limitstate ring

rapid masonry arch analysis software

Product Description

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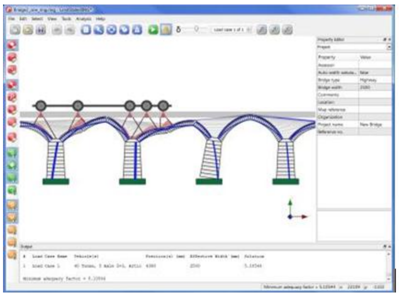
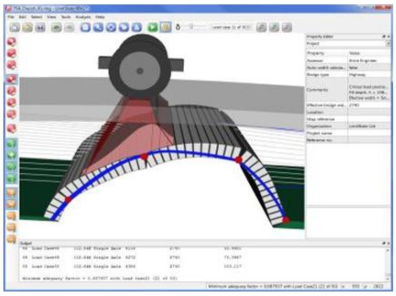
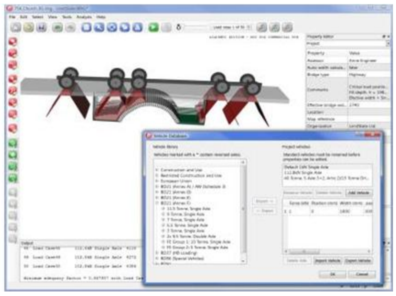
Summary

About LimitState:RING

LimitState:RING is a popular software product for masonry arch bridge analysis - designed from the ground up with the needs of professional engineers in mind. The software uses rigorous mathematical optimization to directly identify a wide range of potential modes of response.

LimitState:RING is the only commercially available masonry arch analysis software to implement the rigid block analysis method, described in a key industry report* as “quick and reliable for a significant range of bridge configurations... a very versatile tool...” and “a significant improvement from basic limit analysis formulations”.

- A rapid analysis tool for computing the ultimate load carrying capacities of single and multi-span masonry arch bridges.
- Numerous features, many of which are unique.
- Developed specifically with engineers in mind.
- Designed to be as quick and simple to use as hand-based methods (e.g. MEXE), but with much of the bespoke modelling capabilities of Finite Element based software.

* CIRIA C656 - Masonry arch bridges: condition, appraisal and remedial treatment.

Main features

Model

- Multiple spans
- Multiple arch-rings
- Multiple load cases
- Arch backing material
- Mortar loss
- Support movements
- Reinforcement
- Rail and highway loading

Define

- Variable thickness arches of arbitrary shape
- Properties of all materials
- New loading vehicles
- Partial factors on load and material

Identify

- Critical failure modes in multi-span bridges (even if this involves only a single span) Properties of all materials
- Critical failure modes involving sliding
- ‘Passive’ backfill pressures (allowing deep arch and multi-span arch problems involving passive pressures to be analyzed)

System requirements

Component	Requirement
Processor	Intel or compatible processor (500 MHz or better)
Operating System	Windows: XP, Vista, 7, 8, 10
Hard Drive Space	120 Mb
System RAM	512 Mb
Virtual Memory	Minimum 50 Mb configured swap
Other Software	Software for viewing PDF documentation (*e.g.* Adobe Acrobat)

History

LimitState co-founder, Dr Matthew Gilbert, is a Chartered Civil Engineer who has been involved in masonry arch bridge assessment and research since 1990. He developed the first version of RING in 1992 and, in 2001, RING 1.x was launched. This was subsequently adopted by practitioners and academics in over 40 countries worldwide.

Developed in association with the International Union of Railways (UIC), LimitState:RING 2.0 constituted a major step forward in technology from previous versions, being both easier to use and much more powerful than before.

LimitState:RING 3.0 introduced many new features and improvements, such as a powerful new solver, improved arch profile modelling and the ability to include reinforcement.

Underlying technology

- Idealizes a masonry arch structure as an assemblage of rigid blocks.
- Uses 'computational limit analysis' methods to analyse the collapse state.
- The structure is divided into a large number of discrete rigid blocks connected by zero thickness and zero tensile strength joints.
- Rigorous optimization techniques are used to find the critical failure mechanism.

Modelling capabilities

Model a bridge comprehensively:

- Model bridges containing localized areas of weak masonry, local mortar loss etc.
- Place supports at arbitrary positions and model support movements.
- Allocate separate properties to near-surface and deep fill.
- Model an unlimited number of spans and rings.
- Model an unlimited number of load cases.
- Model variable thickness arches with and without multi-rings.
- Perform effective bridge width calculations.
- Specify partial safety factors for loads and materials.

Analysis capabilities

Identify many potential failure types, including those involving:

- Material failure.
- Radial sliding failure between voussoirs.
- Slippage between rings (ring separation).

- For multi-span bridges with stocky or slender intermediate piers the critical failure mode will be automatically identified, whether this involves one, two or more spans.

Interactive 3D environment

Define, alter and experiment with the model:

- Click on-screen objects and view / edit the properties using the Property Editor.
- Compare the properties of multiple objects using the Explorers.
- Use the 'drag and solve' functionality to rapidly investigate bridge behaviour.
- View the model from any angle and save / load a previous viewpoint.
- Benefit from a comprehensive context sensitive help system.

Accessibility

Many features designed to help the user:

- A database of standard highway and railway vehicles, to which further vehicles can be added.
- A 'new bridge wizard' for rapid development of new bridge models.
- Modify models by adding or deleting spans as necessary.
- Copy and paste data to / from a spreadsheet.
- Customized reports of the analysis findings can be automatically generated, printed and saved in PDF format.
- Modern, user-friendly interface.

Validation

- Results validated using experimental data from many real-life tests - e.g. by comparison with TRL (1980s / 90s) and Bolton (1990s).
- RING referenced in reports by Network Rail (2001), CIRIA (2006) and UIC (2007/08).

Contents

User interface

Figure 1 illustrates the main features of the LimitState:RING user interface:

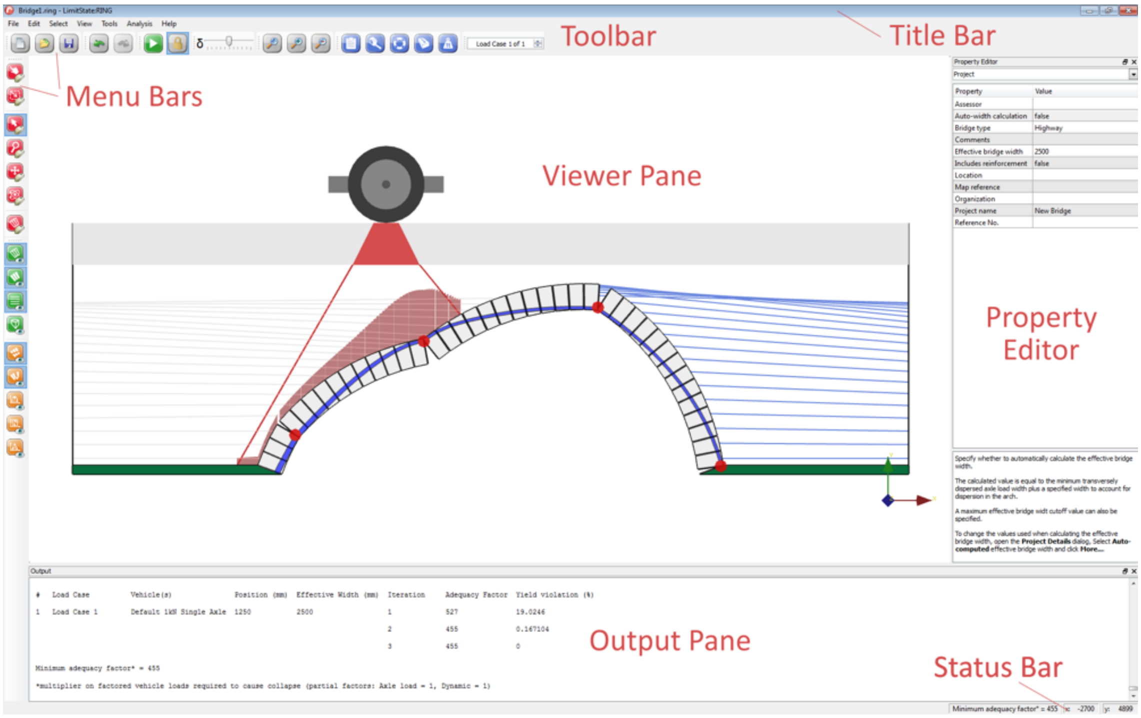


Figure 1 - The LimitState:RING user Interface

Property editor

The Property Editor is allows the user to quickly query and / or modify the attributes of one or more objects within the current project.

- Read and / or modify the properties of one or more objects within the current project.
- Changes made in the property editor can be undone / redone using ‘undo’ and ‘redo’.
- Select objects on screen and modify their properties to better reflect the real-life circumstances of the bridge.
- Change an individual block property or select a large area containing multiple objects, divide into the constituent object types and modify the common properties en masse.
- Access some of the more specialized functions such as mortar loss and the ability to control hinging and sliding modes.

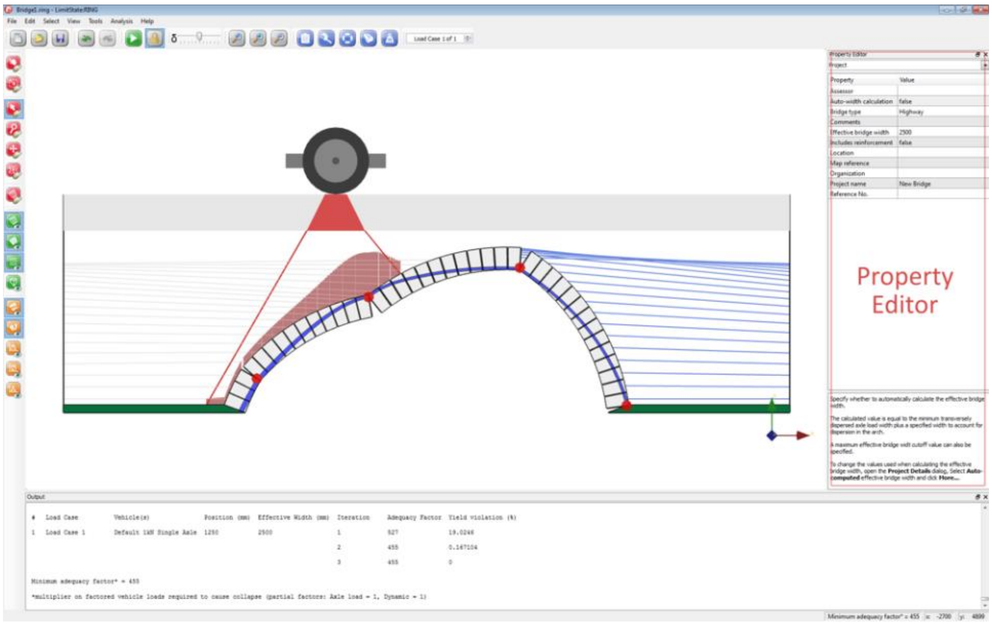


Figure 2 - The LimitState:RING Property Editor

It is possible to view and / or modify the properties of the following objects:

- **Fill elements** – bar elements that represent the effects of fill material in restraining arch sway
- **Blocks** – masonry blocks forming the arches, piers and abutments.
- **Contacts** – inter-block interfaces.
- **Nodes** – potential intersection-points of slip-lines.
- **Vehicles** – predefined or user-specified loading vehicles that are applied to the bridge.
- **Axles** – individual loads from the vehicles applied to the bridge.

The following tables describe, in detail, the properties found in the Property Editor for each of the described features:

Fill elements

Property	Description	Editable?
Actual force	The actual force (kN per metre width) in the fill element (vertical block height x fill pressure)	
ID	Identification text for each object	✓
Limiting Force	The force (kN per metre width) at which fill or backing material yields (vertical block height x limiting pressure)	

Blocks

Property	Description	Editable?
Area	Cross-sectional area in the *xy* plane (mm^2)	
Displacement: *x*	Displacement of the block in the *x* direction (mm)	
Displacement: *y*	Displacement of the block in the *y* direction (mm)	
Fill force (H): actual	The actual horizontal (passive) fill or backing force applied to the selected block(s) (kN per metre width).	

Fill force (H): maximum	Maximum horizontal (passive) fill or backing force that can be applied to the block (kN per metre width)	✓
Fill force (H): user-defined	Specify whether the user is overriding the automatically calculated horizontal force applied to the block	✓
Fill force (V)	Fill vertical force applied to the block (kN per metre width). This force results from overlying fill, surface fill and track self weight loads	✓
Fill force (V): user-defined	Specify whether the user is overriding the automatically calculated vertical force applied to the block	✓
Fill stress (H): actual	*Actual* horizontal (passive) fill stress applied to the block (kPa)	
Fill stress (V)	Fill vertical stress applied to the block (kPa). This results from overlying fill, surface fill and track self weight loads	
ID	Identification text for each object	✓
Rotation	Rotation of the block (radians)	
Support movement: rotation	Allows a rotational displacement (radians) to be imposed on the block(s)	✓
Support movement: *x*	Allows a displacement (mm) to be imposed on the block(s) in the *x* direction	✓
Support movement: *y*	Allows a displacement (mm) to be imposed on the block(s) in the *y* direction	✓
Support: Mz	Specifies whether support is given to the block(s) to prevent rotation about the *z* axis	✓
Support: *x*	Specifies whether support is given to the block(s) to prevent displacement in the *x* direction	✓
Support: *y*	Specifies whether support is given to the block(s) to prevent displacement in the *y* direction	✓
Unit weight	Masonry unit weight (kN/m^3)	✓

Contacts (standard)

Property	Description	Editable?
Bending moment	The bending moment at the contact surface (kNmm per metre bridge width)	
Contact length	The length of the contact surface (mm)	
Crushing strength	The effective crushing strength of the masonry at the contact surface (MPa)	✓
Enabled	Specifies whether the selected contact(s) are active	✓
Friction coefficient	The coefficient of friction at the contact surface	✓
ID	Identification text for each object	✓
Mortar loss (A)	Length of mortar loss from endpoint A (intrados) of contact (mm)	✓
Mortar loss (B)	Length of mortar loss from endpoint B (extrados) of contact (mm)	✓
Normal force	The normal force transmitted across the contact surface (kN per metre bridge width)	
Permit crushing	Specifies whether crushing failures are permitted at the selected contact(s)	✓
Permit hinges	Specifies whether hinging failures are permitted at the selected contact(s)	✓
Permit sliding	Specifies whether sliding failures are permitted at the selected contact(s)	✓
Shear force	The shear force transmitted across the contact surface (kN per metre bridge width)	

Contacts (with reinforcement)

Property	Description	Editable?
Reinforcement depth (A)	The depth (mm) to the reinforcement from contact endpoint A (intrados if radial).	✓
Reinforcement depth (B)	The depth (mm) to reinforcement from contact endpoint B (extrados if radial).	✓
Reinforcement max force C (A)	The limiting compressive force (kN per metre bridge width) in the reinforcement nearest endpoint A.	✓
Reinforcement max force C (B)	The limiting compressive force (kN per metre bridge width) in the reinforcement nearest endpoint B.	✓
Reinforcement max force T (A)	The limiting tensile force (kN per metre bridge width) in the reinforcement nearest endpoint A.	✓
Reinforcement max force T (B)	The limiting tensile force (kN per metre bridge width) in the reinforcement nearest endpoint B.	✓
Reinforcement shear capacity	The limiting shear force (kN per metre bridge width) of the reinforced section.	✓

Vehicles

Property	Description	Editable?
Axles	Number of axles in this vehicle	
ID	Identification text for each object	✓
Length	Length of this vehicle, i.e. distance between first and last axle (mm)	
Mirror	Mirroring a vehicle will reverse its direction of travel to right to left	✓
Position	Horizontal (*x*) distance from the springing of the first abutment to the centre of the first axle in the vehicle (mm)	✓

Axles

Property	Description	Editable?
Distance	The local distance (x direction) from the vehicle origin (0) to the centre of the selected axle(s) (mm).	✓*
Dynamic factor	Specifies whether the dynamic partial factor of safety (specified in the 'Partial Factors' dialog) is applied to the current axle	✓*
Effective width	The effective transverse width of the selected axle(s) on the bridge (mm).	
ID	Identification text for each object.	✓*
Length	The length (x direction) of wheel in contact with the carriageway (mm).	✓*
Magnitude	The unfactored magnitude of the vertical load imparted by the selected axle(s) (kN).	✓*
Magnitude (factored)	The magnitude of the vertical load imparted by the selected axle(s) (kN) once Axle and (if applicable) Dynamic partial factors have been applied.	
N^{o}	The axle number - measured from the datum axle, which is '0'.	
Width	Transverse width (z direction) of the axle (mm).	✓*
Width on fill	Transverse width (z direction) of the axle on top of the backfill (mm).	✓*

* Editing of these properties is only permitted for user-defined vehicles

Explorers

- Explorers present all the data from the project in a convenient tabulated form.
- Objects selected explorers are highlighted in the viewer pane (and *vice versa*).
- Quickly check, compare or edit the properties of similar objects.
- Changes made in the property editor can be reversed / redone using 'undo' and 'redo'.
- Data can be cut and pasted between LimitState:RING explorers and a spreadsheet.
- Very useful for checking the current state of the model after changes have been made to local properties.
- Explore Blocks, Contacts, Vehicles and Load Cases.

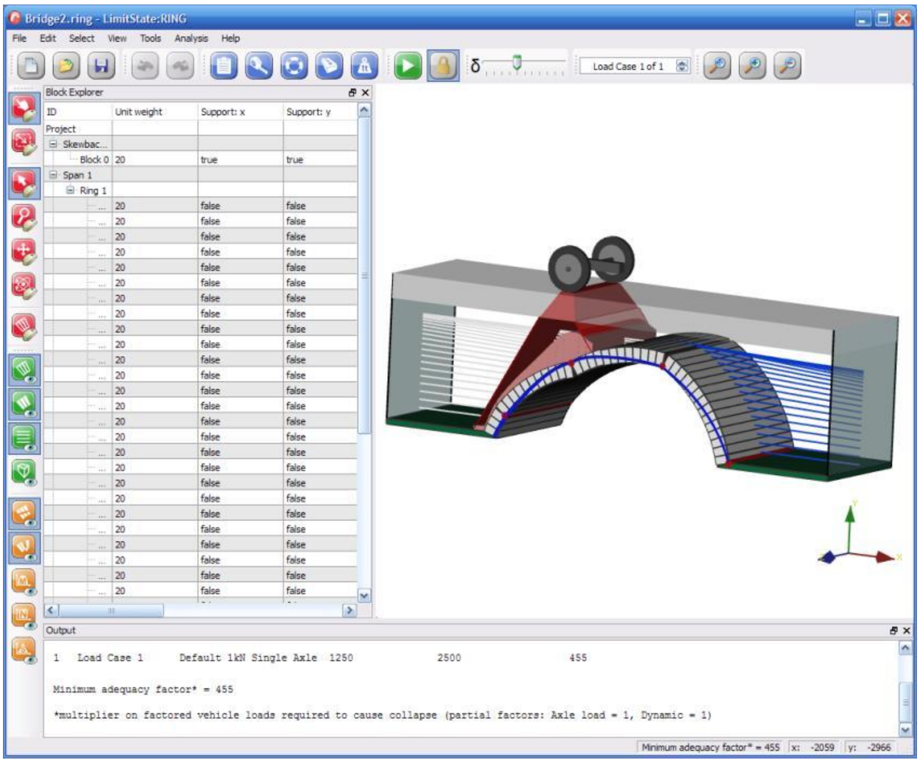


Figure 3 - The LimitState:RING Block Explorer

- For details of the properties displayed in the Block, Contact and Vehicle explorers, please refer to the corresponding table in the Property editor section (pages 5 and 6); editable fields remain the same as for the Property editor.
- Load cases explorer:
  - Similar to the Vehicle explorer.
  - Displays information about the Distance, Magnitude, Length and Width of vehicles.
  - Information given in terms of individual load cases.
  - For example, data for a '40-tonne, 5-axle, 3+2 artic' is displayed for each load case that this vehicle appears within, rather than just once.

Support movement analysis

- Impose translational and / or rotational displacements to support blocks.
- Accessed via a convenient wizard system
- Allows, for example, the modelling of settlement.
- Opens up a range of possibilities, for example:
    - Investigate the likely causes of observed cracks in an existing structure.
    - Verify the model idealization using the observed response of a settled bridge.
    - Run vehicles across a settled bridge to investigate load paths and see whether the hinge positions move.
    - Replicate ‘bedding down’ of a structure by moving the supports appropriately.

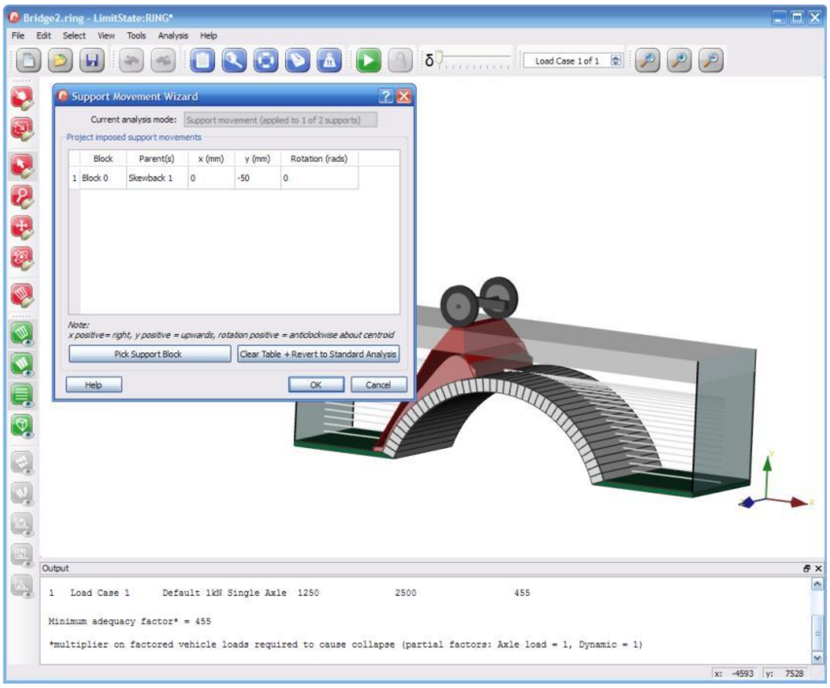


Figure 4 - The LimitState:RING Support Movement wizard

Interactive 3D environment

- The freedom to view the model from any angle and zoom into areas of interest.
- Select any part of the model with the mouse and view / modify its properties.
- Use 'drag and solve' to move a load vehicle to a new position and automatically analyse the new case.

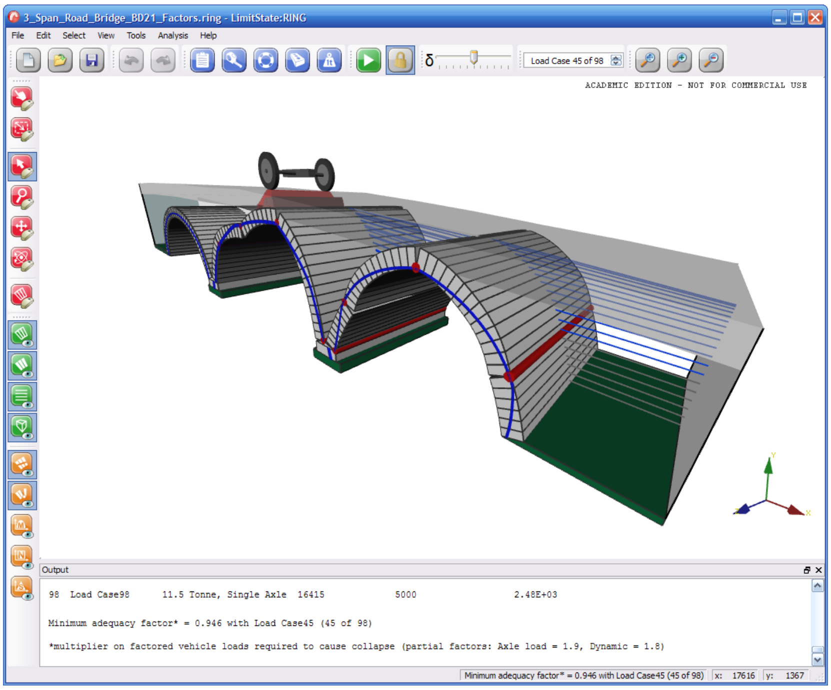


Figure 5 - The LimitState:RING modelling environment

In addition to the standard pan and zoom options, LimitState:RING 3.0 has the following features incorporated into the graphical user interface:

Selection options

- Select objects by clicking or by enclosing with a rectangle.
- Select 'only contact elements'.

Show / hide functions

- Show or hide contacts.
- Show or hide blocks.
- Show or hide fill elements.
- Show or hide thrust zones.
- Show or hide hinges.
- Show or hide bending moment diagrams.
- Show or hide normal force diagrams.
- Show or hide shear force diagrams.

Define a 3D view

- Choose from a number of convenient, pre-set views (top / bottom / left / right / front / back).

- Toggle between 2D and 3D views.
- Toggle 3D views between isometric and perspective.
- Rotate the view about any of the 3 principal axes or use the intelligent 3D rotate functionality.
- Save a custom viewpoint and re-load it again when required.

Drag and solve mode

- Vehicles can be moved to any position using the mouse.
- Combine this with the option to automatically solve the problem and experience the 'drag and solve' model
- 'Drag and solve' permits the user to rapidly investigate the way in which a bridge is behaving:

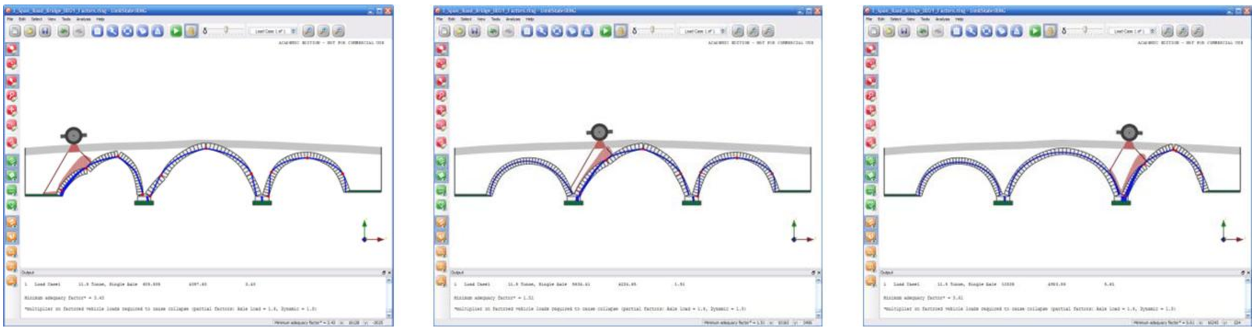


Figure 6 – Using Drag and Solve mode gives an insight into bridge behaviour

Effective bridge widths

- When a bridge has a deep layer of fill above the masonry structure, loads will be dispersed transversely and calculations using the width of load at the surface can give over-conservative answers .
- To take account of this, LimitState:RING 3.0 can automatically calculate the effective width of a bridge according to the width of loading at the base of the fill. Users can set:
  - A maximum effective bridge width cutoff.
  - Transverse distribution of load through the surface fill.
  - Transverse distribution of load through the backfill.
  - An additional transverse width of bridge.

New bridge wizard

- Rapidly produce a model using the 'New bridge wizard', which guides users through the process of defining the bridge geometry, materials, loading etc.
- Click 'Finish' at any point: LimitState:RING 3.0 will automatically fill in any information that has not been explicitly supplied by assuming default values and using information already given.

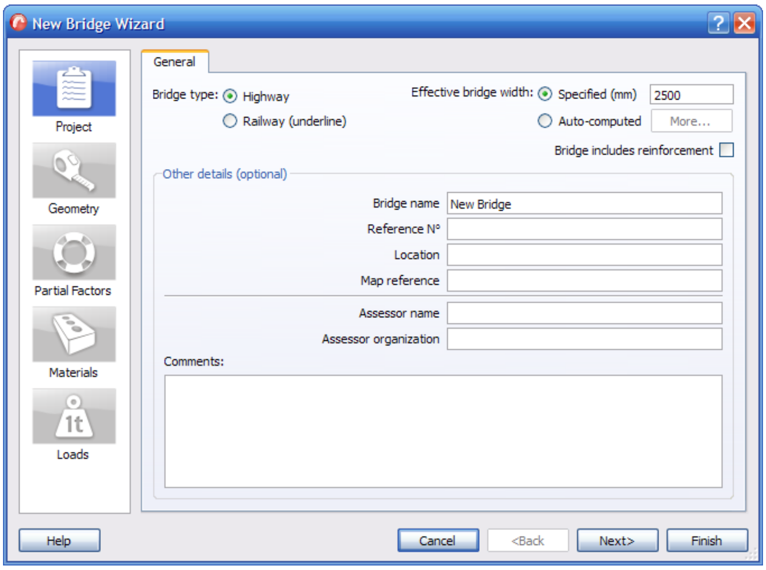


Figure 7 – The 'New bridge wizard' allows problems to be set-up in very little time

- The 'New bridge wizard' allows problems to be set-up in very little time.
- Move backwards and forwards through the various steps of the wizard and insert, delete or edit as necessary – a very useful feature should any detail accidentally be omitted initially.
- Access any dialog of the wizard after the 'Finish' button has been pressed - return to the model at any time and refine any aspect of the bridge.
- The dialogs found within the 'New bridge wizard' are:
  - **Project** – defines the general properties of the bridge.
  - **Geometry** – defines the form of the bridge abutments, spans, piers and fill profile.
  - **Partial factors** – defines the partial safety factors applied to the loads and materials .
  - **Materials** – defines the material properties of the masonry, backfill and surface fill.
  - **Loads** – defines the vehicles used throughout the analysis and their use in different load cases.

Project details

- Deals with 'general' aspects of the bridge model.
- Click 'Finish' at any point: LimitState:RING will automatically fill in any information that has not been explicitly supplied by assuming default values and using information already given.

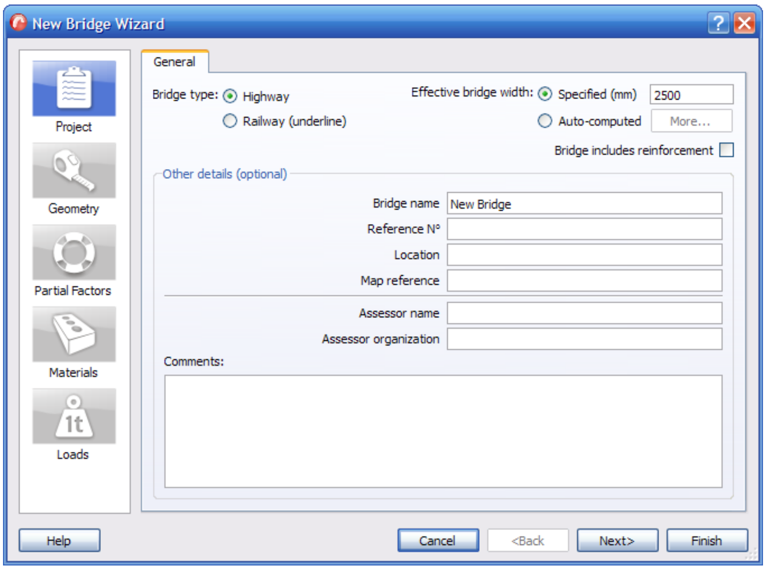


Figure 8 – The LimitState:RING Project Details dialog

- Many of the details that can be specified here are optional.
- There are a number of choices that are not optional and therefore require the user's attention:

Bridge type

- Specify whether the bridge is subject to loading from a highway or a railway.
- The choice made will determine the information required / displayed during modellingImport pre-defined regimes from file.

Effective bridge width

- Specify whether the bridge is of a fixed width or, alternately, automatically calculate an effective width
- Click 'More…' to specify the following:
  - Maximum effective bridge width cut-off.
  - Additional transverse width of arch to include.
  - Transverse dispersion angle through backfill.
  - Transverse dispersion angle through surface layer.

Bridge includes reinforcement

- Specify whether the problem includes reinforcement (causes reinforcement properties to be shown in the Property Editor for contacts).

Optional details

- Specify the following:
  - Bridge name
  - Reference number
  - Location
  - Map reference
  - Assessor name
  - Assessor organization
  - Comments

Geometry dialog

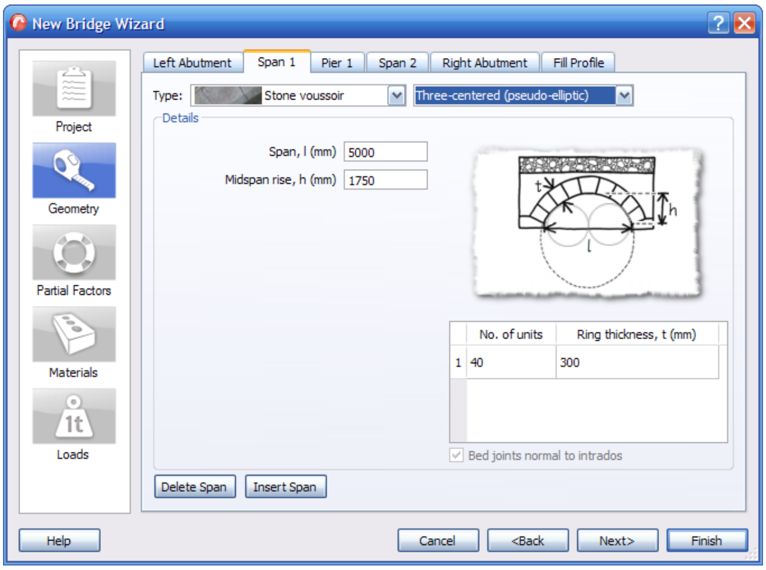


Figure 9 – The LimitState:RING Geometry dialog

- Presents each part of the bridge geometry on a separate tab.
- The following tables list the editable features found on each of the tabs:

Abutments

Property	Description
Backing height	Height of any backing material above the top of the skewback (mm)
Height	Total height of the abutment (mm)
Thickness at top	Width (x direction) at the top surface of the top block in the abutment (mm)
Thickness at base	Width (x direction) at the bottom surface of the bottom block in the abutment (mm)
Number of blocks	The number of blocks in the abutment

Spans

Property	Description
Type	Choose from a **stone voussoir**, **bonded brick** or **multi-ring (debonded)** span
Shape	Define the shape of each span. Choose from: • Segmental • User-defined (multi-segment) • User-defined (interpolated) • Three centered • Pointed
Span	The distance (*x* direction) from the springing at the left of a span to the springing at the right (mm)
Rise at midspan	The maximum distance (*y* direction) from the springing at the left of a span to the intrados face of the arch (mm)

Rise at quarterspan	The distance (*y* direction) from the springing at the left of a span to the intrados face of the arch at the
Type	Choose from a **stone voussoir**, **bonded brick** or **multi-ring (debonded)** span quarterspans (mm)
Abutment angles	**Auto-calculate** the angles that a span makes at the abutments or **specify each** individually
Number of units	The number of blocks contained within each ring of an arch
Ring thickness	The thickness (depth) of each ring of an arch
Intrados details	The *x* and *y* coordinates of various points around the intrados profile of a user-defined ring profile
Bed joints normal to intrados	When abutment angles are not auto-calculated, having contacts (joints) normal to the intrados face of the arch can cause irregular shaped blocks to occur. Deselecting this option alters the angle of the joints to create a span of regularly shaped blocks.
Assume uniform ring thickness	When a user-defined ring profile is chosen, this option causes LimitState:RING 3.0 to assume that the specified ring thickness is continuous throughout the arch. By un-checking, the user is able to enter a profile for the intrados and extrados faces of each ring
Insert span / Insert span after this?	Allows the user to insert a span to either side of the current location
Delete span	Allows the user to delete the current span and the pier from one side

Piers

Property	Description
Backing height	Height of any backing material above the top of the skewback (mm)
Height	Total height of the pier (mm)
Thickness at top	Width (*x* direction) at the top surface of the top block in the pier (mm)
Thickness at base	Width (*x* direction) at the bottom surface of the bottom block in the pier (mm)
Number of blocks	The number of blocks in the pier

Fill profile

Property	Description
X	The *x* distance of a point at the base of the surface fill, measured from the left springer of the first arch (mm)
Y	The *y* distance of a point at the base of the surface fill, measured from the left springer of the first arch (mm)
Surface fill depth	The absolute (*y* direction) depth to the base of the surface fill, measured from a point on the surface directly above (*x*,*y*) (mm)

Partial factors dialog

- Apply factors of safety for loading and material properties, according to any code of practice.
- By default, all factors are set to 1.0.

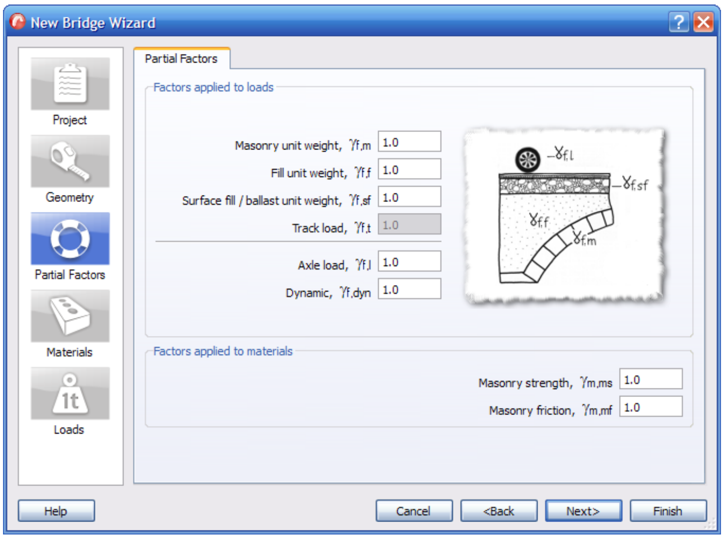


Figure 10 – The LimitState:RING Partial Factors dialog

The following tables list the partial factors that can be modified:

Loads

Factor	Description
Masonry unit weight	Factor of safety applied to the unit weight of all masonry in the model
Fill unit weight	Factor of safety applied to the unit weight of all fill material in the model
Surface fill / ballast unit weight	Factor of safety applied to the unit weight of all surface fill (highway) or ballast (railway) material in the model
Track	Factor of safety applied to the loading from the track (railway bridges only)
Axle load	Factor of safety for the loading from vehicles
Dynamic	Dynamic factor of safety applied to selected vehicle axle loads

Materials

Factor	Description
Masonry strength	Factor of safety applied to the crushing strength of all masonry in the bridge
Masonry friction	Factor of safety applied to the friction coefficients of all masonry in the bridge

Materials dialog

- Access and edit the properties of all the materials encountered when modelling a masonry arch bridge
- Conveniently split on to 3 different tabs:
  - Masonry
  - Backfill
  - Surface fill

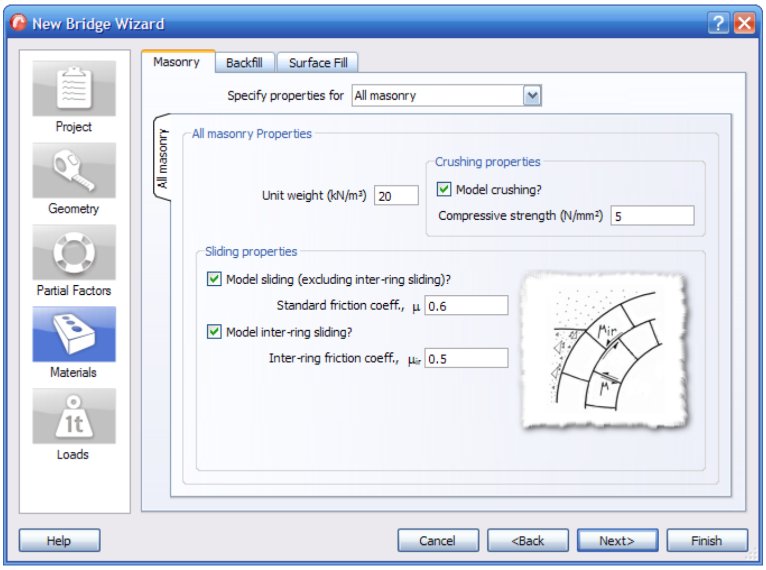


Figure 11 – The LimitState:RING Materials dialog (masonry tab)

Masonry properties

The following table describes the features found on the **Masonry** tab:

Property	Description
Specify properties for: All	Allows the user to define one set of masonry properties that will be applied to all masonry throughout the bridge
Specify properties for: Spans vs. piers / abutments	As well as including the above tab, this option generates three additional tabs that allow the user to define separate properties for the masonry found in: • All spans • All piers • All skewbacks
Specify properties for: All bridge parts	As well as including the above four tabs, this option generates additional tabs that allow the user to define separate properties for the masonry found in: • Each span • Each pier • Each skewback
Unit weight	Masonry unit weight (kN/m^3)
Model crushing?	Determines whether masonry crushing is considered during an analysis
Compressive strength	Masonry compressive strength (N/mm^2) (requires model crushing to be permitted)
Model sliding?	Determines whether masonry sliding is considered during an analysis
Standard friction coefficient	Masonry friction coefficient (requires model sliding to be permitted)
Model inter-ring sliding?	Determines whether inter-ring sliding is considered during an analysis
Inter-ring friction coefficient	Masonry inter-ring friction coefficient (requires inter-ring sliding to be permitted)

Backfill properties

The following table describes the features found on the **Backfill** tab:

Property	Description
Unit weight	Backfill material unit weight (kN/m^3)
Angle of friction	Specify the angle of friction ϕ (in degrees) of the backfill material.
Cohesion	Specify the cohesion *c* (in kN/m^2) of the backfill material.
Model dispersion of live load	Specify whether the backfill model should include dispersion of the live load.
Model horizontal 'passive' pressures	Specify whether the backfill model should include modelling of the 'passive' pressures arising when a the arch moves into the backfill.
Boussinesq distribution	Specify that the magnitude of the pressure exerted on the back of the arch is to be calculated according to the Boussinesq equation. This is the default option.
Uniform distribution	Specify that the magnitude of the pressure exerted on the back of the arch is to be constant.
Cutoff angle	The length of arch assumed to be subject to vertical loading pressures is controlled by the specified cutoff angle (degrees)
Friction multiplier on ϕ	Specify the multiplier on the soil angle of friction ϕ that gives the soil-arch interface angle of friction δ
Adhesion multiplier on *c*	A multiplier on the soil cohesion *c* that gives the soil-arch interface adhesion.
Factor m_p	Specify the mobilization factor m_p used to scale down the resultant lateral earth pressure coefficient K_{pr}
Factor m_{pc}	Specify the mobilization factor m_{pc} used to scale down the resultant lateral earth pressure resulting from soil cohesion, K_{pcr}
Keep m_pk_p >= 1.0	Checking this box ensures m_pK_p is always greater than or equal to 1.0.
Auto-identify passive zones	Unchecking this box causes the fill elements to act both in the 'passive' and 'active' senses, i.e. applying pressure to the arch whether this moves towards or away from the fill
Position	Areas of the bridge where horizontal pressures will be applied
Passive?	A Boolean (yes / no) function to state whether horizontal pressures are applied at 'Position'

Surface fill properties

The following table describes the features found on the **Surface fill** tab:

Property	Description
Unit weight	Surface fill unit weight (kN/m^3)
Angle of dispersion of live loads	The angle to the vertical through which an imposed live load is assumed to spread (degrees)

Loading dialog

- Add vehicles to the project from a database of built-in and user-defined loading vehicles and use these to form a load case.
- Rapidly define multiple load cases by copying and repositioning an existing load case at regular intervals across a bridge.
- Specify those axles that are subject to a dynamic partial factor of safety (the value of which is defined in the Partial Factors dialog).
- Specify the direction of travel of a vehicle using the 'Mirror' function.

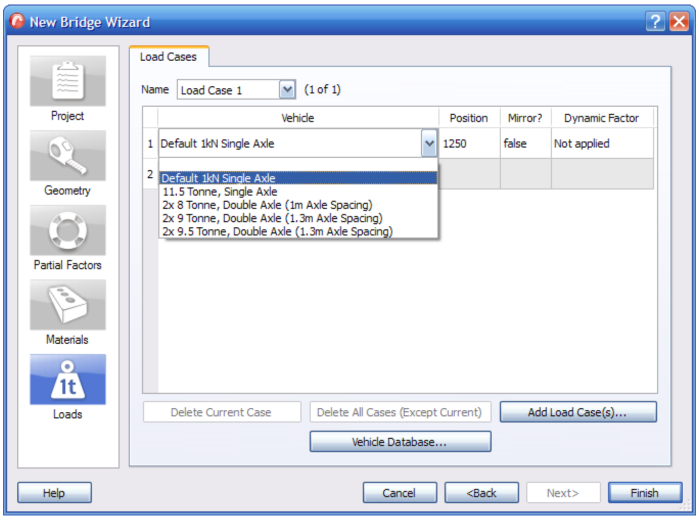


Figure 12 – The LimitState:RING Loading dialog

Vehicle database

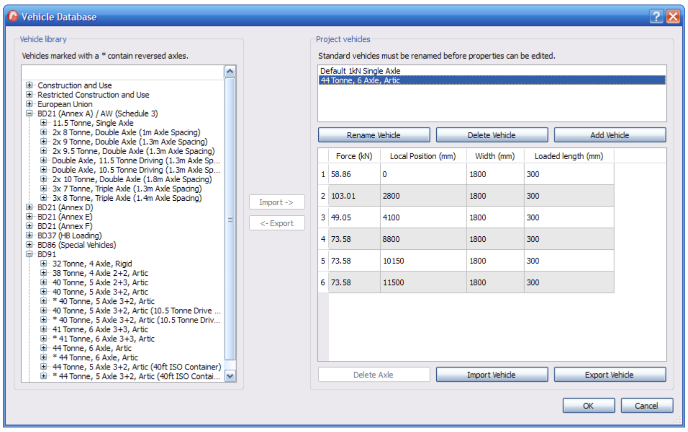


Figure 13 – The LimitState:RING Vehicle database

- A useful resource of commonly used vehicles that can be placed on a bridge in LimitState:RING.
- Choose from a comprehensive library of industry standard railway and highway vehicles or define (and save) custom vehicles for later reuse.

Standard railway vehicles

The following railway vehicles are pre-installed into the LimitState:RING vehicle library:

Body	Vehicles in library
UIC	• LM71 (without UDL) Load train D4 • Load train C3 • Load train E4 • Load train E5
Network Rail (NR/GN/CIV/025)	• RA1 load, 1 BSU, No UDL • RA1 load (Short Lengths), 1 BSU, No UDL RA1 load, 20 BSU, No UDL • RA1 load (Short Lengths), 20 BSU, No UDL • Assessment load wagon
BD37	• RU Loading (no UDL) • RL Loading (no UDL, Single 200kN Axle) • RL Loading (no UDL, 300kN and 150kN Axles)
Indian railways	• Modified broad gauge – without UDL (A) • Modified broad gauge – without UDL (B)

Standard road vehicles

The following road vehicles are pre-installed into the LimitState:RING vehicle library:

Body	Vehicles in library
Construction and use	• Single axle • Double axle (1.02m) • Double axle (1.85m) • Triple axle (1.40m) • Triple axle (2.70m) • Air suspended axle (1.40m) • B1 (30 tonne, 4-axle rigid) • C1 (30 tonne, 4-axle rigid) • D1 (32 tonne, 4-axle articulated) • E1 (32 tonne, 5-axle articulated) • F1 (38 tonne, 5-axle articulated) • G1 (38 tonne, 5-axle articulated) • H1 (38 tonne, 5-axle articulated)
Restricted construction and use	• RA (20 tonne, 3-axle rigid) • RB (24 tonne, 3-axle rigid) • RC (24 tonne, 3-axle rigid) • RD (24 tonne, 3-axle rigid) • RE (17 tonne, 2-axle rigid) • RF (7.5 tonne, 2-axle rigid) • RG (3 tonne, 2-axle rigid)
European union vehicles	• Single axle • Double axle (1.00m) • Double axle (1.30m) • Double axle air (1.30m) • Double axle (1.80m) • Triple axle (2.60m) • Triple axle (2.80m) • EC1 (26 tonne, 3-axle rigid) • EC2 (32 tonne, 4-axle rigid) • EC3 (40 tonne, 5-axle rigid) • EC4 (44 tonne, 6-axle rigid)
BD91 vehicles	• 32 tonne, 4-axle rigid • 38 tonne, 4-axle, 2+2 articulated • 40 tonne, 5-axle, 2+3 articulated • 40 tonne, 5-axle, 3+2 articulated • 40 tonne, 5-axle, 3+2 articulated (10.5 tonne drive axle) • 41 tonne, 6-axle, 3+3 articulated • 44 tonne, 6-axle articulated • 44 tonne, 5-axle, 3+2 articulated (40ft ISO container)
BD21 Vehicles	**Annex A / AW (Schedule 3)** • 11.5 Tonne, Single Axle • 2x 8 Tonne, Double Axle (1m Axle Spacing) • 2x 9 Tonne, Double Axle (1.3m Axle spacing) • 2x 9.5 Tonne, Double Axle (1.3m Axle Spacing) • Double Axle, 11.5 Tonne Driving (1.3m Axle Spacing) • Double Axle, 10.5 Tonne Driving (1.3m Axle Spacing) • 2x 10 Tonne Double Axle (1.8m Axle Spacing) • 3x 7 Tonne Double Axle (1m Axle Spacing) • 3x 8 Tonne Double Axle (1m Axle Spacing) **Annex D** • 32 tonne, 4-Axle Rigid • 38 tonne, 4-Axle, 2+2 Artic • 40 tonne, 5-Axle, 2+3 Arctic • 40 tonne, 5-Axle, 3+2 Artic • 40 tonne, 5-Axle, 3+2 Artic (10.5 tonne drive axle) • 41 tonne, 6-Axle, 3+3 Artic • 44 tonne, 6-Axle, 3+3 Artic, (maximum axle weight 10.5 tonnes) • 44 tonne, 5-Axle, 3+2 Artic (40ft ISO container) **Annex E** • Dennis DF Dennis RS Dennis Rapier • Dennis Sabre 3.8m • Dennis Sabre 4.2m • Leyland MS 3.68m • Leyland MS 4.62m • Leyland MS 5.26m • Dodge 3.5m • Dodge 3.8m • Dodge 4.04m • Dodge 4.5m • Dodge 5.2m • Dodge 5.8m • Ford 3.73m • Ford 4.04m • Bedford SLR1 • Bedford SLRA • Mercedes-Benz ATEGO DAF FF55.230 • Dodge 3.5m • Dodge 3.6m

	Annex F • Dennis DF Dennis RS Dennis Rapier • Dennis Sabre 3.8m • Dennis Sabre 4.2m • Leyland MS 3.68m • Leyland MS 4.62m • Leyland MS 5.26m
BD37 (HB Loading)	• HB Load - 1 Unit (6m Inner Axle Spacing) • HB Load - 1 Unit (11m Inner Axle Spacing) • HB Load - 1 Unit (16m Inner Axle Spacing) • HB Load - 1 Unit (21m Inner Axle Spacing) • HB Load - 1 Unit (26m Inner Axle Spacing) • HB Load - 30 Units (6m Inner Axle Spacing) • HB Load - 30 Unit (11m Inner Axle Spacing) • HB Load - 30 Unit (16m Inner Axle Spacing) • HB Load - 30 Unit (21m Inner Axle Spacing) • HB Load - 30 Unit (26m Inner Axle Spacing) • HB Load - 37.5 Unit (6m Inner Axle Spacing) • HB Load - 37.5 Unit (6m Inner Axle Spacing) • HB Load - 37.5 Unit (6m Inner Axle Spacing) • HB Load - 37.5 Unit (6m Inner Axle Spacing) • HB Load - 37.5 Unit (6m Inner Axle Spacing) • HB Load - 45 Unit (6m Inner Axle Spacing) • HB Load - 45 Unit (6m Inner Axle Spacing) • HB Load - 45 Unit (6m Inner Axle Spacing) • HB Load - 45 Unit (6m Inner Axle Spacing) • HB Load - 45 Unit (6m Inner Axle Spacing)
BD86 Special Vehicles	• SV80 (1.2m Inner Axle Spacing) • SV80 (5m Inner Axle Spacing) • SV80 (9m Inner Axle Spacing) • SV100 (1.2m Inner Axle Spacing) • SV100 (5m Inner Axle Spacing) • SV100 (9m Inner Axle Spacing) • SV150 (1.2m Inner Axle Spacing) • SV150 (5m Inner Axle Spacing) • SV150 (9m Inner Axle Spacing) • SVTrain / SV196 (1.2m Bogie Spacing) • SVTrain / SV196 (5m Bogie Spacing) • SVTrain / SV196 (9m Bogie Spacing) • SVTT Vehicle

Non-standard vehicles

- Define vehicles by modifying existing vehicles or adding an entirely new one.
- Vehicles can be added within LimitState:RING 3.0 or, alternately, by importing from a text (.txt) or spreadsheet (.csv) file.
- The following attributes may be specified for each axle of a new vehicle:

Attribute	Description
Force	The force imparted by the axle under consideration (kN)
Position	The position of the current axle, relative to the first axle in the vehicle (mm)
Width	The transverse (*z* direction) width of the current axle (mm)
Loaded length	The length of contact between the current wheel (axle) and the carriageway surface (mm)

- No limit on the number of vehicles may be imported from the vehicle library for use in the project.
- No limit on the number of vehicles that can be used in an individual load case.

Multiple load cases

- Multiple load cases are specified using the Add Load Case(s) function.
- There is no limit on the number of cases that can be used in a project.
- Specify an ‘empty’ case and manually add vehicles, or copy an existing load case at regular intervals across the bridge.
- Delete a load case by selecting the correct case and clicking the Delete Current Case button.
- Delete all other load cases except for the chosen one by clicking the Delete All Cases (Except Current) button.

Load positioning

- Using the Position function, determine the position of each constituent vehicle within a load case.
- Switch the direction of travel of a load vehicle using the Mirror? function.
- Specify those axles that are subject to a Dynamic Factor (value entered in the Dynamic Factors dialog).

Analysis

Analysis types

The output is dependent upon the choices made when developing the model:

Load factor analysis

- For a single load case the load factor that would, when applied to the specified live loading, cause the bridge to collapse is displayed.
- For multiple load cases the collapse load factor associated with each load case is computed and the critical one is displayed.
- An iterative analysis is used when finite masonry crushing strength is specified (the governing contact moment vs. normal force failure envelope is non-linear). In such a case, the failure envelope is progressively refined until the true non-linear failure envelope is accurately represented.
- Detailed information on an iterative analysis is available in the Preferences dialog.

Support movement analysis

- A support movement analysis is carried out when one or more supporting blocks are prescribed to have moved from their original positions.
- Multiple load cases, each containing one or more vehicles, can be placed on a bridge subject to support movements (in this case an axle load factor can if necessary be manually specified for all axles via the Partial factors dialog)
- Result expressed in terms of energy (Joules).
- Uses small displacement theory.

Analysis engine

- Uses MOSEK, a powerful linear programming solver.
- Option to swap to CLP (the solver used in v2.0).
- For maximum efficiency, problem data is passed to the solver via memory.

Report output

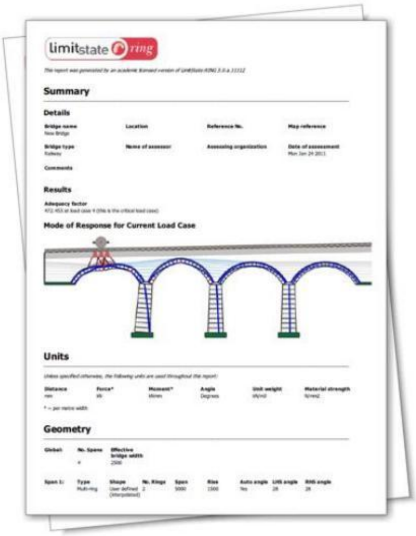


Figure 14 –LimitState:RING report output

- View / edit the report using the integrated word processor (or copy and paste to an external word processor)
- Make the document organization specific using customized html headers and footers
- Print the report directly from the LimitState:RING 3.0 word-processor or save the file as a pdf

By default, each report gives the following details:

Section	Contents
Summary	• Bridge name • Location • Reference No. • Map reference • Bridge type • Name of assessor • Assessing organization • Date of assessment • Comments • Analysis result
Failure mechanism	A graphical representation of the failure mechanism (including details of the associated load case)
Geometry	• Global o Number of spans o Bridge width • Abutments o Backing height o Height o Width (top) o Width (base) o Number of blocks • Spans o Type o Shape o Number of rings o Span o Midspan rise (if applicable) o Quarterspan rise (if applicable) o User-defined profile points (if applicable) o Auto calculate angles? o LHS abutment angle o RHS abutment angle • Piers o Backing height o Pier height o Width (top)

	◦ Width (base) ◦ Number of blocks
Fill profile properties	• Horizontal distance (x) • Height to surface fill (y) • Surface fill depth (d) • Surface level (y+d)
Partial factors	• Loads ◦ Masonry unit weight ◦ Fill unit weight ◦ Surface fill unit weight ◦ Axle load ◦ Dynamic • Materials ◦ Masonry strength ◦ Masonry friction
Backfill properties	• Unit weight Angle of friction Cohesion • Model dispersion of live load? • Model horizontal 'passive' pressures? • Dispersion type • Cutoff angle • Soil arch interface, friction multiplier Soil arch interface, cohesion multiplier Mobilization multiplier on K_p (mp) Mobilization multiplier on cohesion (m_{pc}) Keep $m_p.K_p > 1$? • Auto identify passive zones? • Table of structural features and whether they are subject to passive pressures
Surface fill properties	• Unit weight • Load dispersion limiting angle
Backing properties	• Position in bridge • Backing height • Passive pressures modeled?
Vehicles	For each vehicle: • Name • Axle number • Load magnitude • Axle position
Load cases	For each load case: • Load case number • Load case name • Constituent vehicles • Vehicle positions Mirror? • Dynamic axles • Effective width • Adequacy factor
Blocks	• Label • Position • Corner co-ordinates (2D) • Cross-sectional (xy) area • Unit weight • Support (x/y/rotation)? • Support movement (x/y/rotation)? • Fill force (vertical) • Fill force (horizontal)
Contacts	**Standard** • Label • Position • Endpoint co-ordinates (2D) • Length • Mortar loss (intrados and extrados) • Crushing Strength • Friction Coefficient • Whether Sliding / Hinging / Crushing are enabled • Whether inter-ring sliding is apparent • Normal force Shear force Bending moment **Reinforcement** As Standard, plus: • Point 1 • Point 2 • Reinforcement depth (A) • Maximum tensile force (A) • Maximum compressive force (A) • Maximum tensile force (B) • Maximum compressive force (B) • Shear capacity

Preferences

- Accessed via the **Tools** menu.
- Allows users to customize various aspects of the look and feel or behaviour of LimitState:RING.

General preferences

Program configuration

- **Language** – Change the language that LimitState:RING uses.
- **Window style** – Change the appearance of the LimitState:RING 3.0 toolbars and menus.
- **Show start up dialog next time** – Choose whether to display the startup dialog when starting LimitState:RING, or whether to start with a blank project.
- **Clear recent files list** – Remove the list of recently accessed files from the start up dialog.

Solve

- **Solver** – Change between MOSEK and CLP (the solver used in LimitState:RING 2.0.)
- **Solve automatically after dragging a vehicle** – turn on / off the 'drag and solve' mode.

Output

- Number of significant figures to display in the solution.
- Default scale for post-solve deformation – choose how much to scale deformations by default Display iteration information in output window – show detailed, real-time information of an iterative analysis (used when finite masonry crushing strength is specified).

Report preferences

- **Import template** – Specify a custom .css file to determine the style of the report output.
- **Import header** – Specify a custom .html file to use in the header of the report output.
- **Import footer** – Specify a custom .html file to use in the footer of the report output.

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