The Experimental Study of Precast Concrete Panel Connection System for Rigid Pavement in Indonesia

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Abstract. Since 2014, Indonesian government has made a program to accelerate infrastructure construction for all regions in Indonesia. To support the program, however, highway constructions using the existing technologies (flexible or conventional rigid pavement) often fails to reach their design service lives. For rigid pavement system using precast concrete panels, the early damage of their connections is the main problem leading to shorter pavement service lives. The condition has stimulated the development new pavement system using combination of continuously reinforced concrete pavement and precast prestressed concrete pavement technology. This study focuses on connection system used to connect pavement panels. The proposed connection system used dowel and called dowel activator. The connection system was designed three actions of axial tensile force, shear force and bending moment. Experimental program was developed to measure the structural performance of connection system against three actions of internal forces. The results show the connection system has actual strength higher than theoretical strength used in the design.

INTRODUCTION

Since 2014, in an attempt to improve economic growth and distribution, Indonesian government has made a concerted effort to accelerate infrastructure development throughout Indonesia. This results in many constructions of new roads or highways that normally cause traffic disruption and congestion. In addition, many pavements constructed in Indonesia fail to reach their design service lives due to unfulfilled specified pavement construction specifications, traffic overload, suboptimum surface preparation dan poor drainage system. This condition demands new pavement technologies that are more reliable and efficient to construct to be developed and implemented in pavement construction in Indonesia.

A relatively recent innovative technology developed for highway pavement that can potentially solve the previously mentioned problems is precast concrete pavement. Precast concrete pavement offers faster construction time and better-quality control. As part of integrated development effort on highway rigid pavement technology based on precast prestressed concrete system initiated since 2015, study [1] on several precast concrete pavement systems (Prestressed Precast Concrete Pavement (PCP), Precast Concrete Pavement Panel (PCPP) and Precast Prestressed Concrete Pavement (PPCP)) implemented in Indonesia since 2007 reveals that PPCP technology demonstrates best performance. The study also conducted comparative qualitative study on the application of precast system in several highway constructions in United States in 2015 [2-5]. From the study, it is found that the main problems related to the use of precast pavement system are pavement support condition, traffic overload and connection system. To overcome these problems, new precast pavement system based on Continuously Reinforced Concrete Pavement (CRCP) and PPCP was developed from 2015 to 2017[1]. The newly developed pavement system has the re-centering capability and reliable connection system [1,6]. Detailed system development including re-centering system is discussed elsewhere [1]. This study will focus on the experimental/testing program developed to verify the structural performance of proposed connection system.

EXPERIMENTAL PROGRAM

The connection system among pavement panels uses reinforcing bars called dowel activator as shown in Fig. 1. The connection is designed as strong connection. Both end parts of dowel overlap with the main reinforcing bar inside the connecting pavement panels. The overlap part is confined with spiral steel bar to strengthen the bond between the dowel and pavement panel. This connection system is designed to fail at mid-part of dowel. As the role of dowel activator is to maintain continuity among installed pavement panels, it must be able to resist the expected internal forces (axial force, shear force and moment) generated by traffic load. The experimental program was developed to determine the structural performance of dowel connection against each of internal forces.

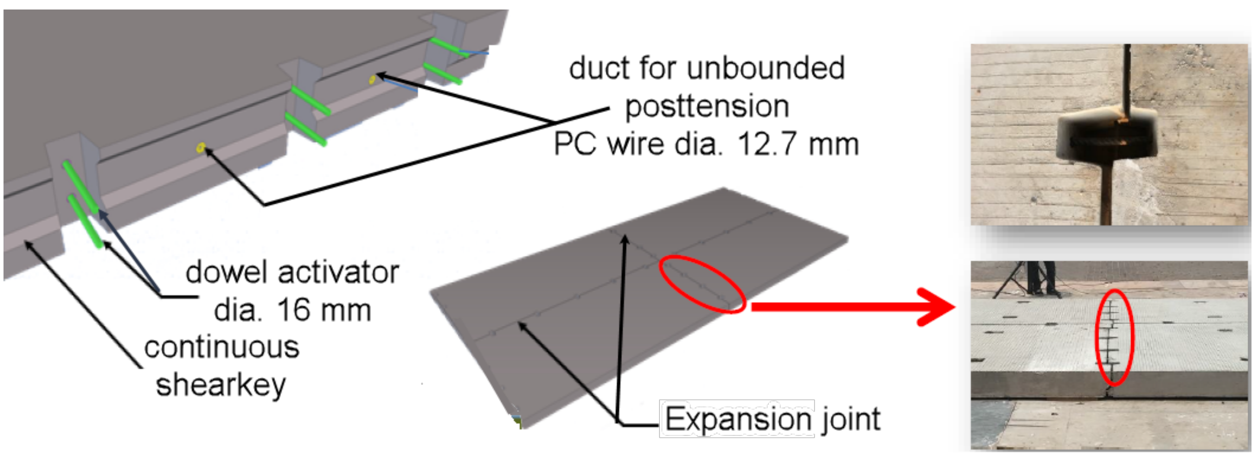


FIGURE 1. PPCP using unbonded post-tensioned technology with re-centering capability and connection system called dowel activator

Materials

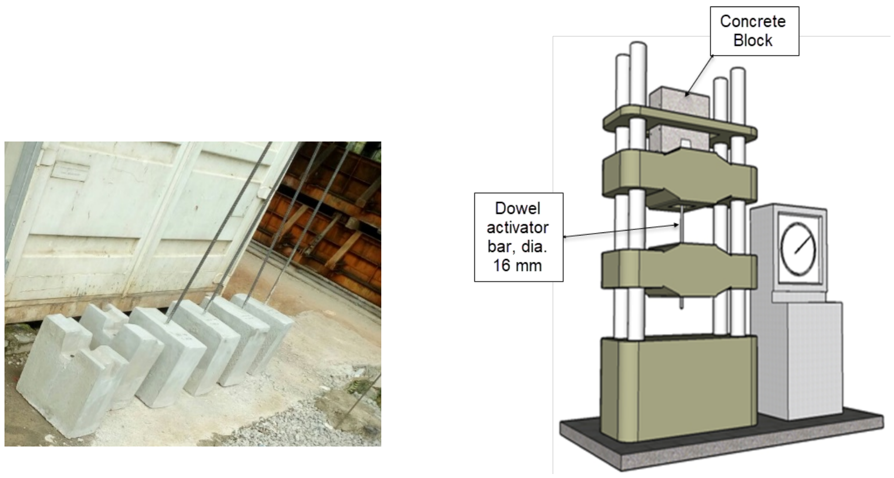
The materials used in the testing specimens are the same as those used in actual pavement panel, i.e.: 28-day concrete compressive strength of $f_c' = 41.5$ MPa and steel reinforcement and dowel bar of $f_y = 390$ MPa.

Experiment

As mentioned before, under traffic load, the connection mainly undergoes internal forces in the forms of moment, shear force as well as tensile force. To develop a reliable connection of precast and prestressed concrete pavement, it is necessary to develop an experimental program that addresses the internal forces. Thus, in this study three experimental tests had been programmed, i.e.: Pull-Out Dowel Activator Test; Flexural Test and Shear Test. The detail of each experimental program will be given below.

Pull-Out Dowel Activator Test

The pull-out test was conducted to determine the performance of dowel against tensile force. To simulate the actual connection system, specimens for dowel pull-out tests were prepared by embedding the dowel of diameter 16 mm into a concrete block of 400 mm x 400 mm. Two types of specimens were prepared, one with thickness of 180 mm for representing the precast panel thickness of 180 mm (SpRigWP_180) and the other with thickness of 200 mm for precast panel thickness of 200 mm (SpRigWP_200). There is a rebar with diameter of 16 mm inside the block that represents longitudinal rebar and overlap the dowel bar. The overlap part between longitudinal rebar and dowel bar was confined with spiral rebar of diameter 6 mm. The specimens for pull-out dowel activator test is shown in Fig. 2(a) and the setup configuration for pull-out dowel activator test is shown in Fig. 2(b). The testing was designed and carried out according to ASTM E8M-13 [7].

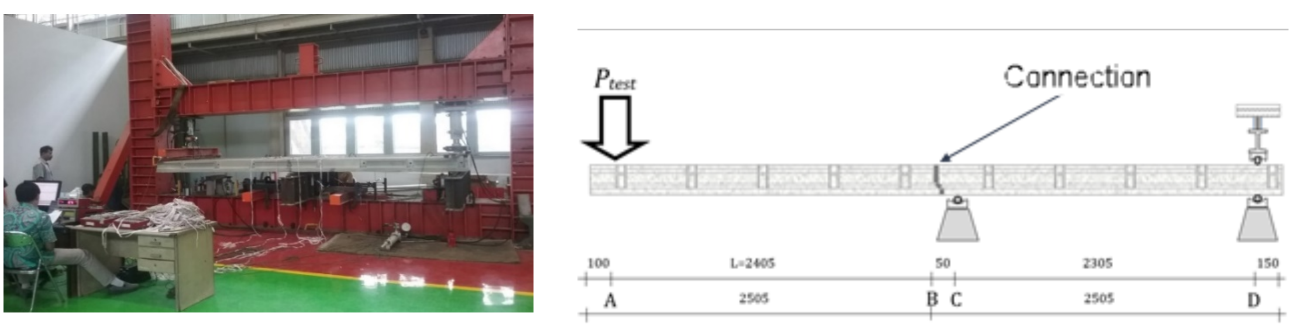


(a) (b)

FIGURE 2. (a) Specimens pull-out test of dowel activator and (b) Setup configuration for pull-out dowel activator test

Flexural Test

The purpose of flexural testing on two precast concrete panel connected with dowel activator is find out the performance of connection system under flexural load. The setup configuration of flexural test is shown in Fig. 3. The testing load, P_{test}, will be applied and increased incrementally until the connection fails near the mid-support where the maximum moment taken place. Two types of specimens were prepared for the test, one with precast panel thickness of 180 mm (SpRigWP_180) and the other with thickness of 200 mm (SpRigWP_200). The dimension of specimen is of 5010 mm in length by 1800 mm in width. The testing was designed and carried out according to ASTM C78M-13 [8].

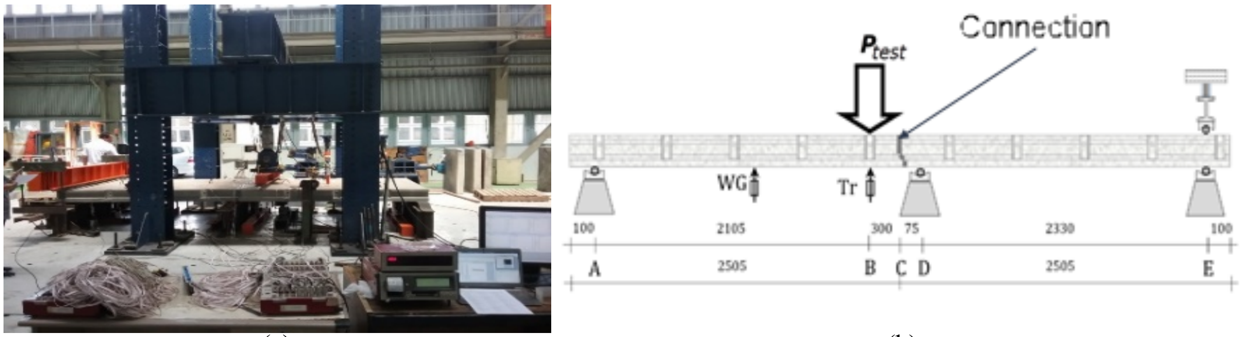


(a) (b)

FIGURE 3. Flexure test: (a) picture of specimen test setup and (b) configuration of specimen test setup

Shear Test

Shear test was carried out on specimen that consists of two panel connected in the middle and supported by three (3) supports as shown in Fig. 4 below. This test is conducted to determine the shear performance of the connection by applying the vertical load to test specimen until failure load. Two types of specimens were prepared, one with the thickness of 180 mm (SpRigWP_180) and the other with thickness of 200 mm (SpRigWP_200). The dimension of specimen is of 5010 mm in length by 1800 mm in width. The testing was designed and carried out based on ASTM C293M-13 [9].



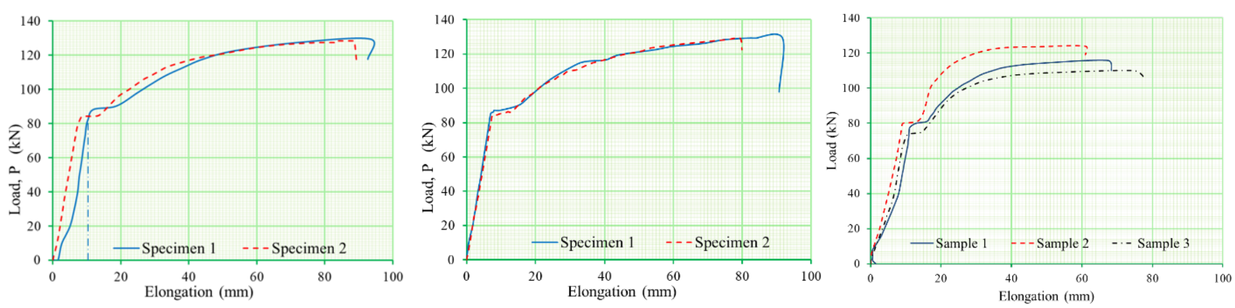
(a) (b)

FIGURE 4. Shear test: (a) picture of specimen test setup and (b) configuration of specimen test setup

RESULTS AND DISCUSSIONS

Results of Pull-Out Dowel Activator Test

Figures 5(a) and 5(b) show the relationship between load and elongation for specimens SpRigWP_180 and SpRigWP_200, respectively. The results show that the tensile test behavior of dowel is similar to that of steel reinforcing bar test shown in Figure 5(c). This shows that dowel anchorage system is able to mobilize the strength of dowel steel bar. Since the design of precast concrete panel is based on strength of steel reinforcing bar, it means that the connection system is safe against tensile force generated from the design traffic load.



(a) (b) (c)

FIGURE 5. Graphs of load vs. elongations (a) and (b) from pull-out dowel test for specimens SpRigWP_180 and SpRigWP_200, respectively, and (c) from tensile test steel bar diameter 16 mm

Results of Flexural Test

The flexural test results are presented in Table 1 for specimens SpRigWP_180 and SpRigWP_200. From the values of testing loads, one can derive the actual nominal moment capacity at the connection ($P_{test}{\cdot}L$, where P_{test} is the testing load and L is the lever Arm shown in Figure 3). The actual nominal moment capacity of tested specimens at yield condition are M_{test_180} = 18.624 kN·2.405 m = 44.79 kN·m and M_{test_200} = 19.214 kN·2.405 m = 46.21 kN·m for specimens SpRigWP_180 and SpRigWP_200, respectively. Theoretical nominal moment capacity for specimen can be determined from the section compatibility and the results of nominal moments capacity of specimens SpRigWP_180 and SpRigWP_200 are of M_{n_180} = 30.82 kN·m and M_{n_200} = 37.18 kN·m, respectively. Comparing nominal moment strength from experimental work and theoretical calculation shows that the moments from experimental work are higher than those of theoretical calculations (M_{test_180} = 44.79 kN·m > M_{n_180} = 30.82 kN·m and M_{test_200} = 46.21 kN·m > M_{n_200} = 37.18 kN·m). The results show that the actual nominal flexural strength of connection system of specimens is higher than the theoretical nominal flexural strength of specimens. Since the panel was designed based on theoretical capacity, it means that the connection is safe against maximum internal moment generated from design traffic load.

TABLE 1. Flexural Test Results

No.	Specimen Condition	SpRigWP_180 Load, P (kN)	SpRigWP_180 Deflection (mm)	SpRigWP_180 Strain (x 10^{-6})	SpRigWP_200 Load, P (kN)	SpRigWP_200 Deflection (mm)	SpRigWP_200 Strain (x 10^{-6})
1	Self-weight	9.716	0.80	13	10.796	7.09	738
2	Initial Crack	12.460	2.15	69	11.560	7.74	815
3	Yield	18.624	15.87	1958	19.214	17.47	1882
4	Ultimate	23.475	227.56	13092	27.681	156.17	21559
5	Failure	19.428	320.95	*)	21.752	396.85	*)

*) no data

Results of Shear Test

Table 2 shows a summary of shear test results from specimens SpRigWP_180 and SpRigWP_200. The ultimate testing load, $\boldsymbol{P}_{test}$, for specimens SpRigWP_180 and SpRigWP_200 are of 382.96 kN and 415.52 kN, respectively. Using the approximation, actual shear strength from test results, $V_{\text{n\_test}}$, can be estimated using expression of $V_{\text{n\_test}} = 0.91\boldsymbol{P}_{\text{test}}$. Thus, the actual shear strength of specimens SpRigWP_180 and SpRigWP_200 are of 348.49 kN and 378.12 kN, respectively. Meanwhile, theoretical nominal shear force capacity of specimens SpRigWP_180 and SpRigWP_200 are then of 286.9 kN and 328.4 kN, respectively. It can be seen that for both types of specimens the actual nominal shear capacity from test results are higher than those of from theoretical calculations. Since the precast concrete panel is designed based on theoretical shear strength capacity, it means that the dowel connection system is safe against internal shear force generated from design traffic load.

TABLE 2. Shear Test Results

No.	Condition	SpRigWP_180 Load, P (kN)	SpRigWP_180 Deflection (mm)	SpRigWP_180 Strain (x 10^{-6})	SpRigWP_200 Load, P (kN)	SpRigWP_200 Deflection (mm)	SpRigWP_200 Strain (x 10^{-6})
1.	Initial Crack	172,48	2,19	121	76,44	1,39	111
2.	Yield	309,63	4,41	1977	398,96	7,89	1977
3.	Ultimate	382,20	9,29	2184	415,52	8,59	3626
4.	Failure	301,84	20,29	14615	370,44	14,49	19633
5.	Failure	157,78	33,29	*)	129,36	35,59	*)

*) no data

CONCLUSIONS

One of main concerns on using precast panels for construction of highway pavement is the early damage of connection system. This study proposed the connection system called dowel activator and classified as strong connection. The experimental program for testing the connection system that includes dowel pull-out test, flexural test and shear test were conducted. Overall, from test results, the connection system shows a good performance against internal forces that include tensile force, shear force and moment. The term of good performance means that the actual strength capacity of connection system against each of internal forces is higher than that of the theoretical strength capacity. The connection system should be able to maintain continuity and to distribute traffic load among connected precast concrete pavement panels.

The newly developed CRCP system constructed from PPCP panels with connection system discussed here is expected to be an alternative for the performance improvement of highway construction and maintenance in Indonesia. Highway construction using precast concrete pavement panels is more efficient compared with the conventional highway construction method. In addition, with a reliable connection, the newly developed CRCP system offers durable highway pavement system.

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REFERENCES

1. H. N. Nurjaman, L. Faizal, N. Suaryana, B. Hariandja, Gambiro, Purnomo, and S. Wicaksono, "Design, development, and application of precast and prestressed concrete system for rigid pavement in Indonesia," In *Proceedings of the 3rd International Conference on Construction and Building Engineering* (ICONBUILD), (2017).
2. B. Choubane, (private communication, 2015).
3. S.L. Gillen (private communication, 2015).
4. S.S. Tyson (private communication, 2015).
5. T.E. Nantung (private communication, 2015).
6. H. N. Nurjaman, L. Faizal, H.R. Sidjabat, B. Hariandja, R. Rivky, and Y. Put, Elsevier. Procedia Eng. J. 95, 82–86 (2014).
7. ASTM C78M-13, Standard test method for flexural strength of concrete (using simple beam with third-point loading), West Conshohocken (PA), 2013.
8. ASTM E8M-13, Standard Test Methods for Tension Testing of Metallic Materials, West Conshohocken (PA), 2013.
9. ASTM C293M-13, Standard test method for flexural strength of concrete (using simple beam with center-point loading), West Conshohocken (PA), 2013.