REPORT ON FULL SCALE LABORATORY TESTS ON TRIPSTOP^{TM} PVC JOINERS FOR RESIDENTIAL PAVEMENT (FOOTPATH / SIDEWALK) OF 100 mm THICKNESS

by

Y.M. Xie, S. Setunge and **Y.C. Koay**
School of Civil and Chemical Engineering
RMIT University, Melbourne, Australia

Phone: +61 3 9925 3655
E-mail: mike.xie@rmit.edu.au

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REPORT ON FULL SCALE LABORATORY TESTS ON TRIPSTOP™ PVC JOINERS FOR RESIDENTIAL PAVEMENT (FOOTPATH / SIDEWALK) OF 100 mm THICKNESS

1. Introduction

This report presents the findings of laboratory tests on TripStop™ PVC joiners. These tests were conducted in the Heavy Structures Laboratory of the School of Civil and Chemical Engineering at RMIT University, Melbourne, Australia. A full scale prototype residential pavement (footpath / sidewalk) 5m long, 1.5m wide and 100 mm thick was cast on a steel 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 pavement (footpath / sidewalk). They were 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 Figure 1.

Four tests have been conducted - with loading on the slabs ranging from 0 to 300 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 pavements (footpaths / sidewalks) and therefore the most critical measurement for assessing the adequacy and performance of TripStop™. 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 pavement (footpath / sidewalk) of 100 mm thickness is 3 kN on one panel of the pavement which is approximately 300 kg.

The 300 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 300 kg / 1.2 = 250 kg (long-term load) or 300 kg / 1.5 = 200 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. 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 80 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 26.2 MPa. The specification in Australian Standard AS 3727 [1] for 100 mm slabs is 20 MPa.

4.1 Jacking up at line AB

The plan of the testing frame is shown in Figure 2. In this test, the concrete slabs were pushed up from the bottom of Slab 1 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 1 as shown in Figure 3. No additional load was applied to any of the slabs during the first test. Later, a uniformly distributed dead load of 300 kg was added to Slab 2 in the test.

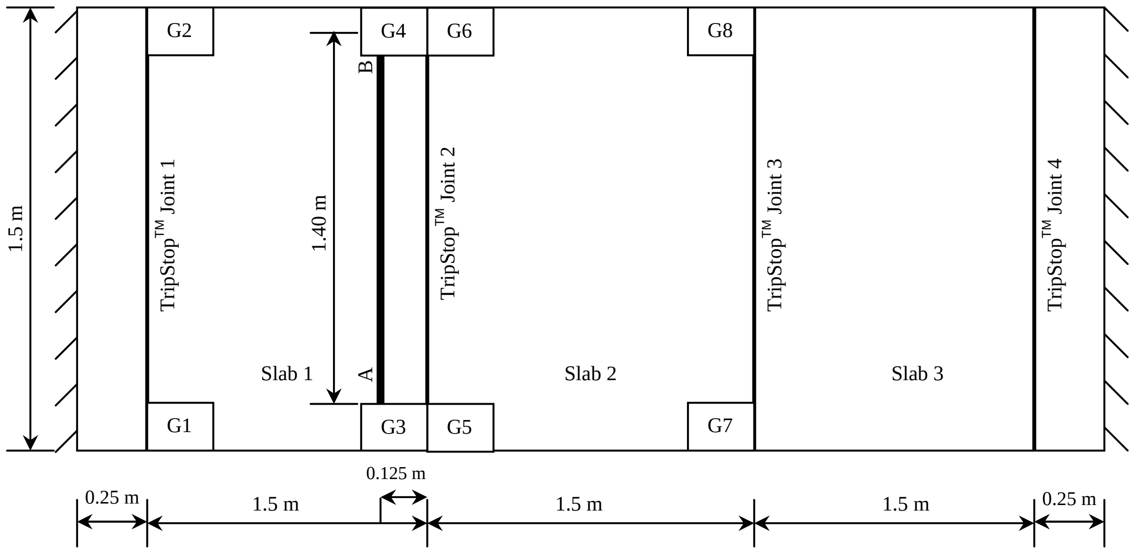


Figure 2. Plan of testing frame - Jacking up at line AB

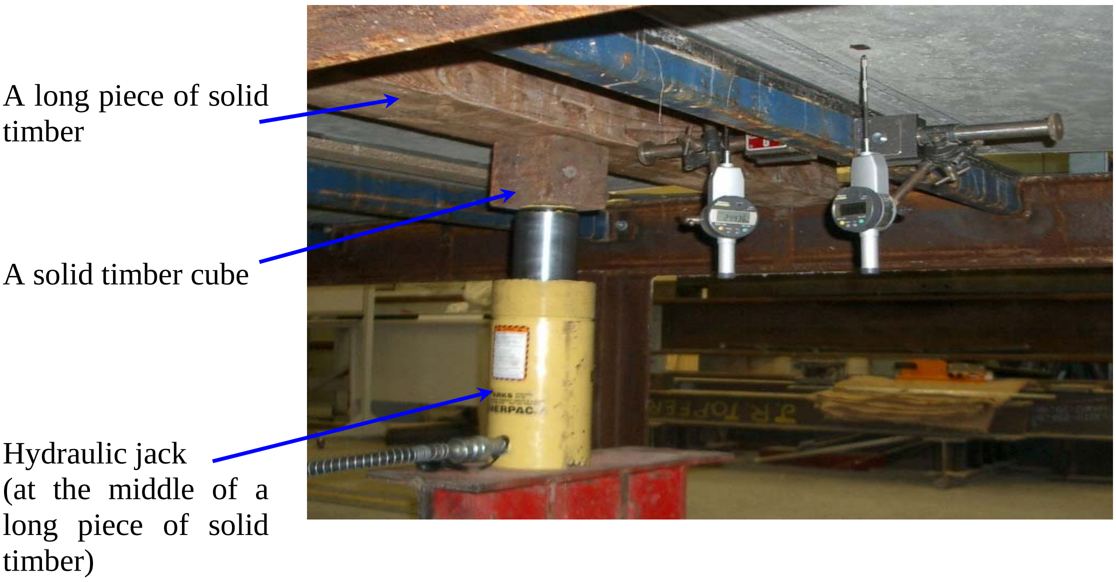


Figure 3 : Slabs being pushed up by a hydraulic jack

To measure the displacements, linear variable differential transformers (LVDTs) were mounted at critical points. As the 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. The results are shown in Table 1 and Figure 4.

Table 1. Stepping displacement when jacking up at line AB

Load \ Lift	Stepping displacement G3 – G5				Stepping displacement G4 – G6			
	0	10mm	30mm	50mm	0	10mm	30mm	50mm
No additional load	0.00	0.35	0.61	1.05	0.00	0.35	0.90	1.32
300 kg	0.00	0.83	1.52	1.88	0.00	0.86	1.89	2.11

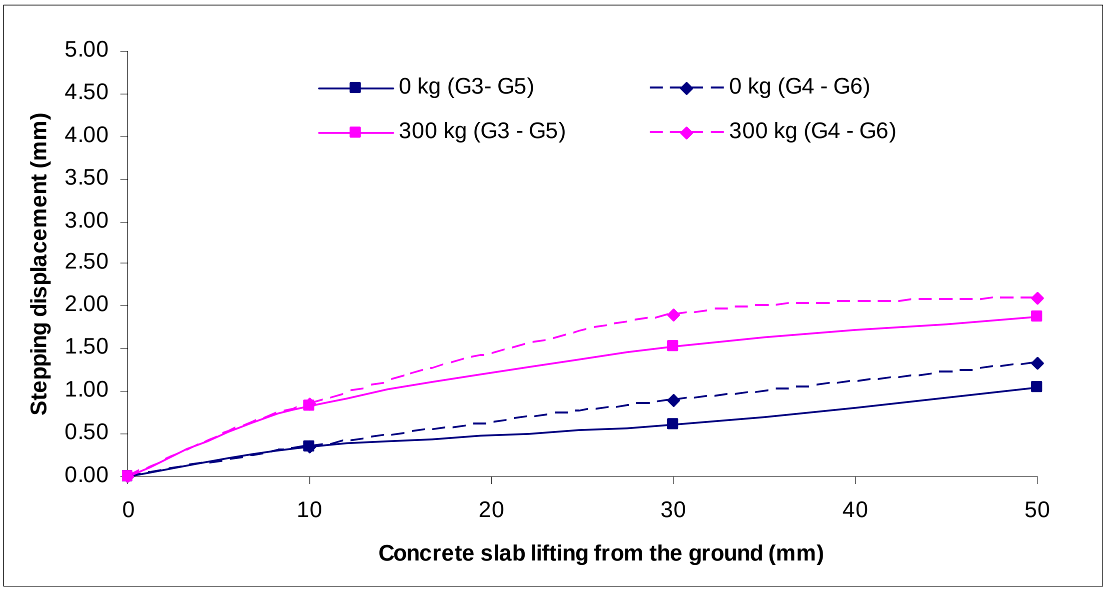


Figure 4. Stepping displacement when jacking up at line AB

From Figure 4, 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 1.05 mm, which happened when the corresponding stepping displacement on the other side of the slab was 1.32 mm. This indicates that the slabs were slightly tilted. It could be because the jacking force was not exactly at the centre or the slabs / joiners were not perfectly symmetrical. The self-weight of each slab was about 540 kg. The maximum stepping displacement recorded in the test was 2.11 mm when 300 kg of dead load was put on Slab 2, as shown in Figure 5.

Figure 5. 300 kg dead load added on the Slab 2

4.2 Jacking up at point C

With the previous tests, the slabs were moved up almost uniformly across the width, resulting in a uniform distribution of force on the TripStop^{TM} PVC joiner. A more challenging case would be the one where Slab 1 is pushed up at a corner as shown in Figure 6.

Figure 6. Slab 1 being pushed up at a corner

In this test, Slab 1 was jacked up at point C as shown in Figure 7. No additional load was applied to any of the slabs during the first test. In the second test, Slab 1 was pushed up at point C and a 300kg concentrated load was applied to point D in slab 2. The results are shown in Table 2 and Figure 8.

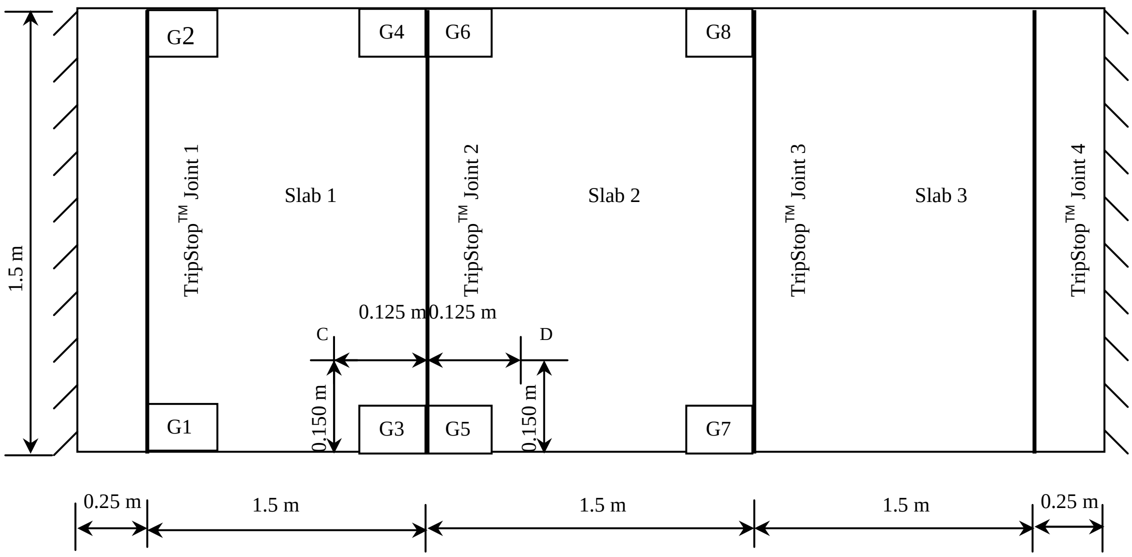


Figure 7. Plan of testing frame – Jacking up at point C.

Table 2. Stepping displacement - Slab 1 was jacked up at point C with no additional and the 300kg of concentrated load was applied to point D in Slab 2.

	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	1.19	1.90	2.44	0.00	0.31	-0.33	-0.99
300 kg point load at Point D	0.00	1.62	2.39	2.98	0.00	-0.70	-1.48	-2.01

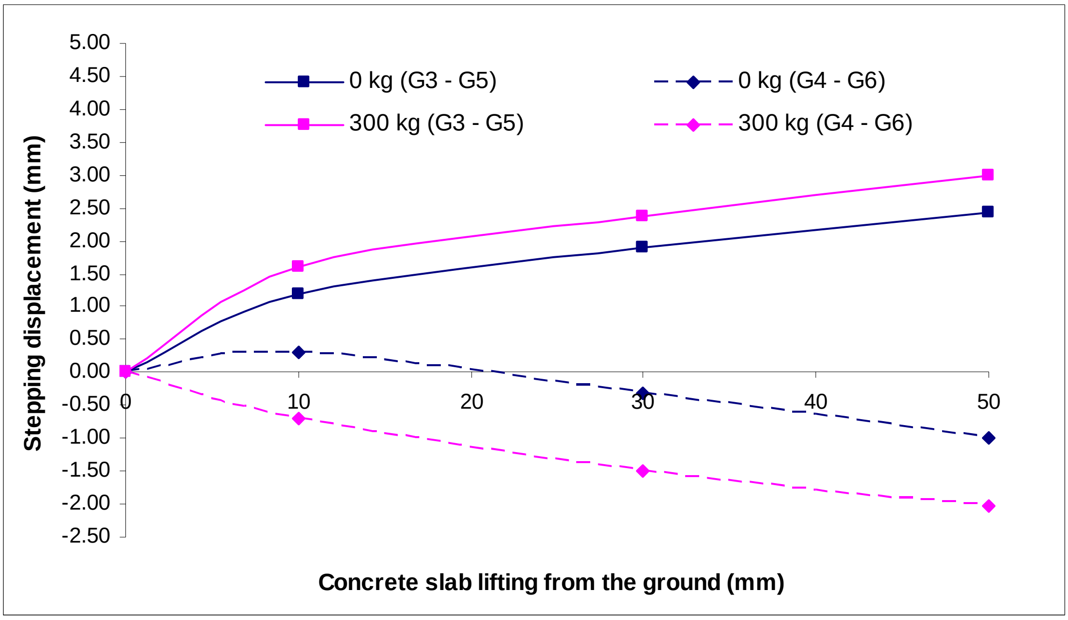


Figure 8. Stepping displacement - Slab 1 was jacked up at point C with no additional and the 300 kg of concentrated load was applied to point D in Slab 2.

It is seen that the stepping displacement with no additional load near G3 (where the jacking force was applied) was 2.44 mm. On the other side of the slab, the stepping displacement was - 0.99 mm. This indicates that the slabs were slightly tilted due to Slab 1 being pushed up at a corner.

The last test on Joint 2 was the most challenging one where a 300 kg concentrated load was applied. Figure 9 shows such a set-up. The hydraulic jack pushed up Slab 1 at point C and the 300 kg concentrated load was applied to point D in Slab 2 (refer to Figure 7). To assess the performance of TripStop^{TM}, 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 G6 was 2.98 mm, while on the other side of the slab the stepping displacement was -2.01 mm.

Figure 9. Slab 1 being jacked up at a corner with 300 kg concentrated load applied to adjoining slab

4.3 Creep displacement test

To examine the effect of sustained loading over a period of time, a creep displacement test was carried out. The plan of the concrete testing frame is shown in Figure 10. In this test, Slab 2 was jacked up at line EF and a distributed load of 300 kg was added on top of Slab 3. Two additional dial gauges BG9 and BG10 were placed to the bottom of Slabs 2 and 3 respectively (refer to Figure 10).

The creep displacement results were recorded over a period of 6 weeks from 23 December 2005 to 2 February 2006 and the details are given in Appendix 1. Figure 11 shows the additional stepping displacement due to creep. The maximum creep displacement measured over the period of 6 weeks was 0.15 mm, which is negligible.

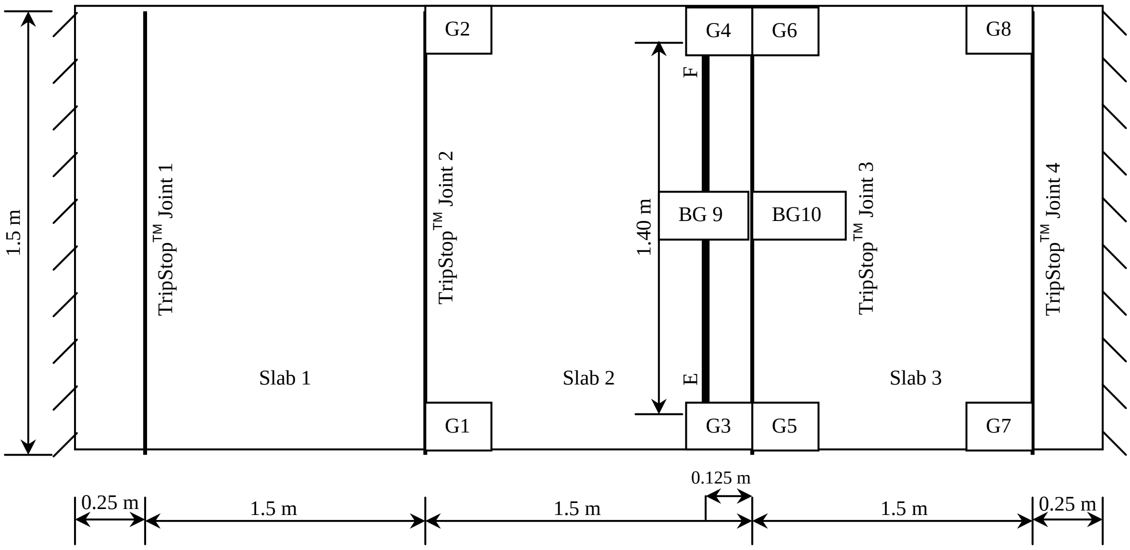


Figure 10. Plan of testing frame for the creep displacement test

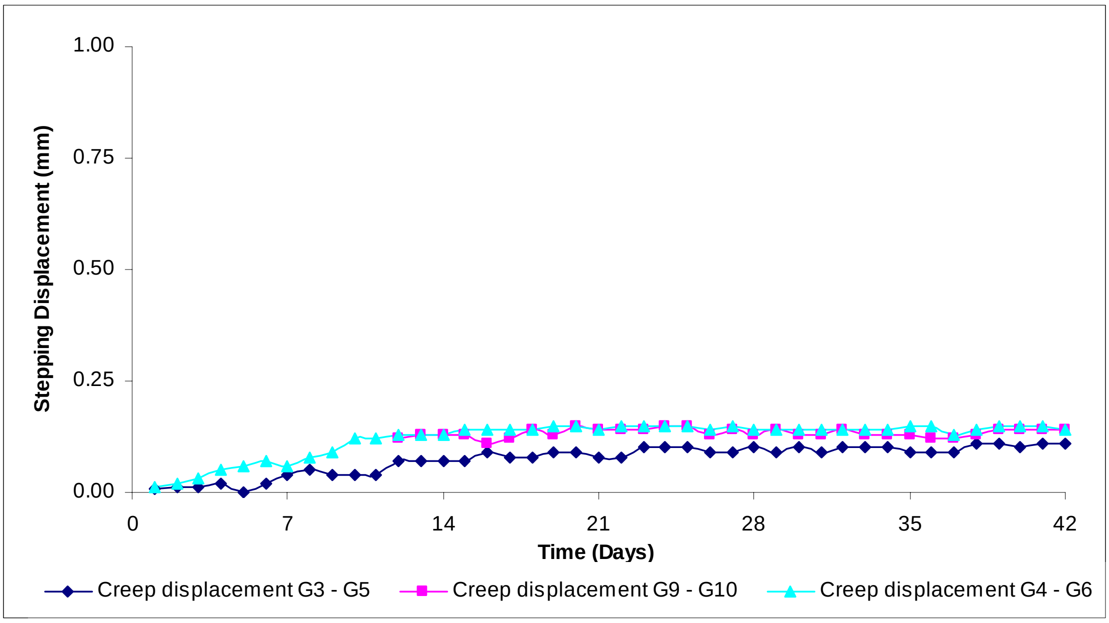


Figure 11 Stepping displacement due to creep

4.4 Mirror test (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 10. The results are shown in Table 3 and Figure 12. The stepping displacement varied from 0.50 mm to 2.55 mm when the additional load on Slab 3 increased from zero to 300 kg. The magnitude of the stepping displacement was similar to the result of the same test on Joint 2.

Table 3. Stepping displacement when jacking up at line EF

	Stepping displacement G3 – G5				Stepping displacement G4 – G6			
Lift / Load	0	10mm	30mm	50mm	0	10mm	30mm	50mm
No additional load	0.00	0.50	0.95	1.72	0.00	1.13	1.95	2.27
300 kg	0.00	0.54	1.08	1.89	0.00	1.38	2.13	2.55

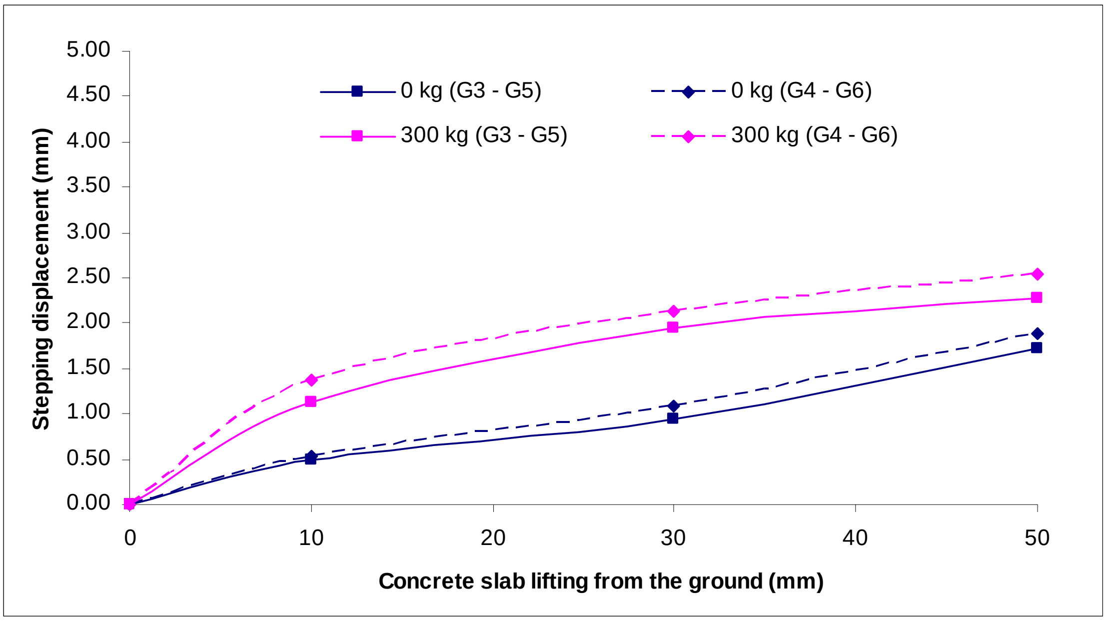


Figure 12. Stepping displacement when jacking up at line EF

4.5 Mirror 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 300kg 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 2.32 mm which compared similar with the result of test on Joint 2 (2.44 mm). When a 300 kg concentrated load was applied to point H, the maximum stepping displacement was 2.81 mm which was the similar as the result of test on Joint 2 (2.91 mm).

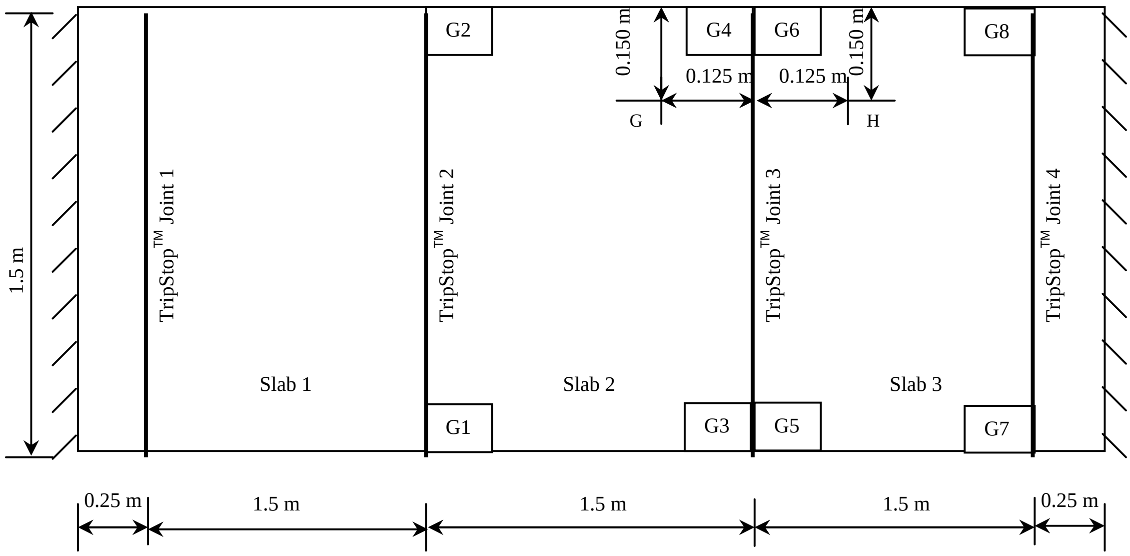


Figure 13. Plan of testing frame – jacking up at point G

Table 4. Stepping displacement - Slab 1 was jacked up at point G with no additional and the 300kg of concentrated load was applied to point H in Slab 3.

	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	0.42	0.15	0.02	0.00	1.15	1.72	2.32
300 kg point load at Point D	0.00	-0.02	-0.77	-1.51	0.00	1.54	2.32	2.81

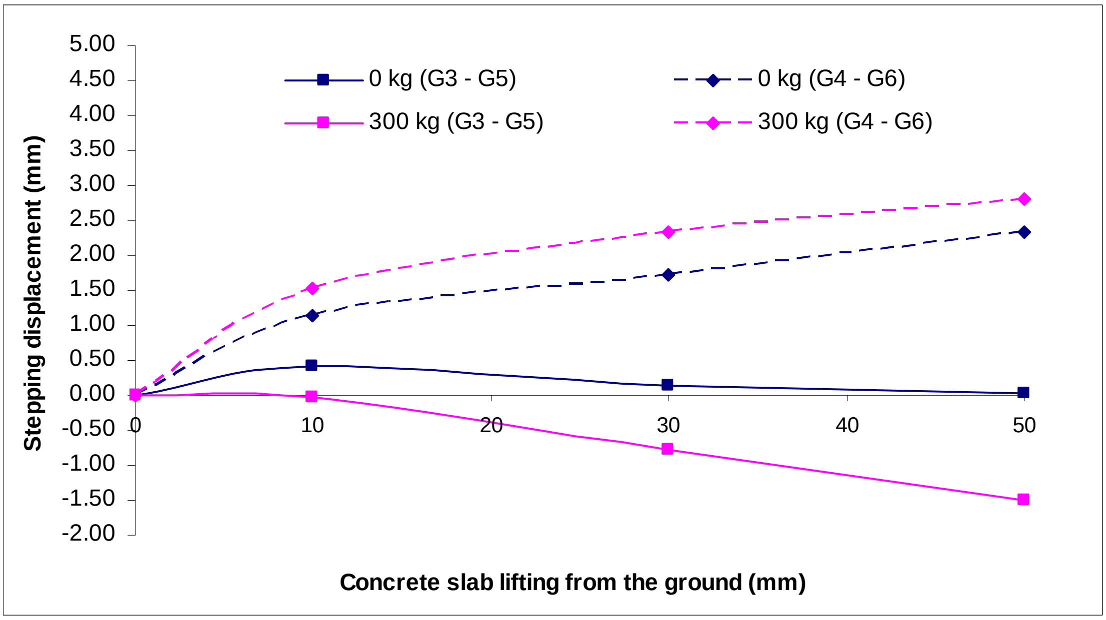


Figure 14.Stepping displacement - Slab 2 was jacked up at point C with no additional and the 300 kg of concentrated load was applied to point D in Slab 3.

4.6 Overloading test – Jacking up at line EF

After all the tests were carried out, overloading test was conducted. The plan of concrete testing frame is shown in Figure 10. Slab 2 was jacked up at line EF and a massive 2,000 kg load was added on Slab 3 as shown in Figure 15. This was to confirm the PVC joiner had more than enough capacity to resist vertical shear force and control differential vertical movement, thus reducing the potential for serviceability problems and stepping displacement.

The stepping displacement results are presented in Table 5 and graphically shown in Figure 16. The maximum stepping displacement was 4.49 mm. There was no cracking of the concrete slabs and the PVC joiner remained completely undamaged.

Figure 15. Slab 2 being jacked up at line EF with 2,000kg load added on Slab 3

Table 5. Stepping displacement - Slab 2 was jacked up line EF
with 2,000kg load added on Slab 3.

	Stepping displacement G3 – G5				Stepping displacement G4 – G6			
Lift / Load	0	10mm	25mm	50mm	0	10mm	25mm	50mm
2,000 kg	0.00	1.86	3.60	4.19	0.00	2.01	3.81	4.49

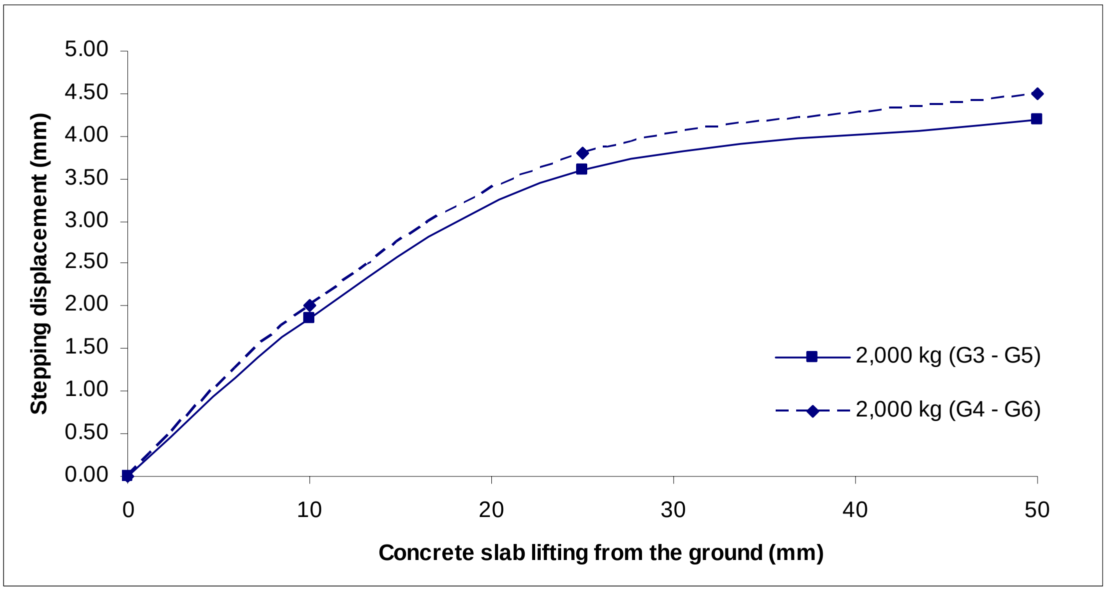


Figure 16. Stepping displacement - Slab 2 was jacked up line EF
with 2,000kg load added on Slab 3.

5. Conclusions

A comprehensive series of tests was conducted on the TripStop® PVC joiners under various loading conditions according to AS3727. 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 stepping displacement of 2.98 mm. Even with the massive overloading of 2,000 kg, the stepping displacement was only 4.49 mm.

The maximum creep displacement measured over the period of 6 weeks was 0.15 mm, which is negligible.

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.

6. 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 7/12/05]

7. Certification

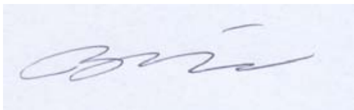
The tests have been conducted in the Heavy Structures Laboratory of RMIT University by the following qualified Civil Engineers:

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 Engineering
RMIT University

Date : 22/03/2006

Appendix 1 Results of the creep test

		Stepping Displacement (mm) - G3 to G6 based on LVDTs and G1, G2, G7, G8, BG9 and BG10 based on Gauges												
Date	Day (s)	G1	G2	G3	G4	G5	G6	G7	G8	BG9	BG10	***G3-G5***	***BG9-BG10***	***G4-G6***
22/12/05	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	***0.00***		***0.00***
23/12/05	1			0.24	0.23	0.13	0.12					***0.01***		***0.01***
24/12/05	2			0.31	0.30	0.15	0.13					***0.01***		***0.02***
25/12/05	3			0.34	0.33	0.15	0.12					***0.01***		***0.03***
26/12/05	4			0.33	0.31	0.16	0.11					***0.02***		***0.05***
27/12/05	5			0.40	0.40	0.22	0.16					***0.00***		***0.06***
28/12/05	6			0.44	0.42	0.22	0.15					***0.02***		***0.07***
29/12/05	7 (1st Wk)			0.49	0.45	0.21	0.15					***0.04***		***0.06***
30/12/05	8			0.48	0.43	0.22	0.14					***0.05***		***0.08***
31/12/05	9			0.55	0.51	0.25	0.16					***0.04***		***0.09***
01/01/06	10			0.54	0.50	0.25	0.13					***0.04***		***0.12***
02/01/06	11			0.52	0.48	0.24	0.12					***0.04***		***0.12***
03/01/06	12	0.15	0.20	0.56	0.49	0.25	0.12	0.14	0.08	0.41	0.29	***0.07***	***0.12***	***0.13***
04/01/06	13	0.16	0.21	0.56	0.49	0.25	0.12	0.14	0.08	0.40	0.27	***0.07***	***0.13***	***0.13***
05/01/06	14 (2ndWk)	0.14	0.21	0.55	0.48	0.24	0.11	0.12	0.09	0.38	0.25	***0.07***	***0.13***	***0.13***
06/01/06	15	0.16	0.20	0.53	0.46	0.24	0.10	0.12	0.10	0.36	0.23	***0.07***	***0.13***	***0.14***
07/01/06	16	0.18	0.19	0.54	0.45	0.23	0.09	0.12	0.11	0.34	0.23	***0.09***	***0.11***	***0.14***
08/01/06	17	0.19	0.18	0.53	0.45	0.24	0.10	0.12	0.12	0.34	0.22	***0.08***	***0.12***	***0.14***
09/01/06	18	0.19	0.18	0.52	0.44	0.22	0.08	0.12	0.12	0.34	0.20	***0.08***	***0.14***	***0.14***
10/01/06	19	0.18	0.18	0.46	0.37	0.24	0.09	0.12	0.13	0.33	0.20	***0.09***	***0.13***	***0.15***
11/01/06	20	0.17	0.18	0.47	0.38	0.25	0.10	0.13	0.14	0.32	0.17	***0.09***	***0.15***	***0.15***
12/01/06	21 (3rdWk)	0.17	0.17	0.48	0.40	0.26	0.12	0.13	0.14	0.32	0.18	***0.08***	***0.14***	***0.14***
13/01/06	22	0.17	0.16	0.50	0.42	0.28	0.13	0.13	0.14	0.33	0.19	***0.08***	***0.14***	***0.15***
14/01/06	23	0.16	0.15	0.50	0.40	0.28	0.13	0.13	0.15	0.33	0.19	***0.10***	***0.14***	***0.15***
15/01/06	24	0.16	0.15	0.50	0.40	0.28	0.13	0.13	0.15	0.34	0.19	***0.10***	***0.15***	***0.15***
16/01/06	25	0.15	0.14	0.50	0.40	0.28	0.13	0.13	0.16	0.34	0.19	***0.10***	***0.15***	***0.15***

		Stepping Displacement (mm) - G3 to G6 based on LVDTs and G1, G2, G7, G8, BG9 and BG10 based on Gauges												
Date	Day (s)	G1	G2	G3	G4	G5	G6	G7	G8	BG9	BG10	***G3-G5***	***BG9-BG10***	***G4-G6***
17/01/06	26	0.15	0.14	0.51	0.42	0.27	0.13	0.14	0.17	0.34	0.21	***0.09***	***0.13***	***0.14***
18/01/06	27	0.14	0.14	0.51	0.42	0.28	0.13	0.13	0.17	0.35	0.21	***0.09***	***0.14***	***0.15***
19/01/06	28 (4th Wk)	0.13	0.13	0.51	0.41	0.27	0.13	0.13	0.17	0.35	0.22	***0.10***	***0.13***	***0.14***
20/01/06	29	0.13	0.13	0.50	0.41	0.26	0.12	0.13	0.17	0.36	0.22	***0.09***	***0.14***	***0.14***
21/01/06	30	0.12	0.13	0.52	0.42	0.27	0.13	0.13	0.16	0.37	0.24	***0.10***	***0.13***	***0.14***
22/01/06	31	0.12	0.12	0.51	0.42	0.25	0.11	0.14	0.16	0.38	0.25	***0.09***	***0.13***	***0.14***
23/01/06	32	0.11	0.12	0.51	0.41	0.27	0.13	0.14	0.15	0.38	0.24	***0.10***	***0.14***	***0.14***
24/01/06	33	0.11	0.12	0.52	0.42	0.26	0.12	0.14	0.15	0.38	0.25	***0.10***	***0.13***	***0.14***
25/01/06	34	0.11	0.11	0.54	0.44	0.25	0.11	0.15	0.15	0.38	0.25	***0.10***	***0.13***	***0.14***
26/01/06	35 (5th Wk)	0.11	0.11	0.53	0.44	0.26	0.11	0.14	0.16	0.37	0.24	***0.09***	***0.13***	***0.15***
27/01/06	36	0.10	0.10	0.52	0.43	0.27	0.12	0.13	0.16	0.38	0.26	***0.09***	***0.12***	***0.15***
28/01/06	37	0.10	0.09	0.52	0.43	0.25	0.12	0.13	0.16	0.38	0.26	***0.09***	***0.12***	***0.13***
29/01/06	38	0.10	0.09	0.55	0.44	0.26	0.12	0.13	0.17	0.39	0.26	***0.11***	***0.13***	***0.14***
30/01/06	39	0.10	0.08	0.52	0.41	0.26	0.11	0.13	0.17	0.40	0.26	***0.11***	***0.14***	***0.15***
31/01/06	40	0.09	0.08	0.53	0.43	0.27	0.12	0.15	0.17	0.41	0.27	***0.10***	***0.14***	***0.15***
01/02/06	41	0.09	0.08	0.51	0.40	0.25	0.10	0.15	0.17	0.42	0.28	***0.11***	***0.14***	***0.15***
02/02/06	42 (6th Wk)	0.09	0.08	0.52	0.41	0.24	0.10	0.15	0.16	0.43	0.29	***0.11***	***0.14***	***0.14***