Load Rating Bridge Structures –VicRoads Practice

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Abstract  This paper provides guidelines for load rating of existing bridges. It is based on internal notes regarding criteria and practice for load rating of bridges and consideration of multiple vehicle presence over structures with varying numbers of heavy commercial vehicles. It extends the provisions of the current AS 5100 Bridge Design 2004 [1] by providing a guide for bridge designers in regards to multiple presence of heavy vehicles and loading criteria for legal, restricted and permit vehicle travel. The main objectives of this paper are to facilitate consistent rational bridge rating methods for assessment Engineers. This will foster national practices for load rating bridges and allow uniform travel potential of varying types and load configurations of vehicles.

Introduction

This paper provides current practice, criteria and efficient choice of load rating vehicle(s) for load evaluation of existing bridges. It is based on internal notes regarding criteria and practice for load rating of bridges and consideration of multiple vehicle presence over structures with varying numbers of heavy commercial vehicles. It refers to the provisions of the current AS 5100 Bridge Design – 2004 [1], the relevant sections of the Austroads Guide for Bridge Design [2] and other background literature that has shaped current practices.

The main objectives of this paper are to facilitate consistent rational and simplified bridge rating methods for load assessment Engineers.
Background to bridge loading standards

Information herein is partially extracted from the NRTC discussion paper [11] and the AS5100 Part 7 [1]. A design standard specifies maximum stresses that key elements of the bridge can sustain under repeated loading without incurring damage. When a heavy vehicle crosses a bridge and the maximum stresses are exceeded, it is possible that damage to the bridge may result. Even if the damage is minor, repeated crossings may result in a requirement to repair the damage and, in extreme circumstances, the bridge may collapse.

The AS 5100 Part 7 [1] includes a method of evaluation of the load capacity of existing bridges and a means to establish the maximum load that can be carried on the bridge as a rating factor RF (or fraction) of the chosen rating vehicle. The rating strength equation is detailed as follows:

For the purpose of rating, the general strength equation for bridges is

$$\phi R_u \geq \gamma_s S^*_s + \gamma_p S^*_p + \gamma_d S^*_d + \gamma_l (RF) S^*_l + \gamma_f (1 + \alpha)$$

The general equation to determine the rating factor (RF) for bridges is therefore:

$$RF \leq \frac{\phi R_u - \left( \gamma_s S^*_s + \gamma_p S^*_p + \gamma_d S^*_d + \gamma_l S^*_l \right)}{\gamma_l (1 + \alpha) W S^*_l}$$

i.e.,

$$RF = \frac{\text{Available bridge capacity for live load effects}}{\text{Live load effects of nominated rating vehicle}}$$

Therefore the rated load ($L_R$) can be expressed as follows:

$$L_R = (RF) L_{RV}$$

where

- $\phi$ = capacity reduction factor
- $R_u$ = calculated ultimate capacity
- $\gamma_s$ = load factor for dead load
- $S^*_s$ = load effects due to dead load
- $\alpha$ = dynamic load allowance
- $L_R$ = rated load
- $L_{RV}$ = nominated rating vehicle

For the rest of symbol definitions refer to the AS5100.7 [1]

The evaluation should be carried out by experienced professional engineers and in brief, should determine the capacity of the bridge under serviceability and the ultimate limit state. The rating assessment may include the following functions:
• Desktop analysis based on as built bridge information and current condition measured by inspection.
• Field measurement and inspection for missing information
• Determining characteristic strengths by material testing

An alternative to analytical load rating is to carry out full scale load testing on the bridge. This may be suitable for some specific bridges such as complex arch bridges and would include the following type of testing:

• Static Non-destructive or destructive to the ultimate limit.
• Proof ultimate elastic.
• Dynamic for performance under specific vehicles.

The present AS5100 [1] bridge design standard requires that a bridge be designed for an SM1600 design vehicle with a ‘load factor’ of 1.8, i.e. the bridge must be capable of supporting a load that is 1.8 times the design load. This load caters for:

• Deterioration of the bridge through aging over its design life;
• The passage of loaded vehicles over the life of the bridge; and
• The support of vehicles carrying indivisible loads and for the occasional overloaded vehicle to traverse the bridge without failure.

Presently, general access vehicle access performance is approximated by level 1 axle spacing mass schedules with bogie mass regulatory limits. Refer to current typical vehicle mass indicated by Fig. 1.

Fig. 1. Mass limits for trucks in Victoria

- Refer to VicRoads publication [12] for other details
- Note that GML refers to general mass limit and MLR refers to the higher mass limit allowed
for a road friendly suspension. Refer to the NRTC [13] for further details.

The design loads used in the past do not necessarily simulate current vehicle mass. Refer to Fig. 2 which shows the trend of increase in design loads versus the increase in vehicle mass.

![Fig. 2. Increases in legal mass and design loads](image)

Specific mass configurations of relatively recent design vehicles are detailed in Fig. 3.

Note that the HLP Platforms provide a reasonable resemblance to current single platforms and should be utilized in determining an upper bound load rating of the bridge for such permit vehicles, under permit vehicle criteria. This will assist in and expedite the approval of current platforms by comparing their respective vehicle effects.

The Austroads Bridge Assessment Group (ABAG) [4] produced typical commercial vehicle configurations to be used for assessment of potential travel throughout Australia. The configurations for a six-axle articulated semitrailer, a nine-axle B-Double and a Double Road Train are set in Fig. 4. For a triple road train, a third trailer identical to the second trailer of the double road train is added.
### Load rating bridge structures – VicRoads Practice

#### Fig. 3. Bridge Design Loads

<table>
<thead>
<tr>
<th>NAASRA 1976</th>
<th>AUSTROADS 1992</th>
<th>Length 9.10m</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-44 Truck</td>
<td>Lane Loading</td>
<td>3.0m in width</td>
</tr>
<tr>
<td></td>
<td>(12.5kN/m)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NAASRA 1976</th>
<th>AUSTROADS 1992</th>
<th>Length 18m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormal Vehicle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(90 t approx Gross)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NAMSA 1976</th>
<th>AUSTROADS 1992</th>
<th>Length 27m</th>
</tr>
</thead>
<tbody>
<tr>
<td>HLP-200</td>
<td>16 axles at 1.8m centres</td>
<td></td>
</tr>
<tr>
<td>(420 kN approx gross)</td>
<td>15.0 m</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>NAMSA 1976</th>
<th>AUSTROADS 1992</th>
<th>Length 27m</th>
</tr>
</thead>
<tbody>
<tr>
<td>HLP-400</td>
<td>10 axles at 1.8m centres</td>
<td></td>
</tr>
<tr>
<td>(450 kN approx gross)</td>
<td>25.0 m</td>
<td></td>
</tr>
</tbody>
</table>

#### Fig. 4. Typical freight vehicles.

**ABAG VEHICLES**

6 axle articulated vehicle

42.5t - 45.5t (MLR)

9 axle B double

62.5t - 65.5t (MLR)

Double road train

79t - 85t (MLR)

Triple road train

115t - 124t (MLR)
Note that the 45.5t Semi-trailer and the 68t 9 axle B-Double are the high mass vehicles utilised by all States to check and formulate the (MLR) road network for such vehicle travel. The network consists mainly of MS18 design load bridges or equivalent in good working order (or under monitor status) for such travel.

Load Rating Criteria for Specific Vehicles

Information in this section is partially based on a recent TMR Queensland survey response on VicRoads policy, Colosimo [2]. For short to medium length bridges having two or more lanes (total both directions)

Accompanying vehicle(s) and associated lane factors.

For restricted network combination vehicles; medium mass special purpose vehicles and permit vehicles (travelling with other traffic): we can use the same vehicle in the accompanying lane or other heavy vehicles relevant to the expected, surveyed or measured traffic. In addition multiple lane modification factors should be used as per the AS5100.7 Table 6.6 for the design vehicle. In brief, the first lane vehicle loading shall not be factored; the second lane load shall be factored by 0.8 and subsequent lanes by 0.4.

For the heavier permit vehicles such as platforms, for undivided bridges we usually do not allow other vehicles on the structure (apart from the permit pilot vehicle when necessary). For divided carriageway bridges we usually don’t consider additional vehicle loading in the carriageway with the platform. In addition for bridges that carry both carriageways consideration should be made for accompanying vehicles by the use of the AS5100 [1] 50% MS1600 loading (or the Austroads 1996 [3] T44 design loading) in the other carriageway, positioned to give the worst effects with accompanying lane factors as per AS5100.2, Table 6.6. Both of these loadings reflect potential additional vehicles on the structure. The accompanying Factors do not vary with the size of accompanying vehicle but with the number of additional lanes loaded.

Position of rating vehicle on the bridge.

The rating vehicle is usually positioned on the design lanes since they are extracted from the as built drawings of the structure. For existing bridges the rating vehicle should be positioned on the marked traffic lanes. This is especially
appropriate when they do not coincide with the design lanes. This can be adopted provided that there is no likelihood of additional lanes being created by reducing lane width in the foreseeable future, to allow more traffic on the structure.

**Multiple vehicle presence for longer span bridges.**

**Multiple vehicles in the same lane.**

The AS5100 Bridge Design does not require consideration of multiple vehicles in the same lane when rating for the SM1600 Standard bridge capacity. If the bridge is located on structures where convoys of heavy rating vehicles or similar are expected statistically, such as freeways and major high commercial vehicle traffic count roads, then consideration should be given to consider more than one vehicle. The number of such vehicles should be restricted to the potential number expected that may affect the capacity of the bridge. Multiple rating vehicle queuing presence should not be considered where such traffic is unlikely i.e. usually well away from the metropolitan areas.

The ABAG Guidelines 1997 [4] adopted by VicRoads make the following recommendations. For vehicles in the same lane adopt headway of 17 m (minimum clear between the rear axle of front vehicle and front axle of the rear vehicle). A reduced 8 m headway may be considered for roads with a high number of commercial vehicles, in areas of low speed where traffic queuing is likely. This can occur close to traffic lights or other traffic congestion. Other values have been and should be considered when necessary to portray future traffic and or produce worse loading effects on the specific structure, such as alternating 8 m and 17 m between following vehicles.

The AS5100 Bridge Standard [1] does not allow other vehicles in the same lane, when designing for the SM1600 loading. The ABAG Guideline [4] recommended that for vehicles in the same lane multiple presence factors should be used. It is therefore recommended that the AS5100 adjoining lane factors be adopted also for additional vehicles in the same lane, when the spans are long enough to make this effect relevant. These factors are relevant to other than the SM1600 loading i.e. they can apply to the T44 rating truck or other chosen rating vehicles.
Live Load Factor (LF) for rating structures.

The Live Load Factor (LF) should be in accordance with the AS5100 Standard [1] and as recommended herein:

Current recommended practice is 2.0 for general access vehicles,

1.8 for the SM1600 AS5100 design vehicle; restricted (MLR) network vehicle travel and higher performance freight vehicles),

1.5 For the heavy load platform(s) including the HLP320 and HLP400 with 0.1 Dynamic Load Allowance (DLA) at slow 10 km/h travel (or full DLA at normal speed). The current practice is to use the approximately equivalent 1.4 for a single trip permit vehicle with 0.0 DLA at 5km/h (or full DLA at normal speed) for very heavy vehicles. Note that this equivalence was generally allowed by the NAASRA 1976 Specifications [6] Clause 11.6.2 for the overload vehicle, subject to centreline travel without other vehicles on the bridge.

1.6 For period permit and special purpose vehicles under period permit. This usually applies to restricted network vehicles such as Cranes and short Low Loaders.

The rationale for these factors has been extrapolated from the following references. The AS5100 Standard [1], the NAASRA RoRVL Review Report 1986 [5] and the NAASRA Study Report 1981 [6] publication on road movement of indivisible items.

Dynamic Load Allowance (DLA) for the Rating (or Assessment) vehicle.

For general access legal vehicles and restricted network access vehicles, which include the medium combination vehicles such as B-Doubles and high performance freight vehicles, we use the DLA as per the AS5100.2 [1].

For heavy permit vehicles (e.g. platform vehicles), we use DLA = 0.1 as per the AS5100.2 Table 6.7.2 [1]. (Or equivalent DLA = 0 at a steady walking speed of 5 km/h as detailed in section 2 of this paper on Live Load Factors).
Load Rating Procedure for Specific Vehicles

General Requirements

Most bridges that require rating are the older bridges of short spans. The following procedure aligns itself to rating such bridges with particular emphasis on timber bridges. It can be applied to most other bridges as well.

Current rating Practice

Current practice for load rating is generally in accordance with the AS5100 Bridge Design Part 7 [1]. For timber bridges the rating should also be in accordance with the AS 1720.1 Timber Code [7].

Clause 4.1 of the AS5100.7 [1] states that the procedure shall be to rate the available live load capacity of the bridge compared with the effects of a nominated rating vehicle, that is:

- the SM1600 loading for general capacity rating
- a specific live load configuration(s) for general access vehicles e.g. a legal limit loading; or
- a specific live load configuration for restricted access vehicles, e.g., an indivisible heavy load vehicle operating under nominated conditions.

Our VicRoads traditional and current practices align very closely with the AS 5100 [1] requirements. The current practice is to rate the bridge to the above vehicles but to also include the 42.5t 1,2,3 axle bogie semi-trailer. For a limit that reflects most current vehicles the current practice is to rate the bridge to the previous T44 1,2,2 Design truck (of 44 tonne), because it has the following specific advantages:

- For simple spans up to 8 metre the vehicle can simulate the semi-trailer as well as shorter and lighter vehicles relevant to the original bridge designs.
- For continuity effects, the 1,2 axle bogie portion and the tandem axle straddle the bridge pier and thus provide a check on continuity effects from the older A Class bridge design and their associated uniform loading.
- Historically we have proven that this is the most efficient and simplest design vehicle for rating bridges, to the extent that we have rated most of the older bridge structures as a percentage of the T44 vehicle gross mass. For example timber bridges designed to the order of 15t to 25t design loads, if maintained in
relative good working order, were proven by the same T44 vehicle to have the same 15t to 25t order of load capacity.

- For longer spans, the same T44 vehicle closely simulates the current high mass 45t restricted access semi-trailer vehicle subject to consideration of multiple presence. In addition for the medium span range bridges where longer restricted 68t B-Double vehicles cannot fully load a whole span, this same vehicle provides reliable load limit values. This takes its usefulness to the order of 20 m spans and this span range covers most if not all of the older bridges requiring rating.

Load rating considerations

The NAASRA ERVL Review of Road Vehicle Limits for vehicles using Australian roads reported in 1974 [8] that in order to allow travel by typical modern vehicles and define new axle spacing schedules for their creation (such as the semi-trailer) that they would consider as part of the review potential maximum overstress limits on different bridge materials which included an over stress factor of 133 % for timber. This over stress was then translated into an equivalent over stress factor of 1.35 with respect to the design bending moment. The same information was confirmed in the 1986 RoRVL review of road vehicle limits [5] with a 20 % reduction for setting the actual axle spacing mass schedules. The RoRVL report noted that "Bridges stressed within this range will be serviceable for sufficient time to defer reconstruction or strengthening". The NAASRA committee defined acceptable levels of repeated over stress which included the 133 % for timber.

The traditional NAASRA Specification [9] design live load distribution to superstructure beams is considered relevant for older bridges designed prior to 1992. The simple distribution was based on the beam spacing. That same distribution should not be used for current rating without due consideration of potential changes to the original bridge beam arrangement etc.

For modified bridges where actions have been taken in order to reduce the original loading over the structure or improve the distribution of such loading the NAASRA distribution is not considered appropriate. For example additional beams may have been placed under the anticipated wheel line travel of vehicles. For such modified bridges a finite element analysis or grillage analysis is required to ensure that the strengthening is properly considered in regards to the remaining weakest member of the superstructure and in turn the substructure components. Examples of such modifications include the following:
• Reducing the width between kerbs in order to reduce the bridge to one lane travel and also to position the vehicle near the bridge centre line to improve the load distribution.

• Adding and or strengthening beams covering the expected wheel tracks of the heavy truck vehicles.

• Replacing current beams with stronger beams which tend to attract additional loading and lighten the rest.

Previous rating examples for short span bridges have indicated that the T44 vehicle represents/COVERS most others including smaller and shorter vehicles. In other words some shorter vehicles can create lower rating limit values (in comparison to the relevant parts of the T44 vehicle that is on the same span) but the difference is not exceptional and can be considered as not providing undue risk in regards to the additional stresses. Refer to Fig. 5 which shows legal loads relevant to rating the older design load bridges.

The alternative of placing emphasis to a short lighter vehicle check alone, (which by the way may tend to represent the original two axle design vehicle of 1.1 axle bogie to approximately 15 t) would not allow travel by appropriate longer vehicles such as the 42.5t semitrailers. In other words when we allow a semitrailer of 42.5t
over a short span timber bridge in reality we are allowing a 1,2 axle vehicle of 22.5t or a tri-axle bogie 2.4 m long of 20t but not both. For most short to medium span bridges the 42.5t legal semi-trailer produces similar loading effects to the MS18 design vehicle. Refer to Fig. 6 which compares the simple loading effects of the MS18 (42.5t) Legal load to the older A Class bridges etc. This plot as expected indicates that the short span A Class bridges in good working order would be expected to have in the order of 0.6 T44 capacity or an approximate load rating of 26 tonne on the 1,2,2 axle bogie semi-trailer.

Fig. 6. Comparison of Simply Supported Vehicle Bending Moments

Traditionally the structures group (represented by the decisions of past experts in this field both in Victoria and some other states), have accepted that the T44 vehicle is the most reliable design vehicle, for load rating the older short span (and timber) bridges. This has allowed the continued successful use of such bridges in Victoria. The current heavy load inventory shows the bridge rating as a factor of T44 which is also used (often, by comparison) to consider travel of most other vehicles on such structures. This vehicle is therefore still considered the most relevant rating vehicle for the purpose of allowing travel by most current legal vehicles.
Future Load Rating.

Rating of the older bridges should be carried out in accordance with both current bridge design standards and the original design taking into account later bridge modifications and the current condition of the structure. In addition, analysis should be carried out for the T44 design vehicle representing most current vehicles. Multiple presence of heavy vehicles (both in adjacent lanes and following lanes) should be considered, if relevant to the bridge site and for anticipated future traffic trends.

For strengthened or modified bridges an appropriate and more detailed analysis such as grillage analysis should also be undertaken.

Posting of load limits should also be considered for specific single, tandem and tri-axle bogie mass of heavy trucks, rather than the current single gross mass load limit.

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References