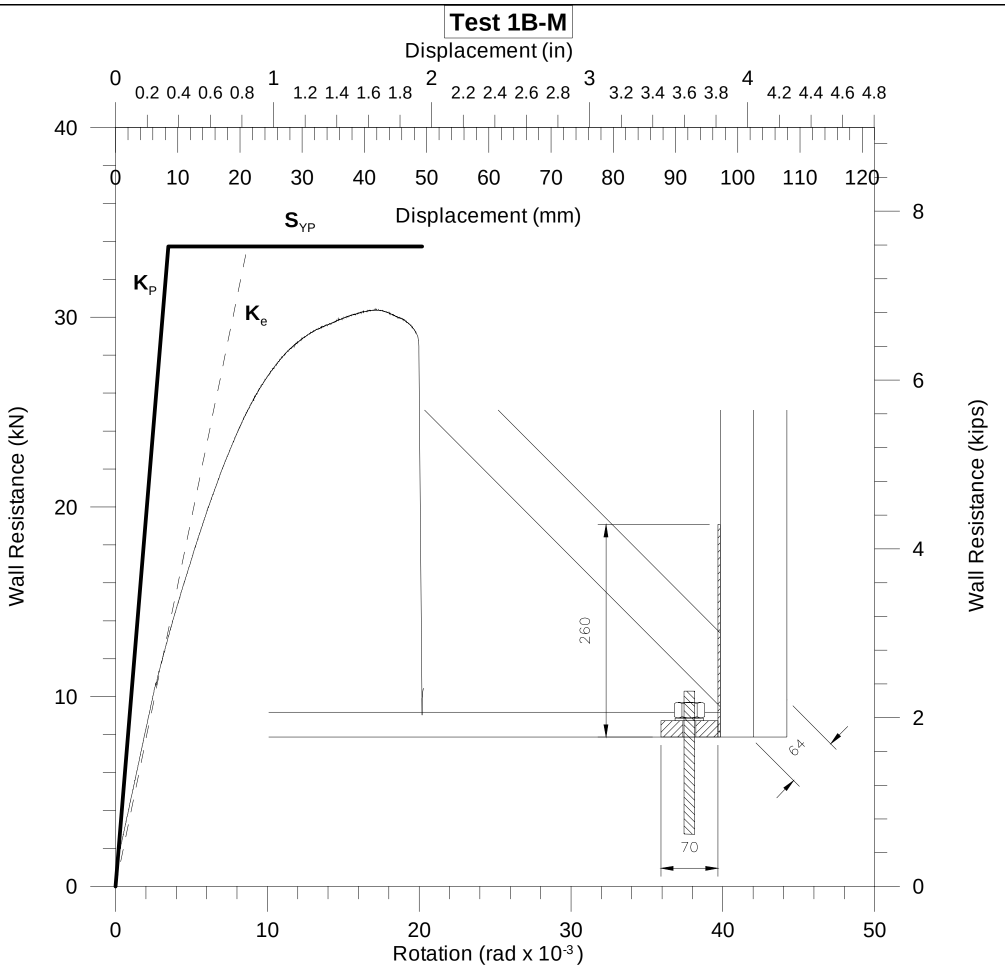


Figure 52: Test results specimen 1A-M



		Parameters	Units
Test Result	S_Y	30.39	kN
	$S_{0.8}$	24.31	kN
	$S_{0.4}$	12.16	kN
	K_e	1.59	kN/mm
	Ductility (μ)	2.32	mm/mm
Prediction (Actual Dimensions)	S_{YP}	33.73	kN
	K_P	3.98	kN/mm
Prediction (Nominal Dimensions)	S_{YN}	25.40	kN
	K_N	4.60	kN/mm

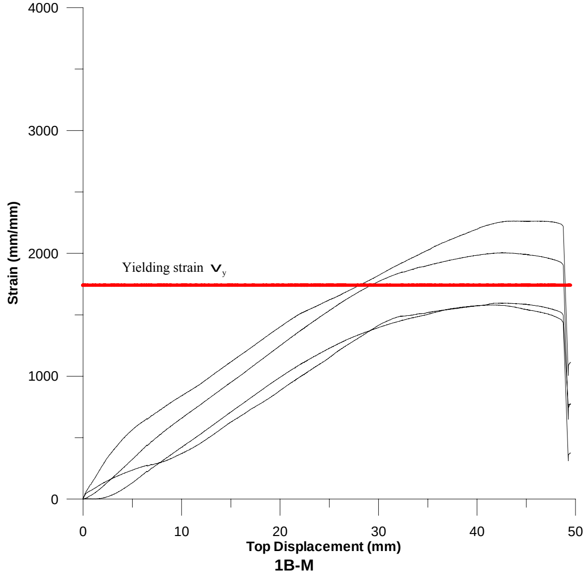
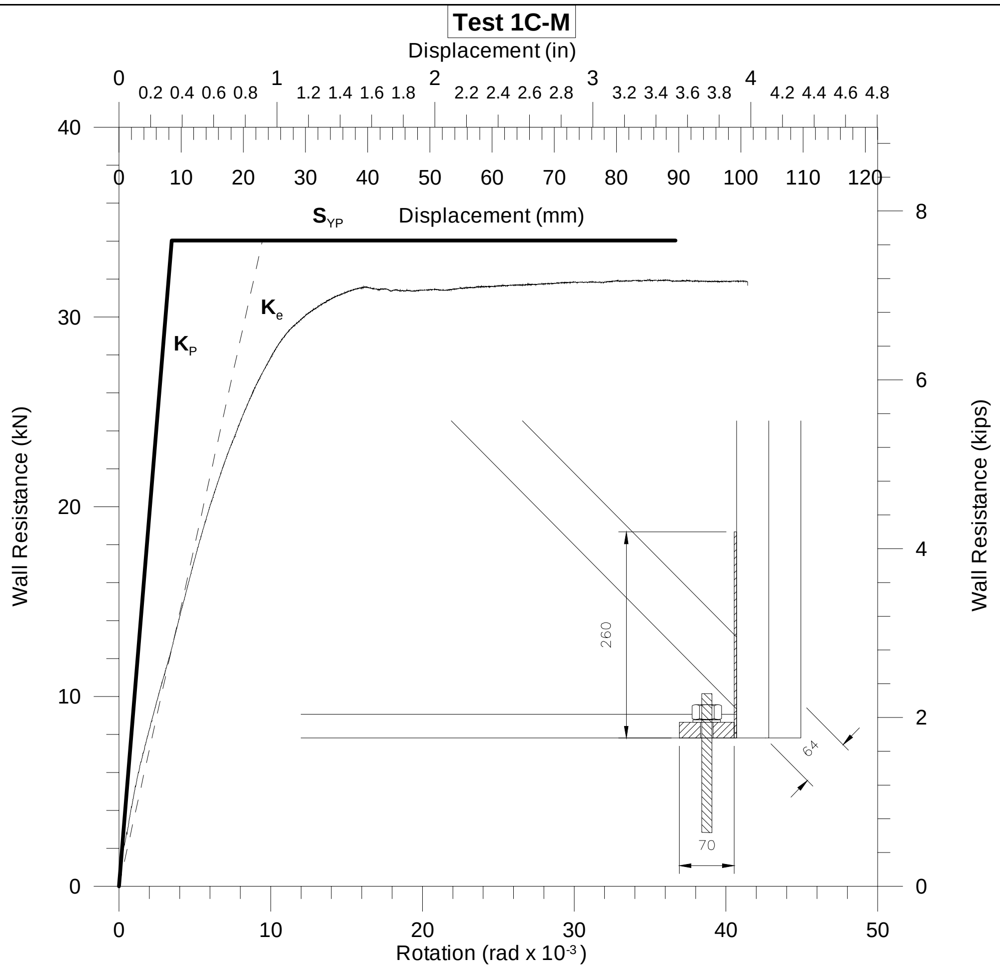


Figure 53: Test results specimen 1B-M



		Parameters	Units
Test Result	S_Y	31.96	kN
	$S_{0.8}$	25.57	kN
	$S_{0.4}$	12.79	kN
	K_e	1.48	kN/mm
	Ductility (μ)	3.88	mm/mm
Prediction (Actual Dimensions)	S_{YP}	34.03	kN
	K_P	4.01	kN/mm
Prediction (Nominal Dimensions)	S_{YN}	25.40	kN
	K_N	4.60	kN/mm

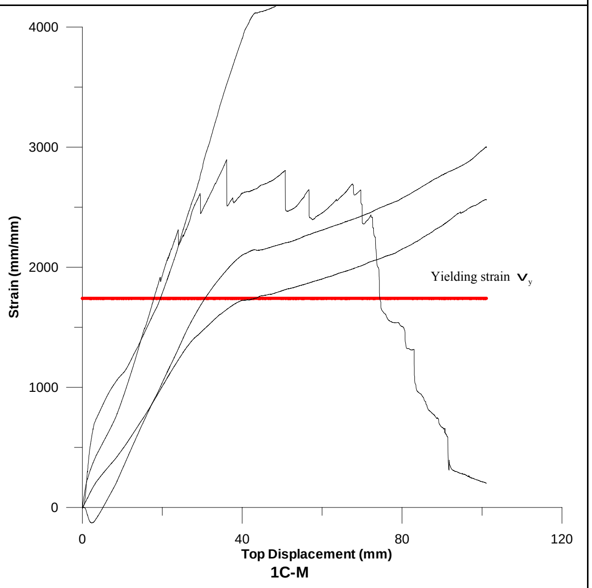
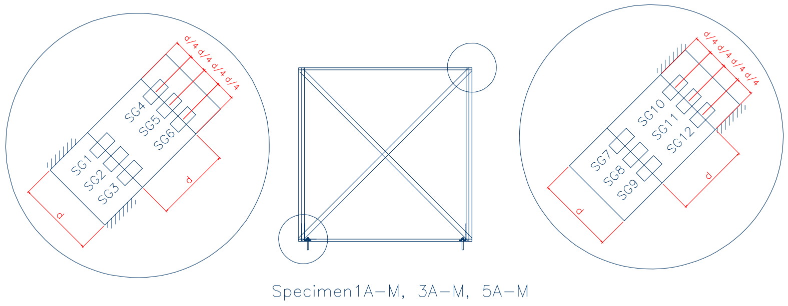


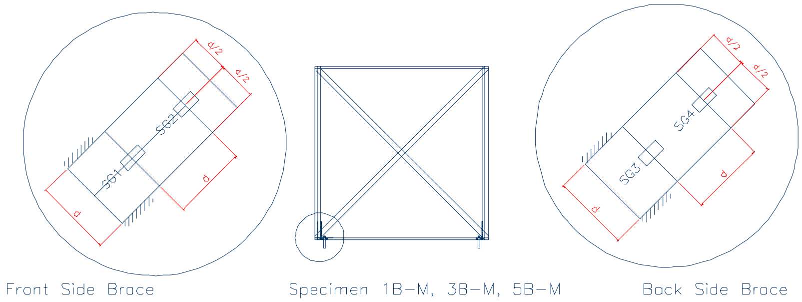
Figure 54: Test results specimen 1C-M

1A-M



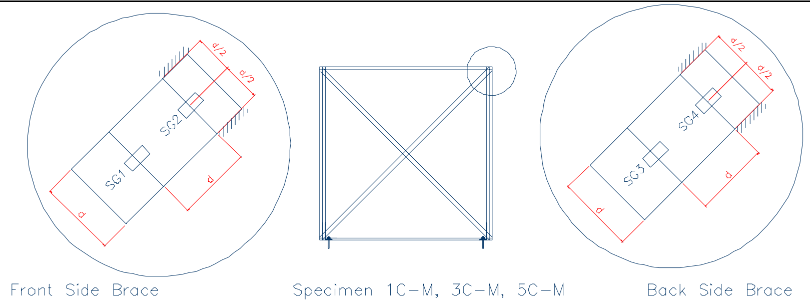
Strain Gauge	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8	SG9	SG10	SG11	SG12
Max strain Reached (mm/mm)	3381.2	4490.0	14031.3	2869.6	2900.1	2944.0	3840.8	4167.7	4191.6	9578.6	5959.2	15810.2
Yielding Strain (mm/mm)	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3
Yielding Status	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

1B-M



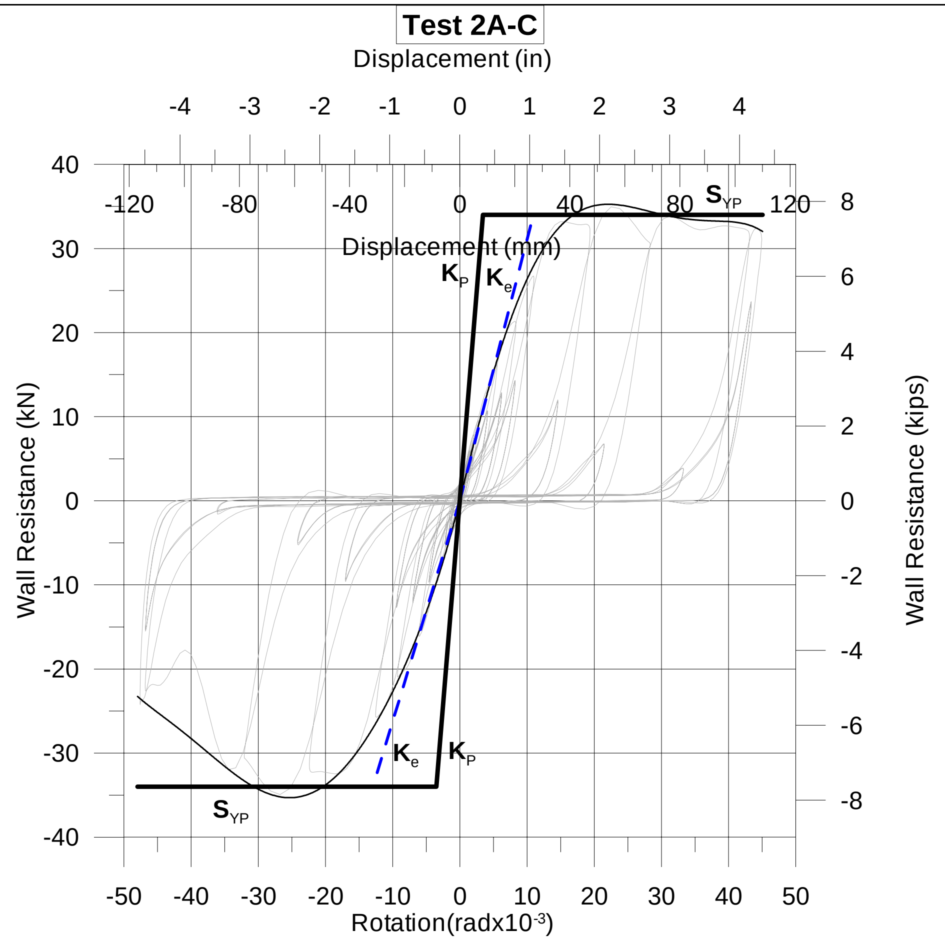
Strain Gauge	SG1	SG2	SG3	SG4
Max strain Reached (mm/mm)	2264.0	1581.0	1596.0	2005.0
Yielding Strain (mm/mm)	1741.3	1741.3	1741.3	1741.3
Yielding Status	OK	NO	NO	OK

1C-M



Strain Gauge	SG1	SG2	SG3	SG4
Max strain Reached (mm/mm)	3004.8	15836.6	2565.8	2895.9
Yielding Strain (mm/mm)	1741.3	1741.3	1741.3	1741.3
Yielding Status	OK	OK	OK	OK

Figure 55: Strain gauge results specimens 1A-M, 1B-M and 1C-M



		Negative	Positive	Units
Test Result	S_Y	-35.29	35.26	kN
	$S_{0.8}$	-28.23	28.21	kN
	$S_{0.4}$	-14.12	14.10	kN
	K_e	1.08	1.27	kN/mm
	Ductility (μ)	3.10	4.11	mm/mm
Prediction (Actual Dimensions)	S_{YP}	-34.00	34.00	kN
	K_P	-4.01	4.01	kN/mm
Prediction (Nominal Dimensions)	S_{YN}	-25.40	25.40	kN
	K_N	-4.60	4.60	kN/mm

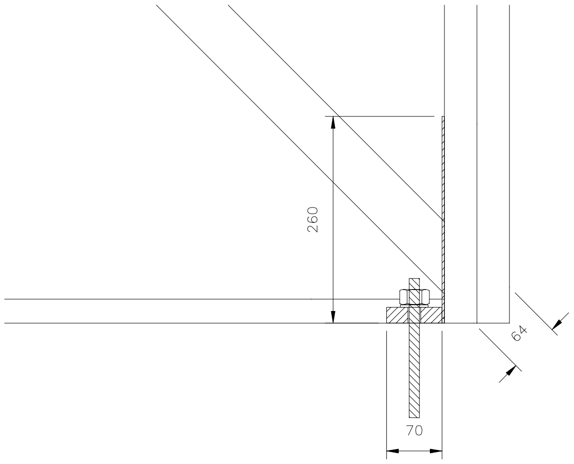
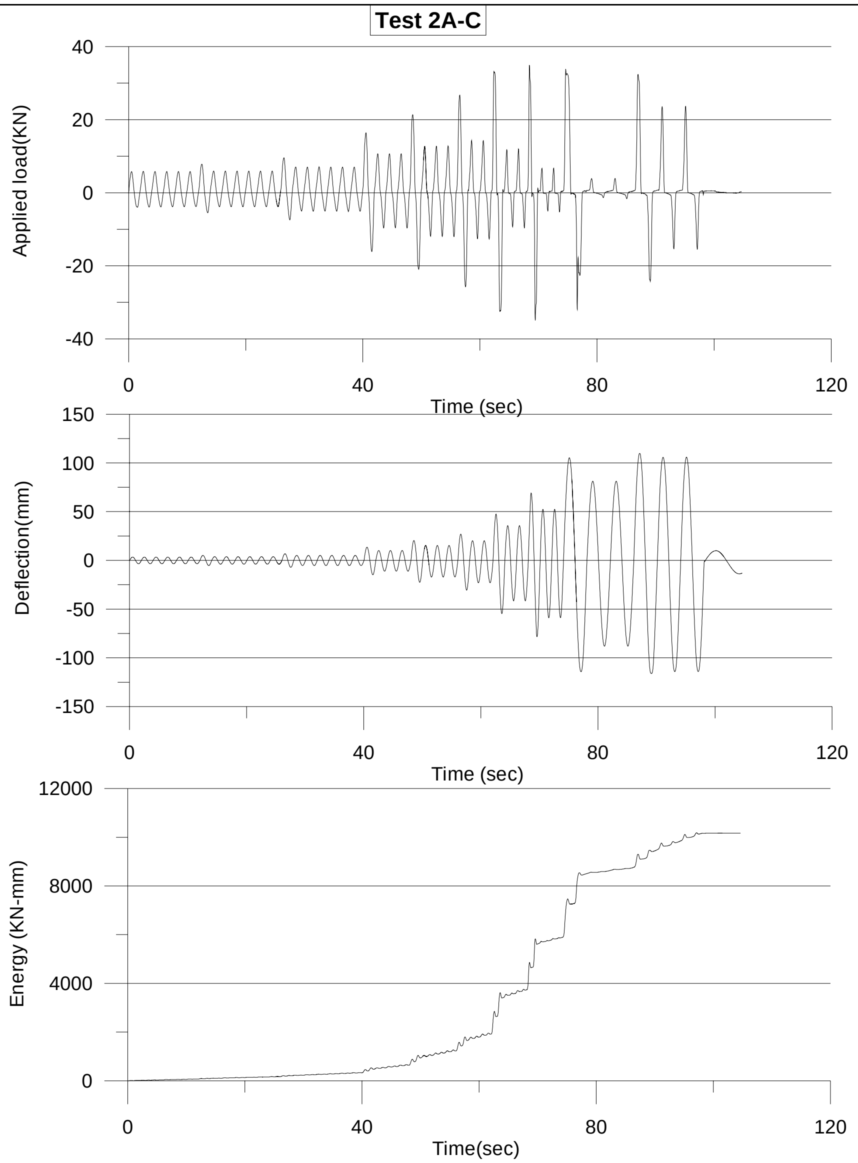


Figure 56: Test results specimen 2A-C



Strain Gauge	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8	SG9	SG10	SG11	SG12
Max strain Reached (mm/mm)	4245.6	3109.6	6719.2	3357.2	3866.9	4394.3	2493.0	2689.4	2754.0	6043.3	2832.9	4729.1
Yielding Strain (mm/mm)	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3	1741.3
Yielding Status	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

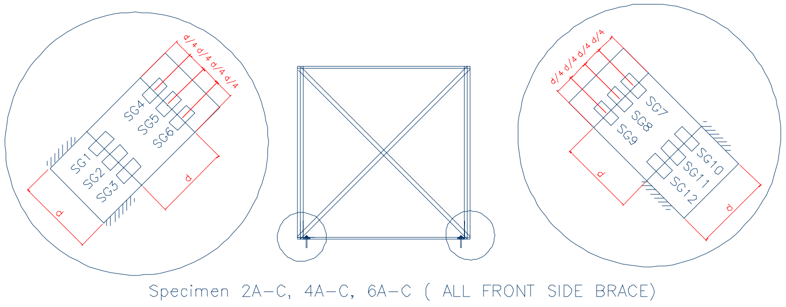
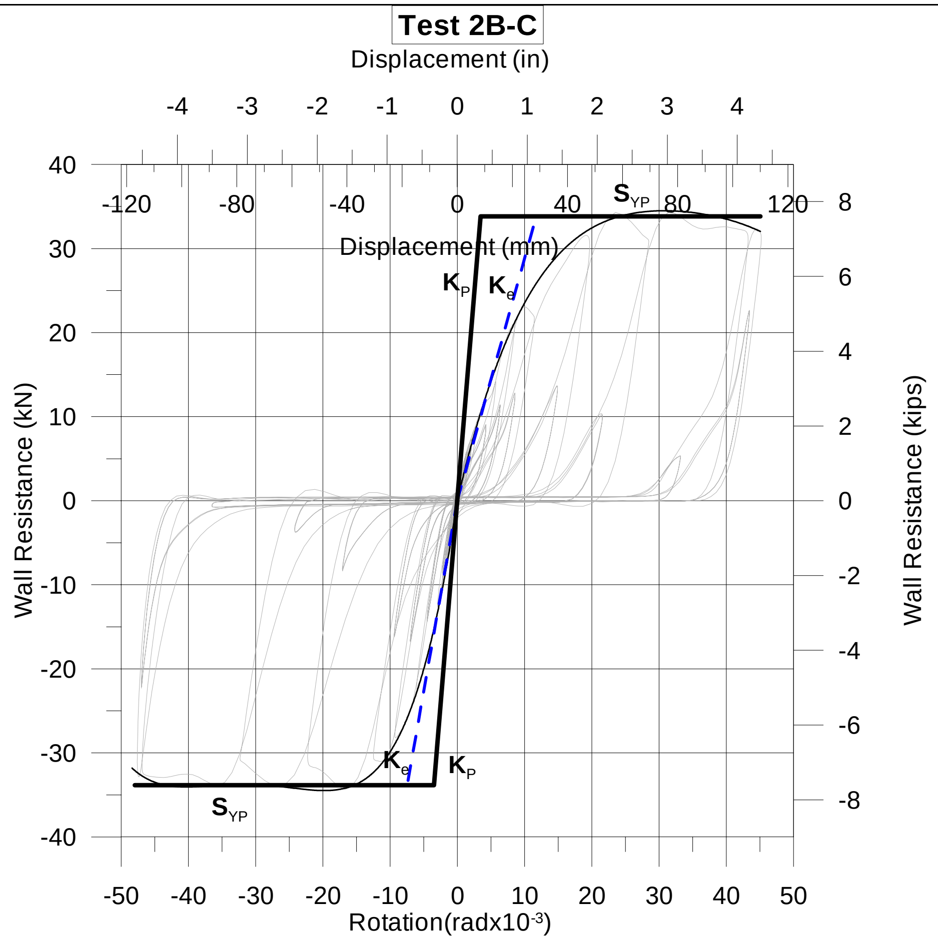


Figure 57: Time history and strain gauge results specimen 2A-C



		Negative	Positive	Units
Test Result	**S$_Y$**	-34.47	34.50	kN
	S$_{0.8}$	-27.58	27.60	kN
	S$_{0.4}$	-13.79	13.80	kN
	K$_e$	1.86	1.18	kN/mm
	Ductility (μ)	6.44	3.83	mm/mm
Prediction (Actual Dimensions)	**S$_{YP}$**	-33.83	33.83	kN
	K$_P$	-3.99	3.99	kN/mm
Prediction (Nominal Dimensions)	**S$_{YN}$**	-25.40	25.40	kN
	K$_N$	-4.60	4.60	kN/mm

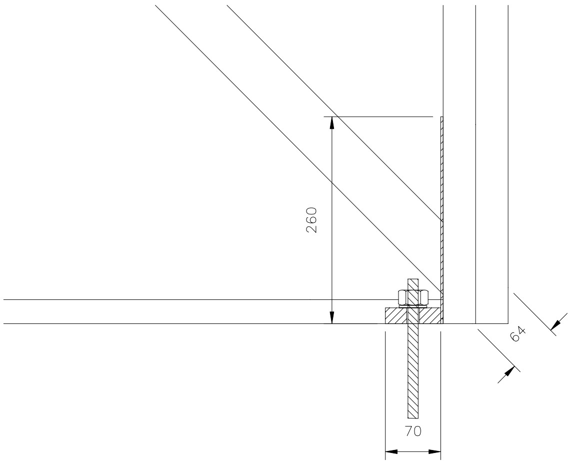
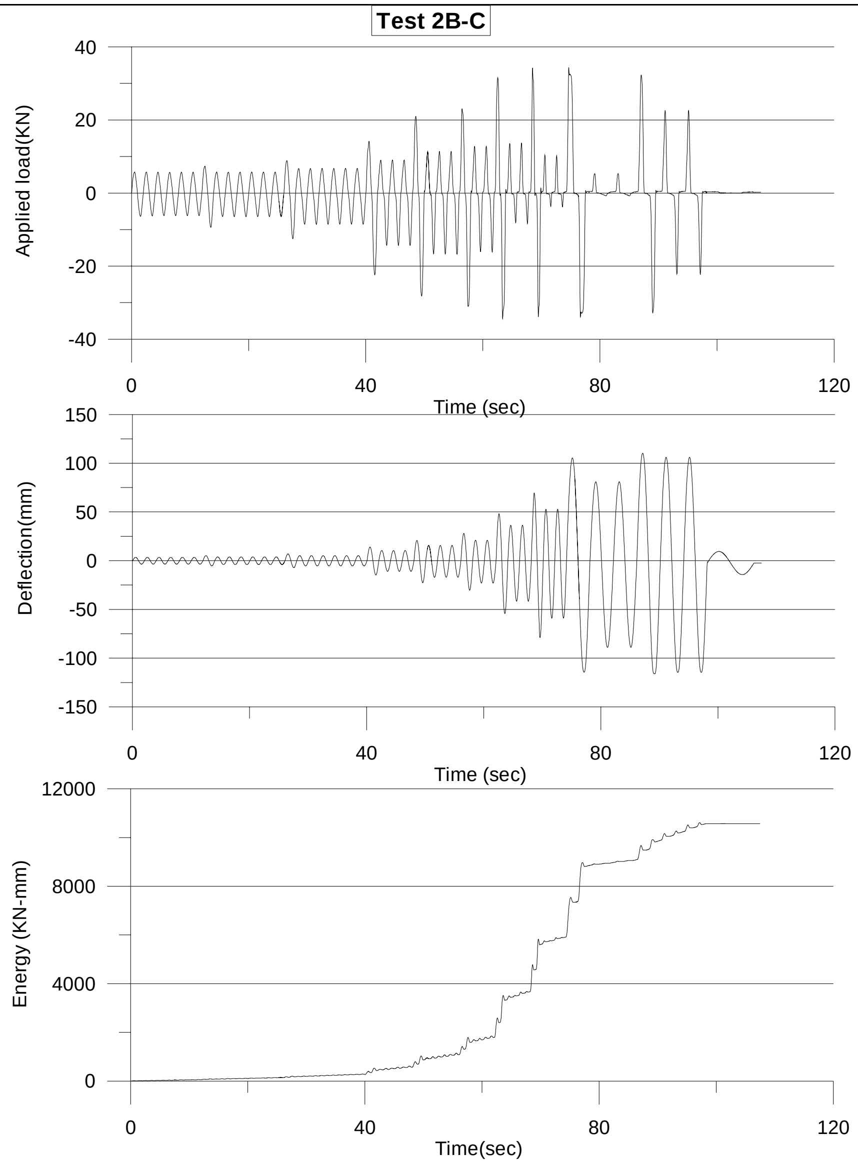


Figure 58: Test results specimen 2B-C



Strain Gauge	SG1	SG2	SG3	SG4
Max strain Reached (mm/mm)	2902.5	2434.1	5579.8	4236.2
Yielding Strain (mm/mm)	1741.3	1741.3	1741.3	1741.3
Yielding Status	OK	OK	OK	OK

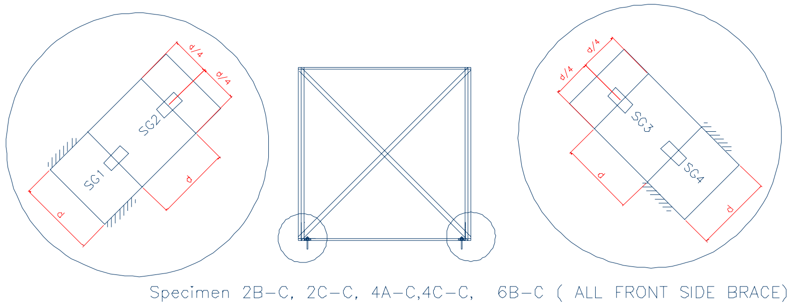
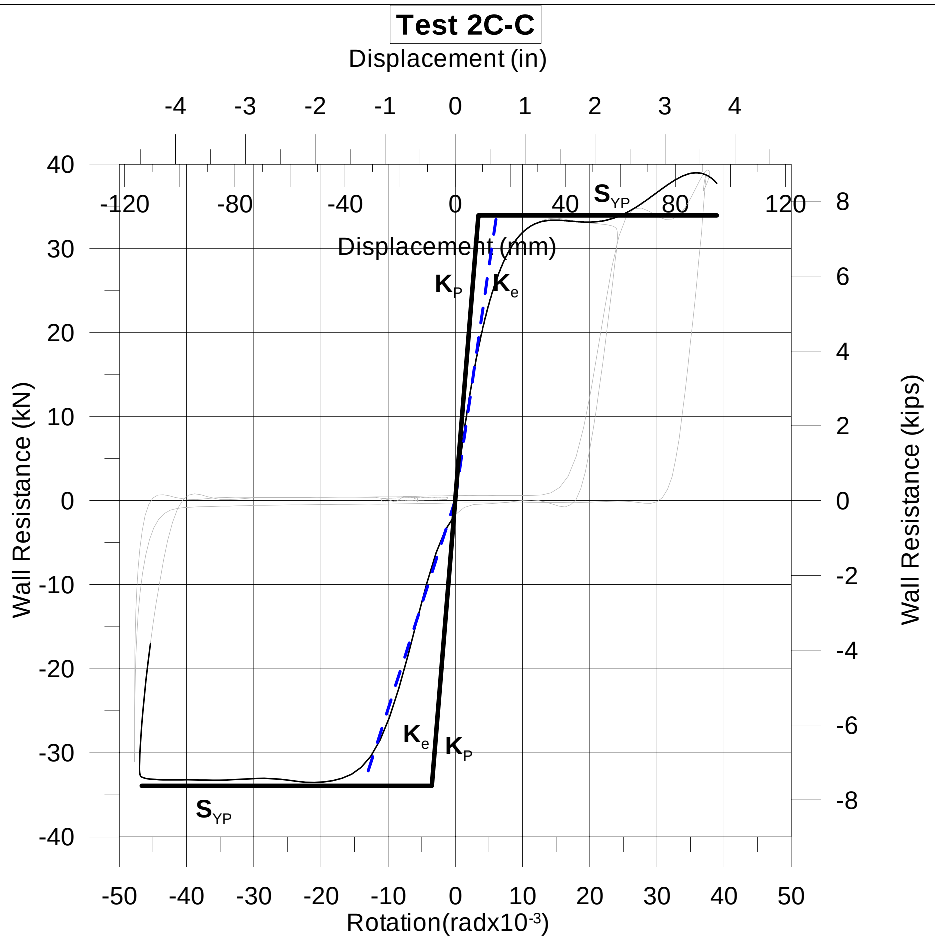


Figure 59: Time history and strain gauge results specimen 2B-C



		Negative	Positive	Units
Test Result	S_Y	-33.51	38.97	kN
	$S_{0.8}$	-26.81	31.18	kN
	$S_{0.4}$	-13.40	15.59	kN
	K_e	1.02	2.26	kN/mm
	Ductility (μ)	3.42	6.33	mm/mm
Prediction (Actual Dimensions)	S_{YP}	-33.91	33.91	kN
	K_P	-4.00	4.00	kN/mm
Prediction (Nominal Dimensions)	S_{YN}	-25.40	25.40	kN
	K_N	-4.60	4.60	kN/mm

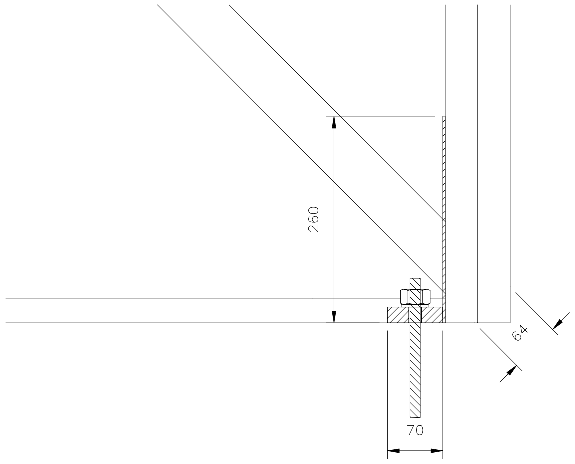
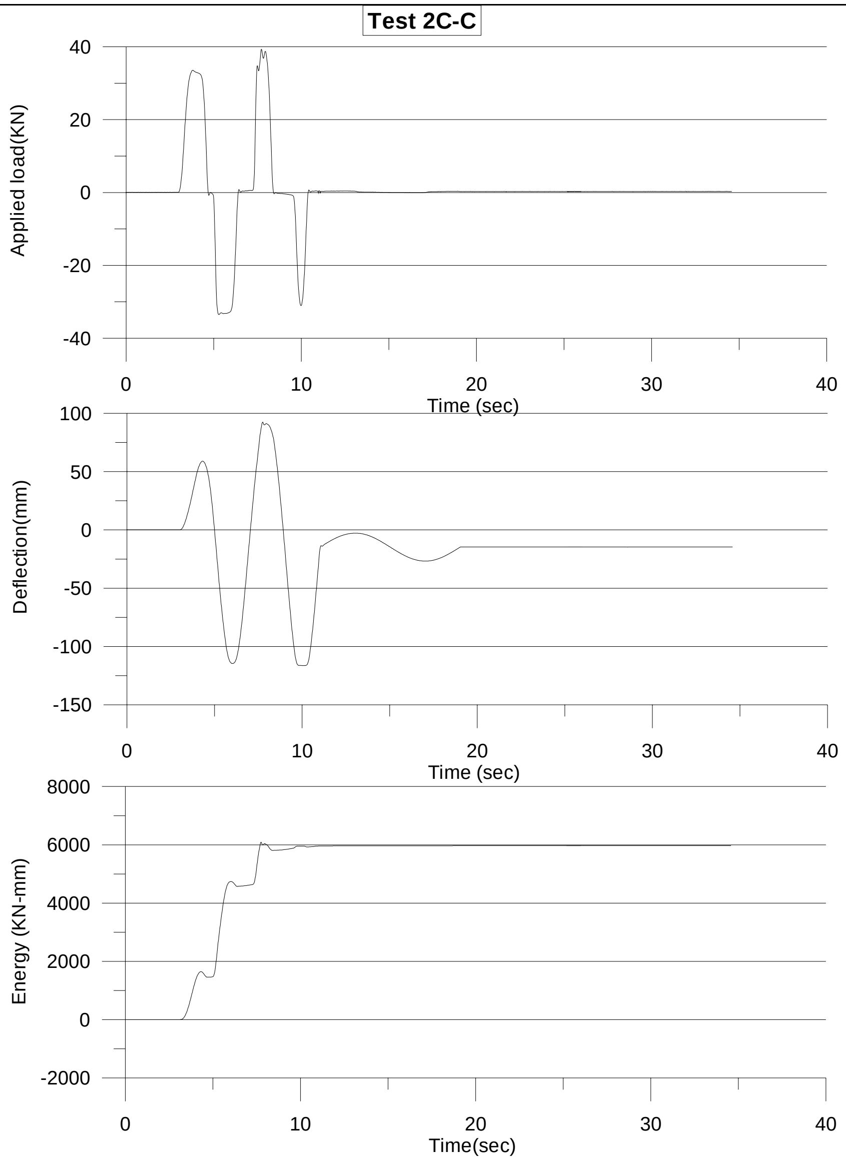


Figure 60: Test results specimen 2C-C



Strain Gauge	SG1	SG2	SG3	SG4
Max strain Reached (mm/mm)	9019.1	3919.5	4187.0	7428.7
Yielding Strain (mm/mm)	1741.3	1741.3	1741.3	1741.3
Yielding Status	OK	OK	OK	OK

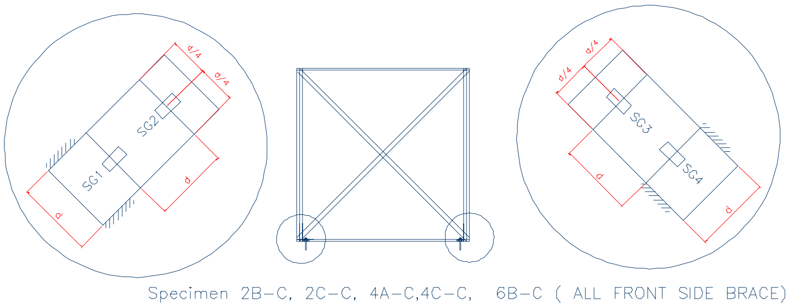
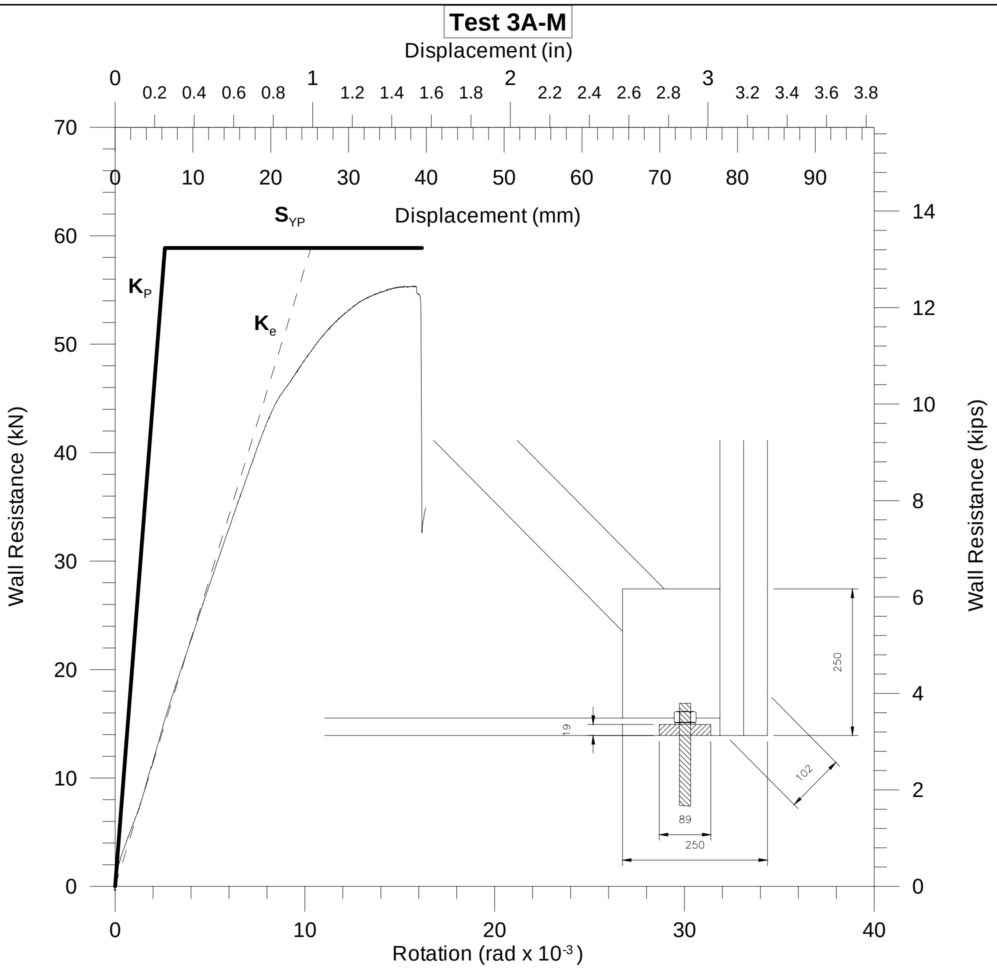


Figure 61: Time history and strain gauge results specimen 2C-C



		Parameters	Units
Test Result	S_Y	55.37	kN
	$S_{0.8}$	44.29	kN
	$S_{0.4}$	22.15	kN
	K_e	2.34	kN/mm
	Ductility (μ)	1.57	mm/mm
Prediction (Actual Dimensions)	S_{YP}	58.88	kN
	K_P	9.20	kN/mm
Prediction (Nominal Dimensions)	S_{YN}	50.43	kN
	K_N	9.56	kN/mm

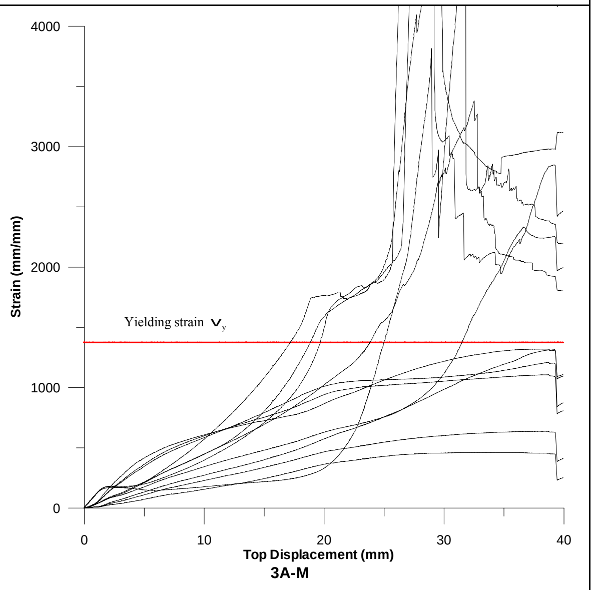
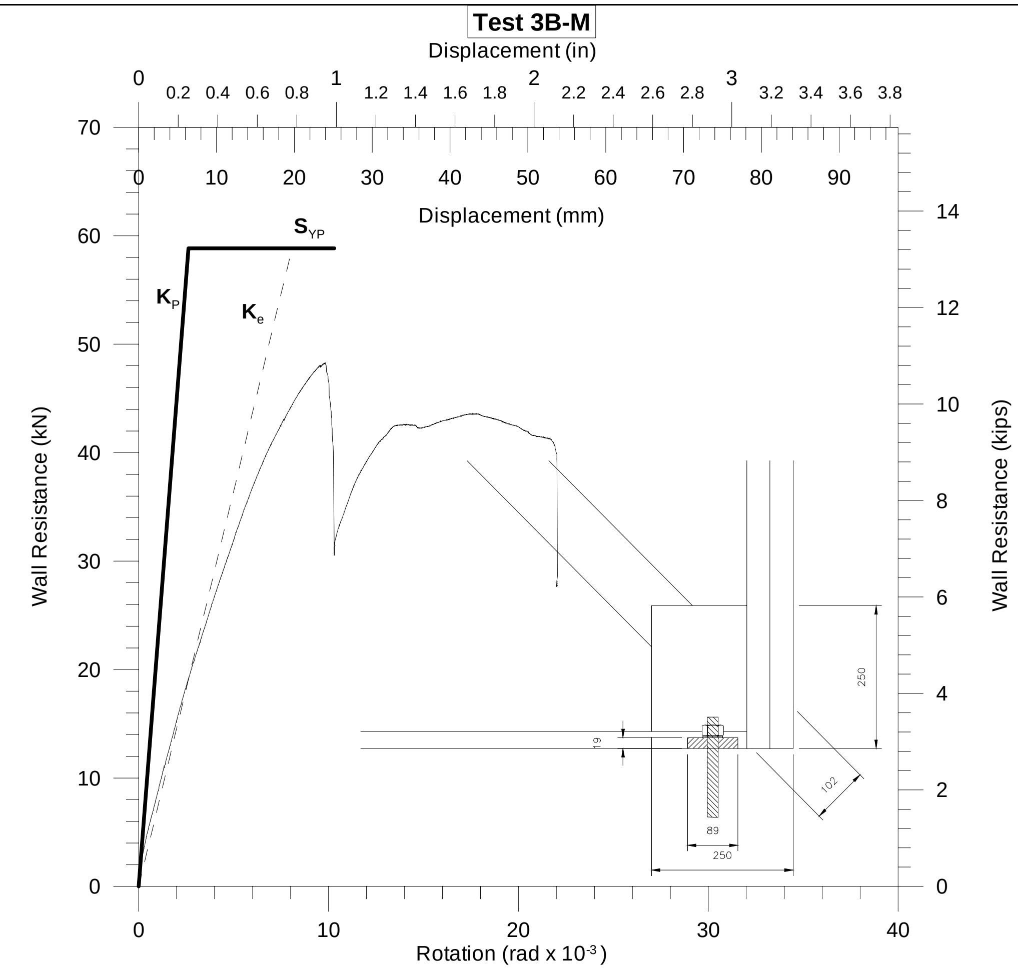


Figure 62: Test results specimen 3A-M



		Parameters	Units
Test Result	S_Y	48.29	kN
	$S_{0.8}$	38.63	kN
	$S_{0.4}$	19.32	kN
	K_e	2.99	kN/mm
	Ductility (μ)	1.28	mm/mm
Prediction (Actual Dimensions)	S_{YP}	58.84	kN
	K_P	9.20	kN/mm
Prediction (Nominal Dimensions)	S_{YN}	50.43	kN
	K_N	9.56	kN/mm

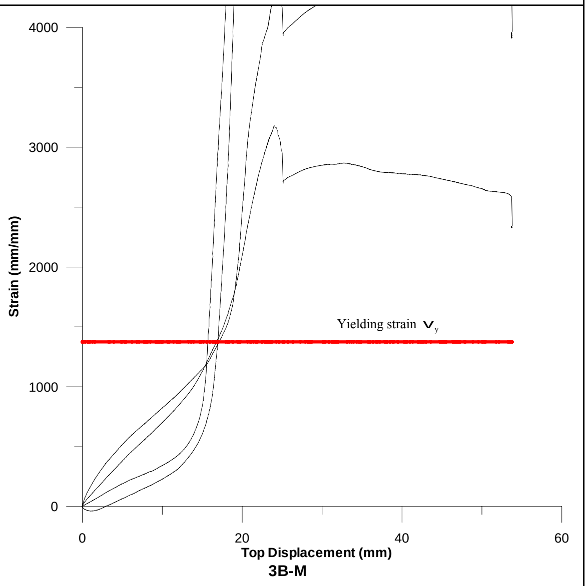
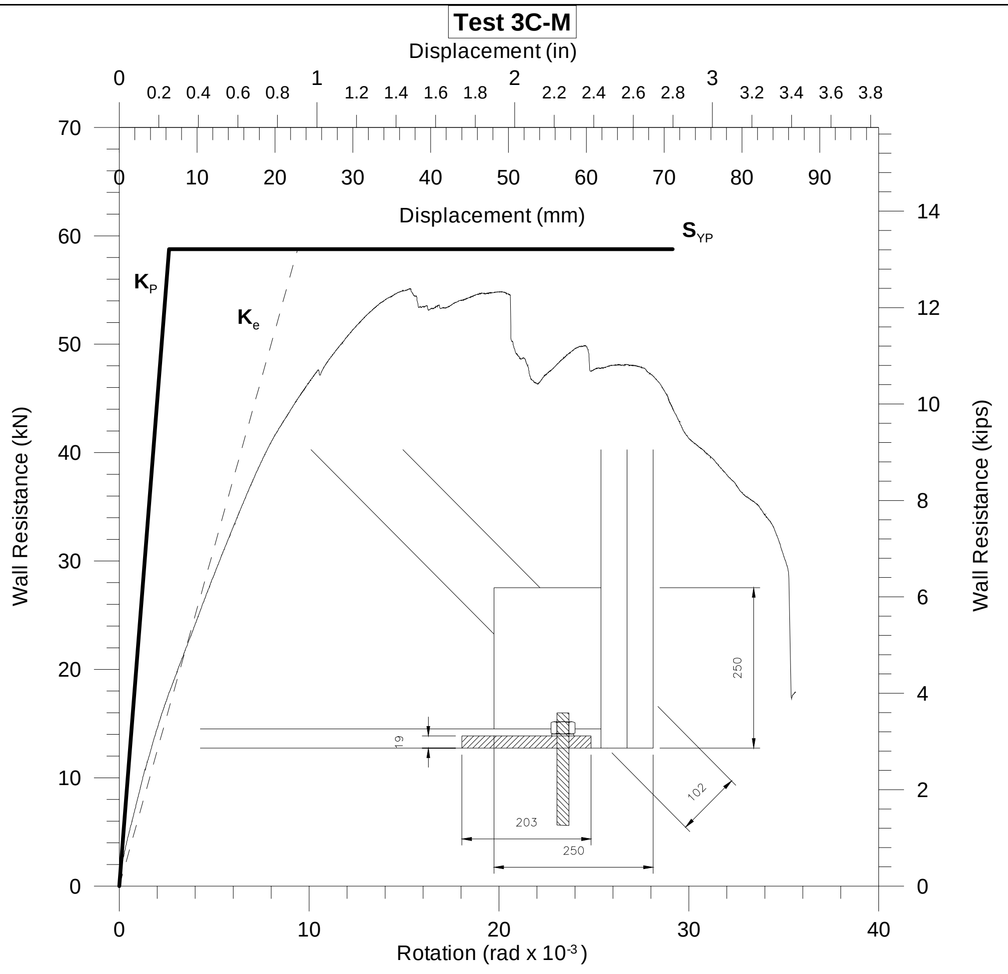


Figure 63: Test results specimen 3B-M



		Parameters	Units
Test Result	S_Y	55.12	kN
	$S_{0.8}$	44.10	kN
	$S_{0.4}$	22.05	kN
	K_e	2.56	kN/mm
	Ductility (μ)	3.10	mm/mm
Prediction (Actual Dimensions)	S_{YP}	58.77	kN
	K_P	9.19	kN/mm
Prediction (Nominal Dimensions)	S_{YN}	50.43	kN
	K_N	9.56	kN/mm

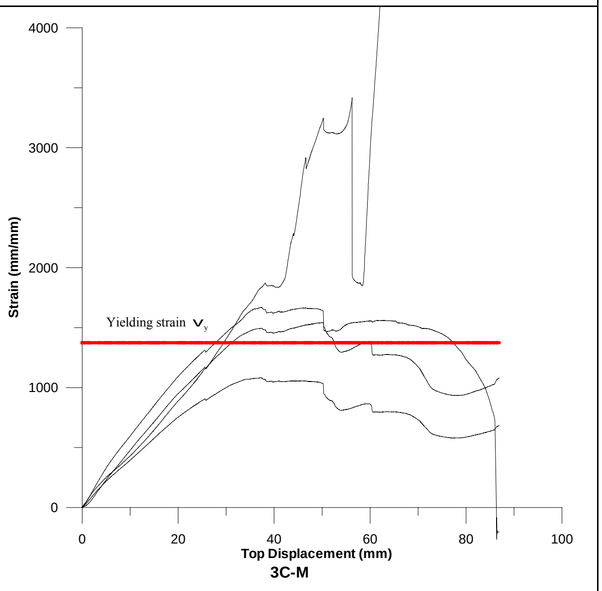
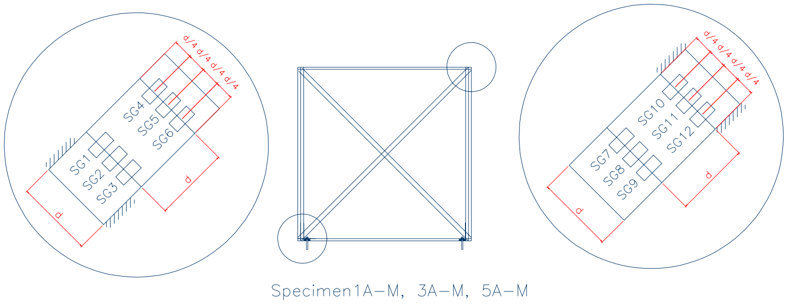


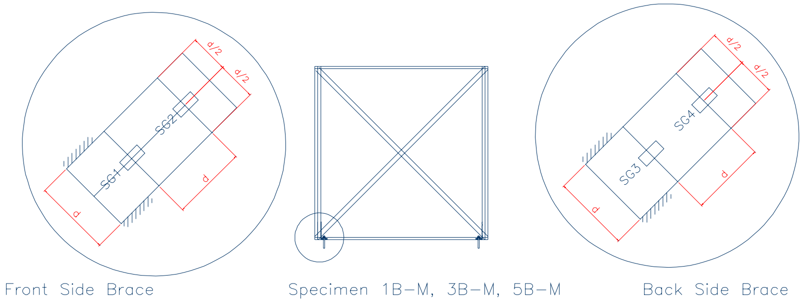
Figure 64: Test results specimen 3C-M

3A-M



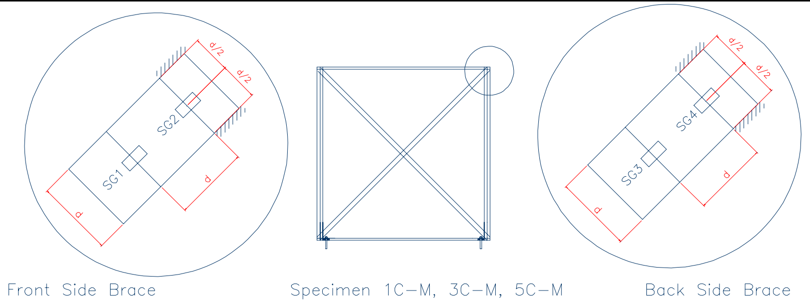
Strain Gauge	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8	SG9	SG10	SG11	SG12
Max strain Reached (mm/mm)	1320.0	1107.0	1210.0	4889.0	10303.0	8183.0	13187.0	2959.0	2332.0	462.0	638.0	1315.0
Yielding Strain (mm/mm)	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4
Yielding Status	NO	NO	NO	OK	OK	OK	OK	OK	OK	NO	NO	NO

3B-M



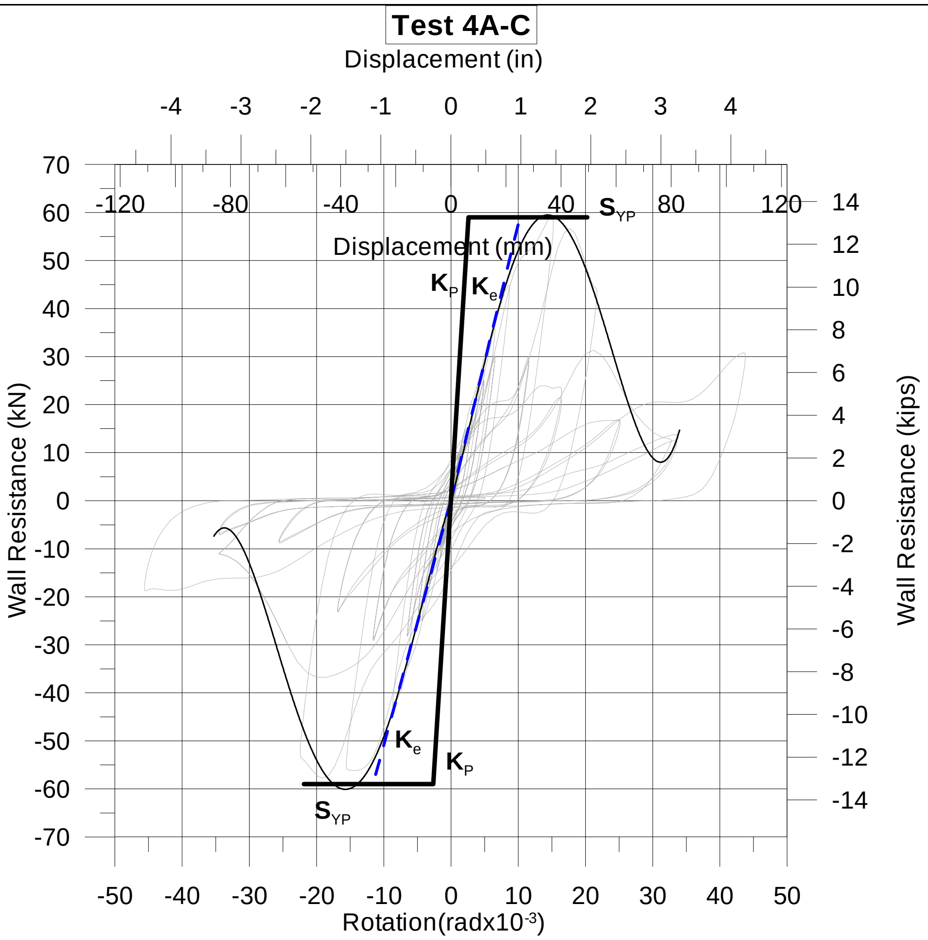
Strain Gauge	SG1	SG2	SG3	SG4
Max strain Reached (mm/mm)	10031.0	3179.0	15833.0	13014.0
Yielding Strain (mm/mm)	1374.4	1374.4	1374.4	1374.4
Yielding Status	OK	OK	OK	OK

3C-M



Strain Gauge	SG1	SG2	SG3	SG4
Max strain Reached (mm/mm)	1561.0	6890.0	1670.0	1082.0
Yielding Strain (mm/mm)	1374.4	1374.4	1374.4	1374.4
Yielding Status	OK	OK	OK	NO

Figure 65: Strain gauge results specimens 3A-M, 3B-M and 3C-M



		Negative	Positive	Units
Test Result	**S_Y**	-60.07	59.47	kN
	$S_{0.8}$	-48.06	47.58	kN
	$S_{0.4}$	-24.03	23.79	kN
	K_e	2.09	2.36	kN/mm
	Ductility (μ)	1.89	1.98	mm/mm
Prediction (Actual Dimensions)	**S_{YP}**	-58.98	58.98	kN
	K_P	-9.22	9.22	kN/mm
Prediction (Nominal Dimensions)	**S_{YN}**	-50.43	50.43	kN
	K_N	-9.56	9.56	kN/mm

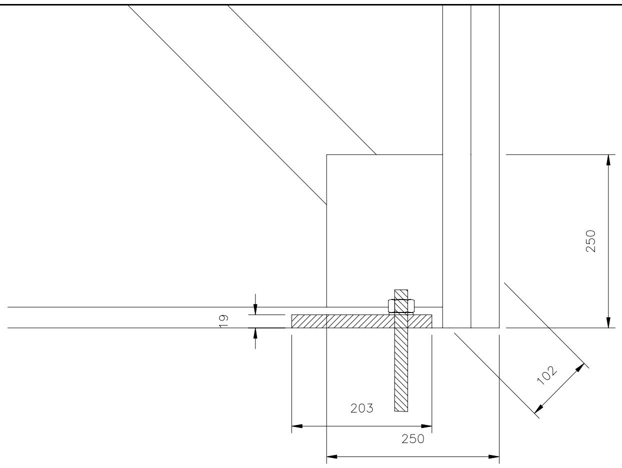
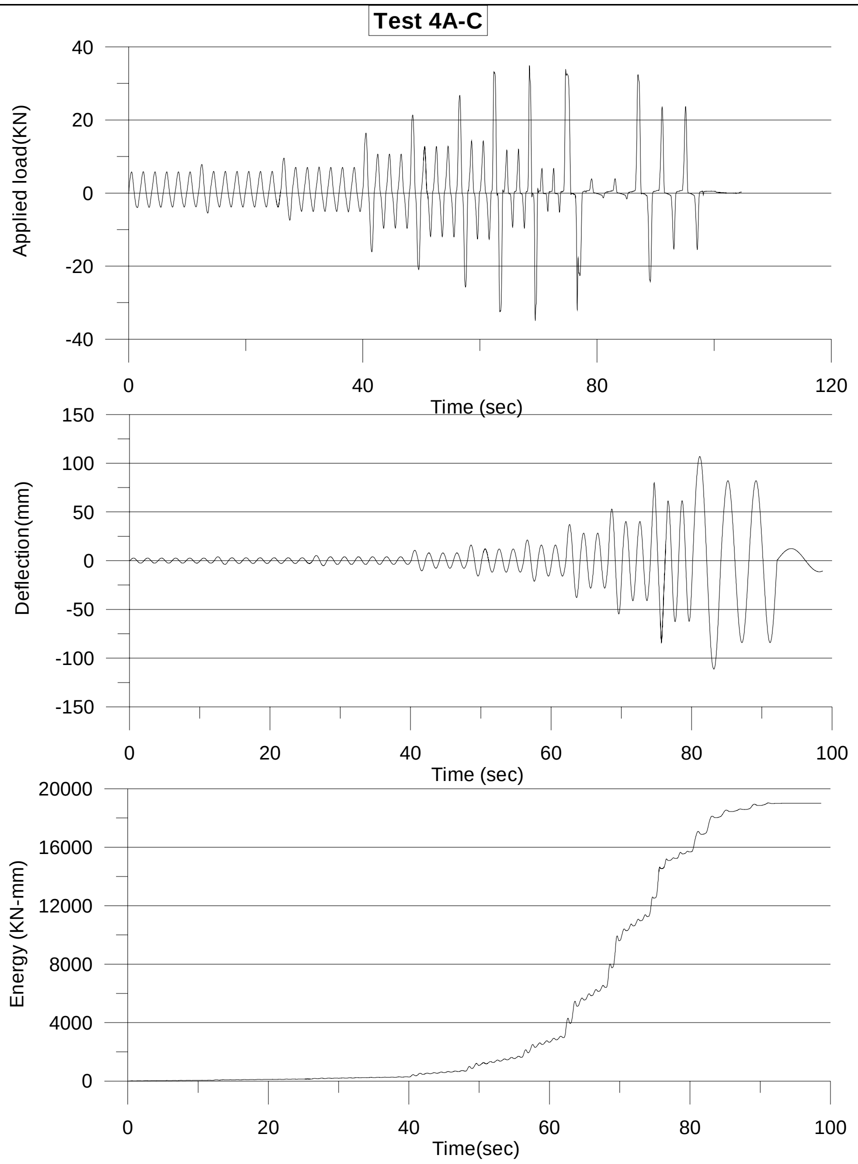


Figure 66: Test results specimen 4A-C



Strain Gauge	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8 on	SG9	SG10	SG11	SG12
Max strain Reached (mm/mm)	3648.0	2765.0	3550.0	9191.0	15809.0	15739.0	10918.0	14935.0	9442.0	1140.0	1721.0	2216.0
Yielding Strain (mm/mm)	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4	1374.4
Yielding Status	OK	OK	OK	OK	OK	OK	OK	OK	OK	NO	OK	OK

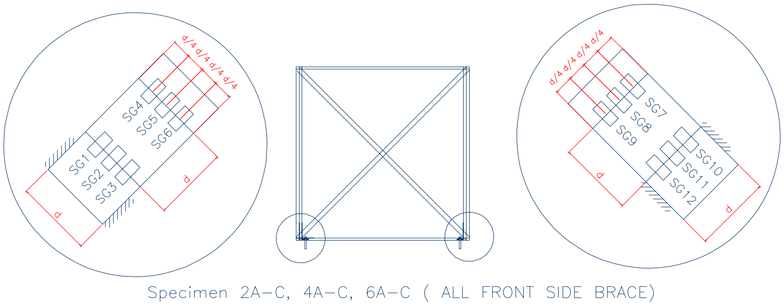
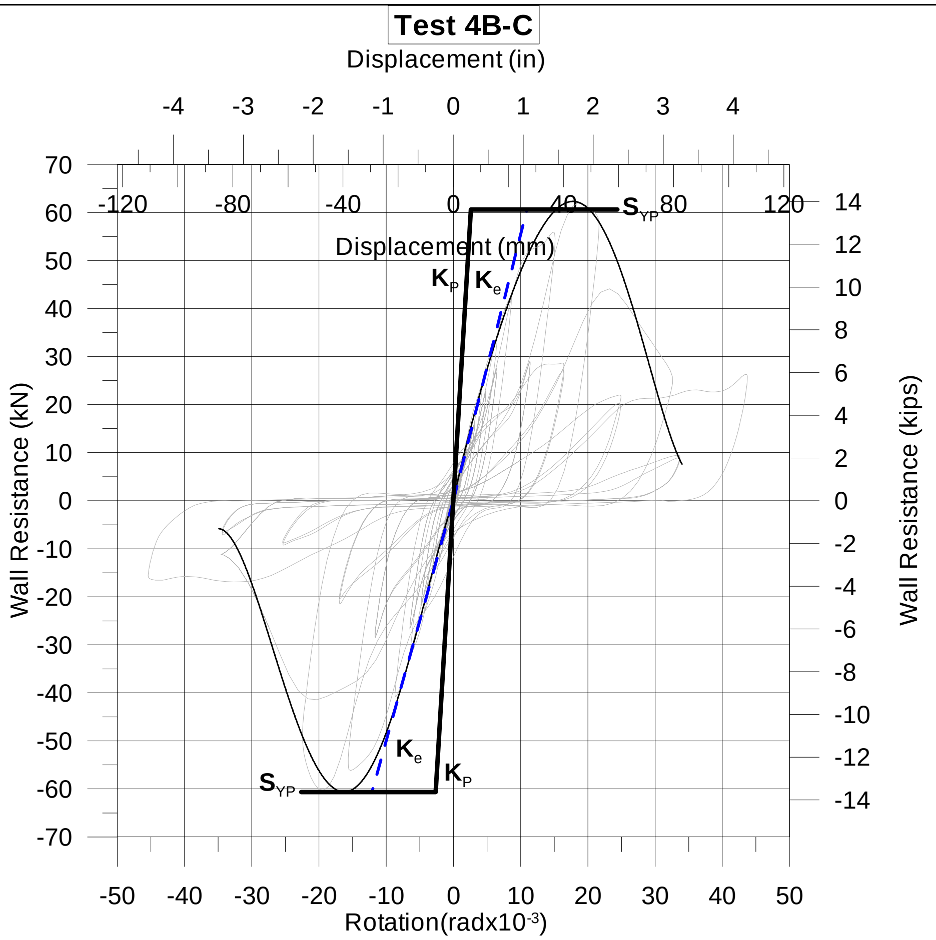


Figure 67: Time history and strain gauge results specimen 4A-C



		Negative	Positive	Units
Test Result	S_Y	-60.59	62.31	kN
	$S_{0.8}$	-48.47	49.84	kN
	$S_{0.4}$	-24.24	24.92	kN
	K_e	2.05	2.27	kN/mm
	Ductility (μ)	1.87	2.23	mm/mm
Prediction (Actual Dimensions)	S_{YP}	-60.64	60.64	kN
	K_P	-9.48	9.48	kN/mm
Prediction (Nominal Dimensions)	S_{YN}	-50.43	50.43	kN
	K_N	-9.56	9.56	kN/mm

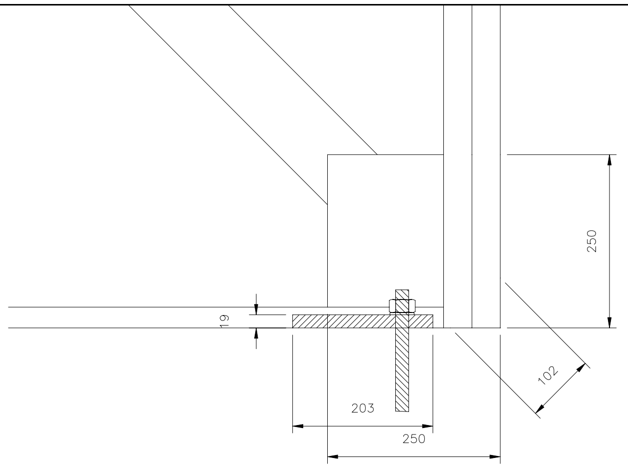
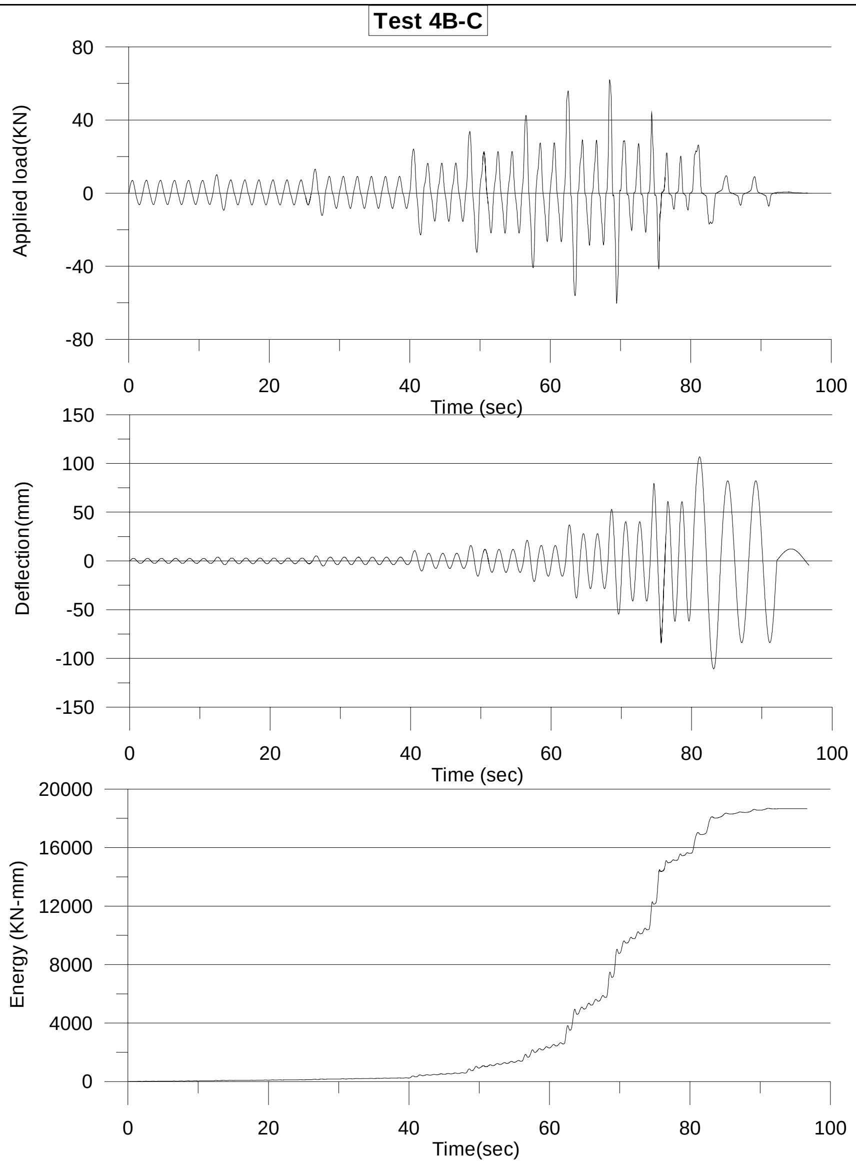


Figure 68: Test results specimen 4B-C



Strain Gauge	SG1	SG2	SG3	SG4
Max strain Reached (mm/mm)	4476.0	7589.0	8936.0	2003.0
Yielding Strain (mm/mm)	1374.4	1374.4	1374.4	1374.4
Yielding Status	OK	OK	OK	OK

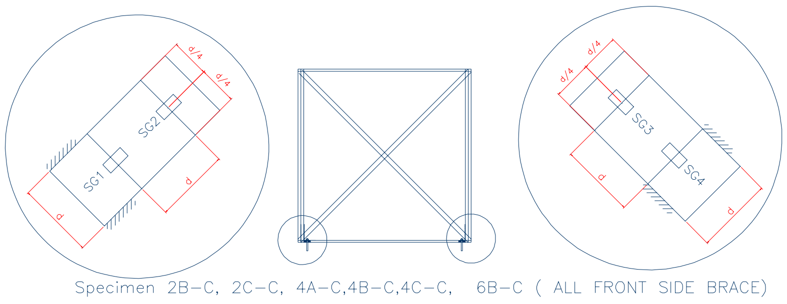
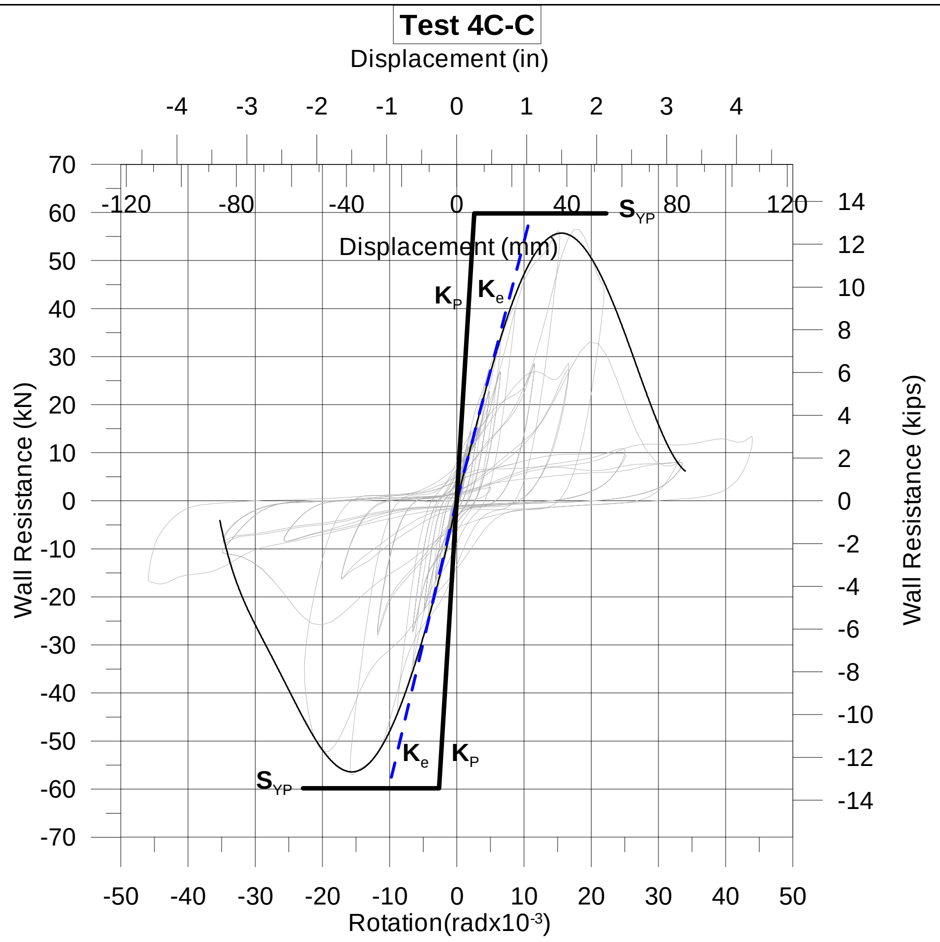


Figure 69: Time history and strain gauge results specimen 4B-C



		Negative	Positive	Units
Test Result	S_Y	-56.40	55.69	kN
	$S_{0.8}$	-45.12	44.55	kN
	$S_{0.4}$	-22.56	22.27	kN
	K_e	2.43	2.21	kN/mm
	Ductility (μ)	2.26	2.00	mm/mm
Prediction (Actual Dimensions)	S_{YP}	-59.80	59.80	kN
	K_P	-9.35	9.35	kN/mm
Prediction (Nominal Dimensions)	S_{YN}	-50.43	50.43	kN
	K_N	-9.56	9.56	kN/mm

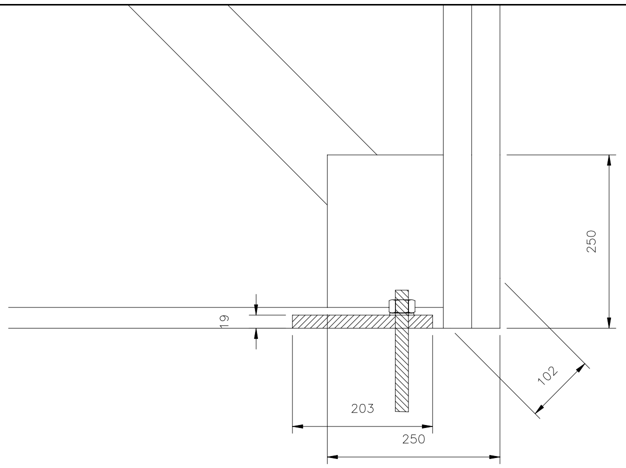
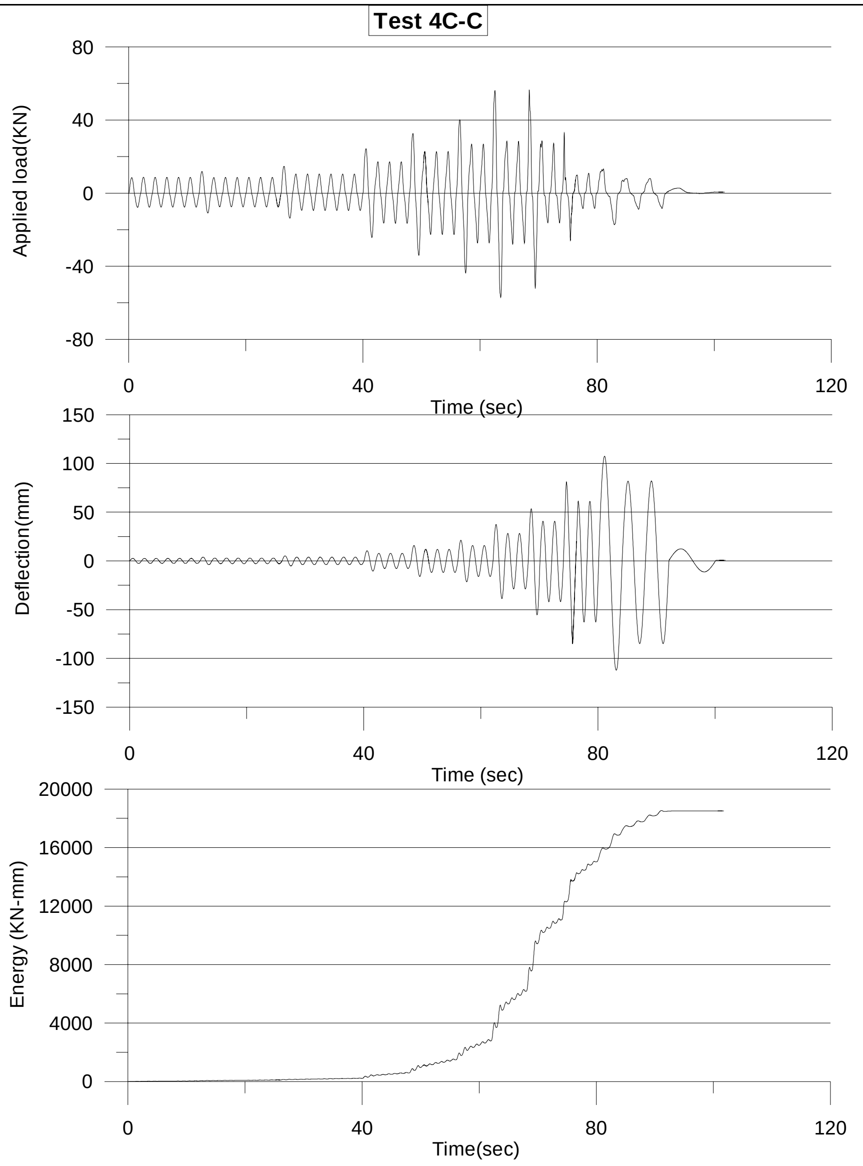
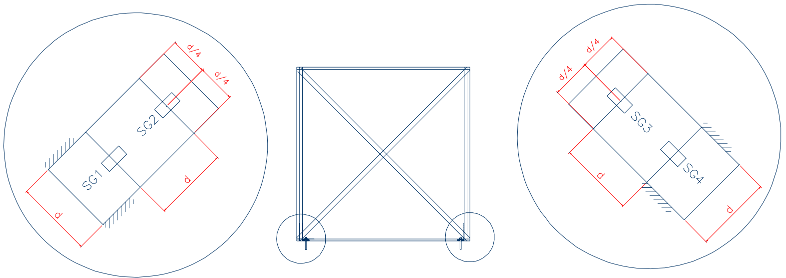


Figure 70: Test results specimen 4C-C

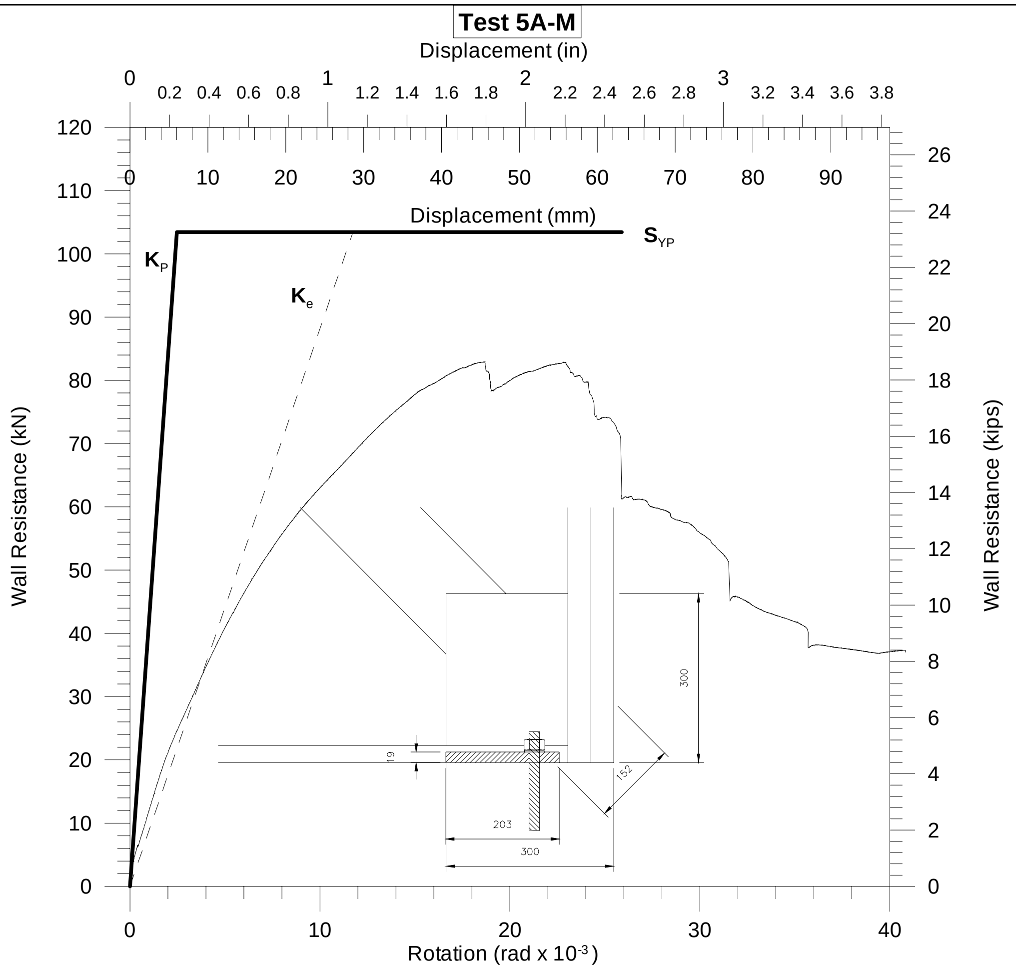


Strain Gauge	SG1	SG2	SG3	SG4
Max strain Reached (mm/mm)	1239.0	15737.0	13020.0	606.0
Yielding Strain (mm/mm)	1374.4	1374.4	1374.4	1374.4
Yielding Status	NO	OK	OK	NO



Specimen 2B–C, 2C–C, 4A–C,4B–C,4C–C, 6B–C (ALL FRONT SIDE BRACE)

Figure 71: Time history and strain gauge results specimen 4C-C



		Parameters	**Units**
Test Result	**S_Y**	82.93	kN
	$S_{0.8}$	66.34	kN
	$S_{0.4}$	33.17	kN
	K_e	3.61	kN/mm
	Ductility (μ)	2.21	mm/mm
Prediction (Actual Dimensions)	**S_{YP}**	103.44	kN
	K_P	17.20	kN/mm
Prediction (Nominal Dimensions)	**S_{YN}**	94.43	kN
	K_N	17.90	kN/mm

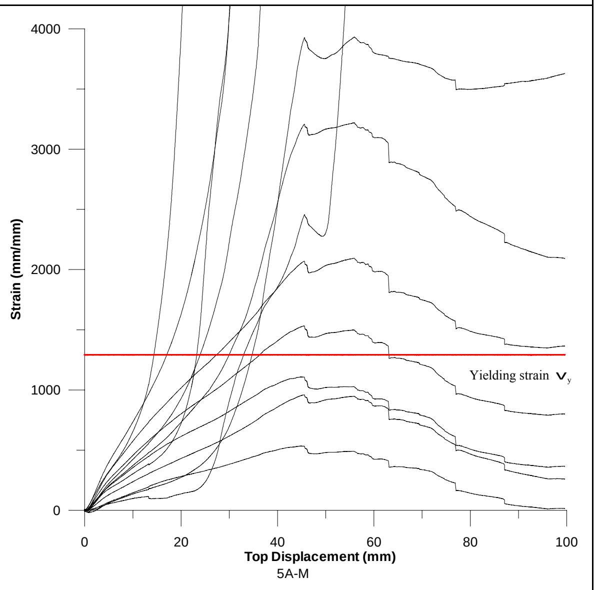
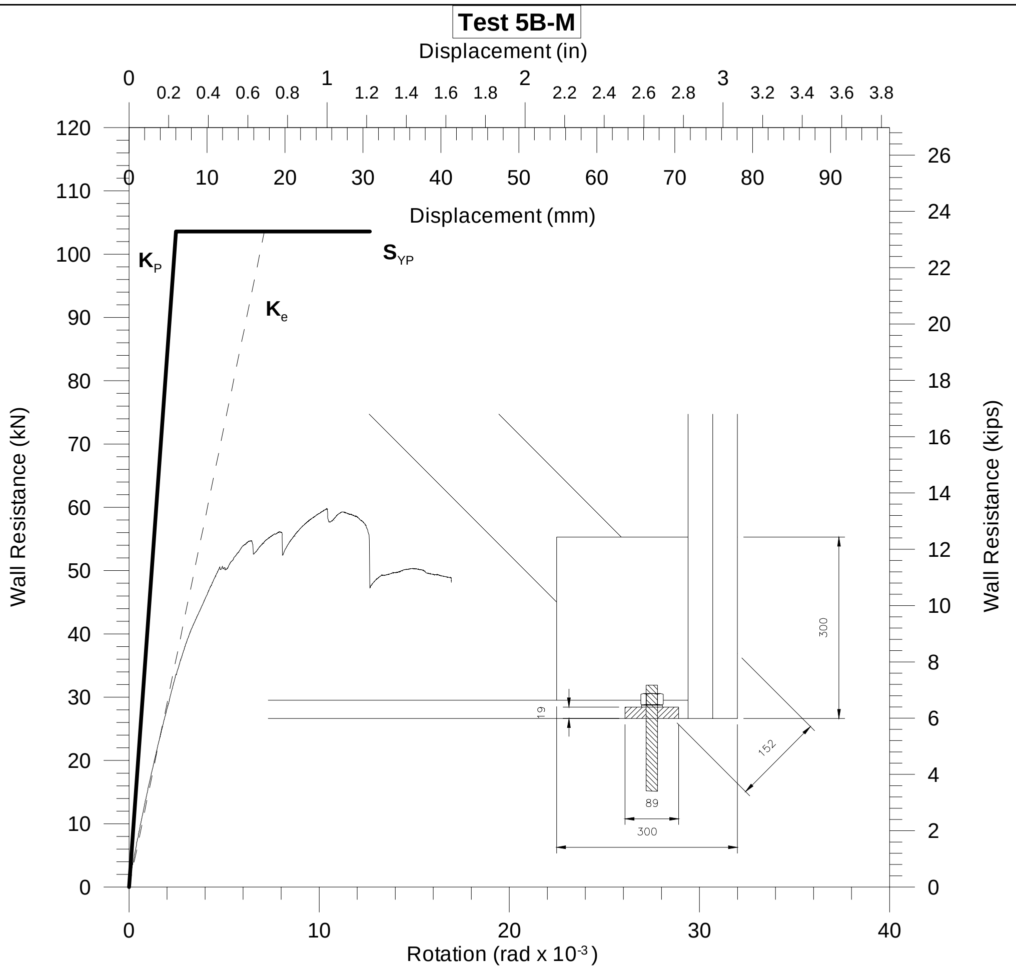


Figure 72: Test results specimen 5A-M



		Parameters	Units
Test Result	**S_Y**	59.79	kN
	$S_{0.8}$	47.83	kN
	$S_{0.4}$	23.92	kN
	K_e	5.97	kN/mm
	Ductility (μ)	1.78	mm/mm
Prediction (Actual Dimensions)	**S_{YP}**	103.59	kN
	K_P	17.22	kN/mm
Prediction (Nominal Dimensions)	**S_{YN}**	94.43	kN
	K_N	17.90	kN/mm

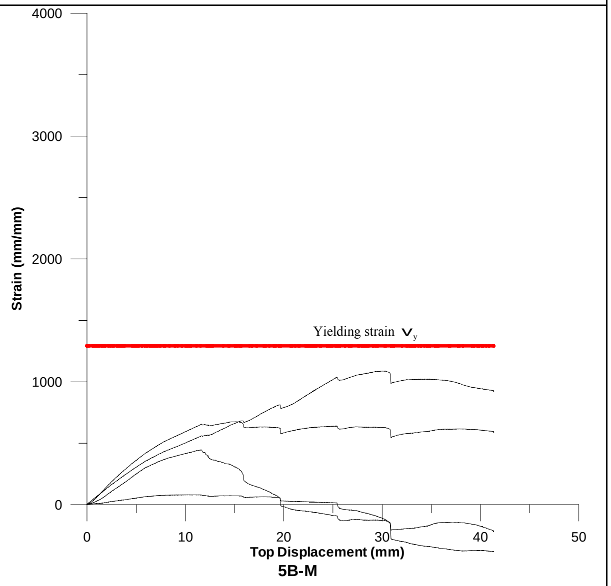
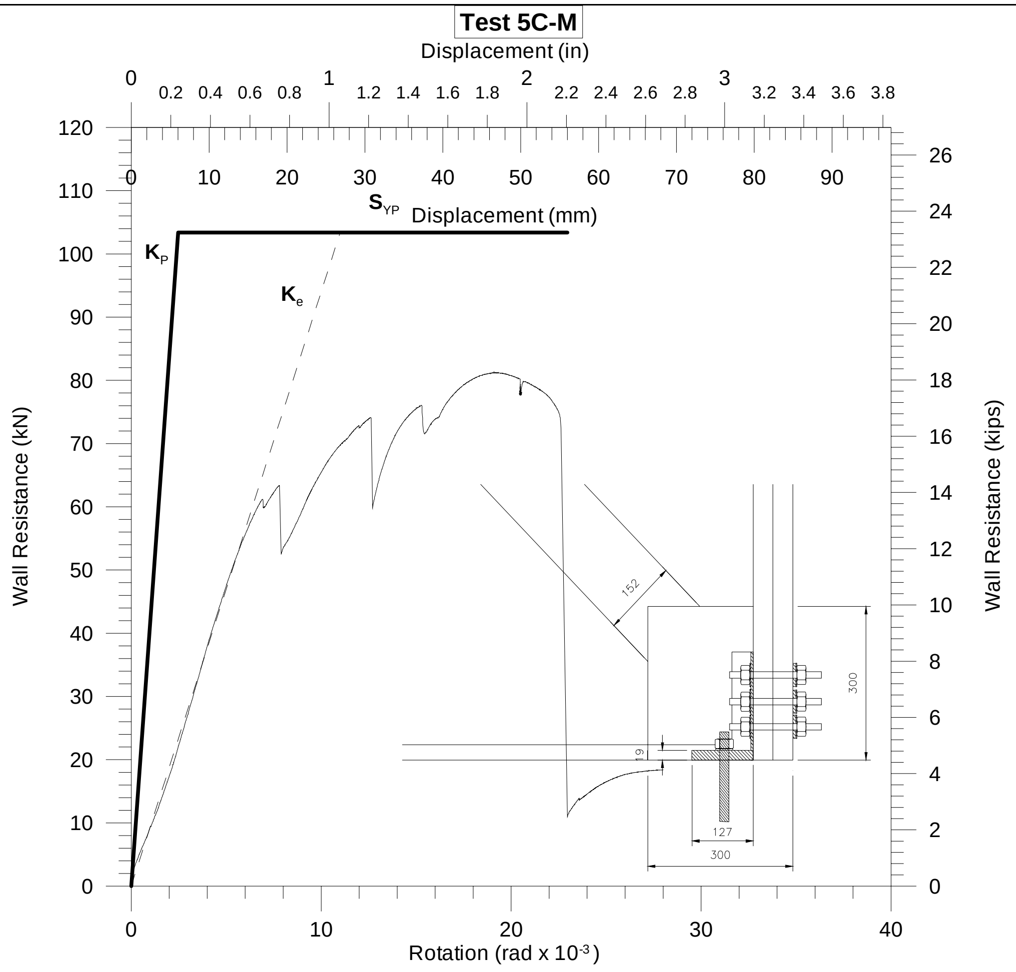


Figure 73: Test results specimen 5B-M



		Parameters	Units
Test Result	S_Y	81.23	kN
	$S_{0.8}$	64.99	kN
	$S_{0.4}$	32.49	kN
	K_e	3.85	kN/mm
	Ductility (μ)	2.09	mm/mm
Prediction (Actual Dimensions)	S_{YP}	103.38	kN
	K_P	17.18	kN/mm
Prediction (Nominal Dimensions)	S_{YN}	94.43	kN
	K_N	17.90	kN/mm

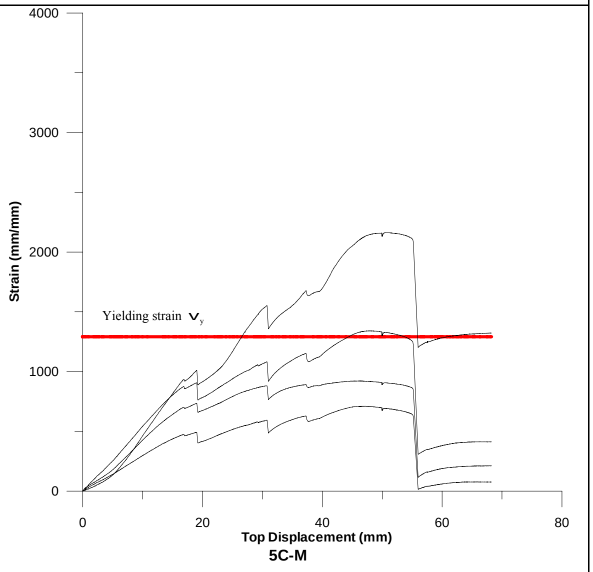
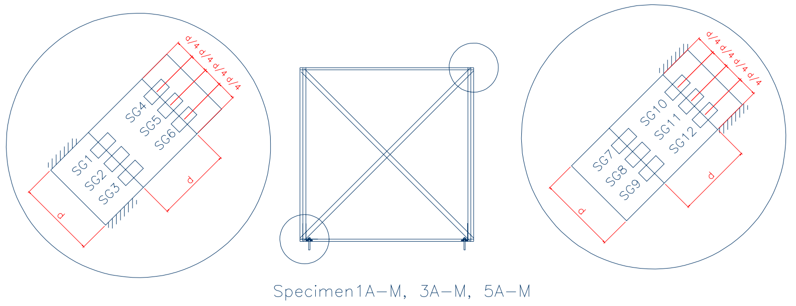


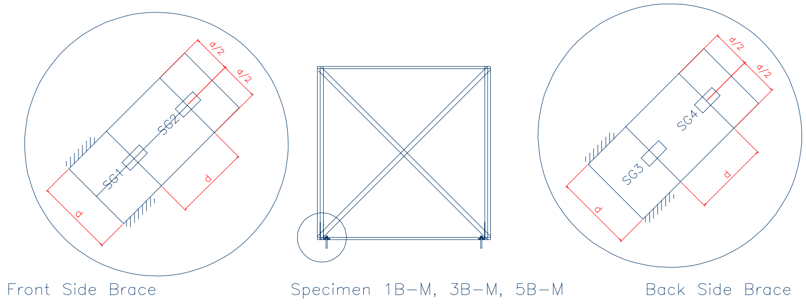
Figure 74: Test results specimen 5C-M

5A-M



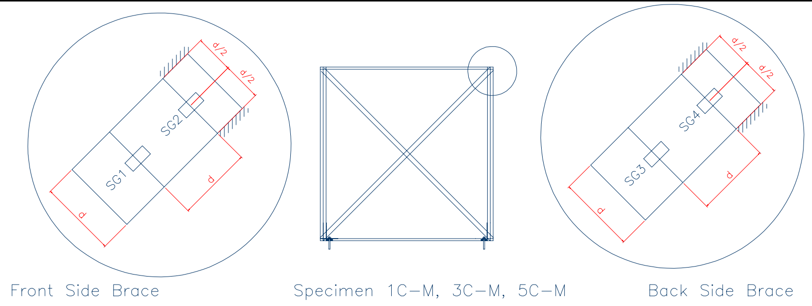
Strain Gauge	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8	SG9	SG10	SG11	SG12
Max strain Reached (mm/mm)	5807.0	15804.0	15846.0	3932.0	11302.0	15884.0	2095.0	1532.0	1108.0	3220.0	960.0	534.0
Yielding Strain (mm/mm)	1292.1	1292.1	1292.1	1292.1	1292.1	1292.1	1292.1	1292.1	1292.1	1292.1	1292.1	1292.1
Yielding Status	OK	OK	OK	OK	OK	OK	OK	OK	NO	OK	NO	NO

5B-M



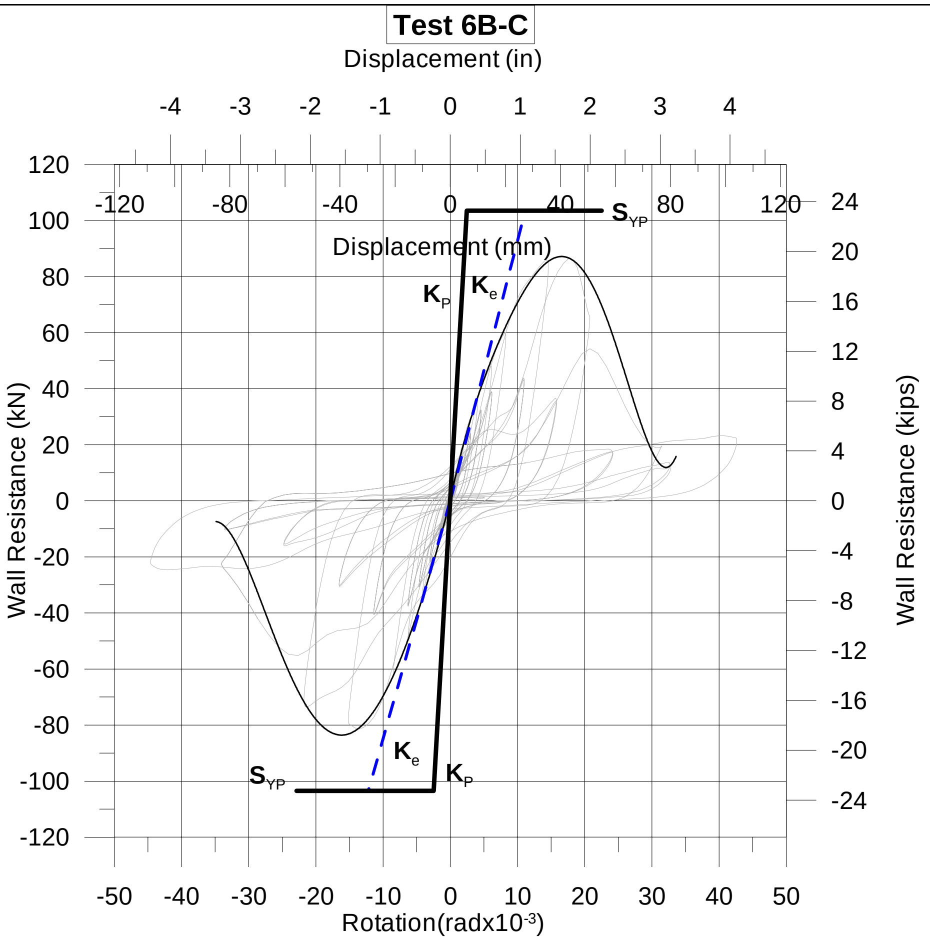
Strain Gauge	SG1	SG2	SG3	SG4
Max strain Reached (mm/mm)	447.0	675.0	81.0	1088.0
Yielding Strain (mm/mm)	1292.1	1292.1	1292.1	1292.1
Yielding Status	NO	NO	NO	NO

5C-M



Strain Gauge	SG1	SG2	SG3	SG4
Max strain Reached (mm/mm)	2163.0	922.0	1341.0	710.0
Yielding Strain (mm/mm)	1292.1	1292.1	1292.1	1292.1
Yielding Status	OK	NO	OK	NO

Figure 75: Strain gauge results specimens 5A-M, 5B-M and 5C-M



		Negative	Positive	Units
Test Result	S_Y	-83.56	87.13	kN
	$S_{0.8}$	-66.85	69.70	kN
	$S_{0.4}$	-33.42	34.85	kN
	K_e	3.48	3.79	kN/mm
	Ductility (μ)	1.88	2.01	mm/mm
Prediction (Actual Dimensions)	S_{YP}	-103.48	103.48	kN
	K_P	-17.20	17.20	kN/mm
Prediction (Nominal Dimensions)	S_{YN}	-94.43	94.43	kN
	K_N	-17.90	17.90	kN/mm

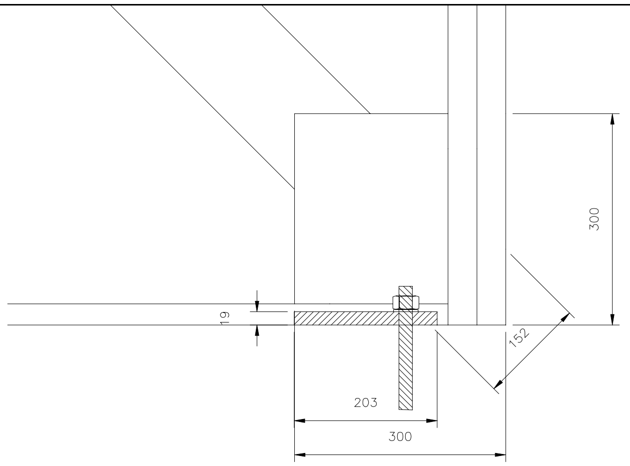
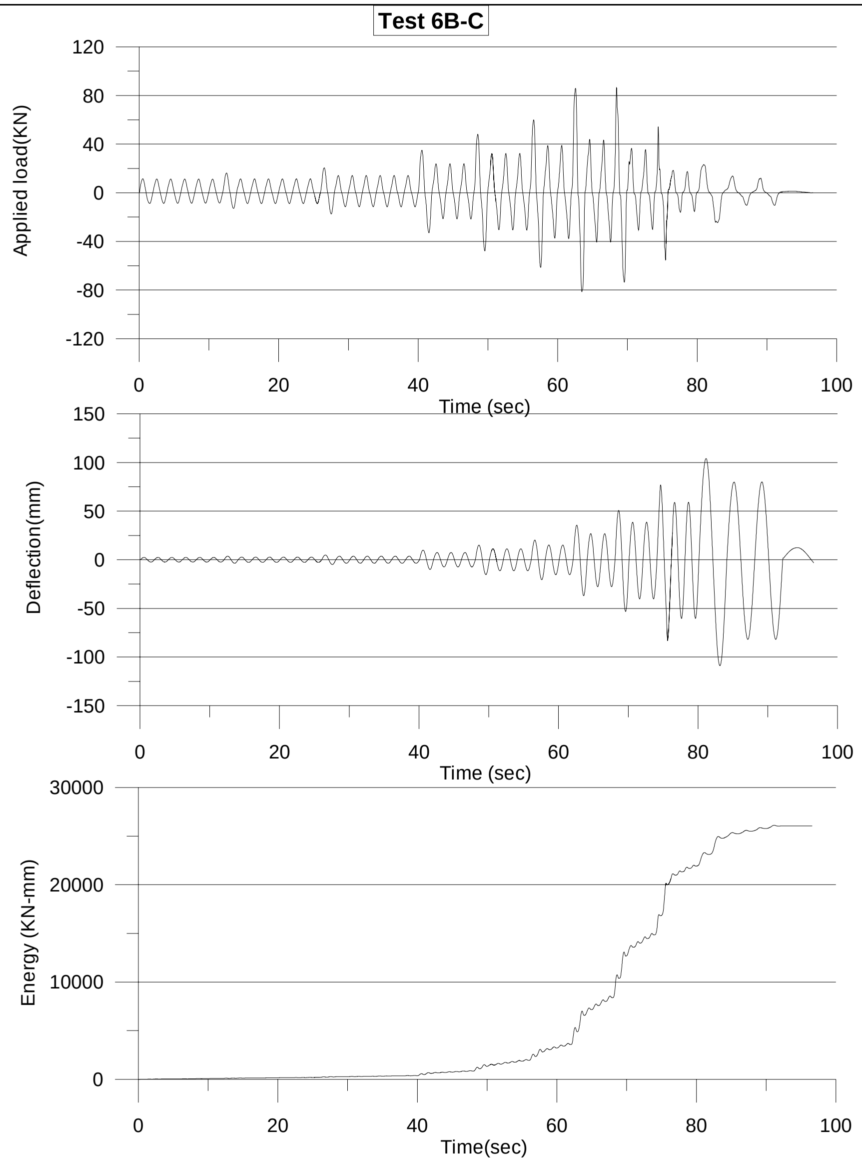


Figure 76: Test results specimen 6B-C



Strain Gauge	SG1	SG2	SG3	SG4
Max strain Reached (mm/mm)	1348.0	6330.0	11730.0	1089.0
Yielding Strain (mm/mm)	1292.1	1292.1	1292.1	1292.1
Yielding Status	OK	OK	OK	NO

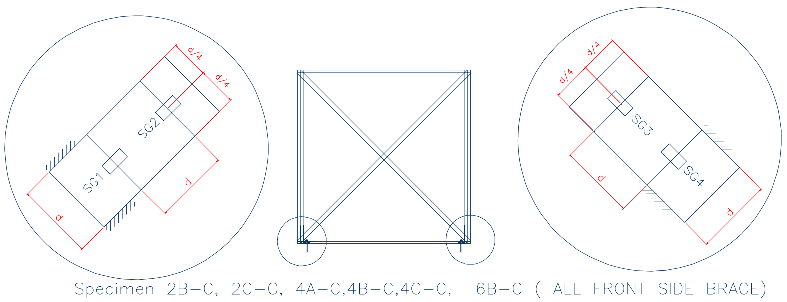
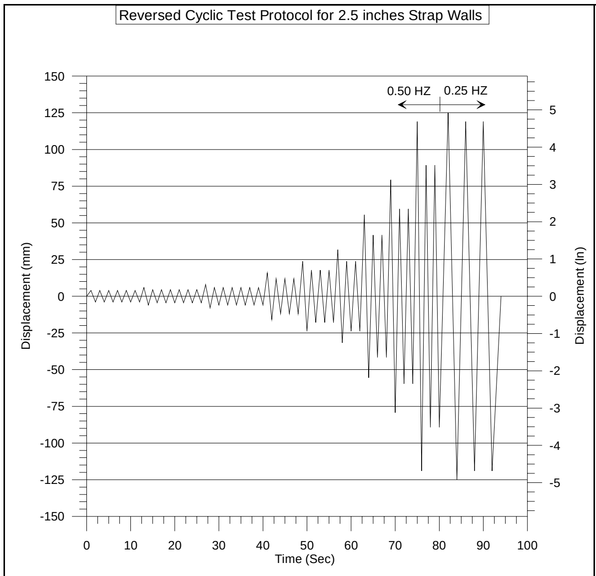


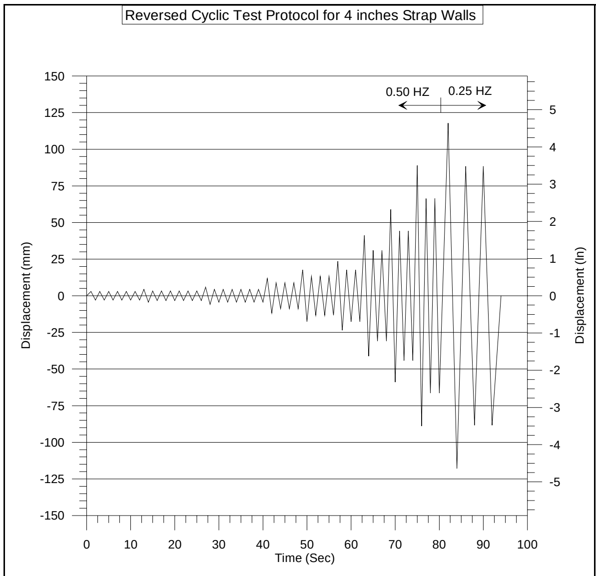
Figure 77: Time history and strain gauge results specimen 6B-C

APPENDIX B: CYCLIC PROTOCOLS



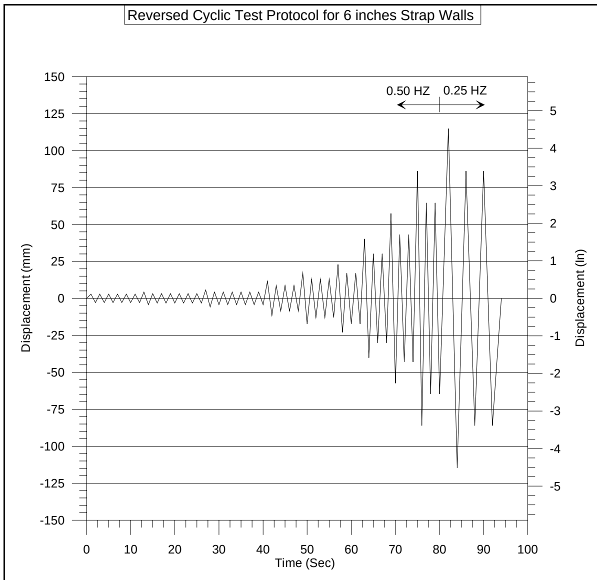
2.5 inches Strap Wall		
	Cycles	Distance (mm)
0.50 HZ	6	3.967
	1	5.951
	6	4.443
	1	7.934
	6	5.951
	1	15.868
	3	11.901
	1	23.802
	3	17.852
	1	31.737
	2	23.802
	1	55.539
	2	41.654
	1	79.341
	2	59.506
	1	119.010
	2	89.259
0.25 HZ	1	125.000
	2	119.010

Figure 78: Target and input displacements specimens 2A-C, 2B-C and 2C-C



4 inches Strap Wall		
	Cycles	Distance (mm)
0.50 HZ	6	2.947
	1	4.420
	6	3.300
	1	5.893
	6	4.420
	1	11.786
	3	8.840
	1	17.679
	3	13.259
	1	23.572
	2	17.679
	1	41.252
	2	30.939
	1	58.931
	2	44.198
	1	88.937
	2	66.297
0.25 HZ	1	117.860
	2	88.397

Figure 79: Target and input displacements specimens 4A-C, 4B-C and 4C-C



6 inches Strap Wall		
	Cycles	Distance (mm)
0.50 HZ	6	2.870
	1	4.305
	6	3.215
	1	5.741
	6	4.305
	1	11.480
	3	8.601
	1	17.222
	3	12.916
	1	22.962
	2	17.222
	1	40.184
	2	30.138
	1	57.405
	2	43.054
	1	86.108
	2	64.581
0.25 hHZ	1	114.810
	2	86.108

Figure 80 : Target and input displacements specimen 6B-C

APPENDIX C: STRAIN GAUGE PLACEMENT

<table>
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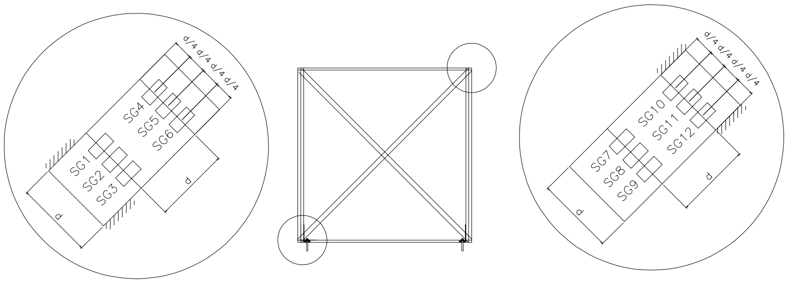

Specimen1A-M, 3A-M, 5A-M
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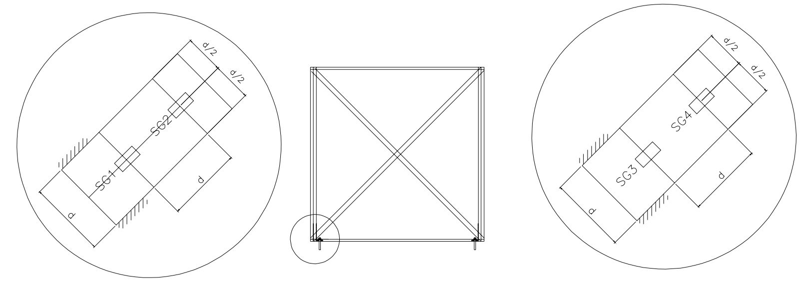

Front Side Brace Specimen 1B-M, 3B-M, 5B-M Back Side Brace
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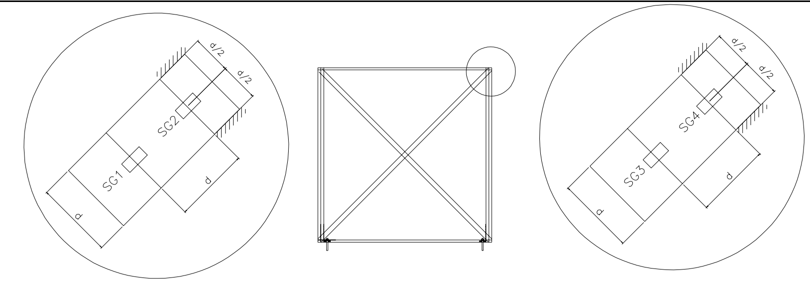

Front Side Brace Specimen 1C-M, 3C-M, 5C-M Back Side Brace
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1C-M, 3C-M, 5C-M</td>
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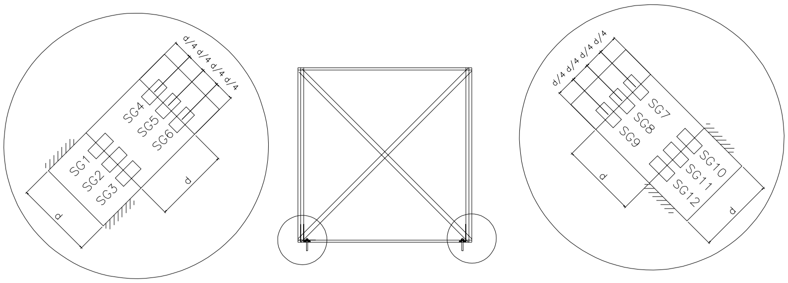

Specimen 2A-C, 4A-C, 6A-C (ALL FRONT SIDE BRACE)
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(All front side brace)</td>
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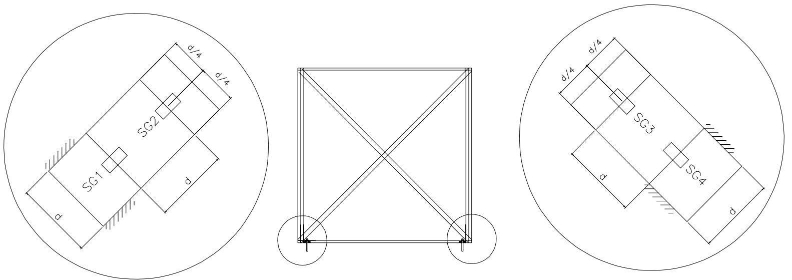

Specimen 2B-C, 2C-C, 4A-C,4B-C,4C-C, 6B-C (ALL FRONT SIDE BRACE)
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2B-C, 2C-C, 4A-C,4B-C,
4C-C, 6B-C
(All front side brace)</td>
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APPENDIX D: TEST DATA SHEETS

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 1A - M

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 27-Jul-04 **TIME:** 11:00

DIMENSIONS OF W 8 FT X 8 FT X 3-5/8" IN.

INITIAL STRAP SURVEY:

Front	Tight
Back	Loose

STRAP FASTENER CONFIGURATION: See page

MFR: Genesis by KML

STRAP SIZE:

X	2.3"
	4"
	6"

INTERIOR STUDS:

X	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
	6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING:

X	16" O.C.
	Other :

FRONT-TO-FRONT CHORD STUDS:

X	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
	6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
	6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:

Straps	X	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
		Fillet Weld				
Framing:	X	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
Hold down	X	Fillet Weld				
Front-to-Front						
Chord Stu	X	Fillet Weld				
Anchor Ro	X	5/8" Rod A307				
		3/4" Rod A307				
Loading B	X	A325 3/4" bolts	10 bolts	X	2 Anchor Rods	X
Base	X	A325 3/4" bolts	4 bolts	X	2 Anchor Rods	X

TRACK:

Web:	3-5/8"	inches	X	0.048" (1.22mm) 33ksi (230 MPa)
Flange:	1-3/16"	inches		Other:

HOLD DOWNS:

X	2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then welded
	250 mm x 250 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm
	300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm

Width:		Height:	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	

TEST PROTOCOL AND DESCRIPTION:

X	Monotonic	Rate of Loading 2.5 mm/min
	Cyclic	CUREE

LVDT MEASUREMENTS:

X	Actuator LVDT	X	North Uplift	X	East Frame Brace
X	North Slip	X	South Uplift	X	West Frame Brace
X	South Slip	X	Top of Wall Lateral		

TOTAL: 8

STRAIN GAUGE LOCATIONS:

X	Front Side Brace	X	Top	6	Right		Left
		X	Bottom		Right	6	Left
	Back Side Brace		Top		Right		Left
			Bottom		Right		Left

WIDTH OF STRAP:

Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
58.93				58.35			
58.30				58.17			
58.64				59.10			
AVG	58.62	AVG	0.00	AVG	58.54	AVG	0.00

STRAP WIDTH BEFORE TEST:

Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
AVG	0.00	AVG	0.00	AVG	0.00	AVG	0.00

WELD LENGTHS:

1a		2a		3a		4a		5a		6a		7a		8a	
1b		2b		3b		4b		5b		6b		7b		8b	
1c		2c		3c		4c		5c		6c		7c		8c	

DATA ACQ. RECORD RATE: 2 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement 0.336 mm

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 1B - M

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 22-Jul-04 **TIME:** 11:00

DIMENSIONS OF WALL: 8 FT X 8 FT X 3-5/8" IN.

INITIAL STRAP SURVEY:
Front Tight
Back Loose on one side

STRAP FASTENER CONFIGURATION: See page

MFR: Genesis by KML

STRAP SIZE:	X	2.3"
		4"
		6"

INTERIOR STUDS:	X	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)	**STUD SPACING:**	X	16" O.C.
		6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)			Other :

FRONT-TO-FRONT CHORD STUDS:	X	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
		6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
		6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:	Straps	X	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
			Fillet Weld				
	Framing:	X	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
	Hold downs:	X	Fillet Weld				
	Front-to-Front Chord Studs:	X	Fillet Weld				
	Anchor Rods	X	1/2" Rod A307				
			3/4" Rod A307				
	Loading Beam:	X	A325 3/4" bolts	10 bolts	X	2 Anchor Rods	X
	Base	X	A325 3/4" bolts	4 bolts	X	2 Anchor Rods	X

TRACK:	Web:	3-5/8"	inches	X	0.048" (1.22mm) 33ksi (230 MPa)
	Flange:	1-5/8"	inches		Other:

HOLD DOWNS:	X	2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec					
		250 mm x 250 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm	Width:	1		Height: 1	
		300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm		2		2	
				3		3	
				4		4	
				5		5	
TEST PROTOCOL AND DESCRIPTION:	X	Monotonic Rate of Loading 2.5 mm/min		6		6	
				7		7	
		Cyclic CUREE		8		8	

LVDT MEASUREMENTS:	X	Actuator LVDT	X	North Uplift	X	East Frame Brace
	X	North Slip	X	South Uplift	X	West Frame Brace
	X	South Slip	X	Top of Wall Lateral		
					TOTAL:	8

STRAIN GAUGE MEASUREMENTS:	X	Front Side Brace		Top		Right		Left
			X	Bottom		Right	2	Left
	X	Back Side Brace		Top		Right		Left
			X	Bottom		Right	2	Left

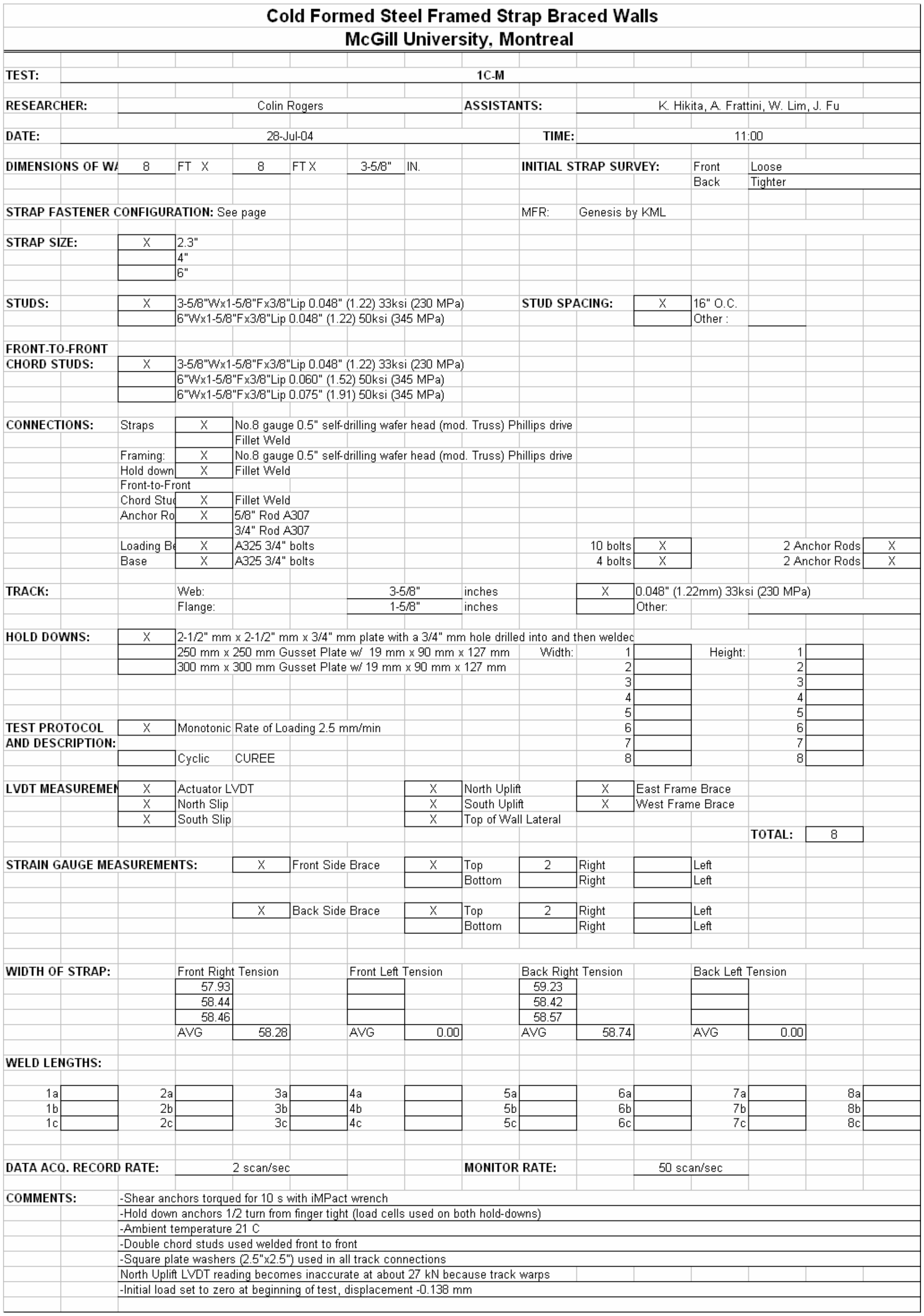
	Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
WIDTH OF STRAP:	57.90	mm			58.35			
	58.28				57.76			
	58.35				58.54			
	AVG	58.18	AVG	0.00	AVG	58.22	AVG	0.00

WELD LENGTHS:

1a		2a		3a		4a		5a		6a		7a		8a	
1b		2b		3b		4b		5b		6b		7b		8b	
1c		2c		3c		4c		5c		6c		7c		8c	

DATA ACQ. RECORD RATE: 2 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with Impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 23 C
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement 0.737 mm



Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 1C-M

RESEARCHER: Colin Rogers
ASSISTANTS: K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 28-Jul-04
TIME: 11:00

DIMENSIONS OF WA 8 FT X 8 FT X 3-5/8" IN.

INITIAL STRAP SURVEY:	Front	Loose
	Back	Tighter

STRAP FASTENER CONFIGURATION: See page
MFR: Genesis by KML

STRAP SIZE:	X	2.3"
		4"
		6"

STUDS:	X	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)	**STUD SPACING:**	X	16" O.C.
		6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)			Other :

FRONT-TO-FRONT CHORD STUDS:	X	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
		6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
		6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:	Straps	X	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
			Fillet Weld				
	Framing:	X	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
	Hold down	X	Fillet Weld				
	Front-to-Front						
	Chord Stuc	X	Fillet Weld				
	Anchor Ro	X	5/8" Rod A307				
			3/4" Rod A307				
	Loading Be	X	A325 3/4" bolts	10 bolts	X	2 Anchor Rods	X
	Base	X	A325 3/4" bolts	4 bolts	X	2 Anchor Rods	X

TRACK:	Web:	3-5/8"	inches	X	0.048" (1.22mm) 33ksi (230 MPa)
	Flange:	1-5/8"	inches		Other:

HOLD DOWNS:	X	2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec						
		250 mm x 250 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm	Width:	1		Height:	1	
		300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm		2			2	
				3			3	
				4			4	
				5			5	
TEST PROTOCOL	X	Monotonic Rate of Loading 2.5 mm/min		6			6	
AND DESCRIPTION:				7			7	
		Cyclic CUREE		8			8	

LVDT MEASUREMEN	X	Actuator LVDT	X	North Uplift	X	East Frame Brace
	X	North Slip	X	South Uplift	X	West Frame Brace
	X	South Slip	X	Top of Wall Lateral		
					TOTAL:	8

STRAIN GAUGE MEASUREMENTS:	X	Front Side Brace	X	Top	2	Right		Left
				Bottom		Right		Left
	X	Back Side Brace	X	Top	2	Right		Left
				Bottom		Right		Left

WIDTH OF STRAP:	Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
	57.93				59.23			
	58.44				58.42			
	58.46				58.57			
	AVG	58.28	AVG	0.00	AVG	58.74	AVG	0.00

WELD LENGTHS:

1a		2a		3a		4a		5a		6a		7a		8a	
1b		2b		3b		4b		5b		6b		7b		8b	
1c		2c		3c		4c		5c		6c		7c		8c	

DATA ACQ. RECORD RATE: 2 scan/sec
MONITOR RATE: 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with iMPact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 21 C
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
North Uplift LVDT reading becomes inaccurate at about 27 kN because track warps
-Initial load set to zero at beginning of test, displacement -0.138 mm

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 2A-C

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 29-Jul-04 **TIME:** 11:00

DIMENSIONS OF WA 8 FT X 8 FT X 3-5/8" IN. **INITIAL STRAP SURVEY:** Front tight
Back loose

STRAP FASTENER CONFIGURATION: See page MFR: Genesis by KML

STRAP SIZE:

X	2.3"
	4"
	6"

STUDS:

X	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
	6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING: X 16" O.C.
☐ Other : Except for the extreme south interior stud which c/c spacing from the build up chord stud is 14"

FRONT-TO-FRONT CHORD STUDS:

X	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
	6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
	6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:

Straps	X	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
		Fillet Weld				
Framing:	X	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
Hold down	X	Fillet Weld				
Front-to-Front						
Chord Stud	X	Fillet Weld				
Anchor Ro	X	5/8" Rod A307				
		3/4" Rod A307				
Loading Be	X	A325 3/4" bolts	10 bolts	X	2 Anchor Rods	X
Base	X	A325 3/4" bolts	4 bolts	X	2 Anchor Rods	X

TRACK: Web: 3-5/8" inches X 0.048" (1.22mm) 33ksi (230 MPa)
Flange: 1-5/8" inches ☐ Other:

HOLD DOWNS:

X	2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec
	250 mm x 250 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm
	300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm

Width:		Height:	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	

TEST PROTOCOL AND DESCRIPTION:

	Monotonic	Rate of Loading 2.5 mm/min
X	Cyclic	CUREE

LVDT MEASUREMEN

X	Actuator LVDT	X	North Uplift	X	East Frame Brace
X	North Slip	X	South Uplift	X	West Frame Brace
X	South Slip	X	Top of Wall Lateral		

TOTAL: 8

STRAIN GAUGE MEASUREMENTS:

X	Front Side Brace		Top		Right		Left
		X	Bottom	6	Right	6	Left
	Back Side Brace		Top		Right		Left
			Bottom		Right		Left

WIDTH OF STRAP:

Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
58.52		58.86		59.06		59.24	
58.44		58.26		58.16		59.16	
58.61		58.33		59.24		58.34	
AVG	58.52	AVG	58.48	AVG	58.82	AVG	58.91

WELD LENGTHS:

1a		2a		3a		4a		5a		6a		7a		8a	
1b		2b		3b		4b		5b		6b		7b		8b	
1c		2c		3c		4c		5c		6c		7c		8c	

DATA ACQ. RECORD RATE: 50 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 23 C
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement 0.038 mm

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 2B-C

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 29-Jul-04 **TIME:** 13:50

DIMENSIONS OF WA 8 FT X 8 FT X 3-5/8" IN.

INITIAL STRAP SURVEY:
Front tight
Back tight, but relatively looser

STRAP FASTENER CONFIGURATION: See page

MFR: Genesis by KML

STRAP SIZE:
☒ 2.3"
☐ 4"
☐ 6"

STUDS:
☒ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☐ 6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING:
☒ 16" O.C.
☐ Other :

FRONT-TO-FRONT CHORD STUDS:
☒ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☐ 6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
☐ 6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:
Straps ☒ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
☐ Fillet Weld
Framing: ☒ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
Hold down ☒ Fillet Weld
Front-to-Front
Chord Stud ☒ Fillet Weld
Anchor Ro ☒ 5/8" Rod
☐ 3/4" Hardened Steel Rod
Loading Be ☒ A325 3/4" bolts 10 bolts ☒ 2 Anchor Rods ☒
Base ☒ A325 3/4" bolts 4 bolts ☒ 2 Anchor Rods ☒

TRACK:
Web: 3-5/8" inches ☒ 0.048" (1.22mm) 33ksi (230 MPa)
Flange: 1-5/8" inches ☐ Other:

HOLD DOWNS:
☒ 2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec
☐ 250 mm x 250 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm
☐ 300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm

Width:		Height:	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	

TEST PROTOCOL AND DESCRIPTION:
☐ Monotonic Rate of Loading 2.5 mm/min
☒ Cyclic CUREE

LVDT MEASUREMEN
☒ Actuator LVDT ☒ North Uplift ☒ East Frame Brace
☒ North Slip ☒ South Uplift ☒ West Frame Brace
☒ South Slip ☒ Top of Wall Lateral

TOTAL: 8

STRAIN GAUGE MEASUREMENTS:
☒ Front Side Brace ☐ Top ☐ Right ☐ Left
☒ Bottom 2 Right 2 Left

☐ Back Side Brace ☐ Top ☐ Right ☐ Left
☐ Bottom ☐ Right ☐ Left

WIDTH OF STRAP:

Front Right Tension	Front Left Tension	Back Right Tension	Back Left Tension
58.46	58.39	58.35	58.41
58.42	58.38	58.36	58.38
58.47	58.42	58.38	58.37
AVG 58.45	AVG 58.40	AVG 58.36	AVG 58.39

WELD LENGTHS:

1a		2a		3a		4a		5a		6a		7a		8a	
1b		2b		3b		4b		5b		6b		7b		8b	
1c		2c		3c		4c		5c		6c		7c		8c	

DATA ACQ. RECORD RATE: 50 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 23 C
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement -0.073 mm

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 2C-C

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 30-Jul-04 **TIME:** 11:00

DIMENSIONS OF WA 8 FT X 8 FT X 3-5/8" IN. **INITIAL STRAP SURVEY:** Front loose
Back loose

STRAP FASTENER CONFIGURATION: See page MFR: Genesis by KML

STRAP SIZE:
X 2.3"
4"
6"

STUDS:
X 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING: X 16" O.C.
Other :

FRONT-TO-FRONT CHORD STUDS:
X 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:
Straps X No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
Fillet Weld
Framing: X No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
Hold down X Fillet Weld
Front-to-Front
Chord Stu X Fillet Weld
Anchor Ro X 5/8" Rod A307
3/4" Hardened Steel Rod
Loading B X A325 3/4" bolts 10 bolts X 2 Anchor Rods X
Base X A325 3/4" bolts 4 bolts X 2 Anchor Rods X

TRACK:
Web: 3-5/8" inches X 0.048" (1.22mm) 33ksi (230 MPa)
Flange: 1-5/8" inches Other:

HOLD DOWNS:
X 2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then welde
250 mm x 250 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm
300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm

Width:		Height:	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	

TEST PROTOCOL AND DESCRIPTION:
Monotonic Rate of Loading 2.5 mm/min
X Cyclic CUREE

LVDT MEASUREMEN
X Actuator LVDT X North Uplift X East Frame Brace
X North Slip X South Uplift X West Frame Brace
X South Slip X Top of Wall Lateral
TOTAL: 8

STRAIN GAUGE MEASUREMENTS:
X Front Side Brace
Top Right Left
X Bottom 2 Right 2 Left

Back Side Brace
Top Right Left
Bottom Right Left

WIDTH OF STRAP:

Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
	58.44		58.47		58.45	58.45	
	58.67		58.77		58.79	58.77	
	58.43		58.46		58.38	58.28	
AVG	58.51	AVG	58.57	AVG	58.54	AVG	58.50

WELD LENGTHS:

1a		2a		3a		4a		5a		6a		7a		8a	
1b		2b		3b		4b		5b		6b		7b		8b	
1c		2c		3c		4c		5c		6c		7c		8c	

DATA ACQ. RECORD RATE: 50 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 23 C
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement -0.919 mm

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 3A-M

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 18-Aug-04 **TIME:** 9:30

DIMENSIONS OF WALL: 8 FT X 8 FT X 6 IN. **INITIAL STRAP SURVEY:** Front A little Lose

Back Tighter

STRAP FASTENER CONFIGURATION: See page MFR: Genesis by KML

STRAP SIZE:

	2.3"
X	4"
	6"

STUDS:

	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
X	6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING:

X	16" O.C.
	Other :

Interior stud at wall ends are 13.5" and 15" away from the N & S chord studs respectively

FRONT-TO-FRONT CHORD STUDS:

	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
X	6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
	6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:

Straps		No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
	X	Fillet Weld				
Framing:	X	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
Hold downs:		Fillet Weld				
Front-to-Front Chord Studs:	X	Fillet Weld				
Anchor Rods		5/8" Rod A307				
	X	3/4" Rod A307				
Loading Beam:	X	A325 3/4" bolts	10 bolts	X	2 Anchor Rods	X
Base	X	A325 3/4" bolts	4 bolts	X	2 Anchor Rods	X

TRACK:

Web:	6"	inches	X	0.060" (1.52mm) 55ksi (345 MPa)
Flange:	1-5/8"	inches		Other:

HOLD DOWNS:

	2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec					
X	250 mm x 250 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm	Width:	1		Height: 1	
	300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm		2		2	
			3		3	
			4		4	
			5		5	
			6		6	
			7		7	
			8		8	

TEST PROTOCOL AND DESCRIPTION:

X	Monotonic	Rate of Loading 2.5 mm/min
	Cyclic	CUREE

LVDT MEASUREMENTS:

X	Actuator LVDT	X	North Uplift	X	East Frame Brace
X	North Slip	X	South Uplift	X	West Frame Brace
X	South Slip	X	Top of Wall Lateral		

TOTAL: 8

STRAIN GAUGE MEASUREMENTS:

X	Front Side Brace	X	Top	6	Right		Left
		X	Bottom		Right	6	Left
	Back Side Brace		Top		Right		Left
			Bottom		Right		Left

WIDTH OF STRAP:

Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
101.0				101.04			
101.1				101.35			
101.3				101.41			
AVG	101.15	AVG	0.00	AVG	101.27	AVG	0.00

WELD LENGTHS:

1a	55	2a	50	3a	65	4a	60	5a	50	6a	65	7a	50	8a	60
1b	95	2b	100	3b	100	4b	100	5b	108	6b	105	7b	100	8b	105
1c	50	2c	60	3c	60	4c	60	5c	60	6c	65	7c	50	8c	55

DATA ACQ. RECORD RATE: 2 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:

-Shear anchors torqued for 10 s with impact wrench

-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)

-Ambient temperature 23 C

-Double chord studs used welded front to front

-Square plate washers (2.5"x2.5") used in all track connections

-Initial load set to zero at beginning of test, displacement 7.75 **mm**

test started -ve 0.22 kN, add this value to the results

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 3B-M

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 18-Aug-04 **TIME:** 15:00

DIMENSIONS OF WALL: 8 FT X 8 FT X 6 IN.

INITIAL STRAP SURVEY:
Front A little Lose
Back Tighter

STRAP FASTENER CONFIGURATION: See page

MFR: Genesis by KML

STRAP SIZE:

	2.3"
X	4"
	6"

STUDS:

	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
X	6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING:

X	16" O.C.
	Other :

Interior stud at wall ends are and 15" and 13 1/4" away from the N & S chord studs respectively

FRONT-TO-FRONT CHORD STUDS:

	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
X	6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
	6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:

Straps		No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
	X	Fillet Weld				
Framing:	X	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
Hold downs:		Fillet Weld				
Front-to-Front Chord Studs:	X	Fillet Weld				
Anchor Rods		5/8" Rod A307				
	X	3/4" Rod A307				
Loading Beam:	X	A325 3/4" bolts	10 bolts	X	2 Anchor Rods	X
Base	X	A325 3/4" bolts	4 bolts	X	2 Anchor Rods	X

TRACK:
Web: 6" inches
Flange: 1-5/8" inches

X	0.060" (1.52mm) 55ksi (345 MPa)
	Other:

HOLD DOWNS:

	2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec
X	250 mm x 250 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm
	300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm

Width:			Height:	
1			1	
2			2	
3			3	
4			4	
5			5	
6			6	
7			7	
8			8	

TEST PROTOCOL AND DESCRIPTION:

X	Monotonic	Rate of Loading 2.5 mm/min
	Cyclic	CUREE

LVDT MEASUREMENTS:

X	Actuator LVDT	X	North Uplift	X	East Frame Brace
X	North Slip	X	South Uplift	X	West Frame Brace
X	South Slip	X	Top of Wall Lateral		

TOTAL: 8

STRAIN GAUGE MEASUREMENTS:

X	Front Side Brace		Top		Right		Left
		X	Bottom		Right	2	Left
X	Back Side Brace		Top		Right		Left
		X	Bottom		Right	2	Left

WIDTH OF STRAP:

Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
102.0				101.14			
101.4				100.49			
101.3				100.62			
AVG	101.55	AVG	0.00	AVG	100.75	AVG	0.00

WELD LENGTHS:

1a	50	2a	40	3a	45	4a	50	5a	40	6a	50	7a	45	8a	50
1b	105	2b	105	3b	105	4b	105	5b	100	6b	105	7b	105	8b	100
1c	45	2c	40	3c	45	4c	45	5c	50	6c	55	7c	55	8c	45

DATA ACQ. RECORD RATE: 2 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 23 C
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement -0.711 **mm**

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 3C-M

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: **TIME:**

DIMENSIONS OF WALL: 8 FT X 8 FT X 6 IN.

INITIAL STRAP SURVEY:
Front A little Lose
Back Tighter

STRAP FASTENER CONFIGURATION: See page

MFR: Genesis by KML

STRAP SIZE:
☐ 2.3"
☒ 4"
☐ 6"

STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING:
☒ 16" O.C.
☐ Other : Interior stud at wall ends are 13.75" and 15.25" away from the N & S chord studs respectively

FRONT-TO-FRONT CHORD STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
☐ 6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:
Straps ☐ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
☒ Fillet Weld
Framing: ☒ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
Hold downs: ☐ Fillet Weld
Front-to-Front Chord Studs: ☒ Fillet Weld
Anchor Rods ☐ 5/8" Rod A307
☒ 3/4" Rod A307
Loading Beam: ☒ A325 3/4" bolts 10 bolts ☒ 2 Anchor Rods ☒
Base ☒ A325 3/4" bolts 4 bolts ☒ 2 Anchor Rods ☒

TRACK:
Web: 6" inches ☒ 0.060" (1.52mm) 55ksi (345 MPa)
Flange: 1-5/8" inches ☐ Other:

HOLD DOWNS:
☐ 2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec
☒ 250 mm x 250 mm Gusset Plate w/ 19 mm x 127 mm x 203 mm
☐ 300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm

	Width:		Height:
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	

TEST PROTOCOL AND DESCRIPTION:
☒ Monotonic Rate of Loading 2.5 mm/min
☐ Cyclic CUREE

LVDT MEASUREMENTS:
☒ Actuator LVDT ☒ North Uplift ☒ East Frame Brace
☒ North Slip ☒ South Uplift ☒ West Frame Brace
☒ South Slip ☒ Top of Wall Lateral
TOTAL: 8

STRAIN GAUGE MEASUREMENTS:
☒ Front Side Brace ☒ Top 2 Right ☐ Left
☐ Bottom ☐ Right ☐ Left
☒ Back Side Brace ☒ Top 2 Right ☐ Left
☐ Bottom ☐ Right ☐ Left

WIDTH OF STRAP:

Front Right Tension	Front Left Tension	Back Right Tension	Back Left Tension
101.6		101.09	
101.2		100.79	
101.1		101.19	
AVG 101.28	AVG 0.00	AVG 101.02	AVG 0.00

WELD LENGTHS:

1a	95	2a	75	3a	80	4a	85	5a	65	6a	80	7a	75	8a	90
1b	105	2b	100	3b	110	4b	105	5b	105	6b	105	7b	105	8b	110
1c	90	2c	95	3c	85	4c	75	5c	75	6c	90	7c	85	8c	90

DATA ACQ. RECORD RATE: 2 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 23 C
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement -0.927 **mm**

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 4A-C

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 31-Aug-04 **TIME:** 12:00

DIMENSIONS OF WALL: 8 FT X 8 FT X 6 IN.

INITIAL STRAP SURVEY:
Front Loose
Back Tighter

STRAP FASTENER CONFIGURATION: See page

MFR: Genesis by KML

STRAP SIZE:
☐ 2.3"
☒ 4"
☐ 6"

STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING:
☒ 16" O.C.
☐ Other :

Interior stud at wall ends are 13 3/8" and 15 3/8" away from the N & S chord studs respectively

FRONT-TO-FRONT CHORD STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
☐ 6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:
Straps ☐ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
☒ Fillet Weld
Framing: ☒ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
Hold downs: ☐ Fillet Weld
Front-to-Front Chord Studs: ☒ Fillet Weld
Anchor Rods ☐ 5/8" Rod A307
☒ 3/4" Rod A307
Loading Beam: ☒ A325 3/4" bolts 10 bolts ☒ 2 Anchor Rods ☒
Base ☒ A325 3/4" bolts 4 bolts ☒ 2 Anchor Rods ☒

TRACK:
Web: 6" inches ☒ 0.060" (1.52mm) 55ksi (345 MPa)
Flange: 1-5/8" inches ☐ Other:

HOLD DOWNS:
☐ 2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec
☒ 250 mm x 250 mm Gusset Plate w/ 19 mm x 127 mm x 203 mm
☐ 300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm

Width:		Height:	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	

TEST PROTOCOL AND DESCRIPTION:
☐ Monotonic Rate of Loading 2.5 mm/min
☒ Cyclic CUREE

LVDT MEASUREMENTS:
☒ Actuator LVDT
☒ North Slip
☒ South Slip
☒ North Uplift
☒ South Uplift
☒ Top of Wall Lateral
☒ East Frame Brace
☒ West Frame Brace
TOTAL: 8

STRAIN GAUGE MEASUREMENTS:
☒ Front Side Brace ☐ Top ☐ Right ☐ Left
☒ Bottom 6 Right 6 Left
☐ Back Side Brace ☐ Top ☐ Right ☐ Left
☐ Bottom ☐ Right ☐ Left

WIDTH OF STRAP:

Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
101.2		101.6		100.8		101.19	
102.3		101.9		100.83		101.34	
101.5		101.2		101.06		101.76	
AVG	101.66	AVG	101.54	AVG	100.90	AVG	101.43

WELD LENGTHS:

1a	90	2a	80	3a	90	4a	95	5a	75	6a	80	7a	75	8a	75
1b	100	2b	105	3b	105	4b	100	5b	100	6b	100	7b	110	8b	105
1c	85	2c	70	3c	100	4c	80	5c	85	6c	85	7c	75	8c	70

DATA ACQ. RECORD RATE: 50 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 23 C
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement -0.155 mm
we tried to zero SG1, on channel 11, but a -26.44 percent error occurred. See notes for more details

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 4B-C

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 30-Aug-04 **TIME:** 15:22

DIMENSIONS OF WALL: 8 FT X 8 FT X 6 IN.

INITIAL STRAP SURVEY:

Front	Tight
Back	Tight

STRAP FASTENER CONFIGURATION: See page

MFR: Genesis by KML

STRAP SIZE:

	2.3"
X	4"
	6"

STUDS:

	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
X	6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING:

X	16" O.C.	
	Other :	Interior stud at wall ends are 13" and 14.5" away from the N & S chord studs respectively

FRONT-TO-FRONT CHORD STUDS:

	3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
X	6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
	6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:

Straps		No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
	X	Fillet Weld				
Framing:	X	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
Hold downs:		Fillet Weld				
Front-to-Front Chord Studs:	X	Fillet Weld				
Anchor Rods		5/8" Rod A307				
	X	3/4" Rod A307				
Loading Beam:	X	A325 3/4" bolts	10 bolts	X	2 Anchor Rods	X
Base	X	A325 3/4" bolts	4 bolts	X	2 Anchor Rods	X

TRACK:

Web:	6"	inches	X	0.060" (1.52mm) 55ksi (345 MPa)
Flange:	1-5/8"	inches		Other:

HOLD DOWNS:

	2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec						
X	250 mm x 250 mm Gusset Plate w/ 19 mm x 127 mm x 203 mm	Width:	1		Height:	1	
	300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm		2			2	
			3			3	
			4			4	
			5			5	
			6			6	
			7			7	
			8			8	

TEST PROTOCOL AND DESCRIPTION:

	Monotonic	Rate of Loading 2.5 mm/min
X	Cyclic	CUREE

LVDT MEASUREMENTS:

X	Actuator LVDT	X	North Uplift	X	East Frame Brace
X	North Slip	X	South Uplift	X	West Frame Brace
X	South Slip	X	Top of Wall Lateral		

TOTAL: 8

STRAIN GAUGE MEASUREMENTS:

X	Front Side Brace		Top		Right		Left
		X	Bottom	2	Right	2	Left
	Back Side Brace		Top		Right		Left
			Bottom		Right		Left

WIDTH OF STRAP:

Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
102.8		105.6		104.8		102.69	
104.2		104.3		105.1		104.75	
105.3		103.0		103.1		105.25	
AVG	104.11	AVG	104.28	AVG	104.34	AVG	104.23

WELD LENGTHS:

1a	105	2a	85	3a	90	4a	90	5a	100	6a	75	7a	90	8a	95
1b	110	2b	110	3b	105	4b	110	5b	110	6b	110	7b	110	8b	105
1c	95	2c	105	3c	100	4c	85	5c	100	6c	75	7c	90	8c	95

DATA ACQ. RECORD RATE: 50 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:

-Shear anchors torqued for 10 s with impact wrench

-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)

-Ambient temperature 23 C

-Double chord studs used welded front to front

-Square plate washers (2.5"x2.5") used in all track connections

-Initial load set to zero at beginning of test, displacement 9.466 **mm**

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 4C-C

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 31-Aug-04 **TIME:** 16:30

DIMENSIONS OF WALL: 8 FT X 8 FT X 6 IN.

INITIAL STRAP SURVEY:
Front Loose but tighter than back
Back Loose

STRAP FASTENER CONFIGURATION: See page

MFR: Genesis by KML

STRAP SIZE:
☐ 2.3"
☒ 4"
☐ 6"

STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING:
☒ 16" O.C.
☐ Other : Interior stud at wall ends are 13.5" and 14.5" away from the N & S chord studs respectively

FRONT-TO-FRONT CHORD STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
☐ 6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:

Straps	☐	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
	☒	Fillet Weld				
Framing:	☒	No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive				
Hold downs:	☐	Fillet Weld				
Front-to-Front Chord Studs:	☒	Fillet Weld				
Anchor Rods	☐	5/8" Rod A307				
	☒	3/4" Rod A307				
Loading Beam:	☒	A325 3/4" bolts	10 bolts	☒	2 Anchor Rods	☒
Base	☒	A325 3/4" bolts	4 bolts	☒	2 Anchor Rods	☒

TRACK:
Web: 6" inches ☒ 0.060" (1.52mm) 55ksi (345 MPa)
Flange: 1-5/8" inches ☐ Other:

HOLD DOWNS:
☐ 2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec
☒ 250 mm x 250 mm Gusset Plate w/ 19 mm x 127 mm x 203 mm
☐ 300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm

	Width:		Height:
1	☐	1	☐
2	☐	2	☐
3	☐	3	☐
4	☐	4	☐
5	☐	5	☐
6	☐	6	☐
7	☐	7	☐
8	☐	8	☐

TEST PROTOCOL AND DESCRIPTION:
☐ Monotonic Rate of Loading 2.5 mm/min
☒ Cyclic CUREE

LVDT MEASUREMENTS:

☒	Actuator LVDT	☒	North Uplift	☒	East Frame Brace
☒	North Slip	☒	South Uplift	☒	West Frame Brace
☒	South Slip	☒	Top of Wall Lateral		

TOTAL: 8

STRAIN GAUGE MEASUREMENTS:

☒	Front Side Brace	☐	Top	☐	Right	☐	Left
		☒	Bottom	2	Right	2	Left
☐	Back Side Brace	☐	Top	☐	Right	☐	Left
		☐	Bottom	☐	Right	☐	Left

WIDTH OF STRAP:

Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
101.2		105.6		102.35		101.99	
101.7		105.0		102.26		102.37	
101.9		103.9		102.33		102.87	
AVG	101.61	AVG	104.83	AVG	102.31	AVG	102.41

WELD LENGTHS:

1a	60	2a	75	3a	85	4a	65	5a	45	6a	55	7a	40	8a	45
1b	100	2b	95	3b	105	4b	100	5b	105	6b	105	7b	105	8b	100
1c	60	2c	90	3c	85	4c	70	5c	50	6c	60	7c	40	8c	55

DATA ACQ. RECORD RATE: 50 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 23 C
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement 0.213 **mm**

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 5A-M

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: **TIME:** 9:30:00 AM

DIMENSIONS OF WALL: 8 FT X 8 FT X 6 IN.

INITIAL STRAP SURVEY: Front Loose
Back Tight

STRAP FASTENER CONFIGURATION: See page

MFR: Genesis by KML

STRAP SIZE:
☐ 2.3"
☐ 4"
☒ 6"

STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING:
☒ 16" O.C.
☐ Other :

Interior stud at wall ends are 14" and 15.5" away from the N & S chord studs respectively

FRONT-TO-FRONT CHORD STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☐ 6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:
Straps ☐ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
☒ Fillet Weld
Framing: ☒ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
Hold downs: ☐ Fillet Weld
Front-to-Front
Chord Studs: ☒ Fillet Weld
Anchor Rods ☐ 5/8" Rod A307
☒ 3/4" Rod A325
Loading Beam: ☒ A325 3/4" bolts 10 bolts ☒ 2 Anchor Rods ☒
Base ☒ A325 3/4" bolts 4 bolts ☒ 2 Anchor Rods ☒

TRACK:
Web: 6" inches ☒ 0.075" (1.91mm) 55ksi (345 MPa)
Flange: 1-5/8" inches ☐ Other:

HOLD DOWNS:
☐ 2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec
☐ 250 mm x 250 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm
☒ 300 mm x 300 mm Gusset Plate w/ 19 mm x 127 mm x 203 mm

Width:		Height:	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	

TEST PROTOCOL AND DESCRIPTION:
☒ Monotonic Rate of Loading 2.5 mm/min
☐ Cyclic CUREE

LVDT MEASUREMENTS:
☒ Actuator LVDT ☒ North Uplift ☒ East Frame Brace
☒ North Slip ☒ South Uplift ☒ West Frame Brace
☒ South Slip ☒ Top of Wall Lateral
TOTAL: 8

STRAIN GAUGE MEASUREMENTS:
☒ Front Side Brace ☒ Top 6 Right ☐ Left
☒ Bottom ☐ Right 6 Left
☐ Back Side Brace ☐ Top ☐ Right ☐ Left
☐ Bottom ☐ Right ☐ Left

WIDTH OF STRAP:

Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
152.3				152.56			
152.2				152.50			
152.1				152.67			
AVG	152.18	AVG	0.00	AVG	152.58	AVG	0.00

WELD LENGTHS:

1a	60	2a	65	3a	60	4a	60	5a	55	6a	58	7a	60	8a	60
1b	150	2b	150	3b	150	4b	150	5b	150	6b	154	7b	145	8b	145
1c	50	2c	60	3c	62	4c	55	5c	55	6c	58	7c	58	8c	55

DATA ACQ. RECORD RATE: 2 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 23 C
-Double chord studs used welded front to front

-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement **-0.424 mm**

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 5B-M

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 19-Aug-04 **TIME:** 13:00

DIMENSIONS OF WALL: 8 FT X 8 FT X 6 IN.

INITIAL STRAP SURVEY:
Front Tight
Back Tight

STRAP FASTENER CONFIGURATION: See page

MFR: Genesis by KML

STRAP SIZE:
☐ 2.3"
☐ 4"
☒ 6"

STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING:
☒ 16" O.C.
☐ Other :

Interior stud at wall ends are 13 3/4 " and 15 1/4 " away from the N & S chord studs respectively

FRONT-TO-FRONT CHORD STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☐ 6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:
Straps ☐ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
☒ Fillet Weld
Framing: ☒ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
Hold downs: ☐ Fillet Weld
Front-to-Front
Chord Studs: ☒ Fillet Weld
Anchor Rods ☐ 5/8" Rod A307
☒ 3/4" Rod A325
Loading Beam: ☒ A325 3/4" bolts 10 bolts ☒ 2 Anchor Rods ☒
Base ☒ A325 3/4" bolts 4 bolts ☒ 2 Anchor Rods ☒

TRACK:
Web: 6" inches ☒ 0.075" (1.91mm) 55ksi (345 MPa)
Flange: 1-5/8" inches ☐ Other:

HOLD DOWNS:
☐ 2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec
☐ 250 mm x 250 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm
☒ 300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm

Width:		Height:	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	

TEST PROTOCOL AND DESCRIPTION:
☒ Monotonic Rate of Loading 2.5 mm/min
☐ Cyclic CUREE

LVDT MEASUREMENTS:
☒ Actuator LVDT ☒ North Uplift ☒ East Frame Brace
☒ North Slip ☒ South Uplift ☒ West Frame Brace
☒ South Slip ☒ Top of Wall Lateral

TOTAL: 8

STRAIN GAUGE MEASUREMENTS:
☒ Front Side Brace ☐ Top ☐ Right ☐ Left
☒ Bottom ☐ Right 2 Left
☒ Back Side Brace ☐ Top ☐ Right ☐ Left
☒ Bottom ☐ Right 2 Left

WIDTH OF STRAP:

Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
152.3				153.18			
152.3				152.91			
152.4				152.67			
AVG	152.34	AVG	0.00	AVG	152.92	AVG	0.00

WELD LENGTHS:

1a	75	2a	80	3a	70	4a	45 + 65	5a	60	6a	80	7a	85	8a	65
1b	90+50	2b	0	3b	160	4b	95 + 50	5b	145	6b	150	7b	155	8b	155
1c	30 + 65	2c	70	3c	70	4c	60	5c	55	6c	65	7c	80	8c	75

DATA ACQ. RECORD RATE: 2 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 23 C
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement -0.132 **mm**

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 5C-M

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 24-Aug-04 **TIME:** 11:30

DIMENSIONS OF WALL: 8 FT X 8 FT X 6 IN.

INITIAL STRAP SURVEY:
Front Tight
Back Tight

STRAP FASTENER CONFIGURATION: See page

MFR: Genesis by KML

STRAP SIZE:
☐ 2.3"
☐ 4"
☒ 6"

STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING:
☒ 16" O.C.
☐ Other : Interior stud at wall ends are 13.5" and 15" away from the N & S chord studs respectively

FRONT-TO-FRONT CHORD STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☐ 6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:
Straps ☐ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
☒ Fillet Weld
Framing: ☒ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
Hold downs: ☐ Fillet Weld
Front-to-Front
Chord Studs: ☒ Fillet Weld
Anchor Rods ☐ 5/8" Rod A307
☒ 3/4" Rod A307
Loading Beam: ☒ A325 3/4" bolts 10 bolts ☒ 2 Anchor Rods ☒
Base ☒ A325 3/4" bolts 4 bolts ☒ 2 Anchor Rods ☒

TRACK:
Web: 6" inches ☒ 0.075" (1.91mm) 55ksi (345 MPa)
Flange: 1-5/8" inches ☐ Other:

HOLD DOWNS:
☐ 2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec
☐ 250 mm x 250 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm
☒ 300 mm x 300 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm + C130x10

Width:		Height:	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	

TEST PROTOCOL AND DESCRIPTION:
☒ Monotonic Rate of Loading 2.5 mm/min
☐ Cyclic CUREE

LVDT MEASUREMENTS:
☒ Actuator LVDT ☒ North Uplift ☒ East Frame Brace
☒ North Slip ☒ South Uplift ☒ West Frame Brace
☒ South Slip ☒ Top of Wall Lateral

TOTAL: 8

STRAIN GAUGE MEASUREMENTS:
☒ Front Side Brace ☒ Top 2 Right ☐ Left
☐ Bottom ☐ Right ☐ Left

☒ Back Side Brace ☒ Top 2 Right ☐ Left
☐ Bottom ☐ Right ☐ Left

WIDTH OF STRAP:

Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
152.5				152.21			
152.2				152.93			
152.5				152.41			
AVG	152.39	AVG	0.00	AVG	152.52	AVG	0.00

WELD LENGTHS:

1a	80	2a	65	3a	90.0	4a	55	5a	60.00	6a	85.00	7a	80.00	8a	85.00
1b	150	2b	145	3b	150.0	4b	135	5b	140.00	6b	135.00	7b	145.00	8b	150.00
1c	85	2c	50	3c	100.0	4c	75	5c	60.00	6c	70.00	7c	60.00	8c	85.00

DATA ACQ. RECORD RATE: 2 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 23 C
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement -0.52035 **mm**

Cold Formed Steel Framed Strap Braced Walls
McGill University, Montreal

TEST: 6B-C

RESEARCHER: Colin Rogers **ASSISTANTS:** K. Hikita, A. Frattini, W. Lim, J. Fu

DATE: 2-Sep-04 **TIME:** 3:00

DIMENSIONS OF WALL: 8 FT X 8 FT X 6 IN. **INITIAL STRAP SURVEY:** Front Tight
Back Tight

STRAP FASTENER CONFIGURATION: See page MFR: Genesis by KML

STRAP SIZE:
☐ 2.3"
☐ 4"
☒ 6"

STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 50ksi (345 MPa)

STUD SPACING:
☒ 16" O.C.
☐ Other : Interior stud at wall ends are 13.5" and 15 away from the N & S chord studs respectively

FRONT-TO-FRONT CHORD STUDS:
☐ 3-5/8"Wx1-5/8"Fx3/8"Lip 0.048" (1.22) 33ksi (230 MPa)
☐ 6"Wx1-5/8"Fx3/8"Lip 0.060" (1.52) 50ksi (345 MPa)
☒ 6"Wx1-5/8"Fx3/8"Lip 0.075" (1.91) 50ksi (345 MPa)

CONNECTIONS:
Straps ☐ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
☒ Fillet Weld
Framing: ☒ No.8 gauge 0.5" self-drilling wafer head (mod. Truss) Phillips drive
Hold downs: ☐ Fillet Weld
Front-to-Front Chord Studs: ☒ Fillet Weld
Anchor Rods ☐ 5/8" Rod A307
☒ 3/4" Rod A325
Loading Beam: ☒ A325 3/4" bolts 10 bolts ☒ 2 Anchor Rods ☒
Base ☒ A325 3/4" bolts 4 bolts ☒ 2 Anchor Rods ☒

TRACK:
Web: 6" inches ☒ 0.075" (1.91mm) 55ksi (345 MPa)
Flange: 1-5/8" inches ☐ Other:

HOLD DOWNS:
☐ 2-1/2" mm x 2-1/2" mm x 3/4" mm plate with a 3/4" mm hole drilled into and then weldec
☐ 250 mm x 250 mm Gusset Plate w/ 19 mm x 90 mm x 127 mm
☒ 300 mm x 300 mm Gusset Plate w/ 19 mm x 127 mm x 203 mm

Width:		Height:	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	

TEST PROTOCOL AND DESCRIPTION:
☐ Monotonic Rate of Loading 2.5 mm/min
☒ Cyclic CUREE

LVDT MEASUREMENTS:
☒ Actuator LVDT ☒ North Uplift ☒ East Frame Brace
☒ North Slip ☒ South Uplift ☒ West Frame Brace
☒ South Slip ☒ Top of Wall Lateral
TOTAL: 8

STRAIN GAUGE MEASUREMENTS:
☒ Front Side Brace ☐ Top ☐ Right ☐ Left
☒ Bottom 2 Right 2 Left
☐ Back Side Brace ☐ Top ☐ Right ☐ Left
☐ Bottom ☐ Right ☐ Left

WIDTH OF STRAP:

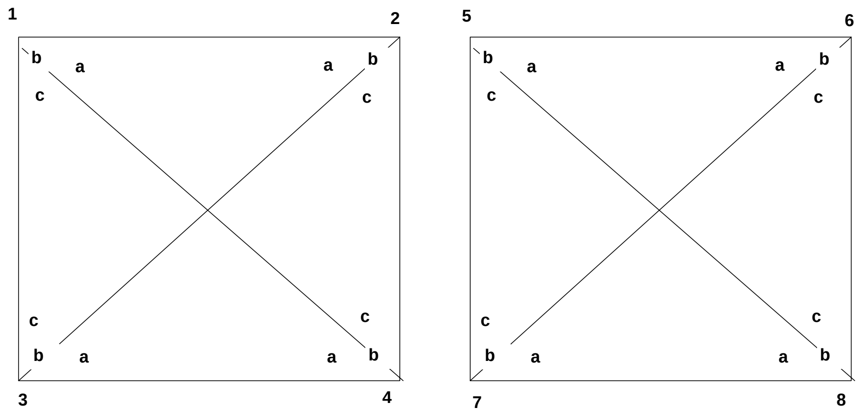
Front Right Tension		Front Left Tension		Back Right Tension		Back Left Tension	
152.37		152.49		152.3		152.63	
152.32		152.4		152.4		152.39	
152.47		152.3		152.5		152.67	
AVG	152.39	AVG	152.40	AVG	152.42	AVG	152.56

WELD LENGTHS:

1a	85	2a	95	3a	90.0	4a	90	5a	90.00	6a	95.00	7a	85.00	8a	80.00
1b	160	2b	155	3b	150.0	4b	155	5b	150.00	6b	150.00	7b	150.00	8b	140.00
1c	90	2c	100	3c	100.0	4c	90	5c	80.00	6c	80.00	7c	80.00	8c	70.00

DATA ACQ. RECORD RATE: 50 scan/sec **MONITOR RATE:** 50 scan/sec

COMMENTS:
-Shear anchors torqued for 10 s with impact wrench
-Hold down anchors 1/2 turn from finger tight (load cells used on both hold-downs)
-Ambient temperature 23 C
-Double chord studs used welded front to front
-Square plate washers (2.5"x2.5") used in all track connections
-Initial load set to zero at beginning of test, displacement 0.163 **mm**



Schematic of weld positions

APPENDIX E: MODES OF FAILURE : PHOTOGRAPHS

1. Modes of Failure for Test Walls with 58.4 mm (2.3”) Strap Braces

Figure 81: Net cross section failure : Specimen 1A-M

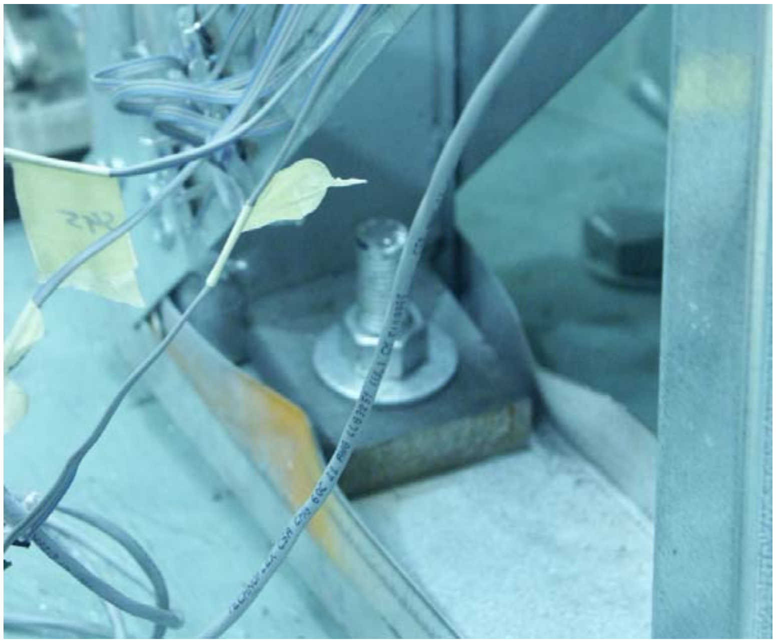


Figure 82: Bending in the bottom track : Specimen 1A-M

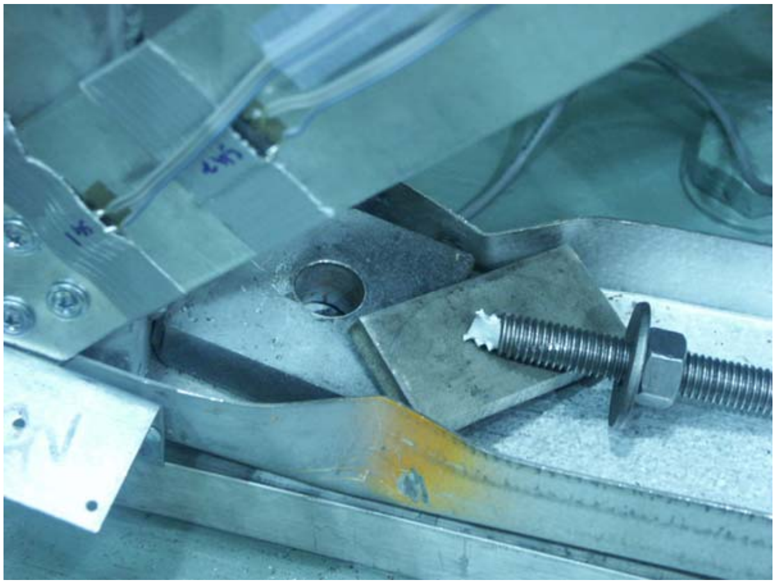


Figure 83: Tension failure of anchor rod : Specimen 1B-M

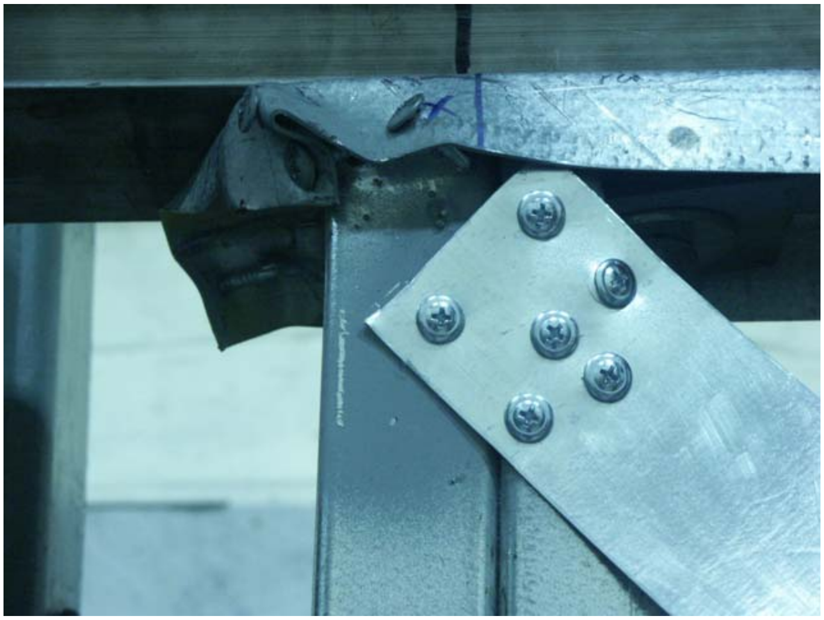


Figure 84: Chord stud to track connection failure : Specimen 2A-C

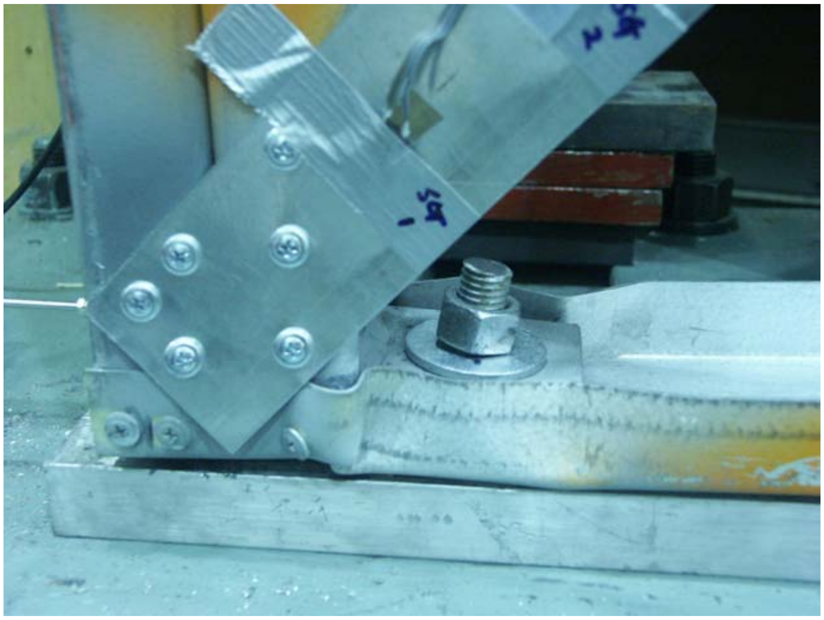


Figure 85: Compression failure in bottom track : Specimen 2B-C

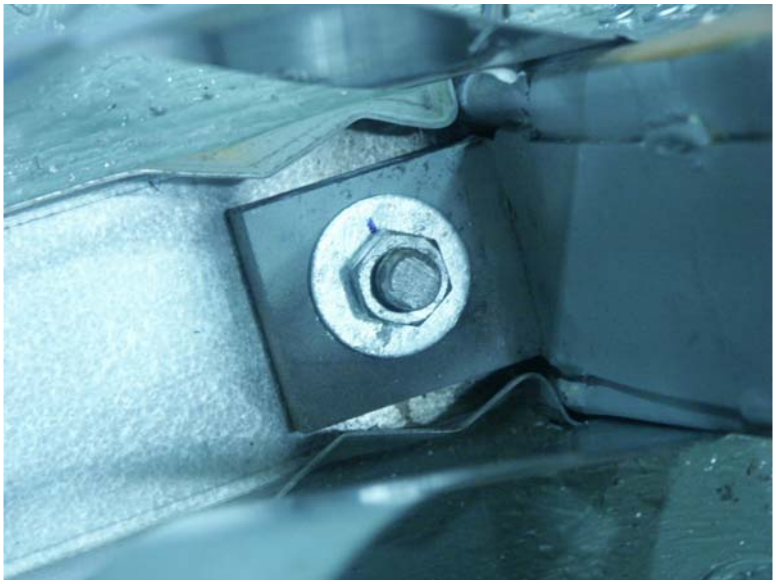


Figure 86: Compression failure in bottom track (overhead view) : Specimen 2B-C

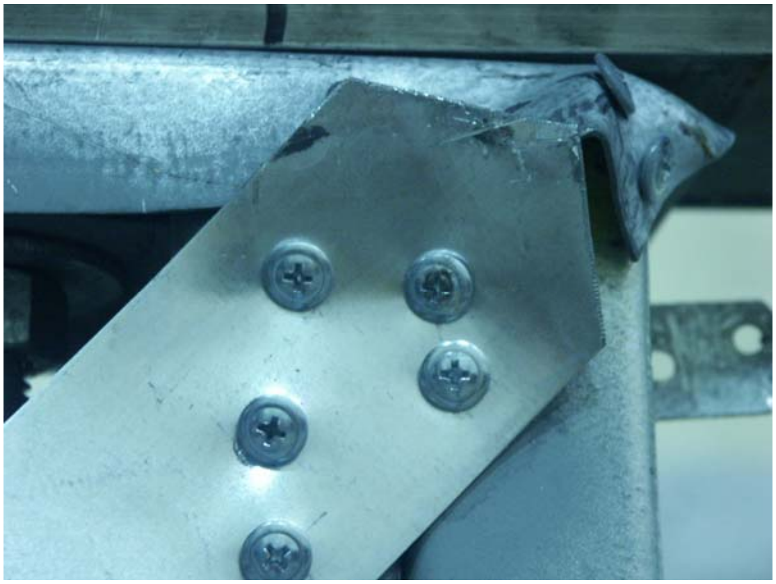


Figure 87: Chord stud to track connection failure : Specimen 2C-C

2. Modes of Failure for Test Walls with 101 mm (4") Strap Braces

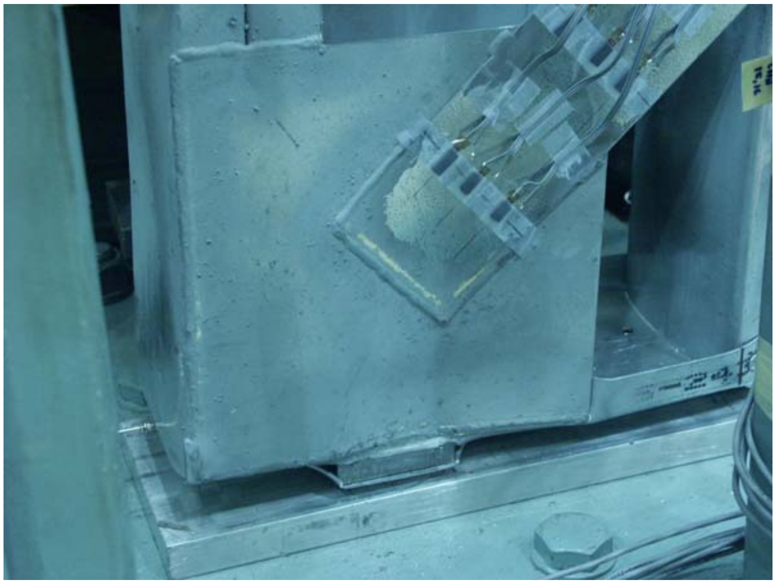


Figure 88: Punching / shear failure of bottom track : Specimen 3A-M

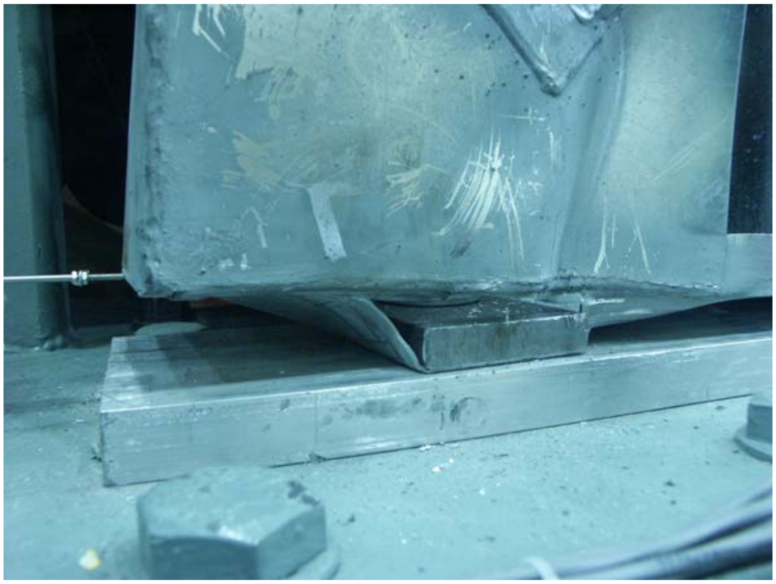


Figure 89: Punching / shear failure of bottom track : Specimen 3B-M

Figure 90: Local buckling of chord studs : Specimen 3B-M

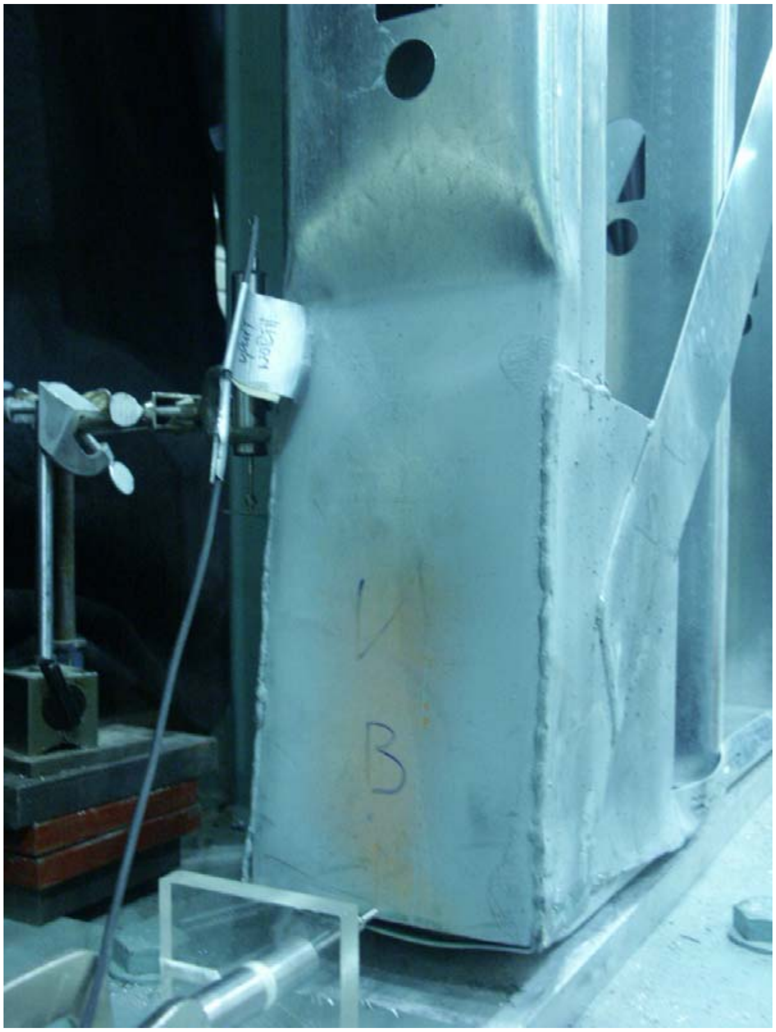


Figure 91: Local buckling of chord studs : Specimen 3C-M

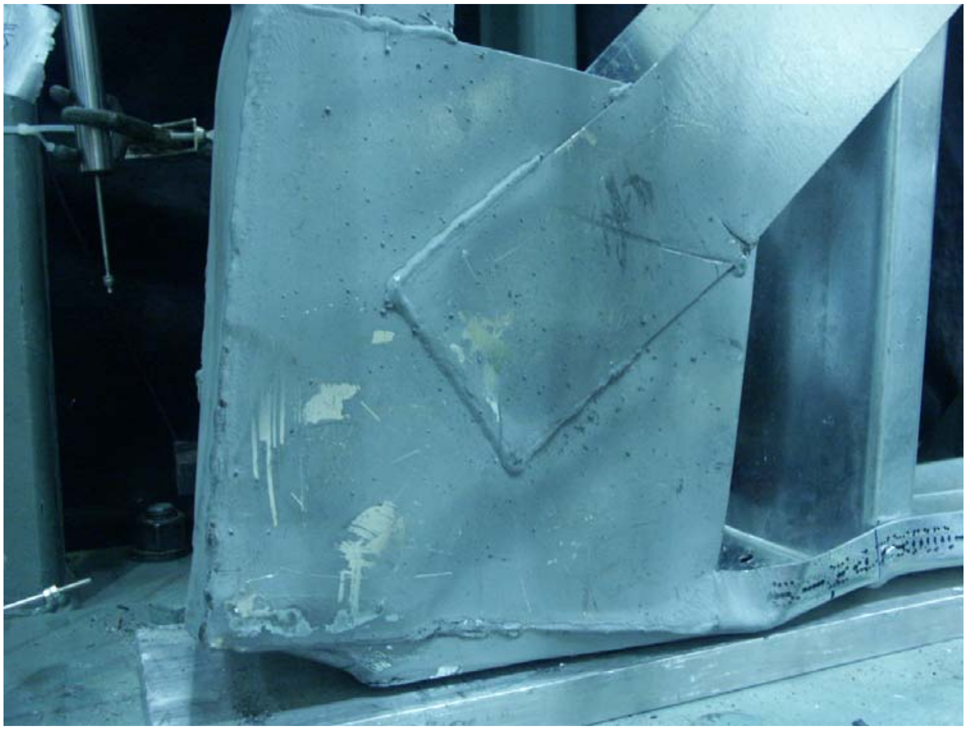


Figure 92: Initiation of tensile fracture in 101 mm (4”) strap brace : Specimen 3C-M

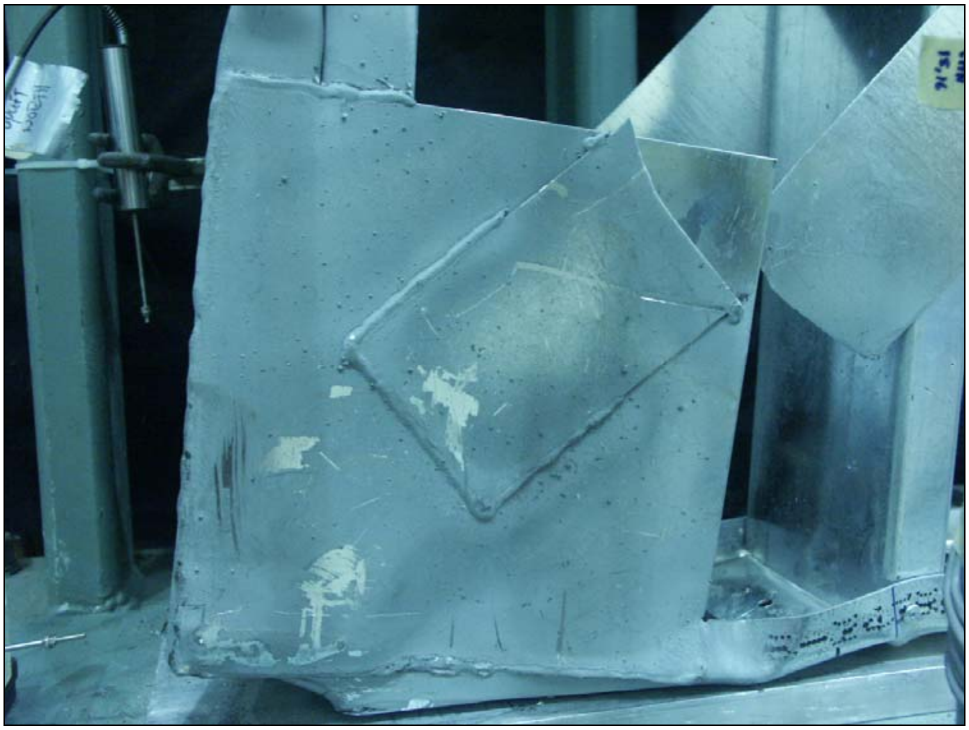


Figure 93: Cross section failure of 101 mm (4”) strap with punching / shear failure in bottom track : Specimen 3C-M

Figure 94: Local buckling of chord studs : Specimen 4A-C

Figure 95: Punching / shear failure of bottom track : Specimen 4A-C

Figure 96: Punching / shear failure of bottom track with compression damage to gusset plate : Specimen 4B-C

Figure 97: Local buckling of chord studs : Specimen 4B-C

Figure 98: Punching / shear failure of bottom track : Specimen 4B-C

Figure 99: Punching / shear failure of bottom track : Specimen 4C-C

Figure 100: Punching / shear failure of bottom track : Specimen 4C-C

3. Modes of Failure for Test Walls with 152 mm (6”) Strap Braces

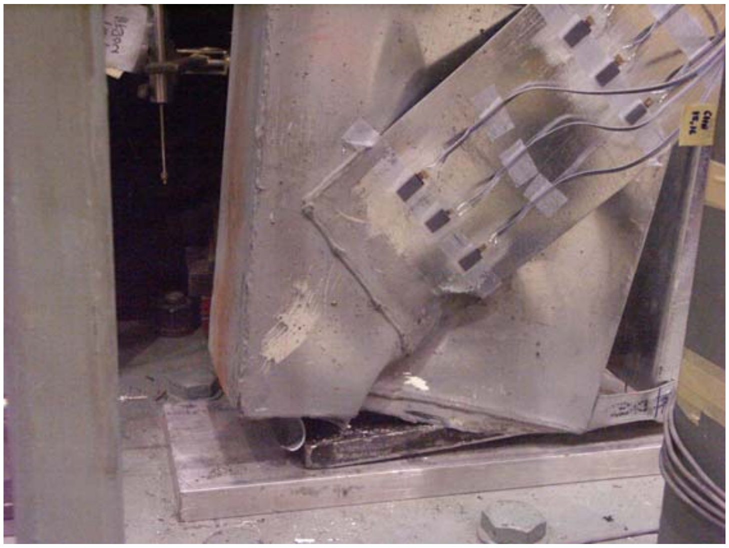


Figure 101: Punching / shear failure of bottom track with compression damage to gusset plate : Specimen 5A-M

Figure 102: Local buckling of chord studs : Specimen 5A-M

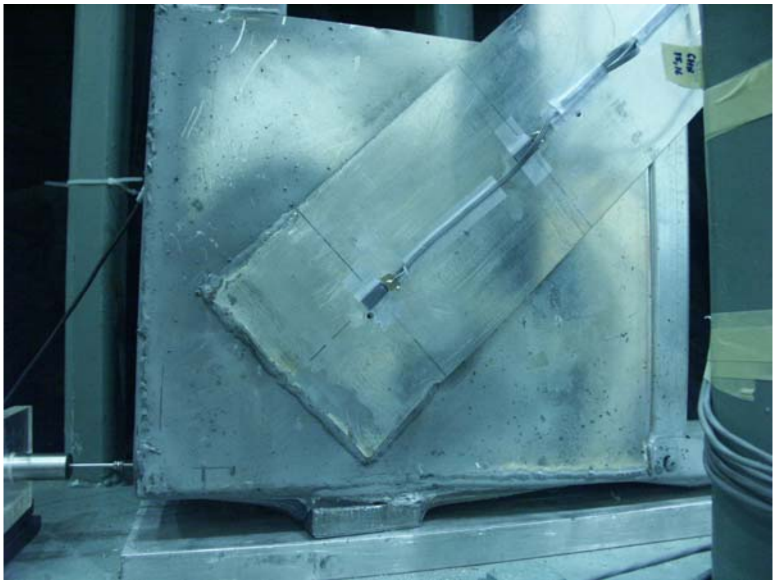


Figure 103: Punching / shear failure of bottom track : Specimen 5B-M

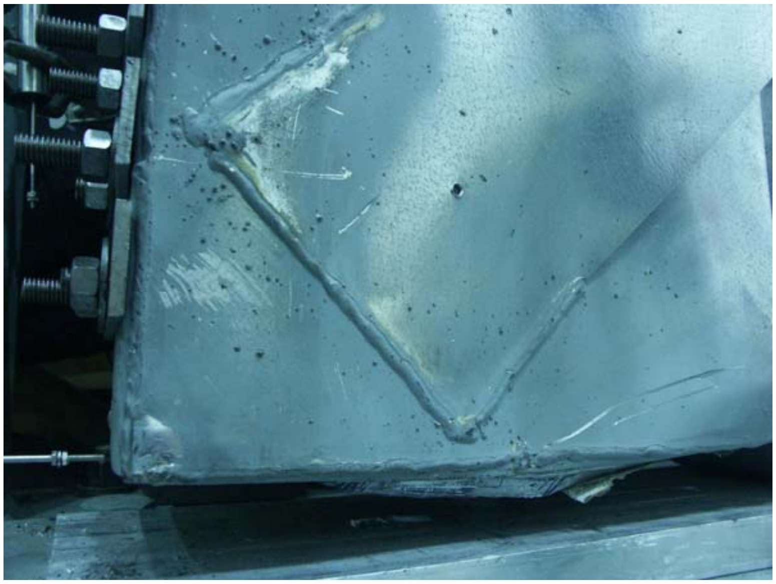


Figure 104: Punching / shear failure of bottom track : Specimen 5C-M

Figure 105: Anchor rod failure : Specimen 5C-M

Figure 106: Punching / shear failure of bottom track : Specimen 6B-C

Figure 107: Punching / shear failure of bottom track with compression damage to gusset plate : Specimen 6B-C

Figure 108: Punching / shear failure of bottom track with uplift of interior studs : Specimen 6B-C