TECHNICAL CONSULTING
STRUCTURES TEAM

Response to

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PROPOSED HLR METHODOLOGY FOR CONTINUOUS BRIDGES WITHOUT CAPACITY SET DATA

A. ANALYSIS OF FLAT SLAB OR BOX GIRDER BRIDGES IN HLR

B. ANALYSIS OF GIRDER BRIDGES IN HLR

Version Date: 14 November, 2008

EXECUTIVE SUMMARY

Historical Background

On the 20 October, 2008, Alistair Paul indicated that as part of a review he was undertaking into the methodology to analyse those continuous bridges without capacity set data, he would like to invite input from VicRoads.

He submitted his proposed methodology and flowchart for comment.

The methodology was split into two bridge types, namely those bridges without girders (e.g. flat slab/box girders) and those bridges with girders.

Following a review of his methodology, an alternative is proposed

Comparison of Methodologies

The following tables (Tables ES1 and ES2) compare the methodologies currently used by HLR, suggested by Alistair Paul, and suggested for the VicRoads response.

Table ES1
Flat Slab/Box Girders
(GSpacing =0)

Methodology Consideration	**Current HLR**	**Transport SA Proposal**	**VicRoads Alternative**
Bridge Capacity a) Lane Reduction Factors **Equations used by HLR**	a)Does not consider Lane Reduction Factors $\mathbf{M_{cap} = R_a \times M_{dv} \times (1 + DLA_{dv}) (1 + OS)}$ per lane	a) Does not consider Lane Reduction Factors $\mathbf{M_{cap} = R_a \times M_{dv} \times (1 + DLA_{dv}) (1 + OS)}$ per lane	a) Considers a Lane reduction Factor (LRF_{dv}) as included in Design Codes for multilane bridges, based on number of Design Lanes (L_{dv}) and the structure date of construction $\mathbf{M_{cap} = L_{dv} \times R_a \times M_{dv} \times (1 + DLA_{dv}) \times (1 + OS) \times LRF_{dv}}$ per total width
Heavy Vehicle Loading a) No. of Heavy Vehicles on Structure b) Axle Load Reduction c) Lanes available to other legal vehicles d) Vehicle Reduction Factor **Equations used by HLR**	a) One Heavy Load Vehicle on structure, and VRF (refer d))applied if there is enough kerb to kerb width remaining for at least a second traffic lane b) Does not reduce axle loads to a per 3 metre wide lane equivalent c) Not considered, apart from application of VRF d) Used to represent the AustRoads 1992 Bridge Code Multiple Lane Reduction Factor for M_1 only $\mathbf{M_1 = M_{hl} \times (1 + DLA_1) \times VRF}$ $\mathbf{M_2 = M_{hl} \times (1 + DLA_2)}$ $\mathbf{M_3 = M_{hl} \times (1 + DLA_3) / 2}$ per lane	a) All Design Lanes loaded with Heavy Load Vehicles irrespective of Heavy Load Vehicle width (except in the case for M_3 where the Heavy Vehicle is assumed to take up 2 lanes) b) Does not reduce axle loads to a per 3 metre wide lane equivalent. c) Assumes that the Heavy Vehicle takes up only one lane (or more correctly, does not reduce the number of remaining Design Lanes) for M_1 and M_2 irrespective of width, and two lanes for M_3 d) Used to represent the AustRoads 1992 Bridge Code Multiple Lane Reduction Factor for M_1 only $\mathbf{M_1 = M_{hl} \times (1 + DLA_1) \times VRF}$ $\mathbf{M_2 = M_{hl} \times (1 + DLA_2)}$ $\mathbf{M_3 = M_{hl} \times (1 + DLA_3) / 2}$ per lane	a) Lanes loaded with one Heavy Load Vehicle and other “legal vehicles” as actual width allows (except in the case for M_3 where Heavy Vehicle is assumed to take up entire structure). b) Does not reduce axle loads to a per 3 metre wide lane equivalent. c) Considers that the number of lanes on a structure available to other legal loads may be reduced by a very wide Heavy Load Vehicle d) Does not use Vehicle Reduction Factors as Lane Reduction Factors are used instead. Lane Reduction Factors are based on AS5100 for M_1 and M_2 (i.e. 1.0, 0.8, 0.4, ... ,0.4). For L_{hl} = 1 lane $\mathbf{M_1 = M_{hl} (1 + DLA_1)}$ For $L_{hl} \geq 2$ lanes $\mathbf{M_1 = \{ M_{hl} + (0.4 \times L_{hl} \times M_{legal}) \} \times (1 + DLA_1)}$ $\mathbf{M_2 = M1 – M_{hl} (DLA1 – DLA2)}$ $\mathbf{M_3 = M_{hl} (1 + DLA_3)}$ per total width
Comparison of Moments a) M_{cap} compared with. M_1, M_2 & M_3	Compares the moment produced by the full width of the Heavy Load Vehicle with the moment capacity based on one design lane loaded with a Design Vehicle	Compares the moment produced by the full width of the Heavy Load Vehicle with the moment capacity based on one design lane loaded with a Design Vehicle	Compares the moment produced by a Heavy Load Vehicle and any other legal loads that can be physically placed on the specific structure, with the total moment produced by all design lanes loaded with Design Vehicles for that structure

Table ES2
Girder Bridges
(GSpacing >0)

Methodology Consideration	Current HLR	Transport SA Proposal	VicRoads Alternative
Bridge Capacity			
a) Distribution Factor	a) Used to reduce loads to a per girder basis.	a) Distribution Factor (DF) was common to all equations, and hence removed as part of a simplification. The variation in Distribution Factors for a structure effectively a single lane under M_3 is accounted for by the use of the factor 1.7/2.1. Refer notes below.	a) Distribution Factor (DF) was common to all equations, and hence removed as part of a simplification. The variation in Distribution Factors for a structure effectively a single lane under M_3 is accounted for by the use of a Vehicle Reduction Factor (VRF) which varies according to deck type - Refer notes below.
Equations used by HLR	$\mathbf{M_{cap} = R_a \times (M_{dv} / 2) \times (S / 1.7) (1 + DLA_{dv}) (1 + OS)}$ per girder	$\mathbf{M_{cap} = R_a \times M_{dv} \times (1 + DLA_{dv}) (1 + OS)}$ per lane	$\mathbf{M_{cap} = R_a \times M_{dv} \times (1 + DLA_{dv}) \times (1 + OS)}$ per lane
Heavy Vehicle Loading			
a) No. of Heavy Vehicles on Structure	a) One Heavy Load Vehicle on the structure, and VRF applied if there is enough kerb to kerb width remaining for at least a second traffic lane. Considers load on a girder under the Heavy Load Vehicle	a) One Heavy Load Vehicle on portion of structure containing girder/s under consideration.	a) One Heavy Load Vehicle on portion of structure containing girder/s under consideration.
b) Axle Load Reduction	b) Reduces axle loads to a per 3 metre wide lane equivalent.	b) Reduces axle loads to a per 3 metre wide lane equivalent.	b) Reduces axle loads to a per 3 metre wide lane equivalent.
c) Lane Reduction Factors	c) Uses the Vehicle Reduction Factor instead (refer below)	c) Uses the Vehicle Reduction Factor instead (refer below)	c) Not used. Considers the girders under the Heavy Load Vehicle without any factor
d) Vehicle Reduction Factor	d) Used to represent the AustRoads 1992 Bridge Code Multiple Lane Reduction Factor for M_1 only	d) Used to represent the AustRoads 1992 Bridge Code Multiple Lane Reduction Factor for M_1 only	d) Vehicle Reduction Factor is used to represent the improvement in Distribution Factor due to a Heavy Load Vehicle being the only vehicle permitted on a structure for M_3. Instead of just applying (1.7 / 2.1) which represents steel or PSC I-beams, it is based on the actual deck type and is a value in the range of 0.80 to 0.90 after rounding.
Equations used by HLR	$\mathbf{M_1 = (M_{hl} / 2) \times (S / 1.7) \times (1 + DLA_1) \times VRF}$ where generally VRF=0.90 $\mathbf{M_2 = (M_{hl} / 2) \times (S / 1.7) \times (1 + DLA_2)}$ $\mathbf{M_3 = (M_{hl} / 2) \times (S / 2.1) \times (1 + DLA_3)}$ per girder	$\mathbf{M_1 = M_{hl/L} \times (1 + DLA_1) \times VRF}$ where generally VRF=0.90 $\mathbf{M_2 = M_{hl/L} \times (1 + DLA_2)}$ $\mathbf{M_3 = M_{hl/L} \times (1 + DLA_3) \times (1.7 / 2.1)}$ per lane	$\mathbf{M_1 = M_{hl/L} \times (1 + DLA_1)}$ $\mathbf{M_2 = M_{hl/L} \times (1 + DLA_2)}$ $\mathbf{M_3 = M_{hl/L} \times (1 + DLA_3) \times VRF}$ where 0.80 <VRF<0.90 per lane
Comparison of Moments			
a) M_{cap} compared with. M_1, M_2 & M_3	Compares the moment produced on a girder under the Heavy Load Vehicle with the moment capacity based a Design Vehicle	Compares the moment produced by the reduced axle load Heavy Load Vehicle with the moment capacity based on one design lane loaded with a Design Vehicle.	Compares the moment produced by the reduced axle load Heavy Load Vehicle with the moment capacity based on one design lane loaded with a Design Vehicle.

A. ANALYSIS OF FLAT SLAB OR BOX GIRDER BRIDGES IN HLR

Aim:

To derive generic formulae for flat slab or box girder bridges of any number of traffic lanes.

To be applicable to any HLR structure that has

a) Girder Spacing (GSpacing) = 0
b) No ultimate or working stress capacities given

Capacity of Structure

The live load moment capacity of a structure is given by the following equation

$$\mathbf{M_{cap} = L_{dv} \times R_a \times M_{dv} \times (1 + DLA_{dv}) \times (1 + OS) \times LRF_{dv}}$$

[Eqn 1]

Where:

M_{cap}	=	Live load moment capacity of the structure at the cross-section under consideration
L_{dv}	=	number of design vehicle lanes refer Eqn 2 below
R_a	=	bridge rating according to the Design Vehicle (e.g. 100%, 75% 113% x of Design Vehicle)
M_{dv}	=	Design Vehicle moment (100% of Design Vehicle)
DLA_{dv}	=	Dynamic Load Allowance used for the Design Vehicle For pre 1992 = 16/(Span + 40) For post 1991 = AustRoads Section 2 Clause 2.4
OS	=	Overstress permitted for heavy load (e.g. 25%, 40% etc)
LRF_{dv}	=	Lane Reduction Factor a.k.a. "modification factor for multi-lane" "reduction in load intensity"

In the above equation the Vehicle Reduction Factor (VRF) currently used in HLR is replaced with the Lane Reduction Factor (LRF). The VRF is used for a separate purpose as discussed later in this text.

To determine the number of design lanes, the equation from NASSRA 1976 2.3.5, could be used

$$\mathbf{L_{dv} = N = w_k/3.1} \quad \text{(rounded down to the nearest whole number)}$$

[Eqn 2]

Where:

L_{dv} = number of design vehicle lanes (a.k.a. "N" in the NAASRA code)

w_k = carriageway width in m, between kerbs

The Lane Reduction Factor (LRF_{dv}) can be represented in tabular form, based on the Year of construction. If the year is unknown to HLR, the last row (minimums) could be used.

L_{dv}= **Year =**	1	2	3	4	5	6 or more
Pre 1992	1.00	1.00	0.90	0.75	0.75	0.75
Post 1991 Pre 2004	1.00	0.90	0.80	0.70	0.60	0.55
Post 2004	1.00	0.90	0.73	0.65	0.60	0.56
Unknown	1.00	0.90	0.73	0.65	0.60	0.55

Table 1: Values for LRF_{dv} based on Year and number of design lanes

Post 2004 values are based on AS5100.2 values
1 Lane = 1.00
2 lanes = (1.00 + 0.80) / 2 = 0.9
3 lanes = (1.00 + 0.80 + 0.40) / 3 = 0.73
4 lanes = (1.00 + 0.80 + 0.40 + 0.40) / 4 = 0.65 etc, etc

Moments due to Heavy Load

In HLR, three heavy load moments are derived, namely

M_1 = Unrestricted travel

M_2 = Restricted travel speed but not position

M_3 = Restricted travel speed and position

These moments are then compared to M_{cap} and the appropriate travel restriction is flagged to the user via the reports.

As heavy load vehicles may be larger than a standard design lane, the number of Heavy Vehicle Lanes may not equal the number of Design Vehicle Lanes (i.e. L_{hv} may not equal L_{dv}) for a given structure.

HLR currently uses the following formula to determine the number of lanes available when a heavy vehicle is crossing a structure

$$\mathbf{L_{hl} = \{(w_k - W) / 3.7\} - 1} \quad \text{(rounded down to the nearest whole number)}$$

[Eqn 3]

Where:

L_{hl} = Number available lanes on the structure whilst the Heavy Load Vehicle is present

w_k = carriageway width in m, between kerbs

W = width in m, of Heavy Load Vehicle

Figure 1 also shows relationship between L_{hl} and L_{dv}

For HLR purposes, the Heavy Load Vehicle is always assumed to be in "Lane 1". A "legal vehicle" is assumed to be in the other lanes representing other traffic/live loads on the structure.

Note/Issue:
There is a need to define what is a "legal vehicle" in HLR
Options may include:

- 90%T44
- 45.5t semi trailer
- 68t B-double
- Other ?

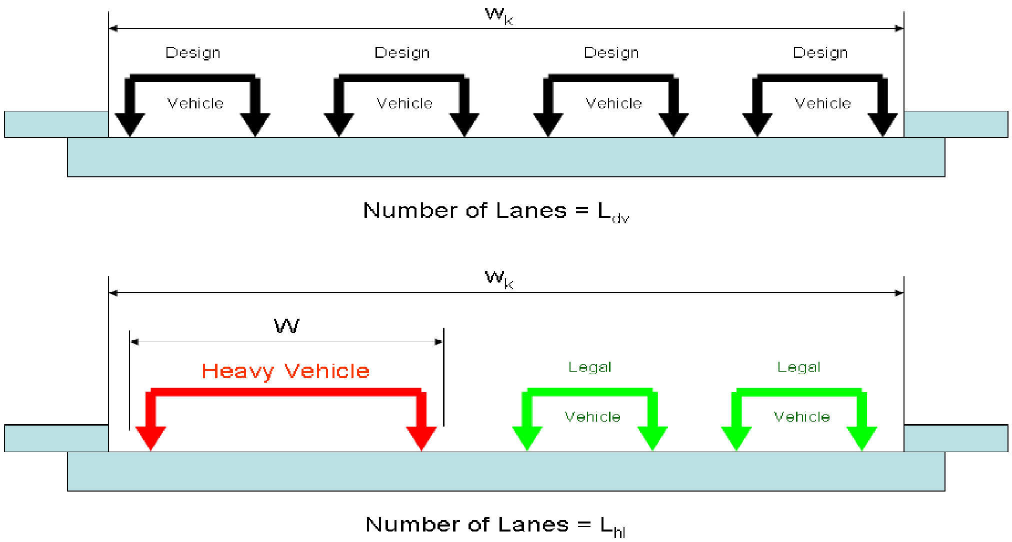

Figure 1: Relationship between L_{dv} and L_{hl}

The moment produced by an unrestricted Heavy Load Vehicle and other legal loads on a structure can be determined from the equation

$$\mathbf{M_1 = M_{hl} \times (1 + DLA_1) \times VRF_1 + M_{legal} \times (1 + DLA_1) \times VRF_2}$$

$$\mathbf{+ M_{legal} \times (1 + DLA_1) \times VRF_3 + \ldots + M_{legal} \times (1 + DLA_1) \times VRF_{Lhl}}$$

[Eqn 4]

Where

M_1	=	Total moment on structure due to unrestricted travel of heavy load vehicle and other legal vehicles
Mhl	=	Heavy Load Vehicle moment
DLA_1	=	Dynamic Load Allowance for unrestricted travel
VRF	=	Vehicle Reduction Factors for each lane based on AS5100.2 Table 6.6 Where VRF_1 = 1.00 VRF_2 = 0.80 $VRF_{3,\ 4,\ 5,\ \ldots,\ Lhl}$ = 0.40
M_{legal}	=	Moment produced by a legal vehicle also on the structure

Simplifying Equation 4:-

M_1

$= M_{hl}$ x $(1+DLA_1)$ x 1 + M_{legal} $(1+DLA_1)$ x 0.8 + M_{legal} x $(1+DLA_1)$ x 0.4 x $(L_{hl} -2)$

$= \{ M_{hl} + 0.8 \times M_{legal} + 0.4 \times (L_{hl} – 2) \times M_{Legal} \} \times (1+DLA_1)$

$= \{ M_{hl} + 0.4 \times (2 + (L_{hl} – 2)) \times M_{legal} \} \times (1+DLA_1)$

For L_{hl} = 1 lane

$$\mathbf{M_1 = M_{hl} (1 + DLA_1)}$$

[Eqn 5]

For $L_{hl} \geq 2$ lanes

$$\mathbf{M_1 = \{ M_{hl} + (0.4 \times L_{hl} \times M_{legal}) \} \times (1 + DLA_1)}$$

[Eqn 6]

The moment produced by a Heavy Load Vehicle restricted in speed but not position and other legal loads on a structure can be determined from the equation.

$$\mathbf{M_2 = M_{hl} \times (1 + DLA_2) \times VRF_1 + M_{legal} \times (1 + DLA_1) \times VRF_2}$$

$$\mathbf{+ M_{legal} \times (1 + DLA_1) \times VRF_3 + ... + M_{legal} \times (1 + DLA_1) \times VRF_{Lhl}}$$

Eqn 7]

Where

M_2	=	Total moment on structure due to heavy load vehicle restricted in speed but not in position and other unrestricted legal vehicles
Mhl	=	Heavy Load Vehicle moment
M_{legal}	=	Moment produced by a legal vehicle also on the structure
DLA_1	=	Dynamic Load Allowance for unrestricted travel Applies only to the legal vehicles
DLA_2	=	Dynamic Load Allowance for restricted Heavy Vehicle travelling at slow speed

VRF = Vehicle Reduction Factors for each lane based on AS5100.2 Table 6.6
Where $VRF_1 = 1.00$
$VRF_2 = 0.80$
$VRF_{3, 4, 5, ..., Lhl} = 0.40$

Simplifying Equation 7:-

M_2

$= M_{hl} \times (1+DLA_2) \times 1 + M_{legal} (1+DLA_1) \times 0.8 + M_{legal} \times (1+DLA_1) \times 0.4 \times (L_{hl} -2)$

$= M_{hl} \times (1 + DLA_2) + \{0.4 \times (2 + (L_{hl} – 2)) \times M_{Legal} \times (1+DLA_1)\}$

$= M_{hl} \times (1 + DLA_2) + \{0.4 \times L_{hl} \times M_{legal} \} \times (1+DLA_1)\}$

For L_{hl} = 1 lane

$$\mathbf{M_2 = M_{hl} (1 + DLA_2)}$$

[Eqn 8]

For $L_{hl} \geq 2$ lanes

$$\mathbf{M_2 = M_{hl} \times (1 + DLA_2) + (0.4 \times L_{hl} \times M_{legal}) \} \times (1 + DLA_1)}$$

[Eqn 9]

Now

$M_1 = \{ M_{hl} + (0.4 \times L_{hl} \times M_{legal}) \} \times (1 + DLA_1)$

$= M_{hl} \times (1 + DLA_1) + (0.4 \times L_{hl} \times M_{legal}) \} \times (1 + DLA_1)$

Hence

$M_2 = M_1 + M_{hl} (1 + DLA_2) – M_{hl} (1 + DLA_1)$

$= M_1 + M_hl (1 + DLA_2 – 1 – DLA_1)$

$= M_1 + M_{hl} (DLA_2 –DLA_1)$

As $DLA_1 \geq DLA_2$, this is best rewritten as

$$\mathbf{M_2 = M1 – M_{hl} (DLA1 – DLA2)}$$

[Eqn 10]

It can be shown that Equation 10 can apply to all cases of L_{hl} , as the only difference in the two scenarios is the speed of the Heavy Vehicle, hence the difference in the dynamic effects.

The moment produced by a Heavy Load Vehicle restricted in speed and position is simplified by the requirement that no other legal vehicles traverse the structure at the same time and the Heavy Vehicle.

Effectively, irrespective of structure width L_{hl} = 1 lane

For all $L_{hl} \geq 1$ lane

$$\mathbf{M_3 = M_{hl} (1 + DLA_3)} \qquad \text{[Eqn 11]}$$

Where

M_3	=	Total moment on structure due to heavy load vehicle restricted in speed and position and no other vehicles permitted on the structure
M_{hl}	=	Heavy Load Vehicle moment
DLA_3	=	Dynamic Load Allowance for restricted Heavy Vehicle travelling at very slow speed

Summary

Flat Slabs/Box Girders, *GSpacing* = 0

For the whole structure:-

The live load moment capacity of the whole structure is given by the following equation

$$\mathbf{M_{cap} = L_{dv} \times R_a \times M_{dv} \times (1 + DLA_{dv}) \times (1 + OS) \times LRF_{dv}}$$

[Eqn 1]

The moments produced by an unrestricted Heavy Vehicle and other legal vehicles

For L_{hl} = 1 lane $\mathbf{M_1 = M_{hl}\,(1 + DLA_1)}$

[Eqn 5]

For $L_{hl} \geq$ 2 lanes $\mathbf{M_1 = \{ M_{hl} + (0.4 \times L_{hl} \times M_{legal}) \} \times (1 + DLA_1)}$

[Eqn 6]

The moments produced by Heavy Vehicle restricted in speed but not position and other legal vehicles

For all $L_{hl} \geq$ 1 lane $\mathbf{M_2 = M1 - M_{hl}\,(DLA1 - DLA2)}$

[Eqn 10]

The moment produced by a Heavy Vehicle only (no other vehicles on structure) restricted in speed and position is

For all $L_{hl} \geq$ 1 lane $\mathbf{M_3 = M_{hl}\,(1 + DLA_3)}$

[Eqn 11]

B. ANALYSIS OF GIRDER BRIDGES IN HLR

Aim:

To derive generic formulae for girder bridges of any number of traffic lanes.

To be applicable to any HLR structure that has

a) *Girder Spacing (GSpacing > 0)*
b) *No ultimate or working stress capacities given*

Capacity of Structure

The live load moment capacity of a structure is given by the following equation

$$M_{cap} = R_a \times M_{dv/L} \times DF \times (1 + DLA_{dv}) \times (1 + OS)$$

[Eqn 12]

Where:

M_{cap}	=	Live load moment capacity of the girder at the section under consideration
R_a	=	bridge rating according to the Design Vehicle (e.g. 100%, 75% 113% x of Design Vehicle)
$M_{dv/L}$	=	Design Vehicle moment per lane
		= M_{dv}, as all codes have one design vehicle per lane
M_{dv}	=	Design Vehicle moment per lane
DLA_{dv}	=	Dynamic Load Allowance used for the Design Vehicle For pre 1992 = 16/(Span + 40) For post 1991 = AustRoads Section 2 Clause 2.4
OS	=	Overstress permitted for heavy load (e.g. 25%, 40% etc)
DF	=	Distribution factor, transferring a line of wheels to a girder loading e.g. NAASRA 1976 Table 3.1

$$\mathbf{M_{cap} = R_a \times M_{dv} \times DF \times (1 + DLA_{dv}) \times (1 + OS)}$$

[Eqn 13]

Moments due to Heavy Load

In HLR, three heavy load moments are derived, namely

M_1 = Unrestricted travel

M_2 = Restricted travel speed but not position

M_3 = Restricted travel speed and position

These moments are then compared to M_{cap} and the appropriate travel restriction is flagged to the user via the reports.

As the capacity has been determined on a per girder basis, the use of the distribution factor (DF) is again required.

To be taken into consideration is the fact that distribution factors are based on a design lane, whereas the Heavy Load Vehicle may be wider.

HLR currently overcomes this situation by determining a moment per design lane by factoring individual axle loads on the basis of their width compared to a design lane.

Effectively

Axle load = Total Axle Load x (3 / W)

Where:

W = width in m, of heavy Load Vehicle axle under consideration

Note:
This is different to PCLegal reduction factors.,

Figure 2 shows the relationship between PCLegal reduction factors and those assumed for HLR. The HLR approach is simpler, and has been shown to be more conservative, and is adopted currently by VicRoads trial of HLR. Use of different factors however would not alter the following algorithms, only amend the value of $M_{hl/L}$, the moment produced by the Heavy Load Vehicle within one design lane.

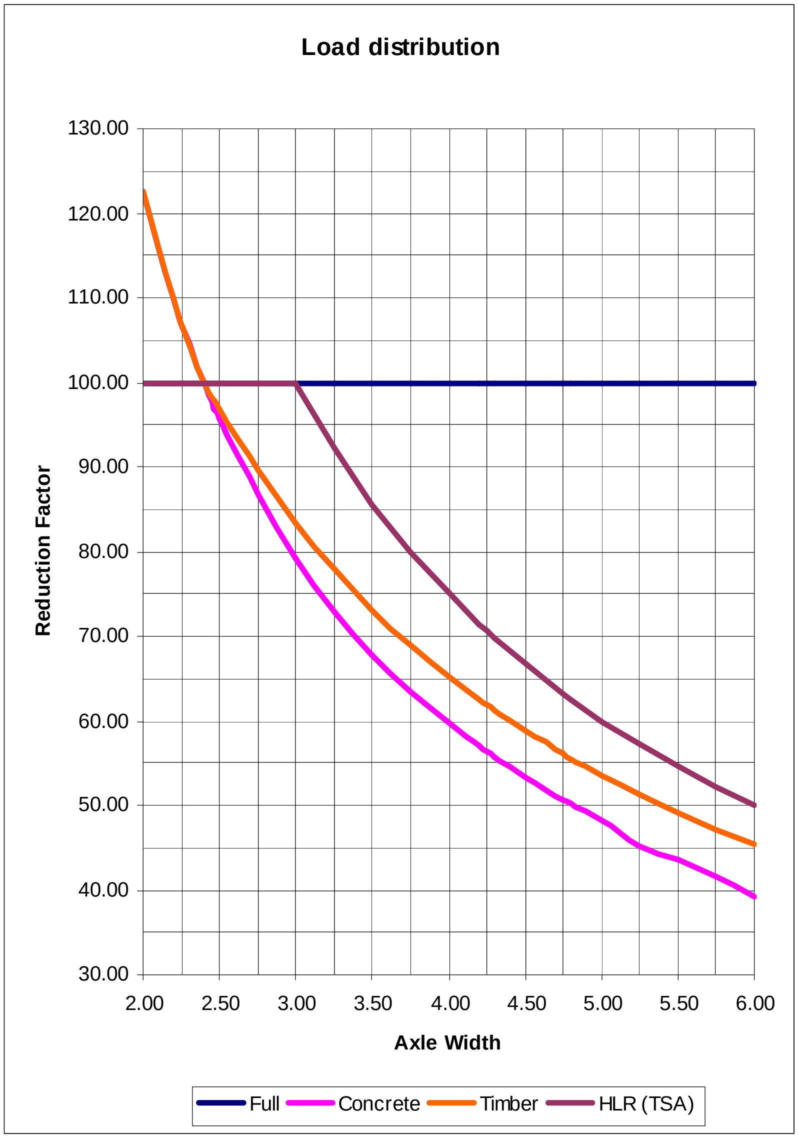

Figure 2: Comparison of HLR and assumed VicRoads distribution factors for timber and concrete deck (source PCLegal).

As indicated above, the net result is that HLR produces $M_{hl/L}$, the moment produced by the Heavy Load Vehicle within one design lane. As a reduction factor is being used, and a single girder being considered, one should not apply any other Load Reduction Factor (LRF) as used for box girders and flat slabs.

For M_1 and M_2, HLR's Vehicle Reduction Factor also should not be considered for this same reason, however in the case of M_3 there is justification for a factor which will be discussed later.

The moments produced in a girder by an unrestricted or speed only restricted Heavy Load Vehicle and other legal loads on a structure can be determined from the equation

$$\mathbf{M_1 = M_{hl/L} \times DF \times (1 + DLA_1)}$$

[Eqn 14]

$$\mathbf{M_2 = M_{hl/L} \times DF \times (1 + DLA_2)}$$

[Eqn 15]

Where:

M_1	=	Total moment on a girder due to unrestricted travel of a Heavy Load Vehicle
M_2	=	Total moment on a girder due to the travel of a Heavy Load Vehicle restricted in travel speed but not in position
$M_{hl/L}$	=	Heavy Load Vehicle moment, based on the load in one design lane (3m wide)
DF	=	Distribution factor, transferring a line of wheels to a girder loading e.g. NAASRA 1976 Table 3.1
DLA_1	=	Dynamic Load Allowance for unrestricted travel
DLA_2	=	Dynamic Load Allowance for restricted Heavy Vehicle travelling at slow speed

M1 and M2 allow for other legal vehicles in other lanes, however it only considers the girders under the Heavy Load Vehicle. The existence of the legal vehicles is considered by the selection of a Distribution Factor applicable to a multi-lane structure**.**

M3 however assumes that the Heavy load Vehicle is

a) Travelling on the structure with no other traffic

b) Travelling on the best portion of the structure (e.g. in the SA scenario, travelling along the centre of the bridge, traversing two design lanes)

Considering a); this makes the structure effectively a one traffic lane structure, and a benefit from the fact that no other legal vehicles are on the structure should be incorporated into the analysis

As indicated above, the legal loads for M_1 and M_2 were addressed by the Distribution Factor DF. These Distribution Factors do vary for single and multilane structures. Based on NAASRA 1976 Table 3.1, the Distribution Factors vary by the following ratios between multi and single lane structures

Type of Deck	Ratio of bridge designed for two lanes to bridge designed for one lane
For Concrete Deck	
(i) On steel I-beam stringers or prestressed concrete beams	1.7/2.1 = 0.81 say 0.80
(ii) On concrete T-beams	1.8/2.0 = 0.90 say 0.90
(iii) On timber stringers	1.5/1.8 = 0.83 say 0.85
Concrete box girders	N/A
For Timber Deck Plank	
All cases	1.1/1.2 = 0.91 say 0.90
For Steel Grid	
(i) Less than 100 mm thick	1.2/1.3 = 0.92 say 0.90
(ii) 100 mm thick or more	1.5/1.8 = 0.83 say 0.85

On this basis, a Vehicle Reduction Factor (VRF) could be reintroduced into the equations, but only for M_3 moments, and only with values only in the range of 0.81 to 0.92 (say rounded 0.80, 0.85 and 0.90)

i.e.

$$\mathbf{M_3 = M_{hl/L} \times DF \times (1 + DLA_3) \times VRF}$$

[Eqn 16]

For M_3, HLR currently introduces a factor of 0.5, justified by the straddling of two lanes. This is not included in the above for the following reasons:-

- The value of $M_{hl/L}$ already is already only considering the load in one lane, with individual axle loads factored down by 3.0/W
- The VRF factor above takes into consideration that other legal loads are not permitted on the structure
- Geometry of a specific structure and Heavy Load Vehicle may not allow such an un-conservative idealised distribution of load.

Summary

Girder Bridges, *GSpacing* > 0

For an individual girder under the Heavy Load Vehicle:-

The live load moment capacity of the whole structure is given by the following equation

$$M_{cap} = R_a \times M_{dv} \times DF \times (1 + DLA_{dv}) \times (1 + OS)$$

[Eqn 13]

The moment produced by an unrestricted Heavy Vehicle and other legal vehicles

$$M_1 = M_{hl/L} \times DF \times (1 + DLA_1)$$

[Eqn 14]

The moments produced by Heavy Vehicle restricted in speed but not position and other legal vehicles

$$M_2 = M_{hl/L} \times DF \times (1 + DLA_2)$$

Eqn 15]

The moment produced by a Heavy Vehicle only (no other vehicles on structure) restricted in speed and position is

$$M_3 = M_{hl/L} \times DF \times (1 + DLA_3) \times VRF$$

[Eqn 16]

It is observed that the Distribution Factor is common to all equations, and therefore for comparison purposes can be eliminated, making the equation for HLR:-

$$\mathbf{M_{cap} = R_a \times M_{dv} \times (1 + DLA_{dv}) \times (1 + OS)}$$

[Eqn 13 modified]

$$\mathbf{M_1 = M_{hl/L} \times (1 + DLA_1)}$$

[Eqn 14 modified]

$$\mathbf{M_2 = M_{hl/L} \times (1 + DLA_2)}$$

[Eqn 15 modified]

$$\mathbf{M_3 = M_{hl/L} \times (1 + DLA_3) \times VRF}$$

where $0.80 < VRF < 0.90$

[Eqn 16 modified]