limitstate ring

a rapid analysis tool for masonry arch bridges

Application Note - Practical assessment of UK highway masonry arch bridges

(Based on recommendations given in UK Highways Agency Standard DMRB CS 454 Revision 1, 2020)

This application note discusses how the output from LimitState:RING can be used to calculate the maximum gross vehicle weight which can safely be applied to a typical highway masonry arch bridge according to standard UK practice.

1. Critical loading case

- HA type loading is not applicable to masonry arch bridges.
- For short spans (e.g. 5m or less), which are very common, a single axle loading case will generally be critical.
- For medium spans multiple axle loading cases may be critical and should be checked for.
- For long span bridges foreseeable live loadings will typically be small compared with the dead weight of the structure.

2. Effective bridge width

When using two-dimensional analysis software (e.g. LimitState:RING) appropriate assumptions are required in order to determine the effective bridge width (w). For cases in which there are no longitudinal cracks in evidence in the barrel of the bridge being considered and when centrifugal effects are absent, then the effective width may be calculated as the minimum of all the expressions given in Table 1 (prepared in accordance with DMRB CS 454).

N$^{o.}$	Loading Configuration	Effective width (w) for an Axle Loading	Notes
1	Single wheel	$(1.5+h)\times 2/F_A$	
2*	Single axle	1.8+(1.5+h)	Wheels at 1.8m spacing (see DMRB CS 454 Appendix B1)
3	Single axle	Bridge width	
4	Two axles side by side	[0.7+2×1.8+(1.5+h)]/2	Wheels at 1.8m spacing; 0.7m between axles (see DMRB CS 454 Table 5.9a)
5	Two axles side by side	[Bridge width]/2	

* This case is assumed when an 'auto-computed' effective bridge width is specified in LimitState:RING.

Table 1 - Expressions to be used to calculate the effective width of an axle loading

Where h is the depth of fill at the position of the applied load and where F_A is the centrifugal effect factor; see section 3. below. Note that the minimum notional lane width is 2.5m (i.e. the carriageway must be at least 5m wide to accommodate two lanes/vehicles).

N.B. if centrifugal effects are present the single wheel case should always be considered in addition to other cases.

3. Centrifugal effects and 'axle lift off'

If the horizontal road alignment is curved (i.e. there is a bend in the road over the structure) then centrifugal effects should be considered as more load will act on one wheel than the other. This may mean that a single wheel load is the most critical loading condition.

The equivalent increased static load is obtained by applying a centrifugal effect factor, F_A (from DMRB CS 454 Equation 5.24):

$$F_A = \min\{\, 1 + (0.20v^2/r),\ \ 1 + (200/(r + 150))\,\}$$

Where v = vehicle speed in m/s and r = radius of curvature of carriageway in m. The centrifugal effect factor can be used to modify the effective bridge width for the single wheel load configuration, as indicated in Table 1 above.

If the vertical road alignment is sharply curved (e.g. a hump back bridge) then one should consider the possibility of ‘axle lift off’. Here the load from an axle that has lost contact with the carriageway surface should potentially be distributed among the remaining axles in a bogie (see e.g. DMRB CS454 Table 7.3.1b). This can be modelled in LimitState:RING by creation of a modified loading vehicle with redistributed axle loads.

4. Load Factors and Condition Factor

When using DMRB CS454 the following load factors are suggested for use in LimitState:RING when normal traffic is involved:

Factor	CS 454 Value [BD21/01 Value]	Notes
γ_{f3}	1.0 [1.0]	LimitState:RING validated against test results therefore γ_{f3} = 1.0 implicitly assumed.
$\gamma_{f,\mathrm{dyn}}$	1.8 *or* 1.62* [1.8]	Referred to in the code as an ‘impact factor’, applied only to the most heavily loaded axle.
γ_{fL}	1.8^{+} [1.8]	Applied to all axles, including the dynamic axle.

*When the road surface is a ‘good’ – see DMRB CS 454 section 2.16.

$^{+}$Calculated from γ_{fL} x C_{min} = 1.5 x 1.2 = 1.8, where γ_{fL} and C_{min} are taken from DMRB CS 454 Table 3.4 and Section 7.2 respectively.

Table 2 – Load factors to be used in LimitState:RING

Table 2 also includes values from DMRB BD21/01, which was superseded by CS 454 in 2019. From the table it is evident that the total load factor applied to a single axle using CS 454 is lower than in BD21/01 (3.24, or 2.92 in the case of a ‘good’ road surface, compared with 3.42, usually rounded down to 3.4).

A condition factor (between 0.0 and 1.0) should be applied if the structure under consideration has a defect which affects carrying capacity but which cannot be taken account of in the current analysis. In general it is better to try to model defects directly. Defects such as ring separation, low strength masonry and the effect longitudinal cracks have on the ability of a given bridge to distribute the load transversely can all be accounted for directly when using LimitState:RING in conjunction with suitable effective width calculations.

5. Gross Vehicle weight

The following table can be used to calculate the maximum gross vehicle weight that can safely be carried for a given computed LimitState:RING ‘adequacy factor’, assuming that i) an 11.5 tonne single axle load vehicle is most critical (often the case for short span bridges) and also ii) an appropriate effective bridge width and all relevant partial factors have been entered into LimitState:RING.

LimitState:RING Adequacy Factor on 11.5 tonne Single Axle*	Corresponding Single Axle Loading* (tonne)	Corresponding Single Axle Loading* (kN)	Maximum Gross Vehicle Weight (tonne)
1.0	11.5	113	40/44^{+}
0.783	9	88	12.5
0.609	7	69	10
0.478	5.5	54	7.5
0.174	2	20	3

*Assuming that appropriate effective width and partial factors have been entered into LimitState:RING.
$^{+}$Maximum gross vehicle weight reduces to 32, 26 or 18 tonnes if double or triple axle loading scenarios are critical.

Table 3 - Gross vehicle weights (after DMRB CS 454 Annex E10)

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