Fatigue – It Will Change Our Culture

Dr Wayne S. Roberts, BE, PhD, RPEQ, MIEAust, Senior Engineer – Concrete Technology Queensland Department of Main Roads.

Dr Robert J. Heywood BE, MEngSc, PhD, RPEQ, MIEAust, Manager: Infrastructure & Transport, Texcel Pty Ltd.

SYNOPSIS

The first road bridge design loads represented the load applied by horses and carts. These design loads were followed by the steam roller used to construct the pavement between the bridges, bullock drays, rigid trucks, semi trailers (T44) and now B Triples and Road Trains represented by the Austroads SM1600 design load for bridges. During this progression, design methodology has moved from working stress methods, to designing for the strength limit state and convincing ourselves that the serviceability limit state is satisfied. Fatigue has rarely been a dominant consideration in the design of Australian Road Bridges.

Along with this increase in load, the current strength limit state mindset in combination with the competitive design and construct process has lead to designs adopting higher strength materials. The consequence of this is that the stress ranges induced by live loads are increasing, raising the probability of fatigue failures.

The Austroads SM1600 loading was developed to ensure that bridges were constructed with a 100 year design life in an environment where heavy vehicle masses and dimensions continue to increase for the greater economic benefit of the nation. In the initial development of this loading, the strength and serviceability limit states were considered but not the fatigue limit state. Even a rudimentary analysis of the current T44 fatigue loading (500,000 trucks per lane) will demonstrate that this loading is only appropriate for lowly trafficked roads. It is orders of magnitude too small for our most heavily trafficked routes even before consideration of future growth in both mass and volume of heavy vehicle traffic.

This paper presents the results of an Austroads research project which was designed to develop a new fatigue load model that was consistent with the SM1600 design loading. The findings challenge the current design process and the selection of materials. It raises issues about consistency and how to implement what would be a step change in design culture. Consequently the findings have been debated intensely. This paper documents and encourages the debate with the goal of appropriate fatigue design of bridges that is consistent with the 100 year design life of bridge in an environment of increasing loads.

1 INTRODUCTION

A bridge must be able to resist the maximum possible overload or design load with a very low probability of collapse. The bridge must also be resistant to the damage caused by the enormous number of load applications caused by the traversal of vehicles that may occur several times per minute, otherwise known as fatigue loads (1).

When a bridge is constructed, there is an expectation that it will serve the community for its 100 year nominal design life. The 100 year design life plays an important role in the selection of materials to ensure that the structure has adequate durability. History has also shown us, that the loads bridges carry can change significantly over the life of the structure.

Australia's first road bridge design loads represented the load applied by horses and carts. These design loads evolved to model steamrollers used to construct the pavement between the bridges, bullock drays, rigid trucks, semi trailers (T44) and now B Triples and Road Trains. In Australia, some bridges designed to accept bullock drays, are now being asked to carry B-triples – all within a 100 year period. This change in technology is illustrated in Figure 1.

Figure 1 The old and the new – a steam driven truck and a B-triple (photo by E Ramsay)

The SM1600 design load was developed and approved by Austroads to ensure new bridges were designed to withstand the heavy vehicle traffic expected to evolve during the design life of Australia's bridges (2). It was designed to represent the expected future traffic rather than the current traffic and thus is consistent with designing for a 100 year life. The SM1600 loading is incorporated in DR00375, the Draft Australian Standard for Bridge Design (3).

This paper summarises the development of a fatigue design load model that is independent of the material of construction and consistent with:

1. The vehicles that are expected to evolve during the design life of new bridges as defined by Austroads Project RUM.H.96 Economics of Higher Bridge Design Loading prior to the development of the SM1600 design loading model (4).
2. The required freight task that will also evolve during the expected service life of bridges designed under the code.
3. Current international best practice.

The fatigue load model was limited to:

1. Bridge spans in the range of 1 to 100 m.

2. Bridges subjected to road traffic loadings only.
3. Other general restrictions of the Draft Australian Standard for Bridge Design (3).

The implications of the revised fatigue model on design processes are also discussed.

2 A REVIEW OF CODES OF PRACTICE

A review of the current Australian, New Zealand, North American, European, and British Bridge Design Codes showed that all codes specified the fatigue design load as a vehicle load and a number of cycles. With respect to the vehicle load there were two approaches or philosophies. These being:

1. The use of a fatigue load model related to the ultimate limit state design load as per the current Austroads Code (5) and current North American Codes (6, 7).
2. The use of a spectrum of heavy vehicles typically based on actual heavy vehicles, or a model vehicle that idealises or is equivalent to the heavy vehicle traffic spectrum. This approach is used in the current European Codes (8, 9).

Most codes include a dynamic load allowance. Approaches to multiple presence vary and are somewhat related to the load model. Generally codes, which use a fatigue load model based on the ultimate limit state design model, do not consider multiple-presence, whereas codes that consider traffic spectrums or actual vehicles do consider multiple-presence.

In relation to the number of cycles or vehicles, a figure of 2×10^6 vehicles per year for a 120 year design life is an upper limit. Over the design life, common values range from 2×10^7 to 2×10^8 vehicles depending on road classifications and traffic volumes. This is up to 400 times larger than the current 5×10^5 vehicles for a design life of 100 years specified in the current Austroads Code (5). However it is acknowledged in this code that these figures are based on the NAASRA Bridge Design Code and consequently do not reflect current traffic volumes (10).

Under the SM1600 loading it is expected that a range of vehicles will develop with many vehicles constrained by volume rather than mass, leading to a range of typical vehicle masses in the vehicle fleet rather than a high proportion of vehicles travelling at the legal limit. Thus the decision was made to develop a fatigue load model based on an expected heavy vehicle spectrum rather than an ultimate design load.

3 DEVELOPMENT OF FATIGUE DESIGN VEHICLES

The fundamental basis for the development of the fatigue design model was to equate the fatigue damage induced by the heavy vehicle fleet during the design life of bridges, with the damage induced by the fatigue design load. This methodology is summarised in Equation 1. In simplified terms this involved: developing a value for the left hand side of the equation based on the future heavy vehicle fleet and future heavy vehicle traffic volumes for various road classifications; and then solving the right hand side of the equation based on assuming that the number of passes of the fatigue design vehicle will be equal to the heavy vehicle traffic volume. Thus the fatigue damage induced by the fatigue design vehicle will be equivalent to the average fatigue damage induced by the heavy vehicle fleet.

$$\sum\left\{\begin{pmatrix}\text{Average Fatigue}\\ \text{Damage / Vehicle}\\ \text{Typically Induced}\\ \text{by Heavy Vehicle}\\ \text{Fleet}\end{pmatrix}\times\begin{pmatrix}\text{Heavy}\\ \text{Vehicle}\\ \text{Traffic}\\ \text{Volume}\end{pmatrix}\right\}=\sum\left\{\begin{pmatrix}\text{Fatigue Damage}\\ \text{Induced by}\\ \text{Fatigue Design}\\ \text{Vehicle}\end{pmatrix}\times\begin{pmatrix}\text{Number of}\\ \text{Passes of}\\ \text{Fatigue Design}\\ \text{Vehicle}\end{pmatrix}\right\}$$

Equation 1

3.1 Heavy Vehicle Traffic Volumes

John McLean (10) developed future heavy vehicle traffic volumes. Road Classifications were based on the current Austroads Functional Classes (5) which consider urban and rural roads, with the additional provision that Functional Class 1 roads would also include freeway standard connections between Functional Class 1 roads in urban areas. The process used to determine the number of trucks that would traverse the bridge during the 100 year design life of new bridges is summarised below:

1. Determine current traffic volumes (AADT) for the different functional road classes and typical percentages of heavy vehicles for these road classes.
2. Forecast these traffic volumes forward, considering various growth factors including a possible reduction of trucks due to increased payload capacity, and levels of saturation.
3. Calculate the number of trucks that would pass over a bridge during a 100 year design life from now for the various functional road classes.
4. Estimate the distribution of trucks per lane for various multi lane roads.

Table 1 summarises the calculation of traffic volumes. Comparison of this data with current international bridge codes shows that it is consistent with current practice. For example, the British code (9) uses 2×10^6 vehicles per year for motorways that corresponds to 2×10^8 vehicles per 100 years while the Canadian Code (7) recommends a figure of around 1.5×10^8 vehicles for Class A highways. These values correspond to 3,000 to 4,000 trucks per day.

3.2 Future Heavy Vehicle Fleet

Historically legal loads have been increasing at 10 % per decade (12, 13). The SM1600 vehicle loading was designed to allow for the traffic of the future. The loading was developed with consideration of the typical bridge service life of 100 years, continual historic increases in vehicle loading, costs and benefits, and the expectation that there is an upper limit to the loads that can be safely transported by trucks. The result of this analysis was an expected upper bound of 40 t axle groups and B-Triples as general access vehicles (2, 4, 13).

It is expected that as these limits and the resulting vehicles evolve with time, the distribution of the gross mass of the vehicles travelling on the road system will also change. This is because as the mass limits increase, more of the freight task will become volume limited rather than mass limited. Thus a spectrum of vehicles with a variety of configurations and masses will evolve to suit the freight task. Table 2 to Table 4 give details of the proposed vehicles developed for this project by Pearson (2, 4, 13, 14). These vehicles include fully laden or mass constrained vehicles, partly laden or volume constrained vehicles, and empty vehicles. The fully laden vehicles were based on the vehicles used in the derivation of the SM1600 loading (2, 4).

Table 1 One Hundred Year Truck Passes by Road Functional Class and Opening Year Traffic

	Functional Road Class	Initial Construction	Opening Year Traffic			100 year Heavy Lane Truck Passes	Multiplier [x]
			AADT (veh/d)	**% Trucks**	**Heavy Lane (trucks/d)**		
Rural	1[+]	2-lane	400	30%	60	1.6×10^7	2.7×10^5
		2-lane	3,500	25%	438	8.9×10^7	2.0×10^5
		4-lane	10,000	20%	900	1.6×10^8	1.8×10^5
		6-lane	50,000	15%	2,250	1.5×10^8	6.8×10^4
	2	2-lane	250	25%	31	5.5×10^6	1.8×10^5
		2-lane	700	20%	70	1.2×10^7	1.8×10^5
		2-lane	2,500	15%	188	3.1×10^7	1.6×10^5
		4-lane	15,000	10%	675	8.7×10^7	1.3×10^5
	3/4	2-lane	100	15%	8	1.3×10^6	1.8×10^5
		2-lane	700	10%	35	6.1×10^6	1.8×10^5
Urban	6	4-lane	40,000	9%	1,620	1.0×10^8	6.3×10^4
	7	4-lane	25,000	7%	788	5.8×10^7	7.4×10^4
	8	2-lane	1,000	2%	10	1.8×10^6	1.8×10^5
		2-lane	4,000	7%	140	2.2×10^7	1.8×10^5

[+] *This functional class also extends to cover freeway standard connections between Functional Class 1 Roads in urban areas.*

[*] *Heavy Lane (HL) – Lane(s) carrying highest number of trucks.*

[x] *Multiplier – Total heavy lane truck passes divided by opening year heavy lane trucks per day.*

Consideration was also given to truck travel patterns on various route types for various truck configurations. Issues considered included:

1. Travel by B Doubles is increasing.
2. B Doubles will have a greater presence in urban areas compared with Road Trains and B Triples.
3. Travel by B Doubles and road trains will increase as more routes are made available.

Table 2: Proposed Fully Laden Vehicles (10, 14)

Vehicle	O/A length (metres)	Gross mass (tonnes)	Configuration, axle distances and axle group mass (note: distances are from front of vehicle to centreline of axle group)						
Rigid	7.6	17	**O** 1.25 m 7 t	**O** 5.25 m 10 t					
Articulated	14.8	73	**O** 1.25 m 7 t	**OOO** 5.25 m 26.5 t	**OOOO** 12.8 m 39.5 t				
B-double	21.4	112.5	**O** 1.25 m 7 t	**OOO** 5.25 m 26.5 t	**OOOO** 11.7 m 39.5 t	**OOOO** 19.2 m 39.5 t			
B-triple	27.9	152	**O** 1.25 m 7 t	**OOO** 5.25 m 26.5 t	**OOOO** 11.7 m 39.5 t	**OOOO** 18.2 m 39.5 t	**OOOO** 25.7 m 39.5 t		
RT triple	40.6	205	**O** 1.25 m 7 t	**OOO** 5.25 m 26.5 t	**OOOO** 12.8 m 39.5 t	**OOO** 18.1 m 26.5 t	**OOOO** 25.6 m 39.5 t	**OOO** 31 m 26.5 t	**OOOO** 38.5 m 39.5 t

Note: spacing between axles in a group assumed to be 1.2 m.

Table 3: Proposed Partly Laden and Volume Constrained Vehicles (10, 14)

Vehicle	O/A length (metres)	Mass (tonnes)	Configuration, axle distances and axle group mass (note: distances are from front of vehicle to centreline of axle group)						
Rigid	7.6	13	**O** 1.25 m 5 t	**O** 5.25 m 8 t					
Articulated	14.8	59	**O** 1.25 m 7 t	**OOO** 5.25 m 22 t	**OOOO** 12.8 m 30 t				
B-double	21.4	89	**O** 1.25 m 7 t	**OOO** 5.25 m 22 t	**OOOO** 11.7 m 30 t	**OOOO** 19.2 m 30 t			
B-triple	27.9	119	**O** 1.25 m 7 t	**OOO** 5.25 m 22 t	**OOOO** 11.7 m 30 t	**OOOO** 28.2 m 30 t	**OOOO** 25.7 m 30 t		
RT triple	40.6	163	**O** 1.25 m 7 t	**OOO** 5.25 m 22 t	**OOOO** 12.8 m 30 t	**OOO** 18.1 m 22 t	**OOOO** 25.6 m 30 t	**OOO** 31 m 22 t	**OOOO** 38.5 m 30 t

Note: spacing between axles in a group assumed to be 1.2 m.

Table 4: Proposed Empty Vehicles (10, 14)

Vehicle	O/A length (metres)	Tare mass (tonnes)	Configuration, axle distances and axle group mass (note: distances are from front of vehicle to centreline of axle group)						
Rigid	7.6	7.5	**O** 1.25 m 4 t	**O** 5.25 m 3.5 t					
Articulated	14.8	21	**O** 1.25 m 6 t	**OOO** 5.25 m 8.5 t	**OOOO** 12.8 m 6.5 t				
B-double	21.4	28	**O** 1.25 m 6 t	**OOO** 5.25 m 8.5 t	**OOOO** 11.7 m 7 t	**OOOO** 19.2 m 6.5 t			
B-triple	27.9	35.5	**O** 1.25 m 6.5 t	**OOO** 5.25 m 8.5 t	**OOOO** 11.7 m 7 t	**OOOO** 18.2 m 7 t	**OOOO** 25.7 m 6.5 t		
RT triple	40.6	47	**O** 1.25 m 6.5 t	**OOO** 5.25 m 8.5 t	**OOOO** 12.8 m 7t	**OOO** 18.1 m 5.5 t	**OOOO** 25.6 m 7 t	**OOO** 31 m 5.5 t	**OOOO** 38.5 m 7 t

Note: spacing between axles in a group assumed to be 1.2 m.

Figure 2 shows the distribution of truck types and loading conditions for the future vehicle fleet and includes both the percentage of vehicle types on each road type, and the mass distribution of these vehicle types. The data shows for example that there would be no Road Trains or B Doubles on urban local roads, and that articulated vehicles would still be a dominant vehicle type on rural highways. Also evident is that volume constrained or partly loaded vehicles would be more prevalent in the vehicle fleet compared to mass constrained vehicles.

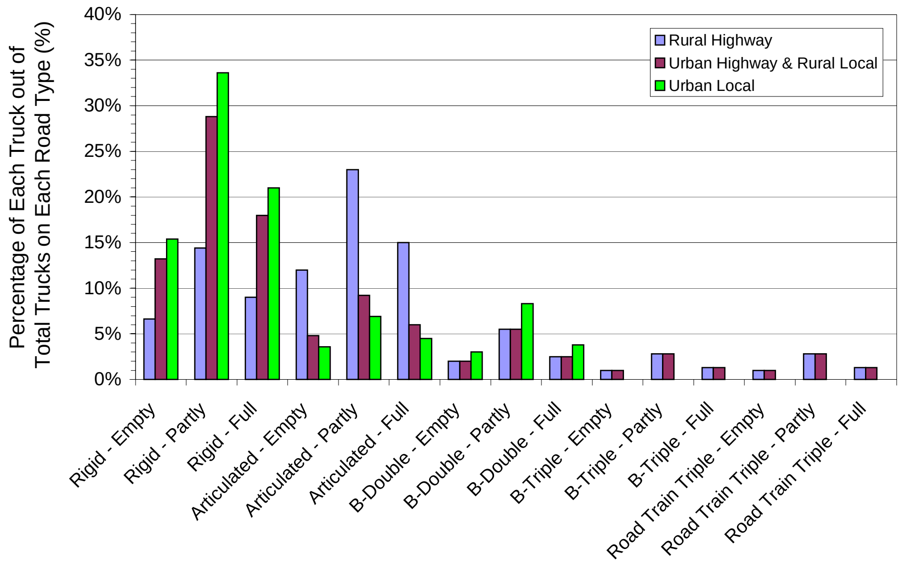

Figure 2 Distribution of Truck Type and Loading Condition for Different Road Types (10).

It should be noted that the vehicle fleet defined for this project is representative of the vehicle fleet in 40 to 50 years time and that in terms of a fatigue design load, these vehicles will be a conservative representation of the vehicle fleet for this time period. It is noted that the most important influence on the total fatigue damage is the upper mass limit of the vehicles. The rate at which this is achieved is less critical.

4 DERIVATION OF FATIGUE DESIGN LOAD FROM VEHICLE FLEET

The derivation of a fatigue design vehicle representative of the future vehicle fleets developed involved a number of steps including:

1. Calculating the structural response versus time for vehicles traversing spans from 1 to 100 m for simply supported end shear, simply supported midspan bending, and two span continuous bending over the centre support. A rainflow analysis to count the fatigue cycles was then undertaken on these responses for each fleet vehicle. These bending moments and shears were taken to be representative of the stresses induced in bridges.

2. Calculating the fatigue damage using a cubic damage law and then calculating the average fatigue damage for the vehicle fleet for a particular fleet type. The four types considered were rural highway, rural local, urban highway, and urban local. Generally damage is expressed as a ratio of the number of cycles at a particular stress range to the number of cycles to cause failure at that same stress range. When developing a fatigue load model, neither the actual stress range nor the number of cycles to failure is known. In this project, damage was defined as the sum of the bending moment or shear cycles each raised to the 3^{rd} power. Bending moments were calculated in tm. Thus the fatigue damage versus span for the rural highway fleet considering simply supported midspan bending presented in Figure 3 has damage units of $(tm)^3$. Superimposed on this plot is the average fatigue damage per vehicle for the rural highway fleet (defined as Traffic Stream). This average shows that for shorter spans the partly loaded articulated vehicle is typical of the average fatigue damage per vehicle for the fleet while for longer spans the fully loaded articulated vehicle is more representative.

3. A fatigue design vehicle was derived which would induce the same fatigue damage as the average fatigue damage per vehicle for the fleet for each of the different fleet types using an optimisation process.

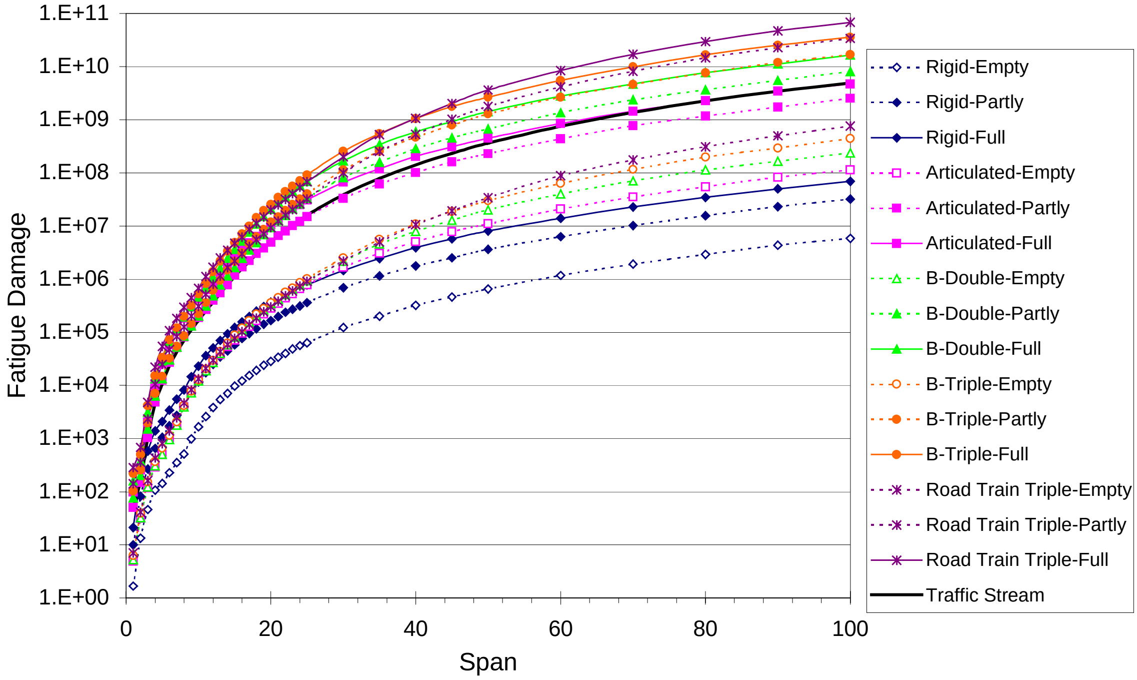

Figure 3 Fatigue Damage Versus Span, Rural Highways, Simply Supported Midspan Bending (10)

This optimisation process led to two vehicles being developed. One for bridges up to around 30 m that became known as the F620 Short Span Fatigue Design Vehicle and one for spans in the range of 25 to 100 m known as the F770 Fatigue Design Vehicle. These vehicles are illustrated in Figure 4. An F80 Axle Fatigue Load was also developed.

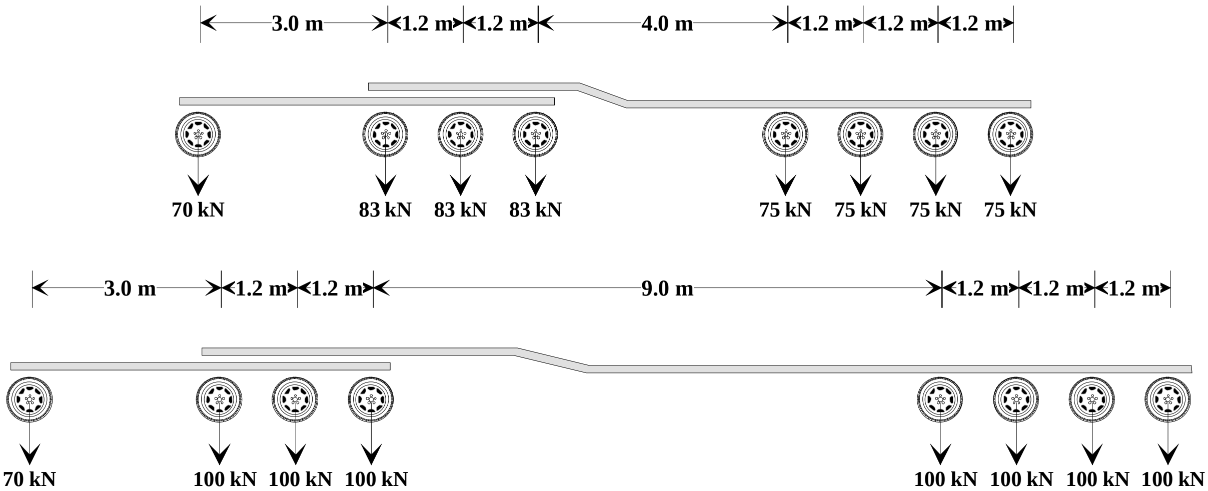

Figure 4 F620 and F770 fatigue design vehicles (10).

The number of passages of these loadings per lane for the design life of the bridge was also defined. In summary 10^8 passes was used for heavily trafficked Rural and Urban areas and 10^7 passes was used for lightly trafficked rural and urban roads. These figures correspond to 2740 and 274 vehicles per day respectively. For the axle load, 8×10^8 and 8×10^7 passes were used for heavily and lightly trafficked roads respectively. Dynamic load effects were as already defined in the draft code (3). These proposed requirements represent a step change of two to three orders of magnitude compared to the current design code requirements (5).

Multiple presence events are relatively rare and therefore insignificant in the total fatigue damage experienced by an element. Consequently, it was recommended that the fatigue damage to a particular element be calculated by summing the damage induced by the fatigue load applied to each lane independently. Dynamic effects were to be included by applying the dynamic load allowance to all stresses before the fatigue damage was calculated.

It should be noted that to evaluate the fatigue damage using these proposed clauses, some form of stress cycle counting analysis such as a rainflow analysis was required to analyse the fatigue damage from the vehicles driving over the bridge. This was particularly relevant to short elements where combination vehicles, for example, induce multiple fatigue cycles whereas in longer elements only one fatigue cycle is induced per vehicle.

These proposed clauses and vehicles were not adopted in the code for a number of reasons including:

1. The vehicle configurations were different from the proposed S1600 and M1600 vehicles and thus additional analysis effort would be required over and above the ultimate and serviceability design limit state.

2. The analysis of stress cycles (rainflow analysis) further complicated the analysis and would lead to confusion.

Thus the decision was made to base a fatigue design model on the M1600 vehicle, with the proposed method being to calculate the maximum stress range from a passage of the M1600 vehicle and calculate an equivalent number of cycles. This method was thought to reduce the quantity and complexity of the calculations required but with an associated loss of precision.

5 DERIVATION OF FATIGUE LOADING BASED ON M1600 LOADING

Thus a fatigue design load model was developed based on the A160 and M1600 loading including the uniformly distributed load component of the M1600 loading. The methodology adopted was to calculate the damage assuming one stress cycle equal to the peak-to-peak response due to the passage of these design loads over the structure and then determine an equivalent number of cycles required to induce the same damage as the fleet (15). Thus the number of cycles required varies with the span. For example, a B-triple crossing a very short element induces multiple cycles of fatigue compared with the single cycle assumed in this model. The number of cycles required was calculated using Equation 2 with the left-hand side of the equation calculated using the same principles and data for the previous model.

$$\sum\left\{\begin{pmatrix}\textit{Average Fatigue}\\ \textit{Damage / Vehicle}\\ \textit{Typically Induced}\\ \textit{by Heavy Vehicle}\\ \textit{Fleet}\end{pmatrix}\times\begin{pmatrix}\textit{Heavy}\\ \textit{Vehicle}\\ \textit{Traffic}\\ \textit{Volume}\end{pmatrix}\right\}=\sum\left\{\begin{pmatrix}\textit{Single Cycle}\\ \textit{Fatigue Damage}\\ \textit{Induced by}\\ \textit{Design Load}\end{pmatrix}\times\begin{pmatrix}\textit{Equivalent}\\ \textit{Number of}\\ \textit{Cycles}\end{pmatrix}\right\}$$

Equation 2

The results of this analysis are summarised in Figure 5 after consideration of 3 representative structural actions - simply supported moment and end shear, and the moment over the support of a continuous structure. The variations in the number of cycles between functional road classes is due to differences in traffic volumes, while the variations in the shape of the curves is due to differences in vehicle fleet characteristics between the functional road classes. Regression analysis showed that the number of cycles was reasonably proportional to the inverse of the square root of the span. For the A160 fatigue design load the number of cycles varied from 5 x 10^5 to 8 x 10^7 depending on the functional road class.

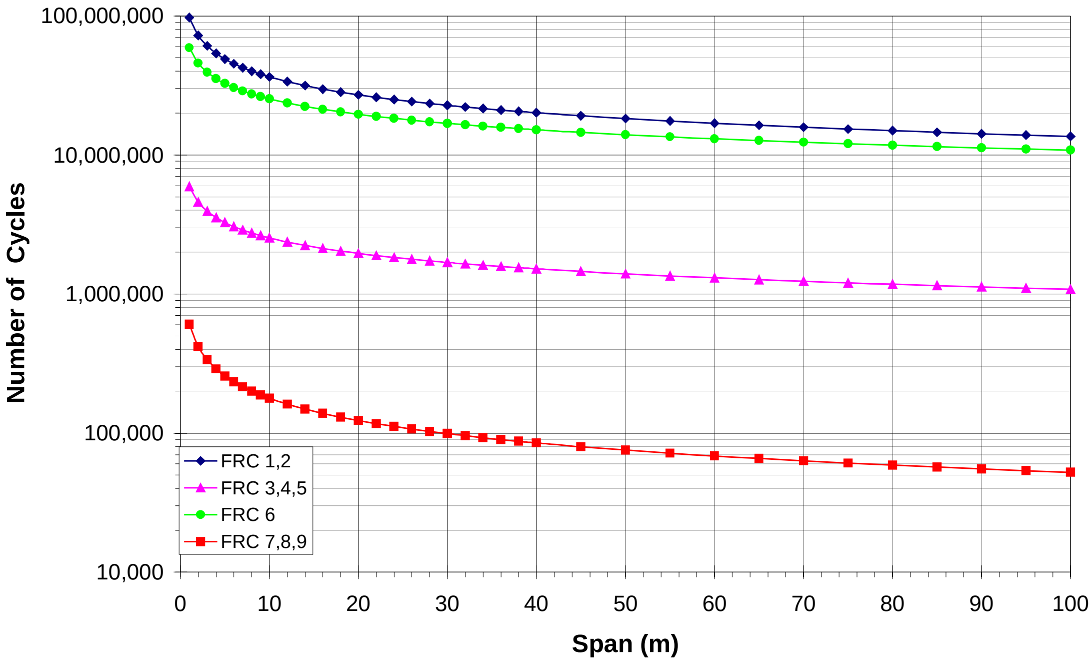

Figure 5 Number of Cycles Versus Span For Stress Ranges Derived from the M1600 Moving Traffic Loading for the Various Road Functional Road Classes (15)

In relation to multiple presence for multi lane bridges the fatigue damage in each element of the bridge, was defined as *the sum of the fatigue damage induced by the most adverse fatigue load applied to each design lane independently* and the dynamic load allowance was maintained as per the previous model.

It was recommended that a second tier method for more complicated structures and design actions using the vehicles shown in Section 4, to determine the number of cycles be included in the commentary section of the code (15).

6 CURRENT PROPOSED FATIGUE LOADING (16)

Since the loadings described in the previous sections of this report were developed, much debate, discussion and lobbying has taken place. This has led to the following proposed fatigue design loading for the draft Australian Standard for Bridge Design (16) which is based on similar principles to the loading developed in Section 5 of this paper.

1. The loading is the most adverse of *70% of the A160 axle load*, or *70% of the M1600 loading without the UDL*. In both cases a load factor of 1.0 is used with the loading

being increased by the dynamic load allowance. The loading is placed within any design traffic lane to maximise the fatigue effects for the component under consideration.

2. The number of stress cycles is calculated using the formula *number of heavy vehicles per lane per day* $\times 4\times 10^4 \times$ *route factor* for the A160 loading and for the M1600 loading the formula is *number of heavy vehicles per day* $\times 2\times 10^4(L^{-0.5}) \times$ *route factor*, with the clause *unless otherwise determined by the relevant authority* applying to both loadings.

The route factors vary from 1.0 for principal interstate freeways and highways, to 0.7 for urban freeways, to 0.5 for other rural routes, and to 0.3 for other urban roads. There is a note in the draft code that this loading does not apply to the fatigue design of roadway expansion joints.

7 COMPARISON WITH PREVIOUSLY DEVELOPED FATIGUE DESIGN LOADINGS

The proposed fatigue design loading (16) is compared with the previously developed (15) loading in the following sections:

7.1 Loading

The setting of equivalent loadings for fatigue design is complex and involves many factors including the actual loading spectrum, cut off limits and crack initiation. However if the fatigue design loading is reduced, then for the total fatigue damage to be consistent the number of cycles must increase.

The loading has been significantly reduced in the draft code (16). The UDL component of the M1600 loading has been removed and the remaining axle group load components of the loading have been reduced to 70%. Thus the fatigue load model corresponds to vehicles with 25 tonne axle groups rather than the 40 t axle groups that formed the basis of the M1600 loading. The magnitude of the single axle loading has also been reduced to 70% of the A160 loading.

Thus the fatigue load model is the draft code induces approximately 60% of the effects of the standard M1600 truck which formed the basis of the fatigue model presented in Section 5. For a cubic damage law this translates into a reduction in damage by a factor of 5.

7.2 Stress Cycles

The calculation of stress cycles relies on the designer obtaining the current number of heavy vehicles per day for the route under consideration. The $2\text{x}10^4(L^{-0.5}) \times$ route factor converts the current heavy vehicle traffic volume to the number of cycles in 100 years. Figure 6 presents a comparison of the number of cycles from the current draft standard (heavy lines and filled markers) with those presented in Figure 5 (thin lines and open markers). The draft code results were calculated using the following current heavy vehicles per lane per day:

2,250 for Principal Interstate, 1620 for Urban Freeway; 188 for Other Rural, and 140 for Other Urban (refer Table 1).

Generally the number of fatigue cycles is reduced by a factor of between 2 and 6 with the exception of the "other urban" category which has a modest increase. The slight differences in shape reflect the rationalisation in the span exponents.

For the A160 axle loading the number of cycles specified is similar to the original proposal.

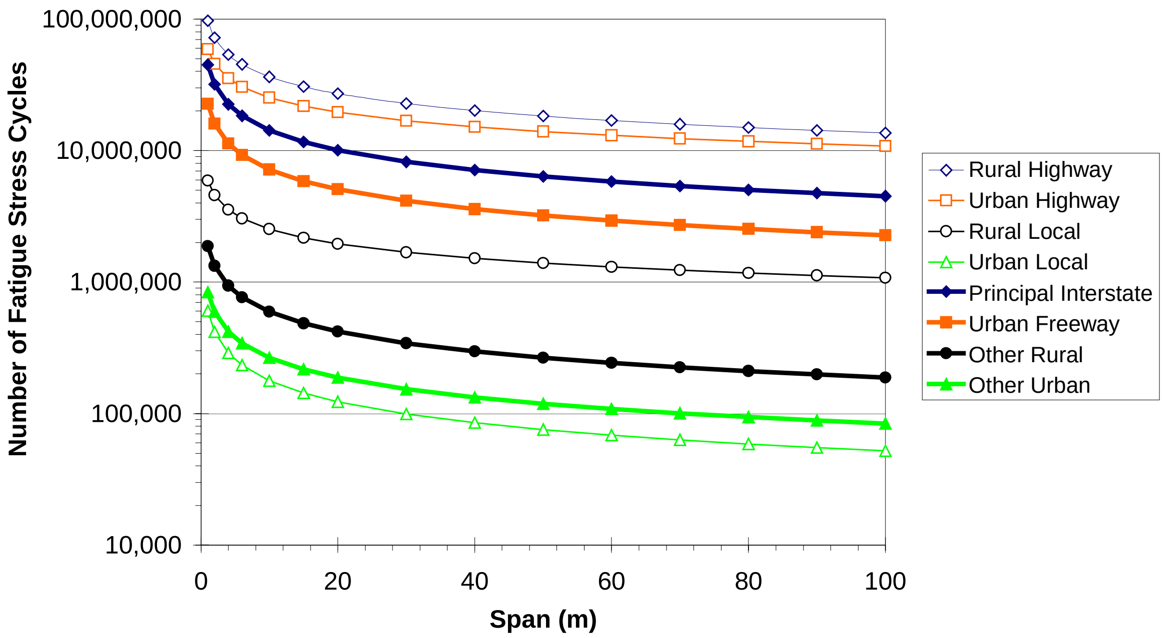

Figure 6 Number of cycles versus span for Stress Ranges comparison of models described in Section 5 of this paper (thin lines) and current draft code (thick lines).

7.3 Discussion

The current proposed fatigue design load for the new Australian Standard for Bridge Design is an evolution of the original proposal. The sensitivity to the current traffic volume has been added. The size of the loading has been reduced and the number of the cycles has also generally been reduced. The overall effect is a reduction in the total damage by a factor between 10 and 30. This significant difference is a direct result of different assumptions relating to the future of heavy vehicles in Australia.

Clearly, predicting the future of Australia's traffic for the next 100 years is very problematic with the draft code accepting a lower bound. It appears that the fatigue damage calculated using the proposed clauses for the new draft code are more consistent with modest increases in current heavy vehicle weights and traffic volumes rather than those utilised in the development of the SM1600 loading. Thus there is potentially an inconsistency between the basis of the SM1600 loading and the proposed fatigue loading. It is noted that the draft code provisions still represents an order of magnitude increase in the design fatigue damage compared to the current T44 Austroads fatigue bridge design load.

The proposed loading is a significant step forward compared to the current Austroads Bridge Design Code, but there remains a concern that a larger step may have been appropriate –

especially for major freight routes. Clearly designers need to be aware of fatigue as a design issue and build robustness into their designs so as to avoid any fatigue issues that may develop into the future.

8 EFFECT OF THIS FATIGUE LOADING

The significant debate that has surrounded the development of the new fatigue design load has been fuelled in part by the consequences of the change. The current fatigue load of 500,000 cycles of the T44 loading is demonstrably low compared with international standards and is rarely critical. Australia's adoption of a limit state approach for bridge design in 1992 focused the design approach on satisfying the strength limit state. Should a design then fail to satisfy serviceability limits such as deflection then this requirement tended to be questioned or regarded as irrelevant, especially for bridges without pedestrian traffic.

In an environment where fatigue was not an issue, reducing the cost of bridges could be achieved by reducing the amount of material in bridges. The development of higher strength concretes, reinforcement and structural steels allowed significant reductions in materials and hence cheaper bridges. The direct consequence of these stronger materials is an increase in the stress ranges induced by heavy vehicles and an increase in the risk of fatigue damage.

A century ago Australian's were designing road bridges for an occasional traction engine. Bridges currently being designed will see vastly different traffic conditions during their design life. Australia's vast distances will continue to demand road transport productivity increases. These will be achieved through heavier longer vehicles. Increasing traffic volumes will ensure larger numbers of trucks per lane per day supported by intelligent transport systems aimed at delivering smaller headways and larger through puts. The loading on major freight routes is becoming much more consistent with railway loading. The proposed changes in the draft code represent an order of magnitude increase in the fatigue damage for bridges on major corridors compared to current practice. Depending on ones crystal ball, it can be argued that this increase maybe an order of magnitude too small.

Failures of expansion joints due to traffic damage, problems with bridge bearings, fatigue cracks appearing in older and occasional new structures may be an indicator of future problems. With the proposed fatigue loads in the new draft code, attention to detailing and stress levels will be required, particularly with steel bridges, to the point where steel bridges may become less economic for major freight routes. Attention to stress levels under service loadings may also be required in reinforced and prestressed concrete bridges. Thus, changes in traffic and heavy vehicles are demanding that we change our bridge design culture from being able to ignore fatigue to needing to consider fatigue in all stages of the design.

9 CONCLUSION

The current Austroads Bridge Design Code's fatigue model is demonstrably low compared with international standards and low for Australia's current heavily trafficked routes. Currently the ultimate limit state rather than fatigue generally controls the design of Australian bridges. As our road networks carry more and more heavy vehicles, fatigue will become more and more significant.

This paper has detailed the development of a number of fatigue design loads for consideration for the new draft Australian Standard for Bridge Design (3, 16). Two models were developed as part of an Austroads Project based on the vehicles that were the basis of the SM1600 design loading. Like the SM1600 loading, the fatigue models were based around the notion that for a bridge to have a design life of 100 years, then the bridge should be capable of withstanding the traffic loading it will experience during its design life. Thus there is a responsibility to design for the future traffic rather than the present if the design life is to be taken seriously.

These fatigue models represented a two order of magnitude change from the current fatigue provisions of the Austroads Bridge Design Code. They generated much debate, discussion and lobbying. The change was sufficiently large to make fatigue the critical design factor on heavily trafficked routes and thus changed the competitive balance between popular bridge construction materials and technologies.

The current proposed fatigue design load for the draft code (16) is an evolution of the models developed in accordance with the heavy vehicles that were the basis of the SM1600 loading. The review process has reduced both the magnitude and the number of cycles to the extent that the total damage is an order of magnitude smaller but a significant step forward compared to the current Austroads Bridge Design Code (5).

The fatigue damage calculated using the proposed clauses for the new draft code appear to be more consistent with current vehicle fleets and traffic volumes rather than those proposed to develop in the future. Based on the findings of this paper there is some allowance for increases in vehicle mass in the proposed model but not to cover the full extent of the proposed vehicles that formed the basis of the SM1600 loading and there is little allowance for increases in heavy vehicle traffic volume. Should the heavy vehicle traffic increase to the levels consistent with the SM1600 loading, then the fatigue loading will need to be reviewed. Road Authorities and designers need to be aware of these issues when specifying bridge designs using the proposed code clauses for fatigue design loading

Thus, Australian road bridge design is in the process of moving from a situation where fatigue very rarely controlled to one where fatigue could and should be a primary design consideration on Australia’s major highways. This change is consistent with the traffic changing from small trucks to road trains and B-triples and from an occasional heavy vehicle to very regular heavy vehicles on our highways. It will change our culture.

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