LUSAS

LNG Tank System User Manual

Part 2 - Design Checks

LNG Tank System User Manual (Online) : Part 2 - Design Checks

LUSAS Version 19.1 : Issue 1

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LNG Tank Design Checks

The LNG Tank System carries out design checks to supported design codes for specified load combinations.

Its use requires the **MicroSoft Excel** spreadsheet application to be installed in advance for full functionality as certain applications may use it during the design or reporting process. For example, the Wizard imports the spreadsheet template for design load combinations.

Due to the low temperature of LNG, a thermal analysis requiring solid elements has to be performed and this often causes difficulties for load combinations that are based on structural results when the structural analysis is performed using shell elements. The LNG Tank System imports the temperatures and temperature gradients that are obtained from thermal analysis using solid elements into shell elements, and allows all required load combinations to be assembled in a single model, to enable design check results to be obtained in an efficient way.

This manual focuses on the procedures involved in performing design checks using the LNG Tank System. A separate manual titled 'LNG Tank System: Part 1 - Tank Wizard' provides details of modelling concepts used to build the range of models supported.

User inputs shown in the manual 'LNG Tank System: Part 1 – Tank Wizard' are used in this manual unless otherwise stated.

Base Model

Preparations

User Inputs

Select the menu item LNG Tank >Tank Definition...

| ink Definition | | | | | | | | | |
|------------------------------------|------------------------------|----------------------|-----------|----------------|-----------------------|-----------------|-----------------|--------------|--|
| 🖂 Include pile data | | 🖉 Include insulation | | 🖌 Includ | le seismic data | | | | |
| Structure Definition | Material Properties | Boundary Conditions | Loading | Prestress Load | Pile Arrangement (3D) | Seismic input 1 | Seismic input 2 | | |
| Concrete tank Inst | ulations | | | | | | | | |
| Base slab and R | oof Wall and Ring | beam | | | | | | | |
| -Base slab (Unit | s: m) | | | | | | | | |
| Circular part len | gth (L_inner) | 1 | 39,8 | | 1 | | Linner | Louter | |
| Circular part de | pth (D_inner) | | 1,2 | | • | | | | |
| Tapered section | h length (W_t) | | 0,6 | | Dinner | Distance | | | |
| Annular part len | gth (L_outer) | Ì | 6,7 | | - | Uneating | | Outer | |
| Annular part dep | oth (D_outer) | Ì | 1,5 | | | | | ↔ <u></u> | |
| Base heating (C | _heating) | İ | 0, 386 | | | | | Wt | |
| Roof (Units: m) |) | | | | | | | | |
| Radius of inner | roof (R_roof_i) | [| 86, 406 | | T | | | | |
| Radius of outer | roof (R_roof_o) | Ĩ | 86,906 | | | 1 | | ch | |
| Height from the the roof (R_Hei | top of the base slab ght) | o to the topmost of | 56,254 | | Rroo | Li Rmafa | - | sl2 | |
| Distance of tap | ered section 1 (sl1) | [| 10,079 | | | | | Hringbeam 2 | |
| Distance of tap | ered section 2 (sl2) | Ĩ | 0,6 | | | | | + Rsl_height | |
| Set zero | Set default |] | | | | | | | |
| | | | Name Tok | 1 | | | v i (1) | | |
| | | | - and the | | | | | | |

Fig 1 User Input for Tank Dimension and Loadings

Complete all the inputs, and click **OK** to save the data with the name ' **Tnk1**'.

Reinforcement and Prestress tendon

A Reinforcement and Prestress tendon arrangement is required to build the corresponding model.

The template is available from the folder where LUSAS is installed. For example:

C:\Program Files

(x86)\LUSAS190\Programs\scripts\Tank\Tank_Template_Reinforcement.xlsx.

Copy this file to the current working folder or download the file from the 'Build model for design check' dialog.

Wall reinforcement

The worksheet named 'Wall' is used to define the inner and outer reinforcement arrangement.

A maximum of 15 sets of wall reinforcement (excluding any in Ringbeam) can be defined.

| Inner Face | | | | | | | | | | |
|------------|---------------|-------------------------|-------------------------|---------------------|------------------|--------------------|-----------------|------------------|--------------------|--------------|
| | | | | Rehar | | Hoop Direction | 1 | v | ertical Direction | on |
| Location | Height (m) | Separate Stage (Y/N) | Cover Thickness (mm) | Arrangement Type | Diameter (mm) | Number of Rebar | Spacing (mm) | Diameter (mm) | Number of Rebar | spacing (mm) |
| Lot 0 | 0.30 | N | 60 | A | 28.6 | 1 | 175 | 25.4 | 1 | 175 |
| Lot 1 | 4.2 | Y | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 |
| Lot 2 | 4.2 | Y | 60 | A | 31.8 | 1 | 175 | 25.4 | 1 | 175 |
| Lot 3 | 4.2 | Y | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 |
| Lot 4 | 4.2 | Y | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 |
| Lot 5 | 4.2 | Y | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 |
| Lot 6 | 4.2 | Y | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 |
| Lot 7 | 4.2 | Y | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 |
| Lot 8 | 4.2 | Y | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 |
| Lot 9 | 4.2 | Y | 60 | A | 25.4 | 1 | 175 | 25.4 | 1 | 175 |
| Lot 10 | 4.58 | Y | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 |
| Lot 11 | | Y | | А | | | | | | |
| Lot 12 | | Y | | A | | | | | | |
| Lot 13 | | Y | | А | | | | | | |
| Lot 14 | | Y | | А | | | | | | |
| RingBeam | | Y | 60 | A | 25.4 | 1 | 175 | 25.4 | 1 | 175 |

If not all of the permitted sets are required, the remaining rows can be left empty.

Fig 2 Reinforcement Arrangement for Inner Face of Wall

- **Location** This will be used as the rebar arrangement dataset name in Modeller.
- □ Height : The height of each section where the same rebar arrangement is used. The sum of 'Height' should be equal to the Height of Wall as defined in the Tank Definition.
- □ Separate Stage(Y/N) if set to 'N', the construction stage for the current section will not be created and the section is activated at the previous stage.
- □ Cover thickness The distance from the rebar surface to the nearest concrete face (mm).
- **Rebar Arrangement Type**
 - A Vertical reinforcement is in the inner face of the wall
 - **B** Horizontal reinforcement is in the inner face of the wall



- **Diameter** Diameter of reinforcement (mm).
- □ Number of Rebar Number of bundled reinforcement bars. If bars are not bundled, the value should be 1.
- **Spacing** Centre to centre distance between reinforcement. (mm)

| Outer Face | • | | | | | | | | | | | |
|------------|-----------------|-------------------------|-------------------------|---------------------|------------------|--------------------|-----------------|--------------------|--------------------|--------------|---|-----|
| | | | | Rebar | | Hoop Direction | | Vertical Direction | | | | |
| Location | Height (m) | Separate Stage (Y/N) | Cover Thickness (mm) | Arrangement Type | Diameter (mm) | Number of Rebar | Spacing (mm) | Diameter (mm) | Number of Rebar | spacing (mm) | | |
| Lot 0 | | | 60 | А | 34.8 | 1 | 175 | 31.8 | 2 | 175 | | |
| Lot 1 | | | 60 | A | 25.4 | 1 | 175 | 31.8 | 1 | 175 | | |
| Lot 2 | | | 60 | A | 25.4 | 1 | 175 | 25.4 | 1 | 175 | | |
| Lot 3 | | | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 | | |
| Lot 4 | | | 60 | A | 25.4 | 1 | 175 | 25.4 | 1 | 175 | | |
| Lot 5 | | | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 | | |
| Lot 6 | Come with Inner | Course with James | Come with James | Come with Incom | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 |
| Lot 7 | face | Same with inner | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 | | |
| Lot 8 | lace | lace | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 | | |
| Lot 9 | 1 | | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 | | |
| Lot 10 | | | 60 | А | 25.4 | 1 | 175 | 25.4 | 1 | 175 | | |
| Lot 11 | | | | А | | | | | | | | |
| Lot 12 | | | | A | | | | | | | | |
| Lot 13 | | | | А | | | | | | | | |
| Lot 14 | | | | А | | | | | | | | |
| RingBeam | | | 60 | A | 25.4 | 1 | 175 | 25.4 | 1 | 175 | | |



Rebar Arrangement Type

- A Horizontal reinforcement is in the outer face of the wall
- **B** Vertical reinforcement is in the outer face of the wall.



Slab reinforcement

The worksheet named '**Slab**' is used to define the inner and outer reinforcement arrangement.

- A maximum of two sets of slab reinforcement can be defined: one for the Annular part, the other for the Central Part. Only reinforcement in the radial and circumferential directions is allowed (i.e. no crosswise reinforcement is permitted)
- The Annular Part relates to the outer part of the Slab as illustrated below. (=Louter)



Fig 4 Definition of the Base Slab Annular Part

| Inner Face | (Top Face) | | | | | | | |
|-------------------|-------------------------|---------------------|------------------|--------------------|-----------------|------------------|--------------------|--------------|
| | | Rebar | Circu | mferential Dire | ection | - | Radial Directio | n |
| Location | Cover Thickness (mm) | Arrangement Type | Diameter (mm) | Number of Rebar | Spacing (mm) | Diameter (mm) | Number of Rebar | spacing (mm) |
| Annular Part | 60 | Α | 28.6 | 2 | 175 | 28.6 | 2 | 175 |
| Central Part | 60 | А | 31.8 | 1 | 175 | 31.8 | 1 | 175 |
| | | | | | | | | |
| Outer Face | e (Bottom F | ace) | | | | | | |
| | | Rebar | Circu | mferential Dire | ection | I | Radial Directio | n |
| Location | Cover Thickness (mm) | Arrangement Type | Diameter (mm) | Number of Rebar | Spacing (mm) | Diameter (mm) | Number of Rebar | spacing (mm) |
| Annular part | 150 | Α | 31.8 | 1 | 175 | 31.8 | 2 | 175 |
| Central part | 150 | A | 28.6 | 1 | 175 | 28.6 | 1 | 175 |

Fig 5 Reinforcement Arrangement for Slab

Rebar Arrangement Type

- A Hoop reinforcement is in the upper face of the slab
- **B** Radial reinforcement is in the upper face of the slab



Roof reinforcement

The worksheet named '**Roof'** is used to define the inner and outer reinforcement arrangement.

- A maximum of two sets of slab reinforcement can be defined..
- The Varying Part relates to the outer part of the Roof as illustrated below. (=sl_1 + sl_2)



Fig 6 Definition of Roof Varying Part

| Inner Face | | | | | | | | |
|--------------|-------------------------|---------------------|------------------|--------------------|-----------------|------------------|--------------------|--------------|
| | | Rebar | Circu | mferential Dire | ection | | Radial Directio | n |
| Location | Cover Thickness (mm) | Arrangement Type | Diameter (mm) | Number of Rebar | Spacing (mm) | Diameter (mm) | Number of Rebar | spacing (mm) |
| Varying Part | 50 | Α | 28.6 | 1 | 175 | 31.8 | 1 | 175 |
| Central Part | 50 | A | 25.4 | 1 | 175 | 25.4 | 1 | 175 |
| | | | | | | | | |
| Outer Face | | | | | | | | |
| | | Rebar | Circu | mferential Dire | ection | | Radial Directio | n |
| Location | Cover Thickness (mm) | Arrangement Type | Diameter (mm) | Number of Rebar | Spacing (mm) | Diameter (mm) | Number of Rebar | spacing (mm) |
| Varying Part | 60 | A | 28.6 | 1 | 175 | 31.8 | 1 | 175 |
| Central Part | 60 | A | 28.6 | 1 | 175 | 28.6 | 1 | 175 |

Fig 7 Reinforcement Arrangement for Roof

Rebar Arrangement Type

- A Hoop reinforcement is in the upper face of the roof
- \mathbf{B} Radial reinforcement is in the upper face of the roof



Prestress Tendon

The worksheet named '**PreStress**' is used to define the Tendon arrangement for the wall and slab.

- A maximum of 15 sets of tendon arrangements (excluding any in Ringbeam) can be defined.
- If not all of the permitted sets are required, the remaining rows can be left empty.
- The cover thickness to be stated is the distance from the <u>outer surface to the</u> <u>tendon surface</u>.
- Fse, the effective stress in prestressing reinforcement for the base slab, applies to the annular part only.

| Wall | | | | | | | | | |
|----------|----------------------------|------------------|-----------------|--------------|----------------------------|------------------|--------------|--------------|---------------|
| | | Hoop D | irection | | | Vertical | Direction | | Ноор |
| Location | Cover Thickness (mm) | Diameter (mm) | Spacing (mm) | fse (MPa) | Cover Thickness (mm) | Diameter (mm) | spacing (mm) | fse (MPa) | No tendons |
| Lot 0 | 600 | 1.00E-03 | 1000 | 1 | 600 | 69.05 | 1262 | 1005 | |
| Lot 1 | 545 | 69.05 | 600 | 1005 | 545 | 69.05 | 1262 | 1005 | 7 |
| Lot 2 | 421 | 69.05 | 525 | 1005 | 421 | 69.05 | 1262 | 1005 | 8 |
| Lot 3 | 375 | 69.05 | 525 | 1005 | 375 | 69.05 | 1262 | 1005 | 8 |
| Lot 4 | 375 | 69.05 | 600 | 1005 | 375 | 69.05 | 1262 | 1005 | 7 |
| Lot 5 | 375 | 69.05 | 840 | 1005 | 375 | 69.05 | 1262 | 1005 | 5 |
| Lot 6 | 375 | 69.05 | 840 | 1005 | 375 | 69.05 | 1262 | 1005 | 5 |
| Lot 7 | 375 | 69.05 | 1050 | 1005 | 375 | 69.05 | 1262 | 1005 | 4 |
| Lot 8 | 375 | 69.05 | 1050 | 1005 | 375 | 69.05 | 1262 | 1005 | 4 |
| Lot 9 | 375 | 69.05 | 1050 | 1005 | 375 | 69.05 | 1262 | 1005 | 4 |
| Lot 10 | 375 | 69.05 | 1145 | 1005 | 375 | 69.05 | 1262 | 1005 | 4 |
| Lot 11 | | | | | | | | | |
| Lot 12 | | | | | | | | | |
| Lot 13 | | | | | | | | | |
| Lot 14 | | | | | | | | | |
| RingBeam | 700 | 69.05 | 680 | 1005 | 700 | 69.05 | 1262 | 1005 | 5 |



Fig 8 Prestress Tendon arrangement for Wall and Base Slab

Build Base Model

The Base Model for a design check can be built by selecting the menu item **LNG Tank> Tank Definition...**

| LNG Tank - Base Model for Design Cheo | :k | | | × |
|---------------------------------------|-----------------------|-------------------------|---------------------------------|---|
| Tank definition data | Tnk1 | | ~ | |
| Model filename | Example | | Half only model | |
| Excel for rebar arrangement | C:₩SVN₩Versions₩LUSAS | V19₩Templates₩Tank_1 | Templa Browse Template Download | |
| Saved model file path | C:\Users\ohsso\Docume | ents₩LUSAS190₩Projects* | ₩Exar | |
| Element size (m) | 2.5 | | Roof ratio for 1st build 0.5 | |
| Wind load (EN1991, 1, 4, 2005) | | | Buttress | |
| Basic wind velocity | 37,5 | (m/s) | Number of buttress 0 🗸 | |
| Roughness length | 3,0E-3 | (m) | Extruded thickness 1.0 (m) | |
| Minimum height | 1,0 | (m) | | |
| Orography factor | 1,0 | | Buttress width 5,0 (m) | |
| Terrain factor | 0,156 | | Eigenvalue | |
| Turbulence factor | 1,0 | | Number of eigenvalue 10 | |
| Air density | 1,25 | (kg/m^3) | | |
| Soil height above slab bottom | 0.9 | (m) | 🗹 Include non-structural masses | |
| | | | OK Cancel Help | |

Fig 9 LNG Tank for Base Model for Design Check

- □ The spreadsheet for the reinforcement arrangement should be selected.
- □ Number of buttresses is set to 0.
- □ Roof ratio for 1st build is set to 0.5. The roof thickness for 1st build will vary according to this value in the staged construction analysis model. The 1st Prestress amount for Ringbeam will also vary at the 'Ringbeam 1st PS stage' in staged construction analysis model.

The model built is shown below.



Fig 10 Base Model for Design Check

Reinforcement arrangement

The Reinforcement arrangement is saved as a Wood-Armer attribute in Modeller.

- □ Hoop Roof reinforcement is defined as **Bar in X**, and *radial reinforcement* as *Bar in Y*.
- □ Horizontal Wall reinforcement is defined as **Bar** in **X**, and *vertical reinforcement* as *Bar* in *Y*.
- □ Radial Slab reinforcement is defined as Bar in X, and *hoop reinforcement* as *Bar in Y*.
- □ Inner face reinforcement is defined at Top Face, and *outer face* at *Bottom Face*. The local z axis of the shell elements is orientated toward the inner direction in the model, hence the bottom face is equivalent to outer surface of wall.

For **bundled reinforcement**, the spacing is defined by **Spacing / Number of rebar**. Note that this may affect the crack width, therefore care should be taken. Alternatively, an equivalent diameter of bundled reinforcement with the Number of rebar set to 1 could be appropriate.

The table that follows shows the reinforcement for Wall Lot 1. Note that all references to 'Lot1', 'Lot 2' etc. relate to 'segments or regions of a wall with a specific reinforcement arrangement'.

Rebar Arrangement Type of **A** for the Wall means that the vertical reinforcement is on the inner face, therefore the Bar in Y is located in Layer 1.



Fig 11 Reinforcement Arrangement for Wall Lot 1

Tendon Arrangement

The Tendon arrangement is also saved as a Wood-Armer/RC Slab attribute. However this cannot be seen in Modeller. <u>Note that because of this, if the reinforcement</u> information is updated from Modeller directly, tendon information will be lost.

Analyses

Six analyses having a total of 95 loadcases are set-up in the model.

- **Base Analysis** A static analysis. A total of 30 loadcases are provided including 5 for user-defined loading.
- □ Thermal Analysis The result of a separate thermal analysis is to be imported here.
- □ Seismic Analysis Equivalent peak seismic acceleration and hydrodynamic loading are to be added.
- □ Staged Construction Analysis 29 construction stages are defined with self weight only.
- □ CRSH Analysis As for Staged Construction Analysis, combinations have been added to consider the pure effect from Creep and Shrinkage alone. This is

obtained by subtracting the results in Analysis 5 (including CRSH) and the results in Analysis 4 (not considering CRSH).

Eigenvalue Analysis To obtain Eigenvalue results



Fig 12 Analyses Available in Base Model

Roof element layers

The roof is built in two layers. Hence, two sets of overlapping surfaces have been created to consider the staged construction. As only the final layer is required for the other analyses, one set of surfaces is deactivated for the 1st loadcase of Base Analysis, Thermal Analysis, Seismic Analysis, and Eigenvalue analysis.

Loadings

Self weight is assigned in all analyses.

- In the Base Analysis, 30 loadcases are provided, including 5 for user-defined loading.
- In the other analyses (with the exception of the self weight) loading is not yet assigned.

Base Load Combinations

As seen in [Fig 12], 10 load combinations are pre-defined. These combinations are used to obtain the isolated effect of adding loading from a Staged Construction Analysis, so that they can be used as a single loadcase in the design load combination.

A staged construction analysis is nonlinear by definition and hence the principle of superposition is not generally applicable. However, this simplified approach provides a systematic and efficient way of verifying hundreds of load combinations in the context of linear design according to a code of practice.

For example, the load combination of '**WO Roof 1**st **PS ONLY**' is for the subtraction of 'Wall Ringbeam[Staged]' from 'Ringbeam 1st PS[Staged]'.

- 1) Wall Ringbeam[Staged] : Wall & Ringbeam is built. (i.e. no roof)
- 2) RingBeam 1st PS[Staged] : Wall & Ringbeam is built. (i.e. no roof). 1st PS is added.

Both loadcases are included in the Staged Construction Analysis, and the combination of 2)-1) is used to obtain the effect of the 1st PS loading during the construction stage.

| Analyses 💌 🗘 🗙 | LUSAS View: Example(CodeChecking).mdl Window 1 x | |
|-------------------------------------------------------------------|--------------------------------------------------------|-----|
| Layers SGroups & Attrib Q Analy / Utiliti Repo | Combination | × |
| Carl Structural analysis Carl Carl Carl Carl Carl Carl Carl C | Method Factored ~ | |
| Go Sciance Analysis Go Sciance Analysis | Available inflooded | |
| | U Umage Pact Post Processing | 2 |
| L- 🍓 Model properties | Name WO Roof Base PS ONLY | |
| | Close Cancel Apply H | elp |

Fig 13 Pre-defined Load Combinations - WO Roof 1st PS only

Template for load combinations

A template for use in defining design load combinations is saved in the current working folder with name of the form: **<Model name>_ComboTemplate.xlsx**.

Update Reinforcement and Prestress

If the reinforcement or prestress tendon arrangement needs to be changed after the model is built, it can be updated by selecting the menu item **LNG Tank > Update Reinforcement...**

This only updates the existing properties. If the attribute is to be deassigned or deleted, it should be done manually.

If one-side only rebar is required, use a negligible value for Es. (e.g. a very small value

Thermal Analysis

Thermal analysis that requires the evaluation of heat transfer through thickness cannot be performed with shell elements, so a thermal analysis using 2D axisymmetric solid elements is required instead.

Thermal Analysis for Max Environmental Temperature

Select the **LNG Tank > Thermal Analysis...** menu item, and assuming the default inputs are for maximum temperature, perform a 2D Thermal Analysis with the input data of **'Tnk1 – Max Temperature**'

• Enter **Example - Max** for the model file name, and click **OK**.

| LNG Tank - Thermal Analysis | | Х |
|-----------------------------------|---------------------------------------------|---|
| | | |
| Tank definition data | Tnk1 - Max Temperature 🗸 🗸 | |
| Model filename | Example - Max | |
| Saved model file path | C:₩Users₩ohsso₩Documents₩LUSAS190₩Projects' | |
| Element size (m) | 0.2 | |
| 🖂 Include soil | | |
| Soil height above slab bottom (m) | 0,9 | |
| Soil depth (m) | 25.0 | |
| | OK Cancel Help | |

Fig 14 Dialog for Thermal Analysis (Max)

The current shell model will be closed and a new 2D axisymmetric solid model suitable for thermal analysis will be built.

| LUSAS Bridge Plus - Example_Max_Th | hermal.mdl | | - 🗆 × |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| <u>File Edit View G</u> eometry <u>A</u> ttribut | tes Analyse <u>s U</u> tilities <u>T</u> ools | <u>B</u> ridge <u>D</u> esign <u>L</u> NG Tank <u>W</u> indow <u>H</u> elp | |
| 🗈 📽 🖬 📽 🚍 🖻 🛍 X 🖻 | ೧-೧- ೧ ೦- /- | ⊐•@• ⊠ m⊢∆ ≸• *↓• ∻‰⊛•∅ ◣•₭• | 🕫 🚾 Kỹ Kỷ 👔 🗄 🔛 🛄 |
| Analyses | ▼ # × L | JSAS View: Example_Max_Thermal.mdl Window 1 x | |
| Course and residence in the second seco | A Willie List Report 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | . 49.0 . 49.0 . 29.0 . 0.0 . 20.0 . Analysis Analysis 1 (Thermal) Loadcase: 30.0 preating Condition(Thermal), 3: Time Step 2 Time = 0.1 Results 1/e: Example Max, Thermal-Analysis 1 (Thermal).mys Response time: 100 0E6 Entity Potential Component PHI (Units: C) - 130, 3996 - 130, 3996 - 430, 4995 - 430, 49 | 449 . 660 . 840 . 1899 . 1290 D0000E+09 |
| Text Output | | | |
| Viting coupling data Viting output control low Viting analysis control low Viting analysis control low Tabulation of datafile "C:WJ USAS Solver returned exit of Scenning LUSAS Solver output Viti | adcase 1 adcase 4 sers'ohsso/Documents/Lt ode 0 file "Example Max They HDAT TEMPERATHERS WITT | sas190-Frojects'Associated | |
| e | | | la exercita de service la sua |

Fig 15 Thermal Analysis for Max Environmental Temperature

- Solve the model, and in the Analyses 🕀 treeview, set the loadcase **Operating Condition** (**Thermal**) active.
- The Equivalent Uniform Temperature and Linear Temperature Gradient through thickness can be computed and saved in a spreadsheet by selecting the menu item LNG Tank > Export Temperatures to Excel (2D)...

| LNG Tank - Export Temperature | s to Excel (2D) X |
|-------------------------------|----------------------------------------------------|
| Output filename | ThermalResult-Max |
| Working folder | Current O User Defined |
| Save in | C:₩Users₩ohsso₩Documents₩Lusas190₩Projects₩Thermal |
| | OK Cancel Help |

Fig 16 Extraction Thermal Max Results

In the current working folder, the file **ThermalResult-Max.xlsx** containing the extracted results for Roof/Slab/Wall is created.

| > 내 PC > 문서 > Lusas190 > Projects | |
|--------------------------------------|--|
| 이름 | |
| ThermalResults_Max(Temperature).xlsx | |
| 🚼 Example - Min_Thermal_Thermal.mdl | |
| ThermalResult-Min(Temperature).xlsx | |
| 🛃 Example - Max_Thermal.mdl | |
| | |

| Temperature o | of Roof | | | |
|---------------|------------|---------------------|----------------------|-----------------------|
| Туре | Tempe | erature | | |
| Location | Ro | oof | | |
| Unit | Cels | sius | | |
| | | | | |
| No of Slices | Gap (m) | Outer Radius (m) | Rad. Origin Y (m) | Min. Thickness (m) |
| 90.00 | 0.50 | 86.91 | -30.65 | 0.50 |
| | | | | |
| Distance | Inner Temp | Outer Temp | Thickness | Average Temp |
| (m) | (°C) | (°C) | (m) | (°C) |
| 0.00 | 23.89 | 25.33 | 0.50 | 24.52 |
| 0.50 | 23.61 | 25.33 | 0.50 | 24.47 |
| 1.00 | 23.62 | 25.33 | 0.50 | 24.47 |
| 1.50 | 23.60 | 25.32 | 0.50 | 24.47 |
| 2.00 | 23.61 | 25.33 | 0.50 | 24.47 |

Fig 17 Extracted Thermal Results in a Spreadsheet

Thermal Analysis for Min Environmental Temperature

To perform additional thermal analyses for a minimum environment temperature, reselect the menu item **LNG Tank >Tank Definition...**

| I poludo pilo doto | 🗔 looludo in | oulation | 🖂 laaluda a | olomia data | | | |
|------------------------------|------------------------|----------------------------------------|--------------------------------------------|-------------------------------------------------------------|--------------------------|----------------|--|
| Include plie data | | isulation (E | | ersmic data | | | |
| ructure Definition Material | Properties Bound | lary Conditions | Loading Prestre | ess Load Pile Arrangement (3 | D) Seismic input 1 S | eismic input 2 | |
| tructural Dead Loading Str | uctural Variable Lo | ading Thermal L | Loading | | | | |
| Loading Type | Spillage Height (m) | Temperature (C) | Convective Coefficient (J/m^2,s,C) | Type of boundary Descrip | tion | | |
| iquid Temperature | 0,0 | -170,0 | 0,0 | Convection 🛛 🗠 Liquid T | emperature | | |
| xternal Temperature | 0.0 | 10 | 25,0 | Convection <pre> </pre> Convection External | Temperature | | |
| ase Heating | 0,0 | 5,0 | 0,0 | Prescribed 🛛 🗠 Base He | ating | | |
| itial Temperature (Soil) | 0,0 | 10 | 0.0 | Prescribed 🛛 🗠 Initial Te | mperature of Soil | | |
| itial Temperature (Structure |) 0,0 | 15,1 | 0,0 | Prescribed V Initial Te | mperature of Structure | | |
| | | | | | | | |
| | | | | | | | |
| Set zero Set defaul | s + If ter Other | nperature for bas rwise base heatin | se heating is defin ng will not be cons | ed as other than zero, it will b idered in the analysis, | e considered in the anal | ysis, | |

Fig 18 User Input for Min Environmental Temperature

- Enter **10** (Celsius) for both the **External Temperature** and the **Initial Temperature** (Soil). The **Initial Temperature** (Structure) is the temperature at the time when concrete is poured, hence there is no need to change at the moment.
- Save these inputs with name 'Tnk2-Min Temperature'.
- Select the menu item LNG Tank > Thermal Analysis... and enter Example Min for the model file name, then click OK.

| LNG Tank - Thermal Analysis | | × |
|-----------------------------------|------------------------|---|
| Tank definition data | Tnk2 - Min Temperature | |
| Model filename | Example - Min | |
| Saved model file path | C:\Users\operatory | |
| Element size (m) | 0.2 | |
| 🖂 Include soil | | |
| Soil height above slab bottom (m) | 0,9 | |
| Soil depth (m) | 25,0 | |
| | OK Cancel Help | |

Fig 19 Dialog for Thermal Analysis (Min)

- Solve the model, and in the Analyses 🕀 treeview, set the loadcase **Operating Condition** (**Thermal**) active.
- Export results into a spreadsheet by selecting the menu item LNG Tank > Export Temperatures to Excel (2D)...

| LNG Tank - Export Temperatures to Excel (2 | 2D) | \times |
|--------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| Output filename | ThermalResult-Min | |
| Save in | C:\Users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\users\usersung\users\users\users\users\users\usersu | |
| | OK Cancel Help | |

Fig 20 Extraction Thermal Min Results

Update Base Model

The thermal analysis results can be converted to 3D loading for load combinations.

- Close the thermal model, and open the shell model of 'Example(CodeChecking).mdl'.
- Select the menu item LNG Tank > Add Thermal Loading... then select the spreadsheets for thermal analysis results and click OK.

| LNG Tank - Add Thermal Loading | | × |
|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
| Maximum temperature | C:\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users\Users | Browse |
| Minimum temperature | $\fbox{C:} wusers wohsso work to current to the set of the$ | Browse |
| The result of thermal analysis is Import the spreadsheet created b | converted into equivalent structural loading in 3D shell model, y [Extract 2D Temperatures to Excel] menu, | |
| | 0K Cancel | Help |

Fig 21 Dialog for Adding Thermal Loading

The thermal analyses results are converted into equivalent structural temperature loadings in the 3D shell model.



Fig 22 Temperature Loading from Thermal Analyses

Seismic Analysis

Preparation

A seismic analysis considering fluid-soil-structure interaction under seismic action should be carried out prior to the 3D shell model investigation. The inertial and hydrodynamic peak effects obtained from a seismic analysis can be transformed to equivalent static loading for a 3D model in the form of accelerations that will act on the structural masses and other structural loadings.

Update Base Model

Both OBE and SSE loadings can be defined by selecting the menu item LNG Tank > Add Seismic Loading...

| OBE | SSE | |
|---------|------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4.0 | 8,0 | m/s^2 |
| 2,5 | 5,0 | m/s^2 |
| 2,0 | 4,0 | m/s^2 |
| 250,0E3 | 500, 0E3 | kN |
| 500,0E3 | 960, 0E3 | kN-m |
| 50,0E3 | 60,0E3 | kN-m |
| | | |
| OBE | SSE | |
| 3,0 | 6,0 | m/s^2 |
| 1.5 | 3,0 | m/s^2 |
| 1.5 | 3.0 | m/s^2 |
| | | |
| 1,5 | 3,0 | m/s^2 |
| | OBE 4.0 2.5 2.0 250.0E3 500.0E3 500.0E3 50.0E3 0BE 3.0 1.5 | OBE SSE 4.0 8.0 2.5 5.0 2.0 4.0 250.0E3 500.0E3 500.0E3 960.0E3 50.0E3 60.0E3 50.0E3 60.0E3 50.0E3 60.0E3 50.0E3 50.0E3 50.0E3 50.0E3 |

Fig 23 Dialog for Adding Seismic Loadings

Horizontal Loadings

Based on the given inputs, the loadings are defined as shown below. The acceleration loadings are directly used for defining Body Force loading in Modeller, and the other loadings are converted to equivalent structural loadings.



Fig 24 Horizontal Seismic Loading for Roof (SSE)



Fig 25 Horizontal Seismic Loading for Wall (SSE)



Fig 26 Horizontal Seismic Loading for Base Slab (SSE)



Fig 27 Horizontal Seismic Loading of Liquid Force (SSE)

- □ The force of the liquid is transferred to the Base Slab through the inner tank, so the loading is applied at the location of the inner tank wall.
- □ The total force defined from user input is 500E3 kN in the global X direction, however the pressure of the liquid acts perpendicular to the inner tank wall surface with an intensity following a cosine variation.
- □ A cylindrical local coordinate system is applied to the lines to ensure loading is in a radial direction.



Fig 28 Horizontal Seismic Loading of Overturning Moment from Base Slab (SSE)



Fig 29 Horizontal Seismic Loading of Overturning Moment from Inner Tank (SSE)

Vertical Loadings

The acceleration loading is directly used to define Body Force loading in Modeller except for the acceleration for the Inner Tank. As the Inner Tank is not included in the meshed model, the loading is converted to equivalent structural loading.



Fig 30 Vertical Seismic Loading for Roof (SSE)



Fig 31 Vertical Seismic Loading for Wall (SSE)



Fig 32 Vertical Seismic Loading for Base Slab (SSE)



Fig 33 Vertical Seismic Loading for Inner Tank (SSE)

□ The inner tank is not included as structural elements, so the vertical loading from the inner tank should be converted for structural loading.



Fig 34 Vertical Seismic Loading for Liquid (Hydrostatic, SSE)

□ The given liquid pressure is 400E3 kN is converted as a distributed load for 3D model.

| Attributes | → ∓ × | Global Distributed | × |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| Layers SGroups & Attrib (Analys & Utilities 349:LiveLoad(Staged) & 315:rowLoad(Staged) & 35:SRow(Loger Vet Concrete 1 | Reports | Analysis category 30 | |
| 353:Roof_Upper_Wet_Concrete2 354:Roof_Upper_Wet_Concrete3 355:Roof_Upper_Wet_Concrete4 356:RoofFirmen1(Staged, temporary) | | O Total | unit area |
| 357:Roof Frame2(Staged, temporary 358:Roof Frame2(Staged, temporary) 359:Roof Lower Wet Concrete(Staged, temporary) 359:Roof Lower Part(Staged) 361:D2_WholePart(Staged) | emporary) | Component Value X Direction 60.485153 Y Direction 0.0 Z Direction -34.921E3 Moment about X axis 0.0 Moment dout Y axis 0.0 | |
| Grain Cordinate (4) Grain Cordinate (4) Grain Cordinate (3) Grain Cord | | Moment about Z axis 0.0 | |
| LSpherical for ForceExtraction | | | |
| | | Name Roof Frame 1(Staged, temporary) | ✓ ★ (356) |
| RC Slab (16) RC Slab (16) SiRoof(Central Part) (T[C=60mm, DiaX=: SiRoof(Varying Part) (T[C=60mm, DiaX=: SiBaseSlab(Central Part) (T[C=60mm, DiaX=: Control Part) | 28.6mm, Di 28.6mm, Di aX=31.8mm v | Close Cancel | Apply Help |

Fig 35 Roof Frame1 Loading

As these loadings are not permanent loading, they are not inherited by the subsequent stages and are marked as '**temporary**' in the loadcase name.



Fig 36 Stage 18 of Staged Construction Analysis

Stage 18 assumes that the inner tank has been built. All insulation loading except for 'Roof Liner' will be defined and assigned at this stage.



Fig 37 Stage 20-22 of Staged Construction Analysis

Stage 20 assumes that the lower half of the roof is being built and the poured concrete is acting as a loading on the ringbeam.



Fig 38 Stage 20 of Staged Construction Analysis

Stage 21 assumes that the lower half of the roof is built (if Roof ratio for 1^{st} built = 0.5 from **Tank Definition**), and the lower part of the roof is newly activated. As shown below, the geometric properties used represent those for only half of the Roof at stage 21, only becoming geometric properties for the whole roof at stage 24.

Stage 22 assumes that the lower part of roof is completed. At this stage the wet concrete loading assigned at Stage 21 is removed and replaced with the body force of the lower part of Roof.





Fig 39 Roof Shape at Stage 21, 24.



Fig 40 Stage 23 ~ 24 of Staged Construction Analysis



Fig 41 Stage 23 of Staged Construction Analysis

Stage 23 models the upper half of the Roof being built with the poured concrete acting as a load on the already cast lower half of the Roof.

Stage 24 assumes that the upper part of the Roof is now built. The wet concrete loading assigned at Stage 23 is removed and replaced with the body force of the upper part of the Roof.

At Stage 25, 50% of additional RingBeam Prestress is added. (The Load Factor is updated from 0.5 to 1.0 for Horizontal Prestress_Ringbeam load.)



Fig 42 Stage 26 ~ 27 of Staged Construction Analysis

At Stage 26, the vertical prestress is added.

At Stage 27, all the horizontal prestress for the Wall is added.

Stage 28 is the final stage. The structures is complete as built, and all loadings for the operating condition are added.

Stage 29 models long-term effects. The prestress values are updated to those for long-term PS.

If 'Roof ratio for 1st built' is set to 1, the following sequence for the staged construction analysis will be applied.

| Stage | Description | Note |
|-------|--------------|------|
| No. 1 | Annular part | |

| Stage | Description | Note |
|----------|----------------------------------------------|------|
| No. 2 | 1) + Circular part | |
| No. 3 | 2) + Base PS | |
| No. 4~14 | 3) + Wall & Ringbeam is added up in stages | |
| No. 15 | 4) + Ringbeam 1 st PS | |
| No. 16 | 15) + Roof Frame 1 | |
| No. 17 | 15) + Inner Tank Work | |
| No. 18 | 17) + Roof Frame 2 | |
| No. 19 | 17) + Roof Frame 3 | |
| No. 20 | 17) + Roof Wet Concrete | |
| No. 21 | 17) + Roof Complete | |
| No. 22 | 21) + Roof Lower Inside Load | |
| No. 23 | $22) + Ringbeam 2^{nd} PS$ | |
| No. 24 | 23) + Vertical PS | |
| No. 25 | 24) + Horizontal PS | |
| No. 26 | 25) + Final Short term | |
| No. 27 | 25) + Final Long term (Long term PS applied) | |

Table 1 Sequence of construction stages (Roof ratio for 1st built = 1)

User Updates

Construction Sequence

If required, additional loadings or stages can be added.

To duplicate loading types within the Analyses \bigcirc treeview, the Copy and Paste options can be used as shown below. This will create additional stages (loadcases) and include all loadings previously assigned to the copied loadcase.



Fig 43 Copy and Paste of Stages (Loadcases)

The required activation/deactivation/loadings/support can now be assigned or removed for this stage. The loadings at other loadcases can be also copied and pasted in the same way if required.

User Updates

Loadings

As discussed at in the section titled **Error! Reference source not found.**, some loadings may need updated.

Construction Schedule

The duration (length of time) of each stage is set to 10 days by default for all stages. This should be updated to follow the actual construction schedule.

Each stage uses a Nonlinear Control, and both the time and Total Response Time should be updated together.

For example, if the time gap between Stage 5 and Stage 6 needs to be changed to 15 days, Nonlinear Control for Stage 5 should be updated.

• # × LUSAS View: Example(CodeChecking).mdl Window 1 🗙 📴 Layers 🔯 Groups 歳 Attributes 🕒 Analyses 🥜 Utilities 🛄 Reports Nonlinear & Transient ----- 05 CRSH Analysis ^ Incrementation Solution strategy 🔅 📄 Material Age Nonlinear Same as previous loadcase Incrementation Manual 🗸 Max number of iterations . Supports Residual force norm Starting load factor 0.1 0.1 E-C Loading Deactivate Max change in load factor 0.0 Incremental displacement norm 0.0 Nonlinear and Transient Max total load factor 67:Circular Part(CRSH) 1.0 Advanced... 🗄 📄 Loading Adjust load based on convergence Incremental LUSAS file output Activate Iterations per increment 4 Nonlinear and Transient Same as previous loadcase Displacement reset Output file - 🔲 Loading Advanced... honlinear and Transient Plot file 69:Lot 1(CRSH) Time domain Restart file 🖲 📄 Loading Activate Max number of saved restarts 0 Initial time step 10.0 honlinear and Transient Log file 🕀 70:Lot 2(CRSH) Total response time 50.0 Loading History file natic time stepping bonlinear and Transient Advanced... Save a restart at the end of this control 71:1 of 3(CR5F 🖲 📄 Loading Common to all Activate Max time steps or increments 100000 Nonlinear and Transient Contracting OK Cancel Help Loading
 Activate

Default settings for Stage 5 are shown below.

Fig 44 Nonlinear Control for Stage of Lot 2 (Default)

- □ Initial Time Step : Analysis is performed at every 10 days.
- □ **Total Response Time** : This stage lasts up to 50 days from the start of 1st Stage.

The number of days that the current stage lasts for is the <u>Total Response Time of</u> current stage minus <u>Total Response Time of the previous stage</u>.

By modifying **Total Response Time** to **55**, this stage lasts for 5 more days. (e.g. a total of 15 days)

Note that the Total Response Time for the subsequent stages should be also updated. Otherwise the 6^{th} Stage will last only 5 days.

Modifying **Initial Time Step** is optional and depends on the accuracy required. With a smaller time step, the creep and shrinkage material properties are updated frequently (e.g. using smaller time gaps) hence the accuracy would increase, however the solution time will increase accordingly.

Tip

The unit of time is set on the Model Properties dialog by selecting the **File > Model Properties** menu item.

| Properties | | | × |
|-------------------|--------------|--------------------------------------|--------------------------|
| General Backups | Geometry M | eshing Attributes | s Options D |
| Title | | | |
| Analysis category | 3D ~ | Precision shown i Significant fig | in dialogs gures 6 – |
| Model units | N,m,kg,s,C ~ | Vertical axis | Gravity m/s ² |
| Timescale units | Days ~ | Y axis | -9.01 |
| Decimal marker | As Windows 🖂 | • Z axis | |
| Close | Cance | el Apply | Help |

Fig 45 Model Properties

Age

The Wizard built model assumes that each member is activated at the same concrete Age. The Age property represents the concrete age at the time of activation. (i.e. the time gap between pouring the concrete and removal of formwork.) If a different age is required for some members, another Age attribute should be defined and assigned manually for those

Design Load Combinations

Template for Design Load Combinations

The template for Design Load Combination is saved in the current working folder where the Base Model was built, with the name [Model name]_ComboTemplate.xlsx, as shown below. The template can also be downloaded from the Design Load Combination dialog.





- □ Loadcase Index The numbers in this row are used to match a Modeller loadcase number with a loadcase and its associated details in this template. The row should contain a series of numbers with no duplication.
- **Code** and **Details** Code and Details are used for naming the combination data in Modeller.
- **Load Factors** Load factors for each loadcase is defined here.
- **Others** All other data are for users reference, and not used for processing.
- □ Loadcase to consider can be added. (more columns as necessary can be added.)
- □ Load combinations can be added. (more rows as necessary can be added)

Loadcases Worksheer

| Α | В | С | D | E F | G | н | 1 | J | K | | L | M |
|--------|-----------------------------------------------|--------|------------------|------------|--------------|--------------------|-------------|--------------|-------------|----------|-----------|-------|
| LC No. | Loadcase Name | Column | Load Category | | | | | | | | | |
| 1 | SelfWeight | 6 | Outer tank Full | User Gui | de for 'Lo | adcases' sheet | | | | | | |
| 2 | Dead Loads of Steel Structure | 7 | Others | 1. Loadca | ise Name (| (Column B) | | | | | | |
| 3 | Dead load of liner and steel roof | 7 | Others | - Shoul | d be identi | cal with loadcase | name in t | he model | | | | |
| 4 | Dead load of steel structures on the roof | 7 | Others | 2. LF colu | umn (Colui | nn C, Load Facto | or Column) | | | | | |
| 5 | Dead load of Insulation | 7 | Others | - Refer t | o the num | ber at 1st row o | f 'LoadFact | tors' sheet | | | | |
| 6 | Pressure on outer tank wall due to insulation | 7 | Others | - Put 0 | if the loade | ase is not used i | in the com | bination. | | | | |
| 7 | Wall piping loading | 7 | Others | 3. Note | | | | | | | | |
| 8 | Dead load of Insulation Constr | 0 | | - Loadca | ises not to | be used in the o | ombinatio | ns can be re | emoved fron | n 'Loade | cases' si | neet. |
| 9 | Liquid bottom(Max) | 22 | LNG Max | - Loadca | ises can be | e added at any n | ow, as mar | y as require | ed. | | | |
| 10 | Liquid bottom(Min) | 23 | LNG Min | 1 | | | | | | | | |
| 11 | Liquid wall (Max) | 0 | | User Gui | de for 'Lo | adFactors' sheet | | | | | | |
| 12 | Liquid wall (Min) | 0 | | 1. LF colu | umn index | | | | | | | |
| 13 | Gas Pressure(Max) | 24 | Gas Max | - The to | p line shou | uld be maintained | d with uniq | ue number | | | | |
| 14 | Gas Pressure(Min) | 25 | Gas Min | 2. Code 1 | Name / De | tails | | | | | | |
| 15 | Live load | 26 | Live Load (roof) | - This co | olumns are | used for definin | g the nam | e of combin | ation. | | | |
| 16 | Snow load | 27 | Snow Load (roof) | 3. Note | | | | | | | | |
| 17 | Test load (Liquid) | 20 | Hydrostatic | - Row 2 | -4 are for | user's reference | only, and f | ree to upda | te. | | | |
| 18 | Test load (Pneumatic) | 21 | Pneumatic | - Combi | nation data | a should start fro | m the 5th | row. | | | | |
| 19 | Prestress (Short) | 13 | All PS Early | - Loadca | ses to be | factored can be | added as r | nany as requ | uried. | | | |
| 20 | Prestress (Long) | 14 | All PS Late | - Combi | nations car | n be added as m | any as req | uired. | | | | |
| < | LoadFactors Loadcases 🕀 | | | | | | | | 8.4 | 1 | | |

Fig 47 Template for Design Load Combinations, Loadcases

- □ Loadcase Name The loadcase names defined in Modeller. The loadcase number may change during the process of updating the model, so the loadcase name is used in the definition of the Load Combination. Note that the loadcase names used must be the same as the loadcase names defined in Modeller.
- □ (LF) Column This column is used to match a Modeller loadcase to a corresponding loadcase on the LoadFactors worksheet by entering Loadcase Index on the LoadFactors worksheet. For example, the <u>Self Weight</u> loadcase in Modeller is used in the <u>'Outer Tank Full'</u> combination defined in LoadFactors sheet. By entering 0 (zero), the loadcase is ignored and will not be used in the combination.
- **Others** All other data are for users reference only, and not used for processing.

Update Base Model

The template is imported into Modeller by selecting the LNG Tank > Design Load Combination...

| LNG Tank - Design Load Combinations | × |
|-------------------------------------|-------------------|
| | Template Download |
| Combination data | Browse,, |
| | OK Cancel Help |

Fig 48 Dialog for Design Load Combination

- □ **Template Download** Downloads the template to be used for creating load combinations to the current working folder.
- **Combination data** Select the load combination template.

On re-loading this template, the **Code** and **Details** columns in the LoadFactors worksheet will be compared with combination names in Modeller and the load factors will be updated. If any new combinations are present, they will be added. However, any existing combinations will not be deleted.



The design load combinations are created as shown below.

Fig 49 Load Combinations Created in Modeller

Design Check

COP Parameters

Design code parameters can be defined by the selecting the menu item LNG Tank > Enable Design Check...

| Vesign code | EN1992 | | ACI 318-14 | |
|-------------------------------------------------|----------------|----------|------------|------|
| Partial factors for materials | Persistent_Tra | nsient 🗸 | | |
| Long term effect coeff, (α_cc) | 1.0 | | | |
| Elastic modulus of rebar (Es) | 200, 0E3 | MPa | 200,0E3 | MPa |
| Elastic modulus of tendon (Ep) | 195,0E3 | MPa | 195,0E3 | MPa |
| Roof concrete compressive strength(fc_roof) | 40,0 | MPa | 40,0 | MPa |
| Wall concrete compressive strength(fc_wall) | 50,0 | MPa | 50,0 | MPa |
| Base concrete compressive strength(fc_slab) | 40,0 | MPa | 40,0 | MPa |
| Max concrete compressive strain (e_cu) | | | 3,0E-3 | |
| Yield stress of reinforcement (fy) | 400.0 | MPa | 400,0 | MPa |
| Vield stress of tendon (fyp) | 1,674E3 | MPa | 1,674E3 | MPa |
| Tensile strength of tendon (fpu) | | | 1,86E3 | MPa |
| Computation target | | | | |
| Default | ⊖ Selected | | 🔿 Vis | ible |
| ☑ fse is used and PS is being applied as an ext | ernal loading | | | |

Fig 50 Dialog for Design Parameters

- □ Partial Factors for Materials : The partial factors for materials are defined based on Table 2.1N on EN1992. For Persistent & Transient, 1.5, 1.15, 1.15 are given to γ_c for concrete, γ_s for reinforcing steel, γ_s for prestressing steel respectively. For Accidental, 1.2, 1.0, 1.0 are given.
- **Long term effect coeff.** (α_{cc}) : Long term effect coefficient (EN1991 only)
- **Elastic Modulus of rebar (Es) :** Elastic Modulus of reinforcing steel in MPa.
- □ Elastic Modulus of Tendon (Ep) : Elastic Modulus of prestressing steel in MPa
- **Roof Concrete Compressive Strength (fc_roof) :** Concrete strength in MPa.
- □ Wall Concrete Compressive Strength (fc_wall) : Concrete strength in MPa.
- **Base Concrete Compressive Strength (fc_slab):** Concrete strength in MPa.

- □ Max Concrete Compressive Strain : Ultimate strain at concrete failure (ACI 318-14 only)
- **Vield Stress of Reinforcement (fy)** : Yield strength of reinforcing steel in MPa.
- **Yield Stress of Tendon (fyp)** : Yield strength of prestressing steel in MPa.
- □ **Tensile strength of tendon (fpu)** : Tensile strength of prestressing steel in MPa. (ACI 318-14 only)
- □ **Computation Target :** The design check computations will be performed for the targets of
 - **Default**: The node at Y=0 and X>=0.
 - Selected: The nodes that user selected before opening this dialog
 - Visible: All visible nodes in Modeller.
- □ fse is used and PS is being applied as an external loading
 - When '**fse**' is specified in the **reinforcement template** and the PS being applied as external loading, the code-checking that creates the PM chart will <u>double count</u> the PS effect.
 - Ticking this option shifts the results to avoid double counting the PS effect.
 - When a loadcase (or load combination) does not have PS as external loading, this option should be disabled (unticked).
 - It makes no difference if '**fse**' is not specified in the **reinforcement template.**



Shifted force, Pi' = Pi - fse * ApdShifted moment, Mi' = $Mi - fse * Apd * ecc_ps$

Design Checks for Tank

Once design code parameters have been defined and the OK button is pressed a **Tank Design** Entity will then be available for selection in relevant result processing dialogs. The associated available components are shown below.

| Layers Grou & Attri Q Anal & Utilit Repo | Layers 🔻 🕈 🗙 | Properties | × |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Geometry Composition Geometry Composition Display UHPM_t Display U | Layers Sorou Attri Anal Utilit Repo Image: Example(CodeChecking).mdl Image: Example(CodeChecking).md | Contour Results Contour Display Contour Range Seed Colours Entity Tank Design - BS EN 1992-1-1 Component UtiPM_t UtiPM_t UtiPM_t Transform Pcapacity_tz Mcapacity_rz UtiDC_t UtiDC_t UtiDC_t UtiDC_t UtiDC_t UtiDc_t Cose Cancel Apply H | elp |

Fig 51 Components for Design Checks

Whenever a results component is chosen, or a loadcase is set active, the design check for a selected component will take place. Design checks are carried out on a node-bynode basis using analysis results and relevant design code formulae.

UtilPM (PM Utilization)

UtilPM can be checked with reference to a PM chart, as illustrated below. A value of less than 1 means it satisfies the design code.



Fig 52 Definition of UtilPM

- □ UtilPM_t is the force and moment utilization in the hoop direction, and UtilPM_rz is the utilization in the radial direction for the Roof and Base Slab and for the vertical direction for the Wall.
- □ **Pcapacity_t** and **Pcapacity_rz** is for the computed Pc at the given P1/M1 slope, **Mcapacity_t, Mcapacity_rz** is for the Mc at the given P1/M1 slope.



Fig 53 Contour for UtilPM_t, UtilPM_rz

UtilDC (Decompression Utilization)

UtilDC aims to check if 25mm of concrete around a tendon is in compression. <u>UtilDC</u> is only available if **EN1992** is chosen, and <u>a value of less than 1 means it satisfies the design code.</u>

The UtilDC calculation assumes the stress distribution through the thickness is linear.



Fig 54 Zc for Decompression Check

The tendon cover (d_p) is the distance from outer surface to the tendon surface.

When the section is fully in compression the maximum value is set to 100. (ie. if $Zc \le 0.25$ mm, UtilDC becomes 100.)

UtilDC = Zdec /
$$Zc = 25 / Zc$$
.

□ UtilDC_t is the tendon and stress utilization in the hoop direction, and UtilDC_rz is the utilization in the radial direction for the Roof and Base Slab, and in the vertical direction for the Wall.

UtilDC is only available for sections that contain prestress tendons. In the hoop direction, UtilDC_t is available for Wall and Slab. In the radial and vertical direction, UtilDC_rz is available only for Wall.





If concrete at the prestress tendon location is in tension UtilDC is set to 100.

ShearResist (Shear Resistances)

Shear capacity for the tank components is based on concrete shear resistance as per COP specifications.



Fig 56 Contour for ShearResist_t, ShearResist_rv

UtilShear (Shear Utilization)

Shear utilisation factors are given as the absolute ratio between the shear forces (Sp, St, Sz, Sr) and the relevant shear resistances (ShearResist_t and ShearResist_rz). A value for UtilShear > 1 denotes failure in shear.



Fig 57 Contour for UtilShear_t, UtilShear_rv

PM Chart Report

A spreadsheet report that includes a PM chart can be produced by selecting the menu item LNG Tank > Design Check Report with PM Chart...

| LNG Tank - Design Check Report with | PM Chart | × |
|--------------------------------------------------------------|-----------------------------------------------|------------------------------|
| PM chart report filename PM chart spreadsheet will be sav | PM_Report ed in the current working direct | ory |
| Saved file path | C:₩Users₩ohsso₩Docume | nts₩Lusas190₩Projects₩PM_Rep |
| Report target | | |
| Default | ⊖ Selected | ⊖ Visible |
| | | |
| | ОК | Cancel Help |

Fig 58 Dialog for Design Check Report with PM Chart

- □ **Report Target** The design check computations will be performed for the targets of
 - **Default**: The node at Y=0 and X>=0.
 - Selected : Any nodes that were selected before opening this dialog
 - Visible: All visible nodes in Modeller.

If 'Default' is selected for Report Target, pre-defined target nodes will be used for each of the 15 types of different reinforcement arrangements in the current model, and the report will contain 30 worksheets for producing PM charts for two directions (hoop/vertical or hoop/radial) for all 15 rebar arrangements.



Fig 59 Design Check Report with PM Chart for Lot 1

- □ Section Information at maximum thickness (1) The maximum thickness from the selected nodes is printed, for which the PM chart is displayed.
- □ Section Information at minimum thickness (2) The minimum thickness from the selected nodes is printed, for which the PM chart is displayed.
- □ Node Node number for UtilPM computation
- **Element** Element numbers sharing the node
- **Group** Group name where the node is included in.
- **Thickness** Section thickness at the node location
- □ Mi Bending moment at the node
- **Pi** Axial force at the node
- □ Mi', Pi' The shifted Mi, Pi when 'fse is used and PS is being applied as an external loading' option is ticked from the Design Code dialog.
- **UtilPM** PM Utilization
- □ **PM Chart** Two PM Charts are presented; one for the maximum thickness section, the other for minimum thickness section of the selected nodes. The value for Pcapacity in Modeller has different sign from the value of Pcapacity stated in the PM report

Design Checks for RC Slab

By selecting the **Design>RC Slab Design** menu item, followed by an appropriate design code, a number of other design checks are available.

| RC Slab Design: Design Code Settings | × |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Design code United Kingdom Design code BS EN 1992-1-1:2004/NA:2005 | |
| Design calculations ULS section design Bending only (Wood-Armer) SLS crack checking Bending only (Principal moments) | |
| Design parameters 500.0 MPa Characteristic yield strength of reinforcement (fyk) 500.0 MPa Material factor for reinforcing steel (ys) 1.15 1.15 Modulus of elasticity of reinforcing steel (Es) 200.0 GPa Characteristic cylinder strength of concrete (fck) 40.0 MPa Material factor for concrete (yc) 1.5 1.5 Coefficient for long term and unfavorable effects (acc) 0.85 1.5 | |
| Defaults < Back Next > Finish Cancel | Help |

| roperties | | × |
|-------------|------------------------------------------------------------|-----------------|
| Contour Res | Its Contour Display Contour Ran | ge Seed Colours |
| Entity | RC Slab (ULS) - BS EN 199 ~ | |
| Component | UtilMax(T) ~ | |
| Display | UtilMax(T) Util(Mx(T)) | |
| Transform | Util(My(T)) Util(tcx(T)) Util(tcy(T)) Asx(T) | |
| Display o | ASY(1) Diax(T) Diay(T) UtilMax(B) Util(Max(B)) | |
| ĺ. | Util(My(B)) Util(tcx(B)) Util(tcx(R)) | y Help |
| | Asx(B) Asy(B) Diax(B) Diay(B) | |

Fig 60 Dialog for RC Slab Design and Result Components (1)

| RC Slab Design: Design Code Settings | | | × |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|------|
| Design code Country Design code | United Kingdom BS EN 1992-1-1:2004/NA:2005 | ~ ~ | |
| Design calculations ULS section design SLS crack checking | Bending and in-plane forces (Clark-Nielsen) Bending only (Principal moments) | ~ ~ | |
| Design parameters Characteristic yield s Material factor for rein Modulus of elasticity Characteristic cylinde Material factor for con Coefficient for long te | trength of reinforcement (fyk) nforcing steel (γs) of reinforcing steel (Es) er strength of concrete (fck) ncrete (γc) rm and unfavorable effects (αcc) | 500,0 MPa 1.15 GPa 40,0 MPa 1.5 0.85 | |
| Defaults | < Back Next > Fi | nish Cancel | Help |

| Properties | | | | | × |
|-------------|----------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|---------------|--------------|------|
| Contour Res | ults | Contour Display | Contour Range | Seed Colours | |
| Entity | RC S | Slab (ULS) - BS EN 19 | 92-1-1:2 🗸 | | |
| Component | Util(| Nx(T)) | ~ | | |
| Display | UtilM UtilM | lax lax(T) | | | |
| Transform | Util() Util() Util() Ssx() Ssy() Sc(T | Nx(T)) Ny(T)) Fc(T)) T) T) | | | |
| Display | Asx Asy Diax Diay UtilM | (T) (T) (T) (T) lax(B) | | | |
| | Util(I Util(I Ssx(Ssy(Sc(B Asx(Asy(| Nx(B)) (yy(B)) =c(B)) B) B) (B) (B) (B) (B) (C) (C) (C) (C) (C) (C) (C) (C | | Apply | Help |
| | Diax Diay | (B) (B) | | | |

Fig 61 Dialog for RC Slab Design and Result Components (2)



The target group for which design check results are to be obtained must be set in the 'Groups' treeview as shown below.

Fig 62 Show Results for a Selected Group

ULS - Stress Check



Fig 63 RC Slab Design - Stress Checks

- \Box Ssx(T)/Ssy(T) : Inner rebar stress
- \Box Ssx(B)/Ssy(B) : Outer rebar stress
- \Box Sc(T) : Inner surface concrete stress
- □ Sc(B) : Outer surface concrete stress

ULS – Utilization





- □ Util(Mx(T)), Util(My(T)) : Inner surface moment ratio (moment / moment resistance)
- □ Util (Mx(B)), Util(My(B)) : Outer surface moment ratio (moment / moment resistance)
- □ Util(Nx(T)), Util(Ny(T)) : Inner rebar stress ratio (Design rebar stress / rebar Yield stress)
- □ Util(Nx(B)), Util(Ny(B)) : Outer rebar stress ratio (Design rebar stress / rebar Yield stress)



Fig 65 RC Slab Design – Utilization for Concrete Stress

- **Util(Fc(T)) :** Ratio (Concrete stress / Concrete compressive strength)
- □ Util(Tcx(T)),Util(Tcy(T)) : Ratio (Concrete tensile stress / Tensile limit) for inner surface
- □ Util(Tcx(B)),Util(Tcy(B)) : Ratio (Concrete tensile stress / Tensile limit) for outer surface

ULS – Design



Fig 66 RC Slab Design – Reinforcement Design

- □ Asx(T), Asy(T) Minimum reinforcement area required for inner side
- □ Asx(B), Asy(B) Minimum reinforcement area required for outer side
- □ **Diax(T), Diay(T)** Minimum reinforcement diameter required for inner side based on given rebar spacing.
- □ Diax(B), Diay(B) Minimum reinforcement diameter required for outer side based on given rebar spacing.

SLS- Crack Width



Fig 67 RC Slab Design – Crack Width

- □ CWx(T), CWy(T) Maximum crack width for local direction at inner side surface
- □ CWx(B), CWy(B) Maximum crack width for local direction at outer side surface
- **CWMax(T), CWMax(T)** Maximum crack width orthogonal to principle stress at inner side surface
- □ CWMax(B), CWMax(B) Maximum crack width orthogonal to principle stress at outer side surface

SLS- Utilization



Fig 68 RC Slab Design – Crack Width Utilization

- □ Util(CWMax(T)), Util(CWMax(T)) : Ratio (max crack width / allowable limit) for inner surface
- □ Util(CWMax(B)), Util(CWMax(B)) : Ratio (max crack width / allowable limit) for outer surface

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