Strengthening of Bridge over Iron Cove, Sydney NSW - A Realistic Design Load

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ABSTRACT

The bridge over Iron Cove on Victoria Road consists of seven steel truss spans of 52m and four continuous plate girder approach spans of 18m. The bridge has a carriageway width of 13.7m between kerbs and it carries four lanes of traffic. In addition it has one 3.1m wide dedicated BUS lane on the southern side and one footway on the northern side. The bridge is on a major arterial road and carries B-Doubles. The bridge was built in 1955 when the design load was MS18 (33t), which was significantly less than current legal loads (eg 42.5t Semi-Trailers and 62.5t B-Doubles).

Generally, strengthening of bridges is carried out in accordance with the 1996 AUSTROADS Bridge Design Code ('96 ABDC). However, because of the earlier studies conducted in assessing the bridge, it was evident that strengthening the bridge as per '96 ABDC would have been exceptionally expensive. In addition, it was thought that the bridge would not experience the live loads stipulated in the '96 ABDC for the next 50 years or during its expected life.

Therefore, the Bridge Section proposed a realistic method of determining live loads for strengthening the bridge for legal loads based on the current legal loads experienced by the bridge, the probability of multiple presences of legal loads and the predicted future growth of legal loads over the route.

The method was to conduct a traffic survey of the bridge for four weeks and determine the actual legal loads on the bridge and determine the multiple presences of these loads on different lanes. From this data projected legal loads, their multiple presences and the probability of occurrences were estimated. The client accepted the method, the traffic survey was completed and the bridge is currently being designed by the Bridge Section for the projected future legal load combinations.

This realistic approach will result a significant saving in the strengthening of the bridge. This paper discusses the use of the approach and it is believed that the use of such an approach would be beneficial in strengthening other similar bridges with more than two lanes of traffic.

BIOGRAPHIES:

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

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, Australia.

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 & 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.

Henry Fok, ***Project Engineer, Bridge Evaluation & Assessment, Bridge Section***

Henry Fok is a chartered civil and structural engineer with experience in civil, structural and foundation engineering. He has 23 years of work experience, of which 10 years have been in Malaysia and 14 years in Australia. In Malaysia, his experience covered the construction, supervision and design of bridges, roads, buildings, ports, underpinning works to existing foundations and water-retaining structures. In Australia, he was involved in the design of the 70 storeys World Tower (Square) in Sydney. Since joining the RTA of NSW in 1990, he has specialised in the areas of bridge evaluation, testing and rehabilitation.

INTRODUCTION

This paper discusses the strengthening of a major bridge based on findings from two different methods of determining a suitable design live load for its strengthening. The first method used the lane factors from the design code and the second method used statistical analysis based on traffic survey. These two methods gave different requirements of strengthening and there is a significant cost difference between them.

The first method in the analyses was based on the multiple lane factors of '96 AUSTROADS Bridge Design Code ('96 ABDC). This is normally the approach for determining design loads for bridges in Australia. In designing a bridge, this code specifies design vehicles on the number of traffic lanes with relevant lane modification factors for multiple lanes.

The second method in the analyses was based on actual traffic survey carried out over a representative period of four (4) weeks. This survey measured the types and frequency of vehicles crossing the bridge. The results of the survey were analysed and, using laws of probability, the future likelihood of different combinations of vehicles on different lanes were estimated. Concurrence of the client and the traffic planners was obtained for the bridge to be strengthened for this combination of live loading.

1 BRIDGE DESCRIPTION

The Bridge over Iron Cove is a major bridge on a major arterial route in Sydney. It was built in 1955 to accommodate 4 traffic lanes. It has 4 plate girder spans and 7 steel truss spans. In 1970s, one external traffic lane was added to the upstream side of the bridge, mostly for the use of buses. This external lane is supported on cantilevers from the original bridge.

The elevation and cross-section of the bridge are shown in ***Figure 1* and *2*** below. The sequence of span is 2 x 18m continuous plate girders, 7 x 52m steel trusses simply supported and 2 x 18m continuous plate girders. The plate girder spans consist of two main built-up girders supporting the cross girders. The truss spans have 7 panels each and the truss members are built from welded members.

Figure 1: Bridge Elevation

Figure 2: Cross section of Bridge looking towards Sydney

2 LOADINGS CONSIDERED FOR STENGTHENING

Generally, strengthening of bridges is carried out in accordance with the '96 ABDC. However, because of the earlier studies conducted in assessing the bridge, it was evident that strengthening the bridge as per the ABDC would have been exceptionally expensive. It was also thought that the bridge would not experience such a magnitude and combination of loading during its expected life span of 50 years. Accordingly, no detail investigation in accordance with the ABDC was carried out.

The two options of loadings considered were:

(a) current legal loads semi-trailers 42.5t (ST42.5) and B-doubles 62.5t (BD62.5) on all lanes with the application of multiple lane reduction factors as per '96 ABDC.

(b) current legal loads ST42.5 and BD62.5 on different lanes as determined by the traffic survey and with the application of probability principles and due consideration being given to the future growth of traffic on the route.

Vehicles used in the load assessment are shown in *Appendix A*.

3 RESULTS OF THE ANALYSES BASED ON THE MULTIPLE LANE FACTORS OF '96 ABDC

The structure was analysed in accordance with '96 ABDC Section 7 Rating and using a 3-D Microstran model. The results of the analyses for the truss members for the truss spans are shown in ***Table 1*** below:-

LOAD COMBINATION	LIVE LOAD FACTORS (LLF) < 2
4xB-Doubles on internal lanes + 1x26t bus on external lane.	Compression of 2nd verticals = 1.2, Tension of 1st diagonals = 1.35, Tension of 2nd diagonals, compression of principal, top chord = 1.5 to 1.8.
4xB-Doubles on internal lanes + 1xST on external lane.	Compression of 2nd verticals = 1.0, Tension of 1st diagonals = 1.15, Tension of 2nd diagonals, = 1.2 Compression of principal and top chord varies 1.5 to 1.65.
4xB-Doubles on internal lanes + 1xB-Double on external lane.	Compression of 2nd verticals = 0.9, Tension of 1st diagonals = 1.0, Tension of 2nd diagonals, = 1.15 Compression of principal and top chord varies 1.35 to 1.5.
Comments: 1. The above factors which are less than 2, as required by '96 ABDC, indicate the degree of inadequacy of bridge in carrying the specified load combinations. They are significantly inadequate for the load combinations. 2. The above live loads have been reduced by the Multiple Lane Modification Factors as specified in '96 ABDC. 3. The results indicate heavy strengthening for the above members and this strengthening would be difficult and expensive. 4. The results for the deck members (i.e. deck, stringers etc) and approach spans are not discussed here.	

Table 1: Results of the Analyses for the Truss Members for the Truss Spans

4 REASON FOR TRAFFIC SURVEY

Bridge Section's experience indicates that bridges with such low load factors should show signs of significant distress. Other than some deterioration in the external lane (which is not related to a live loading), inspection of bridge did not show any signs of structural distress in the truss members.

The above observations indicated that either the bridge does not experience ST42.5 and BD 62.5 heavy vehicles, or it is not exposed to the combination of all lanes being simultaneously loaded with such heavy vehicles. However, the bridge is experiencing heavy loads as the bridge is on a B-Double route. Therefore, it was determined that the strengthening the bridge to carry ST 42.5 & BD62.5 vehicles on all lanes simultaneously is not realistic.

Accordingly, the decision was made to conduct a traffic survey of the heavy vehicles on the bridge and determine a realistic loading combination for which the bridge needs to be strengthened with due consideration being given to future traffic growth.

5 TRAFFIC SURVEY

5.1. Purpose:

The traffic survey consisted of conducting a 24-hour traffic count of heavy vehicles on all five lanes over a period of four weeks (25 August 2001 to 23 September 2001). These heavy vehicles were separated into following four types (a, b, c, d) commonly used on the route. They are:

a. Six axle articulated semi trailer (ST42.5t)
b. 62.5t B-Double (BD62.5t)
c. Three axle truck or Bus
d. Two axle truck or Bus

5.2. Analysis of Traffic Data:

Only the traffic counts during the peak hours (6am to 11am and 2pm to 8pm) were considered in the analysis as this will give the highest probability of multiple presence of heavy vehicles on different lanes.

A statistical analysis of the above sample was carried out to determine the probability of occurrence of different heavy vehicles on multiple lanes with consideration being given to the future traffic growth and using the assumptions given below.

Assumptions:

- Speed of vehicles 20 km / hour (to obtain highest multiple presence of heavy vehicles at any position on different lanes of a span).
- A factor of 1.5 was applied to the data to account for future traffic growth and some inaccuracies in traffic survey.

The probability of multiple presence was calculated by two methods, using the Binomial and Poisson Model. The results from both methods were similar. The probability of occurrence was first calculated for one year and then evaluated for 10 to 100 year periods.

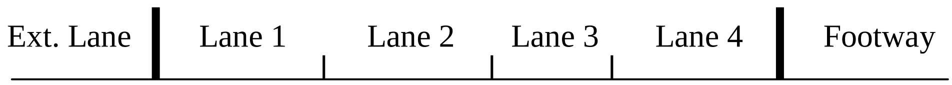
6 RESULTS OF ANALYSIS BASED ON TRAFFIC SURVEY

The structure was analysed in accordance with ’96 ABDC - Section 7 Rating and using a 3-D Microstran model with the following live load combinations determined from the traffic survey.

Load combination on Iron Cove Bridge:

Load case	**Ext. lane**	**Lane 1**	**Lane 2**	**Lane 3**	**Lane 4**	**Probability of occurrence**
Case a	Bus 26t	ST42.5t	ST42.5t	ST42.5t	ST42.5t	2 in 1000 years
Case b	Bus 26t	ST42.5t	BD62.5t	ST42.5t	ST42.5t	2 in 1000 years
Case c	ST42.5t	ST42.5t	ST42.5t	ST42.5t	ST42.5t	Nil in 1000 years
Case d	ST42.5	ST42.5	BD62.5t	ST42.5t	ST42.5t	Nil in 1000 years

Table 2: Loading combination with probability of occurrence



Lane Identification

	Steel Truss span	**Live**	**Load**	**Factor**	**(LLF)**
Mode	Critical Elements	Case a	Case b	Case c	Case d
1^{st}	2^{nd} Vertical (Compression)	1.35	1.30	1.15	1.10
2^{nd}	1^{st} Diagonals (Tension)	1.55	1.50	1.30	1.30
3^{rd}	2^{nd} Diagonals (Tension)	1.65	1.60	1.35	1.3
4^{th}	Top Chord/ Principal (compression)	2.05	1.95	1.75	1.70
	Approach span				
1^{st}	Sagging of main girder	0.8	0.8	0.65	0.6
2^{nd}	Hogging of main girder	1.30	1.30	1.1	1.00
3^{rd}	Sagging of Cross girder	1.85	1.85	1.85	1.85

Table 3: LLF for Different Modes of Failure for Truss and Approach Spans

After reviewing the live load factors for critical members of the bridge for different load combinations as shown in above Tables 2 and 3, it was determined that the bridge should be strengthened for the load Case d. This loading will satisfy all other probable combination of loading expected during the life of the bridge.

Comparison of strengthening required of Steel truss based on '96 ABDC and load combination Case d from Traffic survey is given below in ***Figures 4a*** and ***4b*** respectively.

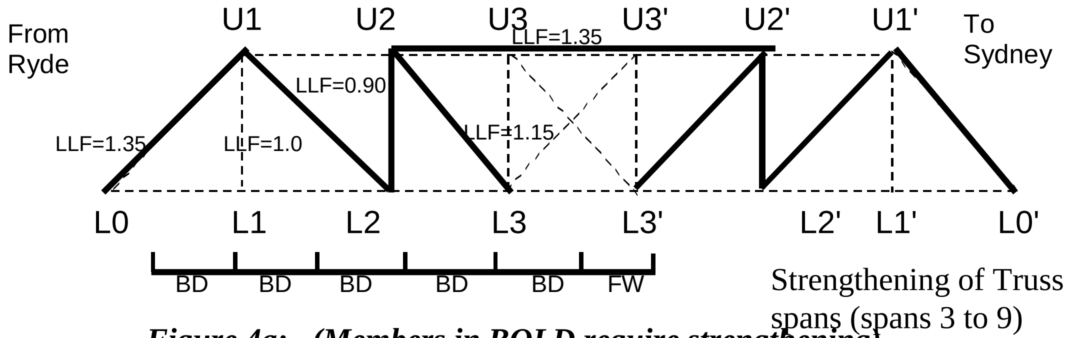


Figure 4a: ***(Members in BOLD require strengthening)***

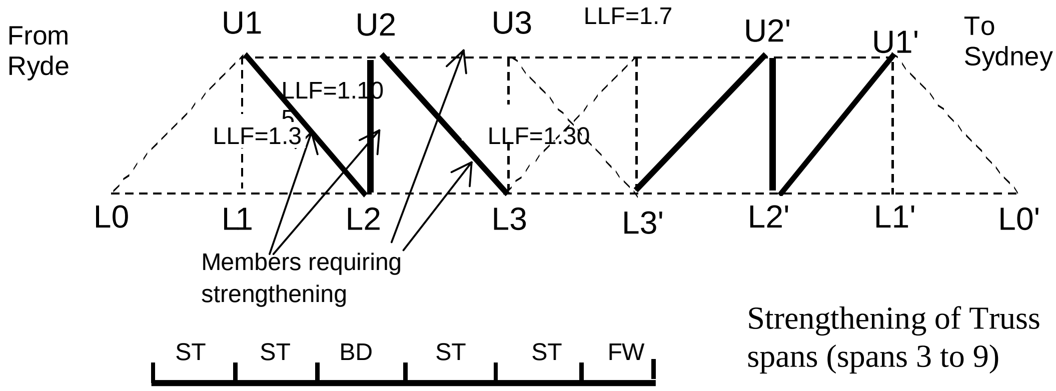


Figure 4b: (Members in BOLD require strengthening.)

8 CONCLUSION

This approach based on a traffic survey will result in a significant saving in the strengthening of the bridge. It can therefore be concluded that the use of such an approach would have significant benefit in strengthening other similar bridges with more than two traffic lanes.

9 ACKNOWLEDGEMENT

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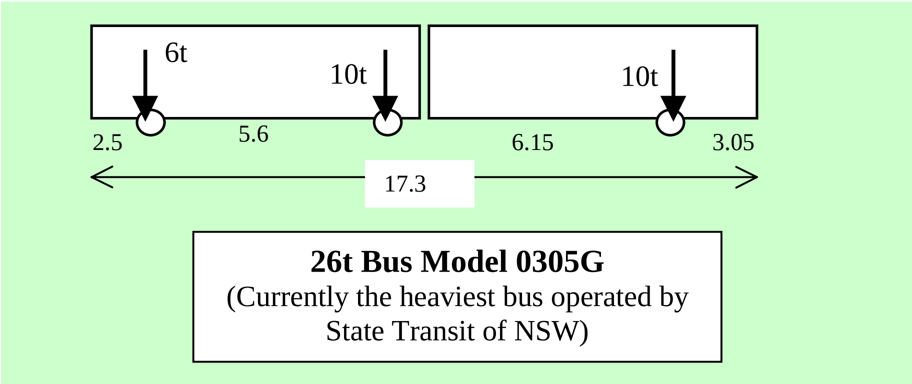
10 DISCLAIMER

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.

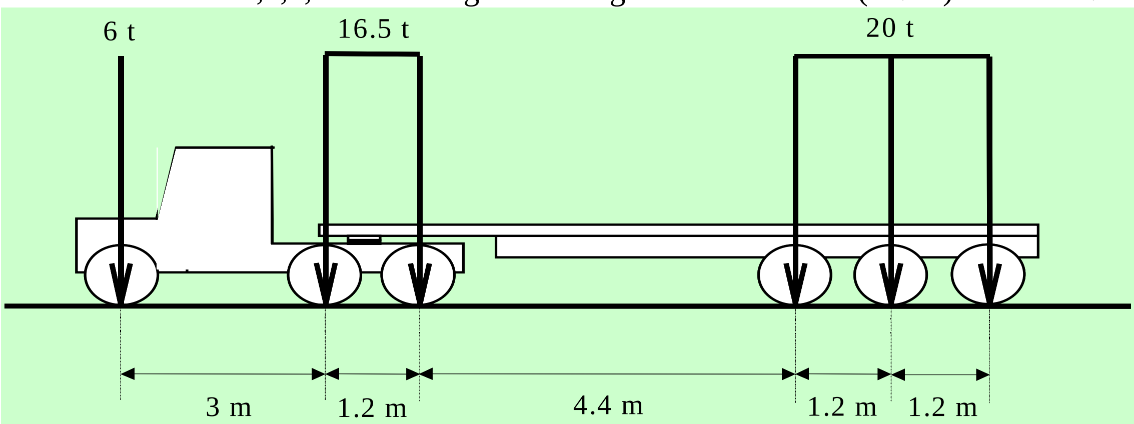
APPENDIX A

VEHICLES USED IN THE ANALYTICAL ASSESSMENT

The design vehicles used in the analyses are shown below:-

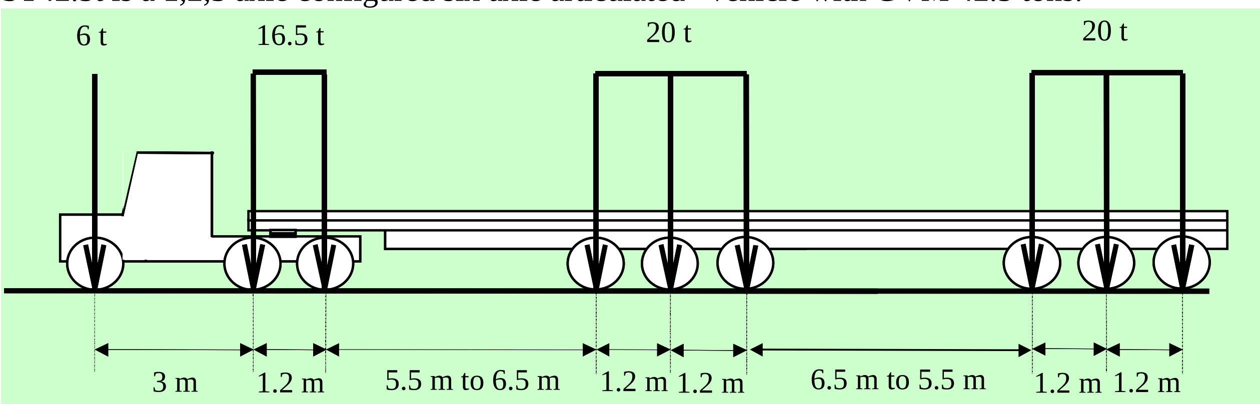


STA BUS 26t is a 1,1,1,1 axle configured with gross vehicle mass (GVM) of 26 tons.



Semi-Trailer 42.5t (ST 42.5)

ST42.5t is a 1,2,3 axle configured six axle articulated* vehicle with GVM 42.5 tons.



B-Double 62.5t (BD62.5)

BD62.5t is a 1,2,3,3 axle configured nine axle articulated* vehicle with GVM of 62.5 tons.