Division / Business Unit:	Engineering & Systems
Function:	Track & Civil
Document Type:	Procedure

Load Rating of Underbridges

ETE-09-05

Applicability

ARTC Network Wide

SMS

Publication Requirement

Internal / External

Primary Source

Document Status

Version #	Date Reviewed	Prepared by	Reviewed by	Endorsed	Approved
1.2	23 Feb 22	Standards	Stakeholders	A/Manager Standards	A/General Manager Technical Standards 29/03/2022

Amendment Record

Amendment Version #	Date Reviewed	Clause	Description of Amendment
1.0	18 Jul 19		First issue of procedure.
1.1	01 Jun 20		Added complete typical ARTC load diagrams (App. A) to comply with ARTC ETE-09-02. Added definition of notations of the form ETE0905F-01 (App. B). Added ARTC structural modelling requirements (App. C) for load ratings to standardise submittals. Applied minor changes in some sentences.
1.2	23 Feb 22		Removed all the requirements already stated in other ARTC COP/procedures. Added many detailed requirements/recommendations for structural modeling using SpaceGass/FEA; many analyses are followed by

	detailed examples and described modeling techniques. Added hyperlink to the ETH-09-01 (bending moments and shear forces for simply supported spans due to the current ARTC operations). Applied some changes in some sentences.

Table of Contents

1 Introduction

This procedure is intended to ensure load limits on ARTC underbridges are efficiently and effectively managed by adopting acceptable Load Rating Factors (RF)s to underbridges at any time considering the structural capacity of underbridge, vehicle loads, axle spacings, speed, structural condition, and fatigue assessment.

1.1 Purpose

This procedure:

- provides the technical requirements or recommendations to facilitate structural modeling and analysis, report RFs, and fatigue assessments to be performed for underbridges on the ARTC rail network.
- standardises Load Rating (LR) technical report submittal and documentation requirements for the ARTC underbridges.

1.2 Document Owner

The General Manager Technical Standards is the Document Owner. Queries should be directd to standards@artc.com.au in the first instance.

1.3 Responsibilities

Business Unit management is responsible for implementing this procedure.

1.4 Reference Documents

The following documents support this procedure:

- AS 5100: 2017 & 2004 Bridge Design Standard
- AS 7636: 2013 RISSB Railway Structures

1.5 Acronyms

The following terms and acronyms are used within this document:

Term or acronym	Description
ARTC	Australian Rail Track Corporation
AS	Australian standard
DLA	Dynamic Load Allowance
FEA	Finite Element Analysis
LR	Load Rating
MTF	Multiple Track Factor
NRV	Nominated Rating Vehicle
RF	Load Rating Factor
RISSB	Rail Industry Safety and Standards Board
SHM	Structural Health Monitoring
SLS	Serviceability Limit State
ULS	Ultimate Limit State

2 Load Rating - Limit States

2.1 Ultimate Limit State (ULS)

As a minimum requirement for LR, Ultimate Limit State (ULS) shall be used in the calculation of RFs for the ARTC underbridges.

2.2 Serviceability Limit State (SLS)

Serviceability Limit State (SLS) may also be required to provide further investigations into a known defect in a specific underbridge. These defects may include signs of reduced stiffness, an evident cross-sectional loss or a deflected or distressed component, cracking, deformations, or abnormal vibrations.

3 Load Rating Procedure

3.1 Capacity Assessment

Following the engineering inspection of underbridges, the ultimate structural capacities (R_u in kN.m / kN) of main super-structure components including, but not limited to the main girders, trusses, cross girders (intermediate and end ones, separately, for through trusses), stringers (intermediate and end ones, separately, for through trusses), bracings, deck slabs, connections, and bearings shall be calculated in accordance with AS5100- Bridge Design standard, other relevant Australian or international standards. Substructure components may also be required to assess for stability (including sliding or overturning) to specify the maximum critical bridge capacity or to further investigate foundation strength under loads. Substructure components shall be assessed, where there are concerns about progressive cracks, movement, rotation, or settlement or where piles or abutments' ultimate capacity under heavier loads are unknown.

As a minimum requirement, capacity assessment under vertical and horizontal forces is required for an underbridge substructure constructed of steel and/or wrought iron.

Note: In determining ultimate structural capacities, AS5100.7:2017 (or 2004, where advised) shall be fully considered. ARTC needs to be consulted at any stage where the Engineer seeks clarification about requirements for application of specific load effect or design standard that is not stipulated in this procedure.

The acceptable assessment methods of ultimate capacity may be categorised as follows:

- Semi-empirical or hand calculation methods
- 3D structural or a Finite Element Analysis (FEA)-Refer to Appendix C.

Calculation reports shall be attached to the load rating form ETE0905F-01, which clearly include, but are not limited to the following results:

- Capacity assessment purpose
- Design standards and material strength assumptions
- Loading summary
- Load cases and combinations summary
- Calculated section, member, and connection capacities (including moment, shear, torsion, axial, interactions and combinations, etc.) and further checks
- Analysis/modeling considerations
- As-New and As-Is structural analysis for damaged sections
- Structural modeling outputs
- Bridge drawings, other technical notes, and site investigation reports
- Conclusion and Recommendations identifying issues and deficiencies of the underbridge, and short term and long-term actions required to ensure safe operation of the bridge

Appendix B includes the definition of notations used in the load rating form ETE0905F-01.

Before any engineering inspection, ARTC will provide the load rating engineer with the latest reviewed and signed load rating form ETE0905F-01 to review and update, if available.

Note: Load rating summary Tables for section line engineering inspection which are separate to the load rating form ETE0905F-01 shall be reported as directed by Business Units.

3.2 Software Requirements

ARTC shall be provided with the output files of SpaceGass software for review, where bridge components are structurally modeled. Appendix C includes minimum requirements for structural modeling of ARTC underbridges.

3.3 Load Rating Factor

ARTC COP section 9 on load rating factors should take precedence over AS5100 for both As-New and As-Is conditions.

No RF shall be considered valid until a recent engineering inspection has been undertaken. As-Is RFs shall consider accurate or rational levels of deterioration in the existing structural components. For each underbridge, the component that has the lowest RF value shall be identified.

RF reports submitted to ARTC shall clearly include, but not be limited to the following results:

- Schematic of nominated rating vehicles
- Summary of recent bridge inspection findings including condition assessment report, technical notes, and photos (for As-Is rating)
- Summary Table of reduction factors, load factors, load effects, dynamic load allowances, multiple track factors, and remarks which clearly shows critical underbridge components or connections
- Summary Tables of RFs (As-New and As-Is)
- Conclusion and Recommendations- Refer to Cl.6.
-

Refer to load rating form ETE0905F-01 which needs to be separately registered on the ARTC Enterprise Asset Management System, Ellipse, for each underbridge.

4 Underbridge Management

Where the Engineer calculates the RF < 1, the following additional information is required in the Engineering report to ARTC:

- What speed reduction is required to increase the rating to 1, that is, the reduction to DLA with respect to a reduced speed.

  The critical component limiting RF shall be identified in the load rating form ETE0905F-01. ARTC may require the Engineer to further explore modification and strengthening of that component so that ARTC can consider the implementation of other ways to increase the capacity of the component.

5 Report Registration

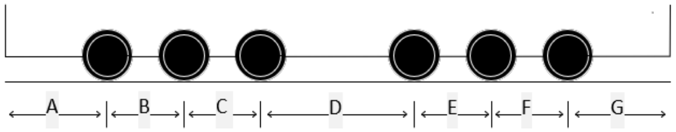
All RFs, structural calculations, output files of structural modeling, fatigue assessments, and other test results shall be registered on the ARTC Enterprise Asset Management System, Ellipse.

Appendix A- Some Typical Load Diagrams

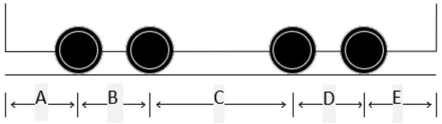
This appendix includes some ARTC typical load diagrams. The engineer shall use a minimum string of at least 3 locomotives hauling 10 wagons where load rating is required for loading traffic rather than 300LA.

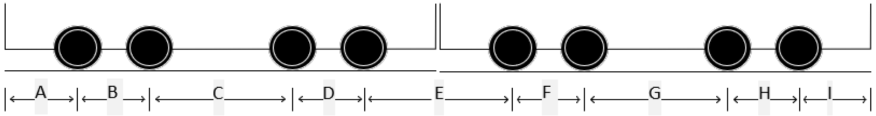
Refer to ARTC guideline ***ETH-09-01 Live Load Effects due to typical ARTC train consists for simply supported spans*** for the tabulated bending moments and shear forces due to the unfactored axle loads of the following trains on simply supported spans varying from 1m to 50m.

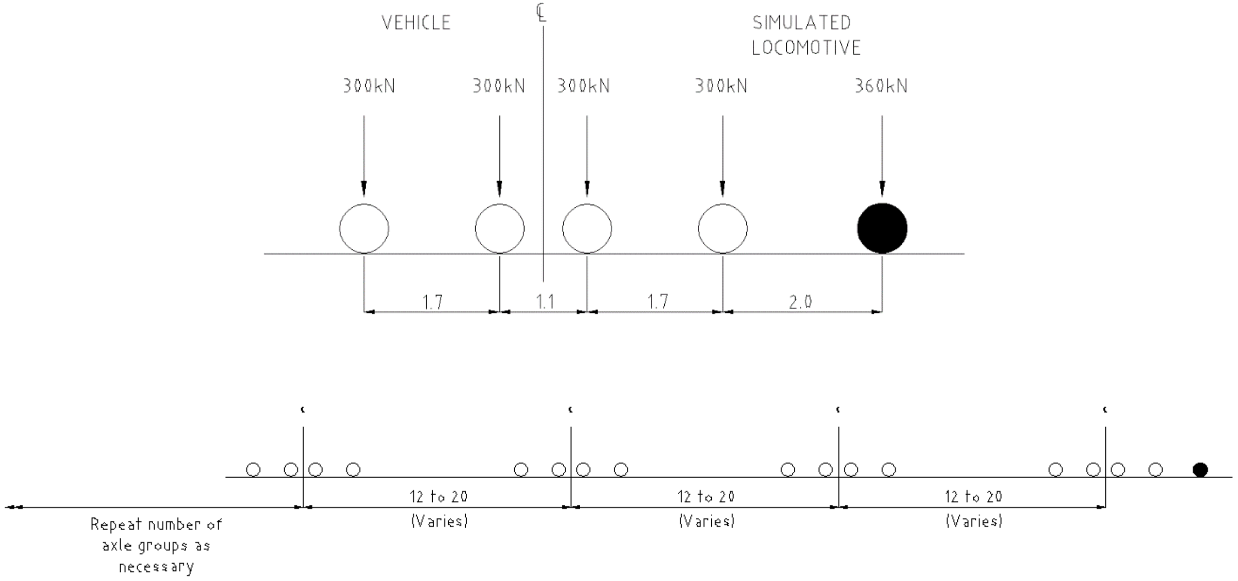
Locomotive Configuration

LOCOMOTIVE	**LOCOMOTIVE MAXIMUM INDIVIDUAL AXLE LOAD (TONNES)**	**LOCOMOTIVE MAXIMUM OVERALL MASS (TONNES)**	**DISTANCE BETWEEN AXLES (MM)**  							**OVERALL LENGTH OF LOCOMOTIVE**
			A	**B**	**C**	**D**	**E**	**F**	**G**	
RAS 270	29.5	177	1800	1800	1800	8200	1800	1800	1800	19000
RAS 210	23.0	138	1800	1800	1800	8000	1800	1800	1800	18800
QR5000	29.33	176	2410	2006	2006	9393	2006	2006	2173	22000
90 Class	27.5	165	1859	2022	2127	9984	2127	2022	1859	22000
L Class	22.83	137	1955	1905	1905	8690	1905	1905	1955	20220

Wagon Configuration

WAGON	WAGON MAXIMUM INDIVIDUAL AXLE LOAD (TONNES)	WAGON MAXIMUM OVERALL MASS (TONNES)	DISTANCE BETWEEN AXLES (MM) 					OVERALL LENGTH OF WAGON
			A	B	C	D	E	
RAS 270	30	120	825	1780	10490	1780	825	15700
RAS 210	25	100	1050	1720	8400	1720	1050	13940
RAS 210	23	92	980	1720	6150	1720	980	11550
General Freight	25	100	1070	1780	11170	1780	1070	16870
Steel	23	92	1250	1750	5000	1750	1250	11000

WAGON	WAGON MAXIMUM INDIVIDUAL AXLE LOAD (TONNES)	WAGON MAXIMUM OVERALL MASS (TONNES)	DISTANCE BETWEEN AXLES (MM) 									OVERALL LENGTH OF WAGON
			A	B	C	D	E	F	G	H	I	
NHEH Coal	30	240	825	1800	10060	1800	1650	1800	10060	1800	825	30620
QR QHCH Coal	30	240	945	1779	10025	1779	1740	1779	10025	1779	945	30796



300LA Traffic Load (AS5100.2:2017)

Appendix B- Notations (Form ETE0905F-01F)

This appendix lists the definition of notations used in the form ETE0905F-01.

Rating Date

The date on which load rating calculations is carried out or submitted to ARTC.

Company / Rating Engineer

Company and Engineer(s) undertaking load rating calculations.

Load Rating-Limit State

ULS or SLS. Refer to Section 2.

Asset (Ellipse Equipment #)-Underbridge Name-Railway Line-Chainage

Ellipse equipment number of the underbridge which includes underbridge name, railway line, and chainage (kilometrage) where the underbridge is located.

Underbridge Type-Year of Construction

Underbridge type e.g. steel truss bridge, super T girder or prestressed planks over concrete abutments, etc. The Year of construction for underbridges may be assumed to be the same as the year of design noted on drawings.

Overall Length-Number of Spans-Spans Configuration

The total length of underbridge, number of spans, and span(s) configuration such as simply supported or continuous spans.

Latest Bridge Inspection Date and Report (Ellipse Equipment #)

The date on which the latest engineering inspection is performed including Ellipse equipment/original report number.

Technical documents including site investigations calculations, tests, fatigue assessment, SHM, computer models, etc. (Ellipse Equipment #)

Ellipse equipment/original report number for documents related to this load rating shall be noted.

Nominated Rating Vehicle

Load rating form shall be filled for 300LA only and rated down/up for any other loadings. In any case, one nominated rating vehicle is only required.

Underbridge component

Refer to Cl.3.1 for the underbridge components to be rated. Each rated component shall be listed in a separate row.

Design action / Combined actions

Each component shall be rated for different design actions such as bending, shear, axial, or torsion.

L

Effective span or Length of member per meter.

L_α

The characteristic length of member per meter. Refer to AS5100.2:2017, Cl.9.5.2.

φ **(As New)**

Capacity reduction factor of member in As New condition.

φ **(As Is)**

Capacity reduction factor of member in As-Is condition.

R_u

The calculated ultimate capacity of member in the moment, shear, torsion, or axial per kN.m / kN.

γ_g

Load factor for the dead load. Refer to AS5100.7:2017, Section 12.

γ_{gs}

Load factor for the superimposed dead load. Refer to AS5100.7:2017, Section 12.

γ_Q

Traffic (live) load factor. Refer to Appendix A of this procedure.

S_g^*

Load effects due to dead load per kN.m / kN.

S_{gs}^*

Load effects due to superimposed dead load per kN.m / kN.

S_p^*

Load effects due to secondary effects of prestressing per kN.m / kN.

S_s^*

Load effects due to shrinkage, creep, differential settlement, and bearing friction per kN.m / kN. In most cases, these load effects can be taken as nil in ULS rating, unless there are obvious signs of member distress, relative settlement, or deformation due to such effects.

S_t^*

Load effects due to temperature per kN.m / kN.

S_Q^*

Load effects due to traffic (live) load per kN.m / kN.

α

DLA for full speed (full speed may be taken as 80km/hr or above). Refer to AS5100.2:2017, Cl.9.5.

W

Multiple Track Factor (MTF). Refer to AS5100.2:2017, Cl.9.4.

RF

Load Rating Factor as calculated below. Refer to AS5100.7:2017, section 14.

$$RF = \frac{Available\ bridge\ capacity\ for\ traffic\ (live)\ load\ effects}{Traffic\ (live)\ load\ effects\ of\ nominated\ rating\ vehicle}$$

$$= \frac{\varphi R_u - (\gamma_g S_g^* + \gamma_{gs} S_{gs}^* + S_p^* + S_s^* + S_t^*)}{\gamma_Q (1 + \alpha) W (S_Q^*)}$$

LR

Load Rating which is represented as LA.

Underbridge Management

Refer to section 4. Reduced speed and amended LR shall be noted in this column if the resulting RF is less than unity. Other actions including a proposal summary for member strengthening method may be noted in this column, provided that such an investigation has been undertaken by Engineer.

Underbridge component limiting LR

The most critical member with the lowest LR shall be noted.

Remaining Fatigue Life Estimation (Yrs)

Members with different fatigue lives (in year) shall be listed in this section. This section is usually requested for steel / wrought Iron components only.

Appendix C- Minimum Requirements for Structural Modelling

The following Table defines structures to be modeled:

Structure type	Required?	
	Yes	No
Concrete ballasted deck		×
Transom top bridge	√ (see Note a)	
U-frame / through girder bridge	√ (see Note a)	
Through truss bridge	√	
Steel trestles and bracings	√ (see Note b)	
Prestressed / posttensioned deck or planks		×
Super T girder		×
Precast culvert		×
Concrete / masonry arch	√ (see C1-1)	
Rail deck culvert		×
Steel box girder		×
Composite / non-composite ballasted bridge		×

Note a-Modelling may only be required, where the assessed structure is complex for hand calculations. Many transom top or through girder bridges which consist of two similar girders connected by only one type of cross beam and/or wind and sway bracings may not necessarily be required to model. Only in these cases, modelling will be optional as recognised by the engineer. It should be noted, however, that modeling of all the assessed underbridges is preferable and ARTC may request for models where this is needed. ARTC shall be consulted, in cases, there are uncertainties about modeling, analysis types, or other requirements.

Note b-Steel trestles and bracings shall be modeled together with its superstructure (including bearings, if any) as one integrated structural model.

C1 Some Modelling Considerations

C1-1 Nodes and Elements

ARTC requires that only an engineer with an appropriate level of competency, structural knowledge, and experience in bridge modeling, design, or load rating creates an underbridge model. The created bridge models shall be as close as possible to the geometry and actual members of the real bridge. In models, all the structural members shall be created precisely as far as applicable in SpaceGass, so that the total calculated mass of the structural model indicates the total approximate mass of the real bridge.

For through trusses, all built-up members including verticals, diagonals, and posts shall be modeled in their correct orientation. ARTC may use created models for other purposes such as dynamic frequency, or other types of analysis, structural rectifications, or nodes transfer to an FEA code for an SHM project in the future.

It is recommended that structural members in complex models are categorised, so that they can be easier filtered by the top drawdown menu.

To model members such as a bearing, pile, arch, abutment, prestressed / post-tensioned girder, or specific damage; an FE or specific software may be used for modeling solid elements or nonlinear spring elements for soil-structure interaction. In many cases, however, SpaceGass can model different members. For example:

- Global linear analysis of a prestressed concrete girder with sufficient design information such as prestressing forces can be carried out using SpaceGass; provided that prestressing tendons are consistent through the girder's length.
- Stiffness analysis of critical steel connections or rigorous nonlinear buckling analysis of steel U-frames (linking with STL) as finite shell/plate elements can be carried out using SpaceGass if the modeling does not need specific solid elements.
- Elastic bearings can be modeled either by the dummy elements or master-slave nodes if an integrated model of superstructure and substructure is required.
- Post-tensioned box girder can be modeled using finite shell/plate element for the box and frame/beam elements for tendons connected by dummy elements.

In different cases, and before using other software than SpaceGass; ARTC can be consulted to ensure modeling is not performable in SpaceGass and will then be provided with the output file of that FE model for reading, review, and registration of that output.

Currently, SpaceGass is unable to model solid/brick elements or to apply different geotechnical modeling inputs such as nonlinear springs, mass springs, or spring-damper elements. Thus, for analysing masonry underbridges or arches, a shell or brick FE model or a specific non-FE package including soil modeling capabilities can be used. If a full 3D FEA developed from brick elements is used, it will be beneficial to consider the modeling of crushing / cracking material, ring separations, soil-structure interaction, and if possible, the existing defects and repairs. In reality, soil-structure interaction under the dynamic load of trains in existing old masonry is a complex issue i.e. effect of the surrounding and underlying soil strength on the global stiffness, mass, damping of the system can be significant, however; some packages have some soil selecting options such as Mohr-Coulomb material and soil continuum parameters. Passive soil pressure can also be modeled using nonlinear springs. Care must be taken to ensure modeling represents close enough to the real bridge condition. In most of the old underbridges, detailed drawings are not available, so it may not be recognisable whether or not the masonry underbridge has an internal spandrel wall directly below the rail. These elements have been shown to have a significant effect on the overall bridge capacity.

NOTE-Modelling of an existing underbridge members in other software than SpaceGass will not be acceptable by ARTC if this can be carried out in SpaceGass.

C1-2 As-Is Damages

Any deterioration in structural members shall be modeled based on actual field measurements after comparing these measurements with available design drawings and undamaged sections. The engineer needs to allocate deterioration to the damaged member only by means of; reducing its section thickness or changing its section or member stiffnesses after sound engineering judgment about such damage.

For modeling corrosion in steel or wrought iron members, section loss may be allocated only where a member has an actual thickness loss with the same extent of corrosion measured at field rather than where they appear to have surface rusting or flaking paint.

Deformed or deflected members may be modeled as tension-only or stiffness-reduced members using the section and material design form in SpaceGass. It is noted that allocation of a global section loss for all the members is a conservative approach that may not obtain correct results, however, it may be justifiable if an underbridge has a significantly higher capacity required for the current/future operations.

C1-3 Fixities

Members' fixities shall be modeled as close as possible to the As-Is condition to ensure load distribution is properly performed in the model. This may even be different from the As-New or designed condition.

Fixities for members with full shear connections and moment connections can be modeled with the Degrees-of-Freedom (DoF) of FFFFFR and FFFFFF, respectively. For example in a through truss, shear connections at both sides of stringers can have the fixities of FFFFFR (no rotational end fixity about the z-axis). For old wind bracings, fixities can be modeled as FFFFRR (no rotational end fixity about the y and z-axises).

It should be noted, however, that the standard fixities may only be controlled for the new constructions designed as per AS5100 rather than As-Is bridges. Clause 3.10.5 of AS5100.6:2017 requires that the gauge from the back of angle to the first line of fasteners in flexing leg of the connection angles over the top third of the stringer is checked to ensure stringers or cross girders act as simply supported members. If the connections at both ends of the member appear to be designed in a way that they could take some level of the moment in the y and/or z-directions, the fixities may be modeled as FFFFFS or FFFFSS using the rotational stiffness of the connection in those directions, if such stiffnesses are available from an FEA or a connection test.

SpaceGass may be used to model connections separately as finite shell/plate elements and results can then be applied as the rotational stiffnesses where fixities are required to specify as above. If a load, P, is applied at a node of an FE connection of a member while, L, is the distance from that load to the intersection point of that member connecting to the other member; $P \times L$, will represent the connection moment, M. A sensitivity analysis is required to be performed to increase the load, P, at the applied node and plot the connection moment, $M,$ versus angle, $\theta,$ which is calculated using the vertical and horizontal displacements in the FEA. This increase can be continued until the buckling of the connection occurs in nonlinear buckling shell/plate analysis (DL plate using "Classic Eigensolver" theory only). Stiffness may then be defined as the slope in the linear region of the connection moment (M) vs. angle (θ) curve as expressed below:

$$Stiffness = \frac{\Delta M}{\Delta \theta}$$

Clause 12.3.1 of AS5100.6:2017 and Cl.7.3.2. of AS5100.9:2017 require that splices (excluding shear connections) in members subjected to axial tensions and flexural members subjected to the bending moment are designed with 75% of the nominal member design capacity in tension and bending, respectively. For modeling purposes, no fixities for an integrated member and end-to-end fixities of FFFFFF for two different cross sections in a member shall be taken, respectively, and then this requirement needs to be checked through the calculation. In the load rating form ETE0905F-01, the capacity of splices, as well as all other connections/members, load, or speed, shall be reduced, If 75% of the nominal capacities of members cannot be achieved.

Care should be taken when an assessment is undertaken for the old connections in the through trusses including gusset plate connections between members to ensure that the requirements of section 12 of AS5100.6:2017 are checked, thoroughly. The fixities of the connections between vertical, diagonal members or posts with chords or with each other, can be modeled as fully fixed connections i.e. FFFFFF unless they are appeared to be designed differently through the inspection.

C1-4 Material

Material design properties such as Young’s modulus, yield, and ultimate strength of each member shall correctly be filled as per appendix A of AS5100.7:2017 or field testing results in the section design form of SpaceGass, even if the model is only used for analysis rather than a full assessment.

SpaceGass cannot consider materials nonlinearity for beam/frame elements such as the ultimate capacities or stiffnesses for composite constructions. However, in any case, the engineer may change the stiffness of a member using section factors by clicking and editing the member form after calculating these parameters, separately.

C2 Loading

C2-1 Dead Load and Superimposed Dead Load

Dead loads or self-weight of a model shall include exact members as measured in the field after members are checked with existing drawings.

All built-up sections, wind and sway bracings, and recently replaced members shall be modeled accurately as they form the real bridge.

AS5100.2:2017, Tables 6.1(A) and 6.1(B) shall be taken as the minimum material weights considered for the calculated dead and superimposed dead loads unless stated otherwise on the drawings. Before analysis, the SpaceGass material library forms need to be checked to ensure all the densities are properly adopted for the purpose of the load rating and bridge assessment.

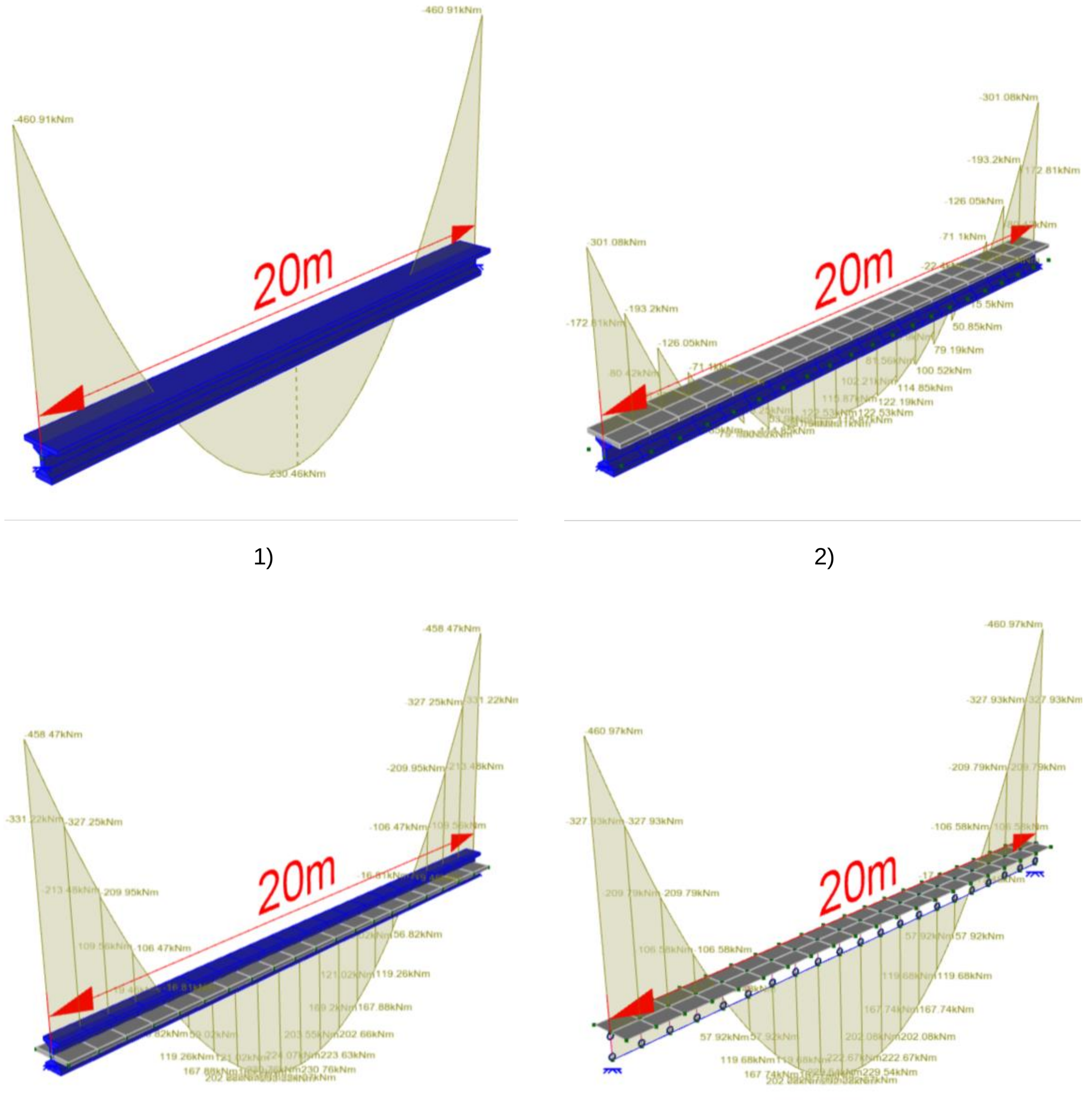
Superimposed dead loads shall be applied as a separate load case to subjected members in the model rather than in the calculations. Existing drawings and field measurements shall be used to calculate dead and superimposed dead loads such as rails, sleepers, ballast, transoms, handrails and barriers, maintenance walkways, or attached services.

Steel, concrete, or timber decking in a truss or any ballasted bridge need not be modeled as finite shell/plate elements in SpaceGass. Also, transoms, steel connections, stiffeners, gussets, barriers, transition slabs, or kerbs need not be modeled, either in the global model. Such members can separately be analysed; however, their dead/superimposed loads need to be applied as a separate load case in the model.

The decking system may be modeled as finite shell/plate elements connected over the frame/beam elements. Although this is not required as mentioned above, the following examples can illustrate different modeling approaches and results, where the engineer would like to do so.

A 20-m long concrete bridge consisting of a 150mm deep concrete deck over a 1000mm deep concrete girder with fixed supports at both ends is modeled.

Fig 1 shows the global bending moment due to the bridge weight when the bridge is modeled as one frame/beam element. Fig 2 shows the bending moment due to the same load case where the beam is modeled as a frame/beam element with offset, while the deck elements are modeled as shell/plate elements. As can be seen, the global bending moment obtained from the Fig 2 is significantly less than the numbers obtained from Fig 1. This is due to the added stiffness by the deck through the whole stiffness matrix and as a result, a large portion of the moment is taken by the deck. Because the global effects are required from a bridge analysis, there are two ways to solve this issue. Fig 3 shows the same model as Fig 2 where the offset is removed from the model and the bending thickness is set to a low number e.g. 1mm in the plate form. The reason is that the moment of inertia for the whole deck and beam system is now reduced as it mostly comes from the beam dimensions rather than the deck which achieves the global results correctly. Alternatively, Fig 4 is a model using a frame/beam element for the concrete girder, shell/plate elements for the concrete deck, and dummy elements with the fixities of FFFFFR (no rotation about the z-axis) at both ends to connect these elements. As can be seen, all models obtain the correct global bending moment for the girder, except Fig 2.



1) 2)

3) 4)

Figs 1 to 4- Bending moment results for the example concrete bridge (Fig 4 shown as wireframed for clarity)

C2-2 Moving (Live) Loads

Separate loading scenarios shall be introduced for different moving loads e.g. 300LA, RAS, etc. in a model. If SLS is considered, separate load cases need to be created as well.

For through trusses and trestles; where moving load other than 300LA is modeled, it is essential to model two wheels with a distance equal to the track gauge rather than a single axle in the middle of the track. The narrow, standard, and broad gauges shall be taken as 1067, 1435, and 1600mm, respectively.

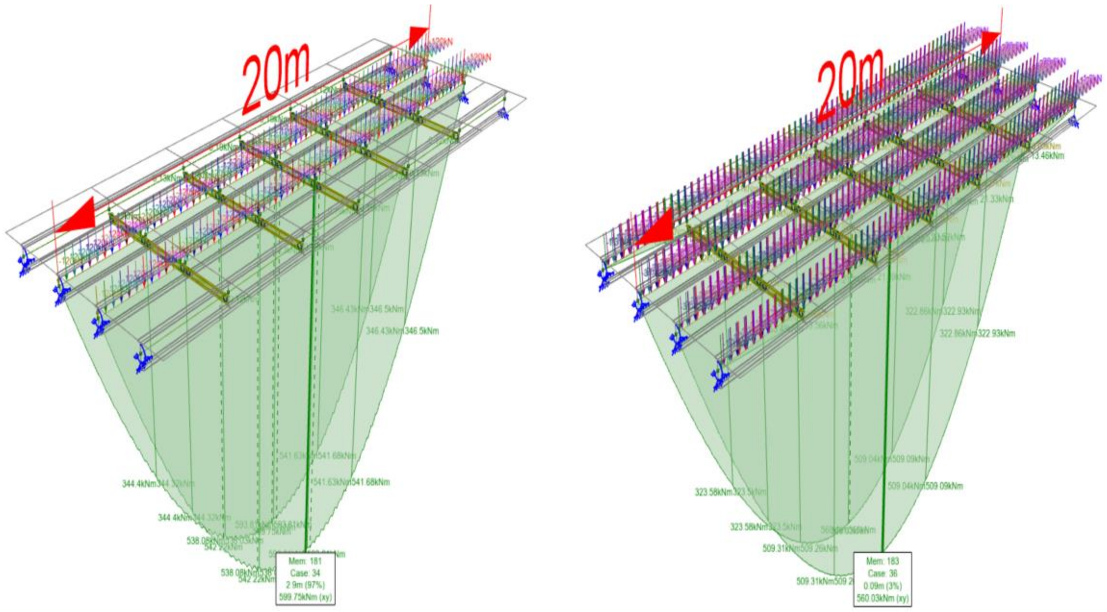
Moving loads shall be generated with the shortest possible increments. A good approximation is to adopt increments to a maximum of 1.5% of the shortest span to obtain the acceptable shear forces and reactions.

It is recommended that for underbridges the “Apply member loads to closest member only” option is always unticked to make sure maximum generated moving loads are applied to the structural members.

Care should be taken to make sure loads are only applied to the appropriate superstructure members, not other secondary or substructure members.

Attention should be paid when moving pressure is modeled instead of moving load within the SpaceGass environment. Clauses 9.6.2, 9.6.3, and 9.6.4 of AS5100.2:2017 have some recommendations for the effective load distribution width and length when a member is designed. Generally, moving pressure will have less effect on members than the moving load for the most track specifications following these clauses, hence, moving pressure is not recommended to model for the load rating of existing underbridges.

Fig 5 shows a 20-m simply-supported ballasted deck steel rail bridge consisting of four steel identical main girders connected using I-cross girders at a maximum of 3.5m intervals with the fixities of FFFFFR. The bridge carries an 8mm steel deck. All the members are modeled as frame/beam elements. A moving axle of 240kN (each wheel with 120kN with a standard gauge of 1435mm) is modeled with moving load increments of 0.3m (using 1.5% of span length, the loads are applied at 0.3m increments). A single track is located in the middle of the bridge and all 4 main girders are loaded in SpaceGass. The maximum bending moment of the two internal girders is shown in Fig 5. Fig 6 shows the maximum bending moment of the two internal girders where the same underbridge is loaded using the moving pressure following Cl. 9.6.3 of AS5100.2:2017 (area of pressure= 1.1m x 3m; assuming the ballast thickness of 500mm and sleeper length of 2500mm). For this example, the maximum bending moment for the bridge, modeled with moving loads, is 7% higher than the one modeled with moving pressure. It should be noted, however, that the load increments are important for obtaining correct shear and reaction results rather than the bending moments for simply-supported spans.



5) 6)

Figs 5 and 6- An example showing the difference between the calculated bending moments using moving loads (Fig 5) and moving pressures following AS5100.2:2017 (Fig 6) (all members shown as outlined for clarity)

RAS moving loads shall be modeled exactly with the same overall length and specifications (including the number of trains and wagons) as stated in the tender documents of engineering inspections. For example, a string of 3 x RAS210 Locomotive(23t) + 10 x RAS210 Wagon(25t) shall be modeled as 116 wheels with a total vertical force of 14140kN downward.

The axle loads shall be determined adopting an acceleration due to the gravity of $g=10m/s^2$ e.g. a 30t axle load will include two wheels; each with a 150kN vertical force downward.

When creating moving load for the through trusses or trestles with two tracks; it is essential to model the following scenarios:

- All vehicles come from one side parallel to each other.
- Each vehicle comes in the opposite direction from each other i.e. one from the east and the other from the west side.
- If the structure is not symmetric or it has more than two tracks; opposite of the first and second scenarios and a combination for all other possible scenarios.

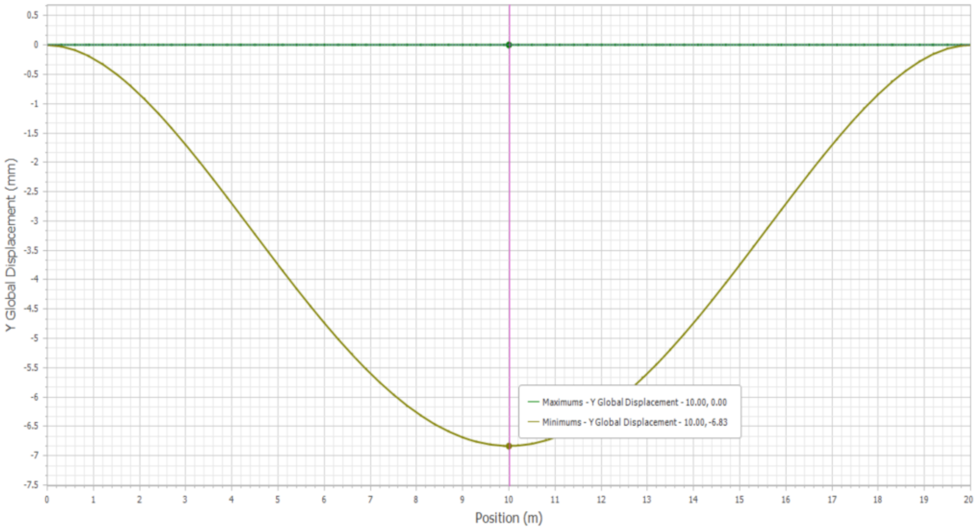
For the load rating assessment of a masonry structure using e.g. an FEA, a nonlinear static moving load analysis can be used as a proper solution. DLA may also be applied in the model as an additional factor to the live load. The analyser for moving load influence line in some commercial FE software can also calculate bending, shear, or torsion stresses and strains on beam, shell, or solid/brick elements due to static moving load. This application solves the stiffness problem similar to the SpaceGass model; however, it benefits from different element types, meshing, and nonlinear spring elements in FE software. For some non-FE software; it may be necessary to predefine how loads should be applied to the elements so that the distribution of train’s loads is followed, properly.

If an FE software is used for the analysis of an underbridge such as a masonry structure or arch, care must be taken when using transient/time-history analysis. This is necessary to ensure that dynamic factors are not considered improperly in the model. Transient analysis in FE models is usually used for generating acceleration data of vehicle-bridge interaction in the time domain due to the passage of a vehicle over a bridge or to generate accelerations of the free vibration of the bridge immediately after getting excited by applying and/or removing an external force such as field noise, wind or train. It should be noted that this type of vibration analysis should only be used for modal identification purposes such as natural frequencies extraction or FE model validation problems e.g. for modal identification tests or SHM projects.

In any analysis code; transient analysis shall not be used as an alternative to the static moving load analysis for bridge rating problems as the external force is applied and/or removed within specified time steps, so it causes different dynamic effects; accelerations, velocities, and displacements.

Fig 7 shows the maximum and minimum mid-span displacement curve for the concrete bridge described in Fig 1 where the bridge is subjected to a single moving axle load of 240kN (the load passes over the bridge from the start to the end). Displacements in Fig 7 are obtained by the static moving load analysis. Fig 8 shows the same model when it is excited by the same force of 240kN at the mid-span (no specific spring/damper rather than modal damping assumption is considered in the model) and the displacements are obtained at the same mid-span node for 10s (in Fig 8, the time step is 0.001s and loads decay from maximum to zero to model an excitation problem). It can be seen for this example that the maximum displacement when the structure is excited using the transient analysis is 18% higher than the results obtained from the static moving load analysis (bridge mass is included in both models).

The transient analysis is solved using the equation of motion and depends on mass and damping matrices while the static moving load analysis can be performed without any relevance to the dynamics parameters.



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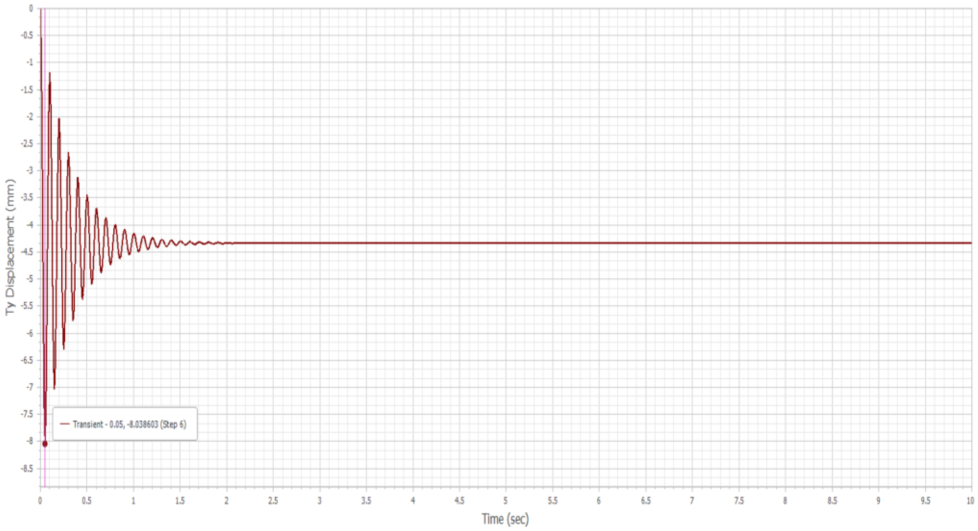

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Figs 7 and 8- An example showing the difference between the calculated displacements using static moving load analysis (Fig 7) and transient analysis (Fig 8)

C2-3 Fatigue loads

Fatigue loads shall be modeled for the through trusses and trestles using the same principles for moving load analysis in other scenarios within the same model as described before. Mid-spans bending stresses at bottom of main members such as stringers and cross girders as well as shear stresses for these members can be drafted vs. load locations for calculating the stress cycles counting using e.g. a reservoir method.

C2-4 Horizontal Forces

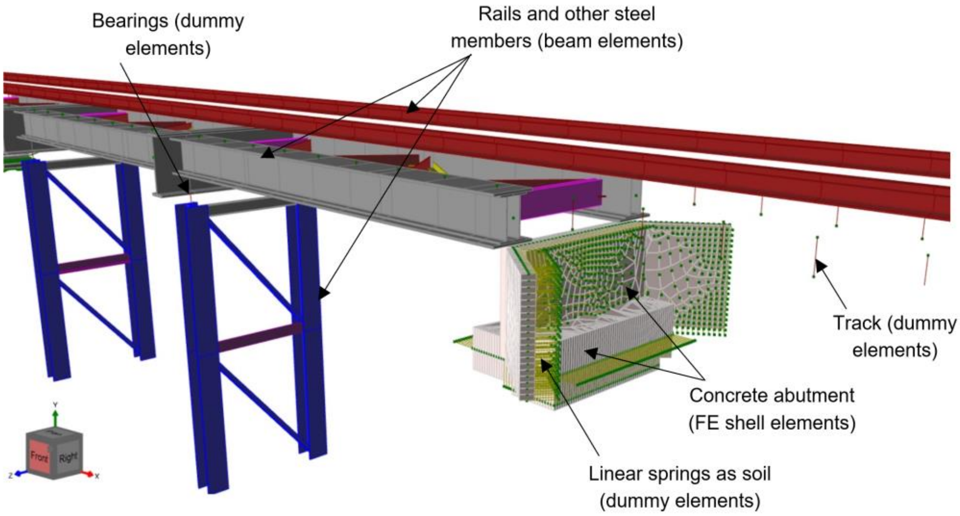
When using the rational method; braking and traction loads may need to be analysed for the assessment of critical steel substructure taking into account the requirements of both UIC 774-3 and AS5100.2:2017. In that case, a rigorous FE model or a simple non-FE model may be developed in other software to analyse rail-structure interactions, nonlinearly; considering track stiffness, vertical effects, braking, traction, thermal, and if required shrinkage, and creep loads using values stated in AS5100:2017 or ARTC procedures. This method of assessment may only be required upon ARTC request; and where the structure does not theoretically pass the empirical forces as stated in AS5100.2:2017, Cl.9.7.2.2.

SpaceGass may be used for the rational analysis of horizontal loading taking into account thermal, vertical, braking, and traction forces applied to the existing rails. The abutments and piers can be modeled as shell/beam elements interacting with soil. Soil stiffness behind the abutments may be considered as linear springs with stiffnesses available from the geotechnical reports or some rational parameters of soil. Steel superstructure and rail can be connected by dummy elements following the field elevations and track depth. For horizontal train loading; train mass and acceleration can be used to calculate the forces (Newton’s second law of motion) and can be modeled as separate scenarios of moving loads applied to the rails in SpaceGass. All the elevations need to be correctly offset and modeled. Bearings can be modeled as dummy elements with one end as spring. Track can also be modeled using dummy elements with fixities of FFFFRR at the connection of rail e.g. with 670mm spacing. Rails can be modeled as frame/beam elements extending 100m on either side of the bridge with spring boundaries at both ends. Most of the time, requirements for the development of a rigorous FE model can be reduced to a good and reasonable model developed in SpaceGass.

Usually, three separate global models of unloaded [factored (dead load+superimposed dead load+ thermal load & other loads e.g. wind)], loaded [factored (dead load+superimposed dead load +train vertical & braking loads + thermal load & other loads e.g. wind)], and loaded [factored (dead load+superimposed dead load +train vertical & traction loads + thermal load & other loads e.g. wind)] are required to be developed and analysed, only nonlinearly, with different longitudinal stiffness of rails and abutments for each model. Prescribed displacements may also be introduced to limit the displacements of rail nodes to observe allowable displacement values as per UIC 774-3. In either case, sensitivity analysis should always be performed to verify the overall stiffness that each abutment would add to the whole model in both active and passive conditions by checking the displacements and load effects in each run of the model. Although passive soil should be modeled as nonlinear springs, the longitudinal stiffness of the whole model including linear springs at each side of the bridge can be altered until validation by a reasonable sensitivity analysis.

Figs 9 and 10 show an example model of an underbridge with all the modeled elements described above. Stress and displacements can be read for all the members and/or plates in all conditions and compared to the allowable levels.

It should be noted that these models will always need to be compared with the models of superstructure-only i.e. without including the rails to investigate the additional stresses applied to the system due to the rails, abutments, and soil. In the end, the engineer will need to interpret the stresses based on the theoretical results from the model, operational loadings, As-Is condition of the existing underbridge, as well as their engineering judgment.



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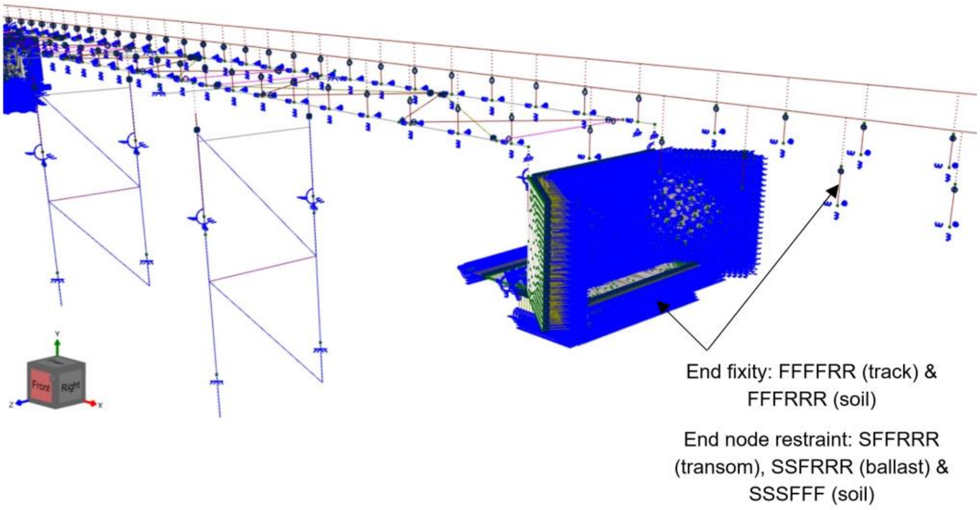

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Figs 9 and 10- An example showing different modeled elements to assess horizontal forces

C2-5 Wind Load

For through trusses and trestles; models shall include applied wind load to structural members in the model, even if such a load case is not critical for the overall assessment of the bridge.

For load rating, a separate moving load scenario shall include wind loads applied to the train which applies additional forces or moments to the stringers.

SpaceGass has an application for wind load calculation as per AS1170.2. It should be noted that the definition of drag coefficient in AS5100.2:2017, section 17 is different from that provided in AS1170.2, so, the results from this application should not be used unless it is checked with AS5100.2:2017.

C2-6 Nosing load

Wind and nosing load need not be simultaneously modeled for transom top, steel/concrete deck bridges, or U-frames.

C2-7 Pedestrian / Maintenance Walkway Load

The minimum pedestrian/maintenance walkway load shall be taken as 5kPa unless otherwise stated on design drawings.

For the application of the pedestrian loads or similar on SpaceGass, the load can directly be applied to a member carrying the load rather than modeling a separate decking system.

C2-8 DLA and MTF

For through trusses and trestles; DLA shall not be considered as a total dynamic factor in the moving load application of SpaceGass. As DLA depends on the characteristic lengths for each member, different members need to be assessed with their own DLAs rather than applying an overall DLA to the whole model.

MTF is only important for bridges carrying more than two tracks. This factor, however, can simply be applied in SpaceGass, as it depends on tracks rather than individual members.

C2-9 Load Factors and Load Case Combinations

Load factors and load case combinations may be applied either through the model or the calculations.

C2-10 Other Load Cases

It should be noted that the mentioned load cases in this procedure shall only be considered as the minimum required loads to be applied to a structure when load rating is undertaken.

In any case, it is the engineer’s responsibility to consider and apply other required loads as stated in AS5100:2017 considering structure geometry, material or application.

Examples that can be given are:

Structural analysis for the minimum restraint or stability where some obvious shortcomings exist about the structural stability in the lateral or longitudinal directions, assessment of thermal load for long steel viaducts, assessment of the damaged members from previous earthquakes or an incident such as train derailment or a vehicle collision, etc.

Where modeling of these effects is deemed to be necessary, the engineer shall consider the assessment of the members subjected to these effects in the model.

ARTC can be consulted, where there is uncertainty about the assessment of an underbridge for other loads than what is stated in this procedure.

C3 Analysis

For the through trusses, steel trestles, or those underbridges with combined superstructure and substructure members, the nonlinear static analysis shall always be performed rather than the linear static analysis.

Care should be taken when buckling analysis of SpaceGass is performed for obtaining the buckling load factors of frame/beam elements. Buckling load factors in SpaceGass shall not be taken as true buckling limits of sections when they are modeled as frame/beam rather than shell/plate elements. This is because the local buckling of non compact sections such as flexural-torsional buckling is neglected through the analysis of the program due to the basic principles assumed for the frame/beam element modeling in SpaceGass.

When modeling members as frame/beam elements is carried out; all main members of underbridges can be modeled as normal; however, sometimes the engineer may model some members such as wind bracings or dummy members as tension-only or compression-only members. In this case, sometimes for tension-only members, the convergence of the nonlinear analysis is difficult to achieve where the “activated” option is selected rather than “no reversal” in the analysis window. It is recommended for this case, all the members including bracings change to normal with the “activated” option thicked, then the tension-only members are checked through the calculations rather than through the model so that the analysis can be performed with no error. As nonlinear static moving load analysis can include some general buckling checks, it can still provide a good overview of the overall capacity of a through truss bridge.

For some simpler models, the engineer may decide to use the design options of SpaceGass to check the factored loads of non-built-up sections. In these cases, care should be taken to review the outputs to ensure e.g. they comply with AS5100 requirements (not only AS4100 or AS3600) as well as e.g. restraint nodes and buckling lengths for compression members are considered, properly.

C4 Naming Model Outputs

Output files need to be named as referenced below:

Ellipse Equipment Number-Underbridge Name-Analysed Loading-Limit State-Rating State-Analysis Date

Example (Glennies Creek Bridge at Hunter Valley):

112873-Glennies Creek Bridge-300LA-ULS-As New-10-09-2020

C5 Model Submittal

ARTC only requires unrun SpaceGass output files for review, as they can readily be transferred by email or registered in Sharepoint. To do this, “include analysis and design results” needs to be unticked in the save as window of the software.