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AUSTRALIA'S NEW BRIDGE DESIGN LOAD - IMPROVING TRANSPORT PRODUCTIVITY

Dr Rob Heywood & Tim Ellis

ABSTRACT

The objective of the research presented in this paper was to develop a new Australian bridge design traffic loading standard for design and construction of Australian bridges. The loading model is expected to set the bridge design standard for the next 25 years for bridges which range from two-lane two-way roads to multi-lane freeways carrying large quantities of heavy vehicle traffic.

This is an important visionary task, an investment for future improvements in transport efficiency, an investment for our grandchildren motivated by the increased transport efficiency that this generation has been able to achieve because of the investment of our grandparents. The challenge is to appropriately and effectively provide for the future in a manner that is consistent with the potential benefits and costs.

This is a study combines the complexities of a range of traffic and vehicle loading scenarios, vehicle loading practices and enforcement, an infinite variety of bridge spans and forms of construction, future unknown vehicle and bridge technologies and develop, in collaboration with AUSTROADS and other interested bodies a recommended way forward.

INTRODUCTION

Trees deliberately felled across streams formed the earliest bridges. Their purpose was to facilitate the movement of people and their produce in a variety of weather conditions. Bridges continue to provide these social and economic benefits. The development of the horse drawn carriage and now the dependence on the car has resulted in bridges becoming wider, longer, and with improved geometrical arrangements. Bridges are becoming stronger as the traffic loads applied to then continue to increase with trends towards longer, heavier vehicles and increased traffic densities.

In Australia, the Mass Limits Review conducted by the National Road Transport Commission recently confirmed that bridges are limiting the productivity of the road transport system - an industry that is estimated to represent up to 20% of Australia's GDP (NRTC 1996). Thus from an economic standpoint (there are also social and environmental benefits), Australia is looking towards (a) the efficient utilisation of its existing bridges and (b) the responsible provision for the future (AUSTROADS 1994). Australia wide, bridge evaluation programs (both analytical and experimental) are currently identifying bridges for strengthening or replacement. The removal of these 'weak links' and controlling the level of overload will permit a more efficient utilisation of Australia's existing bridges.

The efficiency of our current transport system is built on the strength reserves provided by previous generations. Likewise, it is incumbent on this generation to facilitate the international competitiveness of future generations by providing a bridge infrastructure that can safely withstand the truck loads considered likely to be applied during the design life (50 to 100 years) of future bridges. This needs to be achieved within the current economic restraints (i.e. Australia's ability to upgrade its existing pavement and bridge infrastructure as well as the increased cost of new bridges versus the benefits) and the expected developments in truck technology. The general acceptance in Australia of B-doubles and the current trials of B-triples is testament to the continuing innovation in the transport industry.

Earlier studies as part of this project have shown that increases in loads up to 40 t per axle group are likely to be viable (refer to another paper at this conference by Gordon & Boully). These studies included the economic benefits, the increased costs of bridges (less than 5%), pavement costs and vehicle performance / safety issues (Pearson & Bayley, 1997; AUSTROADS, 1997; Doville et. al., 1997). From these studies it has been concluded that the way forward is to ensure that the next generation of bridges have sufficient strength to facilitate the increased productivity of the transport industry rather than provide a limit to its productivity. The cost of providing new bridges for the increased loading standards is understood to be less than 0.25% of road authority expenditure.

This paper presents (a) the heavy vehicles of the future that are suggested to correspond to the end evolution of current road transport technology (b) an overview of the methodology used, (c) a bridge design live load model that is consistent with these vehicles and (d) a comparison of the bending moments and shears induced by these vehicles, the load model and current bridge design loads.

The bridge design live load model presented is an interim model. The final design model will incorporate feedback from a series of workshops to discuss the development of the bridge model.

THE CURRENT SITUATION

The loads applied to Australian bridges has been increasing at a rate of 10% per decade since the beginning of this century. The current bridge design load consists of a 7 t wheel load (W7), a 44 t truck (T44), a 1.25 t/m plus a 15 t concentrated load lane loading (L44) and a 320 or 400 t heavy load platform (HLP320 and HLP400). This design load model has been in place since 1976 with the exception of the HLP loading which was introduced in 1992 (NAASRA, 1976; AUSTROADS 1992a).

Figure 1 Highly productive B-Triples (12333 and 82.5 t) are now operating in Australia

Weigh-in-motion studies have shown that the T44 loading approximates an average extreme daily event for short span structures (Heywood, 1995a & b). The widespread acceptance of B-Doubles and road trains in remote areas, successful trials of B-Triples continue the trend towards longer heavier vehicles. These longer vehicles and observations of closely following heavy vehicles have highlighted short-comings in the current loading model to the extent that most states have constituted a new loading model to deal with these shortcomings. Thus the development of long combination vehicles combined with the imminent increases in axle loads in return for road friendly suspensions and the knowledge of how a weak infrastructure of bridge limits transport efficiency have resulted in the commitment to develop a new bridge loading model.

HEAVY VEHICLES OF THE FUTURE

Pearson & Bayley (1997) defined a series of vehicles based on the average density of the vehicle plus freight. Two families of vehicles featured 40 t axle groups. These became known as L58 (0.58 t/m^3) and S73 (0.73 t/m^3) vehicles (refer **Figure2. and Figure 3.**). These vehicles are believed a reasonable upper limit in terms of the available freight task, vehicle technology and pavement damage. The bridge design live load model is derived from the L58 and S73 series of vehicles. The shorter wheelbase S73 vehicles generally induce the critical effects in bridges and form the basis of the load model.

Of these vehicles, the S73 triple bottom road train (RTS73), the short B-triple (BTS73) and two articulated vehicles (AS73) were significant (refer figure 3.). The gross combination mass (GCM) of these vehicles range from 73 t (AS73) to 205 t (RTS73) with loading intensities up to 5.9 t/m.

The combination mass versus the distance between axles (L) for these vehicles is compared with the current limits for Australian road trains, B-Doubles and general access vehicles (refer **figure 4.**). Also superimposed on this diagram is the envelope associated with European Cranes and the Australian T44, L44 and 3/8HLP400 bridge design loads (AUSTROADS 1997). Thus the loading model represents a significant increase in load for all loaded lengths and would enable the current generation of European cranes to gain general access. It is also noticeable that the T44 and L44 loading are less than that applied by B-Doubles and road trains. The heavy load platform (HLP400) and specialist design loads for road train routes have helped to cover this development.

APPROACH TO THE DEVELOPMENT OF THE LOAD MODEL

General

Investigations based on weigh-in-motion (CULWAY) data indicated that effects equivalent to the current T44 bridge loading were achieved on a daily basis (Heywood, 1995a, b). The load model presented here is likewise developed to represent the average extreme daily event (i.e. the average of the largest events each day).

Studies have shown that the average extreme daily effects induced in bridges by a single lane of traffic can be considered in three groups (refer **Figure 5.**):

a) slightly overloaded individual wheels, axles and axle groups (A to B in figure 5)
b) legally loaded groups of axles or entire vehicles where the distance between axle groups is at a minimum (B to C in figure 5)
c) queues of stationary vehicles (C to D) where the point D is approximately 60% of E where point E corresponds to the load per unit length of a queue of legally loaded vehicles. The value of 60% is dependent on the frequency of traffic queues. It is based on 100 queues per day.

W10 Wheel Load

The critical loading for local bridge elements is an individual axle or wheel. The highest probability of overloading is associated with single axles. This combined with the possibility of asymmetrical loading suggests that an individual wheel should be substantially heavier than the nominal maximum wheel load of 40/6 = 6.7 t (i.e. wheel load on a 40 t tri-axle). Current weigh-in-motion data indicates that the average extreme daily axle load is 20 to 25% greater than the nominal (Heywood 1995a, b). This plus an allowance for asymmetrical loading (15% say) gives a nominal average extreme daily wheel load of 6.7x1.25x1.15 = 9.6 which has been rounded to the 10 t wheel load (W10). This is a 43% increase over the current AUSTROADS W7 wheel loading.

T168 Truck Load

The L58 and S73 vehicles are built around 40 t tri-axle groups. This corresponds to just less than 14 t per axle for a tri-axle group or three AUSTROADS A14 axle loads at 1.2 m centres. Thus a 3x14 = 42 t tri-axle group became the building block for the live load model.

Evidence extracted from weigh-in-motion data indicated that heavy vehicles travel at highway speeds with as little as 5 m between axles (e.g. a 123 followed by a 123 on the Western Ring Road in Melbourne) with distances less than 9.0 m relatively common. Developments associated with intelligent transport systems (ITS) are likely to see platoons of heavy vehicles utilising our highways during the life of this bridge live load model. Thus the bridge live load model should represent both the individual vehicle of the future as well as convoys of the same but subject to more controls.

The model presented in **figure 6**. proved a pragmatic solution to simulate the effects induced by the S73 and L58 vehicles. It features 4x42 t tri-axle groups, a GCM of 168 t, a modular format, a variable spacing between the two halves of the model, all dimensions are multiples of 1.2 m and an overall length of 24 m in its shortest form. The GCM is between that of a BTS73 and a RTS73 but at 7.0 t/m the loading intensity is slightly greater. The central variable axle spacing permits the model to simulate the effects of two vehicles in adjacent spans.

2.4L+109 Lane Load

B-triples (BTS73) and triple bottomed road trains (RTS73) constitute the most intense loading of the S73 and L58 vehicles and were used to define the points C and E in figure 5 with point D taken as 60% of point E. The results are presented in **figure 7** along with queues of other S73 and L58 vehicles.

The simulation studies showed that the relationship between total load (M_{tot} tonnes) and loaded length (L metres) corresponding to average extreme daily queue of stationary traffic was of the form $M_{tot} = aL + b$ where a and b are constants. This is consistent with Australia's current lane loading ($M_{tot} = 1.25L+15$) as well as recent examples from Canada, USA, Japan and Europe.

In the case defined by the S73 vehicles the average extreme daily load applied to a length of bridge (C to D in figure 7.) is as follows:

$$M_{tot} = 2.4L + 109$$

This corresponds to a 109 t truck model plus a uniformly distributed load of 2.4 t/m which extends under the truck. This loading is greater than or equal to one BTS73, one RTS73, two BDS73 at 5.5 m, three AS73 at 5.5 m, five AL58 at 5.5 m (refer figure 7) and queues of BTS73's at 30 m and RTS73's at 45 m all loaded to their proposed legal loads.

The lane load is illustrated in **figure 8**. It consists of 65% of the truck load (T168) plus a uniformly distributed load of 2.4 t/m. The uniformly distributed load is to be applied only to those sections where its application increases the load effect.

Multiple-lane effects

The AUSTROADS Bridge Design Code (1992a) utilises a lane modification factor approach where the total load applied to all lanes is averaged. This contrasts with the accompanying load approach used to model multi-lane events in Europe and the load combination section of the AUSTROADS Code. In the accompanying load approach extreme events are only combined with events that occur frequently. For example, an ultimate limit state vehicle (defined by AUSTROADS (1992b) as the probability of being exceeded in any one year of 0.005) is not assumed to occur simultaneously with an ultimate limit state wind load but rather an average wind load.

In the case of multi-lane events the accompanying load model predicts that an extreme event in one lane is combined with a typical event in adjacent lanes. Simulations of multi-lane queues of traffic confirmed that the accompanying load model was appropriate to model the effects of queues in two or more heavily trafficked lanes. It is recommended that the accompanying load model be applied to multi-lane events as this will result in a more realistic representation of the traffic loading, especially eccentric loads.

It is interesting to note that the accompanying load concept applied to a single lane would suggest that the relatively common uniformly distributed component of the lane load (2.4 t/m) would be combined with a single heavy vehicle. This heavy vehicle would correspond to 109 + 2.4x24 ≈ 168 t or the mass of the proposed T168 truck load.

The proposed accompanying load model generates similar total loads on the bridge compared with the existing lane modification factor model. The proposed model loads the second lane at 80% of the first with additional lanes loaded at 40%. These accompanying load factors (ALF) are compared with the current AUSTROADS lane modification factors (LMF) in Table 1. The ALF are to be applied to both the truck and lane loading.

Table 1 Comparison of Lane Modification Factors and Accompanying Load Factors

No of lanes	AUSTROADS LMF	Equivalent ALF	Proposed ALF	Equivalent LMF
1	1.0	1.0	1.0	1.00
2	0.9	0.8	0.8	0.90
3	0.8	0.6	0.4	0.73
4	0.7	0.4	0.4	0.65
5	0.6	0.2	0.4	0.60

Summary

The proposed bridge loading model consists of a wheel load (W10), a truck load (T168), a lane load (2.4L+109) and accompanying load factors for multiple lanes. The maximum effects of these loads in any element is to be used.

BENDING MOMENTS AND SHEARS INDUCED BY LOAD MODEL

General

Figures 9 to 11 summarise the bending and shears induced by the loading model in selected simply supported and continuous structures with spans up to 50 m. These results can be compared directly with the moments and shears induced by the current design load models. Note that in all these figures the moments and shears have been divided by the span raised to the power of 1.5 for moments and 0.5 for shears. This mechanism simply allows similar scales to be effective over the entire range of spans.

The Max(L58-S73) line is the envelope of the effects induced by single L58 and S73 vehicles. The ‘A14, T44 & L44’ line corresponds to the maximum envelope of the AUSTROADS A14, T44 and L44 loads applied to a single lane. The HLP400 loading has been scaled by a factor of 3/8 for comparison with single vehicles. This has been simply derived by adjusting the load factor (1.5 compared with 2.0) and assuming the HLP loading is applied to two lanes i.e. 1.5/2.0/2 = 3/8. Further factors associated with lane reduction factors (0.9) and differences in dynamic load allowance and the like have not been applied for reasons of simplicity.

Comparison with other bridge design codes

Figures 12. and 13. compare the bending moments and shears induced in simple spans by the bridge design loads from Australia, United States, Ontario and Europe. The loads have been adjusted to account for the variation in the load factors that are applied to give the serviceability limit state for a single lane. For example, the Ontario bridge design code applies a serviceability limit state load factor of 0.75 compared with the 1.0 used in the AUSTROADS Bridge Design Code. Similarly the United States LRFD code increases the load applied to a single lane by applying a multiple presence factor of 1.20 compares with the traditional 1.0.

The above figures indicate that the current AUSTROADS loading (A14, T44 & L44) is similar to the Ontario Highway Bridge Design Load (OHBD Load) and slightly less than the 1994 AASHTO bridge design load with the Eurocode being substantially heavier. When the HLP400 has been specified, the Australian and European loading are similar for spans greater than 30 m. The T168 loading is considerable lighter than the Eurocode loading for spans less than 20 m but heavier for longer spans. This is consistent with the anticipated long combination vehicles, the relatively weak Australian pavements and the heavy wheel loads associated with military loadings in Europe. The proposed model will see the strength of Australia's medium to long span bridges evolve towards current European standards. The very high loads used in the design of European short span structures are not considered consistent with Australia's thin pavements and the relatively weak existing bridge infrastructure.

Discussion

The model provides a good representation of the effects induced in short span simply supported and continuous bridges. The model underestimates the bending moments over piers for continuous spans between 4 and 6 m. This is a result of the RTS73 vehicle exhibiting distances between adjoining groups of 3.6 m compared with the 4.8 m used in the T168 model. The distances between axle groups is an important issue to the transport industry and bridge provision alike.

The model provides a compromise between modelling the effects in simple spans and those in continuous spans, especially the effects of two following B-triple vehicles.

The proposed model (maximum of T168 and 2.4L+109) bending moments and shears are compared with the current (maximum of T44, L44 and 3/8HLP) bending moments and shears in **Figure 14.**. This simple comparison indicates:

- simple spans greater than 15 m will experience an increase of 20 to 30%;
- significant increases (up to 90%) the bending moments and shears in bridges with spans less than 10 m (but still much smaller than the Eurocode loads);
- bending moments over piers in continuous bridges with spans greater than 25 m will need to be designed for bending moments up to twice the current design moments;
- the moments over the piers in continuous spans of 4 m actually decrease. This is a consequence of the minimum spacing between the tandems on the T44 loading being 3.0 m compared with the distance of 4.8 m between the tri-axle groups in the T168 truck. This highlights the need to for clear guidelines with respect to minimum distances between axle groups;
- Bridges designed to the proposed loading would automatically satisfy the requirements of the HLP400 loading. Similar conclusions can be drawn for many of the current cranes from Europe.

SUMMARY

A bridge design load has been developed to model the effects of traffic that is consistent with the heavy vehicles that correspond to the anticipated end evolution of current road transport technology. The model has been developed to be consistent with legal axle groups loads up to 40 t incorporated in B-triple vehicles and / or road trains.

The proposed loading model consists of a 168 t truck (T168), a lane loading (2.4L+109) consisting of 65% of the T168 plus a 2.4 t/m uniformly distributed load and accompanying load factors for evaluating multi-lane loading. The T168 is a simple symmetric model consisting of four tri-axle groups.

Accompanying load concepts are utilised in the AUSTROADS bridge design codes' load combination models. The adoption of the accompanying load concept for the lane load and multiple lane effects provides a consistent approach.

The wheel and truck loading continues the Australian and North American approach of adopting a series of axles to represent the effects induced by traffic in short span structures. The truck model concept has a unique feature in that it incorporates two trucks in the one lane. This provides a variable axle spacing option as well as modelling following articulated vehicles or the effects of B-doubles and B-triples.

The lane loading follows the Ontario concept of a uniformly distributed load plus a reduced truck loading. This fits well with simulations of current traffic for longer span structures. These simulations have also demonstrated that the accompanying load model adopted in European and Japanese codes is appropriate. This concept has been applied to both the truck loading and the lane loading models.

The loading model is simple to apply yet represents the bending moments and shears generated by the anticipated heavy vehicles of the future in both simply supported and continuous bridges.

The loading model has been developed for vehicles loaded to 40 t on a tri-axle group. Future recommendations relating to the maximum anticipated axle load and the minimum distances between axle groups could well result in changes to the model. The effects of these changes together with the feedback received with regard to this model will then be incorporated in the model for incorporation in the AUSTROADS bridge design load.

In summary, the proposed load model is based on the anticipated traffic, truck loads and the expected end evolution of vehicle technology. The model incorporates key features of north American and European practice whilst recognising Australia's bridge design heritage and the special features of Australia's innovative heavy vehicle fleet. It is a robust and pragmatic model that should prove simple to use. It's adoption will provide an essential step to ensuring the productivity of Australia's transport system into the next millennium.

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Rob Heywood is a Director of Infratech Systems and Services, a Senior Lecturer at the School of Civil Engineering and a Principal Researcher of the Physical Infrastructure Centre at the Queensland University of Technology. The first decade of his career was spent designing and supervising the construction of bridges, buildings, dams and industrial projects with Cameron McNamara Pty Ltd and Bornhost and Ward Pty Ltd. The bridge design theme has continued with a bridge research focus since joining QUT in 1985. His research into bridge loads was awarded the WH Warren Medal for 1995.

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Tim Ellis is an Associate of Sinclair Knight Merz and Manager - Structures of the Melbourne office. He has over fifteen years experience in the design and construction management of building and civil infrastructure.

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Figure 1 Highly productive B-Triples (12333 and 82.5 t) are now operating in Australia.

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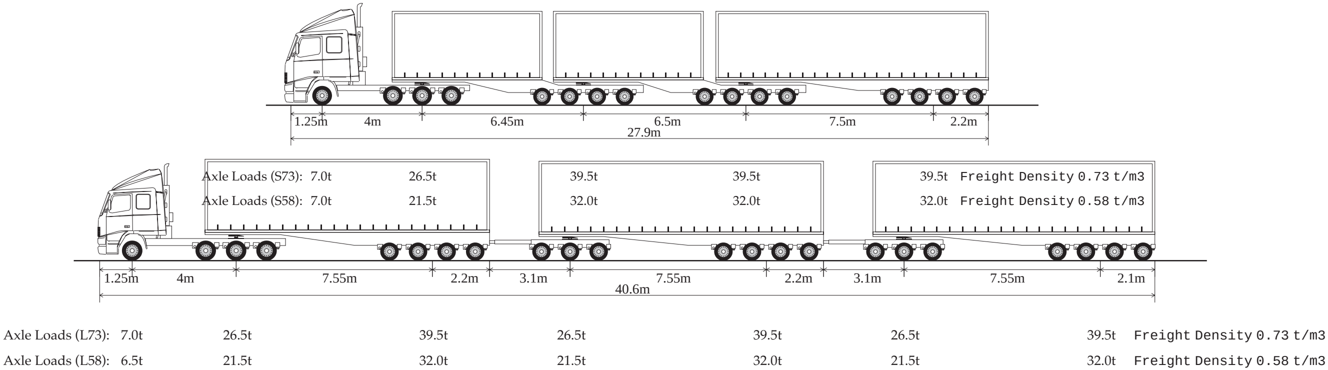

Figure 2 Future B-triples (BTS73) and triple bottomed road trains (RTS73) (Dovile et. al., 1997)

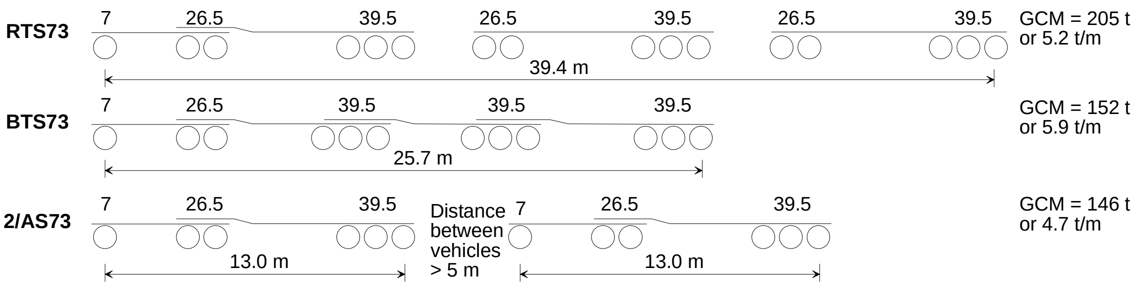

Figure 3 Examples of vehicles of the future

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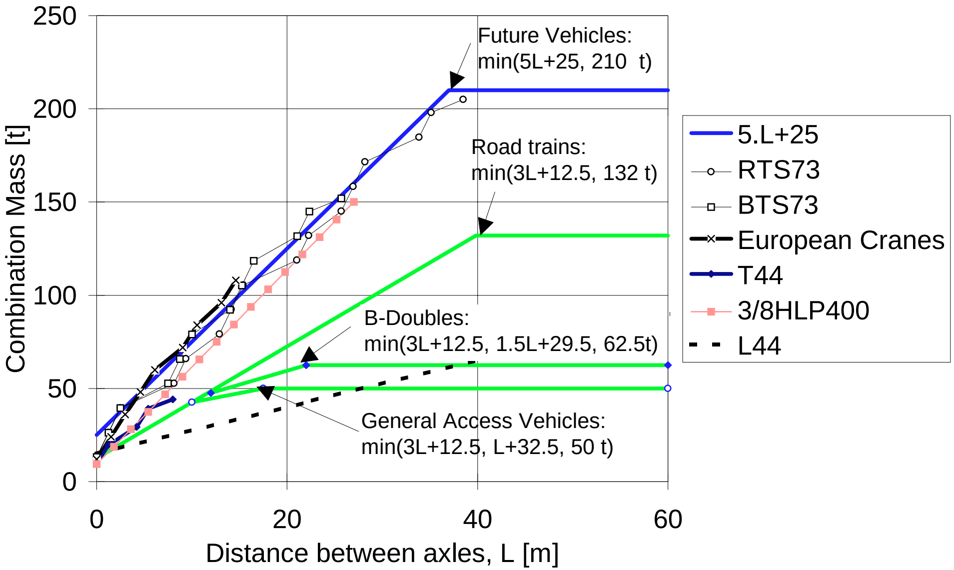

Figure 4 Comparison of current and future bridge formulae with European cranes and Australian bridge design loads.

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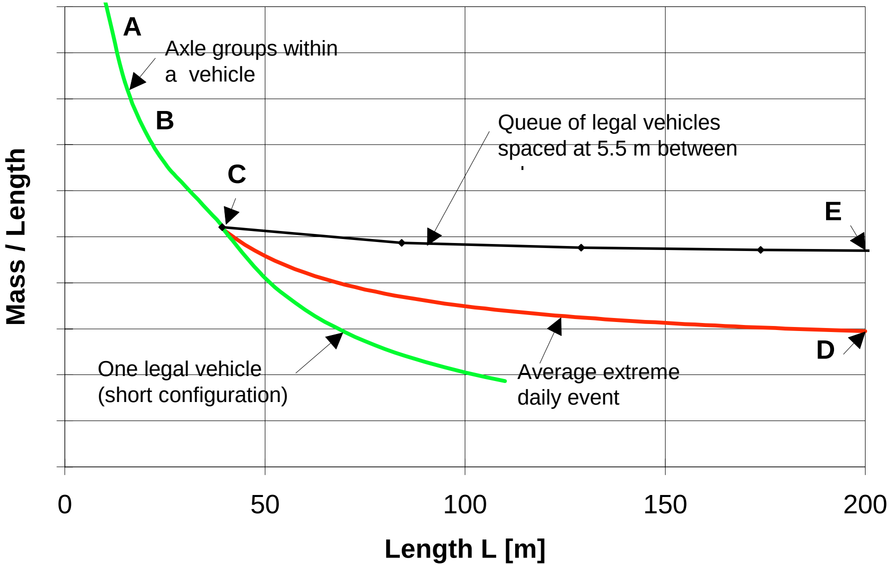

Figure 5 Approach to the derivation of loading model

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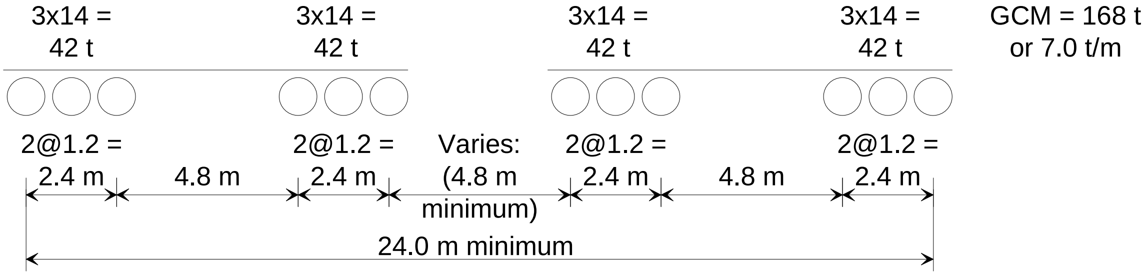

Figure 6 Proposed T168 bridge design truck.

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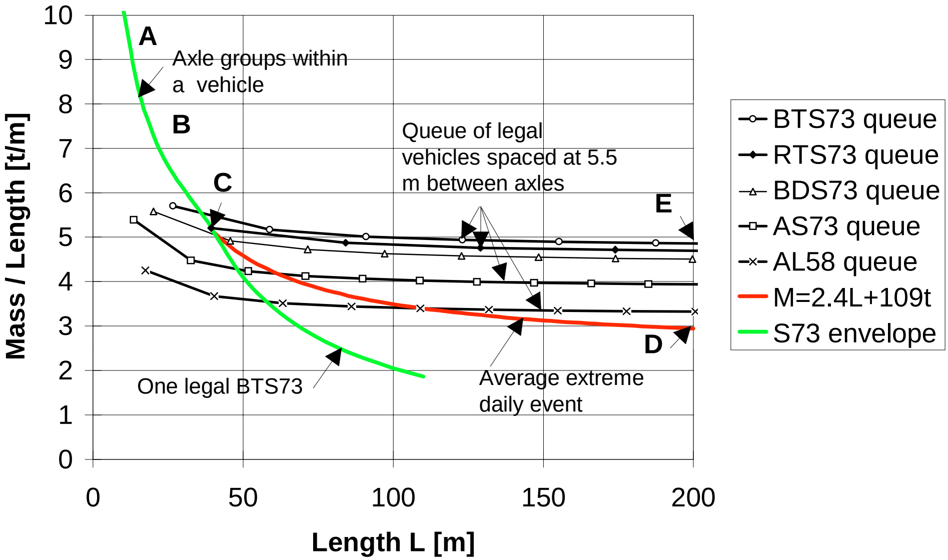

Figure 7 Loading model based on L58 and S73 vehicles

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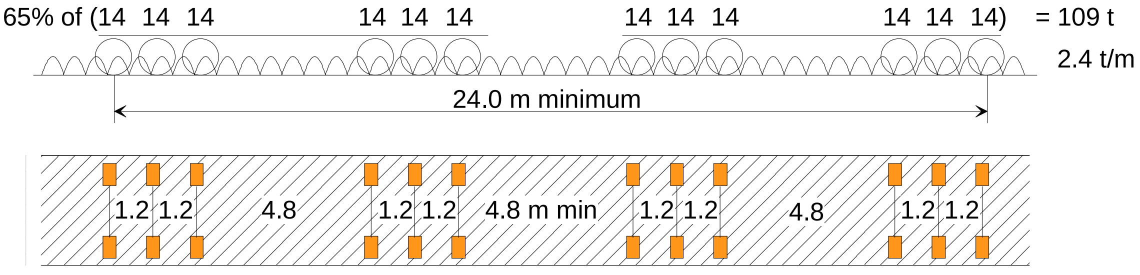

Figure 8 2.4L+109 Lane Load

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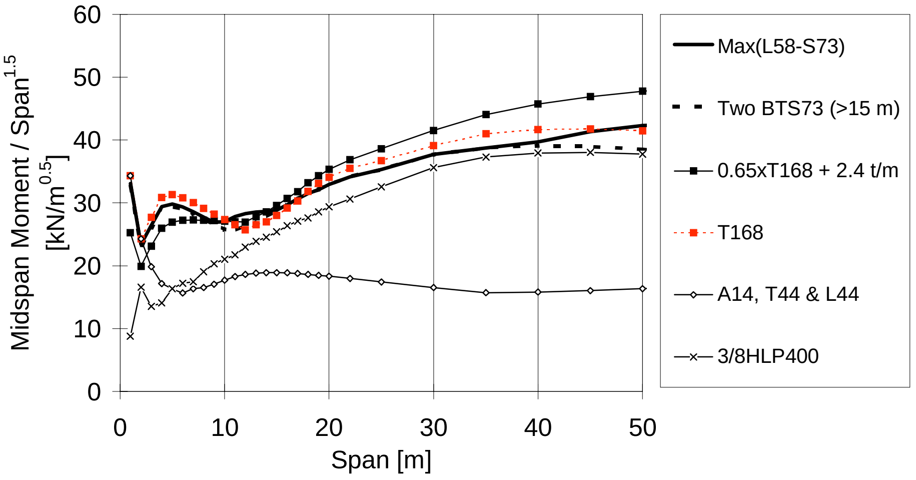

Figure 9 Comparisons for midspan bending moments in simple spans up to 50 m

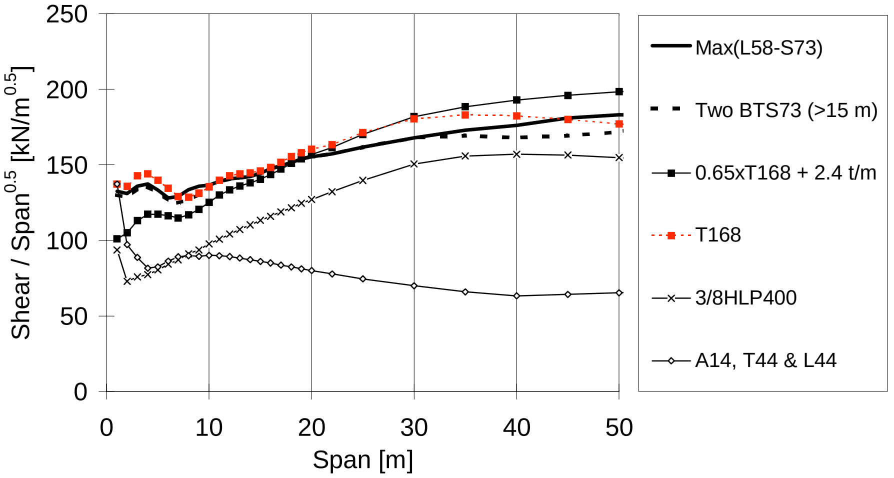

Figure 10 Comparisons for shears in simple spans up to 50 m

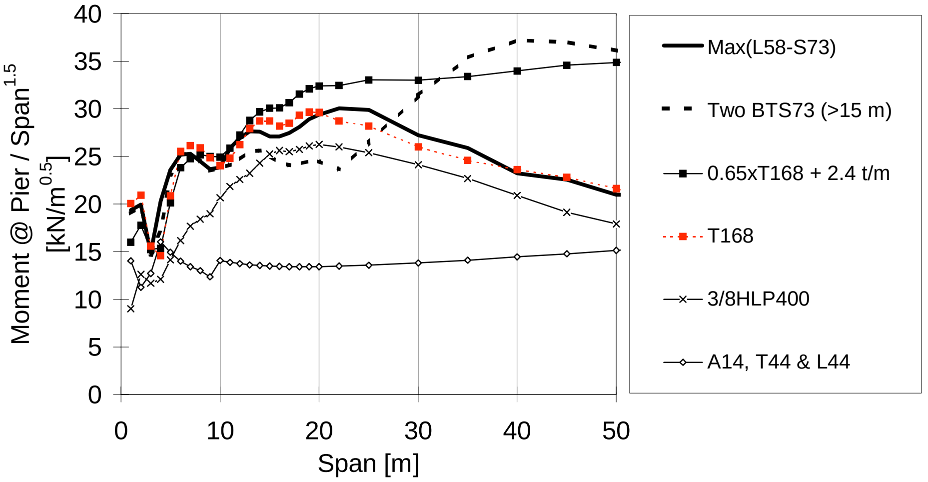

Figure 11 Comparisons for bending moments over the pier in two span continuous bridges with spans up to 50 *m*

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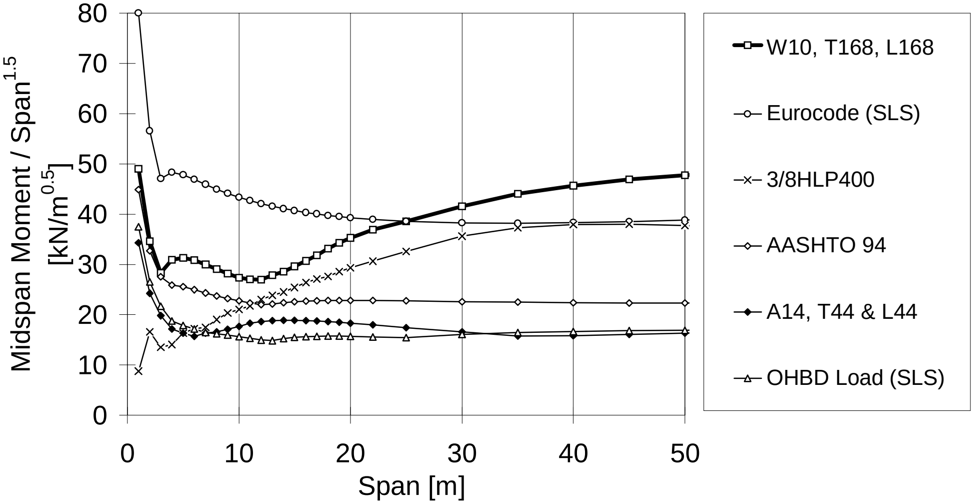

Figure 12 Comparison of serviceability limit state mid-span bending moments in simple beams subject to single lane loading for Australian, American, Ontario and Eurocode bridge design loads.

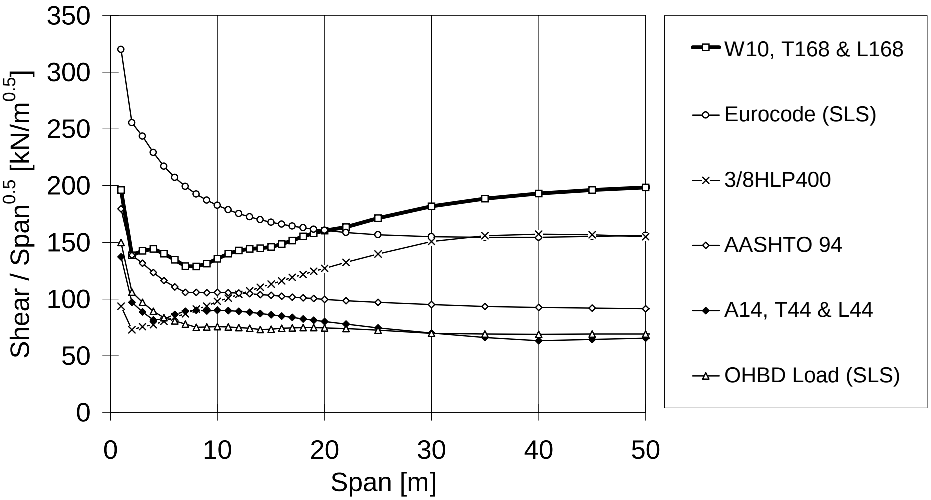

Figure 13 Comparison of serviceability limit state shears in simple beams subject to single lane loading for Australian, American, Ontario and Eurocode bridge design loads.

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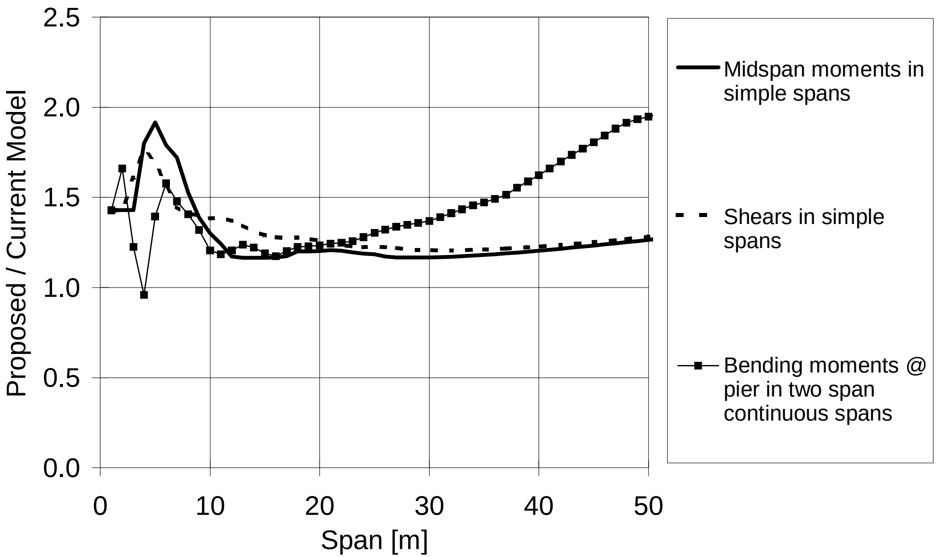

Figure 14 Variation in the ratio of the proposed loading to the current loading with span