Development Precast and Prestressed Concrete Rigid Pavement System in Indonesia

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Abstract. Roadway pavements are important parts of transportation system and thus should be adequately strong and durable. Unfortunately, many pavements constructed in Indonesia fail to reach their design service life. Among major factors contributed to early damages to the pavements in Indonesia are unfulfilled specified pavement construction specifications, traffic overload and poor support condition. As an attempt to produce better pavement system and as part of an accelerated infrastructure program in Indonesia, new precast pavement system using unbonded posttensioned technology that has characteristic of self-centering has recently been developed. This self-centering concrete pavement is expected to reduce the impact of overload and be able to overcome imperfect subbase, subgrade and poor soil condition. The theoretical and experimental development programs of the new concrete rigid pavement system will be described in this paper. The developed pavement system is then implemented to see the effectiveness construction procedures and later on tested using Falling Weight Deflectometer (FWD) method to evaluate its structural performance.

1. Introduction

Since 2014, Indonesian government has conducted acceleration of infrastructure construction for all regions in Indonesia. Roadway or highway is essential part of infrastructure because it is responsible for transportation connectivity in supporting efficient economic activity. As such roadway pavements should be adequately strong and durable for their design service life. Early damages to pavements may cause traffic disruption and thus lead to negative user experiences and economic impact. Unfortunately, many pavements constructed in Indonesia fail to reach their design service life. Among major factors contributed to early damages to the pavements in Indonesia are unfulfilled specified pavement construction specifications dan traffic overload.

Traditional Highway Construction often faces difficulties such as supporting preparation work which is not optimum, shortage in asphalt delivery in flexible pavement case, highway obstructions...
in case of conventional rigid pavement (jointed plain concrete pavement, JPCP, shown in figure 1), thus inability to meet quality specification in case of rigid pavement. In addition, the drainage system often time is addressed properly. This condition demands new pavement technology to be developed and implemented in pavement construction in Indonesia.

Figure 1. Conventional rigid pavement (JPCP)

A relatively recent innovative technology developed for highway pavement is precast concrete pavement. Since the precast concrete pavement system normally fabricated under controlled environment, it offers several potential advantages over traditional highway pavement system such as shorter construction time, higher quality (need less maintenance) and efficient use of materials. There have been several applications of precast concrete pavement system in Indonesia. It started with the use of Prestressed Precast Concrete Pavement (PCP) technology in a section of Cakung-Cilincing highway, Jakarta in 2007 (figure 2). It was then followed by the use of Precast Concrete Pavement Panel (PCPP) system in Suryacipta Industrial Estate (2013, figure 3) and Precast Prestressed Concrete Pavement (PPCP) in Kanci-Pejagan Toll Highway (2011, figure 4).

Figure 2. PCP in Cakung-Cilincing Highway 2007

Figure 3. PCPP in Suryacipta industrial estate, 2013
Study on various application of precast concrete pavement systems in construction condition Indonesia [8] reveals that Prestressed Precast Concrete Pavement technology demonstrates best performance. It is part of integrated development effort on highway rigid pavement technology based on precast prestressed concrete system initiated since 2015, by performing qualitative and quantitative research. Qualitative research was carried out on qualitative performance on the application of precast system in several highway constructions from 2010 to 2015, and in comparative study in United States in 2015. Quantitative research was carried out on performance of application of precast system in highway construction from 2010 to 2015, and in development experimental program from 2015 to 2017. This study will focus on the experimental/testing program developed to produce a precast pavement system that is durable and economics.

2. Program Development

2.1. System Development

The idea behind the system development of pavement is the re-centering capability of unbonded post-tensioned prestressing in resisting earthquake forces in buildings [7]. The use of re-centering capability in highway pavement would allow any imperfection in sub-base and sub-grade as well as overload condition [10]. This technology has been applied in several internal roads in precast plant (2015-2016) as seen in Figure 5. Design process of the system with finite element method which considered overload condition in standard subgrade specification and undersubgrade specification data can be seen on work conducted by Nurjaman et. al. [8].

![Figure 4. PPCP Kanci-Pejagan Tollway 2011](image)

**Figure 4.** PPCP Kanci-Pejagan Tollway 2011

![Figure 5. PCP unbonded post-tensioned technology with re-centering capability. Precast module is 12000x1800x180 and 12000x3600x180 with concrete quality fc’ = 41.5 MPa](image)

**Figure 5.** PCP unbonded post-tensioned technology with re-centering capability. Precast module is 12000x1800x180 and 12000x3600x180 with concrete quality fc’ = 41.5 MPa
2.2. Experimental Program
Under the loading the critical part of a rigid concrete pavement system is at the connection system. The connection mainly undergoes internal flexural bending moment, shear forces as well as tensile force action. To develop a reliable precast and prestressed concrete system for rigid pavement, it is necessary to develop an experimental program that addresses those actions. Thus, in this study three (3) experimental tests had been programmed, i.e.: (1) Pull-Out Dowel Activator Test; (2) Flexural Test and (3) Shear Test. Details of testing specimens and procedures will be given below.

2.2.1. Pull-Out Dowel Activator Test. The connection system between precast panels uses reinforcing bars called dowel activator. As the role of dowel activator is to connect between two precast pavement panel, it must be able to distribute forces due to traffic load. The ability of dowel to distribute forces is determined by conducting pull-out test. Specimens for dowel pull-out tests were prepared by embedding the dowel of diameter 16 mm into a concrete block to simulate the actual connection system. Two types of specimens were prepared, one for representing the precast panel thickness of 180 mm (SpRigWP_180) and the other for precast panel thickness of 200 mm (SpRigWP_200). The preparation and final form of specimens for pull-out dowel activator test is shown in figure 6.

![Figure 6. Preparation and final form of specimens for pull-out test on dowel activator](image)

The setup configuration for pull-out dowel activator test is shown in figure 7. Testing is carried out according to standard tensile test for reinforcing bar.
2.2.2. 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 Figure 8. The testing load will be applied and increased incrementally until the connection fails near the support where the maximum moment taken place. Two (2) 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).
2.2.3. Shear Test. The 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 Figure 9 below. This test is conducted to determine the shear capacity of the connection by applying the vertical load on 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 5100 mm in length by 1800 mm in width.

![Figure 9](image)

**Figure 9.** Picture and configuration for shear test specimen

2.3. Implementation and FWD Testing Program

As part of development program, the newly developed precast prestressed concrete pavement system was installed on segment of Margomulyo road (managed by Directorate of General Highway) in Gresik to evaluate execution aspect especially the effect of construction on traffic, and structural performance of the system in the actual condition. The road was selected because it is frequently suffered damage due to heavy traffic and heavy vehicles. The length of road segment is 48 m and the width is 23.4 m as shown in figure 10. The construction new pavement system was conducted in the month of December 2018. Structural testing was conducted using FWD method by Institute of Research and Development Road and Bridge, Ministry of Public Work and Housing, Bandung, Indonesia, 5 months after installation (May 2019). The locations of points in which FWD tests taken are shown in figure 10.

![Figure 10](image)

**Figure 10.** Road segment used for implementation of SpRigWP pavement and point locations for FWD test
3. Results and Discussions

3.1. Results of Pull-Out Dowel Activator Test

Figure 11 (a) and (b) show the relationship between load and elongation for specimens SpRigWP_180 and SpRigWP_200, respectively. The results show that the tensile behavior of dowel is similar to that of steel bar shown in figure 12. It shows that dowel anchorage system is able to mobilize the strength of dowel steel bar.

![Graph of load vs elongation from pull-out dowel test](image)

Figure 11. Graph of load vs elongation from pull-out dowel test

3.2. Results of Flexural Test

The flexural test results are presented in tables 1 and 2 for specimens SpRigWP_180 and SpRigWP_200, respectively. From the values of testing loads, one can derive the moment at the connection (Ptest·L, where Ptest is the testing load and L is the lever Arm shown in Figure 8). The moment capacity of tested specimens at yield condition are Mtest_180 = 18.624 kN·2.405 m = 44.79 kN·m and Mtest_200 = 19.214 kN·2.405 m = 46.21 kN·m for specimens SpRigWP_180 and SpRigWP_200, respectively. Theoretical nominal moment for specimen can be determined from the section compatibility and the results of nominal moments of specimens SpRigWP_180 and SpRigWP_200 are of Mn_180 = 30.82 kN·m and Mn_200 = 37.18 kN·m, respectively. Comparing moment strength from experimental work and theoretical calculation shows that the values of moments from experimental work are higher than those of theoretical calculations (Mtest_180 = 44.79 kN·m > Mn_180 = 30.82 kN·m and Mtest_200 = 46.21 kN·m > Mn_200 = 37.18 kN·m). The results indicate that the specimens perform satisfactorily against flexural tests.
Design of reinforced concrete against bending moment requires that the moment capacity, $\phi M_n$, is larger than or equal to ultimate moment, $M_u$ ($\phi M_n \geq M_u$), where $\phi$ is a strength-reduction factor, taken 0.9 for flexural moment, $M_n$ is nominal moment strength. The moment capacity of specimens SpRigWP_180 and SpRigWP_200 are of 0.9·30.82 kN·m = 27.73 kN·m and 0.9·37.18 kN·m = 33.46 kN·m, respectively. The internal ultimate moment $M_u$ resulting from the finite element analysis conducted on the specimens SpRigWP_180 and SpRigWP_200 under expected traffic load are of 5.76 kN·m for both of them. One can see that the specimens are safe against flexural moment (27.73 kN·m > 5.76 kN·m).

### Table 1. Flexural Test Results of Specimen SpRigWP_180

| No. | Specimen Condition | Load (P, kN) | Deflection (mm) | Strain ($x 10^{-6}$) |
|-----|--------------------|-------------|----------------|---------------------|
| 1.  | Self-weight        | 9.716       | 0.80           | 13                  |
| 2.  | Initial Crack      | 12.460      | 2.15           | 69                  |
| 3.  | Yield              | 18.624      | 15.87          | 1958                |
| 4.  | Ultimate           | 23.475      | 227.56         | 13092               |
| 5.  | Failure            | 19.428      | 320.95         | No data             |

### Table 2. Flexural Test Results of Specimen SpRigWP_200

| No. | Specimen Condition | Load (P, kN) | Deflection (mm) | Strain ($x 10^{-6}$) |
|-----|--------------------|-------------|----------------|---------------------|
| 1.  | Selfweight         | 10.796      | 7.09           | 738                 |
| 2.  | Initial Crack      | 11.56       | 7.74           | 815                 |
| 3.  | Yield              | 19.214      | 17.47          | 1882                |
| 4.  | Ultimate           | 27.681      | 156.17         | 21559               |
| 5.  | Failure            | 21.752      | 396.85         | No data             |

#### 3.3. Results of Shear Test

Tables 3 and 4 show a summary of shear test results from specimens SpRigWP_180 and SpRigWP_200, respectively. The ultimate testing load, $P_{test}$, for specimens SpRigWP_180 and SpRigWP_200 are of 382.96 kN and 415.52 kN, respectively. Using the approximation, nominal shear strength from test results, $V_{n\_test}$, can be estimated using expression of $V_{n\_test} = 0.91P_{test}$. Thus, the nominal 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 the concrete specimen can be determined using equation of $V_n = 0.17\lambda f_c b_w d$. The theoretical nominal shear strength 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 specimens the nominal shear strength from test results are higher than those of from theoretical calculations. It can be concluded that the specimens perform satisfactorily against shear. Design of reinforced concrete against shear force requires that the shear capacity, $\phi V_n$, is larger than or equal to ultimate shear force, $V_u$ ($\phi V_n \geq V_u$), where $\phi$ is a strength-reduction factor, taken 0.75 for shear, $V_n$ is nominal shear strength. The shear capacity of specimens SpRigWP_180 and SpRigWP_200 are of 0.75·286.9 kN = 215.2 kN and 0.75·328.4 kN = 246.3 kN, respectively. The internal moment shear force $V_u$ resulting from the finite element analysis conducted on the specimens SpRigWP_180 and SpRigWP_200 under expected traffic load are of 80.54 kN for both of them. One can see that the specimens are safe against shear (215.2 kN > 144.97 kN).
Table 3. Shear Performance of Specimen SpRigWP_180

| No. | Condition     | Load (P, kN) | Deflection (mm) | Strain (10^-6) |
|-----|---------------|--------------|----------------|---------------|
| 1   | Initial Crack | 172,48       | 2,19           | 121           |
| 2   | Yield         | 209,63       | 4,41           | 1977          |
| 3   | Ultimate      | 382,20       | 9,29           | 2184          |
| 4   | Failure       | 301,84       | 20,29          | 14615         |
| 5   | Failure       | 157,78       | 33,29          | No Data       |

Table 4. Shear Performance of Specimen SpRigWP_200

| No. | Condition     | Load (P, kN) | Deflection (mm) | Strain (10^-6) |
|-----|---------------|--------------|----------------|---------------|
| 1   | Initial Crack | 76,44        | 1,39           | 111           |
| 2   | Yield         | 398,96       | 7,89           | 1977          |
| 3   | Ultimate      | 415,52       | 8,59           | 3626          |
| 4   | Failure       | 370,44       | 14,49          | 19633         |
| 5   | Failure       | 129,36       | 35,59          | No Data       |

3.4. Results of Implementation and FWD Testing

From impulses of FWD test conducted on the pavement are in the range of 50 – 150, which correspond to the deflection of 0.05 mm - 0.15 mm, respectively. According to circular number 15/SE/M/2015 about guide for implementation of precast prestressed concrete pavement, the allowable maximum deflection is 0.57 mm. This result shows that the developed precast prestressed concrete pavement performed extremely well.

4. Conclusions

With accelerated road infrastructure construction in Indonesia, new technology that is efficient in construction, materials and reliable structurally needs to be developed. Precast concrete rigid pavement offers rapid and efficient construction procedure, higher quality and better structural performance. New pavement system was developed based on precast and prestressed technologies that have re-centering capability.

Precast and/or prestressed components have been employed for rigid pavement in Indonesia since 2007 but the results are not always optimum since the design and construction were not integratedly carried out. As part integrated development effort on highway construction based on industrial manufacture that has been initiated since 2015, theoretical, experimental program that include dowel pull-out test, flexural test and shear test were conducted. To see the performance of newly developed pavement system in real world application, implementation was conducted and later on the constructe pavement was tested structurally using FWD method. Overall, the test results show satisfactory performance.

The developed pavement system offers an attractive alternative for the performance improvement of highway construction and maintenance in Indonesia. The improved performance will lead to better experiences for users. Reliable transportation system will enhance economic activities and contribute to sustainable development in which nowadays considered as a part of global movement to save the world from climate change.

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