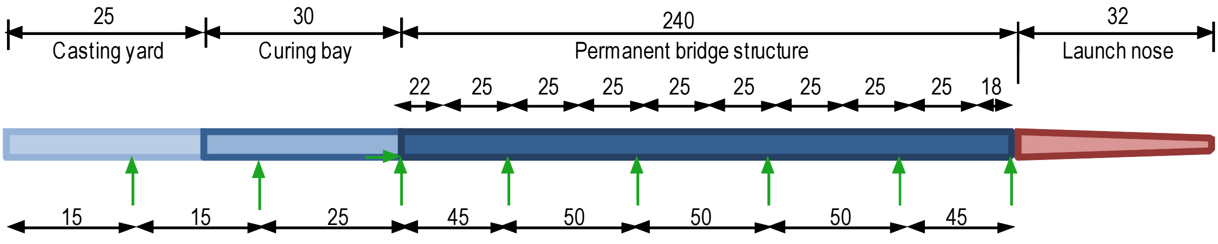
Incrementally launched box girder bridge

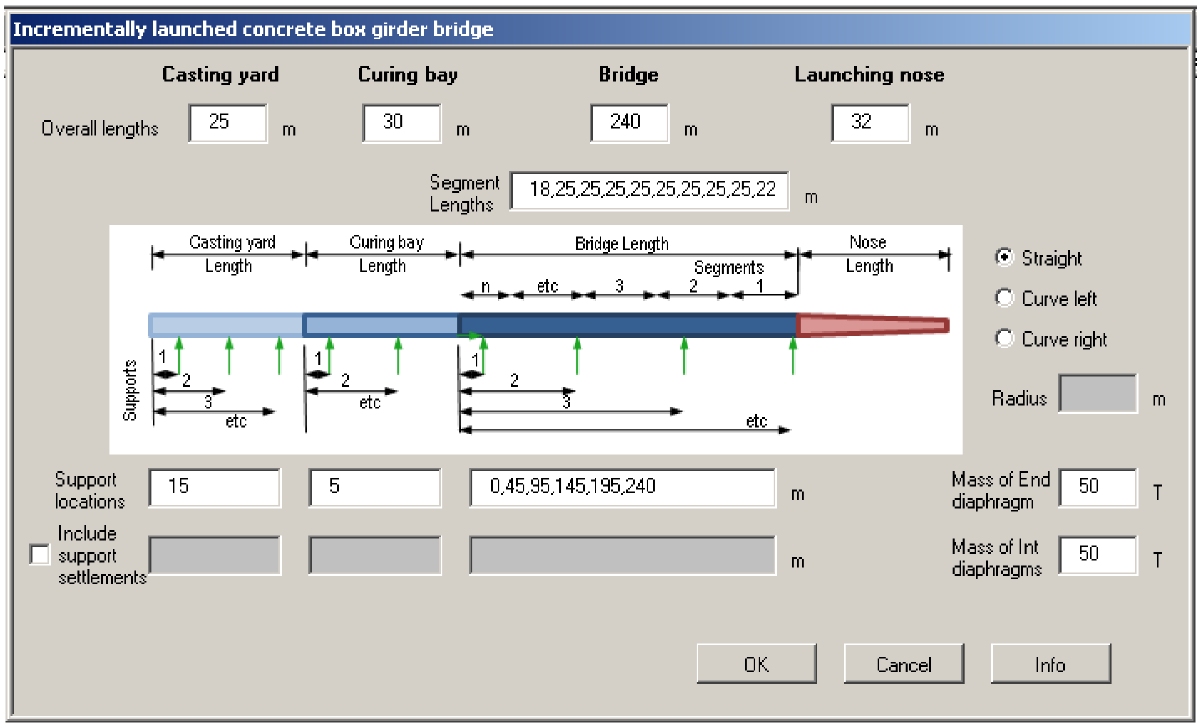
Summary data



Elevation on temporary works arrangement and proposed structure

The incremental launch of a box girder bridge is to be modelled. The analysis method of moving supports is adopted. The repetitive process of assigning supports and loads, and activating segments of deck, is automated using a visual basic script, which has a graphical input screen and is stored as a ".TFM" file.

These notes describe an example model generated using the supplied .TFM file. The results are investigated. It may be possible for the .TFM to be used as a starting point for the analysis of launched bridges of different dimensions and properties as the script and model produced may be modified in all the usual ways.



Input data using the automation VBScript

If a radius is entered, the script will reject radii which are so tight that a circle is created. For a radius on a motorway, a typical minimum value would be approx 510m.

Using the supplied .TFM file

The supplied .TFM is not part of the LUSAS software and, as such, is not quality approved or supported. It is provided for demonstration purposes only. Users are expected to check the outcome of the script and are welcome to modify and improve it if they wish.

1. Read the limitations below.

2. Ensure you are using LUSAS v14.3-5 or later.

3. Create a new (empty) model file.

4. Open the "Incrementally launched box girder.tfm" file using the red "open" folder on the LUSAS toolbar. The dialog on page 1 of this document should appear.

5. Fill in the boxes as appropriate.

    - Dimensions are in metres. Bridge and support dimensions should be integers; this restriction does not apply to the radius of horizontal curve, settlements or mass.

    - Checking the "include support settlement" box activates the appropriate text boxes, in which a support settlement should be entered for each and every support specific in the boxes above (specifying zero is acceptable).

    - Selecting "curve left" or "curve right" activates the "radius" text box

6. When you click "OK" the launch model will be created, which you can modify as required and solve.

7. An intermittent error occurs with curved bridges where supports are not visualised for the model generated, and the model fails to solve with a "current increment failed to converge" error in loadcase 1. This is eliminated by simply pressing the solve button a second time. The cause of this is currently unknown.

Limitations of the supplied .TFM file

1. The supplied .TFM uses SI units, and 1m increments, and all span length data must be rounded to integers.

2. The primary aim of the automation is to deal with the time-consuming process of assigning supports on 1m increments and activation and deactivation. Accordingly the automation does not introduce options for geometric and material attributes as these are very easy to modify (or redefine and reassign) for project-specific dimensions. Instead, an example box girder section and nose sections are generated (the nose is divided into quarters in order to give a tapering stiffness), and example (concrete and steel) materials are used. Project-specific attributes should be defined and assigned as appropriate.

3. Diaphragms are taken into account by use of gravity assigned to lumped mass elements. The mass of diaphragms is clearly of significance in the launch, but their bending stiffness is not significantly different from that of the rest of the box and applies only over relatively short lengths. Since rounding the length of a diaphragm to the nearest 1m (see 3 above) could result in an erroneous calculation of mass, it is expedient and appropriate to use this lumped mass

approach instead. The mass which should be entered is the additional mass at the diaphragms i.e. the mass additional to that which is calculated by using the geometric attribute cross-sectional area (A) and the density (ρ) – typically the mass of the concrete filling the part of the box which is voided in the span sections.

4. Creep is not incorporated in the model. This could be added to the .TFM file.

5. Some users experience visualisation errors with loadcases after loadcase 123 when using OpenGL hardware drivers. These were removed by use of OpenGL software drivers. If necessary you may change this setting using Start > Programs > LUSAS14.x for Windows > Tools > Configuration utility > Graphics tab.

Using the supplied .VBS file

A further automation **Launch reactions to Excel.vbs** script is provided. This is designed to extract the vertical (FZ) reactions from a launched bridge model which was constructed using the supplied .TFM file. It places the reactions in a spreadsheet (.XLS) arranged by loadcase and by pier. The piers are identified in the script and in the spreadsheet by their assigned prescribed displacement attribute; the script will fail if prescribed displacement attributes have been renamed manually (in the Treeview).

The script is run from the File > Script > Run Script menu item or the red folder button on the Main toolbar. It can be edited in Notepad or any other text editor and could be amended to, for example, also extract lateral reactions or rotational reactions.

The script may take longer than expected to run, depending on processer speed etc. It is, however, naturally much quicker than extracting results by hand.

Calculation contents

Introduction

Incrementally launched bridges are almost exclusively box girder structures and the method is generally associated with cast insitu concrete structures. The method is perfectly suitable for precast segmental construction as well, but insitu construction combines the advantages of repetitive workshop processes with small number of construction joints and continuous reinforcement.

General information on incremental launching included in this document is primarily drawn from Benaim (ref 1) and Rosignoli (ref 2).

Launching is most economical when the bridge plan area is greater than 3000m² but practicalities of jacking and friction tend to preclude it being used for bridges of lengths exceeding 1200m. Launchable geometry is straight, or may be on a vertical or horizontal radius (or both), but a fixed soffit form is important. Generally a flat soffit is used (crossfall can be accommodated on the top slab).

Span arrangements & segments

Incrementally launched bridges typically have spans in the range 30m to 55m. The use of regular spans considerably simplifies construction. As for all continuous prestressed bridges, end spans should be of order 90% internal spans (this is different from non-prestressed bridges because of the parasitic moments, which are lower in the end span critical section than in other spans).

The launching nose is typically 65% of a span.

Rate of construction on 15-25m segment per week (one half or one third of a span). The casting yard is positioned at least 30m back behind the first abutment so that it is not affected by the deflections of the deck as it spans from the abutment to the first pier. The area between the casting yard and the first abutment is often referred to as the “curing bay”.

It is often practical for the curing bay to be less than the less of the launching nose, however the span arrangements in the curing bay and casting yard need careful consideration to avoid instability during the early stages of the launch, unnecessarily high hogging moments towards the tail end, and uplift. Uplift can be expected when adjacent spans in a continuous beam are in a ratio of something less than 40% (ref 3, section 4.3.2)

Section geometry

For launched box girders, span:depth ratio is generally less than 15; 13 is the optimum in terms of avoiding excessive cost of prestressing. The final span:depth ratio may be lowered by the use of temporary piers, but of course these can be costly in themselves. Box girder section efficiency is generally in the order 0.55 (ref 1, section 5.3). Guidance on the dimensions of typical boxes is given by Rosignoli (ref 2, sections 3.1 and 3.7.2)

The launching nose is typically 1.5m deep at the front and the same depth as the box at the back. The nose is fitted with landing jacks, since it normally has a deflection of at least 100mm when approaching a pier. Ratio of weight of nose (q_n) to box (q_b) is of order q_n/q_b=0.1 and ratio of stiffness of nose (E_nI_n) to box (E_bI_b) is of the order E_nI_n/E_bI_b=0.2.

Design

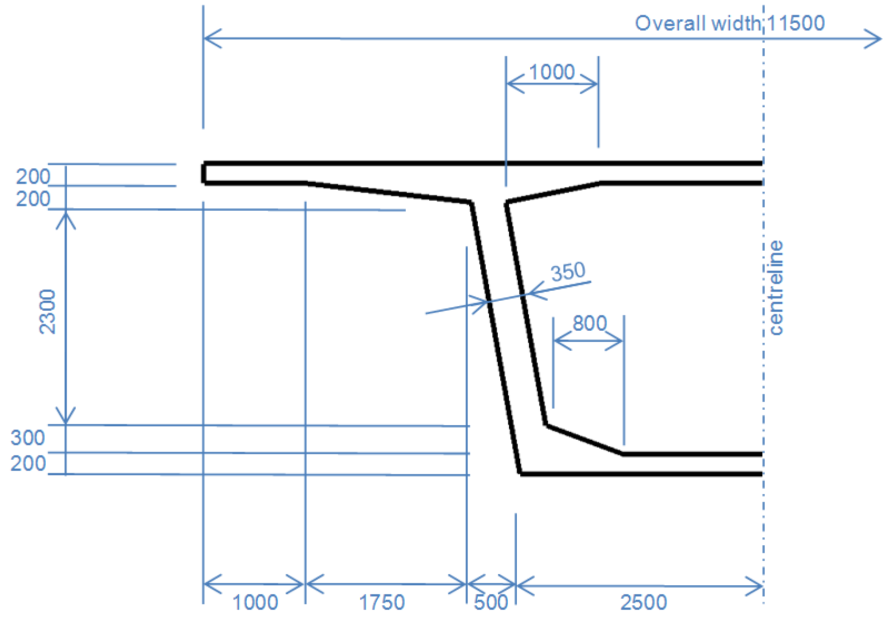
It is generally most economical to design the deck as partially prestressed during launching (i.e. Some tension allowed - crack widths limited by reinforcement). This has the advantage that the deck is more ductile, better accommodating casting errors. Even in partial prestressing, the average compression reach about 5-7MPa.

For reasons of practicality and cost, launch prestressing is often installed by use of coupled or overlapped straight tendons, stressing two or three segments at once and introducing the launch prestress progressively over a number of launches. When second stage prestress is installed, any cracks should close.

The minimum axial prestressing force during launch is $F=\Delta M/rH$, where H is the total depth and r is the section efficiency (of order 0.55 as described above). rH is described as the "central kern". The fluctuation of bending moment during launch is often taken as $\Delta M=kqAL^2$ for preliminary design. Neglecting thermal gradients and differential settlement, $0.16<k<0.22$ for the front zone and $0.12<k<0.15$ in the rear zone, approximately.

Description of structure

The example structure is a box girder bridge of overall length 240m with 5 spans of 45, 50, 50, 50 and 45m. A half-span casting cycle of 25m length segments is assumed, with shorter segment lengths for the first and last segments for practical reasons. The casting yard is accordingly 25m in length. The curing bay is taken to be 30m and the launch nose 32m, in line with the recommendations above. The span arrangement is given in the Summary Data, and the cross-section adopted is illustrated below.



Cross-section on box girder (symmetrical)

Analysis approach

Since highway and railway bridges are, in most cases, tangent or moderately curvilinear, and the adoption of box girders (whose high torsional stiffness limits tangential stresses, even when the torsional moment is relatively high) is the norm, straight beam theory is generally regarded as sufficient. Accordingly the model is analysed using 3D beam elements.

The defining characteristic of incrementally launched bridges is that each part of the structure passes of the supports from the casting yard to its permanent position. This may be modelled by either

a) moving supports backwards along a stationary structure (analytically the same as moving the structure forwards over stationary supports). Each segment is “activated” at the appropriate point in the analysis.

b) Moving a structure forward over stationary supports using contact slidelines.

The analysis in this example uses method (a), since (b) can be cumbersome and difficulties may be encountered using both activation and contact theories in the same model.

Low span/ depth ratio leads to some vulnerability to differential settlement/ misalignment arising from casting tolerance, which should be incorporated in the design calculations. However is may be noted that launch prestressing is often designed for the tensile stresses at the mid span lower edges, the moment variations caused by this do not affect the magnitude of prestress as much as might be at first anticipated and support settlement is often tolerable without increasing prestressing.

Design would typically require:

- ❑ A check against uplift at any of the bearings during the launch sequence
- ❑ An envelope of moments (and other load effects) for each section based upon the entire launch sequence
- ❑ Consideration of deformations and creep

In “full span” launches, creep is like that of a continuous beam cast directly in its final position with no prestress. This means a downward camber in each span, while in most post-tensioned bridges with “parabolic” prestressing creep leads to an upward camber in each span. However most launches are “half span”, therefore the flexural effects are reversed at each stop, and the cumulative effect of creep deformations is significantly reduced. However they could be taken into account by assessing creep at each stop using CEB-FIP Model Code 1990, using a model based on the model generated in this exercise.

The supplied .TFM is used with the input as illustrated in “Summary Data” on page 1 of this document.

Feature geometry

In order to launch the bridge incrementally, the model is constructed using points at 1m spacing connected with line features (the supplied .TFM ensures that these are numbered from 1 upwards in the positive x-direction). The 1m spacing is maintained is a curve is selected and a valid radius entered.

The example model is made up of 272 line features & 273 point features and is constructed in units of kN, m, T, s and C (a consistent set of units). Groups are automatically generated for each casting segment and the launch nose, to assist in manipulation of the model.

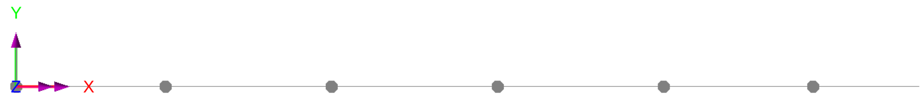
Mesh attributes

Beam elements

3D thick beam (BMS3) elements with 1 division per line are used throughout the model. BMS3 elements replicate a quadratic variation of bending moment, linear variation of shear and constant torsion along an element (ref 4, ch 2).

Lumped mass

The lumped mass of the diaphragms is conveniently modelled using point mass (PM3) elements, assigned to the appropriate points as illustrated below:



Plan on model showing mesh; lumped mass at each diaphragm

Geometric attributes

It is incumbent upon any user who utilises the supplied .TFM for actual bridge designs, to modify the geometric attributes from those generated automatically to suit the prototype structure.

Box girder section

Gross concrete section properties – the entire member cross-section, uncracked and ignoring the presence of reinforcement – are used for the box girder. This is reasonable considering the use of prestressing to mitigate cracking of the section during launch.

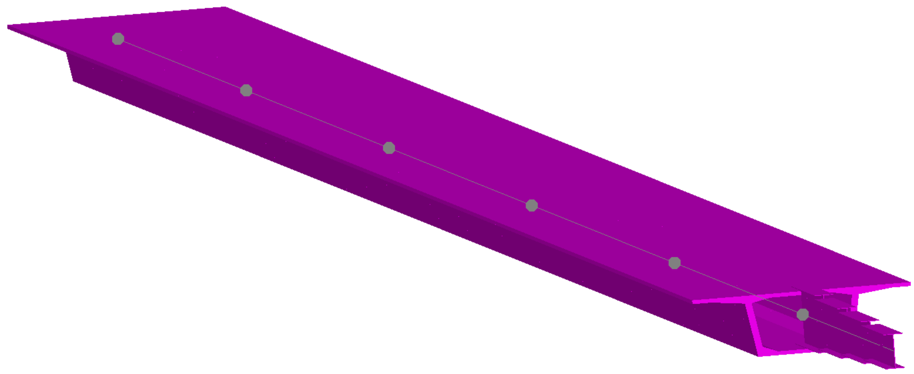
The supplied .TFM always generates the same example geometric attribute for the box girder, as illustrated in the "Description of structure" above. The box section has $A=6.0972m^2$, $Iyy = 9.143m^4$, $J=16.070m^4$. The centroid of this section is at y=1.992m, leading to a section efficiency $\eta=I/(Ay_ty_b)=0.63$, and the kern heights are therefore $\eta y_t=0.756m$ and $\eta y_b=1.246m$. The "example box section" is assigned to all 240 lines representing the permanent bridge structure in the model.

Launch nose sections

The supplied .TFM always generates the same four example geometric attributes for the launch nose. Although the nose is typically two I-sections cross-braced, since this is a simple beam model, these may be rationalised to a single I-section. To model the varying stiffness of the nose from the tip to the connection with the bridge, the nose length is divided approximately into quarters and 4 different depths for the I-section used. It was not possible to assign a section which varied in depth over a range of (short) line features when the .TFM was written, although it is possible in LUSAS v14.4 and later; the .TFM has *not* been updated to account for new developments in the software. At the time of writing the .TFM it was thought pragmatic to use 4 sections rather than generate a geometric attribute for each line feature (32 in this example). Each attribute is assigned to 8 line features as appropriate in this example.

Diaphragms

The diaphragm sections are taken into account using lumped mass assigned to point features only and so have no associated geometric attributes.



3D view on model showing box section and launch nose

Material attributes

It is incumbent upon any user who utilises the supplied .TFM for actual bridge designs, to modify the material attributes from those generated automatically to suit the prototype structure.

Concrete (linear elastic)

The supplied .TFM always generates the same example material attribute for the box girder – a homogenous isotropic linear elastic material intended to represent concrete under short-term loading. The analysis is concerned primarily with short-term effects during the launch loads, therefore a short term Young's Modulus for concrete may be deemed appropriate. The example concrete material is assigned to all 240 lines representing the permanent bridge structure.

Steel (linear elastic)

The supplied .TFM always generates the same example material attribute for the launch nose – intended to represent structural steel. The example steel material is assigned to all 32 lines representing the launch nose.

Lumped mass

The supplied .TFM produces a point mass material for the end diaphragms and internal diaphgrams. The end diaphragm mass material is assigned to the point feature directly over the first and last permanent support locations, and the internal diaphragm mass material is assigned to the point features over the other permanent support locations. In the example model, then, the end diaphragm mass material assigned to points 1 and 241; the internal diaphragm mass material is assigned to points 46, 69, 146 and 196.

Support attributes

The assignment of support attributes changes in each and every loadcase (excluding the final loadcase, which is for removal of the launch nose only).

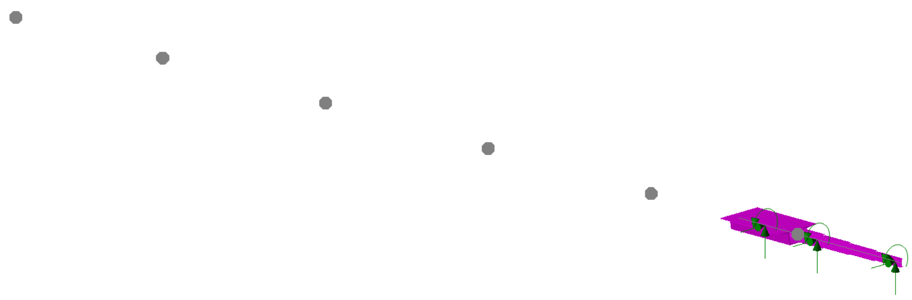
In the first loadcase, the supplied .TFM identifies the valid locations of supports in the casting yard, curing bay and on the bridge for the first bridge segment together with the launch nose. In subsequent loadcases, the location of the supports is moved back by 1m. As further segments are activated (i.e. cast), supports may also be assigned to these sections as appropriate. In each loadcase after loadcase 1 (excepting the final loadcase), the supports from the previous loadcase are eliminated from the present loadcase by the assignment of a “free” support attribute.

Therefore three support attributes are used:

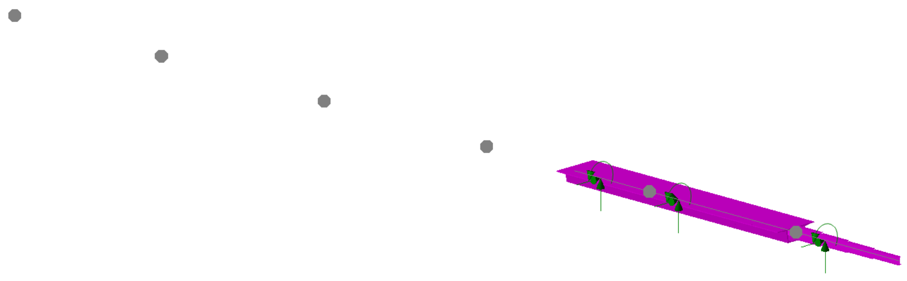
1. Roller support (vertical, lateral and torsional fixity)
2. Point of fixity (vertical, lateral, longitudinal and torsional fixity)
3. Free (no restraints)

The “roller support” attribute is used for all vertical supports except one, where “Point of fixity” is assigned, ensuring numerical stability. The location of this “Point of fixity” is not of importance but the first abutment is used as the reference since it assists the user to be able to identify at a glance the location of the abutment when inspecting loadcases.

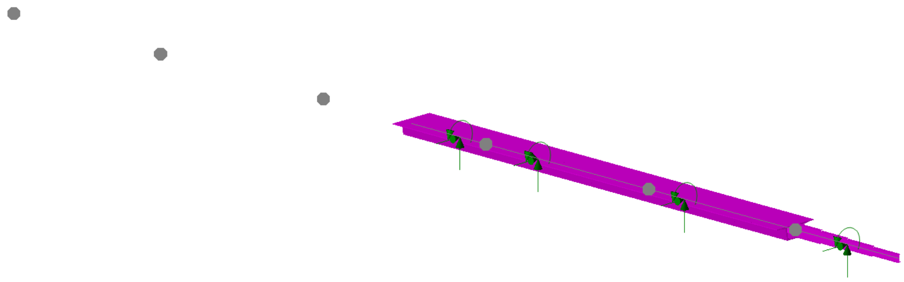
In the instance where the launch nose is too short to reach the first abutment in the first few loadcases, the “point of fixity” is assigned to the last available support location in the x-direction.



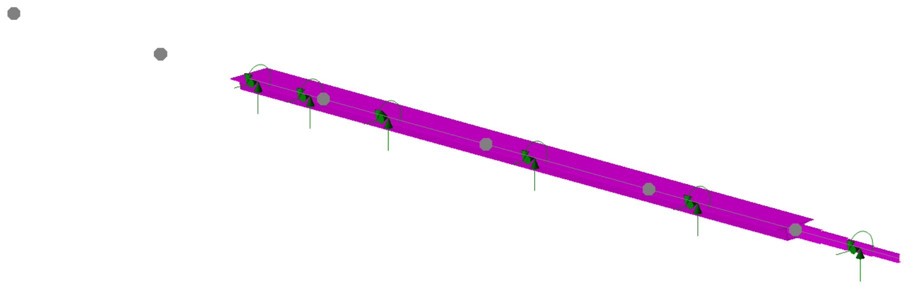
Loadcase 1



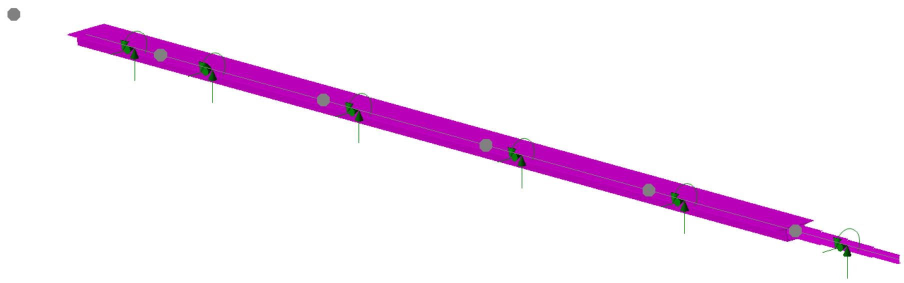
Loadcase 67



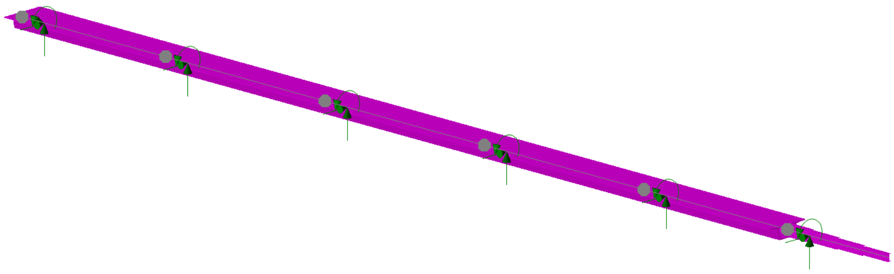
Loadcase 110



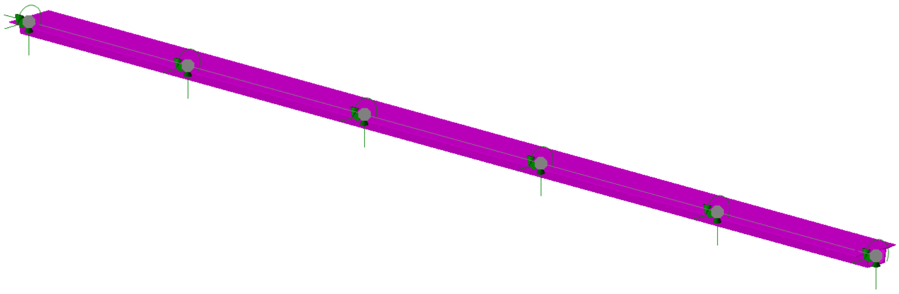
Loadcase 156



Loadcase 210



Loadcase 264



Loadcase 272

Loading attributes

Gravity

The primary load on the bridge during launch is gravity. A constant body force of -9.81m/s² in the Z-direction is used. This is assigned to the line features in the active sections of the bridge and also to the relevant point features with lumped mass (representing the diaphragms), in each loadcase.

Total prescribed displacements

As the bridge is launched, the launch nose deflects, usually by something of the order 100mm. Typically the launch nose is jacked up at each pier to pass over the next set of sliding/ roller bearings (rather than bearings being set low to match the level of the incoming cantilevering launch nose). In order to model this effectively, use a "prescribed displacement" of zero (or =near zero, in fact) is used, together with the support assignment. This ensures that supports are activated in an undeformed location, rather than appearing "just underneath" a deformed (i.e. cantilevering out) launch nose.

The supplied .TFM automatically includes a near zero (1E-15m) total prescribed displacement (TPDSP) for each roller and "point of fixity" support assignment in each loadcase. Each of the actual support location has a dedicated TPDSP, which allows the user to subsequently modify the prescribed displacement to take into account the settlement of supports, mis-casting etc. The dialog box for the supplied .TFM allows the user to set such settlements at the generation of the model if preferred. Settlement (downward) is taken as positive in the dialog box, although it would appear in the total prescribed displacement dialog box as a negative Z-direction displacement.

Prestressing

No prestressing is included in the supplied .TFM. The user would need to add first stage prestress to the launch model, if required, in the appropriate loadcases, in order to obtain a stress build up through the combinations and contouring facilities in LUSAS. Second stage prestress would need to be applied after completion of the launch and could be added to the same model.

Local coordinates

The supplied .TFM uses a local coordinate attribute to orientate 3D beam elements and supports. For straight bridges the local coordinate system is generated as a Cartesian set identical to the global coordinate system. For a curved bridge, the local coordinate system is a cylindrical set positioned at the origin of the horizontal radius, with the local z-axis in the same direction as the global Z.

Activation & deactivation

The features in the model represent the structure in its completed state. In loadcase 1, much of the structure is "deactivated" and in subsequent loadcases segments are activated. The supplied .TFM identifies when a segment has fully left the casting yard, at which point the launch would be stopped to construct the next segment. The segment is activated to model the casting of the next segment (usually on a 7-day cycle) and the launch proceeds.

In the example, segments are activated in loadcases 19, 44, 69, 94, 119, 144, 169, 194 and 219.

In the final loadcase, the launch nose is deactivated.

Nonlinear controls

Technically deactivated elements are not removed from the analysis but are present with a much reduced stiffness (reduced using a factor of 1E-6 by default).

Changes to the stiffness of members (and the other staged construction actions described, like changes to support conditions etc) require updating of the stiffness matrix between stages. Therefore a staged construction analysis is classed as “nonlinear”. Such an analysis might also include other nonlinear behaviours, such as material yielding, P-delta effects or lift-off.

The supplied .TFM requires nonlinear controls as a result of the use of activation and deactivation (no other nonlinearities are included in the model generated). The controls set by the VBScript are for manual incrementation and are stored with Loadcase 1.

Check on nominal loadcases

Before compiling many results and using them in design calculations, it is essential to carry out some checks on the model. The following basic checklist, strictly for linear static analyses, is suggested as a starting point.

1. Reactions.
2. Deformed shape.
3. Magnitude of deformations.
4. Warning or error messages.
5. Mesh refinement.

Reactions

It is advisable to check the reactions you get as this can often identify gross errors early. Many loadcases can be readily calculated by hand and compared using

- **Utilities > Print results wizard** > Entity=Reaction, Type=Summary

The reactions are confirmed for a typical loadcase as below:

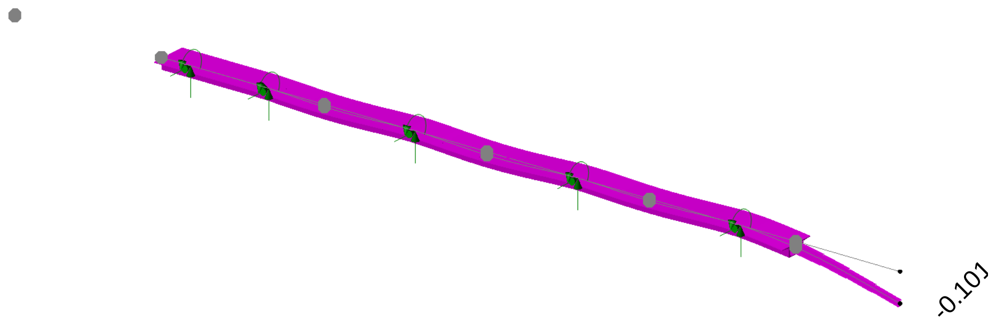
LCID	Description	Hand Calculations (exact)	Expected result (kN)	LUSAS result (kN)
272	Self weight	240×6.072×2.4×9.81=34,310kN 6×50×9.81=2,943kN	37,253	0.3725E+5

Deformed shape

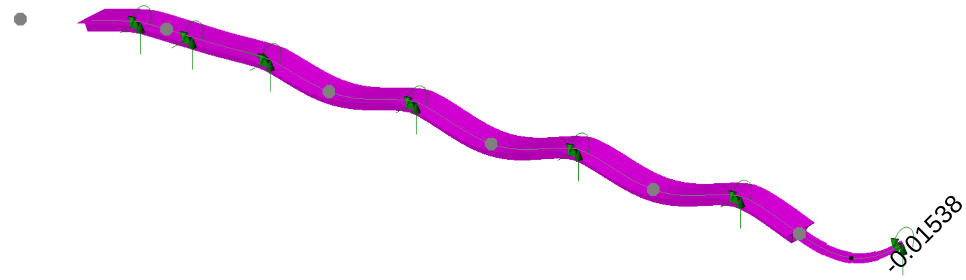
The deformed shape can be compared to the expected shape. The general rule is that “if it looks wrong, it probably is wrong” (although on occasion it may be the expectations rather than the model which requires further scrutiny). The deformed mesh may be obtained using the menu item

- **View > Insert layer > Deformed mesh**

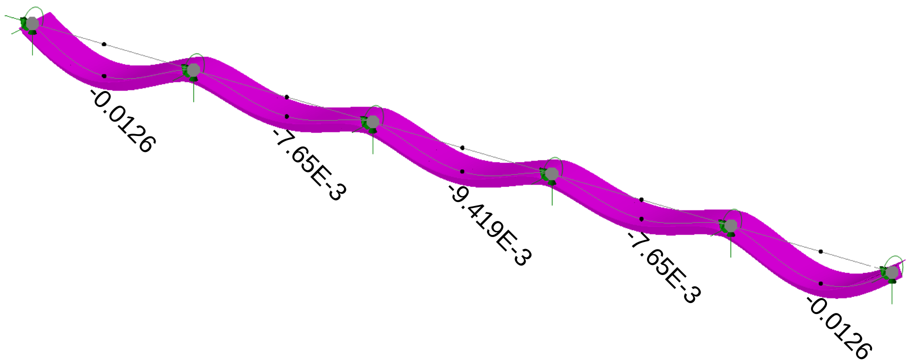
The general shape of the deformed mesh corresponds with the expected shape as illustrated below:



LCID 193: Deformation at maximum cantilever
DZ value at the tip of the launch nose



LCID 194: Deformation with the launch nose jacked up onto the bearings.
DZ value in the sagging portion of the launch nose



LCID 272: Deformation at end of launch with no prestressing applied (with DZ values)

Magnitude of deformations

A broad check on the magnitude of deformations is particularly useful in identifying problems concerning units, material/ geometric properties, or missing supports. Values at selected nodes may be obtained using the menu item:

- **View > Insert layer > Values** > Entity=Displacement, Component = [select] > Values Display tab > (check) Show values of selection

The magnitude of deformations are broadly confirmed for selected loadcases as below:

LCID	Description	Hand Calculations (approximate only) Ref 1 and 5	Expected result (m)	LUSAS result (m)
193	Nose cantilever	Deflection of order 100mm expected	0.1	0.101
272	Permanent	Based on 45m propped cantilever with $W=34,310 \times 45/240=6,433kN$ $d = WL^3/185EI =$ $(6,433 \times 45^3)/(185 \times 34.0E6 \times 9.143) = 0.0128$	0.0102	0.0128

Warning or error messages

The following warning messages occur in the LUSAS Solver text output (*.OUT) file, as reported in the LUSAS Modeller grey text output window:

```
***WARNING*** SUPPORT CONDITIONS FOR NODE        482 HAVE BEEN MODIFIED
(XTSUPP PROCESSOR)
```

```
***WARNING***  LOADS ASSIGNED TO DEACTIVATED ELEMENTS WILL BE REMOVED
(PRACEL PROCESSOR)
```

Neither of these messages are cause for concerns as they both describe intended features of the analysis undertaken

Mesh refinement

A check on mesh refinement is strictly necessary for all FE analyses. A coarse mesh may produce results which are unconservative for design purposes. However, in this case, as described above, BMS3 elements replicate change in load effects along an element sufficiently well that it is deemed unnecessary to consider mesh refinement beyond 1 element per metre in this case.

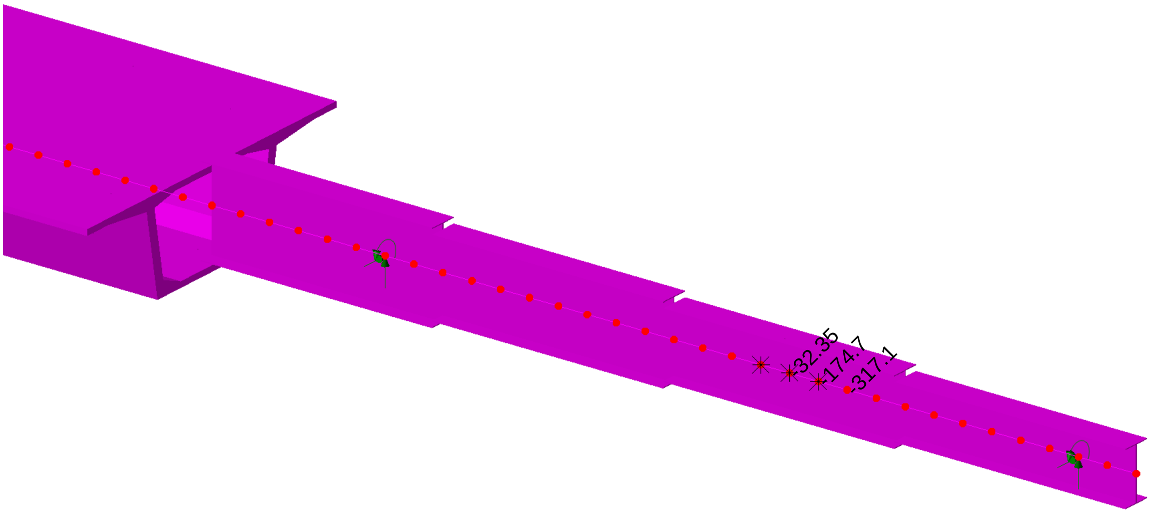
Results

Reactions and uplift

An envelope is created using the menu item:

- Utilities > Envelope

The envelope includes all the loadcases in the result file. By setting the minimum envelope active and requesting an envelope of Reaction (FZ) it is identified that 3 points experience an uplift reaction in this example:



Uplift reaction (FZ, kN) at points 260, 261 and 262

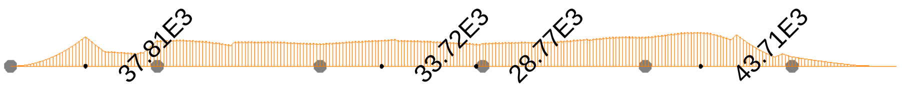
Uplift occurs in loadcases 12, 11 and 10 respectively. As would be expected, this is at the start of the launch, when the light nose is rocked backwards by the weight of the first segment as it leaves the support in the casting yard.

Uplift is generally to be avoided because of instability, however it may be overcome by use of kentledge or by temporary propping through this part of the launch. The launching analysis could be modified to take such measures into account. If supports are de-assigned from the model in order to model the non-presence of holding-down forces at piers in certain loadcases, you should be aware that the associated prescribed displacement attribute needs to be deassigned for the same pier in the same loadcase. Alternatively, the span arrangements in the curing bay and casting yard could be modified and a new launch model generated to suit.

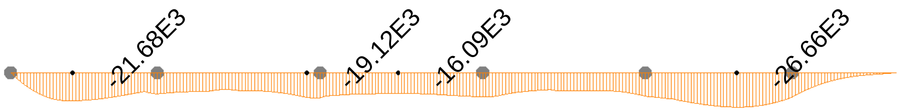
The vertical reactions can be listed in a spreadsheet (.XLS) arranged by loadcase and by pier, using the supplied "**Launch reactions to Excel.vbs**" file (see page 3 for information on running the file and other issues connected with it). The VBS should still deliver the appropriate results with a blank space for the FZ value for the loadcase & pier under consideration when a model has been modified with supports and prescribed displacements de-assigned as described above.

Envelope of moments

For the purpose of this exercise it is assumed that the uplift identified is overcome by use of kentledge, therefore the load effects from the model could be deemed of use in design calculations.



Maximum moments (My, kNm) during launch



Minimum moments (My, kNm) during launch

For the example bridge, the results can be validated against hand calculations as below.

Location	Hand Calculations (approximate only) Ref 1 and 2.	Expected result (kNm)	LUSAS result (kNm)
Main section (hogging)	$-qL^2/12 \pm QL/8$ where q = udl and Q=diaphragm $-qL^2/12=-30.3E3$; $QL/8=3.1E3$	-33.4E3 (-27.2E3)	-33.7E3 (-28.8E3)
Main section (sagging)	$+qL^2/24 \pm QL/8$ $qL^2/24=15.2E3$; $QL/8=3.1E3$	18.3E3 (12.1E3)	19.1E3 (16.1E3)
Front section (hogging)	$-0.105qL^2-0.35QL$ $-0.105qL^2=38.3E3$; $0.35QL=8.6E3$	46.9E3	43.71E3
Front section (sagging)	$0.07qL^2=25.5E3$	25.5E3	26.7E3

Clearly the full model allows the determination of load effects at all locations, including coexistent effects and deformations for which there are no readily available hand formulae.

Support settlements may be incorporated using the supplied .TFM or by modifying the TPDSP (loading) attributes. In such cases an estimate of the expected effect upon hogging moment may be obtained assuming $\Delta M=-kEIW/L^2$, with $3<k<6$ typically.

For a curved bridge, flexural moments generated will be higher due to coupling with torsional effects, ref 6.

Conclusion

A 3D linear elastic beam analysis of a launched box girder bridge may be carried out using LUSAS, expedited by the use of VBScripting. An automation script (TFM) has been used to generate an example model, the results of which have been broadly validated.

The model generated using automation may be modified further. This could include the use of concrete creep materials with viscous nonlinear control and age attributes to effect a full creep model of the launch if required.

It is underlined that the attributes generated by the automation VBScript and the load cases in this example are for illustration only and do not cover all the considerations which might be required for a real design situation.

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