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Design of Reinforced Concrete Slab Bridge for The Use in Plantation Area

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Abstract: In Malaysia, plantation sector such as oil palm play a significant part of the country's economy. To ensure the continuous grow and success of this sector, bridges which serve as a means of crossing over obstruction such as water channels, river, and ditches and join the road network as an important and efficient road infrastructure for plantation area. This paper presents the analysis and design of single span reinforced concrete slab bridges for the use in plantation area. The slab bridges with an effective span ranging from 4 m to 8 m have been analysed and designed based on Eurocode 2 which subjected to a traffic load between 10 tons and 40 tons. The traffic load was converted to equivalent vehicle load intensity applied on the deck slab. The standard design table and detailing produced from the design enable the engineer to refer to when similar site and design condition is encountered in future. The reflection on the outcome of analysis and design of the slab bridge indicate that the slab bridge design is mainly governed by traffic load effect on its bending behaviours and increase of slab thickness is unavoidable as increase the reinforcement ratio alone is not able to achieve the design requirement.

Key words: *Reinforced concrete, slab bridge, traffic load, intensity and bending behaviours.*

1.0 Introduction

Malaysia is full of natural resources such as palm oil, rubber, and cocoa. The climate condition is advantageous for cultivation of crops, and this further drive the growth of agricultural and plantation industries. The agriculture and plantation sector have become one of the backbones of Malaysia economy and provides employment opportunities, generates incomes for individual as well as revenue to the country from the export of the commodities (Raihan et al., 2022; Salleh et al., 2010). The natural forests were mainly converted into plantations in Peninsular Malaysia and plantations and secondary forests in East Malaysia (Yan et al., 2020). The International Trade Administration of Malaysia Agricultural Sector has reported that Malaysia is the world's second largest palm oil producer and exporter after Indonesia which accounted for 26% of world production. Malaysia produced 20 million tonnes of palm oil which equivalent to 27% of the world total production and consume 5.14 million hectares of land for the use for palm oil production (Ritchie, 2021).

Bridges in plantation areas serve a crucial function, often facilitating transportation over water bodies, uneven terrain, or areas prone to flooding. One of the initial tasks when designing a bridge is selecting the most appropriate bridge type for the site. This choice may or may not be straightforward but selecting the right structure type is one of the most important aspects of designing a cost-effective bridge (Ryan, 2022). The bridge design in Malaysia has always been influenced by the British Standard due to the colonization links between Malaysia and Britain.

There are several design loadings applicable in local practice such as JKR Long Term Axle Load (LTAL) specification previously supersede in year 1997 and replaced by JKR term of reference

(TOR). JKR TOR specific both BD37/1 and Eurocode as the prevailing design code to be adopted in Malaysia (Zakaria et al., 2018). According to JKR Bridge Design Division Road Branch for the Term of Reference for Bridges and Viaducts Structures for Design and Build Projects 2008, all the bridge structure shall be designed to highway traffic load. However, directly applied the highway traffic loads to slab bridge analysis in plantation area will be over conservative and lead to uneconomical design. The design manual of small bridges by Overseas Centre Transport Research Laboratory United Kingdom offers standard design that conform with British Standard loading for 40 tonne gross weight vehicle, and with American Association of State Highway and Transportation Officials (AASHTO) loading for 20 tonne gross weight vehicle (Parry & Jones, 1993).

The Indian Road Congress (2000) standard divided vehicle into tracked vehicle and wheeled vehicle for IRC Class AA Loading and this is more suitable for slab bridge design for plantation area which subjected to similar traffic load configuration. Thus, the vehicle loading used in the slab bridges were based on IRC standard. The aim of this project is to produce a standard design table of reinforced concrete slab bridge for the use in plantation area

2.0 Geometry and loadings of Reinforced Concrete Slab Bridges

Figure 1 shows the layout and elevation view of the slab bridge. Due to the slab bridge in the plantation area do not have headroom issue, the height of abutment is fixed at 2.5 m high. The bridge deck width used in the design is 4 m to account for one way and two-way traffic. Two-way traffic is mean for normal vehicle and one way traffic is for one heavy vehicle to travel for each time. The slab bridge is single span with the span ranging from 4 m to 8 m. The slab bridge is designed to withstand vehicle load of 10 tons, 20 tons, 30 tons and 40 tons for plantation use. The geometry of the slab bridge is tabulated in Table 1.

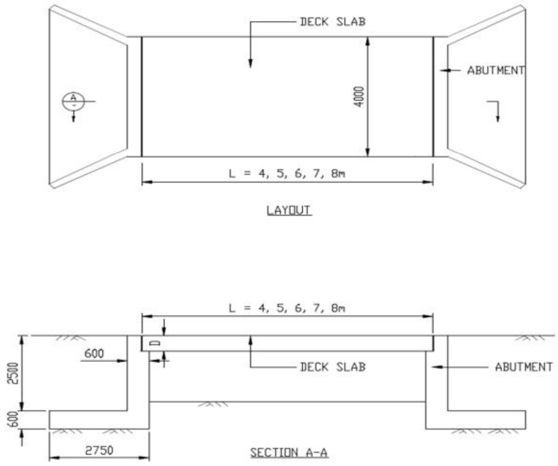

Figure 1: *Slab bridge layout and elevation*

Table 1. Geometry of slab bridge

Capacity (tons)	Width (m)	Deck thickness (mm)	Span (m)				
10	4	375	4	5	6	7	8
20		400					
30		425					
40		450					

2.1 **Analysis and Design of Deck Slab**

The selection of the design criteria and parameters were accordance to the European Standard EN 1990 and EN 1992. Table 2 summarises the design parameters of the slab bridge.

Table 2. Bridge design criteria

Item	Design criteria
Design working life	30 years
Concrete strength	C32/40
Steel strength	500 MPa
Exposure class of concrete	XC4
Minimum concrete cover	30 mm

For the variable load consideration, traffic load is analysed by the effective width method. By converting the axle concentrated load into the equivalent intensity load, the analysis can be carried out for different anticipated load accurately and effectively (Jagadeesh & Jayaram, 2009). Referring to Figure 2 and Figure 3, the effective width of which the vehicle loads acts on slab bridge deck is estimated with the following equation:

$$b_{ef} = \alpha x\ (1 - x/l) + b_1 \qquad (1)$$

Where, b_{ef} = width of the slab over which the load is effective l = effective span *pf* the simply supported slab

x = distance of the centre of gravity of the concentrated loads from the nearest support

α = a constant having values depending on B/l values

b_1 = width of the dispersion area of the wheel load on the slab through the wearing coat

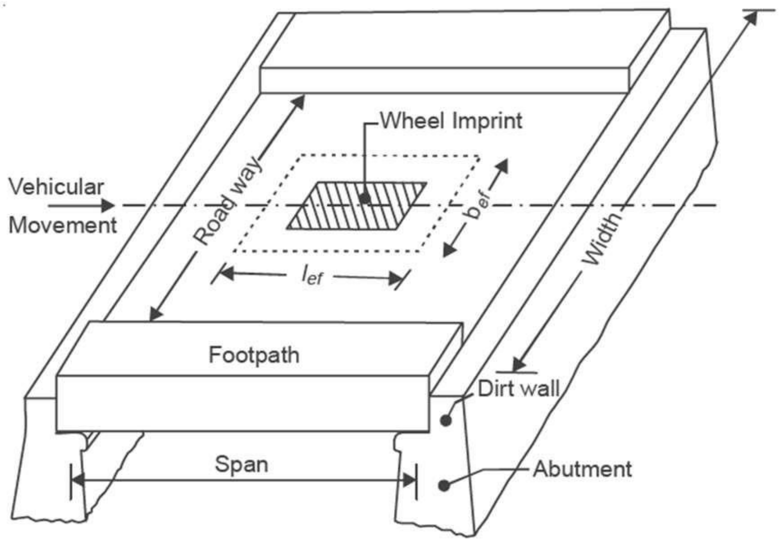

Figure 2: *Load dispersion on slab (Jagadeesh & Jayaram, 2009)*

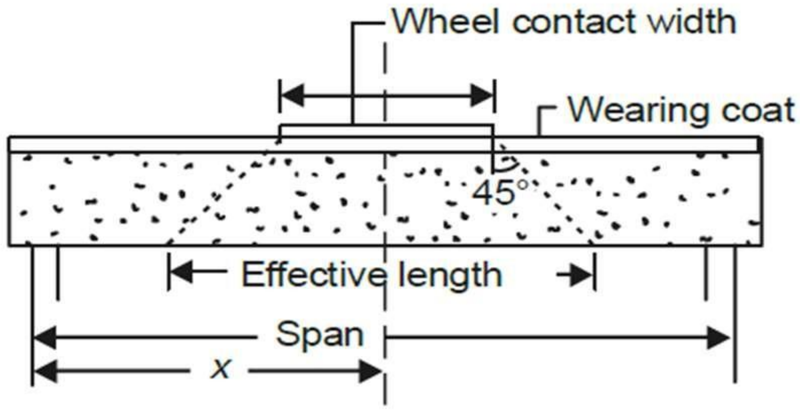

Figure 3: *Span wise dispersion of concentrated load (Jagadeesh & Jayaram, 2009)*

3.0 Methodology

An Excel spreadsheet has been developed to help the analysis and design process of the slab bridge structure under varying design parameters. The design of the RC deck slab is based on EN 1992. Figure 4 shows the design flow chart of the slab bridge.

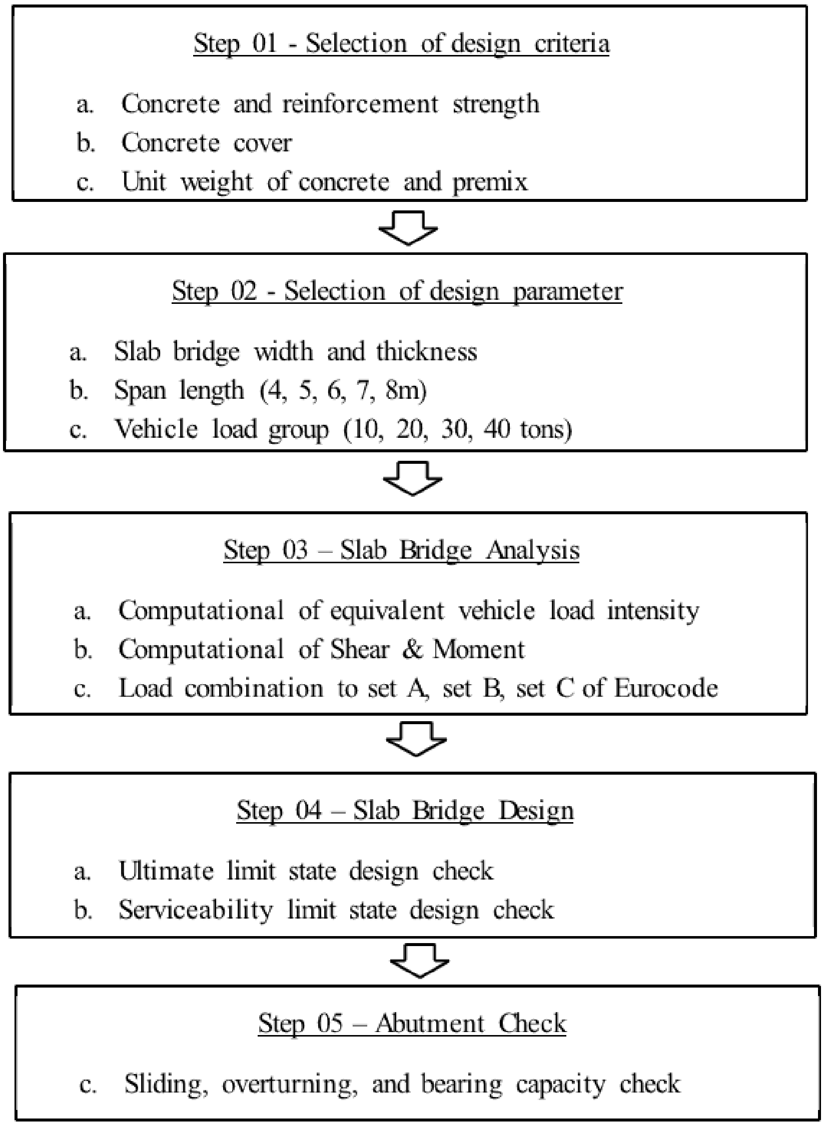

Figure 4: *Analysis and design flowchart*

4.0 Data Analysis and Findings

4.1 Equivalent Vehicle Load Intensity

The slab bridge is analysed and designed to different vehicle weight varies from 10 to 40 tons as well as span length varies from 4m to 8m. Based on the effective width analysis method, the moving loads are translated into equivalent vehicle load intensity for the analysis of slab bridge. Table 3 summarises the equivalent load intensity of each vehicle load for different span length.

Table 3. Equivalent vehicle load intensity by effective width analysis method

Span Length (m)	Equivalent Vehicle Load Intensity (kN/m^2)			
	10 ton	20 ton	30 ton	40 ton
4	6	12	18	25
5	6	11	16	21
6	6	11	16	21
7	6	11	16	21
8	6	11	16	21

4.2 Moment and Shear Force of Deck Slab

The deck of the slab bridge was analysed as simply supported span. The maximum shear force and maximum bending moment of the deck slab are calculated based on the equivalent vehicle load intensity. The plots of the moment and shear force against span with varying load intensity are shown in Figure 5 and Figure 6.

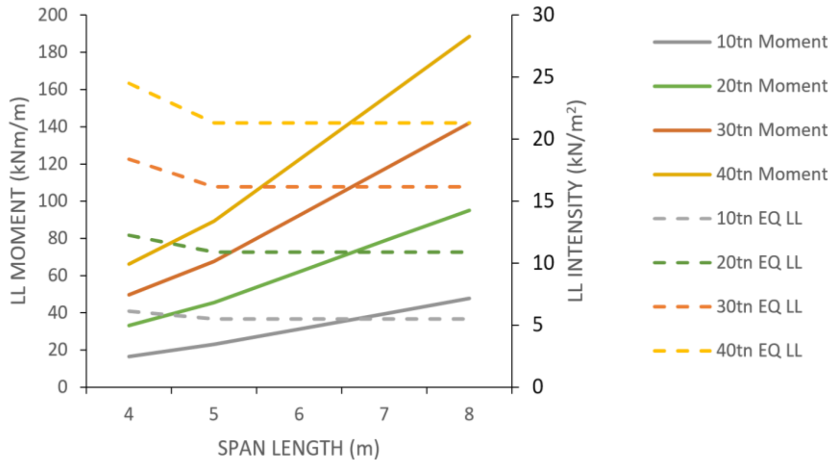

Figure 5: *Graph of moment and equivalent intensity of vehicle load against span*

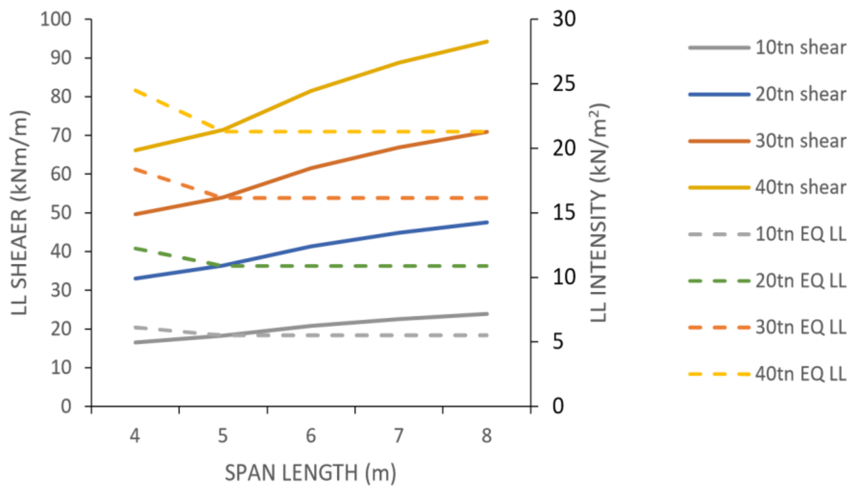

Figure 6: *Graph of shear and equivalent intensity of vehicle load against span*

In general, the equivalent vehicular load intensity and span length are independent. The increase of span length has no noticeable effect on the vehicle load intensity and load intensity is direct proportionate to the corresponding vehicle weight. It is also noticeable that the shear forces increased in linear relationship with the vehicle load intensity whereas the bending moment is in a line that curved upwards in parabola shape. The linear relationship between shear force and span length suggest that slab bridge is subjected to maximum shear due to vehicle located direct above the support abutment which the span length has less noticeable effect on it whereas when the vehicle load which to be applied as influence line located at the mid span introduce maximum moment with the square relationship with the span length. This also indicate that design of slab bridge is governed by bending moment due to vehicle load in compare with shear forces effect.

4.3 Slab Bridge Reinforcement Ratio

Based on the design forces from the analysis, Table 4 summarize the slab bridge deck thickness together with its corresponding reinforcement ratio under varies span length and vehicle loadings

Table 4. Slab Bridge Deck Thickness and Reinforcement Ratio

Vehicle Type	Deck Thickness (mm)	Reinforcement Percentage (%)				
		4m	5m	6m	7m	8m
10tn	375	0.13	0.15	0.25	0.40	0.56
20tn	400	0.14	0.19	0.28	0.44	0.79
30tn	425	0.15	0.20	0.30	0.43	0.74
40tn	450	0.15	0.21	0.30	0.44	0.66

Generally, the rebar ratio is kept as minimum when the span length is less than 4m with the average of 0.15% regardless of vehicle load group and can increase to average 0.7% when span length reached to 8m. The increase of rebar ratio is generally governed by the vehicle loading in compare with permanent loading. The slab thickness required to fulfil the design requirement only increase 25mm or marginally by 6% for different vehicle load group. Hence, appropriate selection of vehicle loading that suitable for the design intent of plantation area is important to achieve optimum and economical slab bridge design for the designated usage.

4.4 Standard Design Table and Detailing

A complete design table with the detailing is shown in Figure 7, Figure 8 and Table 5, 6, 7 & 8. The normal concrete cover (C_{nom}) is 50 mm. Referring to the specific vehicle load group, the designer can determine the thickness of deck slab and its corresponding top, bottom and transverse reinforcements for the chosen span length which varies from 4m to 8m in length.

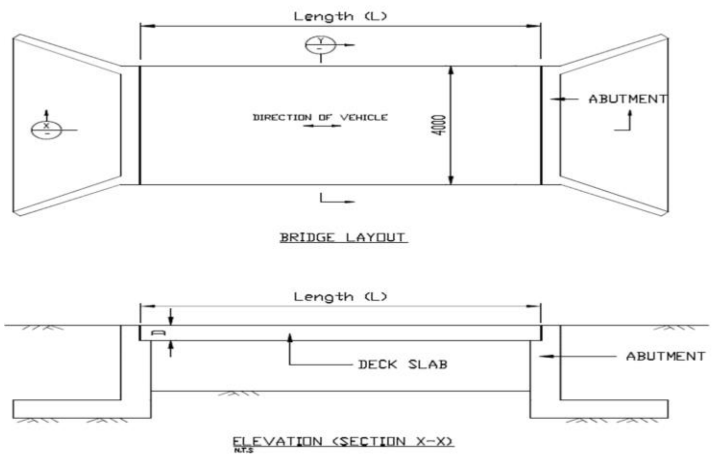

Figure 7: *Standard layout and elevation view of slab bridge*

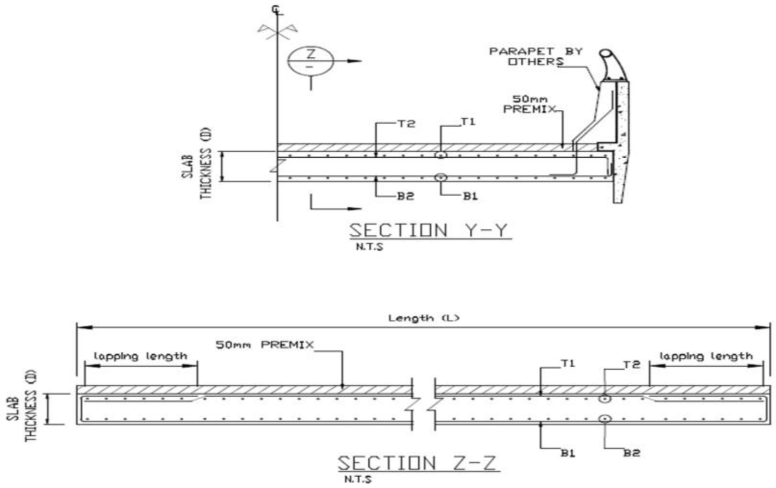

Figure 8: *Standard details of slab bridge*

Table 5 *For Vehicle Group of 10 tons, f_{ck} 32 MPa & f_{yk} 500MPa*

Span, L Length (m)	Slab Thickness, D (mm)	Reinforcements					
		B1 (mm²/ m)		T1 (mm²/ m)		T2 & B2 (mm²/ m)	
4	375	H10-160	491	H10-160	491	H12-200	565
5	375	H10-140	561	H10-140	561	H12-200	565
6	375	H12-120	942	H10-120	654	H12-200	565
7	375	H20-210	1496	H10-115	683	H12-200	565
8	375	H20-150	2094	H10-150	524	H12-200	565

Table 6 *For Vehicle Group of 20 tons, f_{ck} 32 MPa & f_{yk} 500MPa*

Span, L Length (m)	Slab Thickness, D (mm)	Reinforcements					
		B1 (mm²/ m)		T1 (mm²/ m)		T2 & B2 (mm²/ m)	
4	400	H12-200	565	H12-200	565	H12-200	565
5	400	H12-150	754	H10-150	524	H12-200	565
6	400	H16-180	1117	H12-180	628	H12-200	565
7	400	H20-180	1745	H12-180	628	H12-200	565
8	400	H20-100	3142	H10-100	785	H12-200	565

Table 7 *For Vehicle Group of 30 tons, f_{ck} 32 MPa & f_{yk} 500MPa*

Span, L Length (m)	Slab Thickness, D (mm)	Reinforcements					
		B1 (mm²/ m)		T1 (mm²/ m)		T2 & B2 (mm²/ m)	
4	425	H12-180	628	H12-180	628	H12-200	565
5	425	H12-130	870	H10-130	604	H12-200	565
6	425	H16-160	1257	H12-160	707	H12-200	565
7	425	H20-170	1848	H12-170	665	H12-200	565
8	425	H20-100	3142	H10-100	785	H12-200	565

Table 8 *For Vehicle Group of 40 tons, f_{ck} 32 MPa & f_{yk} 500MPa*

Span, L Length (m)	Slab Thickness, D (mm)	Reinforcements					
		B1 (mm²/ m)		T1 (mm²/ m)		T2 & B2 (mm²/ m)	
4	450	H12-170	665	H12-170	665	H12-175	646
5	450	H12-120	942	H10-120	654	H12-175	646
6	450	H16-150	1340	H12-150	754	H12-175	646
7	450	H20-160	1963	H12-160	707	H12-175	646
8	450	H20-105	2992	H10-105	748	H12-175	646

Referring to the specific design span length and vehicle load group with predetermined concrete and reinforcement characteristic strength, the designer then can select the suitable slab thickness, top, bottom, and transverse reinforcement required.

5.0 Conclusions

Normal highway loading appears to be too conservative to be applied for plantation bridges. Directly apply the highway traffic loading led to uneconomical design and over sizing of the structure and is not reflecting the actual case of the slab bridge application for plantation area. Based on the weight and characteristics of the varies common vehicle especially transporting goods and machinery vehicle in agricultural area, the vehicle loadings from 10 tons to 40 tons is more reasonable for the slab bridge analysis and design. Thickness of slab bridge can keep minimal due to optimising in traffic load application that are closer to actual condition on site. In addition, there are also findings obtained from the results which lead to identification of effect of each design parameters to the slab bridge design outcome together with its limitation. Selection of proper traffic load is crucial for short and medium span bridges. Vehicular live load is the most significant component of design load and affect the outcome of design. The analysis and design of the slab bridge elements has been successfully performed for slab bridge for the specified actual vehicle loading.

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