Application Note - Modelling Saddles Using LimitState:RING

Introduction

Use of a reinforced concrete 'saddle', cast over the barrel of a masonry arch bridge, has been a popular method of increasing load carrying capacity for many years. However, assessing the capacity of a bridge that includes a reinforced concrete saddle can be difficult.

The reinforcement option in LimitState:RING 3.0 opens up many new possibilities, including the capability to model a 'saddled' arch bridge. This Application Note describes the steps involved in specifying a reinforced concrete saddle in a LimitState:RING bridge model. A saddled bridge load tested to collapse at the Transport Research Laboratory (TRL) in the UK is used to allow validation of results.

All files used in this note are available in a zip file that can be downloaded from:

http://www.limitstate.com/files/application-notes/LS-R-AN1/Concrete_saddle.zip

Familiarity with the use of LimitState:RING is assumed. (The reader is referred to the User Manual for further information on any features discussed in this note.)

Problem definition

In the late 1990s, a series of full-scale model arch bridges were tested by the Transport Research Laboratory (TRL) to determine the effectiveness of a number of arch strengthening methods. All bridges included a 3-ring (stretcher bonded), 5m span, 2m wide brickwork arch barrel. The bridges were backfilled with soil and were loaded to collapse at quarterspan. The testing programme included bridges comprising:

1) A multi-ring (debonded) brickwork arch barrel without reinforcement (benchmark 1).
2) A multi-ring (debonded) brickwork arch barrel with near-surface steel reinforcement (benchmark 2).
3) A multi-ring (mortared) brickwork arch barrel with a reinforced concrete saddle.

These bridges have been described by Sumon (1; 2), allowing LimitState:RING models to be developed and results validated.

Benchmark multi-ring brickwork arch bridges

Models of the two benchmark multi-ring brickwork arch bridges listed above are described in the LimitState:RING User Manual - Section G.5.2 and by Sumon (1; 2). These can be set up in LimitState:RING using the **New Bridge Wizard** using a **Multi-ring (debonded)** arch profile or, alternatively, completed models can be found in the files accompanying this note (LS-R-AN1_TRL_Debonded_Bridge.ring and LS-R-AN1_TRL_Reinforced_Bridge.ring).

The general geometry of the LimitState:RING models can be seen in Figure 1.

Saddled multi-ring brickwork arch bridge

The bridge containing a reinforced concrete saddle (1) can be modelled using the **New Bridge Wizard** by specifying a multi-ring (debonded) arch profile or, alternatively, can be found in the files accompanying this note (LS-R-AN1_TRL_Saddle_Bridge.ring). Data pertaining to this bridge is presented in Table 1

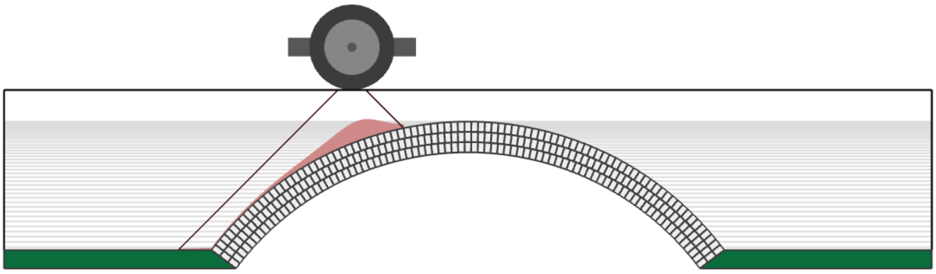


Figure 1: TRL benchmark 3-ring arch, as modelled in LimitState:RING

Parameter	Saddled Bridge	Comments
Effective bridge width	2.00 m	Sumon, 1998 (1)
Arch span	5.00 m	Sumon, 1998 (1)
Midspan rise (to soffit)	1.25 m	Data confirmed by Sumon, 2011
Total masonry thickness	330 mm	Data confirmed by Sumon, 2011
Concrete saddle thickness	150 mm	Sumon, 1998 (1)
Backfill depth at the crown	190 mm	Data provided by Sumon, 2011
Concrete density	2400 kg/m^3	Assumed
Concrete compressive strength	22.4 N/mm^2	Sumon, 1998 (1)
Reinforcement type	B196, Area = 196 mm^2/m (BS 4483)	Sumon, 1998 (1)
Reinforcement tensile strength	90.16 kN per metre bridge width	Assuming 460 N/mm^2 yield stress (grade 460 wire, BS 4483)
Reinforcement cover	50 mm	Sumon, 1998 (1)

Table 1: Problem data for TRL saddled arch bridge

Modelling a saddle in LimitState:RING

Modelling a saddle in LimitState:RING can be achieved by adding an extra ring to the arch barrel and by specifying appropriate material and reinforcement properties (e.g. see Figure 2).

To specify a concrete saddle in the model:

1) In the **Geometry** dialog, on the tab for **Span 1**, add an extra ring (for the TRL model, a ring of 89 units and 150mm thickness was added).

2) In the **Project Details** dialog, check the *Bridge includes reinforcement* box.

3) In the **Select** menu, choose *Contact select tool*. Highlight the appropriate ring (*Ring 4* in this case).

4) If the saddle includes a sound mechanical connection with the abutments, ensure the *Include edge contacts* box is ticked. If no such connection exists, or if there is uncertainty, ensure the box is unticked, so that the reinforcement does not continue into the abutment (this is the normal situation).

5) In the **Property Editor**, enter appropriate values into the fields for *Crushing strength, Friction coefficient, Reinforcement Depth and Reinforcement maximum tensile force* (Figure 3).

   Note that the shear capacity can be left at a high value to prevent shear failure governing (Figure 3).

6) If the concrete has a different unit weight to the masonry, select *Blocks* in the ring representing the saddle and modify the unit weight as necessary (this can be done using either the **Property Editor** or via the **Block Explorer**).

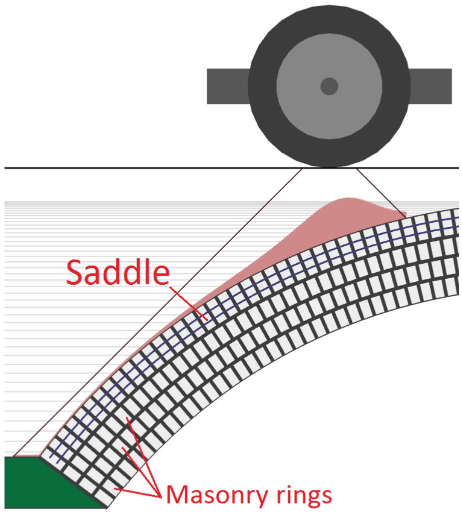


Figure 2: TRL 3-ring arch with saddle, as modelled in LimitState:RING

7) Finally, as a reinforced concrete saddle normally behaves as a curved beam rather than as a reinforced concrete arch, steps should be taken to limit the thrust transmitted to the abutments. This can be achieved by assigning a negligible crushing strength to the end Contacts (e.g. 0.01 MPa - see Figure 4) as in the TRL model, or alternatively by disabling the Contacts altogether (i.e. setting *Enabled* to false).

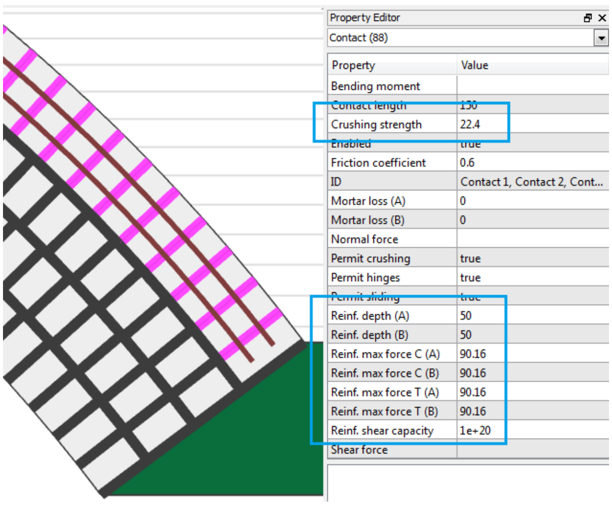


Figure 3: Saddle - general Contact properties

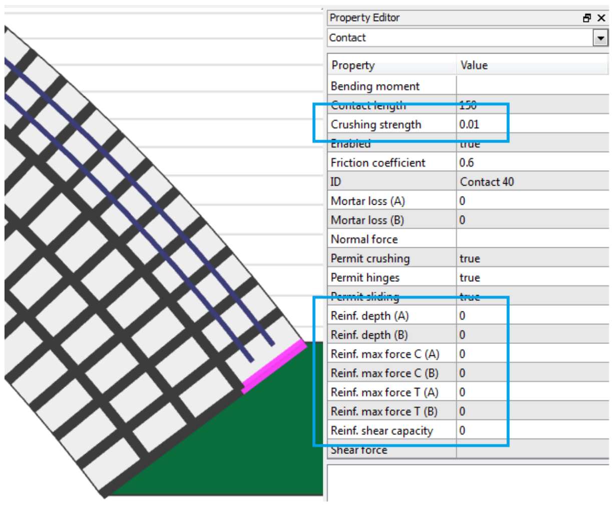


Figure 4: Saddle - end Contact properties

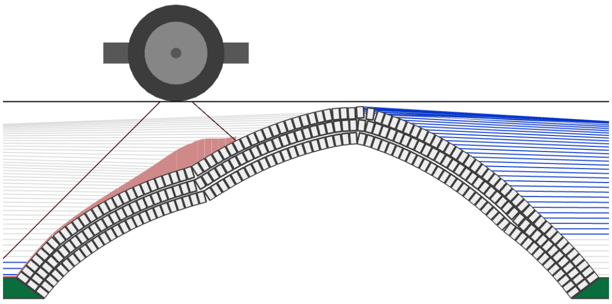
Results

Predicted and experimental results for the two benchmark multi-ring arch bridges and for the saddled multi-ring arch bridge are presented in Table 2. Also Figure 5 shows predicted failure mechanisms of the unreinforced benchmark bridge and of the saddled bridge (note that, for clarity, the thrust lines and hinges are not shown in the latter case as the reinforcement in the saddle causes these to lie outside the thickness of the saddle).

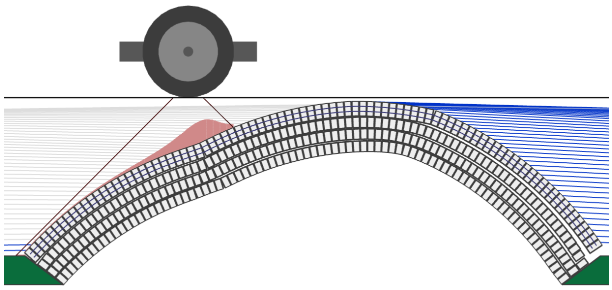
From Table 2 it is evident that the predicted collapse load of the saddled arch bridge is some 78% of the actual failure load observed during testing. The predicted collapse load is somewhat conservative because the saddled bridge contained mortared rather than unbonded arch rings, as conservatively assumed in the LimitState:RING

Bridge details	Max load (kN) TRL	Max load (kN) RING 3.0	RING 3.0 / TRL
Multi-ring (debonded)	200	198*	98%
Multi-ring (debonded) + Reinforcement	320	325*	101%
Multi-ring (mortared) + Saddle	701	549	78%

Table 2: Comparison of LimitState:RING and TRL experimental results (*see Section G.5.2 of LimitState:RING User Manual)



(a)



(b)

Figure 5: LimitState:RING critical failure mechanisms: (a) unreinforced, and (b) saddled TRL arch bridges

model described. (To give an indication of the likely magnitude of this effect, the load carrying capacity of another TRL bridge, not documented here, which contained mortared arch rings was some 20% higher than the load carrying capacity of the corresponding bridge with debonded arch rings listed in Table 2).

Conclusions

The reinforcement option in LimitState:RING 3.0 opens up many new possibilities, including the capability to model a 'saddled' arch bridge. In this application note the steps necessary to successfully model a saddled arch bridge tested at the Transport Research Laboratory have been described. It has been demonstrated that LimitState:RING 3.0 provides a reasonably good prediction of the experimentally recorded load carrying capacity in this case.

References

[1] Sumon, S.K., 1998, *Repair and strengthening of five full scale masonry arch bridges*, in 'Arch Bridges: history, analysis, assessment, maintenance and repair' (Proceedings of the Second International Conference on Arch Bridges, Venice, Italy). ed. A. Sinopoli, Balkema, Rotterdam, 1998, pp. 407-415.

[2] Sumon, S.K., 2005, *Innovative retrofitted reinforcement techniques for masonry arch bridges*, Proceedings of the Institution of Civil Engineers, Bridge Engineering, September 2005, 158, Issue BE3, pp. 91-99.

For more information: www.limitstate.com/ring