ASSESSMENT, REPAIR AND HEALTH MONITORING FOR CONCRETE-STEEL DECK OF HIGHWAY BRIDGES

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ABSTRACT: Concrete slab deck is commonly used for highway steel bridges in Indonesia. The concrete deck slab can be designed as composite slab together with place corrugated steel or separate in which the concrete is used as non structural slab. The corrugated steel is usually also used as stay-in-place formwork in the construction phase. Experiences showed that after the bridge is used in a period of time, cracks appear in the concrete slab in transverse direction above the floor beams along the width of the bridge. Depend on the capability of analysis method in the design period, the concrete deck slab was assumed as one way slab in lateral direction that supported by stringers in the longitudinal direction. The loads are first supported by concrete deck slab then delivered to the floor beams through stringers. In fact, if the load is act near the floor beams, it will be delivered direct to this beams and negative moment will appear in the deck slab above the beams. The paper discuss about the effect of the wheel load on the cracks and degradation of the stiffness and strength of the deck slab. Some inspection procedures can be applied to assess the performance and safety the slab. Local demolition of concrete and replacement of the corrugated steel above the floor beams with new concrete over flat steel is one of the appropriate repairs that enhance strength and avoid cracks of the slab in the future. Simple inspection procedure can be applied to find cause the damage and monitor the health of the deck slab.

KEYWORDS: concrete deck slab, one way slab, reverse cracks, steel deck replacement

1. INTRODUCTION

Floor system of bridge is used to support the weight of the deck traffic load to the main supporting members. The choice of the deck type depends on several factors, which may include the specific application, initial and maintenance cost and durability. The concrete deck slab is commonly used for highway bridges in Indonesia because concrete is adopted as the major material. The deck is typically continuous along the span of the bridge and across the width of the span. For steel bridges, the concrete deck slab is the most often used type. This type of deck also is applied to improve the weather and corrosion-resisting effect of the whole bridge, reduce inspection efforts and maintenance cost and increase structural effectiveness.

Basically, there are three types of floor systems [1]:

a. deck is supported by main supporting members,
b. deck is supported by both stringers and floor beams and transferred to the main supporting members (main girders or truss bridges),
c. deck is simply supported at each end by the floor beams.

For the deck types discussed herein, particular concrete slab deck, that supported by both stringers and floor beams, is given. Floor beams are the transverse members which extend perpendicular to the traffic flow and which support the stringers or deck slab. Stringers run longitudinally and parallel to the roadway, spaced across the length of the floor beams and either rest upon the floor beams or are

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connected to the floor beam.

Concrete deck slab can be constructed with cast-in-place formwork with steel reinforcement in the longitudinal and transverse directions. The cast-in-place formwork is usually made of corrugated steel plate. This kind of deck slab is becoming popular for Indonesian bridges. It gave additional strength to the deck as well as providing strong formwork for the deck concrete.

The concrete deck slab can also be designed as composite between concrete together with corrugated steel or structurally separate. If structurally separate, the load can be fully supported by stay-in-place formwork in the construction phase and also in the service life, and the concrete is only used as non structural slab. Based on the observed performance, after the bridge is operated in a period of time, cracks appear in the concrete slab in lateral direction near the cross girders along the width of the bridge. This paper discuss about the cause of the cracks of the slab, especially the effect of the wheel loads on the bending moment of the slab above/near supporting members (floor beams and stringers), inspection procedures and effective repair based on the experience in Indonesia in order to minimize the cracks in the future.

2. ASSUMPTION OF ANALYSIS AND DESIGN OF CONCRETE DECK SLAB

Based on the report done [2], the numbers of bridges are constructed throughout the ‘50s and ‘60s, and reach the peak in about ‘70s. Structural models, analysis and design of bridge components are usually done by using some establish idealizations in the period of time of bridge construction, e. g. truss steel bridges were modeled as 2D-truss and traffic loads were idealized as point loads in the joints [3]. The concrete deck can be design by traditional method with the equivalent strip method analysis.

The traffic loads along the bridge were first supported by reinforced concrete deck slab or stay-in-place (corrugated steel) concrete composite deck slab then delivered to the stringers then to the floor beams, see Figure 1.

Figure 1. Bridge deck system using corrugated steel

By this method, the stringers act as supports, and the deck acts as a simple or continuous beam spanning from support to support [4]. Analysis and design of the reinforced concrete slab was usually assumed as one way slab in lateral direction supported by these supports (stringers). Usually this assumption is also applied for reinforced concrete slab by using corrugated steel as stay-in-place formwork. Because of the form of the corrugated steel, the produced reinforced concrete slab has strong/high flexural capacity only in one direction, and low capacity in other direction perpendicular. Therefore the corrugated steel-concrete slab is placed in the lateral direction of the bridge. The main reinforcements are usually also applied in this lateral direction in the whole area in of the deck.

3. CRACKING OF THE CONCRETE DECK SLAB

There are many types of concrete deck cracking: transverse, longitudinal and map or random direction cracks. There are three primary reasons for the appearance of cracks in concrete bridge decks: shrinkage, sloughing and load induced cracking. The last crack caused by load, that induces stresses in the concrete that exceed the tensile capacity of the concrete. These stresses are usually caused by vehicle loads [5].

Transverse cracks run perpendicular to the long direction of the bridge. The cracks are usually caused by vehicle loads and are the most common type of cracking of bridges in Indonesia that is used corrugated steel-concrete deck slab. These cracks appear above or near floor beams in the lateral direction along the wide of the bridge deck until site walk, see Figure 2.

(a) Cracks in the deck (b) Tranvese cracks in the side walk

Figure 2. Transverse cracks of the deck slab

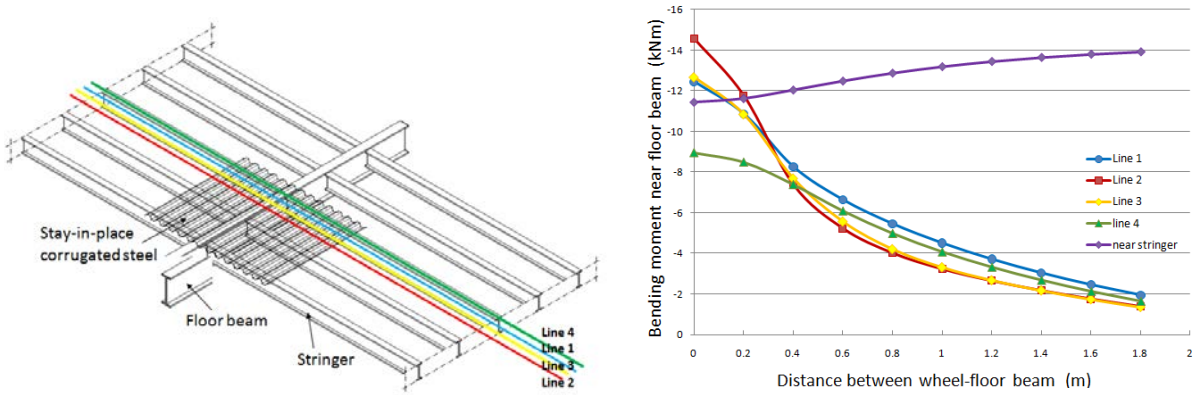
This report discusses the effect of the movable wheel load on the bending moment of the concrete deck slab above floor beams and stringers and also the phenomenon of the appeared cracking of the deck slab, that often happens in some bridges in Indonesia. These experiences might be shared and hope the exchange of information concerning such damage repair and failure or damage prevention in the future.

In order to know the effect of vehicle loads on the cracking of the deck slab, individual wheel load is rolled parallel to the longitudinal direction of bridge. This is simulated with linear finite element model. The wheel load is modeled as vertical load with such area and size based on the standard truck for Indonesian Loading [6]. The slab is modeled as shall elements support by floor beams and stringers as frame elements. The wheel that has a specific contact areas, is simulated running on the slab in the Line 1, 2, 3 and 4 in longitudinal directions, see Figure 3a. Figure 3b showed the bending moment of the slab above the floor beam and stringer caused by these movable wheel loads. From the curves can be seen, if the wheel is coming nearer to the floor beam, the bending moment of the slab above the floor beam is getting higher. If the wheel is about 1.8 m far away from the floor beam or more, it has no significant effect to the slab above the floor beam. That means almost of the whole wheel load is transferred to the stringers. After the wheel load comes nearer, partial of the wheel load is delivered to the floor beam and bending moment appears above this beam.

The maximum appeared negative bending moment above the floor beam is M = -14.75 kNm/m, in which the ultimate moment is about M_u = 32 kNm/m. By this maximum moment, the capacity slab can be evaluated, whether it is crack and strong enough to carry the load. The flexural capacity of the cross section of the reinforced concrete slab in the weak direction is M_r = 22 kNm/m (reinforcement of *Φ13-150* and f'_c = 30 MPa) with the minimum thickness of the slab of 140 mm. This bending capacity is lower than the appeared ultimate bending moment. In this area shear force is also high. These can cause

transverse cracks of the slab above or near the floor beam even under normal working loads. Overloads can cause excessive cracks and also degradation of the stiffness of the deck slab and also whole bridge, see in Fig 2. Running vehicle can produce a relative high deflection and impact to the deck slab, which produce vibration. US Department of Transportation Federal Highway Administration [7] found that vibration is the most significant parameter influencing cracking or advanced deck cracking.

If the crack progresses over a long period of time could significantly accelerate deterioration and reduce the safety of the concrete slab and fatigue failures shall be considered. Because of the cracks and high stress of the materials, the provision in AASTHO [8], that state not requiring fatigue investigation for concrete slab support by stringers and floor beams, can't be applied anymore.



(a) Lines of the wheel loads (b) Bending momen of the slab

Figure 3. Bending moment M of the slab cause by movable wheel load

4. REPAIR METHODS

Bridge deck is an important part of the bridge's structural support system. A good decision of repair method can only be made, if good information of the deterioration is available. The main purpose of the deck's repair cause by transverse cracks described before is to prevent cracks and to enhance the bending moment capacity of the slab above the floor girders. These can be done by thickening of the deck slab. If cracks are not spread to large area, repair can be done by removing and replacing concrete only in the deteriorated portion above the floor beams where cracks appeared. In order to maintain the same surface level of the whole deck slab, thickening must be done in the bottom part of the slab. The stay-in-place corrugated steel should be removed in order to make the slab thicker. Flat steel as stay-in-place formwork is placed in the bottom surface of the slab, onto which concrete is poured. A good bond between old and new concrete is usually obtained by an epoxy bonding agent applied just before the repair material. Compaction is normally done by external vibrator. If excessive cracks have been spread in a large area, repair must be done by concrete replacement in the whole deck slab, see Figures 4 and 5.

Thickener slab in this area will reduce the tensile stress of concrete in the upper surface as well as strengthen its bending resistance of the deck slab. Experiences in Indonesia showed a good performance of the repaired slab, crack is not appeared anymore, although the bridge has been operated more than 10 years.

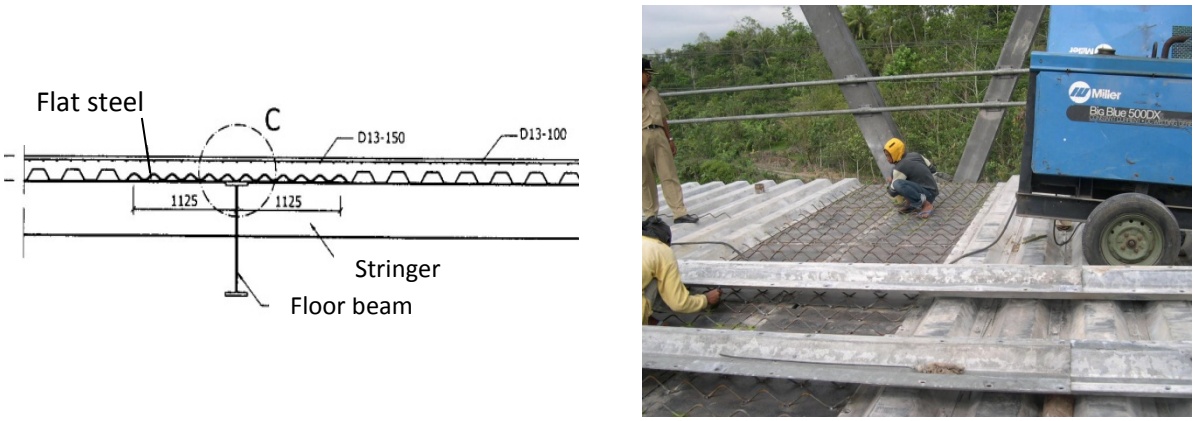


Figure 4. Thickening of the concrete slab above floor beam by removing the corrugated steel and replace with flat steel as stay-in-place formwork

Figure 5. Repaired concrete deck slab with stay-in-place flat steel

5. INSPECTION PROCEDURES FOR DAMAGE ASSESSMENT AND HEALTH MONITORING

Generally, identification of damage conditions and cause of damages must be considered from all points of view. From above discussion, the mechanism of cracks is particularly known well for concrete deck slab with corrugated steel. For the identification, some inspections method must be done to evaluate the condition of whole bridge.

Damage type of corrugated steel-concrete deck slab includes cracks, spalling, exposure of reinforcements, rust staining indication of corrosion of reinforcements and corrosion of stay-in-place steel. Some damages can be detected visually. The shape and width of cracks are frequently checked by visual inspection. Therefore visual inspection is a reliable method to be applied. The ultrasonic method or core sampling is used to check the crack depth, although this can be visually observed from the site of the site walk. Potentiometer can be used for early corrosion of reinforcements in concrete, because this kind of damage usually cannot be visually detected. It should be checked for changes of the surface elevation in the long and lateral direction of bridge which could indicate deflection of the deck slab. It can be done by using surveying instruments as levels and compare with the original profile.

If the crack progresses over a long period of time, stay-in-place forms should be checked for corrosion, although it is not important if it does not contribute to the capability of the deck slab. The cracks permit moisture come into the corrugated steel and cause corrosion. Visible stain indicate a corrosion of the corrugated steel and reinforcement and cause loss of strength of the slab due to cracking and loss of bond between concrete and reinforcement.

6. CONCLUSIONS

From the discussion of failure and repair of the concrete deck slab above, some conclusions can be drawn:

a. Concrete deck slab is commonly used for highway bridges in Indonesia. The concrete slab is made as combination of reinforced concrete with corrugated steel that also used as stay-in-place formwork in the construction phase.
b. After a period of time cracks appear above and near floor beams in the transverse direction along the wide of the bridge deck. The initial cracks usually caused by standard load, overload can caused excessive cracks and also degradation of the stiffness of the deck slab.
c. The main purpose of the deck's repair is to prevent cracks and to enhance the bending moment capacity of the slab, by thickening of the deck slab. Local demolition of concrete and replacement of the corrugated steel with flat steel is one of the appropriate repairs enhance strength and avoid cracks in the future.
d. Simple inspection procedures can be applied to evaluate the performance and safety of the deck and also applied to monitor the health of the deck slab.

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