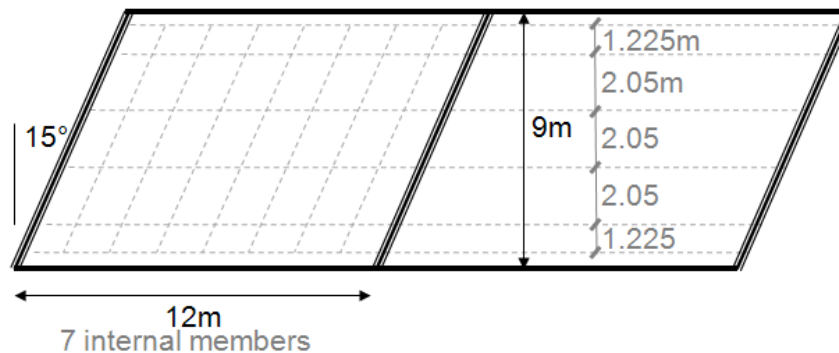


Skew slab as grillage

Summary data



Plan on proposed grillage model

Exercise

1. Build the model using the illustration above and the outline instructions below.
2. Use the basic checklist on page 3. Do you get the correct reaction and deformation?
3. Display diagrams of moment (M_y) under gravity. Can you match the plots on pages 3 and 4?
4. Display values of Wood Armer moments under gravity. Can you match the plots on page 5?
5. Add vehicle loading following the instructions on page 7.

The “Notes on Grillage Model” on page 6 may be of interest.

Building the model

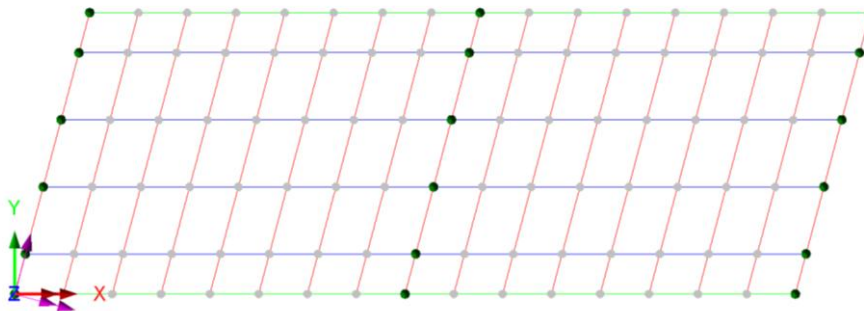
- Units.** Work in kN, m, t, s, C. These are “consistent” units.
- Analysis Category:** 2D Grillage/Plate. This will give you a vertical Z axis.
- Features:** Point and line features generated using **Bridge > Grillage wizard**. See “Spacing of grillage members” below for more information on the dimensions used.
 - Slab deck - Skew angle 15° - transverse members skewed
 - User defined spacing=1.225, 3@2.05, 1.225
 - Number of spans 2, Length of each span=12m, Number of internal transverse beams=7 (spacing 1.5m transversely)
- Mesh attributes:** 2D GRIL elements with 1 division per line (automatically defined and assigned by the wizard).
- Geometric attributes:**
 - Use *Attributes > Geometric > Bridge Deck (Grillage) > Slab* to create 3 sections – Edge, Inner, and Transverse, with the dimensions given in the table below. Use Slab type = Solid and Slab = Uncracked for all. (NB The width for the Edge attribute is

right at the limit of what is expected, so you will get a warning. Click Yes to continue.)

Attribute name	b	t
Edge	0.4	0.75
Inner	2.05	0.75
Transverse	1.5	0.75

- In the *Groups* tab of the Treeview, the wizard has automatically generated some useful groups. Use these to select members and assign the appropriate geometric section (Transverse will need to be applied to both internal transverse members and diaphragm members).

Geometric Key



Plan on grillage model showing geometric assignments

- Material attributes:** A grillage analysis is primarily concerned with transient loads, therefore the short term Young’s Modulus for concrete is used. Concrete Europe EN1992-2 C40/50 assigned to all members.
- Support attributes:** Fixed in translation Z along // (automatically defined and assigned by the wizard).
- Loading attributes and assignments:** from **Bridge > Bridge loading...**

LCID	Description	Type of loading	Parameters	Assignment:
1	Gravity	Bridge > Bridge loading > Gravity	None	Longitudinal members only

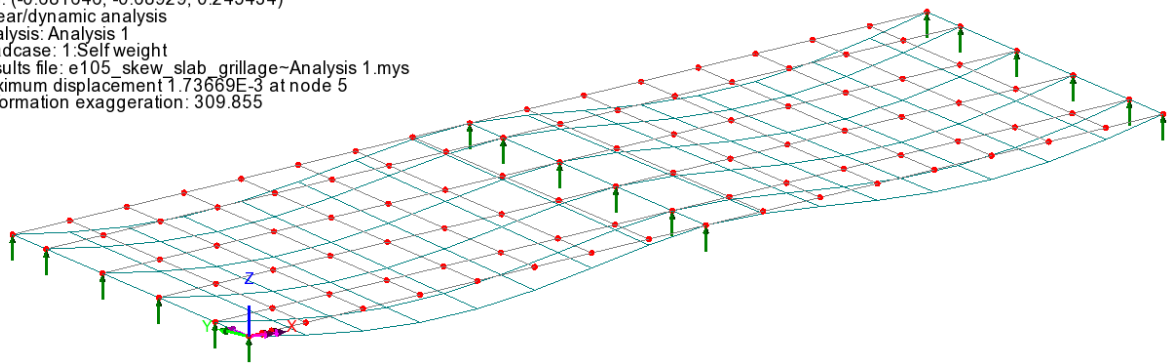
NB We can't use automatic gravity by right-clicking on a loadcase, as that would apply gravity loading to both the longitudinal and transverse members, double-counting the weight of the slab

Solve to get results

NB There appears to be a bug in v20, where it will not solve as no geometric attributes are being written. If this happens to you, go to Tools>Mesh>Mesh Reset. This reset seems to kick Modeller into then writing the geometric attributes properly.

1. Total reaction. $25 \times (12 \times 2) \times 9 \times 0.75 = 4050 \text{ kN}$ Check using *Utilities > Print Results Wizard* [OK]
2. Deformed shape. “If it looks wrong, it probably is wrong”.
3. Magnitude of deformations. Approx 2mm under dead load – sounds reasonable?
4. Warning messages. Number of warnings = 0.
5. Mesh refinement. Not applicable to grillage analyses as described in “Spacing of grillage members” below.

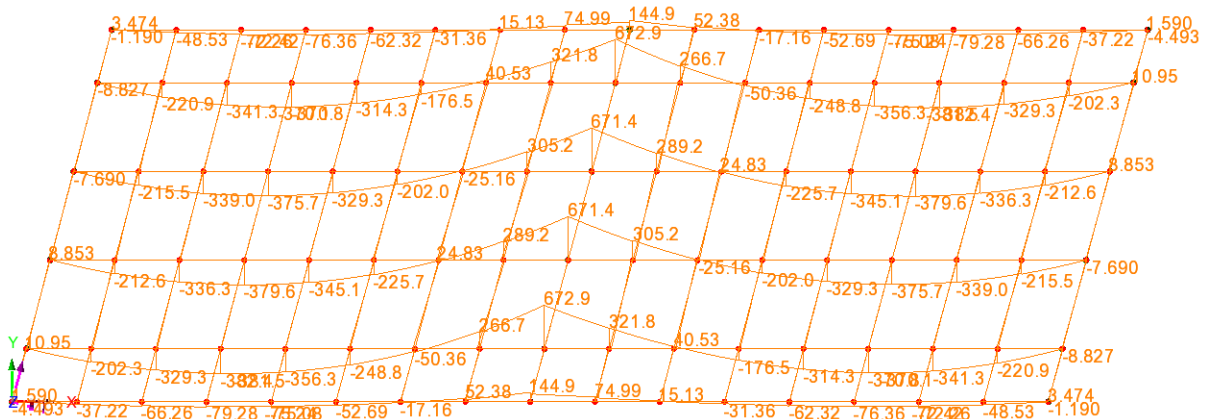
Scale: 1: 89.6869
 Zoom: 108.418
 Eye: (-0.681646, -0.68929, 0.245434)
 Linear/dynamic analysis
 Analysis: Analysis 1
 Loadcase: 1:Self weight
 Results file: e105_skew_slab_grillage-Analysis 1.mys
 Maximum displacement: 1.73669E-3 at node 5
 Deformation exaggeration: 309.855



3D view on model showing deformed mesh

Results

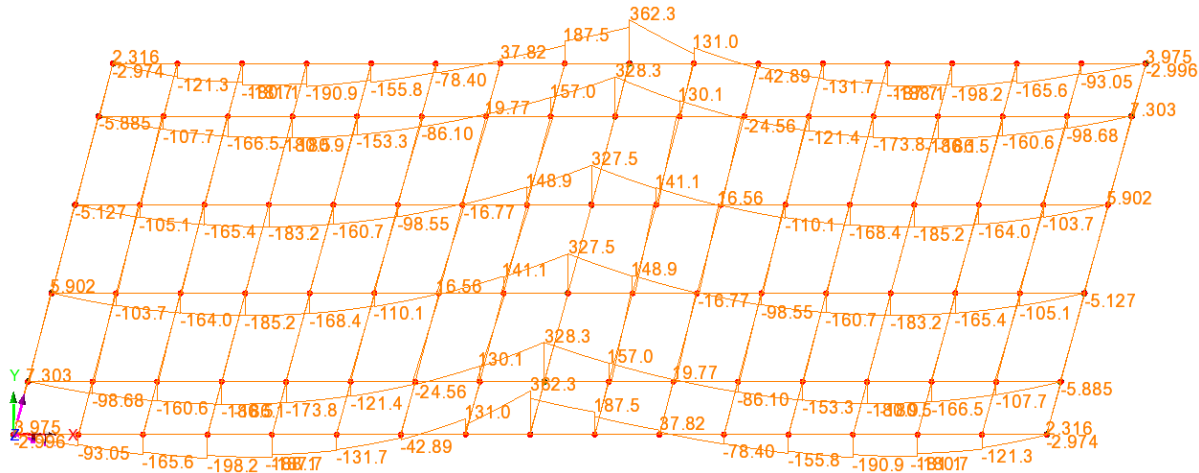
Diagram results



Plan on model showing My flexural moments (kNm per beam)

Note that the results in diagrams are per beam. The moments typically need to be divided by the beam width in order to give a result in kNm/m for design purposes. This can be achieved using the User Defined Results facility:

Utilities > User Defined Results > Entity = Force/moment, Expression = My/Epw, Name = Mcalc



Plan on model showing Mcalc flexural moments (kNm per m width)

The Mcalc results here can be compared with those from a plate model.

Model type	Results	Pier	Span
Plate model (QTF8, element length 2m)	MX (unsmoothed)	327.6	-199.2
Grillage model	Mcalc	362.3 (edge)	-198.2

The results show good agreement, considering that the plate model is mathematically rigorous and has had mesh refinement checked whereas the grillage model is an analogy.

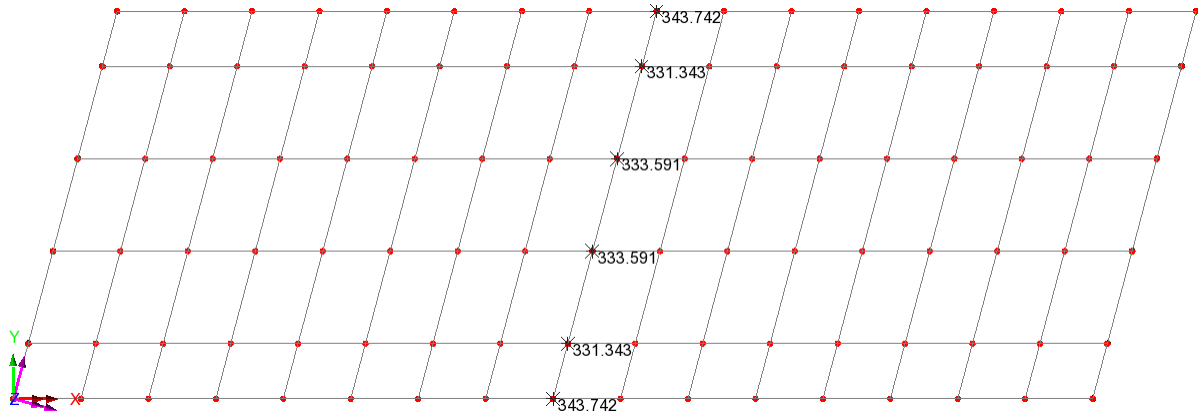
Wood-Armer results

For isotropic slabs, the Wood-Armer equations rationalise the three plate bending components M_x , M_y , M_{xy} to four $[M_x(T), M_y(T), M_x(B), M_y(B)]$ which enable design of reinforcement in the four mats.

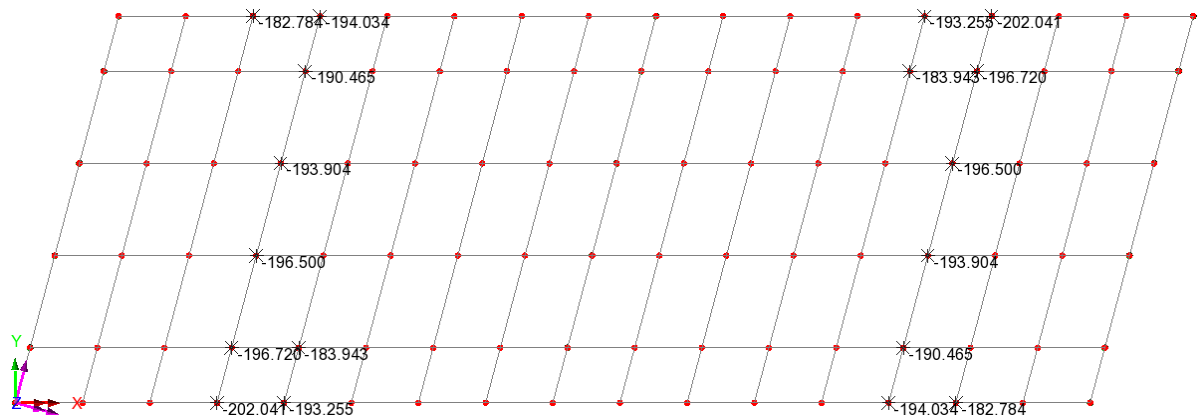
In grillages, plate moments do not exist and so LUSAS converts grillage moments (kNm/beam) and torsion (kNm/beam) first to plate moments (kNm/m) and then applies the same Wood-Armer equations. The results are therefore always given “per unit width” rather than “per beam”, without recourse to User Defined Results.

Attributes > Wood-Armer. Reinforcement angle = 90 degrees. Assign to all points in the model.

As the Wood Armer results are only valid at points, we can't plot them on Diagrams (which are a results entity for lines). Therefore we need to use the Values layer instead to obtain Wood Armer results $[M_x(T), M_y(T), M_x(B), M_y(B)]$ for grillage models.



Values of MX(T) under gravity (LCID1) : kNm/m



Values of MX(B) under gravity (LCID1) : kNm/m

Again the grillage results can be compared with those from a plate model:

Model type	Results	Pier	Span
Plate model (QTF8, element length 2m)	MX(T) contour	336.2	-222.3
	MX(B) contour		
Grillage model	MX(T) values	343.7	-202.0
	MX(B) values		

The results show good agreement, considering that the plate model is mathematically rigorous and has had mesh refinement checked whereas the grillage model is an analogy.

Notes on Grillage model

Spacing of grillage members

The arrangement of grillage members has been selected using the following criteria (ref 1, section 3.5.1, ref 4, section 5.3.7)

- Longitudinal spacing closer than $0.25 \times \text{effective span}$ is essential but closer than $2d$ usually pointless i.e. $1.5\text{m} < \text{spacing} < 2.25\text{m}$
- Longitudinal spacing selected implicitly assumes a width over which bearing support reactions may be reasonably spread. Since strip bearings are used this does not present a criteria in this case
- Edge members should be close to the resultant of the vertical shear flows at the edge of the deck i.e. $0.3d$ for a solid slab – in this case, of order 0.2m from edge of deck
- Orthogonal arrangement of members is always most accurate, unless reinforcement skewed. However for skews up to 20° or 30° , skew arrangement is not significantly inaccurate and more convenient. In this case (skew 15°), use a skew grillage.
- Transverse spacing should be similar to the spacing for longitudinal members for reasonable distribution of loads.

In selecting spacing of members, it should be noted that increasing the refinement of grillages tends to converge on a solution close to, but not the same as, the biaxial bending “exact” solution. However, in some cases, results do not converge at all (ref 3, section 6.3.6). Therefore using the rules set out in references, rather than using a fine grillage, is recommended.

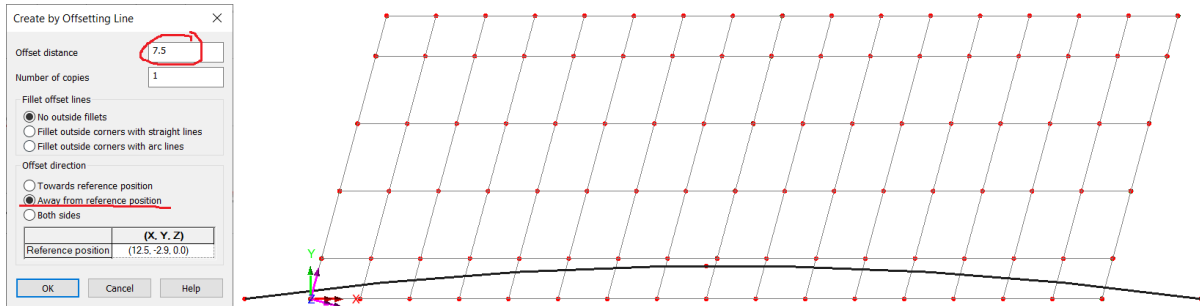
Supports

For high skew or close bearings, compressibility of supports has considerable effect and the model can be readily adjusted to use a spring stiffness rather than a rigid support.

Vehicle loading

First we need to add kerblines – a highway with plan curvature is added as follows:

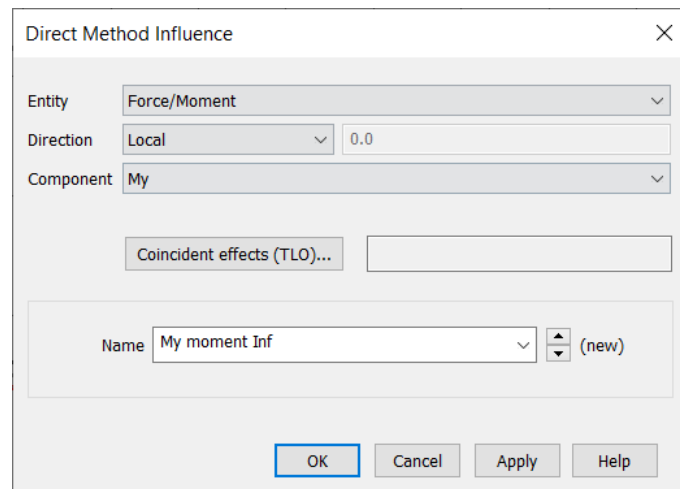
1. Add points at (-2, 0), (12,1) and (27,0). Select the points in order and use Line > Arc... to create the lower kerbline of radius 105.5m
2. Select that line and create a parallel kerbline 7.5m away using geometry > Line > By offsetting as per **Error! Reference source not found.** below.



Second kerb by offsetting

Influence analysis

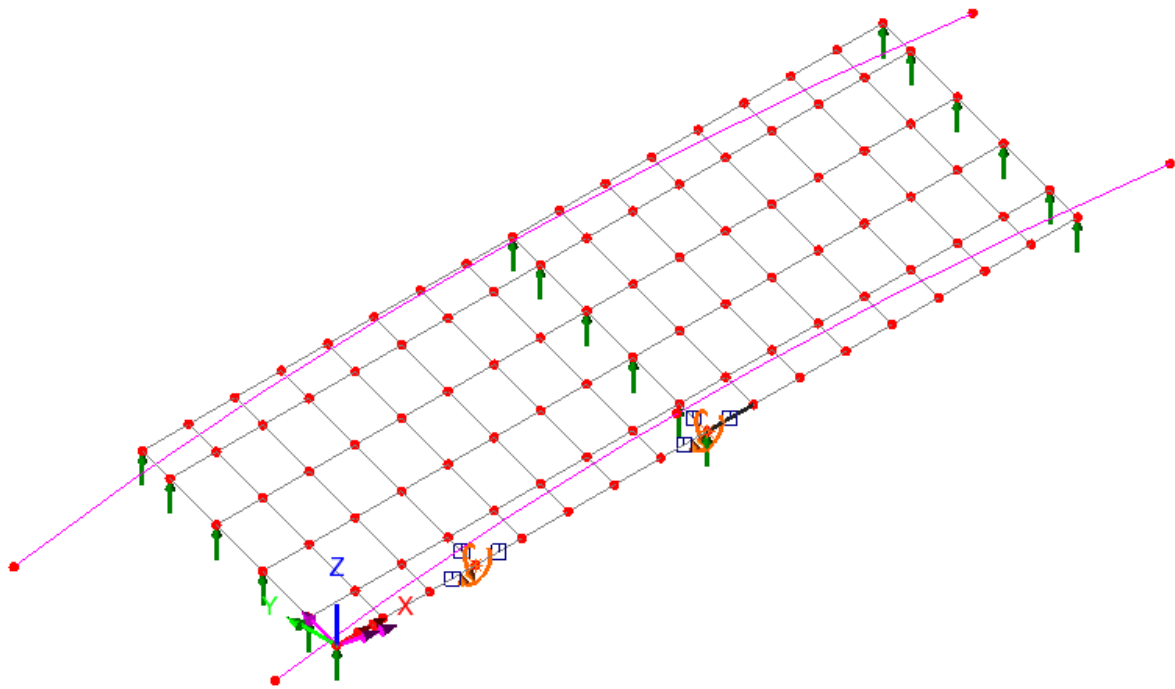
An influence attribute is defined from *Attributes > Influence > Direct Method* as in **Error! Reference source not found.** below.



Direct Method Influence attribute

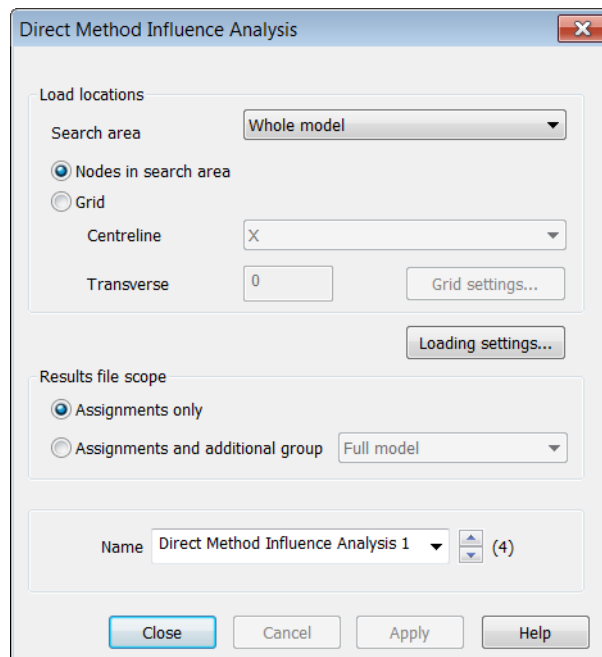
This can be assigned to any number of points or nodes in the model. For this example we will use some sample locations, where we found the largest dead load bending moments:

- An edge beam point at midspan of span 1
- An edge beam point at the central pier



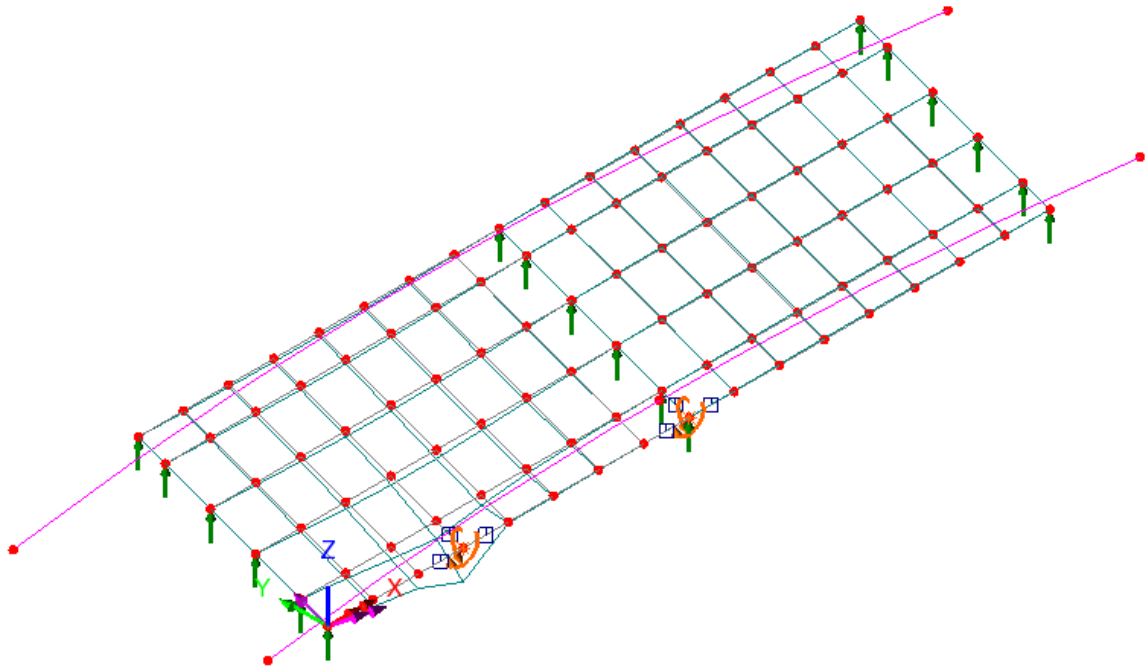
Location of assigned Influence attributes

On the first assignment of a Direct Method Influence (DMI) attribute, the DMI loading grid must be defined as below.

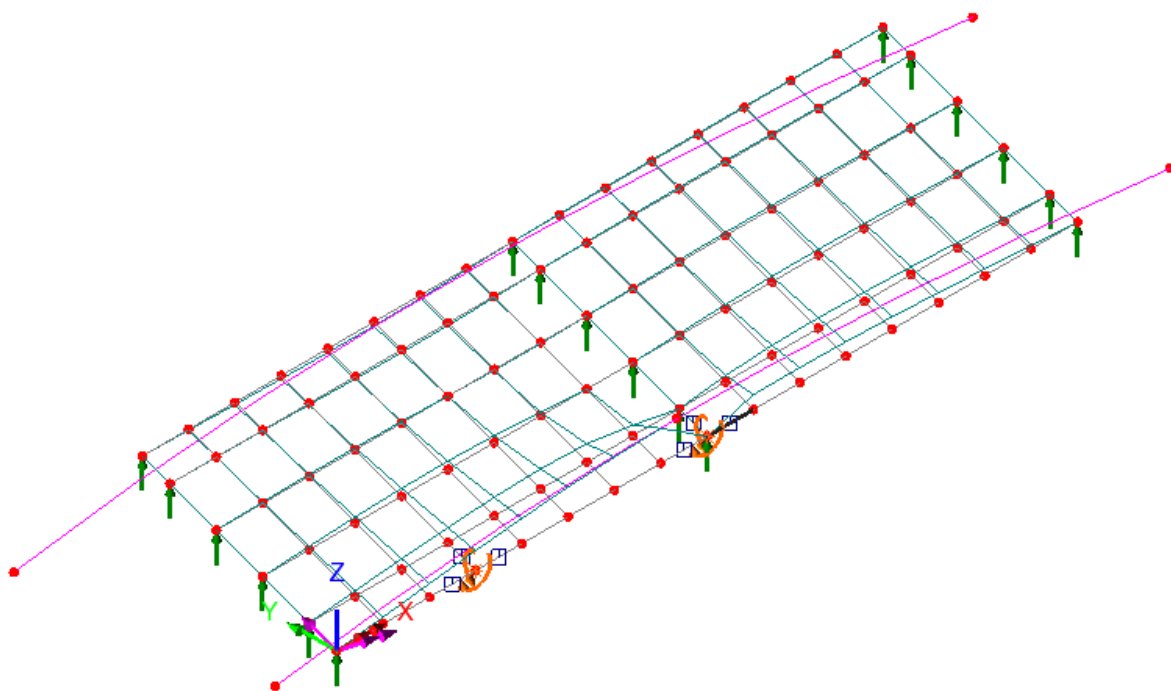


Direct Method Analysis properties dialog

Once the DMI analysis is solved, the influence surfaces can be visualised using the layers tree (deformed mesh is renamed influence shape, so conyours of :



Influence shape for a node near midspan Span 1



Influence shape for a node at the edge of the central pier

Vehicle load optimisation

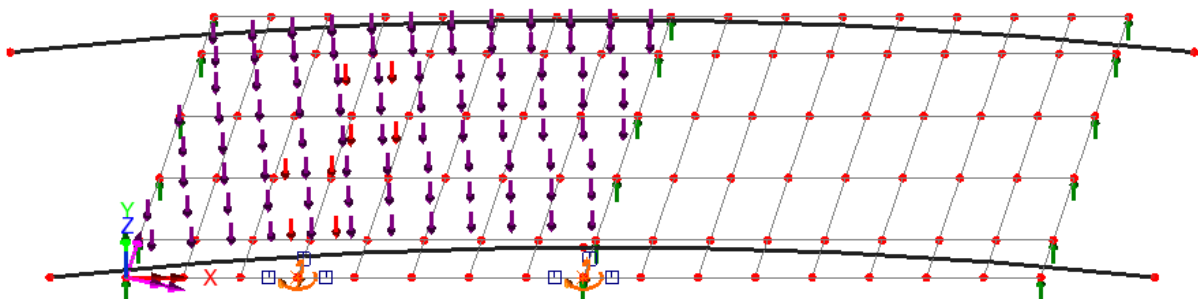
Select kerblines with the mouse.

Use the menu item *Bridge > Vehicle load optimisation > Country = Europe, Design code = EN1991-2 Recommended Values 2009*

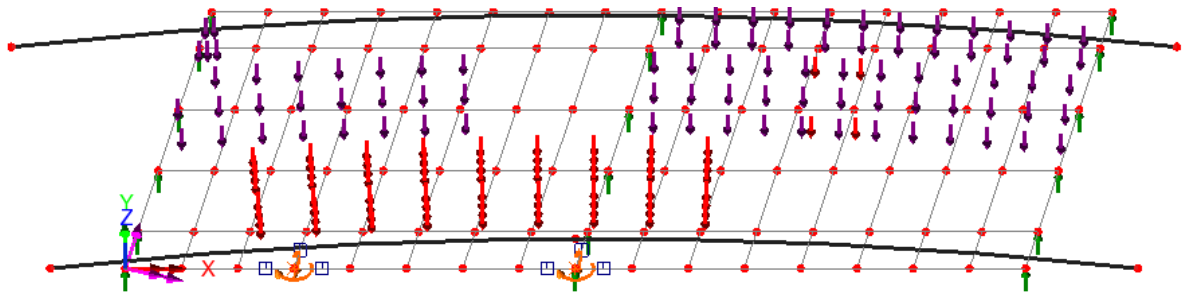
A range of National Annexes are also available for Eurocode, as well as codes for many other countries.

Figure 1: Main VLO dialog

- Click Optional code settings, uncheck Combination, Frequent and Infrequent
- Click Set influence surfaces and choose appropriate influences. The span influence should be loaded Negatively (i.e. for sagging moment); the pier influences should be loaded Positively.
- Click Define carriageways > Apply
- Check to Create loading patterns



Optimised traffic loads for node near midspan on Span 1 – Tandems (in red) and lane load (in purple), plus remaining area load (also purple) moved furthest from the optimised node



Optimised traffic loads for node over pier. SV vehicle displacing lane load/tandem in one lane, remaining area load again moved furthest from node of interest

The My moments from these load patterns can be taken from the tables that are produced. To examine coexistent effects, or to use combinations and loadcases, or to get Wood-Armer results, the VLO loadcases can be solved and treated as normal loadcases.

Links

Quiz

Once you have completed the worked example, please take the Session 1 quiz, accessible from your training index page: https://www.lusas.com/grillage_oct_23/index.html
(https://www.lusas.com/grillage_oct_23/index.html)

Username: **session1**

Password: **LazyDog77##**

Support

If you have any questions or difficulties, please email your trainer: onlinetraining@lusas.com

References

1. Hambly, E C, **Bridge Deck Behaviour**, E&FN Spon, London, 1990
2. The approach described is based on Section 3.5.2 of Hambly, E C, **Bridge Deck Behaviour**, E&FN Spon, London, 1990 but may be code-specific; see clause 4.4.2.1 of BS5400-4:1990, **Code of practice for design of concrete bridges**, British Standards Institution, London, 1990
3. MacLeod, I A, **Modern Structural Analysis: Modelling Process and Guidance**, Thomas Telford, 2005
4. O'Brien, E J, & Keogh, D L, **Bridge Deck Analysis**, E&FN Spon, London, 1999

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