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Investigation of the Strength and Stiffness of Dry-bedded Masonry Ties in Various Veneer Types

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Preface

This report has been prepared to present the findings of a research investigation into the performance of dry-bedded brick veneer ties and to make recommendations on changes to the applicable Standards.

Acknowledgments

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Thanks are extended to the Eagle Wire Company and MiTek for the supply of veneer ties to undertake the study, and to Mr David Barnard of the NZ Master Masonry Trades Federation for his constructive critique of the project.

INVESTIGATION OF THE STRENGTH AND STIFFNESS OF DRY-BEDDED MASONRY TIES IN VARIOUS VENEER TYPES

BRANZ Study Report SR 152 **G.J. Beattie**

ABSTRACT

This report describes a research investigation that was carried out to determine whether it was possible to achieve satisfactory performance in terms of the performance requirements of the Standard AS/NZS 2699.1:2000 when the ties were dry-bedded instead of being fully encapsulated. Dry-bedding is the process in which the ties are placed directly on top of the lower course of bricks or blocks and mortar is placed over the top of the tie only. It was found that dry-bedded ties could achieve the performance requirements required by AS/NZS 2699.1:2000, but care needs to be taken that contact surfaces of concrete blocks are adequately moist.

KEYWORDS

Masonry, veneer, brick ties, standards, strength, stiffness, dry-bedded.

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1. INTRODUCTION

The objective of this project was to investigate the performance of brick veneer ties purposely installed using the dry-bedding approach. It is BRANZ’s understanding that even though the Standard for the construction of brick veneer walls, NZS 4210 [1], requires the ties to be fully encapsulated in the mortar, many bricklayers are installing the ties directly on the top of the lower brick course (dry-bedding) because of construction difficulties encountered when fully encapsulating the tie.

This report describes the testing undertaken to investigate the issue and makes recommendations on the future installation of the ties.

2. TEST SPECIMEN DETAILS

In order to determine whether it is satisfactory to “dry-bed” the ties, consideration must be given to the types of ties and bricks that are generally used in veneers.

Two veneer ties are commonly used in New Zealand. These are manufactured by either Eagle Wire Products Ltd (Eagle Wire Ties) (referenced as Type A in this report) or Mitek New Zealand Ltd (Lumberlok Screw Ties) (referenced as Type B in this report). Both of these are available as hot-dipped galvanised steel ties or as stainless steel ties.

The range of bricks and blocks used in veneer construction is greater than the range of commonly available ties. The testing Standard for the ties, AS/NZS 2699.1 [2], does not provide any guidance on the type of bricks/blocks to be used in the test except to say in the “Materials” clause that “masonry units – clay, concrete, calcium silicate or AAC units, as appropriate, complying with AS/NZS 4455”. In this Standard [3], several block configurations are given as acceptable. These include solid blocks, blocks with a “frog” incorporated, blocks with multiple vertical holes and blocks with slots (hollow blocks).

In order to ensure that the test series covered the range of available blocks, a matrix of combinations was developed. Time and financial limitations meant that not all of the combinations could be tested and it was also decided that not all needed to be tested because the results of some combinations could be applied to others. The matrix of combinations is presented in Table 1.

Views of the bricks and blocks used in the test series are presented in Figure 1 to Figure 6. Views of the ties are given in Figure 7 and Figure 8. All ties were fixed to the framing with a 35 mm x 12 g Type 17 hex head screw. The screw was either hot-dipped galvanised or stainless steel, to match the tie material.

Table 1: Matrix of tie and veneer block combinations

Option Number	Veneer Thickness (mm)	Cavity width	Veneer Material	Tie Type	Tie length (mm)	Tie material	Test Code	
1	90	50	Clay	Type A	110	Galv	GE CL-90	**Test**
2	90	50	Concrete solid	Type A	110	Galv	GE SC-90	**Test**
3	90	50	Concrete hollow	Type A	110	Galv	GE HC-90	**Test**
3A	90	50	Concrete frog	Type A	110	Galv		Don't test - use solid result 2
4	90	50	Clay	Type B	110	Galv	GL CL-90	Don't test - use option 1 result
5	90	50	Concrete solid	Type B	110	Galv	GL SC-90	Don't test - use option 2 result
6	90	50	Concrete hollow	Type B	110	Galv	GL HC-90	**Test**
6A	90	50	Concrete frog	Type B	110	Galv		Use solid result
7	90	50	Clay	Type A	110	St st		Don't test - use option 10 result
8	90	50	Concrete solid	Type A	110	St st		Don't test - use option 2 result
9	90	50	Concrete hollow	Type A	110	St st	SE HC-90	**Test**
9A	90	50	Concrete frog	Type A	110	St st		Use solid result
10	90	50	Clay	Type B	110	St st	SL CL-90	**Test**
11	90	50	Concrete solid	Type B	110	St st	SL SC-90	**Test**
12	90	50	Concrete hollow	Type B	110	St st		Don't test - use option 9 result
12A	90	50	Concrete frog	Type B	110	St st		Use solid result
13	70	50	Clay	Type A	85	Galv		Tested previously
14	70	50	Concrete solid	Type A	85	Galv	GE SC-70	**Test**
15	70	50	Clay	Type B	85	Galv		Tested previously
16	70	50	Concrete solid	Type B	85	Galv	GL SC-70	**Test**
17	70	50	Clay	Type A	85	St st	SE CL-70	**Test**
18	70	50	Concrete solid	Type A	85	St st	SE SC-70	**Test**
19	70	50	Clay	Type B	85	St st		Don't test - use option 17 result
20	70	50	Concrete solid	Type B	85	St st		Don't test - use option 18 result

Figure 1: 70 series clay brick with holes

Figure 2: 70 series concrete block with holes

Figure 3: 90 series clay brick with holes

Figure 4: 90 series solid concrete block

Figure 5:. 90 series concrete block with "frog"

Figure 6: 90 series concrete block with slots

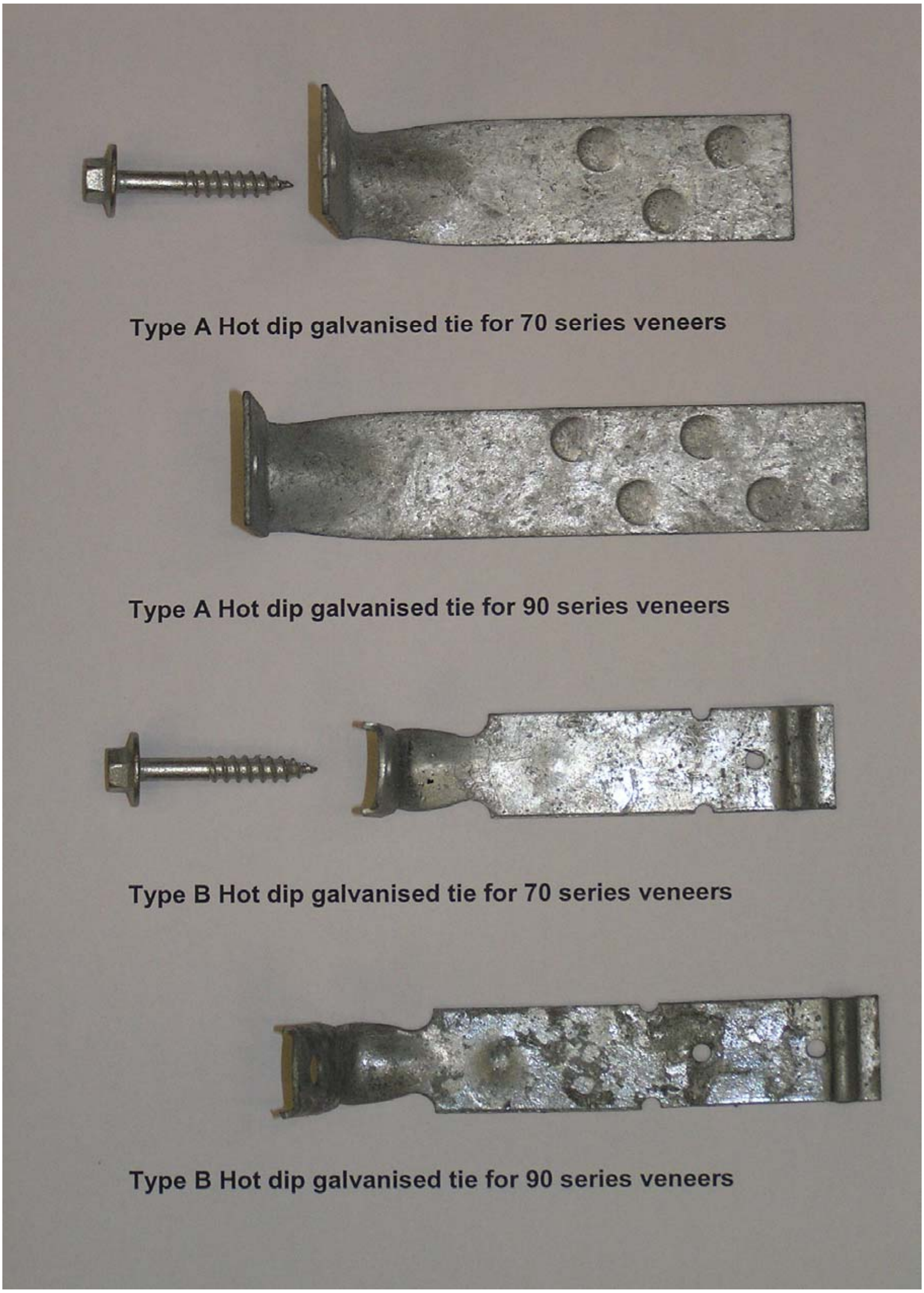

Figure 7: Hot-dipped galvanised ties

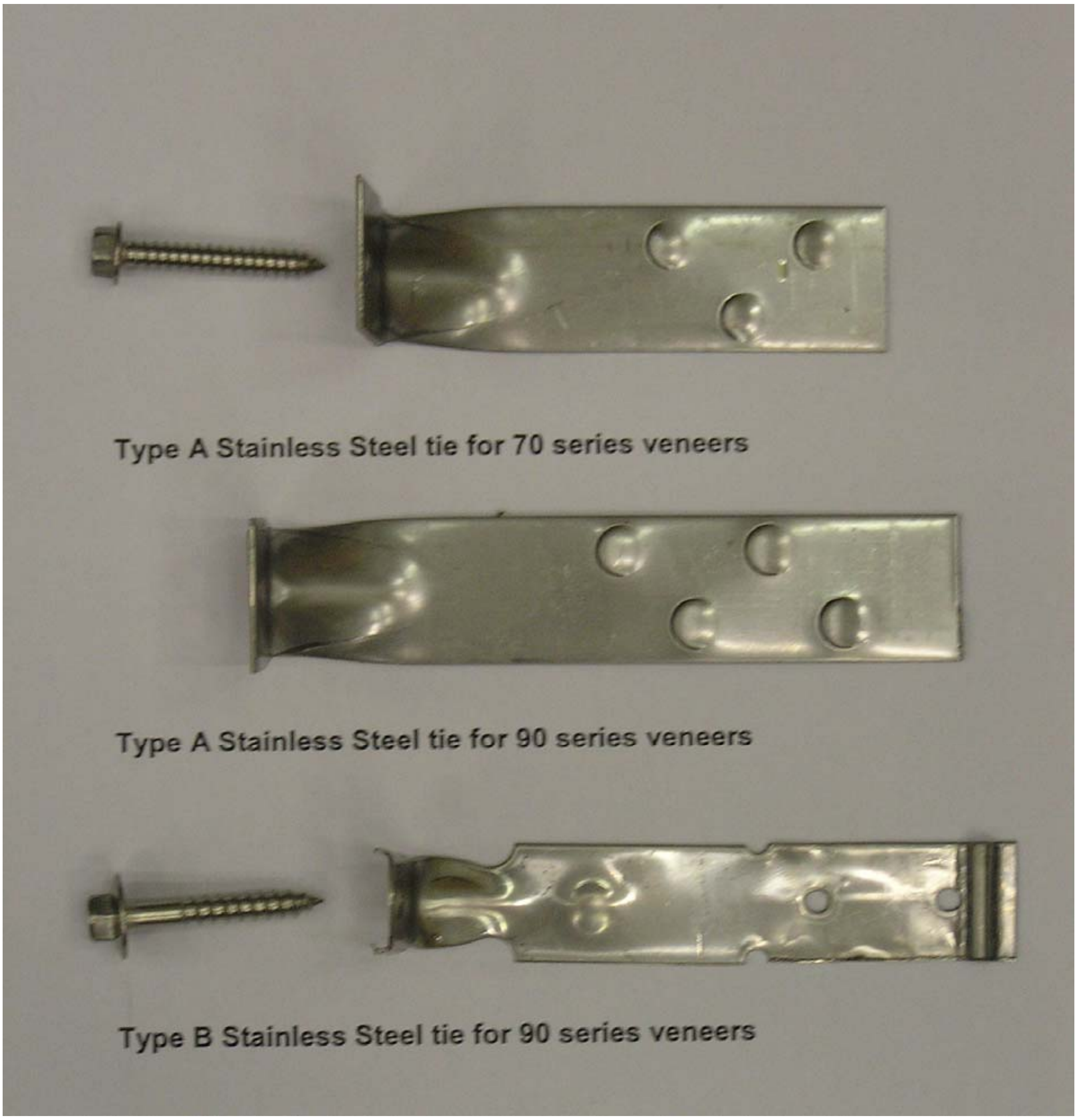

Figure 8: Stainless steel ties

3. SPECIMEN CONSTRUCTION AND CURING

Couplets were constructed by a registered mason using a 50 mm cavity width, in accordance with the requirements of AS/NZS 2699.1, except that:

- the ties were laid directly on the lower block/brick course
- the speed of construction of the block/brick towers was slower than the Standard allowed (to ensure that the mortar in the lower joints was sufficiently set before surcharge load was added).

The Standard requires that a tower be constructed with couplets included but separated from the bricks above and below so that they can be retrieved from the tower to conduct the tests. A total of six replicate test couplets are included in the tower. The mortar used to construct the couplets was Dricon® Trade Mortar™. On the bag of this product it states that it has a minimum 28 day compressive strength of 12.5 MPa.

All couplets were left to cure for a period of between 28 and 35 days before they were tested.

4. SPECIMEN TESTING

Tests were carried out in the Structures Laboratory Dartec Universal Testing Machine in a purpose-made test rig. The base of the rig could be displaced sideways to achieve the pre-test displacements prescribed by Appendix A of the Standard.

Couplets were subjected to the testing regime contained in Appendix A of AS/NZS 2699.1. This involved displacing the couplet vertically 10 mm with respect to the stud section to simulate potential shrinkage of the framing, horizontal movement in the plane of the veneer to ± 20 mm for four cycles, and then displacing the couplet with respect to the stud section (i.e. axially along the tie) to displacements of ± 2 mm (3 cycles), ± 10 mm (3 cycles) and finally one cycle to ± 15 mm.

Applied loads were measured by a 10 kN load cell, and the resulting differential displacement between the bricks and the framing across the cavity width was measured using the LVDT displacement gauge in the test machine. The load cell calibration was within International Standard EN ISO 7500–1 1999 Grade 1 accuracy, and the LVDT was accurate to ± 0.1 mm. Measurements were recorded by purpose-written software as a text file for subsequent analysis by spreadsheet.

5. TEST RESULTS

The detailed results of the testing and the analysis of the results are presented in the Appendix to this report. A summary of the ratings is given in Table 2.

Table 2: Summary of test results and duty ratings

Specimen code	Description	Stiffness duty	10 mm strength duty	15 mm strength duty	Overall duty
GECL 90	Galv. Type A tie – 90 mm clay	Heavy	Light	Heavy	Light
GESC 90	Galv. Type A tie 90 mm solid conc.	Heavy	Light	Heavy	Light
GEHC 90	Galv. Type A tie 90 mm hollow conc.	Medium	Light	Medium	Light
GLHC 90	Galv. Type B tie 90 mm hollow conc.	Fail	Fail	Fail	Fail
SEHC 90	St. st. Type A tie 90 mm hollow conc.	Heavy	Light	Light	Light
SLCL 90	St. st. Type B tie 90 mm clay	Fail	Fail	Heavy	Fail
SLSC 90	St. st. Type B tie 90 mm solid conc.	Fail	Light	Heavy	Fail
GESC 70	Galv. Type A tie 70 mm solid conc.	Light	Light	Light	Light
GLSC 70	Galv. Type B tie 70 mm solid conc.	Light	Fail	Medium	Light
SECL 70	St. st. Type A tie 70 mm clay	Medium	Light	Light	Light
SESC 70	St. st. Type A tie 70 mm solid conc.	Medium	Medium	Medium	Medium
GECL 70*	Galv. Type A tie 70 mm clay	Heavy	Medium	Heavy	Medium
GLCL 70*	Galv. Type B tie 70 mm clay	Medium	Medium	Heavy	Medium

- These results reproduced from BRANZ Test Report ST0596 with the permission of Austral Brick Company Pty Ltd.

Example load displacement plots for the axial loading regime are presented in Figure 9 and Figure 10.

The requirements for the “duty” ratings of the tie with regard to the NZS 3604 [4] earthquake zones are given in Table 2.3 of NZS 4210 [1]. These are reproduced in Table 3 for the convenience of the reader.

Table 3: Specification of Type B(6) veneer tiers for spacing of 600 mm (max) horizontal x 400 mm (max) vertical

Seismic zone	Veneer		
	Less than 180 kg/m²	**180–220 kg/m²**	**More than 220 kg/m²**
	(Typically 70–90 mm thickness)	**(Typically 90–110 mm thickness)**	**(Typically over 110 mm thickness)**
A	EM	EH(1)	SED(2)
B	EM	EM	SED(2)
C	EL	EM	SED(2)

Notes to table:

(1) EM may be used if the supported area does not exceed 0.20 m^2 e.g. 600 x 300 on a timber frame and 500 x 400 on a concrete masonry wall.
(2) Spacing of ties to be determined by specific engineering design (SED).
(3) Type B and prefix E indicates ties are manufactured to meet seismic testing conditions set out in AS/NZS 2699.
(4) L (Light), M (Medium) and H (High) indicate strength capacities of ties to meet the testing conditions set out in AS/NZS 2699.
(5) Using higher strength ties does not permit the maximum spacing of ties to be increased.
(6) Type B ties referred to in the title to this table are defined as “non-flexible” veneer ties in [2].

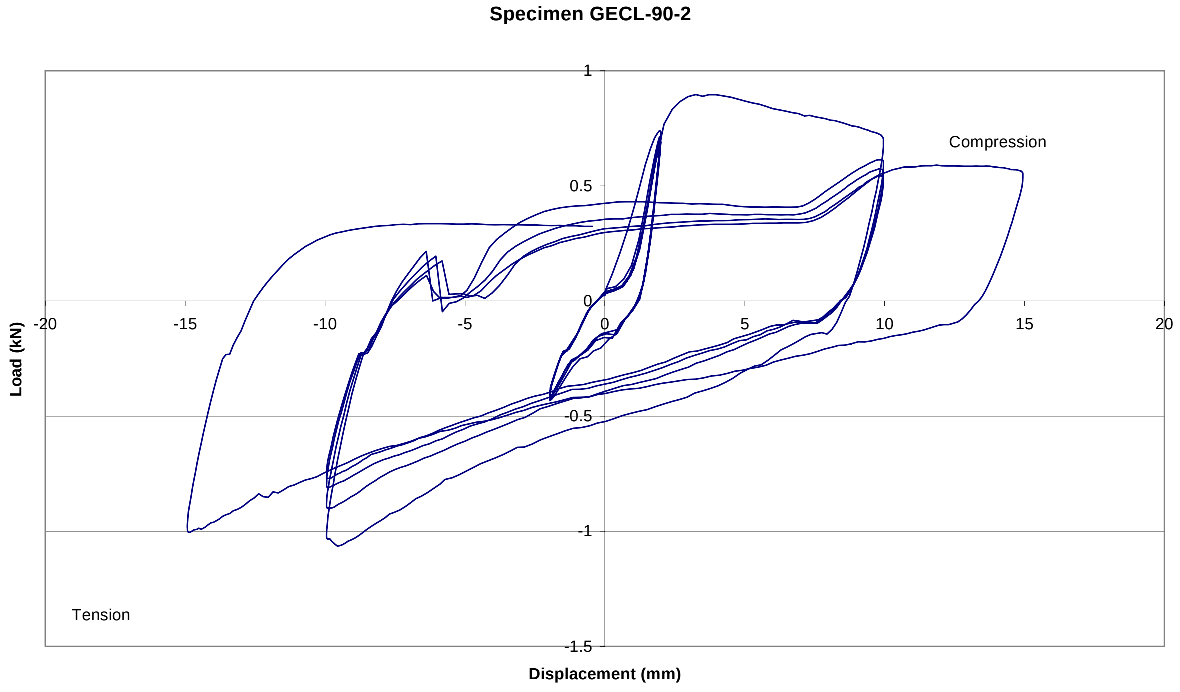

Figure 9: Example load-displacement plot for a galvanised Type A tie in 90 mm clay brick veneer (tie solidly bound to mortar in this example)

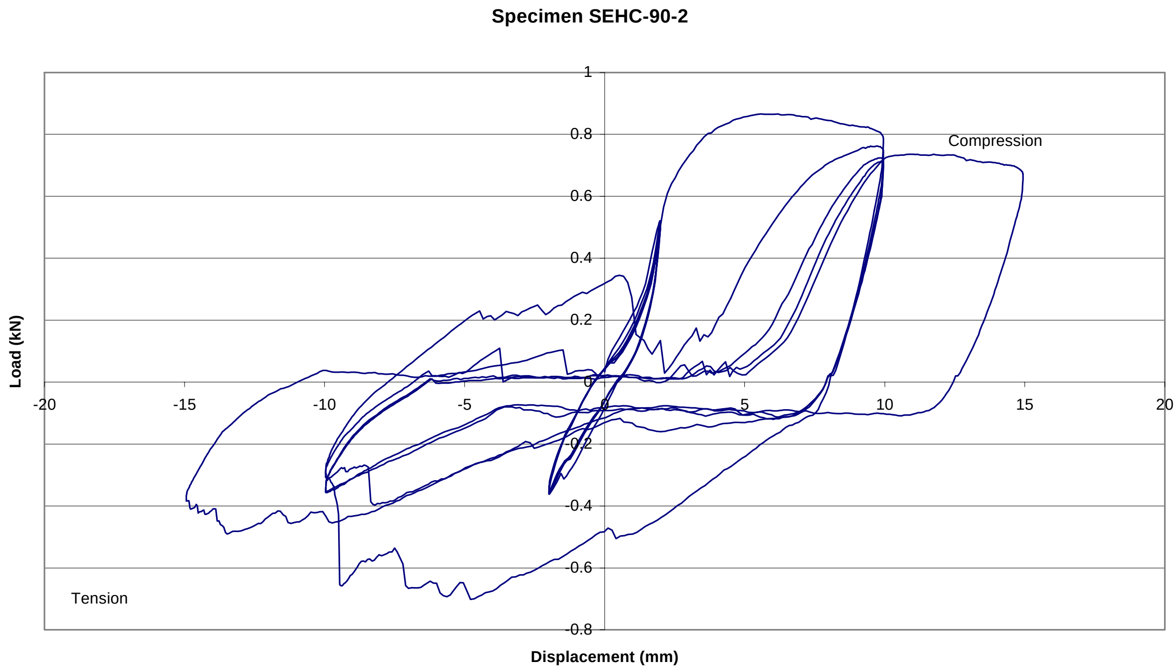

Figure 10: Example load-displacement plot for a stainless steel Type A tie in 90 mm hollow concrete block veneer (tie slipped in the mortar in this example)

6. DISCUSSION OF RESULTS

6.1 15 mm strength duty

With one exception, the performance against this criteria varied over the range of either Light, Medium or Heavy Duty. Close inspection of the results reveals that 90 mm solid concrete and 90 mm clay both yielded a "Heavy" rating, which would be required if the 90 mm veneer was between 180 kg/m^2 and 220 kg/m^2 and was to be used in seismic zone A. Lower results were obtained for the 90 mm hollow concrete veneer, ranging from "Fail" to "Medium". In these cases, the tie was often observed to slip in the mortar. However, the bond between the mortar and the hollow concrete blocks appeared suspect and may have been the cause of the tie loosening (see Section 6.4). In the two 70 mm specimen cases where the results gave a "Light" rating, the lower rating was caused by a single low result that increased the standard deviation and correspondingly reduced the characteristic strength.

6.2 10 mm strength duty

This particular criteria proved to be the most difficult for the couplets to achieve. The predominant rating achieved was "Light" duty. In three cases (stainless steel Type A tie in combination with 70 mm solid concrete, galvanised Type A tie in combination with 70 mm clay bricks and galvanised Type B tie in combination with 70 mm clay bricks) a "Medium" rating was achieved. On three occasions (galvanised Type B tie in combination with 90 mm hollow concrete blocks, Type B tie in combination with 90 mm clay bricks and galvanised Type B tie in combination with 70 mm solid concrete blocks) the specimens failed to reach the "Light" rating.

It is suspected that some of the tie types may be too flexible because "Light" ratings were achieved even when the ties were well-bound to the mortar. However, this apparent flexibility may be due in other cases to the de-bonding of the couplets, thus allowing the ties to slip in the joint (see Figure 10).

6.3 Stiffness duty

The range of performance against this parameter varied across the full range from failure to a "Heavy" duty rating.

The Type A ties generally gave a "Medium" or "Heavy" result for stiffness, with one exception (70 mm solid concrete) which produced a "Light" result. Inspection of the individual results shows that a single result dragged the mean down to a value less than the required value for a "Medium" duty result.

The Type B ties provided a range of stiffness grades from "Medium" down to failure to meet the "Light" stiffness requirement. The galvanised Type B ties were found to be stiffer than the stainless steel Type B ties. The galvanised Type B ties also performed better in combination with a 70 mm solid concrete block (almost reaching a "Medium" rating) than they did in combination with the 90 mm hollow concrete block, which failed to meet the "Light" rating. The stainless steel Type B ties failed to reach the "Light" rating in combination with the 90 mm clay bricks and the 90 mm solid concrete blocks.

6.4 Concrete blocks

During the testing, it was discovered that the concrete block couplet mortar joints (both solid and hollow blocks) appeared to have a greater tendency to de-bond. NZS 4210 [1] makes no reference to the state of the veneer blocks or bricks at the time of laying. With respect to the laying of structural concrete block masonry, NZS 4210 states in commentary clause C2.7.2.2 that "masonry units should be in an air dry state i.e. not wet to the touch". It further notes that some surface damping may be required in hot dry weather to avoid significant amounts of water being drawn out of the mortar. No similar suggestions are given for the veneer components.

It is suggested that the concrete blocks have drawn moisture from the mortar during the construction of the couplets, causing the bond to be less tenacious than if the blocks had been wet-up before laying.

The ties used with the hollow concrete blocks spanned across the hollow centre of the block and were bound to the mortar between the outer shells of the blocks. It appeared that this support for the ties reduced the potential for rotation of the tie in the mortar joint under the in-plane displacement cycles.

6.5 Mortar bond to ties

The test results suggest that the tie material does not have any obvious influence on the performance of the bond between the tie and the mortar. The mortar appeared to bond equally well to both the galvanised and the stainless steel ties.

There was no evidence of fatigue failure of the tie material due to the reversed cyclic loading imposed in the tests.

6.6 Tie type

The results indicate that the Type A tie is stiffer than the Type B tie (compare Figure 11 and Figure 12). This is to be expected, given that the Type A tie has a greater cross-sectional area than the Type B tie and fits flatter against the timber stud. Furthermore, the Type B tie has ribs that bear against the face of the timber stud and these can penetrate the timber during both the in-plane loading and the out-of-plane loading, resulting in a lower stiffness.

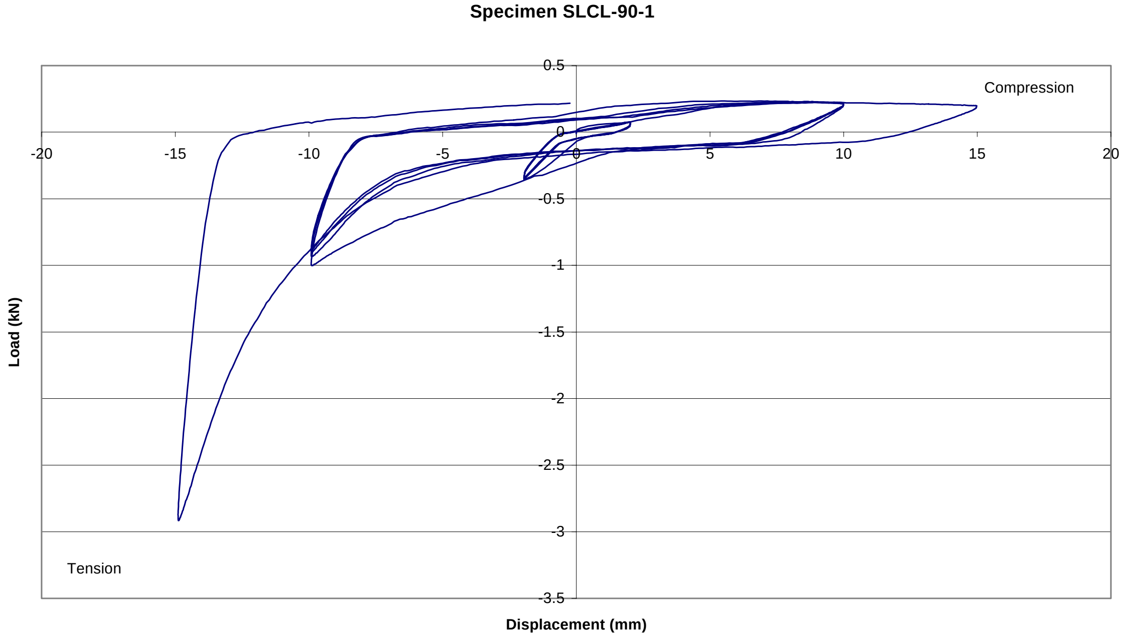

Figure 11: Load-displacement plot for Type B stainless steel tie

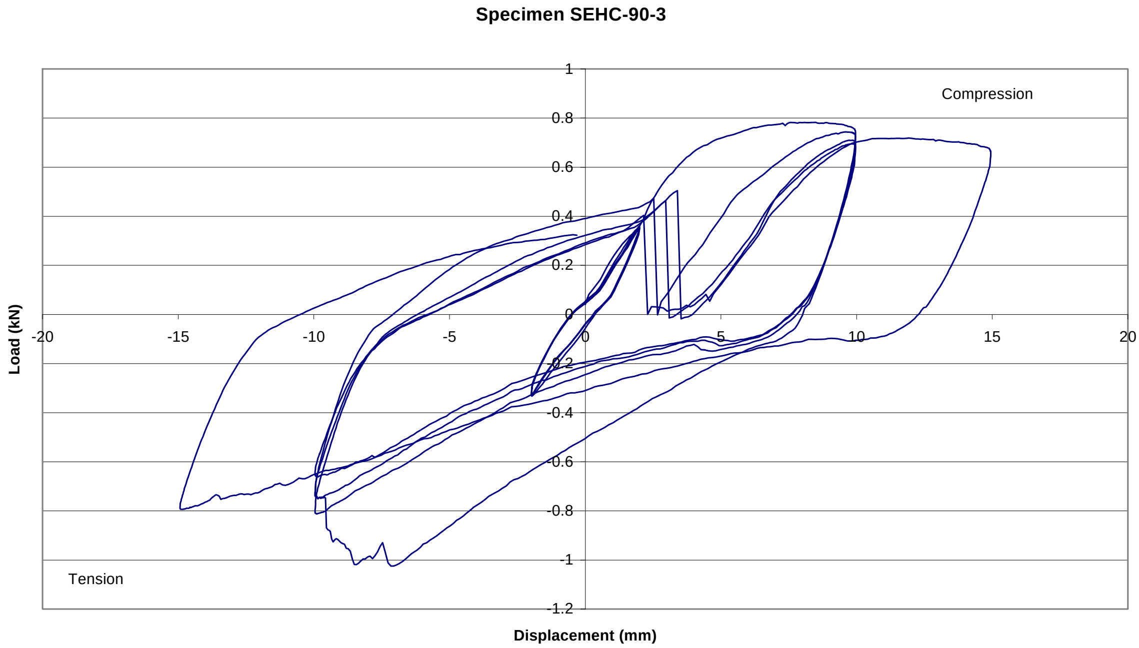

Figure 12: Load-displacement plot for Type A stainless steel tie

7. CONCLUSIONS

Other factors, as explained below, have made it difficult to conclusively state that dry-bedded ties will perform satisfactorily. This is because the results of the testing to the procedure laid down in AS/NZS 2699.1 have shown that certain systems have not passed the minimum criteria for "Light" duty ties. However, the failure of these systems, and the lower than expected ratings for some of the other systems, does not appear to be attributable to the ties being dry-bedded but rather that the de-bonding of the mortar from the blocks has affected the tie performance.

Because the systems involving clay bricks appeared to perform better than those with concrete bricks or blocks (often the mortar appeared to de-bond from the concrete block or brick relatively easily), it appears that the process of building concrete brick or block veneers without wetting the bedding surfaces of the concrete blocks or bricks first may not be producing a well-bound veneer. The follow-on effect of this behaviour was an apparent poor performance of the tie because it was more easily able to move in the failed mortar joint. While a test procedure exists for the measurement of the flexural strength of the couplet (Appendix D of [2]) no specimens were available for undertaking the test in this investigation. When de-bonding did not occur, the dry-bedded ties were generally able to carry the loads associated with either "Medium" or "Heavy" duty ties at the target displacements.

The stiffness of both the galvanised and stainless steel Type B ties appeared to be lower than the requirement for "Medium" duty ties. It is suggested that this low stiffness was probably the reason for the poor strength performance at 10 mm displacement as well because the tie was still deforming relatively easily at the 10 mm displacement point. Discussions have been held with the manufacturer of the Type B ties, and alterations to the design have been made as a result. It is expected that testing of the new tie design will show that the issues identified in this test series will be overcome with the new design.

8. RECOMMENDATIONS

The following recommendations are made following this research:

- dry-bedding of the veneer ties is an acceptable procedure in brick and block veneer construction
- it is necessary to wet-up the contact surfaces of concrete bricks and blocks before placing in veneer construction
- ties used to support 90 mm thick hollow concrete block veneers have sufficient length to allow them to be bound to the mortar on both flanges of the block.

Explanation of recommendations:

Despite the complication of the de-bonded mortar joints, the results of the test series lead to the recommendation that dry-bedding of the veneer ties is an acceptable procedure in brick and block veneer construction. As shown above, the lack of adequate performance in the tests is due to de-bonding of the mortar from the blocks or to ties that are too flexible.

The results of the tests have suggested that it is necessary to wet-up the contact surfaces of concrete bricks and blocks before placing in veneer construction, to ensure that an adequate bond is achieved between the mortar and the bricks or blocks. Wetting-up is not necessary for modern clay bricks that have been produced by an extrusion process, but may be necessary for construction using re-cycled bricks that have been manufactured by pressing.

It is recommended that ties used to support 90 mm thick hollow concrete block veneers have sufficient length to allow them to be bound to the mortar on both flanges of the block, thus reducing the potential for the tie to rotate in a horizontal plane under differential in-plane movement between the veneer and the wall framing. The durability requirement for the tie to have an end cover in the bed joint of not less than 15 mm [1] must still apply.

9. REFERENCES

[1] SNZ. 2001. NZS 4210:2001. *Masonry construction: materials and workmanship*. Standards New Zealand, Wellington, New Zealand.

[2] SNZ. 2000. AS/NZS 2269.1:2000. *Built-in components for masonry construction. Part 1: Wall ties*. Standards New Zealand, Wellington, New Zealand.

[3] SNZ. 1997. AS/NZS 4455:1997. *Masonry units and segmental pavers*. Standards New Zealand, Wellington, New Zealand.

[4] SNZ. 1999. NZS 3604:1999. *Timber framed buildings*. Standards New Zealand, Wellington, New Zealand.

10. APPENDIX

Detailed test results:

Galvanised Type A tie with 90 mm clay brick

Specimen	GECL-90-1	GECL-90-2	GECL-90-3	GECL-90-4	GECL-90-5	GECL-90-6	Characteristic	Rating	**AS/NZS 2699 values**		
P +2mm	0.379	0.688	0.780	0.460	0.322	0.358					
P -2mm	-0.475	-0.423	-0.587	-0.353	-0.295	-0.351					
P2 mean	0.427	0.556	0.684	0.407	0.309	0.355			**Light**	**Medium**	**Heavy**
Stiffness 2mm (kN/mm)	0.214	0.278	0.342	0.203	0.154	0.177	0.228	Heavy	0.15	0.175	0.2
P +10 mm 4th cycle	0.361	0.543	0.394	0.501	0.464	0.355					
P -10mm 4th cycle	-1.098	-0.770	-1.050	-0.866	-0.903	-0.898					
P10 mean	0.730	0.657	0.722	0.684	0.684	0.627	0.652	Light	0.5	0.75	1.5
P -15 mm	-1.820	-0.989	-1.707	-1.388	-1.497	-1.596	1.265	Heavy	0.350	0.55	1.1

Observations: all ties well-bound to mortar

Galvanised Type A tie with 90 mm solid concrete block

Specimen	GESC-90-1	GESC-90-2	GESC-90-3	GESC-90-4	GESC-90-5	GESC-90-6	Characteristic	Rating	**AS/NZS 2699 values**		
P +2mm	0.525	0.809	0.517	0.693	0.345	0.629					
P -2mm	-0.333	-0.443	-0.530	-0.548	-0.392	-0.514					
P2 mean	0.429	0.626	0.524	0.621	0.369	0.572			**Light**	**Medium**	**Heavy**
Stiffness 2mm (kN/mm)	0.215	0.313	0.262	0.310	0.184	0.286	0.262	Heavy	0.15	0.175	0.2
P +10 mm 4th cycle	0.493	0.546	0.375	0.383	0.392	0.548					
P -10mm 4th cycle	-0.931	-0.863	-0.994	-0.946	-0.901	-1.230					
P10 mean	0.712	0.705	0.685	0.665	0.647	0.889	0.647	Light	0.5	0.75	1.5
P -15 mm	-1.734	-1.658	-1.860	-1.650	-1.572	-2.006	1.619	Heavy	0.350	0.55	1.1

Observations: all ties well-bound to mortar

Galvanised Type A tie with 90 mm hollow concrete block

Specimen	GEHC-90-1	GEHC-90-2	GEHC-90-3	GEHC-90-4	GEHC-90-5	GEHC-90-6	Group means	Rating	**AS/NZS 2699 values**		
P +2mm	0.741	0.335	0.574	0.391	0.604						
P -2mm	-0.517	-0.352	-0.395	-0.342	-0.415						
P2 mean	0.629	0.344	0.485	0.367	0.510				**Light**	**Medium**	**Heavy**
Stiffness 2mm (kN/mm)	0.315	0.172	0.242	0.183	0.255		0.233	Heavy	0.15	0.175	0.2
P +10 mm 4th cycle	0.475	0.629	0.582	0.468	0.460						
P -10mm 4th cycle	-0.684	-0.667	-0.457	-0.728	-0.919						
P10 mean	0.580	0.648	0.520	0.598	0.690		0.607	Light	0.5	0.75	1.5
P -15 mm	-1.050	-0.448	-0.613	-1.030	-1.902		-1.009	Medium	0.350	0.55	1.1

Observations: one tie solidly bound to mortar and four ties slipped in the mortar

Galvanised Type B tie with hollow concrete block

Specimen	GLHC-90-1	GLHC-90-2	GLHC-90-3	GLHC-90-4	GLHC-90-5	GLHC-90-6	Characteristic	Rating	**AS/NZS 2699 values**		
P +2mm	0.337	0.226	0.283	0.199	0.294	0.120					
P -2mm	-0.128	-0.077	-0.305	-0.348	-0.165	-0.306					
P2 mean	0.233	0.152	0.294	0.274	0.230	0.213			**Light**	**Medium**	**Heavy**
Stiffness 2mm (kN/mm)	0.116	0.076	0.147	0.137	0.115	0.107	0.116	Fail	0.15	0.175	0.2
P +10 mm 4th cycle	0.432	0.369	0.404	0.402	0.354	0.274					
P -10mm 4th cycle	-0.196	-0.096	-0.520	-0.484	-0.264	-0.542					
P10 mean	0.314	0.233	0.462	0.443	0.309	0.408	0.289	Fail	0.5	0.75	1.5
P -15 mm	-0.394	-0.070	-0.737	-0.880	-0.448	-0.303	0.236	Fail	0.350	0.55	1.1

Observations: one tie solidly bound to mortar, one tie slipped in mortar and four mortar/concrete de-bonds

Stainless steel Type A tie with 90 mm hollow concrete block

Specimen	SEHC-90-1	SEHC-90-2	SEHC-90-3	SEHC-90-4	SEHC-90-5	SEHC-90-6	SEHC-90-7	Characteristic	Rating	**AS/NZS 2699 values**		
P +2mm	0.614	0.521	0.351	0.404	0.529	0.430	0.605					
P -2mm	-0.469	-0.362	-0.332	-0.068	-0.490	-0.413	-0.435					
P2 mean	0.542	0.442	0.342	0.236	0.510	0.422	0.520			**Light**	**Medium**	**Heavy**
Stiffness 2mm (kN/mm)	0.271	0.221	0.171	0.118	0.255	0.211	0.260	0.215	Heavy	0.15	0.175	0.2
P +10 mm 4th cycle	0.692	0.711	0.691	0.758	0.708	0.695	0.807					
P -10mm 4th cycle	-0.781	-0.357	-0.662	-0.079	-0.990	-0.671	-0.686					
P10 mean	0.737	0.534	0.677	0.419	0.849	0.683	0.747	0.542	Light	0.5	0.75	1.5
P -15 mm	-0.850	-0.383	-0.791	-0.073	-1.087	-0.900	-0.895	0.409	Light	0.350	0.55	1.1

Observations: two ties solidly bound to mortar, four ties slipping in mortar

Stainless steel Type B tie with 90 mm clay brick

Specimen	SLCL-90-1	SLCL-90-2	SLCL-90-3	SLCL-90-4B	SLCL-90-5	SLCL-90-6	Characteristic	Rating	**AS/NZS 2699 values**		
P +2mm	0.071	0.091	0.076	0.197	0.163	0.128					
P -2mm	-0.351	-0.290	-0.295	-0.037	-0.231	-0.391					
P2 mean	0.211	0.191	0.186	0.117	0.197	0.260			**Light**	**Medium**	**Heavy**
Stiffness 2mm (kN/mm)	0.106	0.095	0.093	0.059	0.099	0.130	0.097	Fail	0.15	0.175	0.2
P +10 mm 4th cycle	0.219	0.201	0.249	0.324	0.242	0.232					
P -10mm 4th cycle	-0.884	-0.764	-0.792	-0.339	-0.877	-0.880					
P10 mean	0.552	0.483	0.521	0.332	0.560	0.556	0.430	Fail	0.5	0.75	1.5
P -15 mm	-2.911	-1.930	-1.970	-0.522	-2.356	-2.285	1.353	Heavy	0.350	0.55	1.1

Observations: all ties solidly bound to mortar

Stainless steel Type B tie with 90 mm solid concrete block

Specimen	SLSC-90-1	SLSC-90-2	SLSC-90-3	SLSC-90-4	SLSC-90-5	SLSC-90-6	Characteristic	Rating	**AS/NZS 2699 values**		
P +2mm	0.170	0.082	0.115	0.107	0.115	0.229					
P -2mm	-0.165	-0.378	-0.199	-0.298	-0.316	-0.595					
P2 mean	0.168	0.230	0.157	0.203	0.216	0.412			**Light**	**Medium**	**Heavy**
Stiffness 2mm (kN/mm)	0.084	0.115	0.079	0.101	0.108	0.206	0.115	Fail	0.15	0.175	0.2
P +10 mm 4th cycle	0.188	0.223	0.202	0.223	0.220	0.220					
P -10mm 4th cycle	-1.413	-0.818	-2.140	-0.808	-1.070	-1.278					
P10 mean	0.801	0.521	1.171	0.516	0.645	0.749	0.539	Light	0.5	0.75	1.5
P -15 mm	-3.430	-2.457	-3.247	-2.069	-2.896	-3.711	2.473	Heavy	0.350	0.55	1.1

Observations: five ties solidly bound to mortar and one mortar/concrete de-bond

Galvanised Type A tie with 70 mm solid concrete block

Specimen	GESC-70-1	GESC-70-2	GESC-70-3	GESC-70-4	GESC-70-5	GESC-70-6	Characteristic	Rating	**AS/NZS 2699 values**		
P +2mm	0.326	0.675	0.217	0.204	0.503	0.189					
P -2mm	-0.306	-0.251	-0.513	-0.445	-0.236	-0.332					
P2 mean	0.316	0.463	0.365	0.325	0.370	0.261			**Light**	**Medium**	**Heavy**
Stiffness 2mm (kN/mm)	0.158	0.232	0.183	0.162	0.185	0.130	0.175	Light	0.15	0.175	0.2
P +10 mm 4th cycle	0.569	0.604	0.484	0.424	0.673	0.868					
P -10mm 4th cycle	-0.566	-0.659	-1.058	-0.735	-0.712	-0.563					
P10 mean	0.568	0.632	0.771	0.580	0.693	0.716	0.595	Light	0.5	0.75	1.5
P -15 mm	-0.213	-0.817	-1.507	-0.586	-1.089	-0.723	0.469	Light	0.350	0.55	1.1

Observations: One tie solidly bound to mortar and five mortar/concrete de-bonds

Galvanised Type B tie with 70 mm solid concrete block

Specimen	GLSC-70-1	GLSC-70-2	GLSC-70-3	GLSC-70-4	GLSC-70-5	GLSC-70-6	Characteristic	Rating	**AS/NZS 2699 values**		
P +2mm	0.470	0.269	0.209	0.214	0.292	0.340					
P -2mm	-0.122	-0.377	-0.556	-0.581	-0.449	-0.283					
P2 mean	0.296	0.323	0.383	0.398	0.371	0.312			**Light**	**Medium**	**Heavy**
Stiffness 2mm (kN/mm)	0.148	0.162	0.191	0.199	0.185	0.156	0.173	Light	0.15	0.175	0.2
P +10 mm 4th cycle	0.381	0.347	0.342	0.293	0.343	0.380					
P -10mm 4th cycle	-0.102	-0.794	-1.188	-1.241	-0.975	-0.705					
P10 mean	0.242	0.571	0.765	0.767	0.659	0.543	0.435	Fail	0.5	0.75	1.5
P -15 mm	-0.090	-1.340	-0.666	-2.276	-1.605	-1.259	0.601	Medium	0.350	0.55	1.1

Observations: one tie solidly bound to mortar and five mortar/concrete de-bonds

Stainless steel Type A tie with 70 mm clay brick

Specimen	SECL-70-1	SECL-70-2	SECL-70-3	SECL-70-4	SECL-70-5	SECL-70-6	Characteristic	Rating	**AS/NZS 2699 values**		
P +2mm	0.274	0.335	0.241	0.327	0.595	0.761					
P -2mm	-0.379	-0.362	-0.319	-0.364	-0.329	-0.239					
P2 mean	0.327	0.349	0.280	0.346	0.462	0.500			**Light**	**Medium**	**Heavy**
Stiffness 2mm (kN/mm)	0.163	0.174	0.140	0.173	0.231	0.250	0.189	Medium	0.15	0.175	0.2
P +10 mm 4th cycle	0.586	0.462	0.744	0.601	0.658	0.702					
P -10mm 4th cycle	-0.964	-0.815	-0.449	-0.947	-0.847	-0.392					
P10 mean	0.775	0.639	0.597	0.774	0.753	0.547	0.601	Light	0.5	0.75	1.5
P -15 mm	-0.969	-1.068	-0.155	-1.446	-1.285	-0.504	0.514	Light	0.350	0.55	1.1

Observations: four ties solidly bound to mortar and two ties loose in mortar

Stainless steel Type A tie with 70 mm solid concrete block

Specimen	SESC-70-1	SESC-70-2	SESC-70-3	SESC-70-4	SESC-70-5	SESC-70-6	Characteristic	Rating	AS/NZS 2699 values		
P +2mm	0.595	0.421	0.585	0.181	0.589	0.177					
P -2mm	-0.377	-0.388	-0.293	-0.274	-0.416	-0.354					
P2 mean	0.486	0.405	0.439	0.228	0.503	0.266			**Light**	**Medium**	**Heavy**
Stiffness 2mm (kN/mm)	0.243	0.202	0.220	0.114	0.251	0.133	0.194	Medium	0.15	0.175	0.2
P +10 mm 4th cycle	0.669	0.573	0.809	0.638	0.598	0.674					
P -10mm 4th cycle	-0.839	-1.009	-0.822	-0.943	-1.028	-0.782					
P10 mean	0.754	0.791	0.816	0.791	0.813	0.728	0.754	Medium	0.5	0.75	1.5
P -15 mm	-0.886	-1.223	-0.942	-1.067	-1.199	-1.064	0.956	Medium	0.350	0.55	1.1

Observations: two ties solid in mortar, two ties loose in mortar and two mortar/concrete de-bonds