REPORT ON FREEZE / THAW TESTS ON TRIPSTOP™ PVC JOINERS FOR RESIDENTIAL CONCRETE PAVEMENT (FOOTPATH / SIDEWALK) OF 125 mm THICKNESS

by

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REPORT ON FREEZE / THAW TESTS ON TRIPSTOP™ PVC JOINERS FOR RESIDENTIAL CONCRETE PAVEMENT (FOOTPATH / SIDEWALK) OF 125 mm THICKNESS

1. Introduction

This report presents the findings of freeze / thaw tests on TripStop™ PVC joiners. These tests were conducted in the Heavy Structures Laboratory of the School of Civil, Environmental and Chemical Engineering at RMIT University, Melbourne, Australia. A full-scale prototype residential concrete pavement (footpath / sidewalk) 5m long, 1.5m wide and 125mm thick was cast on a steel testing frame. The testing frame was designed in such a way that the formwork can be removed from underneath the concrete slabs and the slabs can be jacked up from virtually any point – to simulate various scenarios of tree root invasion and soil expansion / movement.

Four TripStop™ PVC joiners were installed in the prototype residential concrete pavement (footpath / sidewalk). They were spaced 1.5m apart from each other. The two ends of the pavement were restrained by steel angles. The locations of the PVC joiners and their cross-sectional shape are shown in Figures 1 and 2.

Four tests have been conducted - with loading on the slabs ranging from 0 to 400 kg. Extensive data have been recorded from these tests. This report will focus on stepping displacement (the difference between the vertical movements of adjoining slabs) which is the main cause of tripping hazards in residential concrete pavements (footpaths / sidewalks) and therefore the most critical measurement for assessing the adequacy and performance of TripStop™ in freeze / thaw. The subzero temperature for this study was -30°C. The Australian Standard AS 3727 (1993): *Guide to Residential Pavements* [1] is used to determine the appropriate level of loading on the slabs and the maximum allowable stepping displacement between adjacent slabs.

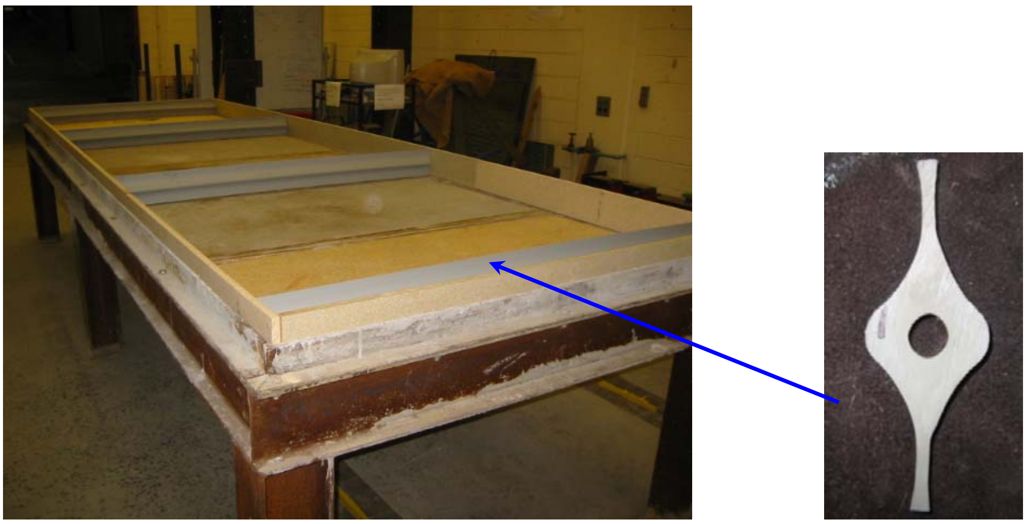


Figure 1 The locations and the cross-sectional shape of TripStop™ PVC joiners

2. Loading on Concrete Slab

According to Australian Standard AS 3727 (1993) : *Guide to Residential Pavements* [1], the minimum breaking load for residential concrete pavement (footpath / sidewalk) of 125 mm thickness is 4 kN on one panel of the pavement which is approximately 400 kg.

The 400 kg load can be considered as the maximum allowable *design load* on the slab. The design load would be calculated by multiplying the **actual applied load** (known as *service load*) by a load factor of 1.2 for dead (or long-term) load or 1.5 for live (or short-term) load. Therefore the **expected service load** would be 400 kg / 1.2 = 333.33 kg (long-term load) or 400 kg / 1.5 = 266.67 kg (short-term load).

3. Maximum Allowable Stepping Displacement / Vertical Movement

In various documents and guidelines, a stepping displacement of 5 - 6 mm is considered to be a threshold level for tripping hazard for a pedestrian. Voice of Safety International (VOSI) is an American private sector standards organization that specializes in public safety standards. In its *Standard for Slip & Trip Resistant Sidewalks and Swimming Pool Decks* [2], VOSI states that the "Maximum vertical mismatch of adjacent sidewalk panels, or utility access covers within walkways, is ¼ inch (6mm) maximum without edge treatment". The Australian standard AS 3727 [1] states that the relative surface level of adjacent paving elements within the expanse of the main pavement shall not be more than 5 mm. In this study, 5 mm will be considered as the maximum allowable stepping displacement.

4. Dry Ice (Solid Carbon Dioxide)

Dry ice was used for the freeze / thaw tests reported here. Dry ice is solid carbon which becomes a solid at -78.5 ^{0}C. The name dry ice refers to the fact that the substance changes from a solid to a gas without first becoming a liquid. The subzero temperature for this study was – 30 °C.

5. Test Results

The concrete was ordered from a ready-mix supplier with a nominal strength of 40MPa. Prior to pouring concrete on the testing frame, the slump for the concrete was measured as 90 mm. All tests were conducted after the standard cylinder strength of concrete of slabs exceeded 20 MPa. The 7 days mean compressive strength of the concrete was found to be 31.75 MPa. The specification in Australian Standard AS 3727 [1] for 125 mm slabs is 25 MPa.

5.1 Jacking up at line AB

The plan of the testing frame is shown in Figure 2. In this test, dry ice was uniformly distributed on the concrete slabs 1, 2 and 3 as shown in Figure 3. Water was poured for freeze / thaw at Joint 2. A thermometer was used to monitor the concrete slab's temperature. When the concrete slabs reached the temperature – 30 °C, the concrete slabs were pushed up from the bottom of Slab 2 along a long piece of solid timber (represented by line AB in Figure 2) using a hydraulic jack. The 1.4 m long solid timber was placed between a solid timber cube (120 mm x 120 mm x 120 mm) and the bottom surface of Slab 2 as shown in Figure 4. No additional load was applied to any of the slabs during the first test. Later, a uniformly distributed dead load of 400 kg was added to Slab 1 in the test.

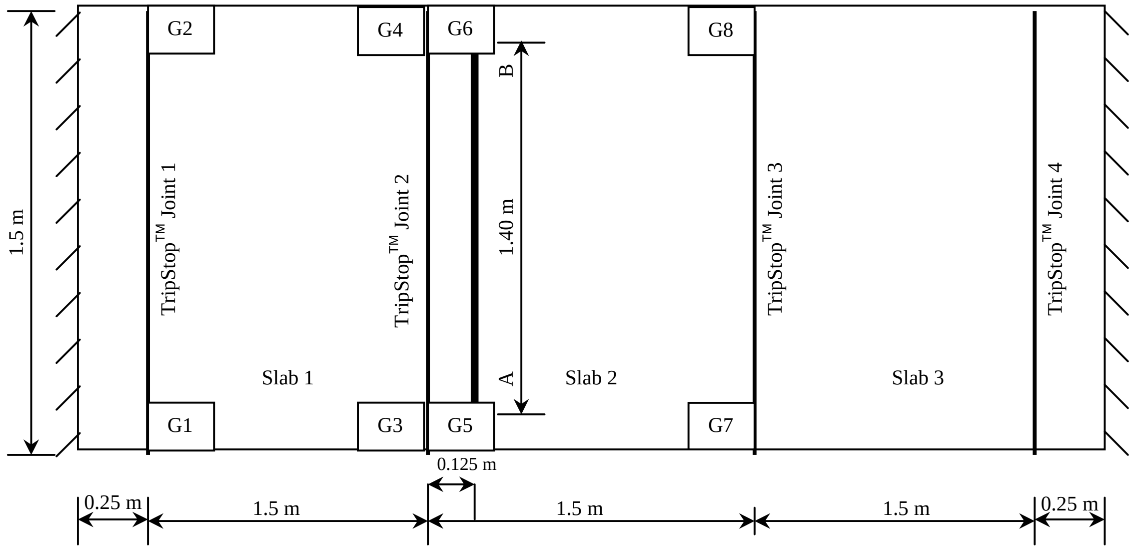


Figure 2. Plan of testing frame - Jacking up at line AB

Figure 3. Dry ice was uniformly distributed on concrete slabs

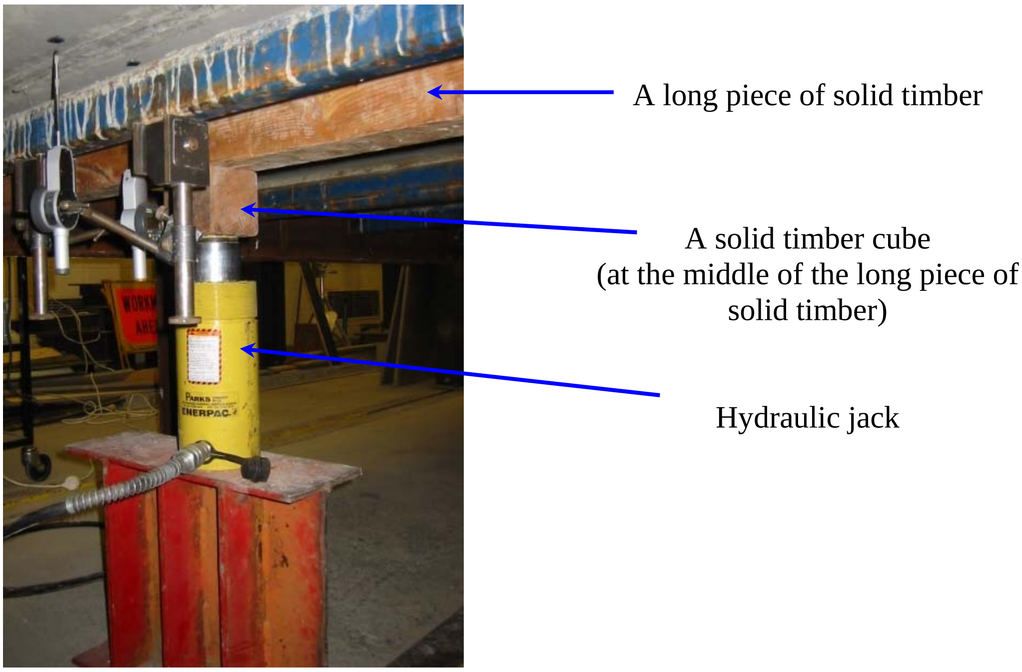


Figure 4. Slabs being pushed up by a hydraulic jack

To measure the displacements, linear variable differential transformers (LVDTs) were mounted at critical points. As the concrete slabs were pushed up, the displacements at the locations G3 to G6 were recorded by LVDTs. It is noted that in this test, the displacements at the locations G1, G2, G7 and G8 were negligible. The stepping displacement was obtained by subtracting displacement reading of G5 from that of G3 and similarly by subtracting displacement reading of G6 from that of G4.

It should be pointed out that the frozen dry ice was broken at the Joint 2 when the concrete slabs were pushed up. No damage was found in the PVC joiners or the concrete slabs. The broken dry ice filled in the gap between the PVC joiner and concrete slabs. When we released the hydraulic jack to slowly lower down the concrete slabs, the dry ice in the gap was squeezed out to the top surface of the slabs. The testing results are shown in Table 1 and Figure 5.

Table 1. Stepping displacement (in mm) when jacking up at line AB

	Stepping displacement G3 – G5				Stepping displacement G4 – G6			
Lift / Load	0	10mm	30mm	50mm	0	10mm	30mm	50mm
No additional load	0.00	1.21	2.08	2.77	0.00	1.14	1.90	2.63
400 kg	0.00	1.65	2.57	3.13	0.00	1.54	2.55	3.10

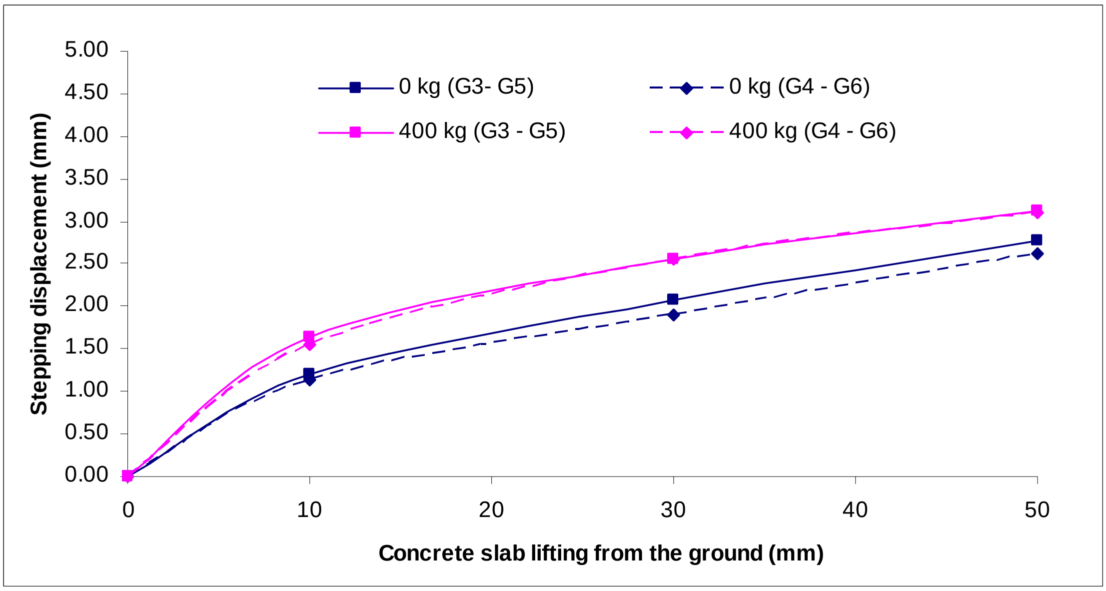


Figure 5. Stepping displacement when jacking up at line AB

From Figure 5, it is seen the stepping displacement increased when additional dead load was added to the slab. The maximum stepping displacement recorded without additional load on slab was 2.77 mm, which happened when the corresponding stepping displacement on the other side of the slab was 2.63 mm. This indicates that the slabs were slightly titled. The self-weight of each slab was about 675 kg. The maximum stepping displacement recorded in the test was 3.13 mm when 400 kg of dead load was put on Slab 1, as shown in Figure 6.

Figure 6. 400 kg dead load added on the Slab 1

5.2 Jacking up at point D

With the previous tests, the slabs were moved up almost uniformly across the width, resulting in a uniform distribution of force along the length of the TripStop^{TM} PVC joiner. A more challenging case would be to push a slab at a corner as shown in Figure 7.

Figure 7. Slab 2 being pushed up at a corner (at point D)

In this test, Slab 2 was jacked up at point D as shown in Figure 8. Before the test began, dry ice was uniformly distributed on the concrete slabs 1, 2 and 3. Water was poured for freeze / thaw at Joint 2. When the concrete slabs was pushed up by 10 mm, 30 mm and 50 mm, each time additional water was poured for freeze / thaw on the Joint 2. No additional load was applied to any of the slabs during the first test. In the second test, Slab 2 was pushed up at point D and a 400 kg concentrated load was applied to point C in slab 1. The results are shown in Table 2 and Figure 9.

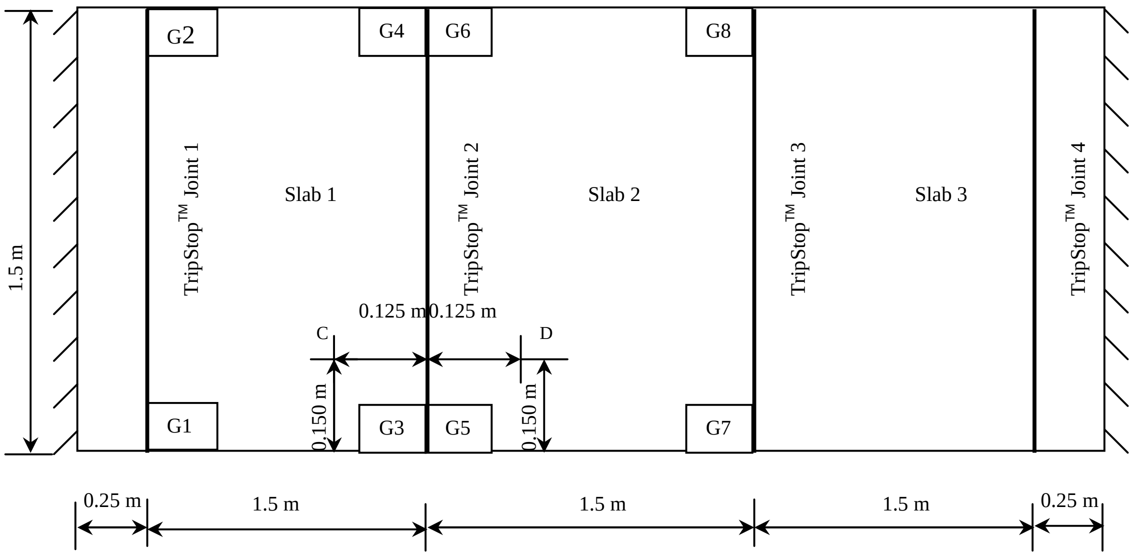


Figure 8. Plan of testing frame – Jacking up at point D.

Table 2. Stepping displacement (in mm) when jacking up at point D

	Stepping displacement G3 – G5				Stepping displacement G4 – G6			
Lift / Dead Load	0	10mm	30mm	50mm	0	10mm	30mm	50mm
No additional load on the slab	0.00	1.59	2.81	3.60	0.00	0.64	0.80	0.92
400 kg point load at point C	0.00	2.46	3.64	4.57	0.00	0.59	0.31	-0.07

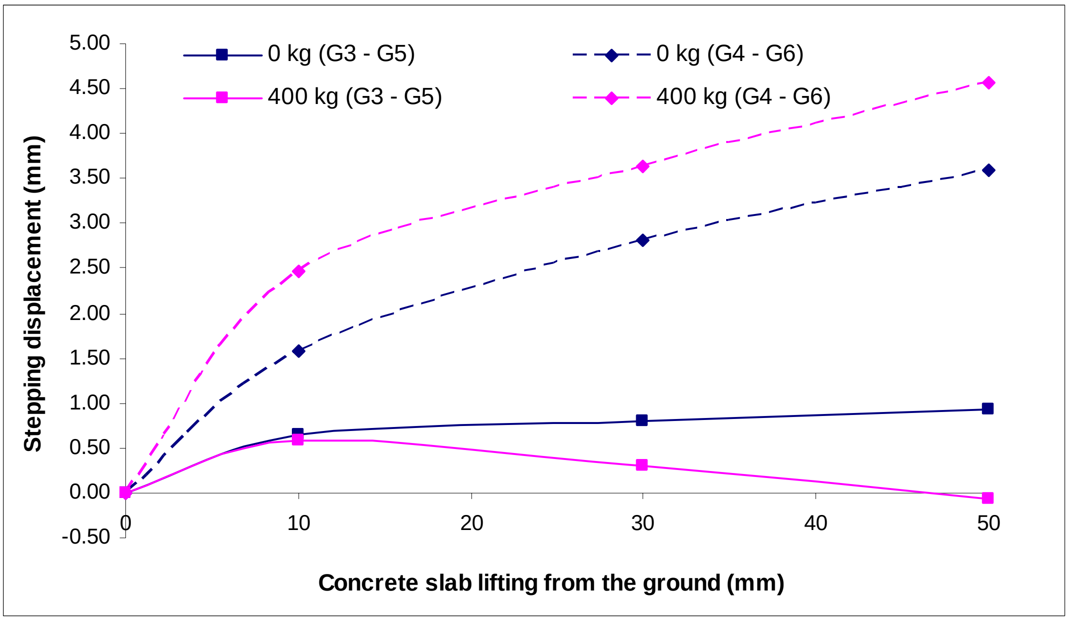


Figure 9. Stepping displacement when jacking up at point D

It is seen that the stepping displacement with no additional load near G3 (where the jacking force was applied) was 3.60 mm. On the other side of the slab, the stepping displacement was 0.92 mm. This indicates that the slabs were tilted due to Slab 2 being pushed up away from the centre.

The last test was the most challenging one where a 400 kg concentrated load was applied. Joint 2 was frozen by the dry ice. Figure 10 shows such a set-up. The hydraulic jack pushed up Slab 2 at point D and the 400 kg concentrated load was applied to point C in Slab 1 (refer to Figure 8). To assess performance of TripStop™, the 'worst scenario' load case was where one slab was pushed up at a corner while a concentrated load was applied next to it on the adjoining slab. The maximum stepping displacement at G3 was 4.57 mm, while on the other side of the slab the stepping displacement was -0.07 mm. This indicates that the slabs were tilted more significantly compared to the case where no additional load was added on concrete slabs.

Figure 10. Slab 2 being jacked up at a corner with 400 kg concentrated load applied to adjoining slab.

5.3 Repeat test – Jacking up at line EF

This test was the same as jacking up at line AB except that the test was carried out on Joint 3. It was to confirm the results of tests on Joint 2. The plan of the concrete testing frame is shown in Figure 11. The results are shown in Table 3 and Figure 12.

The stepping displacement varied from 1.19 mm to 2.62 mm when no additional load was on the slabs. The stepping displacement of 3.02mm was recorded at G3 when the 400 kg dead load was distributed evenly across the whole Slab 3. However, the corresponding displacement measurement on the other side of the slab was 3.22 mm. This indicates that the slabs were slightly titled by about 0.2 mm between G3 and G4. It could be because the jacking force was not exactly at the centre or the slabs / joiners were not perfectly symmetrical.

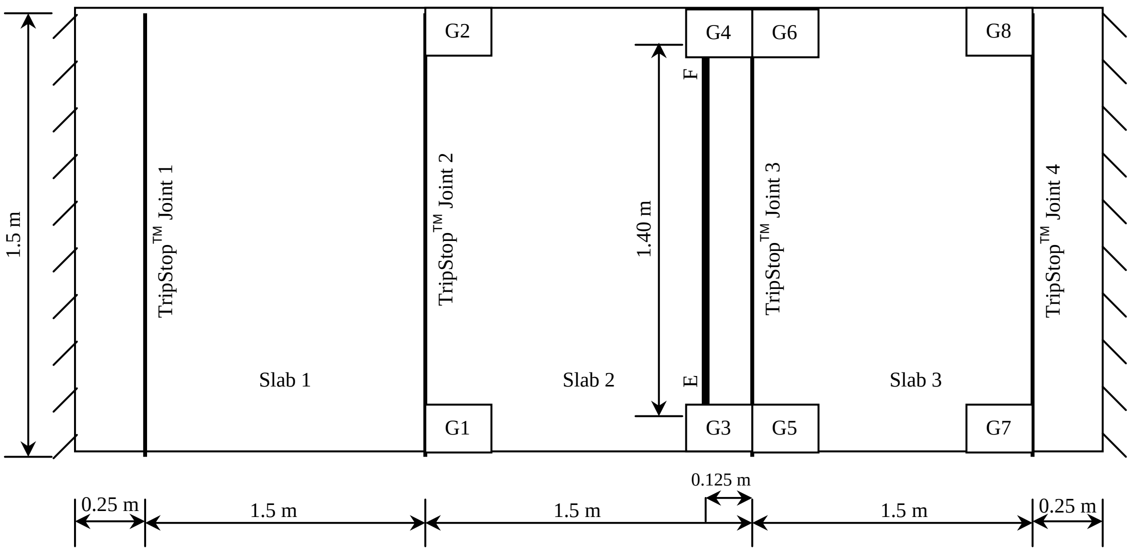


Figure 11. Plan of testing frame for the repeat test

Table 3. Stepping displacement (in mm) when jacking up at line EF

Load \ Lift	Stepping displacement G3 – G5				Stepping displacement G4 – G6			
	0	10mm	30mm	50mm	0	10mm	30mm	50mm
No additional load	0.00	1.23	1.60	2.36	0.00	1.19	1.74	2.62
400 kg	0.00	1.40	2.30	3.02	0.00	1.71	2.74	3.22

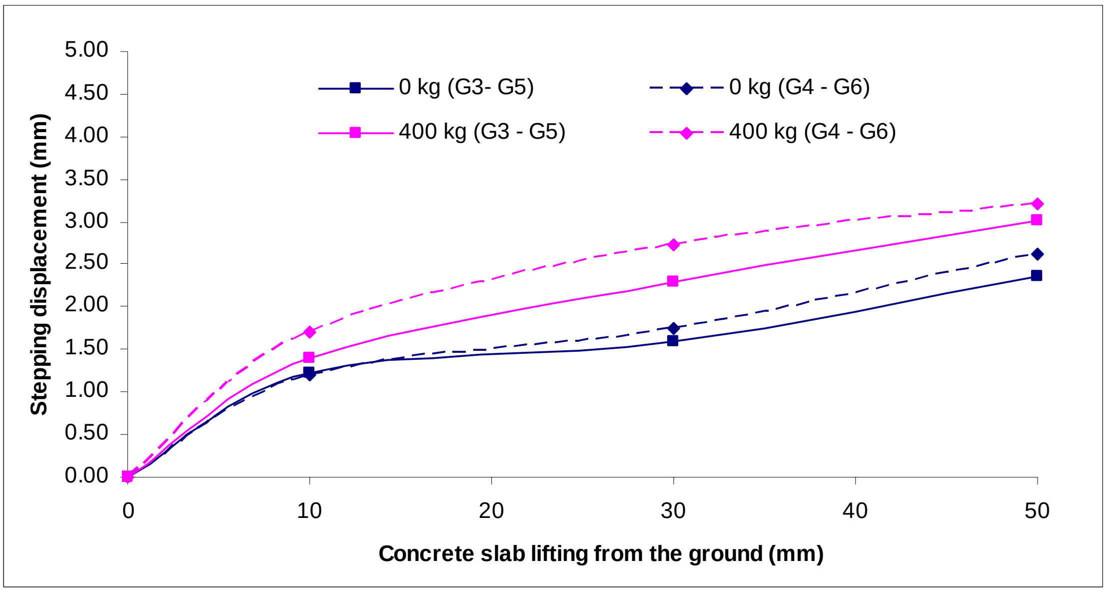


Figure 12. Stepping displacement when jacking up at line EF

5.4 Repeat test – Jacking up at point G

In this test, Slab 2 was jacked up at point G shown in Figure 13. No additional load was applied to any of the slabs at the first test. In the second test a concentrated load of 400kg was applied to point H. The results are shown in Table 4 and Figure 14.

When there was no additional dead load on the slabs, the maximum stepping displacement was 3.08 mm. When a 400 kg concentrated load was applied to point H, the maximum stepping displacement was 4.19 mm.

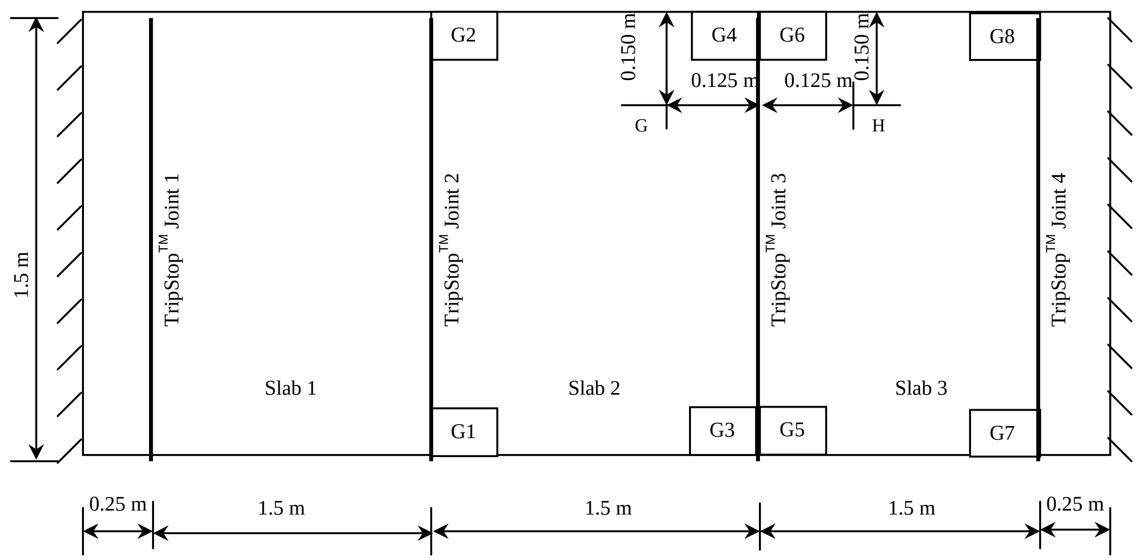


Figure 13. Plan of testing frame – jacking up at point G

Table 4. Stepping displacement (in mm) when jacking up at point H

	Stepping displacement G3 – G5				Stepping displacement G4 – G6			
Lift / Dead Load	0	10mm	30mm	50mm	0	10mm	30mm	50mm
No additional load on the slab	0.00	0.90	0.83	0.68	0.00	1.52	2.17	3.08
400 kg point load at Point D	0.00	0.77	0.48	0.09	0.00	1.82	3.28	4.19

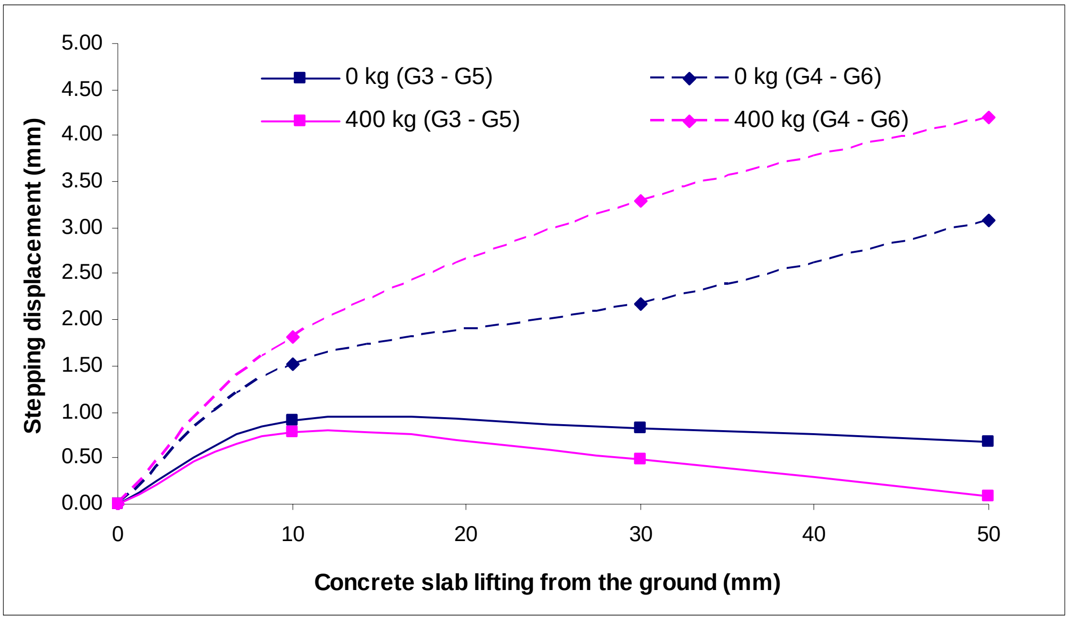


Figure 14.Stepping displacement when jacking up at point H.

6. Conclusions

A comprehensive series of tests was conducted at very low temperature (-30°C) on the TripStop® PVC joiners under various loading conditions according to AS3727. The concrete slabs were pushed up by 10, 30 and 50 mm from the horizontal position using a hydraulic jack to simulate tree root invasion and/or soil heave. The soil that contains water will expand when it freezes in cold climates.

The tests have been repeated on two different joints and similar results have been obtained.

The worst scenario load case of one slab being jacked up at a corner while a concentrated load being applied next to it on the adjoining slab produced a maximum stepping displacement of 4.57 mm.

The test results clearly demonstrate that the current TripStop® PVC joiners satisfy the performance criterion of 5 mm maximum allowable stepping displacement as specified in AS 3727 even in extremely cold climate with temperature reaching -30°C.

8. References

[1] Standards Australia, *Australian Standard AS3727: Guide to Residential Pavements*, 1993.

[2] Voice of Safety International (VOSI), *Standard for Slid & Trip Resistant Sidewalks and Swimming Pool Decks*, 2002 – see website http://www.voicesofsafety.com/t1-sf-v41-23e.htm [accessed on 30 June 2006]

9. Certification

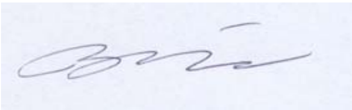
The tests have been conducted in the Heavy Structures Laboratory of RMIT University by the following qualified Civil Engineers:

Professor Mike Xie *BEng, PhD, Fellow of Institution of Engineers Australia.*

Associate Professor Sujeeva Setunge *BEng, PhD, Senior Member of Institution of Engineers Australia.*

Mr Yew-Chin Koay *BEng, MEngSc.*

Signed on behalf of the above RMIT University team:



Professor Mike Xie
Discipline Head, Civil and Environmental Engineering
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