A SIMPLE METHOD FOR RATING OF REINFORCED CONCRETE SLAB BRIDGES

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ABSTRACT

There are over 180 reinforced concrete slab bridges under the jurisdiction of the Roads and Traffic Authority of New South Wales (RTA). Of these bridges about 70 were built prior to 1948 when the design loading was between 16 and 17 tonnes.

The aim of the project is to develop a quick and a simple method to determine the rating of the reinforced concrete slab bridges. Yet this method needed to be safe and be able to deliver realistic results.

This paper discusses three different assessment methods used for a typical concrete slab bridge, which was earlier proof load tested by the RTA. These methods are the NAASRA 1976, Linear Grillage (LG) analysis and Effective Width Method (EWM). The results obtained from these methods are compared with the rating obtained from the proof load testing of this bridge.

Finite Element Analysis (FEA) of a bridge will give rating close to that obtained from a Proof Load Test. However, this is time consuming and is therefore suitable for rating of an individual bridge. Of the three methods compared, the EWM has the advantage of being is easy to apply, less time consuming, reliable and conservative and is therefore suitable for load rating of a group or groups of reinforced concrete slab bridges.

It is therefore concluded that the 'EWM' is a suitable method for load rating of a group or groups of concrete slab bridges.

BIOGRAPHIES

Wije Ariyaratne, ***Manager, Bridge Engineering, Bridge Section, RTA Operations***

Wije Ariyaratne is a graduate in Civil Engineering from the University of Ceylon and has a Masters degree in Structural Engineering from the University of NSW and a Graduate Diploma in Business from the Deakin University.

Prior to joining the Roads and Traffic Authority of NSW (RTA) in 1972, he had five years experience in the design and construction of maritime structures in Sri Lanka.

Since joining the RTA he has had wide experience in design, investigation, construction, contract administration, operations and evaluation and load assessment of bridges.

Since 2000 he has been the Manager, Bridge Engineering leading the Bridge Section and providing the RTA with input and high level advice necessary for the development of strategies for the effective and efficient operation and maintenance of the RTA $4.5 B bridge assets.

He represents the RTA on AUSTROADS and Standards Australia committees. He is also a visiting lecturer at the University of Technology, Sydney and has fourteen technical publications to his credit.

Parvez Shah, ***Manager, Bridge Evaluation and Assessment, Bridge Section***

Parvez Shah is a graduate in Civil Engineering from Bangladesh and has a Master of Engineering in Structural & Construction Management from Asian Institute of Technology, Thailand and a Graduate Diploma in Business & Technology Management from Deakin University, Australia.

He was engaged by World Bank as a local consultant of Hazra International for Infrastructure Master Plan for Bangladesh after graduation. Since joining RTA he has had fourteen years experience in bridge engineering. He was responsible for structural design for more than forty structures including two Voided slab bridges at Yass Bypass, Viaduct on Homebush Bay Drive, support structure for noise wall on Anzac Bridge arterial. He had extensive experience in instrumentation and load testing of different types of bridges. He has successfully conducted load testing of forty-nine bridges in NSW for RTA, local councils and Railways.

He is the Manager, Bridge Evaluation and Assessment Unit of the Bridge Section since July 2000 and he has published six technical papers for international and national conferences.

Vijay Kodakalla, ***Project Engineer, Bridge Evaluation and Assessment, Bridge Section***

Vijay Kodakalla is a graduate in Civil Engineering and postgraduate in Structural Engineering. He also holds a Graduate Diploma in Information Technology from the University of Technology, Sydney. He has more than 20 years of work experience in the design, design management, inspection and assessment of bridges.

He was responsible for the design and design management of bridges on Expressway projects on the National Highways in India, funded by World Bank. He was associated in the design, design management of bridges in the infrastructure projects such as M2 Motorway in Sydney, Pacific Motorway and Melbourne City Link.

Since joining the Roads and Traffic Authority in 1998, he has been involved in the rating of various types bridges and assessment of routes for the movement of various types of heavy loads, Mass Limit Review of B-Doubles, B-Triples and Cranes.

He has a published paper in the International Seminar on 'Bridge Structures and Foundations' organised by the Institution of Bridge Engineers.

1. Introduction

There are over 180 reinforced concrete slab bridges under the jurisdiction of the Roads and Traffic Authority of New South Wales (RTA). Of these bridges about 70 were built prior to 1948 when the design loading was between 16 and 17 tonnes.

The rating of the pre 1948 slab bridges using NAASRA 1976 method is observed to be very conservative when compared with any other method.

The aim of the project is to develop a quick and a simple method to determine the rating of the reinforced concrete slab bridges. Yet this method needed to be safe and be able to deliver realistic results.

2. Bridge selected for study

The bridge over Mulyandry Creek is a five span Reinforced Concrete (RC) Slab Bridge built in 1940 with 6.0m span and a carriageway width of 6.71m between the kerbs and it carries two lanes of traffic. A photograph of the bridge is shown in ***Figure 1***.

This bridge was selected as it represents about twenty RC slab bridges in RTA road network and it was proof load tested in 1998.

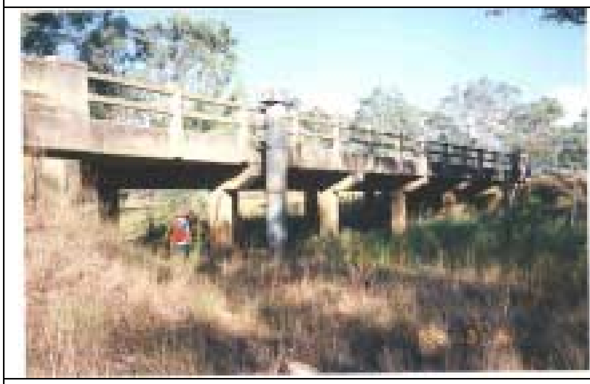
	
Mulyandry Creek	Proof Load Testing over the Bridge

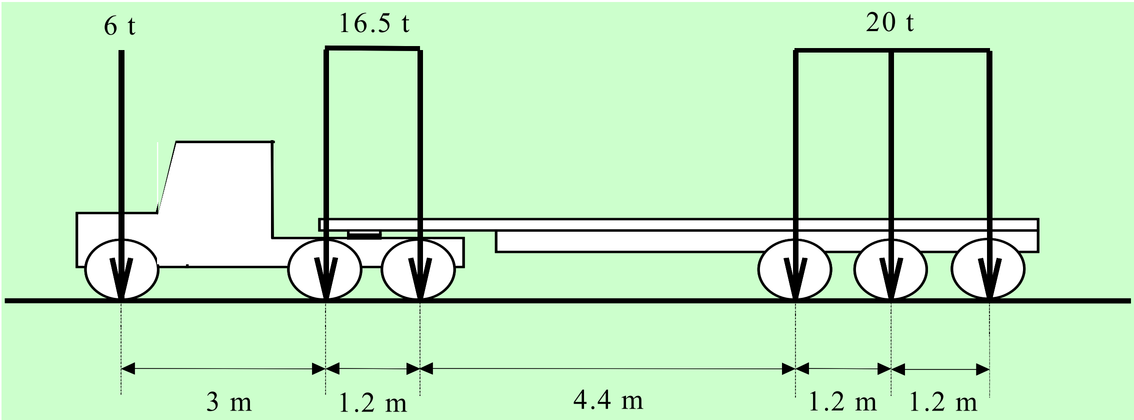
Figure 1: Mulyandry Creek photos

Material strengths:
The concrete compressive strength (concrete Class 'A') f'_c = 17.24 MPa
The yield strength of mild steel reinforcement is not given on the drawings but a value of f_{sy} = 230 MPa is assumed based on the code used at that time.

3. Loads

The loading considered in the analysis included self weight of the structure (DL), superimposed dead load (SDL) and live load of a general access vehicle 42.5t semi-trailer (ST 42.5). The axle loads and spacing for this vehicle are given in ***Figure 2***.

ST42.5 has been used in the study, as it is the critical legal load on short to medium span bridges. The live load factors are determined for ST42.5 based on ultimate limit state in accordance with the Australian Bridge Design Code (ABDC) 1996.



ST42.5t is a six axle articulated vehicle with GVM 42.5t

Figure 2. Semi-Trailer 42.5t

A dynamic load allowance of 25% of the live load was used based on the first natural frequency of the structure. The worst live load case comprised of two trucks passing over the bridge simultaneously.

The critical longitudinal positions and axle locations are shown in ***Figure 3***.

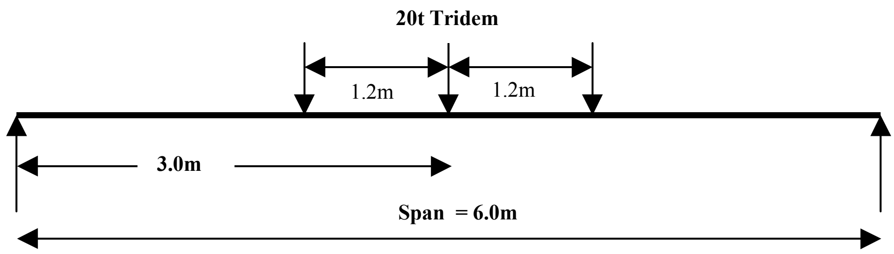


Figure 3. Critical load position for maximum bending moment

4. Rating Equation

The concept of rating is based on ultimate limit state design principle that the assessed minimum capacity of the bridge must be greater than the assessed maximum load effects. Both bending and shear has been considered for RC slab bridge and it has been determined that the critical mode of failure for this bridge is bending.

For bending the rating equation is:

$$\Phi\, M_u \geq M_{1.2xDL} + M_{1.4xSDL} + \gamma_{LL}\, M_{1.25x0.9xLL} \qquad (1)$$

Where

Φ = Capacity reduction factor = 0.8

γLL = Live Load Factor (> 2.0 as per ABDC 1996).

M_u = Ultimate moment capacity of the cross section per metre width

$M_{1.2xDL}$ = Ultimate moment due to dead load

$M_{1.4xSDL}$ = Ultimate moment due to superimposed dead load

$M_{1.25x0.9xLL}$ = moment due to live load including dynamic load allowance (1.25) and lane modification factor for two lanes loaded (0.9)

Therefore

$$\gamma LL = (\Phi M_u - M_{1.2xDL} - M_{1.4SDL}) / M_{1.25x0.9xLL} \qquad (2)$$

5. ANALYTICAL RATING METHODS

The bridge was analysed using the following analytical methods. The methods are described below.

5.1 Empirical Method in NAASRA (1976) Bridge Design Code

The NAASRA BDC Art. 3.3.4.1 (b) specifies the following formula to evaluate the design bending moment per width, when the main reinforcement is parallel to traffic.

$$\mathbf{M/2E} \text{ KNm} \qquad (3)$$

Where

M = the design longitudinal moment per design lane determined by suitable analysis using appropriate standard Vehicle loading.

E = 1.22 + 0.06S (max 2.1m)

S = span (m)

5.2 Grillage method of analysis

The grillage analysis is performed using Microstran V7. The deck slab is modelled with ten longitudinal beams and two edge beams. Transversely the deck has been modelled with nine beams and this is considered appropriate to the span to width ratio of 0.83. The effective widths for calculation of inertias are shown in ***Figure 4***.

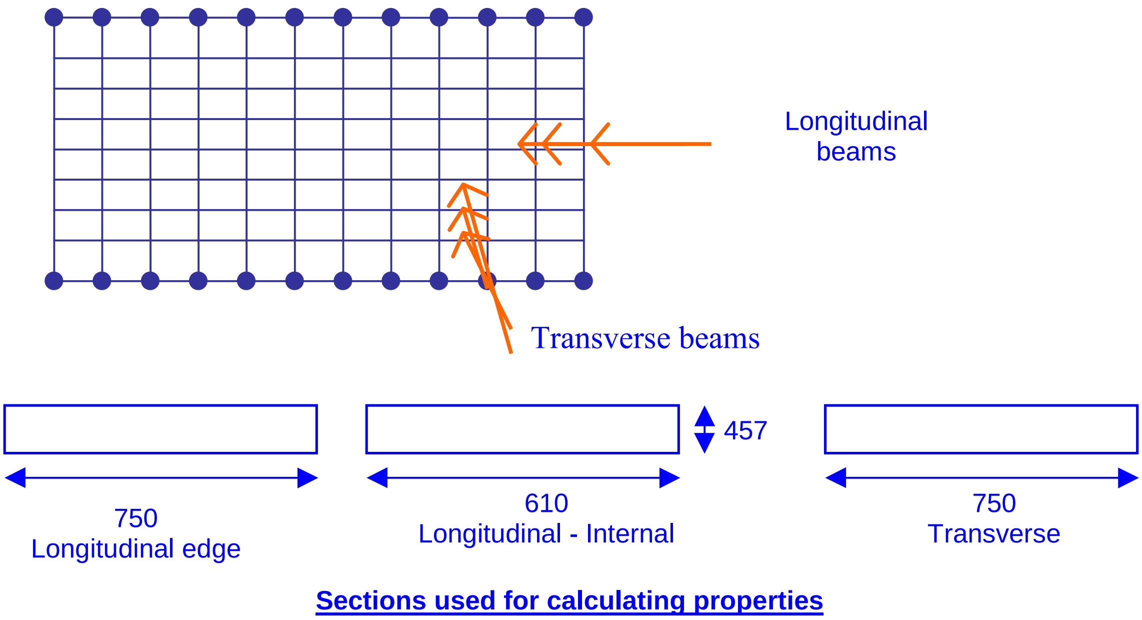
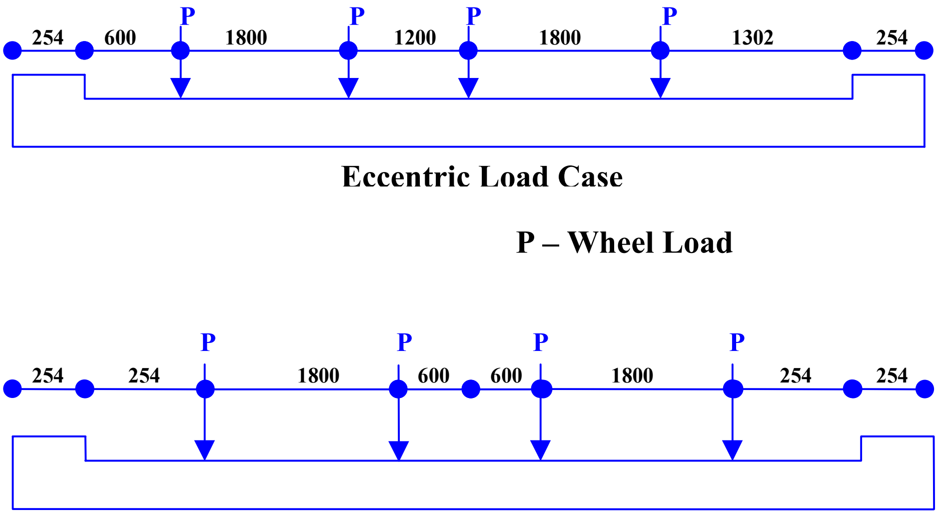


Figure 4. Grillage Model

The live load ST42.5 is applied on the grillage using the moving load generator for two load cases, one 0.6m from the kerb and the other of symmetrical loading as shown in ***Figure 5***.



Eccentric Load Case

P – Wheel Load

Symmetrical Load Case

Figure 5. Critical Load Cases

The maximum bending moment obtained from the above analysis is then calculated per metre width of the slab for comparison with the other methods. The values are tabulated in ***Table 1***.

5.3 Effective Width Method (EWM) of Analysis:

The analysis of moments and shears under concentrated loads is a statically indeterminate problem and to obtain an accurate solution for support conditions in practice is very time consuming and complex. A semi-empirical method can be used when a slab is supported on two opposite edges only.

When a concentrated load acts on the slab, the slab deforms like a saucer. Under a vertical load a slab will have curvature in the direction of the span as well as at right angles to it. Thus bending moments in the slab are created in the direction of the span and normal to it. Accordingly, EWM considers the load distribution on the strip below the load and either side of it. It is therefore assumed that the load is supported by a certain width of the slab, known as the effective width. The details of the effective width of the slab are shown in ***Figure 6***.

If the effective width is known, then the moments in the direction of the span can be calculated using the line beam analysis.

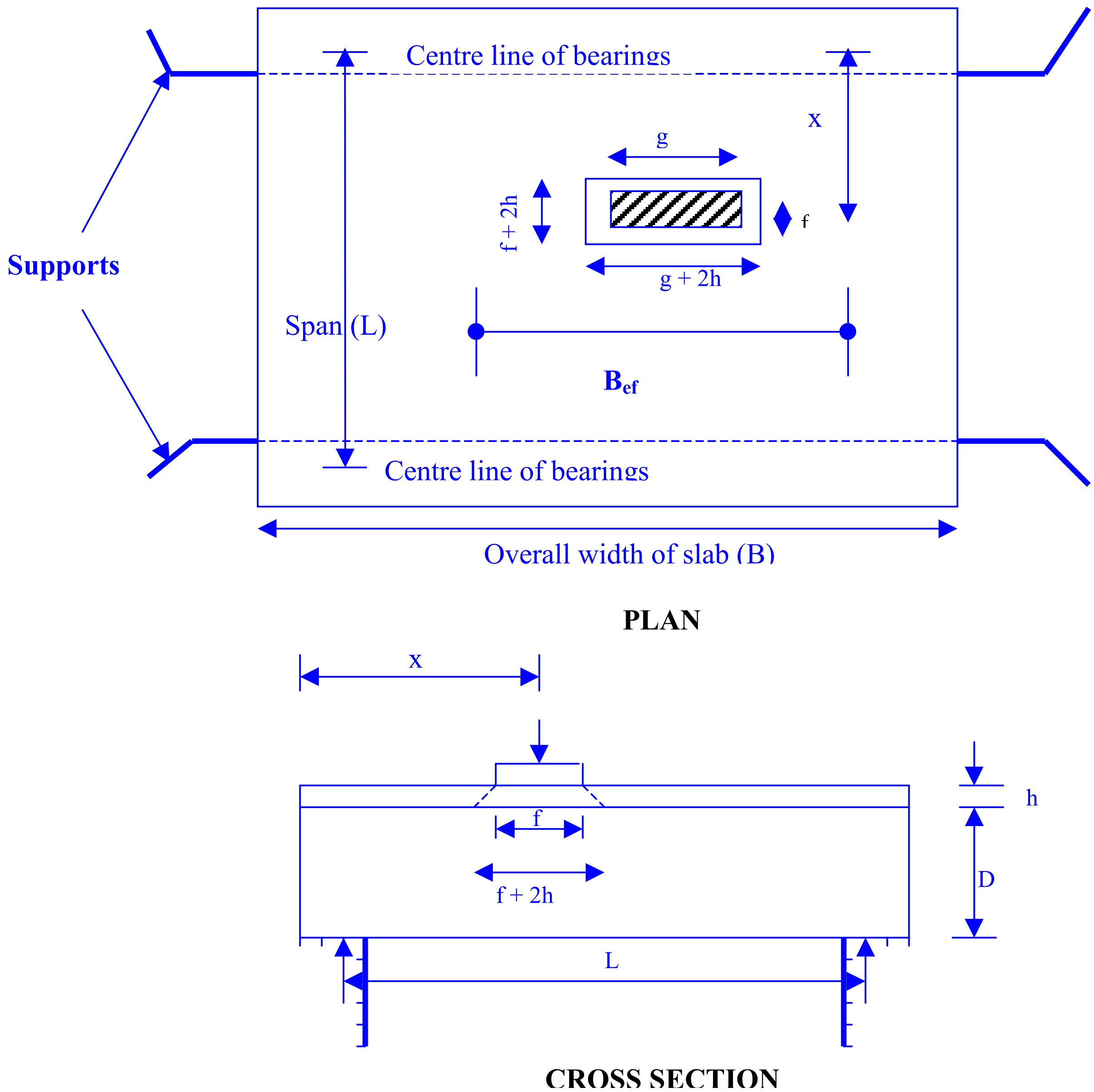


Figure 6 – Effective width of slab

Dispersion across the deck:

For a single concentrated load the effective width **(B_{ef})** is given by

$$B_{ef} = K\ \mathbf{x}\ (1 - \mathbf{x}/L) + b_w \qquad (4)$$

Where

'**x**' is the distance of the centre of gravity of load from the nearer support.

'**L**' is the span

where

L = Clear span for continuous slabs

L = centre to centre of bearings for simply supported spans

'b_w' = (g + 2h),

'**g**' is the length of area of contact of the tyre on the road surface at right angles to the span

'**f**' is the length of area of contact of the tyre on the road surface along the span
'**h**' is the thickness of the wearing surface.
'**B**' is the overall width of the deck.

'**K**' is a constant depending upon the **B/L** ratio and the type of span (simply supported or continuous) – the values can be obtained from the table 2 in Appendix.

Dispersion along the deck:
The dispersion of load along the span of the slab may be taken as follows

$$\mathbf{L_{ef} = f + 2\,(h + D)} \qquad (5)$$

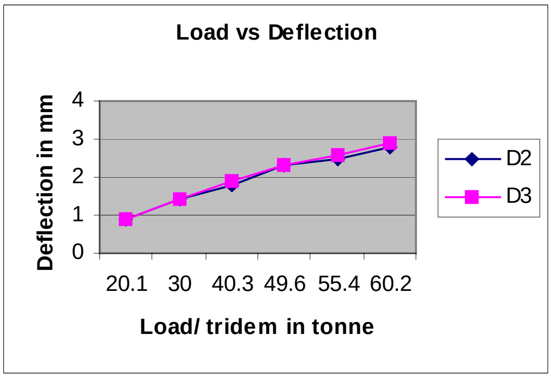
Where
'**D**' is the overall depth of the slab deck.

An analysis of the Mulyandry Creek Bridge using the effective width method is included in the appendix.

6. Proof Load Testing

In proof load test the bridge is carefully and incrementally loaded in the field to a pre-determined target proof load. The effects of these loads on critical members of the bridge are measured by instrumenting these members and monitoring them in 'real' time to ensure that the structure behaves linear- elastically at all stages of loading.

The bridge was incrementally loaded for a maximum load of 60t on the tridem, which was the maximum load allowable on the tridem of the test truck. The results obtained throughout the mid span of the slab in terms of deflection and strain showed linear behaviour. The Load vs Deflection and Load vs Strain at mid span are shown in ***Figure*** *7*.



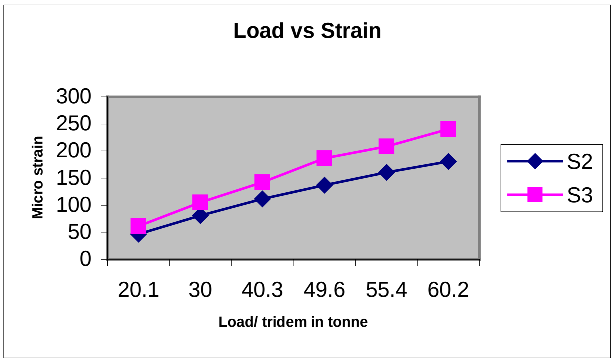


Figure 7. Load Vs Deflection and Strains

From the maximum applied load, the actual live load factor (γLL) for legal load of 20t on the tridem was determined by making allowances for dynamic load allowance and the multiple lane reduction factor.

7. Comparison of Live load factors determined from Analytical and Proof load test

The results of the live load factor obtained by the above analytical methods and proof testing are tabulated in ***Table 1*** below.

Table 1 - Values of the live load factor (γLL)

Method	Capacity ΦM_u	$M_{1.2xDL}$	$M_{ST42.5}$	$M_{1.25x0.9xLL}$	γLL
NAASRA 76	182	60	69	77	1.59
Grillage	182	60	56	63	1.94
EWM	182	60	57	64	1.91
Proof load testing		60			2.64

Note: The superimposed dead load is $M_{SDL} = 0$
The moments are per width of slab.

8. Conclusions

- The live load factor obtained from NAASRA 76 is very low in comparison with that obtained from the proof load test.
- Grillage analysis is time consuming and is more suitable for evaluation of an individual bridge rather than a group of bridges.
- Effective width method of analysis compares well with the grillage analysis and is simple and quick to obtain results.
- The live load factors obtained by EWM are lower bound.
- This method can be made adoptable to continuous slabs, by modifying the span and selecting a suitable K value for continuous spans.
- This method can also be extended to pseudo slabs, by modifying the effective width in the ratio of transverse to the longitudinal stiffness of the pseudo slab.

9. Recommendation

The 'Effective Width Method' is suitable for load rating of groups of concrete slab bridges and pseudo slab bridges.

10. Disclaimer

The opinions expressed in this paper are entirely those of the authors, and do not necessarily represent the Policy of the Roads and Traffic Authority of NSW.

11. Acknowledgements

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APPENDIX

RC SLAB BRIDGE OVER MULYANDRY CREEK

Data:

Span:	Centre to centre of piers	=	6.25m
	Centre to centre of dowels (L)	=	5.99m
	Clear span	=	5.75m
Overall depth of slab (D)		=	457mm
Maim longitudinal reinforcement		=	22.2mm @152 mm c/c MS bars
Effective depth		=	408mm
Area of steel /m width		=	$2553mm^2$
$p = \frac{A_{st}}{bd}$		=	6.26×10^{-3}

Material:

Comprehensive strength of concrete f'_c (Class A concrete)	=	17.24MPa
Yield strength of reinforcement f_{sy}	=	230 MPa (assumed)
Bridge Data: Carriageway between kerbs	=	6.71m
O/A width of deck (B)	=	7.22m
Surfacing above in deck (h)	=	nil

Dead Loads:

Uniformly distributed load due to self weight of:

Deck slab = 0.457 x 24.5	=	11.2 kN/m^2
Dead load moment	=	$0.125 \times 11.2 \times 5.99^2$
	=	50KNm
Factored dead load moment $M_{1.2XDL} = 1.2 \times 50$	=	60 KNm
Factored super imposed dead load movement $M_{1.4XSDL}$	=	0

Moment Capacity of Deck Slab:

ΦM_u $= 0.8 \text{ p } bd^2 f_{sy} (1 - 0.6p \frac{fsy}{f'c})$

$= 0.8 \times 6.26 \times 10^{-3} \times 1000 \times 408^2 \times 230 \times (1 - 0.6 \times 6.26 \times 10^{-3} \times \frac{230}{17.24}) \times 10^{-6}$

ΦM_u = 182 KNm/ 'm' width

Net allowable Live Load Movement Capacity = 182 - 60

$= \Phi M_u - M_{1.2XDL} - M_{1.4XSDL}$ = 122 KNm/ 'm' width

Live Loads:

Effective Width Method of Analysis:
The Analysis consists of finding maximum bending moment and shear force at critical sections due to wheel loads. The dispersion of a single concentrated load, for solid slabs spanning in one direction can be worked out using Eq. 4.

where

B_{ef} – Effective width of slab on which load acts.
L – Effective span = 5.99m
b_w – Breadth of concentration area of load
= Tyre contact area over the road surface of slab in direction at right angles to the span plus + twice the thickness of surfacing
= 400 + 2 (0) = 400 mm

(Thickness of surfacing = NIL)

x Distance of c.g. of load from the nearer support
K Constant depending upon the B/L ratio
B Is over all width of slab – 7.21m

$$B/L = \frac{7.21}{5.99} = 1.2$$

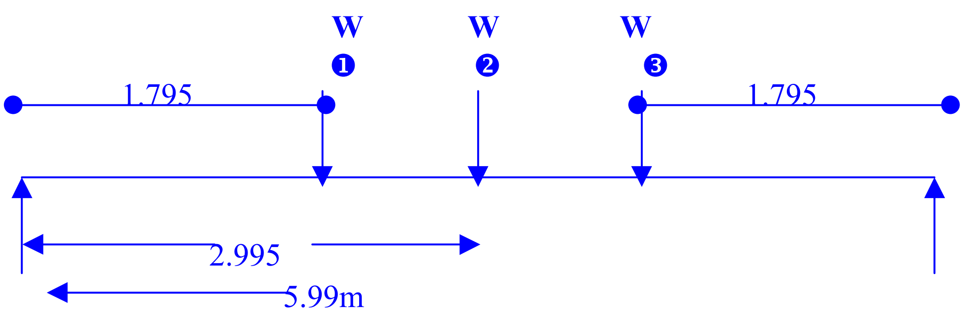
K = 2.64 for simply supported slabs from Table 2

Table 2 - Values of K

B/L	*k* for simply supported slab	*k* for continuous slab	*B/L*	*k* for simply supported slab	*k* for continuous slab
0-1	0.40	0.40	1.1	2.60	2.28
0.2	0.80	0.80	1.2	2.64	2.36
0.3	1.16	1.16	1.3	2.72	2.40
0.4	1.48	1.44	1.4	2.80	2.48
0.5	1.72	1.68	1.5	2.84	2.48
0.6	1.96	1.84	1.6	2.88	2.52
0.7	2.12	1.96	1.7	2.92	2.56
0.8	2.24	2.08	1.8	2.96	2.60
0.9	2.36	2.16	1.9	3.00	2.60
1.0	2.48	2.24	2 and above	3.00	2.60

Dispersion of load along span from Eq. 5

Def = 200 + 2 (0 + 457) = 1114mm. Say '1.2m'



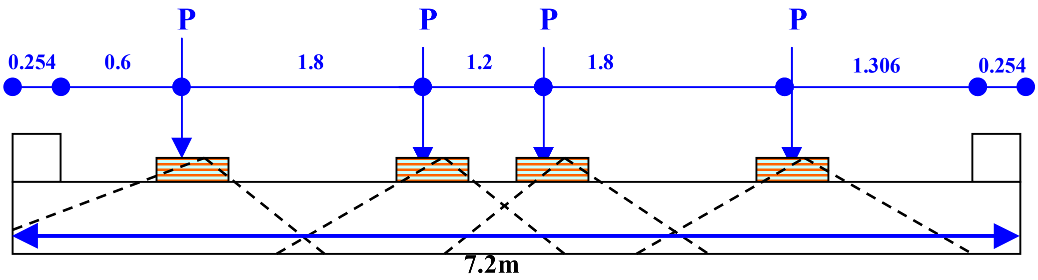
Wheel Load ❶ & ❸

$x = 1.795m$

$b_w = 0.4m$

$L = 5.99m$

$$B_{ef1} = 2.64 \times 1.795 \left(1 - \frac{1.795}{5.99}\right) + 0.4 = 3.72m$$



P is wheel load.

W = 2P – axle load

Placing the two lanes eccentrically.

Dispersion width = 0.854 + 1.8 + 1.2 + 1.8 + 1.56 = 7.51 > 7.21

$\therefore$ effective width = 7.21m

$$\text{Load/m (max)} = \frac{2 \times 65.4}{7.21} = 18.14 \text{ KN/m width}$$

Wheel Load ❷

$x = 2.995m$

$b_w = 0.4m$

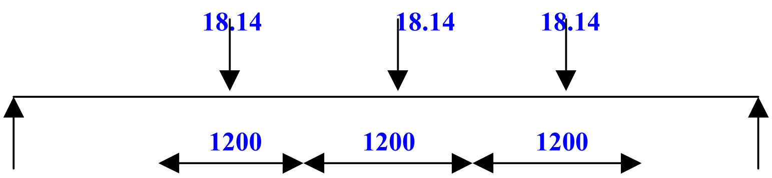
$L = 5.99m$

$B_{ef2} = 4.35m$

Dispersion width = 0.854 + 1.8 + 1.2 + 1.8 + 2.175 = 7.83 > 7.21

= $\therefore$ effective width = 7.21m

$$\text{Load/m} = \frac{2 \times 65.4}{7.21} = 18.14 \text{ KN/m}$$



$$RA = \frac{3 \times 18.14}{2} = 27.2 \text{ KN}$$

$$M = 27.2 \times \frac{5.99}{2} - \frac{18.14}{1.2} \times 1.8 \times \frac{1.8}{2} = 81 - 24 = 57 \text{ KNm}$$

$$\gamma LL = \frac{182 - 60}{57 \times 1.25 x 0.9} = 1.91$$ (Dynamic Load Allowance = 25% and Lane modification factor = 0.9)

$$\text{Rating} = 6.0 + \frac{1.91}{2.0} \times 36.5 = \underline{\underline{ST41}}$$