Comparison of Various Types of Shear Connectors for Minimizing Tripping Hazards in Concrete Footpaths

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Abstract

Simple control joints such as score line cuts or saw cuts are commonly used in the construction of concrete footpaths. These joints do not have a load transfer mechanism and therefore displacement of the concrete slab panels will create a differential vertical movement at the joint when the footpaths are affected by tree root invasion or by soil movement. This differential vertical movement of adjoining slabs create a major tripping hazard to pedestrians.

In this study, three types of joiners (connectors) made of aluminium, EPDM rubber and PVC have been studied to examine their capability for minimizing the tripping hazard.

1. INTRODUCTION

In Australia, plain concrete pavements are commonly constructed for the use of residential footpaths. These pavements do not contain any steel reinforcement and are easy to construct. However, such pavements should not be used in areas where ground conditions are prone to large uneven settlement (AS3727, 1993) because it will cause cracking in the mid slab as well as uneven deformation of adjacent slabs at control joints and thus will create a tripping hazard. Traditionally a simple control joint is formed with a score line cut with a trowel on fresh concrete, a saw cut made on hardened concrete or a crack inducer cast with the slab. Load transfer capability of these joints completely relies on the aggregate interlock between the two cracked faces. If the crack widths are greater than 1 mm at the joint, the load transfer capability will diminish and the adjacent slabs will move up and down independently from each other. In residential footpaths, the differential movement of adjoining slab panels is known as “stepping displacement”, which is a major tripping hazard to pedestrians, particularly the elderly. In United States, tripping hazard incidents by pedestrians are the second largest generator of workplace accidents (Leamon and Murphy, 1995).

In order to overcome this problem, studies on three types of joiners made of aluminium, EPDM rubber and PVC have been carried out by the authors. These joiners are placed between adjoining slabs when the concrete is poured. When the concrete is cured, the footpath will become a series of linked slabs which can flex with the movement of earth thus minimizing the relative displacement of adjoining slabs and the corresponding tripping hazard. The joint formed can be classified as a control joint which regulates cracks as well as transfer loads between adjoining slabs.

This paper discusses the findings in the context of the requirements of Australian Standards for concrete pavements and American private sector standards for slid and trip. This study focuses on the stepping displacement which is the major cause of tripping hazards and therefore the most critical measurement for accessing the adequacy and performance of joiners.

2. DESIGN AND PREPARATION

2.1 Joiner Strips

The shape and cross section of each of the joiner strips is shown in Fig. 1. Aluminium joiner is formed by four 20 x 37.5 x 3 mm unequal angles revetted connection on both angles. EPDM and PVC joiners are made from ethylene-propylene-diene terpolymer (same rubber as used for the car tyres) and plastic, respectively.

(a) Aluminium joiner (b) EPDM rubber joiner (c) PVC joiner

Fig 1. Types and cross section of joiner strips

2.2 Testing Frames

In order to save time to wait for concrete curing at 28 days and testing, two testing frames have been designed and fabricated. Both testing frames were designed to simulate tree root invasion or soil movement so that the formwork can be removed from underneath the concrete slabs and concrete slabs can be jacked up from virtually any point by the use of a hydraulic jack. Additional loads will be added to the top surface of the slab (using standard weights) to simulate the weight of pedestrians or vehicles. The difference between the two types of testing frames are shown in Fig 2 and discussed below:-

2.1.1 First testing frame (0.5 m x 3.5 m)

This testing frame is 0.5 m wide and 3.5 m long. It has been designed to have *two full scale slabs* in the middle plus two smaller slabs (one at each end). The set-up allows for *three joints* between the slabs where the joiner strip can be installed during the concrete pour. *One joiner* connecting the *two full slabs* was tested, as they closely represent the conditions of a footpath of "infinite" length. Aluminium joiner was cast and tested on this testing frame.

2.1.2 Second testing frame (1.5 m x 5.0 m)

This testing frame is 1.5 m wide and 5 m long. It is large enough to have *three full scale slabs* in the middle plus two smaller slabs (one at each end). The set-up allows for *four joints* between the slabs where the joiner strip can be installed during the concrete pour. The *two joiners* connecting the *three full slabs* were tested, as they closely represent the conditions of a footpath of "infinite" length. EPDM rubber and PVC joiners were cast and tested on this testing frame.

(a) First type - 0.5 m x 3.5 m (b) Second type – 1.5 m x 5.0 m

Fig 2. Testing frame

3. EXPERIMENTAL PROGRAMME

3.1 Concrete Properties Tests

Concrete ordered from a ready-mix company with strength varying from 20 to 40 MPa. Some concrete samples, prior to pouring concrete on the testing frame were prepared to study the mechanical properties of concrete such as compressive strength, splitting tensile strength, elastic modulus and flexural strength. Concrete testing of concrete samples was conducted at 7 and 28 days according to AS 1102 (1993). Compressive strength, splitting tensile and elastic modulus tests were performed on 100 mm diameter x 200 mm length cylinders and flexural strength test on 150 x 150 x 550 mm prisms. For the determination of compressive strength, three cylinders were tested at each age. For tensile splitting strength, elastic modulus and flexural strength, two specimens were tested at each age. Two curing regimes were employed, namely air drying and water curing.

3.2 Laboratory Tests on Full Scale Footpaths

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 Slid & Trip Resistant Sidewalks and Swimming Pool Decks* (2002), VOSI states that the Maximum vertical mismatch of adjacent sidewalk panels, or utility access covers within walkways is 6 mm maximum without edge treatment. However, AS 3727 (1999) stated 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, the stepping displacement should be much less than 5mm (which is considered to be a threshold level of tripping hazard, Pedestrian Council of Australia, 1999).

3.2.1 Aluminium joiner

The plan of the testing frame is shown in Fig 3. In this test, the concrete slabs were pushed up from the bottom of Slab 1 along line AB using the hydraulic jack. The line AB represents a long piece of solid timber of 0.45 m in length which was placed between a load cell and the bottom surface of Slab 1. No additional load was applied to any of the slabs at the first testing. To the second and third testing, 40 kg and 80 kg dead loads were added on the Slab 2 respectively. To measure the displacements, gauges were mounted at critical points at G1 to G8 to measure the displacement of the slab. As the slab was pushed up, the displacements at the locations G3 to G6 were recorded. 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 G3 from that of G4 and similarly by subtracting displacement reading of G5 from that of G6.

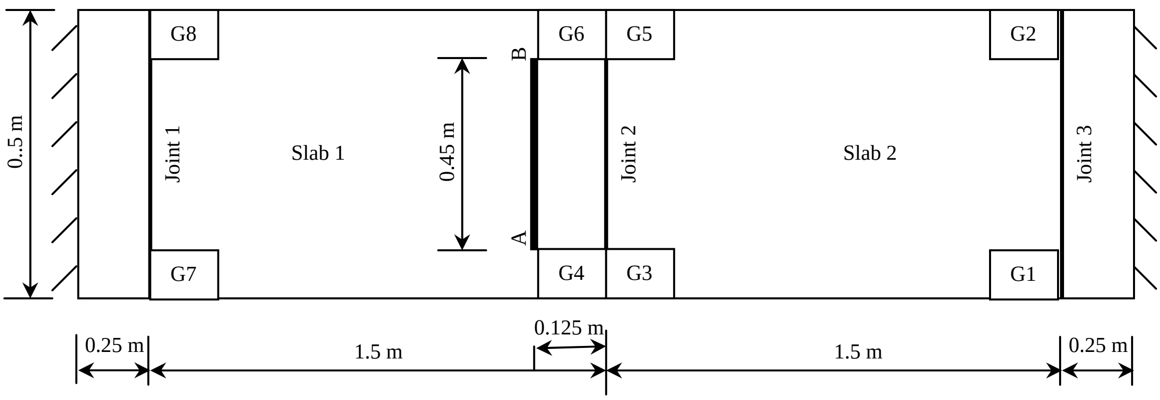

Fig 3 Plan of testing for aluminium joiner

3.2.2 EPDM rubber and PVC joiners

In this test, a similar set up to the aluminium joiner was used. The wider and large testing frame shown in Fig 4 was used. In the first testing of the slab, no additional load was applied to any of the slabs. However, to the second and third testing, a dead load of 200 kg and 490 kg were added on the Slab 3 respectively, which is approximately three times extra dead load compared to the aluminium Joiner testing. This was because the width of the slabs was three times wider than the aluminium Joiner's slabs. The Concrete slab was pushed up from the bottom of Slab 2 with a long piece of solid timber of 1.40 m in length. As the slab was pushed up, the displacements at the locations G3 to G6 were recorded. The stepping displacement was obtained by subtracting displacement reading of G3 from that of G4 and similarly by subtracting displacement reading of G5 from that of G6.

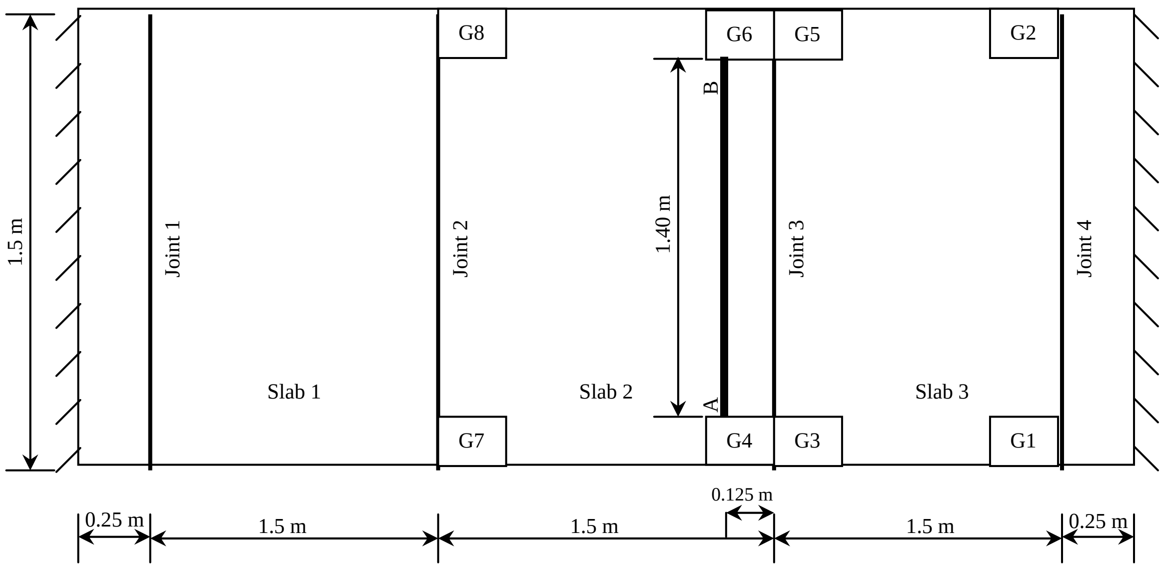

Fig 4 Plan of testing for EPDM rubber Joiner and PVC Joiner

4. RESULTS AND DISCUSSIONS

4.1 Concrete Properties

The results of tests conducted on slump and concrete properties are summarized in Table 1. In this research, concrete samples were used as reference for monitoring slab strength. When the concrete strength achieved more than 20 MPa, the slab testing was carried out so as to comply with the specification AS 3727 (1999). From the Table 1, we can see that all mixtures displayed the workability within the range of 75mm ± 50mm. The concrete samples were either water cured (Water) or air dried (Air drying). The latter was to simulate the actual field practice at different stages of concrete curing. The full scale footpaths by using aluminium and EPDM rubber joiners were tested after 28 days of concrete pouring. However, testing on the full scale footpath by using PVC Joiner was done after 7 days of concrete pouring.

Table 1 : Summary of concrete properties results.

Type of testing	Age (days)	Curing regimes	Aluminium Joiner	EPDM Rubber Joiner	PVC Joiner
Slump (mm)	-	-	80	80	90
Compressive strength (MPa)	7	Water	20.7	15.4	24.0
		Air drying	19.8	14.8	22.9
	28	Water	29.7	21.2	45.3
		Air drying	20.7	18.7	42.4
Flexural strength (MPa)	7	Water	3.0	2.8	3.6
		Air drying	2.6	2.1	3.3
	28	Water	3.6	3.8	4.2
		Air drying	2.9	3.5	3.9
Static modulus of elasticity (GPa)	7	Water	18.0	14.1	18.5
		Air drying	17.1	13.1	17.4
	28	Water	20.9	18.1	24.6
		Air drying	18.1	16.9	22.3
Tensile splitting (MPa)	7	Water	2.9	2.9	2.8
		Air drying	1.6	2.5	2.6
	28	Water	3.0	3.7	4.2
		Air drying	2.2	3.2	3.8

4.2 Laboratory Tests on Full Scale Footpaths

The testing of three types of innovative joiner strip namely aluminium joiner, EPDM rubber joiner and PVC joiner are discussed below :-

4.2.1 Aluminium joiner

The stepping displacement testing results are shown in Table 2 and Fig 5. In this test, the maximum stepping displacement was recorded at 2.91 mm when the 160 kg dead load distributed evenly across the whole Slab 2. However, the corresponding displacement measurement on the other side of the slab was 2.20 mm. This indicates that the slabs were slightly titled about 0.7 mm between G4-G3 and G6-G5. The stepping displacement with no additional load varied from 0.32 mm to 1.19 mm, while 80 kg dead load distributed evenly on the Slab 2 varied from 0.61 mm to 2.54 mm. All the stepping displacement results are less than 5 mm which complied with the AS 3727 (1993).

Table 2 : Aluminium joiner testing results

	Stepping displacement G4 – G3				Stepping displacement G6 – G5			
Dead Load	0	10	30	50	0	10	30	50
W/Load	0.00	0.32	0.58	0.95	0.00	0.63	1.10	1.19
80 kg	0.00	0.61	1.74	1.99	0.00	1.25	2.08	2.54
160 kg	0.00	0.91	1.99	2.20	0.00	1.29	2.41	2.91

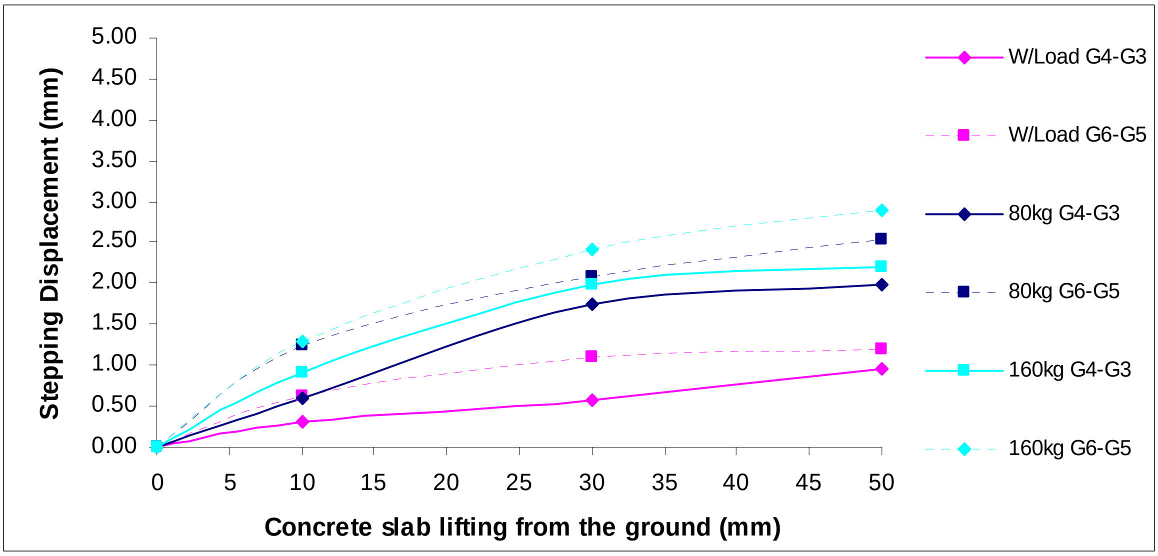

Fig 5 Aluminium joiner testing results

From the Fig 5, it is apparent that added load on the concrete slabs would increase the stress level in the aluminium joiner. In the test, due to the high stresses between the concrete and aluminium joiner, the cracks occurred at the edge of the surface of the concrete as shown in Fig. 6.

Fig 6 Crack occurred at the shape edge of aluminium Joiner

4.2.2 EPDM rubber joiner

The test of the EPDM Rubber joiner was similar to the aluminium joiner except that the testing frame was wider and large enough to have three full scale slabs (Refer to Fig 4). The self weight of each slab was about 400 kg. The results of the testing are shown in Table 3 and Fig 7.

It is clear that the characteristic of the EPDM rubber joiner is quite different to the other two rigid materials investigated. The curves of stepping displacement showed an irregular pattern indicating displacement and recovery upon further lifting. It is because EPDM rubber is a hyperelastic material. Overall maximum stepping displacement did not exceed 4.5 mm. Stress–strain creep properties of rubber needs to be measured and the joiner stress needs to be understood to be able to predict the observed behaviour.

In the first test, no additional load was applied on the slab; the maximum stepping displacement was 1.07 mm, which happened when the corresponding displacement measurement on the other side of the slab was 2.75 mm. This indicates that the slabs were slightly tilted which possibly was because the jacking force was not exactly at the centre. The average stepping displacement of 200 kg load on the slab 3 varied from 1.15 mm to 3.37 mm. The added 200kg load would increase the stress level in EPDM rubber joiner 3 by approximately 15 – 20 % compared to no additional load.

The last test was the same as the previous two tests except that the loading on Slab 3 was now increased to 490 kg. It is seen that despite the excessive loading on the slab, there was very little increment in the stepping displacement compared to the results of no additional load and 200 kg on the slab 3. The stepping displacement in this test varied from 1.21 mm to 3.37 mm, which was similar to that of previous tests where the loading was much smaller.

Table 3 : EPDM Rubber Joiner testing results

	Stepping displacement G4 – G3						Stepping displacement G6 – G5					
Dead Load	0	10	20	30	40	50	0	10	20	30	40	50
W/Load	0.00	0.40	1.00	0.59	1.33	1.07	0.00	1.29	2.62	1.37	2.65	2.75
200 kg	0.00	2.30	1.87	1.69	1.32	1.15	0.00	2.88	2.00	1.80	1.79	3.37
490 kg	0.00	1.29	1.73	2.76	1.21	1.64	0.00	1.53	3.21	4.12	2.10	3.37

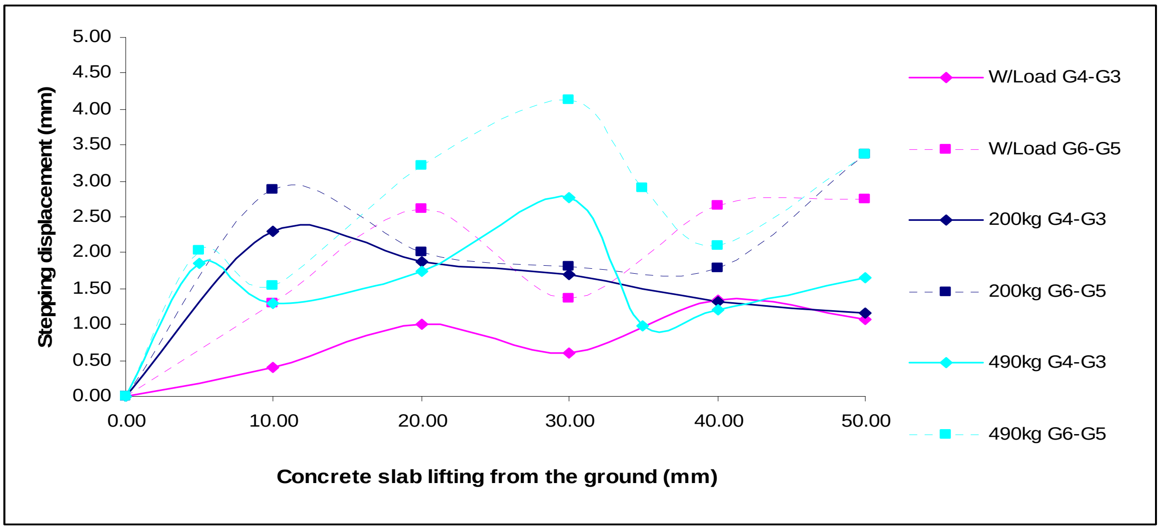

Fig 7 EPDM Rubber Joiner testing results

4.2.3 PVC joiner

Similar test work was carried out on the PVC Joiner. The results of the testing are shown in Table 4 and Fig 8. We can see that the added load would increase the stepping displacement level in PVC joint 3. The trend of the curve as shown in Fig 8 was very similar to that of the Aluminium Joiner. The average stepping displacement with no additional load varied from 0.13 mm to 0.73 mm, while 200 kg load on slab 3 varied from 0.47 mm to 0.98 mm and 400 kg load on slab 3 varied from 0.91 mm to 2.03 mm.

Note that in this test, the maximum stepping displacement was 2.03 mm which is the lowest when compared to 2.91 mm and 3.37 mm of the aluminium and the EPDM rubber joiners. Therefore, the PVC joiner was shown to offer the best load transfer between slabs which reduce the stepping displacement or vertical movement.

Table 4 : PVC Joiner testing results

	Stepping displacement G4 – G3				Stepping displacement G6 – G5			
Dead Load	0	10	30	50	0	10	30	50
W/Load	0.00	0.25	0.68	0.73	0.00	0.13	0.34	0.44
200 kg	0.00	0.55	0.76	0.84	0.00	0.47	0.62	0.98
490 kg	0.00	0.91	1.20	1.82	0.00	1.42	1.80	2.03

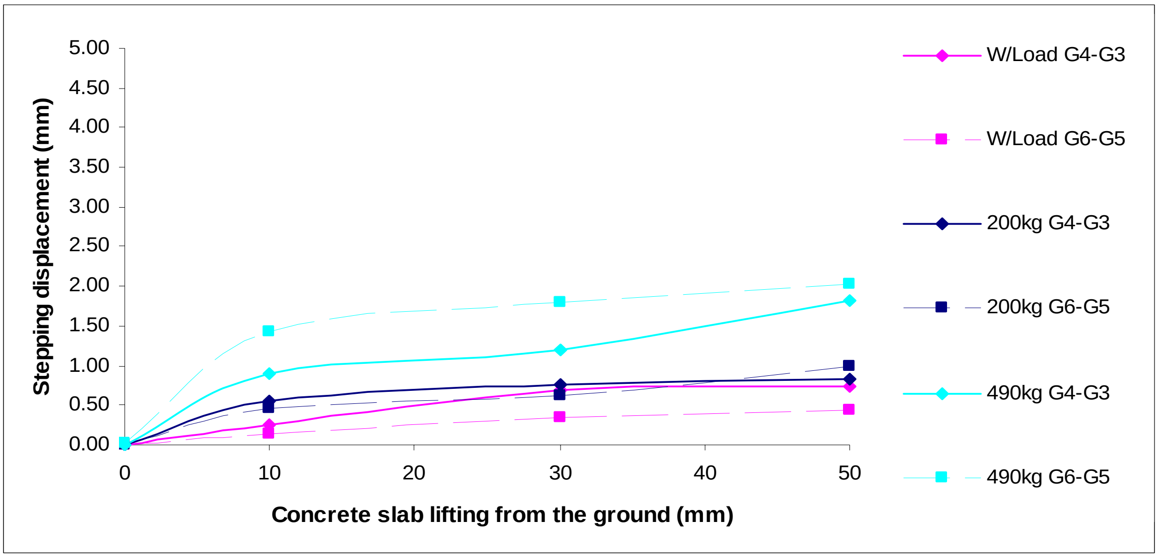

Fig 8 PVC Joiner testing results

5. CONCLUSIONS

This study shows that the proposed joiners are effective in significantly reducing stepping displacements between adjoining slabs in concrete footpaths. From the results obtained from the experiments and tests on the three types of joiners, the maximum stepping displacement was observed to be 2.91 mm for the aluminium joiner, 3.37 for the EPDM rubber joiner and 2.03 mm for the PVC joiner which was less than allowable stepping displacement of 5 mm. Among all the tests on the joiners, the applied loading was distributed across a whole slab. In AS 3727, the specified loading of 2kN could be a concentrated load. It is recommended that the concentrated load need to be investigated. Further tests on the joiners under sustained loading over a period of time also need to be investigated.

The joiner should not be too rigid or too soft. If the joiner is too rigid it would cause high stresses between the joiner and concrete. If the joiner is too soft, the total stepping displacement (including creep) could exceed the allowable limit. Further investigations on the optimal materials and profiles for the joiners are underway.

6. REFERENCES

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7. ACKNOWLEDGEMENT

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