Design, development, and application of precast and prestressed concrete system for rigid pavement in Indonesia

Hari Nurjaman, Lutfi Faizal, Nyoman Suaryana, Binsar Hariandja, Gambiro, Purnomo, and Siswo Wicaksono

Citation: AIP Conference Proceedings **1903**, 030003 (2017);
View online: https://doi.org/10.1063/1.5011510
View Table of Contents: http://aip.scitation.org/toc/apc/1903/1
Published by the American Institute of Physics

Design, Development, and Application of Precast and Prestressed Concrete System for Rigid Pavement in Indonesia

Hari Nurjaman[1,a)] and Lutfi Faizal[2,b)], Nyoman Suaryana[3,c)], Binsar Hariandja[4,d)], Gambiro[5,e)], Purnomo[6,f)], Siswo Wicaksono[7,g)]

[1]*Civil Engineering Department, Faculty of Engineering, Persada Indonesia University, Jakarta, Indonesia*
[2] *Institute of Housing and Settlement, Ministry of Public Work and Housing, Bandung, Indonesia*
[3]*Institute of Road Engineering, Ministry of Public Work and Housing, Bandung, Indonesia*
[4]*Professor of Civil Engineering, Bandung Institute of Technology, Bandung, Indonesia.*
[5]*Wijaya Karya Beton Ltd, Jakarta, Indonesia*
[6]*Waskita Beton Precast Ltd, Jakarta, Indonesia.*
[7]*Saeti Concretindo Wahana Ltd, Jakarta, Indonesia*

[a)]Corresponding author: iappi_ind@yahoo.com
[b)]faizblue_21@yahoo.com
[c)]nyomansuaryana@yahoo.com
[d)]binsar_hariandja@ymail.com
[e)]gambiro_s@yahoo.com
[f)]purnomooke@yahoo.com
[g)]siswo@jhs-system.com

Abstract. The performance of highways in Indonesia until today is yet to be optimum. Flexible or rigid pavement construction generally do not reach designed service lives, either due to the fact that the construction do not meet specifications or unavoidable excessive load. Precast and prestressed concrete system has been applied since 2007, but unfortunately the application has not been optimum due to the fact that the construction method is not integrally carried out. This paper deals with a construction concept that developed in 2015-2017. The concept applies green construction based on integrated manufacture industry, starting from design, construction, function, maintenance and demolition. The concept is applied on the three highway sub-layers, i.e., sub grade, sub base, and surface, and drainage system. Sub grade improvement may use soil dislocation, chemical improvement or concrete matress. Sub base material uses foam mortar, which is material easy in quality control compared to conventional materials. Pavement material uses precast and prestressed concrete components with controlled quality, quickly function as flexible pavement, and moreover, may anticipate excessive loadings. Cost estimation is carried out integrated by life cycle cost: initial investment, obstruction while construction, and maintenance cost during operation. This innovation has passed tests in technical construction method aspects as well as construction work in 2015-2017, so it is available to support infrastructure construction acceleration which achieves quality demanded to date.

INTRODUCTION

Highway construction in Indonesia is yet to be commenced optimally. Flexible and rigid pavements generally do not attain their service life due to the failure to meet specification or due to unavoidable overload.

The paper deals with a highway construction concept developed in 2015-2017, the concept utilizes integrated manufactured industrial base, started from the design, construction, operation, maintenance and demolition.The presentation is started by introduction, followed by method, result and discussion, and is closed by conclusions.

Proceedings of the 3rd International Conference on Construction and Building Engineering (ICONBUILD) 2017
AIP Conf. Proc. 1903, 030003-1–030003-15; https://doi.org/10.1063/1.5011510
Published by AIP Publishing. 978-0-7354-1591-1/$30.00

THE METHOD

The method applied in this research is the combination of the qualitative and quantitative method. A qualitative method performed consists of the description of performance in traditional highway construction material, performance in precast and prestressed concrete component materials on the surface of highway construction in several projects in 2007-2014, and comparative study performed in USA in 2015.

Quantitative method is performed on integrated development of highway construction based on industrial manufactures. Variables included are the quality (strength, dimensions, specification,), time, and cost with life cycle cost (LCC) concept.

The hypothesis proposed is that the highway construction supported by industrial manufactured precast/prestressed concrete may produce better quality and speed compared to conventional system if the design and construction are commenced integrated. In cost aspect, this integrated construction will result in better performance if carried out in life cycle cost method.

THE RESULTS AND DISCUSSIONS

Performance of Traditional Highway Construction

The performance of traditional highway construction quality is considered to be not optimum. Service providers have difficulties in producing highway with the performance that meets specifications during service life, in addition to the inability of authorized officer to control highway loading.

Technical difficulties that often faced, among others are 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), inability to meet quality specification in case of rigid pavement. If rigid pavement deteriorates faster than its design life service, the maintenance or repair would be costly and obstruct highway users. In addition, the drainage system is not addressed properly.

Based on the results mentioned above, it is necessary to take progressive steps to improve quality of highway as a responsibility of authorized officers toward society, if the budget is retrieved from oil subsidy.

(a) (b) (c)

FIGURE 1. Conventional rigid pavement (JPCP)

Performance of Applied Precast/Prestressed Component on Highway Pavement

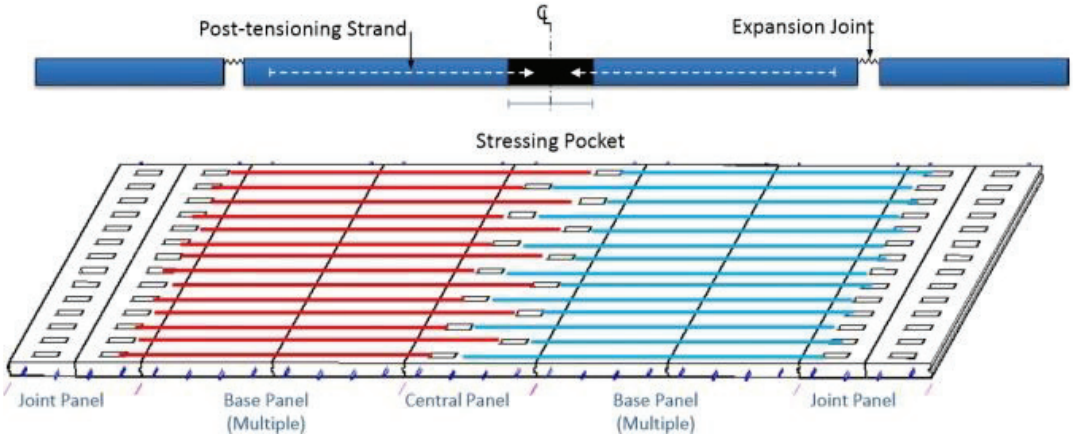
Precast/prestressed components have been applied as highway component, i.e., as pavement component since 2007 in a section of Cakung Cilincing highway, Jakarta. There are several material types that developed ever since: non prestressed precast concrete panel (PcCP), prestressed precast concrete panel (PCP) and precast concrete panel connected by prestressing (precast prestress concrete pavement/PPCP)as depicted in Fig. 2,3,4.

(a) (b) (c)

FIGURE 2. PcPP in Suryacipta industrial estate (2013)

(a) (b) (c)

FIGURE 3. PCP in Cakung-Cilincing Highway (2007)



(a)

(b) (c) (d)

FIGURE 4. PPCP Kanci-Pejagan Tollway (2011)

From observation on quality performance, several conclusions are drawn as follows. First, good performance may be attained if all highway construction components, sub-grade, sub-base pavement and drainage are constructed according to the specifications.

(a) (b) (c)

FIGURE 5. Good performance precast pavement (PCP dan PPCP)

Secondly, the use of good performance precast/ prestressed component would not be optimum if the sub-grade and/or sub-base do not meet specifications, as shown in Fig. 6.

(a) (b) (c)

FIGURE 6. Poor sub-base results in not optimum use of precast rigid pavement (PPCP) in Kanci-Pejagan Tollway (2011)

Thirdly, maintenance of pavement made of the precast component, is mainly at the connection, as seen in Fig. 7.

(a) (b) (c)

FIGURE 7. Connection of precast (PCP) needs regular maintenance in Cakung Cilincing Highway since 2007

Comparative Study in United States of America

Comparative study in United States of America was held in 2015 as a preparation for advanced development of integrated highway construction based on industrial manufacture. Parties involved as information sources were US Federal Department of Transportation, Florida Department of Transportation, and Illinois Tollway.

US Federal Department of Transportation

United States Federal Government nowadays has its policy to promote precast and prestressed concrete system for highway construction [10] based on several reasons. First, more American highways are entering their life service deadline so that maintenance costs become higher. Secondly, maintenance budget retrieved from oil tax

decreases due to the change of citizens' behavior from energy consumptive to energy saving. The consumption of non-renewable energy has been changing to the consumption of renewable energy.

Moreover, the use of precast construction has the advantage in quality and construction speed. The construction does not obstruct highway activities significantly and the high quality prolongs service life (up to 40 years) with efficient maintenance cost.

Initial investation on precast concrete system is generally 5-10% higher than the conventional system, but in recent several tender cases, the contractors tend to bid lower than the conventional system.

(a) (b)

FIGURE 8. Precast highway construction in America (a) New York-New Jersey (b) Los Angeles – Las Vegas

Federal government noted that 3 states have already popularly apply precast system, i.e., California, New York and New Jersey, as seen in Fig. 8. To support the application in other states, the federal government provides incentive as the research grant, technical guidance and technical accompaniment. Dissemination of socialization of precast highway system in USA may be seen in Fig. 9.

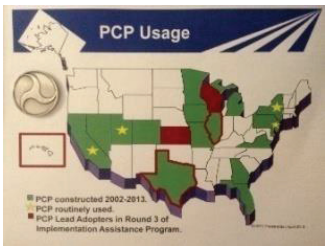
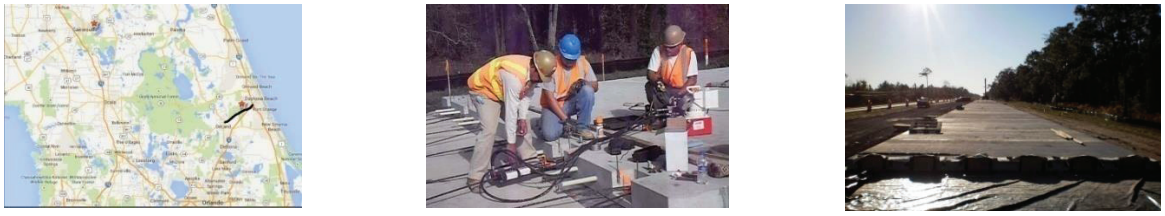


FIGURE 9. Dissemination of socialization of precast highway application in America [10]

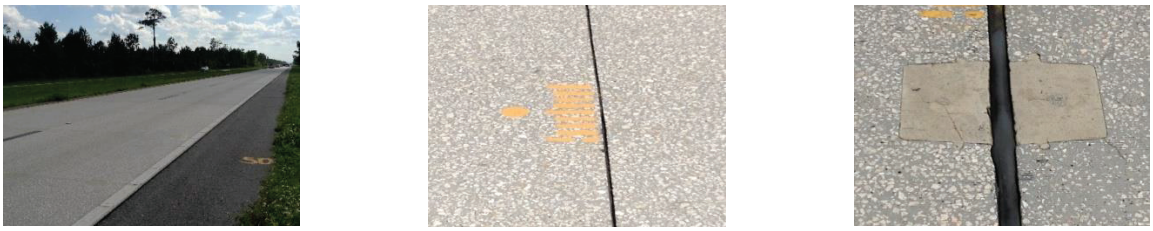
Florida Department of Transportation

Florida Department of transportation is one of the state receiver of research and development grant provided by Federal Government in 2012. The location of the highway is in Sections 600/US 92 H Volusia County, Florida. There were two types of pavement under research, i.e., Precast Prestressed Concrete Pavement (PPCP) 792 ft in length and its comparison, Jointed Plain Concrete Pavement (JPCP) 795 ft in length, shown in Fig. 10. Performance of the two types of pavement was observed within 3 years, as seen in Fig. 11.



(a) (b) (c)

FIGURE 10. PPCP trial section in Section 600/US 92 H [4]



(a) (b) (c)

FIGURE 11. Performance of observed pavement types after 3 years

Based on observation of PPCP trial section performance in 3 years, several observations are withdrawn as follows. First, quality of PPCP is good, no problem with concrete quality, good crack resistance, and good load transfer efficiency (LTE) and moderate smoothness performance.

PPCP has life service up to 40 years, with keen care on joint expansion seals which performance generally decreases faster than the concrete panel, and hence needs periodic replacement as shown in Fig.12.

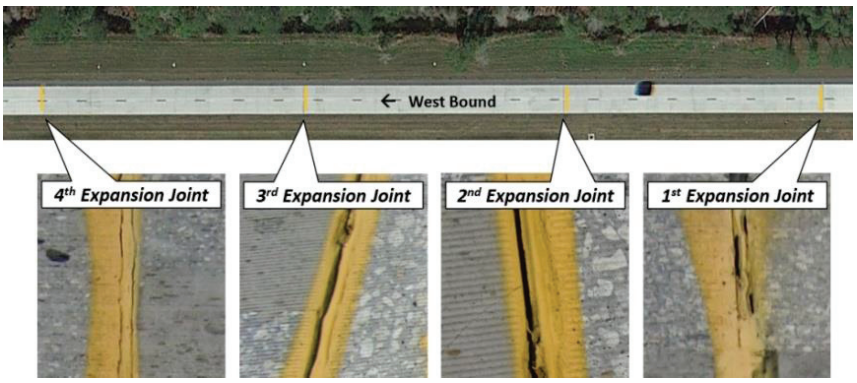


FIGURE 12. Periodic replacement of expansion joint seal [4]

PPCP is very suitable to be applied in repair work, since it needs the short time to implement so that the highway may be reopened in short time, it minimizes the closing of lanes and traffic disruption. Highway closing in America results in US$ 2000/day/lane loss.

Illinois Tollway

Illinois Tollway is the tollway system around Chicago, fully managed by private firms. To preserve the toll performance so as to serve the users well, the operator firm establish research and development division [9,12].

In selection procedure on toll materials and construction technology, the firm always apply Life Cycle Assesment (LCA). Precast CRCP is one of recommended technology since it's accordance with LCA and construction period, primarily for repair or replacement of exceeding life service sections.

(a) (b) (c) (d)

FIGURE 13. Precast CRCP in Illinois Tollway [9, 12]

Development of Integrated Highway Construction Based on Industrial Manufacture

Experience in the application of precast/prestressed components in several portions of highway construction (2007-2014) and comparative study in America (2015) provided a hypothesis that highway construction designed integratedly and based on industrial manufacture will have better performance and longer life service, which is 40 years in America nowadays. Every part of highway construction has the alternate technology needed to suit the condition, and then incorporated Life Cycle Cost (LCC) concept.

Sub-grade Technology

General specification on sub-grade layer is to have CBR 6%. If the soil is extremely poor such as turf (gambut) or organic clay, then traditional compaction may be difficult to be carried out. Several alternatives that may be applied to overcome the condition, among others are,(1) soil replacement, (2) soil improvement with chemical additives, (3) use of micro piles, and(4) the use of pile slab. Alternatives (1) dan (2) may be applied if the poor conditioned soil is not too thick. Alternatives (3) dan (4) are the solutions based on industrial manufacture and may be applied if the poor soil is thick enough. Alternative (4) is an expensive structural solution, while alternative (3) is a geotechnical solution with optimum technical performance and cost effective.

On concrete pile slab with micro piles, the length of micro piles may be designed to meet settlement specification, while concrete mattress acts as load distributor from sub-base to micro piles. This kind of system was firstly applied and tested in Ancol Bridge (1999), and nowadays oftenly applied in highway construction improvement and soft soil embankment in Kalimantan and South Sumatera (2015-2016) as shown in Fig.14.

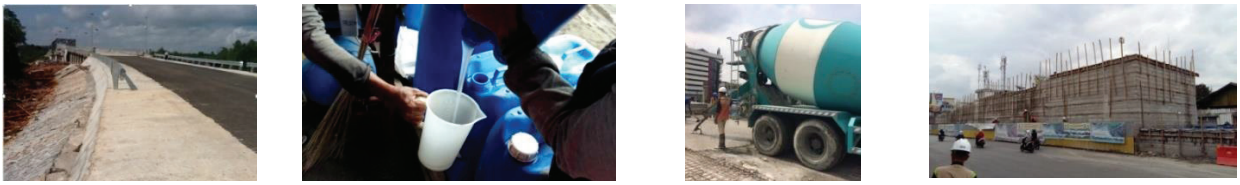
(a) (b) (c)

FIGURE 14. Concrete mattress with micro piles for sub-base improvement

Sub-base Technology

Sub-base layer is a layer to distribute stressess from pavement to sub-grade. Traditionally the material used is compacted aggregate. In construction, this layer is oftenly difficult to implement according to the specification, resulting in shorter life service.

Alternate industrial manufactured based material is mortar foam, a mixture of foam with mortar [3] that produces material with the strength equal to sub-base material strength, but with specific weight lower than water specific weight. The main advantage of using this alternative is assured quality, since it uses industrial ready mix to provide mortar, and the mixture of foam with designed dosage is carried out at casting time. This alternative has been applied in several highways in Sumatera, Kalimantan, and most recently in Antapani Bandung Fly Over (2016), as shown in Fig. 14.



(a) (b) (c) (d)

FIGURE 15. Mortar foam for sub-base dan embankment

Research, development and thorough testing on technology and material used in several precast technology discussed in Section 3.2, have been performed. Monitoring of the application of precast/ prestressed technology was carried out by *Institute of Road Engineering*and*Ditjen Bina Marga* (2010-2015), while research and development technology of unbonded post-tensioned precast system was carried out by *Institute of Housing and Settlement* and *Institute of Road Engineering* (2015-2017).

Monitoring 2010-2015 [11] was carried out at several highway sections with different pavement materials: M1 (PcPP), M4 and M5 (PPCP), M6a (JPCP), and M6b PCP. Several important results that obtained, among others: as follows.

According to crack-ratio analysis, critical condition (30 cm/m^2) JPCP, PcPP,PPCP and PCP, each was achieved around 2022,2017,2016, and 2031, as seen in Fig. 16.

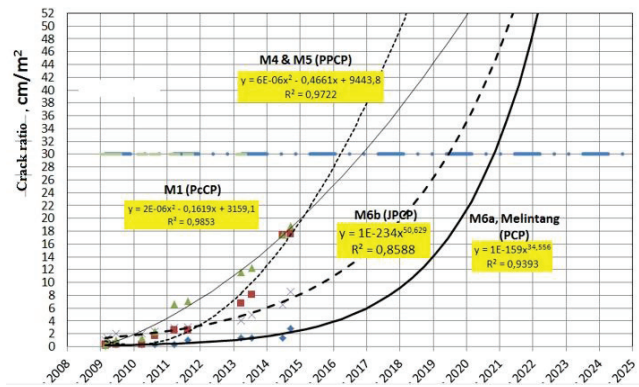


FIGURE 16. Observation on crack ratio - critical condition [11]

Based on highway load, critical condition of each type: JPCP (55 mill. ESA), PcCP (17 mill. ESA), PPCP (20 mill. ESA), and PCP (80 mill. ESA), as shown in Fig.17.

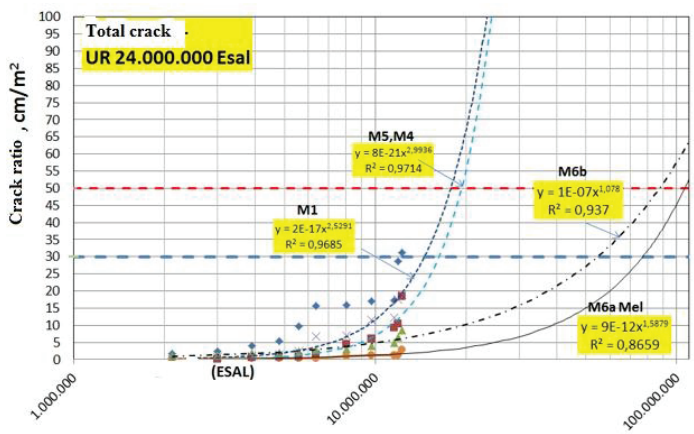


FIGURE 17. Observation on crack ratio – ESAL [11]

Based on structural strength analysis with deflection data, failure condition in JPCP, PcCP, PPCP and PCP each was atained at 2033 (32.4 mill. ESA), 2029 (30.1 mill. ESA), 2078 (62 mill. ESA), and 2041 (51.6 mill. ESA), as depicted in Fig. 18.

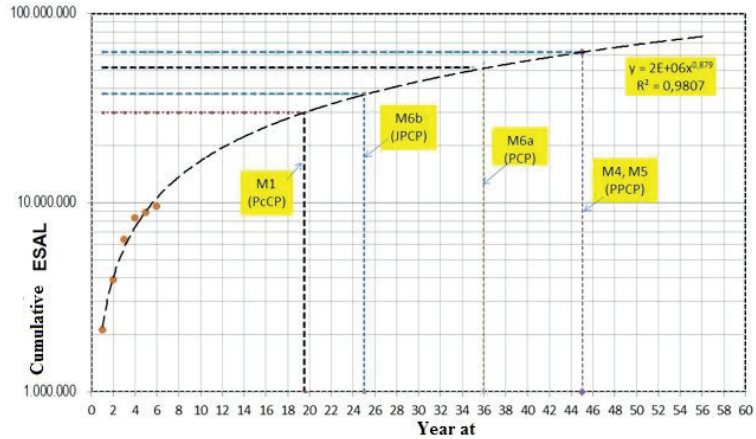


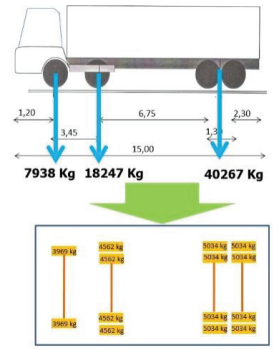
FIGURE 18. Designed life service – ESAL [11]

Based on monitoring results, PCP technology demonstrates best performance in construction condition in Indonesia. Continuing development carried out was the application of unbonded post-tensioned prestress on PCP panel. This technology is inspired from the re-centering capacity of unbonded post-tensioned prestressing in resisting earthquake forces in buildings [15]. Re-centering capacity in highway construction would anticipate imperfection in sub-base and sub-grade as well as overload condition [7]. This technology has been applied in several internal roads in precast plant (2015-2016) as seen in Fig. 17. Design process of the system with finite element method which considered overload in standar subgrade specification and undersubgrade specification data can be seen in Fig 19.

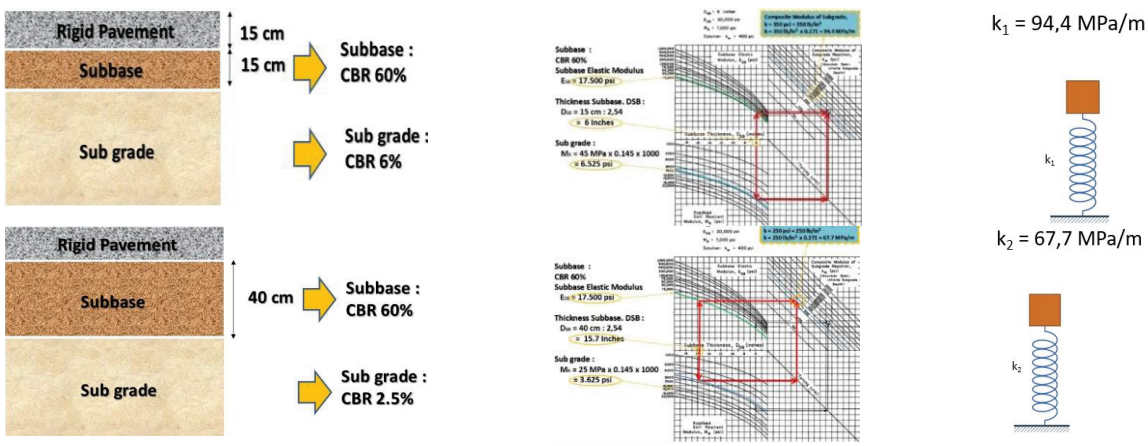
(a) (b) (c) (d)

FIGURE 19. PCP unbonded post-tensioned technology with re-centering capability. Precast module is 12000 x 1800 x180 and 12000 x 3600 x 180 with concrete quality fc' 41.5 MPa

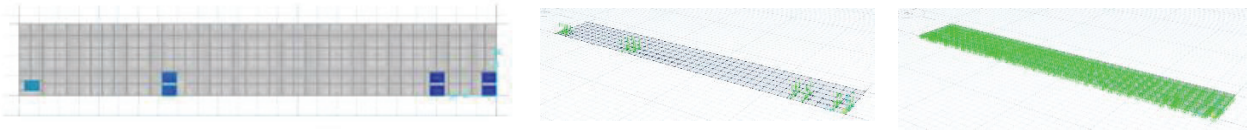
(a) Observation ofoverload data [7]



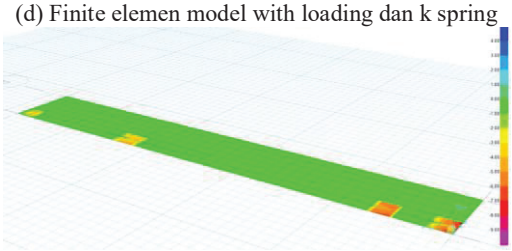
(b) Loading model



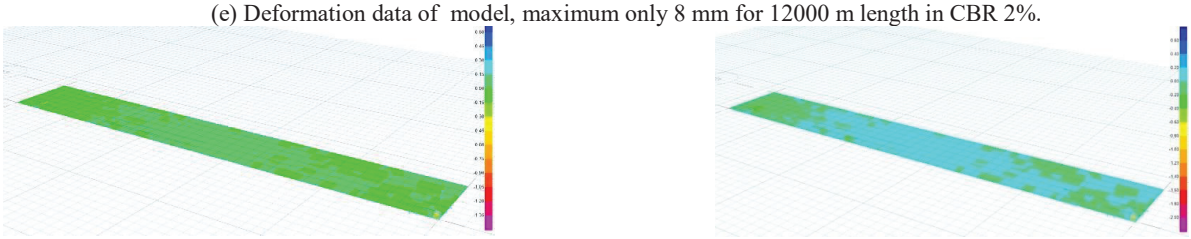
(c) Soil model with k spring relate to CBR. Model 1 with standar subgrade CBR 6%, Model 2 with low subgrade CBR 2.5%



(d) Finite elemen model with loading dan k spring



(e) Deformation data of model, maximum only 8 mm for 12000 m length in CBR 2%.



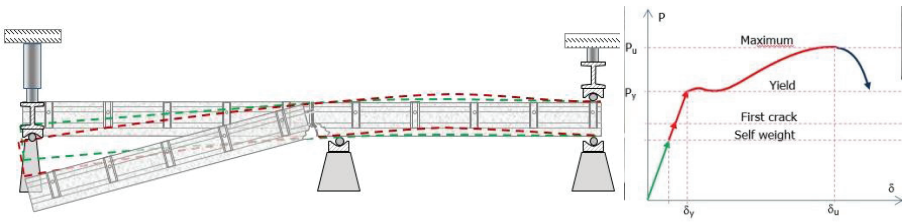
(f) Moment distribution of model in overload and CBR 2%, Maximum moment 2 kN m/m for design post tension panel and dowell connection

FIGURE 20. Design for PCP unbonded post-tensioned technology

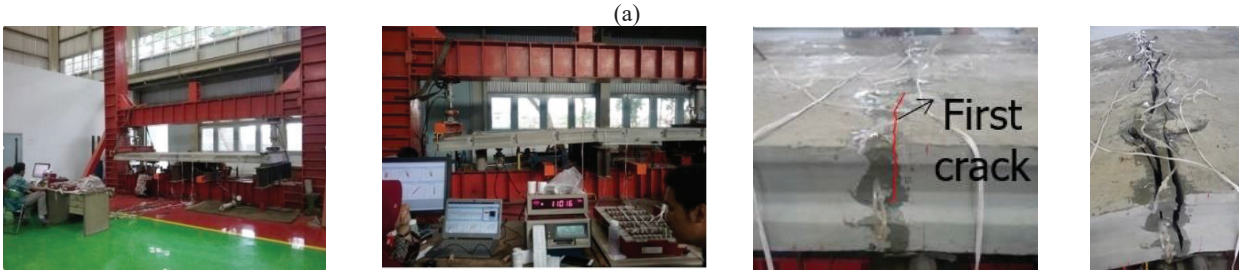
Testing has been carried out in *Institute of Housing and Settlement* (2017) as shown in Fig. 21, 22, 23 and showed that the system can proved to resist overload and bad sugbrade condition. The system now is in fatique test in *Institute of Road Engineering* (2017).

(a) (b) (c)

FIGURE 21. PCP unbonded post-tensioned technology test (Dowel tension test)



(a)



(b) (c) (d) (e)

FIGURE 22. PCP unbonded post-tensioned technology test (Connection dowel flexure test)

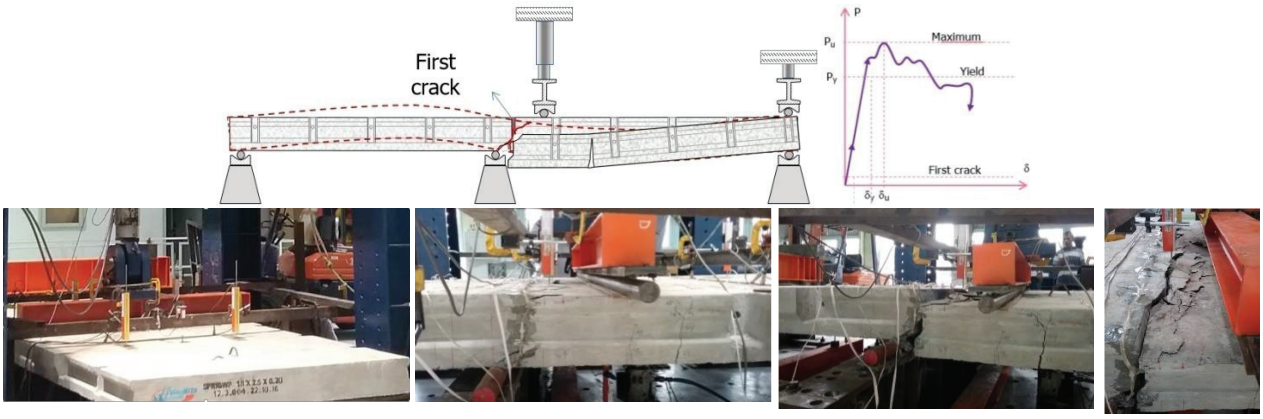


FIGURE 23. PCP unbonded post-tensioned technology test (Connection dowel shear test)

Drainage

The enemies of road are water, water and water; however, drainage system in Indonesia has been paid poor atention and this would shortened life expectancy of highways. Good drainage system, adjusted to climate condition and rainfall in a location may be seen in Fig. 24 [11].

Industrial manufacture may support good drainage system with U-ditch for side drainage with small current volume. Box construction may be used directly in precast highway construction to function as tunnel and pavement as shown in Fig. 25.

(a) (b)

FIGURE 24. Drainage system (a) high rainfall, (b) low rainfall

(a) (b)

FIGURE 25. Industrial manufactured products for drainage (a) U- ditch for low capacity (b) box for high capacity

Integrated design concept with cost estimate based on LCC

Based on Sections 3.4.1 till 3.4.4, an integrated highway design based on industrial manufactured shown in Fig. 26, is proposed below.

At sub-grade component, a minimum CBR 6% should be assured. If the soil is extremely soft but not thick enough, the soil may be replaced with better consistent soil, or chemical stabilization process may be applied. If the soil is thick enough, concrete mattress with micro piles may be used. In sub-base component, mortar foam may be used.

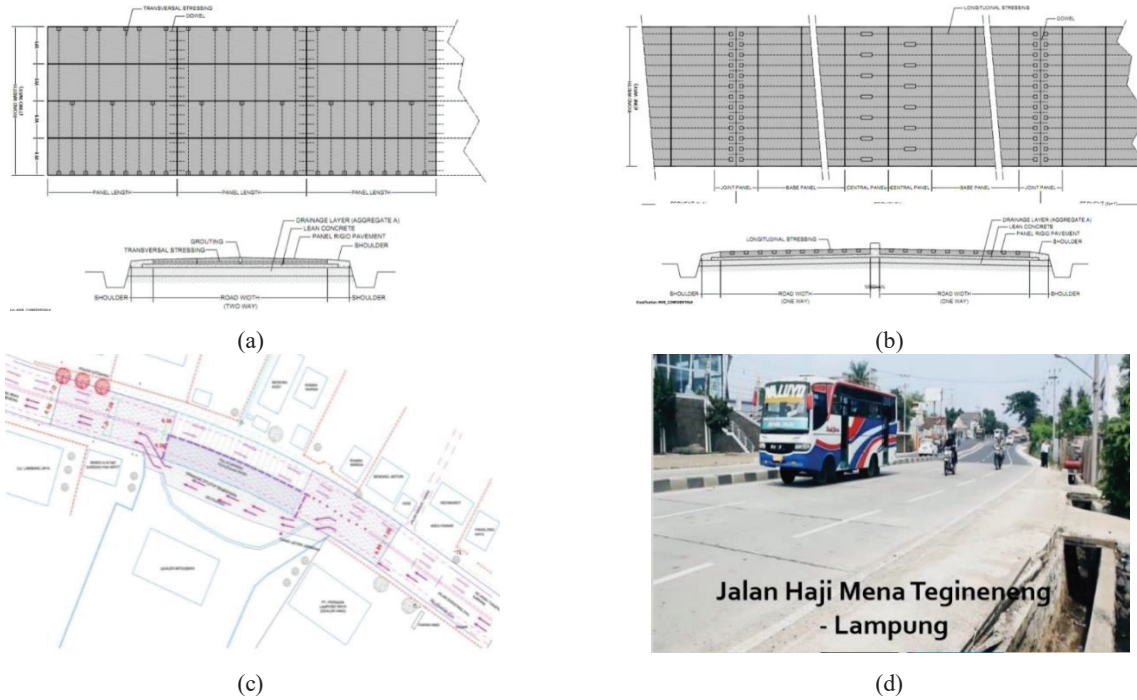
In pavement component, PPCP technology may be applied to sub-grade and sub-base controlled condition, or unbonded post-tensioned PCP for uncontrolled condition sub-grade, sub-base and road load.

In drainage component, U-ditch may be used for side drainage with low current volume, and box component for high current volume.

(a) (b) (c) (d)

FIGURE 26. Integrated highway design based on industrial manufacture: (a) concrete mattress with micro piles for soft sub-grade, (b) mortar foam for sub-base, (c) PPCP/PCP forpavement, (d) U-ditch/box for drainage

One implementation of this concept was in road upgrading project in Haji Mena – Bandar Lampung (2016) with PPCP for pavement as seen in Fig. 27.



(a) (b)

(c) (d)

FIGURE 27. Application integrated highway design in road upgrade project Haji Mena – Bandar Lampung

Integrated design cost estimate is carried out by means of LCC concept [6], so not merely based on initial construction cost. The LCC concept is a method used for obtaining estimate of current value and future value of a highway construction during its life service. The determining factors, among others, are as follows [1, 2, 8].

Functional condition: measure of pavement capacity to serve users at certain time in aspects of safety, comfortability amd vehicle operational cost. The indicators are Present Serviceability Index (PSI) and International Rougness Index (IRI).

Structural condition: the measure of pavement capacity to carry out highway loadings and to protect foundation and base soil. The indicators are deflection and rutting or crack.Cash flow diagram of highway construction operational period may be seen in Fig.26. Initial construction cost (I) on sub-grade, sub-base, pavement, drainage, infrastructures, etc. Routine maintenance cost (R) for sealant replacement, crack grouting, joint replacement, etc.

Periodic maintenance (K) for repair/demolition of damaged pavement, sealant replacement, crack grouting, joint replacement, etc.

The LCC analysis concept may be seen in Table 1, with vehicle operational cost (BOK) consisting of: fuel consumption cost, engine oil consumption cost, tire wearing cost, spare part maintenance cost, vehicle depreciation cost, interest rate, management insurance cost and operational cost.

(a) (b)

FIGURE 28. Cash flow diagram for construction operational period: (a) JPCP, (b) unbonded post-tensioned PCP

TABLE 1. LCC analysis concept

Description	PCP Post tension Unbonded	JPCP
Concrete thibkness	180 mm	320 mm
Concrete quality	fc' = 41.5 MPa	fc' = 37 MPa
Connection	Continuous	4 m interval with dowel
Traffic opening	Immediately	7 days
Life Service	Periodic maintence every 10 years with 20% slab replacement	In 10th years, routine maintenance hotmix overlay 50 mm In 11th-30th years, routine maintenance each years and periodic maintenance each 10 years
Vehicle operational cost BOK***		

TABLE 2. Comparison of construction cost

Description	PCP Post tension Unbonded	JPCP
Concrete Initial cost	Rp 970,000/m2 Rp 21,000,000,-/panel (1.8m x 8m x 0.18 m)	Rp 640,000/m2 Rp 2,000,000,-/m3
Lost of Highway closing - Value of time assumption from GDP Rp 17,000,-/hour - Pantura ADC : 35,000 vehicle/day/lane - 2 passenger average/vehicle		- Traffic opening after 7 days - Traffic jam delay assumption 0.5 hour/day - Loss of money : 7 day x 0.5 hour x Rp 17,000,- x 35,000 vehicle x 2 passenger = Rp 4,100,000,000,-
Total construction per km, 7m width (exclude lean concrete, sub base and subgrade preparation	Rp 970,000,- x 7 x 1,000m = Rp 6,800,000,000,-	Rp 640,000/m2 x 7m x 1,000 = Rp 4,500,000,000 + Rp 4,100,000,000, (Loss of Time

TABLE 3. Comparison of maintenance cost

Description	PCP Post tension Unbonded	JPCP
Routine maintenance		- Joint sealant replacement - Sealing surface crack - Start from 11th year, routine maintenance with asphalt wearing surface, assumed 1% area/year
Periodic maintenance	After 10th year, damaged panel replacement, assumed 20% x Rp 6,800,000,000,- = Rp 1,400,000,000,-	- Each 10 years, concrete slab repair, assumed 30% x Rp 4,500,000,000 = Rp 1,350,000,000,- - Each 10 years, average overlay with hotmix AC-WC Rp 105,000 x 7 x 1,000 = Rp 721,000,000,-
Total maintenance cost in present value (interest rate assumption 12%)		

The LCC analysis clearly states that even if PCP initial construction cost is higher than JPCP, in general, highway life service, cost of PCP will be more economical. In construction period, the cost is more economical if the loss due to the closing time of construction is taken into account. Moreover, maintenance cost is lower during service time of highway.

CONCLUSIONS

Performance of highway construction in Indonesia nowadays is yet to be optimum. Flexible as well as rigid pavement construction generally do not reach their life service, due to the lack of meeting specification or due to unavoidable excessive loading.

Construction based on industrial manufacture made of local materials will provide good performance products and more efficient compared to conventional construction. Precast/prestressed components have been applied since 2007 but the results are not always optimum since the design and construction are not carried out integratedly.

Integrated development effort on highway construction based on industrial manufacture has been initiated since 2015, by performing qualitative and quantitative research. Qualitative research was carried out on qualitative performance in application of precast system in several highway constructions (2010-2015), and in comparative study in United States (2015). Quantitative research was carried out on quantitative performance of application of precast system in highway construction (2010-2015), and in development testing concept (2015-2017).

Based on the results of research mentioned above, a reccomendation on an integrated highway construction using several industrial manufactured products: sub-grade, sub-base, pavement and drainage system suitable to local technical condition. This concept would produce good performance highway with 40 years life service. Cost analysis by applying LCC concept reveals that this concept is more efficient compared to conventional system.

This concept is expected to be an alternative for the improvement of development performance and highway construction maintenance in Indonesia, so as to support improvement service to the users, supports economic activities and participates in sustainable development which nowadays considered as a part of global movement to save the world from climate change.

ACKNOWLEDGMENTS

This research funded by Waskita Beton Precast Ltd., Wijaya Karya Beton Ltd. and JHS Ltd. Also the writers extend their appreciation to the Indonesian Association of Precast and Prestressed Engineersand to the Research Institute of Human Settlement, and Institute of Road Engineering Ministry of Public Works for providing testing facilities.

REFERENCES

1. AAHSTO, *Guide for Design of Pavement Structures*, *(*American Association of State Highway and Transportation Office, 1993).
2. ACI 325.12R-02, *Guide for Design of Jointed Concrete Pavements for Streets and Local Road*, (American Concrete Institute, 2002).
3. Road Geotechnic Research & Development Centre, *Mortar Foam Technology (Light weight Embakmen),* (Ministry of Public Work and Housing, Semarang, Indonesia, 2017).
4. B. Choubane (private communication, 2015).
5. H. N. Nurjaman, L. Faizal, H.R. Sidjabat, B. Hariandja, R. Rivky, and Y. Put, Elsevier. Procedia Eng. J. **95,** 82–86 (2014).
6. L. Faizal, *Applied Strategic Technology of Precast dan Prestress Concrete*, in *Continuous Program Development Conference Proceedings*, edited by Cakranegara*et al*. (Ministry of Public Work and Housing, Jakarta, Indonesia, 2016)
7. N. Suaryana, *Dimension and Load of Prestressed Rigid Pavement,* (Ministry of Public Work and Housing, Bandung, Indonesia, 2016)
8. PCA, *Thickness Design for Concrete Highway and Street Pavements* (Portland Cement Association,1995)
9. S.L.Gillen (private communication, 2015).
10. S.S.Tyson (private communication, 2015).
11. T. Dahlan, *Design and Implementation of Construction using Precast and Prestress Concrete*, in *Technical Guidance Conference Proceedings*, edited by R. Sulaeman*et al*. (Ministry of Public Work and Housing, Jakarta, Indonesia, 2016)
12. T.E.Nantung (private communication, 2015).