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MODIFIED APPROACH FOR TRANSVERSE REINFORCEMENT DESIGN OF BRIDGE DECK SLAB ON PRESTRESSED CONCRETE T-BEAM GIRDERS

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ABSTRACT

This paper focuses on the analysis and design of the bridge deck slab considering the wide flange prestressed T-beam effects. The current practice in transverse reinforcement design method involves the use of prestressed T-beam girders supporting a heavily reinforced concrete bridge deck slab. The slabs are commonly assumed to be supported continuously at the center points of girders, neglecting the effect of the girder flange stiffness. The design in this manner produces a conservative transverse reinforcement in the slab. As alternative, a newly constructed bridge deck is chosen as a case study where the design based on this conservative assumption is compared with that considering the girder flange length, thickness and rigidity. It is found that the amount of transverse reinforcement of the concrete slab obtained from the conventional design is considerably larger than that considering the girder flange stiffness. This promising finding warrants further investigation of the latter approach focusing on the effect of girder flanges in taking bridge loading in the transverse direction.

Key words: Bridge deck; girder flange, prestressed T-beam; Transverse reinforcement.

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1. INTRODUCTION

The design life of bridges is conventionally set to stand for a satisfactory life duration. During this life span, the bridge has to comply with certain basic requirements such as structural resistance, serviceability and durability, which are met by appropriate design, production, execution and use. The objective of this paper is to provide a review on the work related to bridge super structure design, and to offer an insight of the real mechanism involved through a framework of a simple model. This is carried out to devise a sound basis for the possibility of a more economical design approach and justified recommendations for further research work.

Most of concrete slab bridges specifications were developed in 1940s [1]. The AASHTO's Specifications [2] were produced from the works of various researchers [3-9], all of which predicted the ultimate strength capacity as pure flexure. However, ultimate strength tests results on old concrete slab bridges (with assumed low truck loads specification) showed that they are much stronger than the rating procedure suggested by AASHTO, which offers the possible existence of other factors necessary for enhancement [1]. This draws the attention of many researchers. In addition to this, the need for reduction or elimination of total internal steel reinforcement [10] for better durability has also helped in adding the research motivation on the subject. The first major change was the idea of compressive membrane forces in a member enhancing its capacity, which led to the invention of empirical method of design [11, 12]. It had later been revealed that the total deflection of bridge deck is not really flexural but also highly influenced by small girder spacing and/or large deck thickness [13].

In another development by Wisconsin Department of Transportation, a 203 mm thick deck over Wisconsin 54W girder withstand over 890 kN wheel load [14], which is far above factored designed vehicle load of 160 kN provided by AASHTO [2]

Bridge construction in Malaysia mostly uses prestressed beams with reinforced concrete slab deck. This slab system is overdesigned and inefficient because the design procedure usually follows the conventional assumption as is done in conventional design method.

At present the flanges and web thickness of the bridge girders are neglected when the design of the slab is done in practice (Figure 1). The flanges are only used as a supporting platform during the casting of slab. As a result, the slab transverse reinforcement is designed based on its pure flexural strength alone without considering the stiffness of the supporting girder elements. It is expected that, with proper design method, the flange and the web are able to resist vehicle loading together with the slab. As a result, the entire slab reinforcement in the transverse direction can be reduced significantly. This will help to expedite the construction time and reduce the construction cost of the bridge structure.

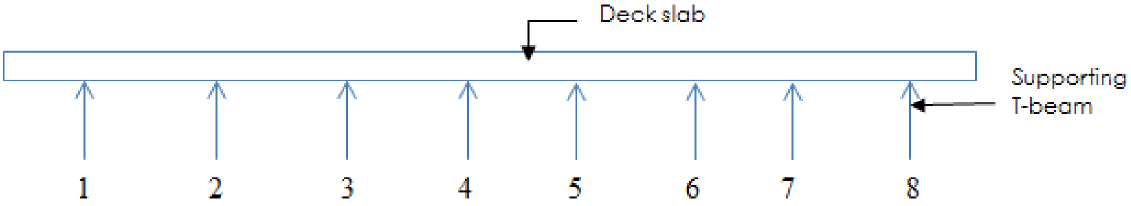


Figure 1 Slab on T-beams assumption

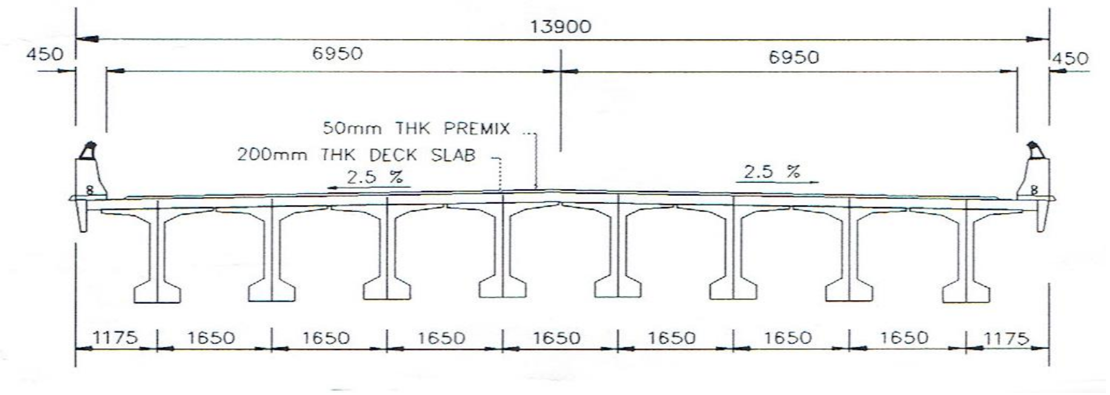


Figure 2 Cross-section of case-study bridge category A

2. CASE STUDY

For reviewing and comparison of existing bridge, the Jalan Kampung Kerinting Bridge is selected to be used as one of the design case study. It is situated in the Kerinting Kelantan express way in Kelantan, Malaysia. The bridge consists of one-span post-tensioned wide T-beam with in situ deck slab type of structure of 40 meters length.

The width of the deck is constant throughout (13.9 meters) with dual carriageway. It consists of 200mm thick deck slab and eight prestressed wide flanged T-beam and the abutments are cantilever wall types. [The cross section of the bridge is shown in Figure 2]. The bridge had been designed in September, 2008. Three other bridges, Taman Tema bridge 1 intersection 6, SG. Kerith and LPT Fasa 2 Ranmmu bridges all in Malaysia were also studied.

The analysis and design of the bridges are reviewed and briefly presented as follows.

3. DESIGN OF SLAB DECK

3.1. Design using the Conventional Method

The bridges had been designed using the conventional method on the basis of assumptions made in accordance with the British standard codes of practice (BS5400, BS8110, BD37/01 BD52/93, BD33/94, BD60/04 and BS 8004). The summary of the design parameters for category A including Kerinting and Taman Tema 1 are shown below:-

Width, w = 13m

Total length = 40m

Slab Thickness = 200mm,

Number of Notional length = 4

The slabs were designed transversely as one way spanning supported by the longitudinal prestressed T-beams and the beams were modeled as point reactions to the slab. Results for all the bridges were obtained for moments and shear forces under the symmetric loading configuration and the resulting moments are presented in Tables 1 and 2.

Table 1 Support moments for the case study bridges obtained using conventional design method

Bridge name	**Support moment (kNm)**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Jalan Kampung Kerinting bridge	-16.9	-2.15	-6.35	-6.34	-6.34	-6.35	-2.15	-16.9
Taman Tema 1 (Interchange 6)	-27.54	-1.15	-7.21	-7.21	-1.15	-27.54	-	-
SG. Kerith and LPT Fasa 2 Ranmmu bridges	-10.47	-3.18	-5.19	-5.19	-3.18	-10.47	-	-

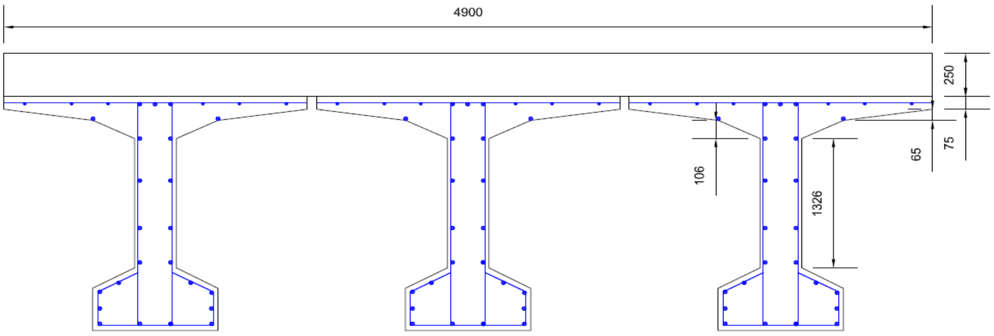
Table 2 Span moments for the case study bridges obtained using conventional design method

Bridge name	**Span moment (kNm)**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Jalan Kampung Kerinting bridge	0.17	4.00	2.46	2.94	2.46	4.00	0.17	0.17
Taman Tema 6/6 01(Interchange 6)	-0.11	5.77	2.20	5.77	-0.11	-0.11	-	-
SG. Kerith and LPT Fasa 2 Ranmmu bridges	0.81	3.05	2.16	3.05	0.81	-	-	-

3.2. Design using the Modified Approach

The bridges were then analyzed and designed differently by considering the effect of concrete flange and web thickness in bearing the slab load as is the case in real constructed deck configuration (Figure 3a). The analysis has been carried out by means of the finite element model using a commercial software ABAQUS 6.14.2

The concrete slab and the T-beam were modeled using a 4 node bilinear plane stress quadrilateral with reduced integration (CPS4R). The boundary conditions comprises the supports conditions of the T-beam, which is restrained in vertical direction (pinned) at the bottom sides of the T-bams. A designed load case 1 for the existing case study bridge is applied uniformly over the deck slab surface as shown in Figure 3b. Results for maximum stresses at the supports and mid spans were obtained as shown in Figures 4 and 6 for the two types of bridges. The sectional nodal stresses (Figure 5) were plotted and used to obtain the maximum support and span moments presented in table 3.



(a)

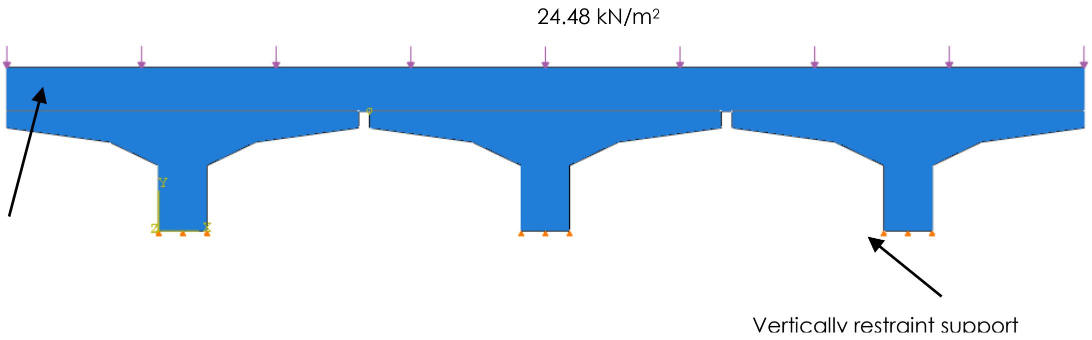


Figure 3 (a) Typical slab on T-beam girder configuration (b) Support conditions and loadings for the system configuration

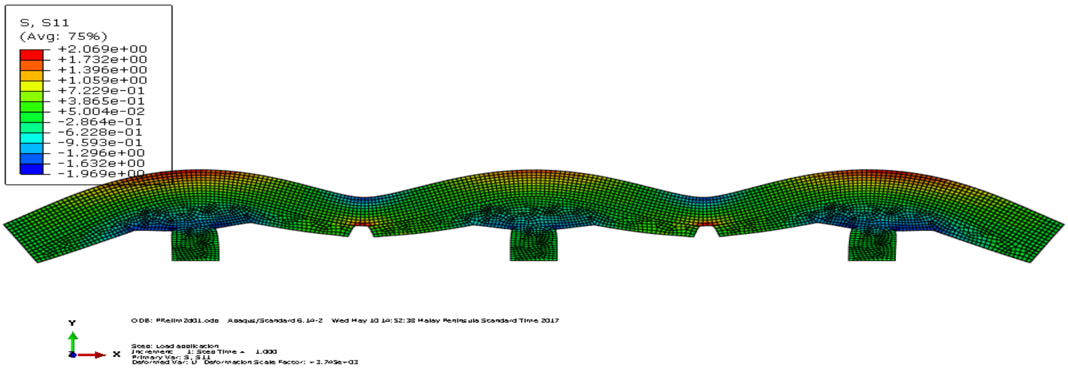
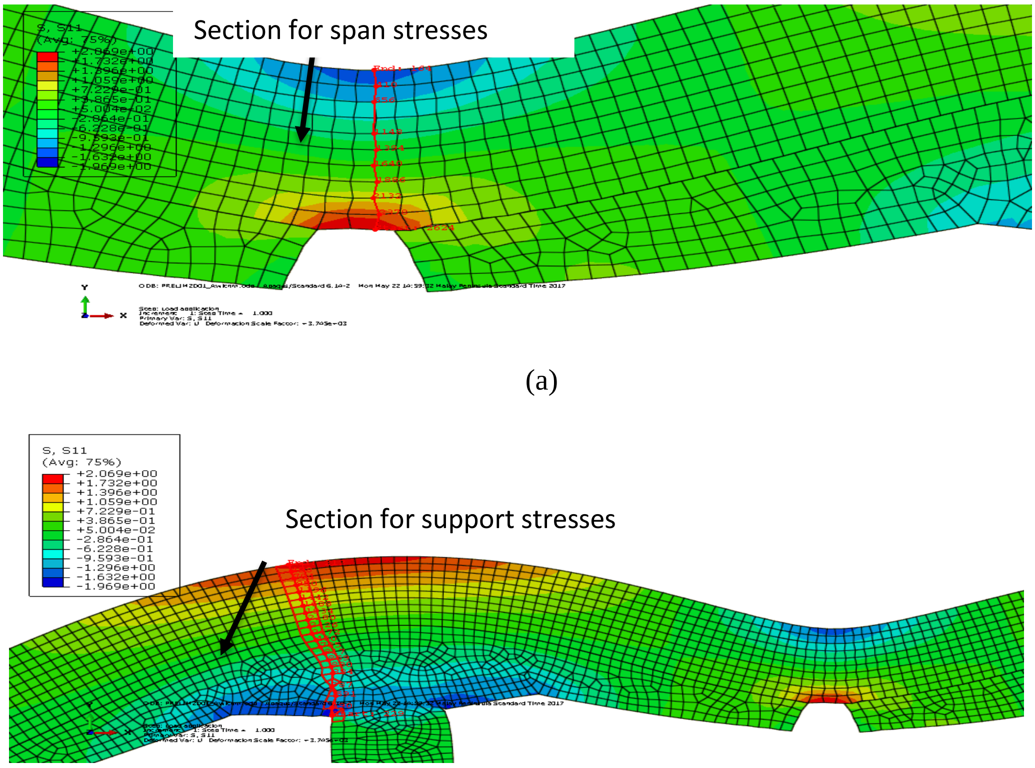


Figure 4 Deck category A stresses



(a)

(b)

Figure 5 Section where stresses are calculated (a) Span (b)Support

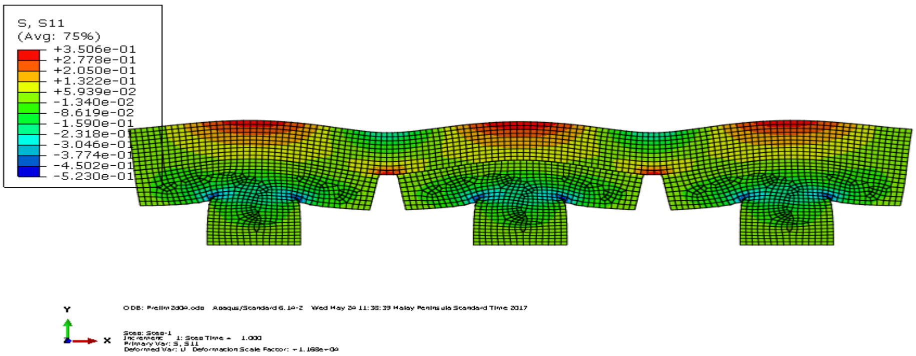


Figure 6 Deck category B stresses

These bridges are divided in to two categories according to the T-beams geometry and clear spaces between the adjacent T-beam flanges as follows:-

Category A-Jalan Kampung Kerinting bridge and Tman Tema 6/6 (01)

Category B-SG. Kerith and LPT Fasa 2 Ranmmu bridges

Table 3 Stresses and moments for the case study bridges from the modified design method

Bridge Category	A	B
Support stress (top)-N/mm2	-1.56	-0.50
Support stress (bottom))-N/mm2	1.77	0.22
Mid span stress (top))-N/mm2	2.06	0.34
Mid span stress (bottom))-N/mm2	-1.44	-0.24
Support moment (top) - kNm	-0.10	-0.03
Support moment (bottom) - kNm	0.12	0.01
Span moment (top)- kNm	0.14	0.02
Span moment (bottom)- kNm	-0.10	-0.02

Table 4 Results comparison

Item	Conventional method	Modified approach	difference	Percentage difference (%)
Analysis				
Maximum support moment for category A (kNm)	-27.54	0.12	27.42	198.26
Maximum span moment for category A. (kNm)	5.77	0.14	5.63	190.52
Maximum support moment for category B (kNm)	-10.47	0.01	10.46	199.62
Maximum span moment for category B (kNm)	3.05	0.02	3.03	197.39
Design				
Area of steel reinforcement required for category A Bridges-Support (mm2/mm) Area of steel reinforcement required for category A Bridges-Span (mm2/mm)	409.49	1.78	407.71	198.27

	85.79	2.08	83.71	190.53
Area of steel reinforcement required for category B Bridges-Support (mm2/mm)	155.68	0.15	155.53	199.61
Area of steel reinforcement required for category B Bridges-Span (mm2/mm)	45.35	0.30	45.05	197.37

4. RESULTS ANALYSIS AND DISCUSSION

The maximum moment obtained from the conventional design method of the case study bridges are found to be much higher than those obtained from the proposed new design approach in the transverse direction because the supporting area provided by the beam flange and web thickness considered in the latter contribute greatly to the slab behavior. Maximum support Moments of 27.54 kNm and 16.9 kNm for category A bridges are far greater than the modified method results of 0.12 kNm. The span moments of 5.77 kNm and 4 kNm for the same category A bridges are also higher than the 0.14 kNm and 0.1 kNm obtained from the modified approach.

For category B, maximum support moments of 10 kNm and 3.05 kNm are much greater than the respective 0.01 kNm and 0.02 kNm.

It is clear that a set of closely spaced girders should have an outstanding stiffness that can provide a full confinement to the slab. The percentage of difference shows a significantly huge margin (about 190-200% for moment), which shows that the assumption used in the conventional method of design is highly conservative.

Furthermore, considering the fact that the vehicle wheel contact area is normally 460mm×460mm [15], designing the system in such a way that the clear space between adjacent flanges is about 100mm or less, vehicular loads could be directly supported by the T-beam girders by making the slab deck acts as the load transferring structure. In so doing, the method would greatly improve the economy aspect of the slab deck design, and thus reducing the long term maintenance cost for reinforcement corrosion within the slab deck.

5. CONCLUSIONS

Design methods for concrete bridge deck system have been reviewed and compared. The findings can be summarized as follows:-

- The conventional method for bridge deck slab, in which T-beam girders are assumed to act as concentrated reactions, requires a large amount of steel reinforcement for the transversely induced moments in the slab.
- Slab supporting T-beams produce an outstanding contribution in the bearing of bridge deck loading due to the wide amount of flange area possessed and their good restraining ability resulting from their high stiffness.
- The result comparison hinted on the need for thorough investigation into the degree of stiffness enhancement of T-beams on slab carrying capacity and other parametric studies associated with the system configuration on improving the design methods and assumptions.

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