 

DUNKERQUE LNG TERMINAL : TANKS DESIGN

Aix en Provence, 30 May 2012

Louis MARRACCI

- General description
- Design data
- Structural problematics and models

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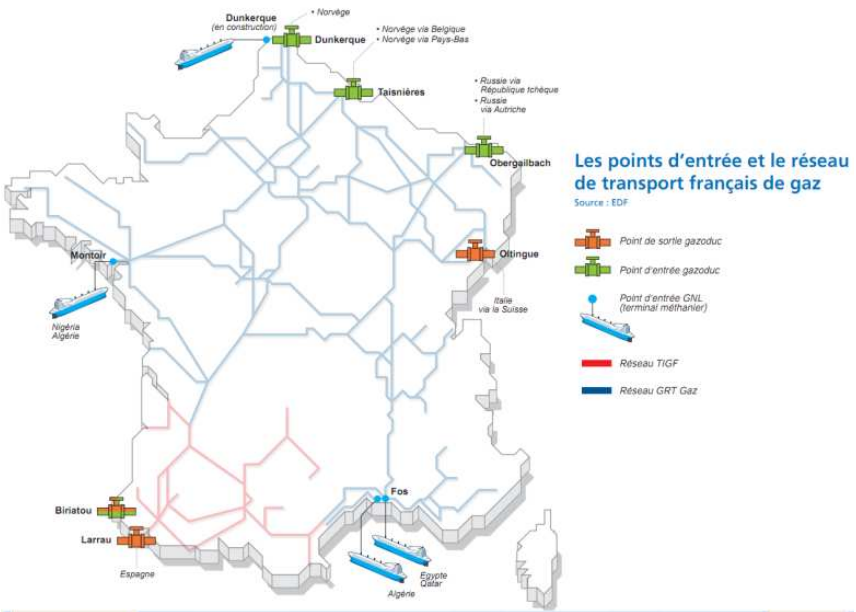
Participants & main figures

Project participants

- Owner : Dunkerque LNG (65% EDF, 25% Fluxys and10% Total)
- Engineer : Sofregaz

Main figures

- investment : 1 billion € (~25% for the tanks)
- Site commencement date : 2012
- Annual capacity : 13 Gm3 (30% of importation French capacity)



4th LNG import terminal in France

Highest regaseification capacity in France

Project parts and awaited functionality of the terminal

Project split into 3 parts

- a LNG regasification plant, with a nominal capacity around 13 bcm (billion cubic meter) natural gas per year.
- a Seawater Tunnel (about 5 km long) which brings the warm seawater discharged from Gravelines power station to the LNG vaporizers of the terminal,
- three LNG storage tanks of each 190,000 m3 net capacity,

These components ensure the following functionalities:

Hot water supply

discontinuous gas supply by methane tanker

Gas in liquid phasis

Cryogenic temperature

Atmospheric pressure

Continuous emission on the gas network

Gas in vapour phasis

Ambient temperature

Pression ~80 barg

Discharge out of cooled water (to the sea)

Consortium participants & main figures

Consortium participants

- Consortium BYTP / Entrepose (prime contractor) on 40% / 60% basis.
- BYTP : concrete structures and carry out the soil improvement
- Entrepose : internal tank, process, pre-commissioning.

main figures

- working capacity : 190.000 m^3 (=75 olympic swimming pools)
- Diameter x height : 93m x 50m
- Constrution delay : 3,5 ans

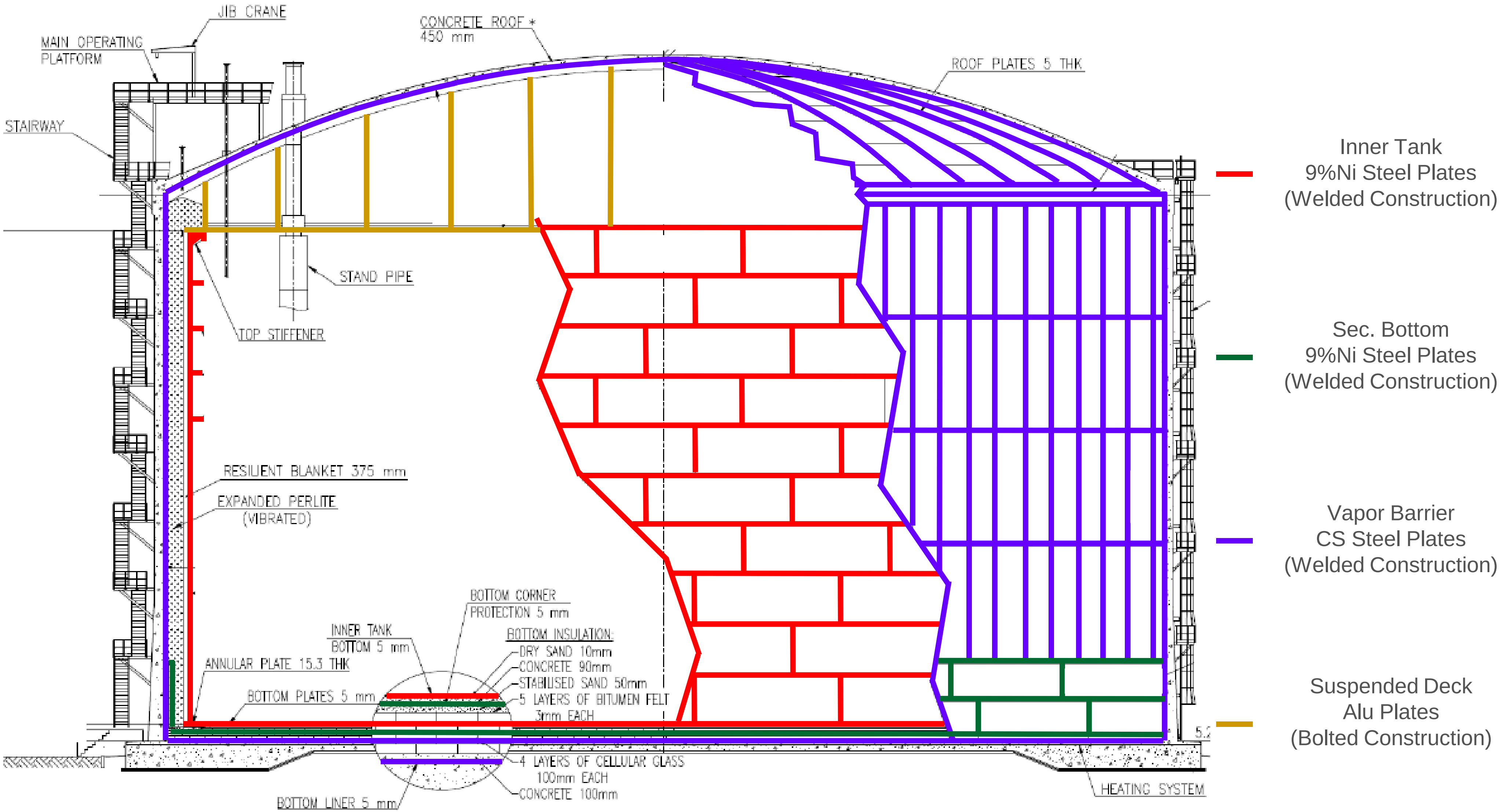
Biggest tank in Europe

Description of a LNG Storage Tank

LNG Storage Tank consists of one self standing concrete outer tank:

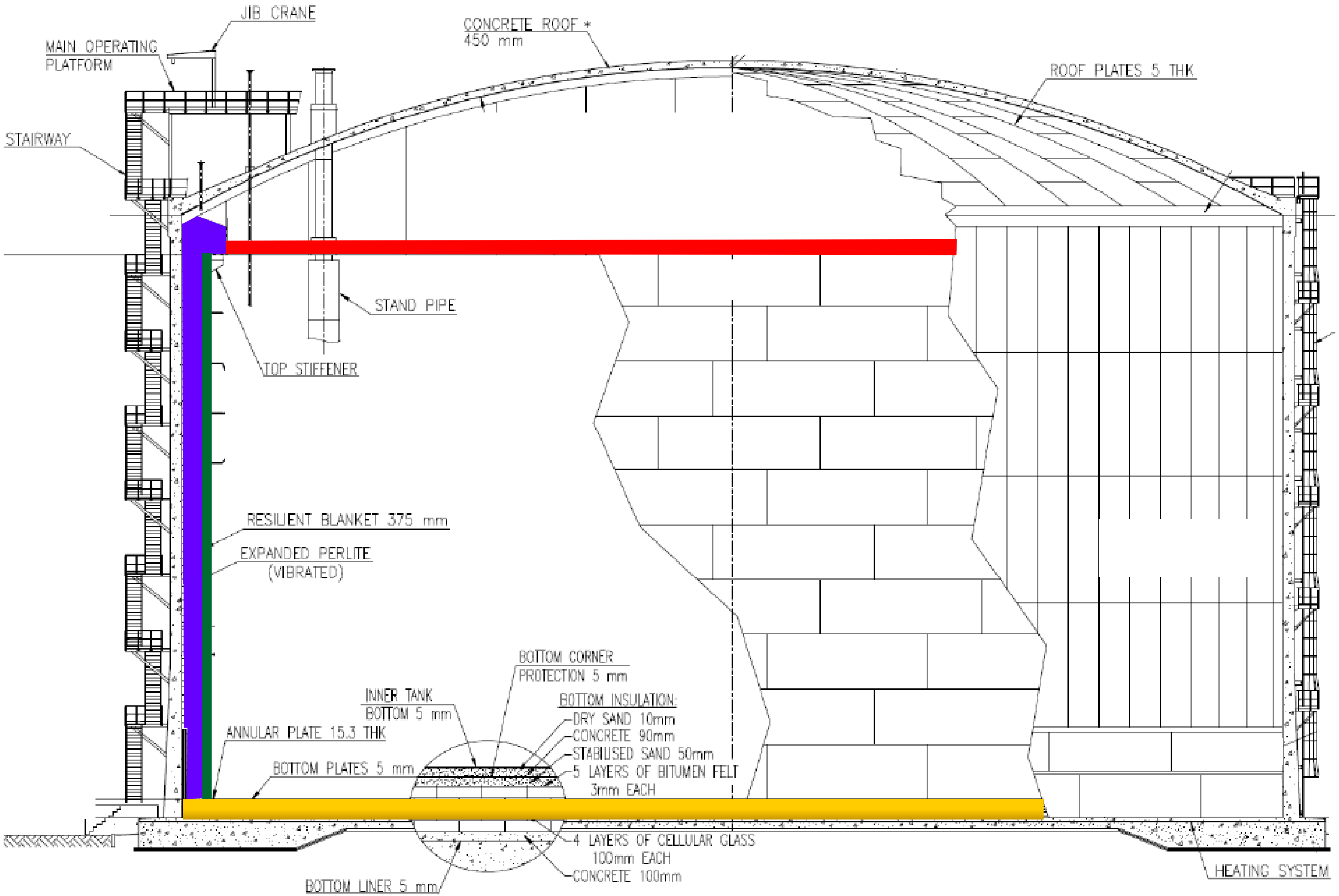
- Within which will be installed:
  - Mechanical components to store the both liquid and vapor.
  - Thermal insulation to limit thermal ingress.
- Around which will be installed piping and access structures.

Internal – Mechanical Components



Internal – Insulation Components

Insulation Components



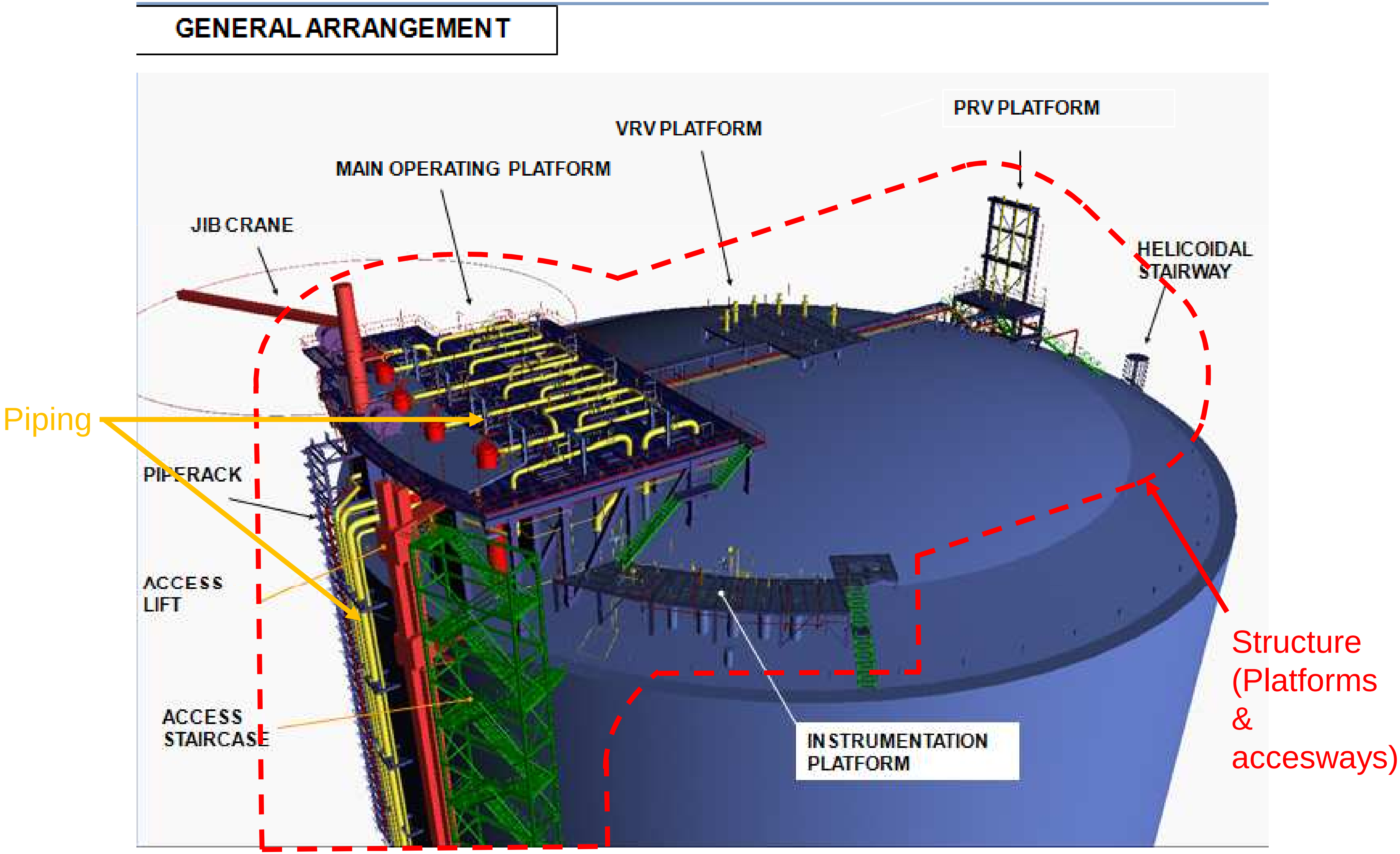
Top Insulation
Fiberglass
(Blanket unrolling)

Lateral Insulation #1
Resilient Blanket
(Blanket unrolling)

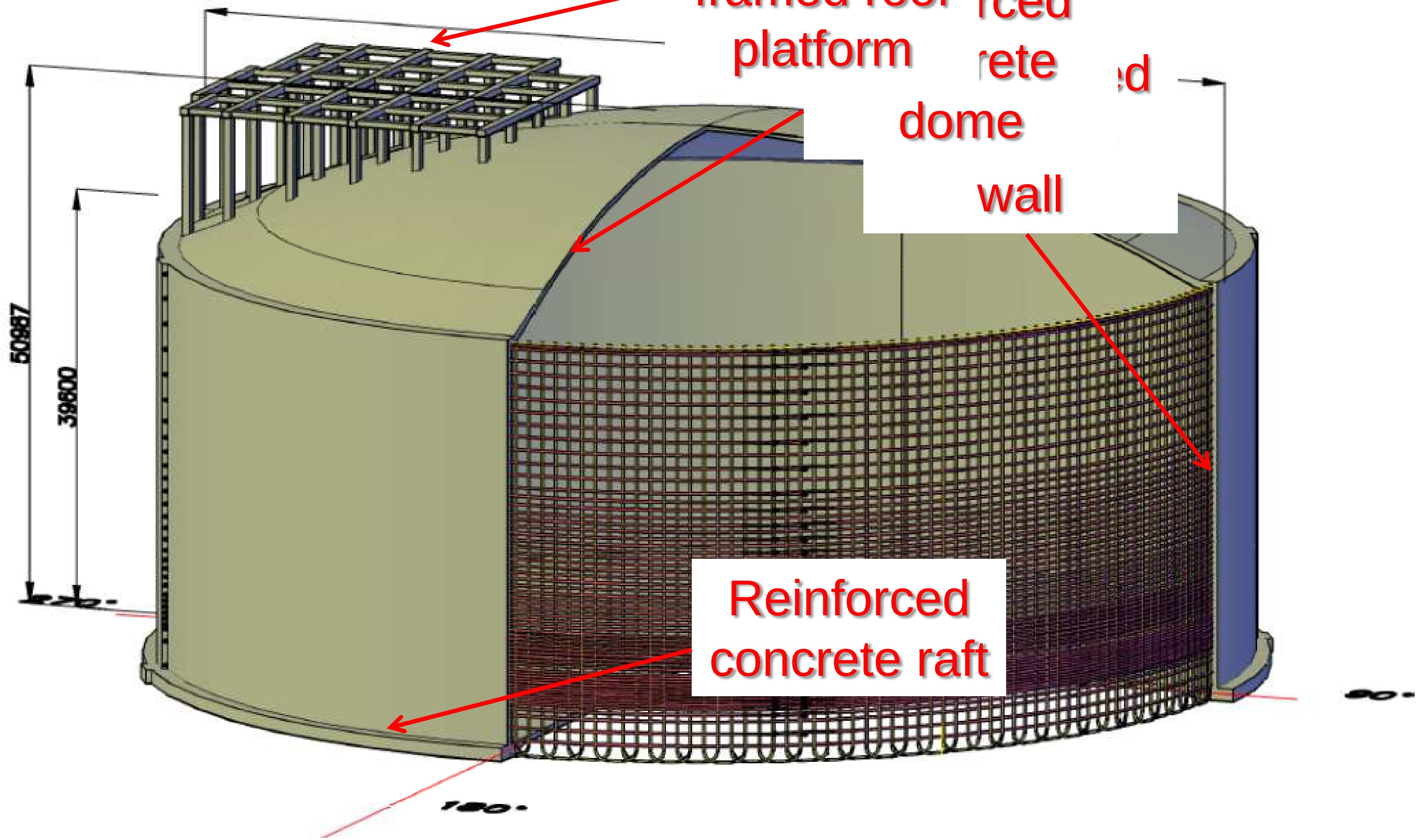
Lateral Insulation #2
Perlite
(installation by specialized Contract)

Bottom Insulation
Cellular Blocks
(Bricks Installation with interleaving material between layers)

Externals


GENERAL ARRANGEMENT
PRV PLATFORM
VRV PLATFORM
MAIN OPERATING PLATFORM
JIB CRANE
HELICOIDAL STAIRWAY
Piping
PIPERACK
ACCESS LIFT
ACCESS STAIRCASE
INSTRUMENTATION PLATFORM
Structure (Platforms & accesways)

General Description of the projec



General Description of the project

General Description of the project

- Tanks designed for **all possible loading conditions** which may occur during
  - erection,
  - testing,
  - commissioning,
  - operation,
  - de-commissioning,
  - maintenance
  - accidental loading conditions.

- Miscellaneous numerical models elaborated in order to cope with the different loading conditions

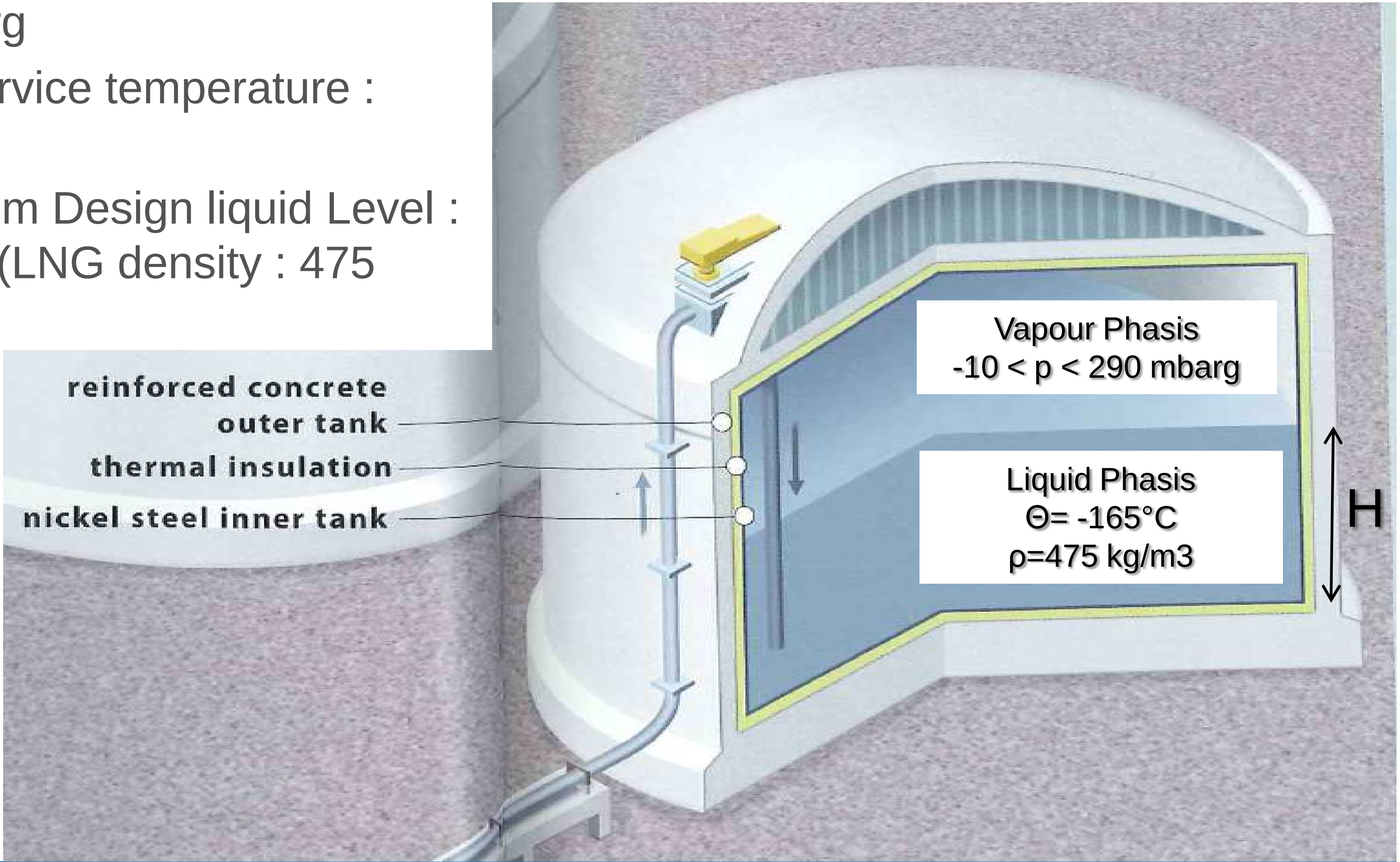
Structural design

- General description
- Design data
- Structural problematics and models

- General description
- **Design data**
- Structural problematics and models

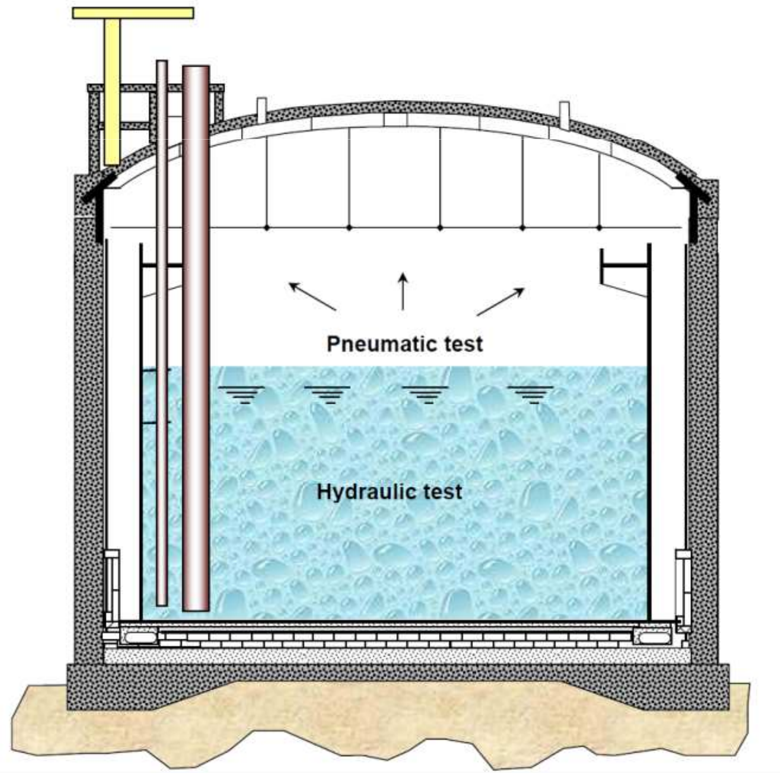
Design data:

- Design pressure: 290 mbarg / -10 mbarg
- LNG service temperature : -165°C
- Maximum Design liquid Level : 33.72 m (LNG density : 475 kg/m3)



Design data:

- Pneumatic test pressure: 362.5 mbarg
- Hydrostatic Test Level for inner tank: 19.32 m = 1.25 * maximum load generated by LNG weight at the basis



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  - Geotechnical models
  - Static models
  - Dynamic models
  - Thermo mechanical models
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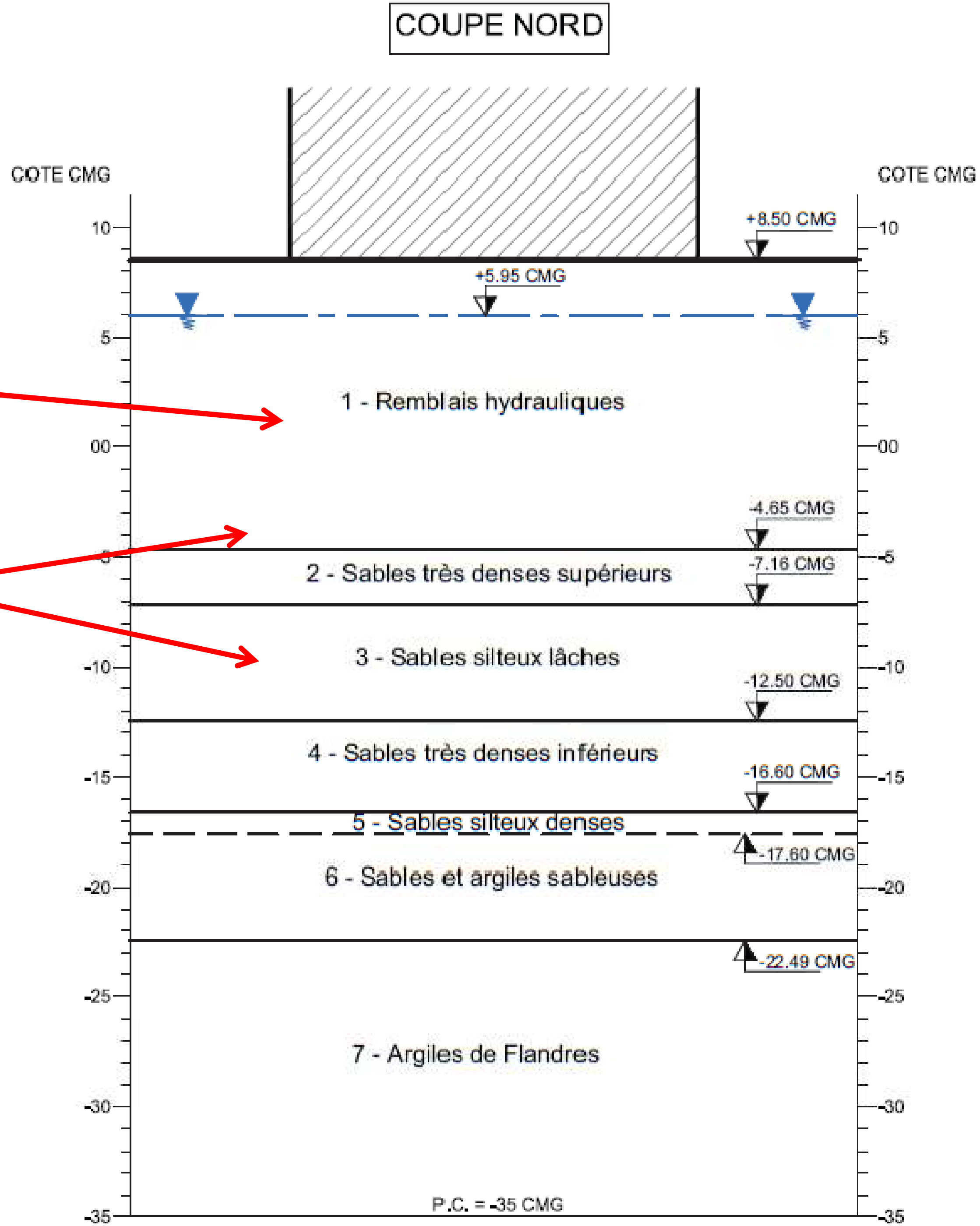
Geotechnical models

Stratigraphy

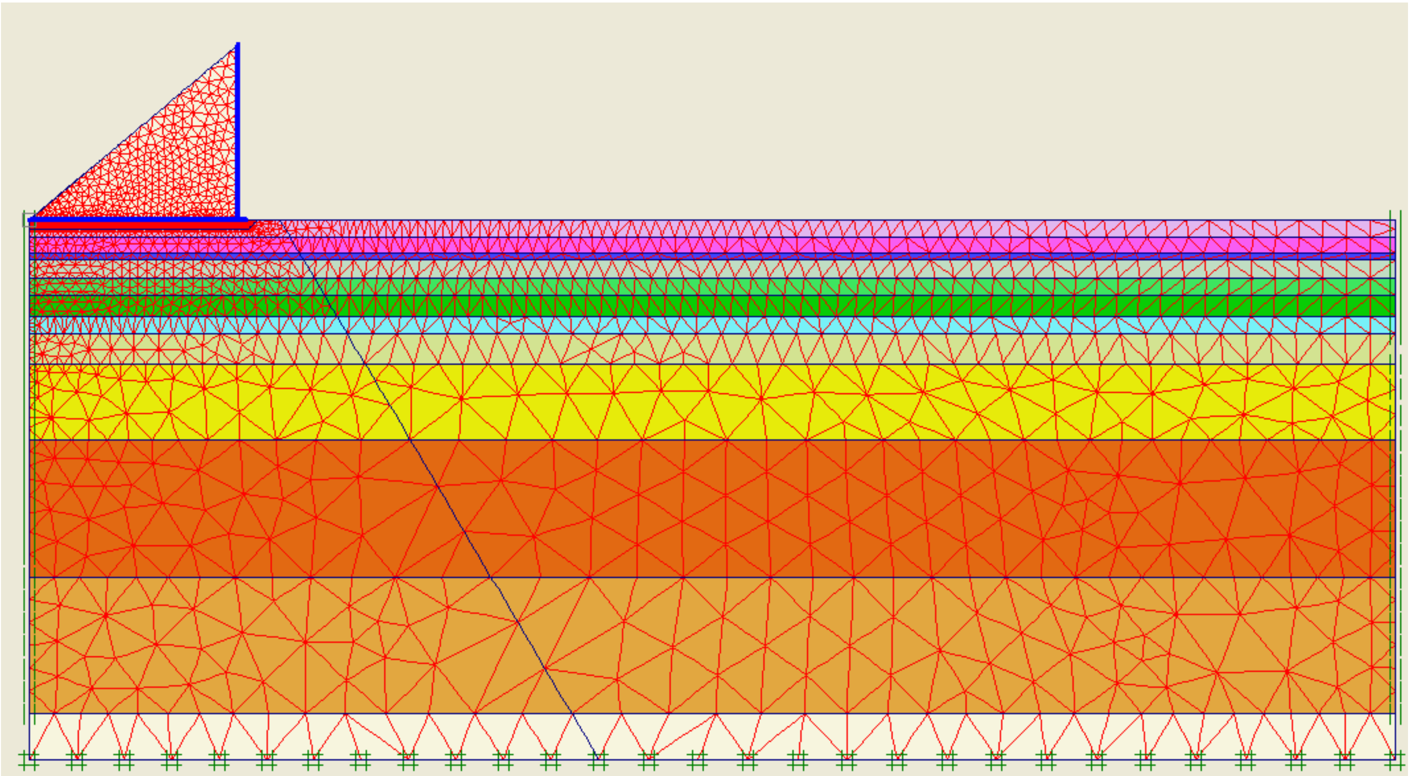
heterogeneous

liquefiable



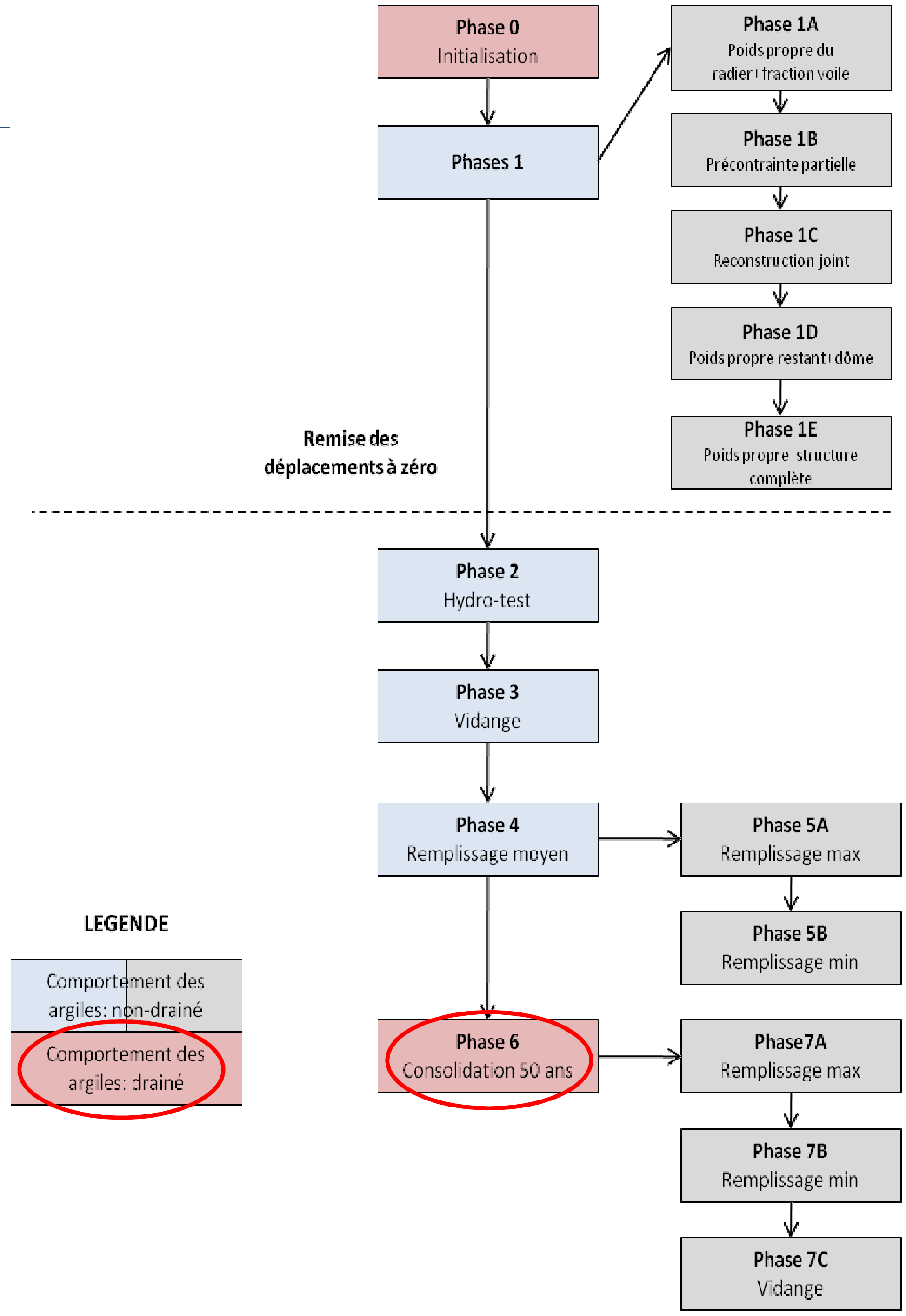
Geotechnical models (Terrasol)

- Superficial foundation
- Sufficient bearing capacity
- Settlement calculation
  - axi symmetrical PLAXIS V9 **non linear** model



Geotechnical models

- Settlement calculation takes into account :
  - Sequence representative of the loading history
  - differed behavior of Flanders clays
  - distinction between the instantaneous part of settlement and the part occuring 50 years after construction.



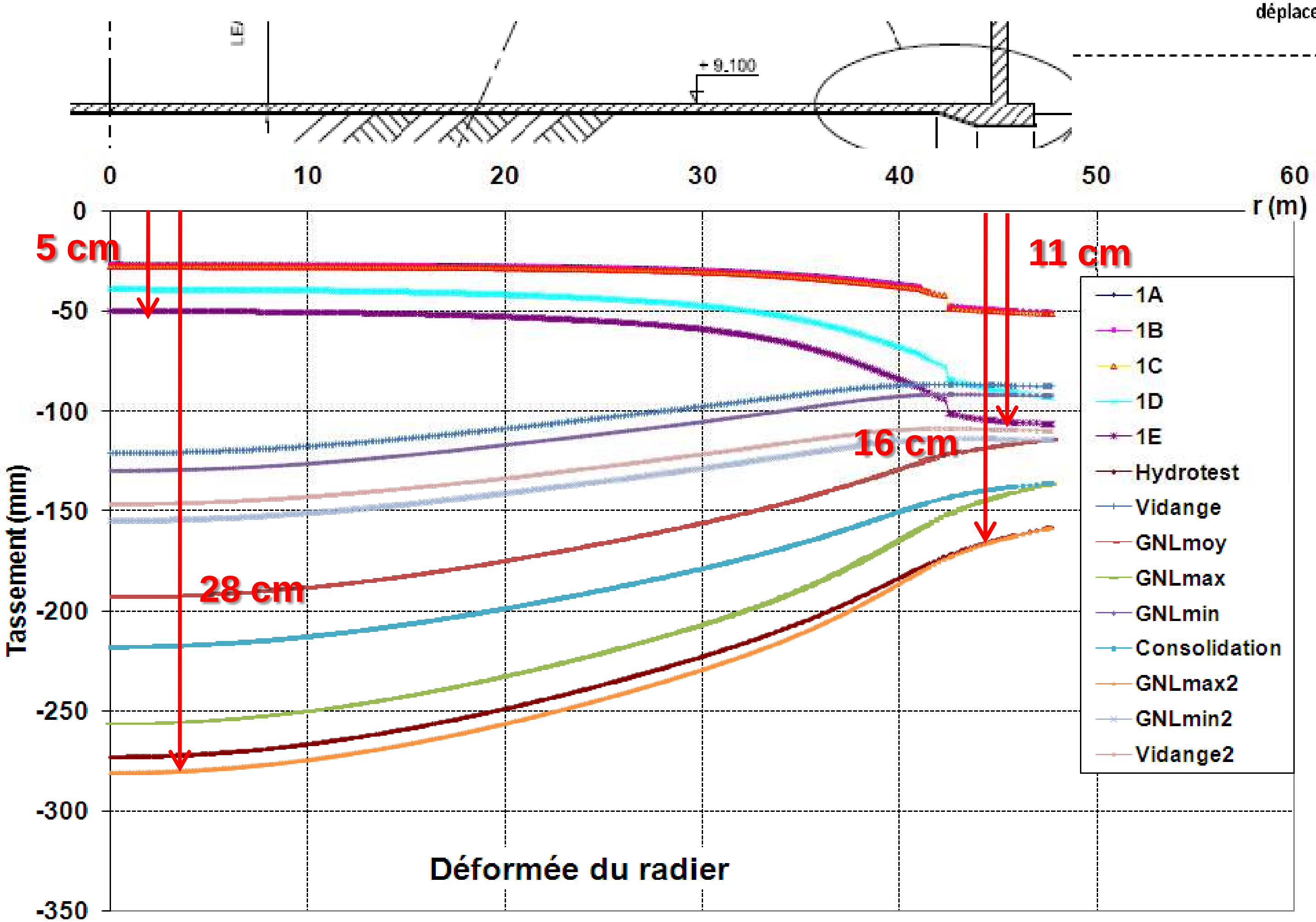
Structural problematics and models

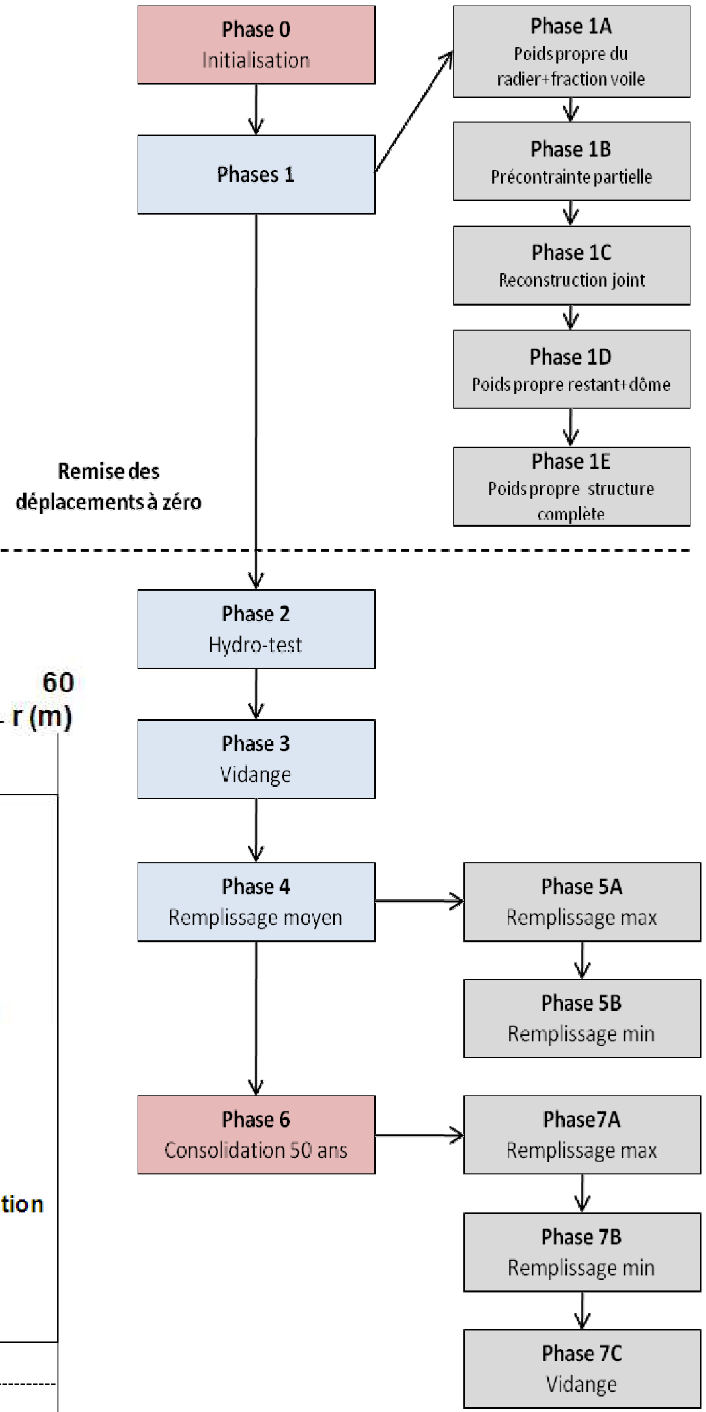
Geotechnical models

Settlement calculation:

Maximum raft deformation = 5+28=33 cm

Maximum differential settlement = 33-16-11 = 6 cm





Geotechnical models

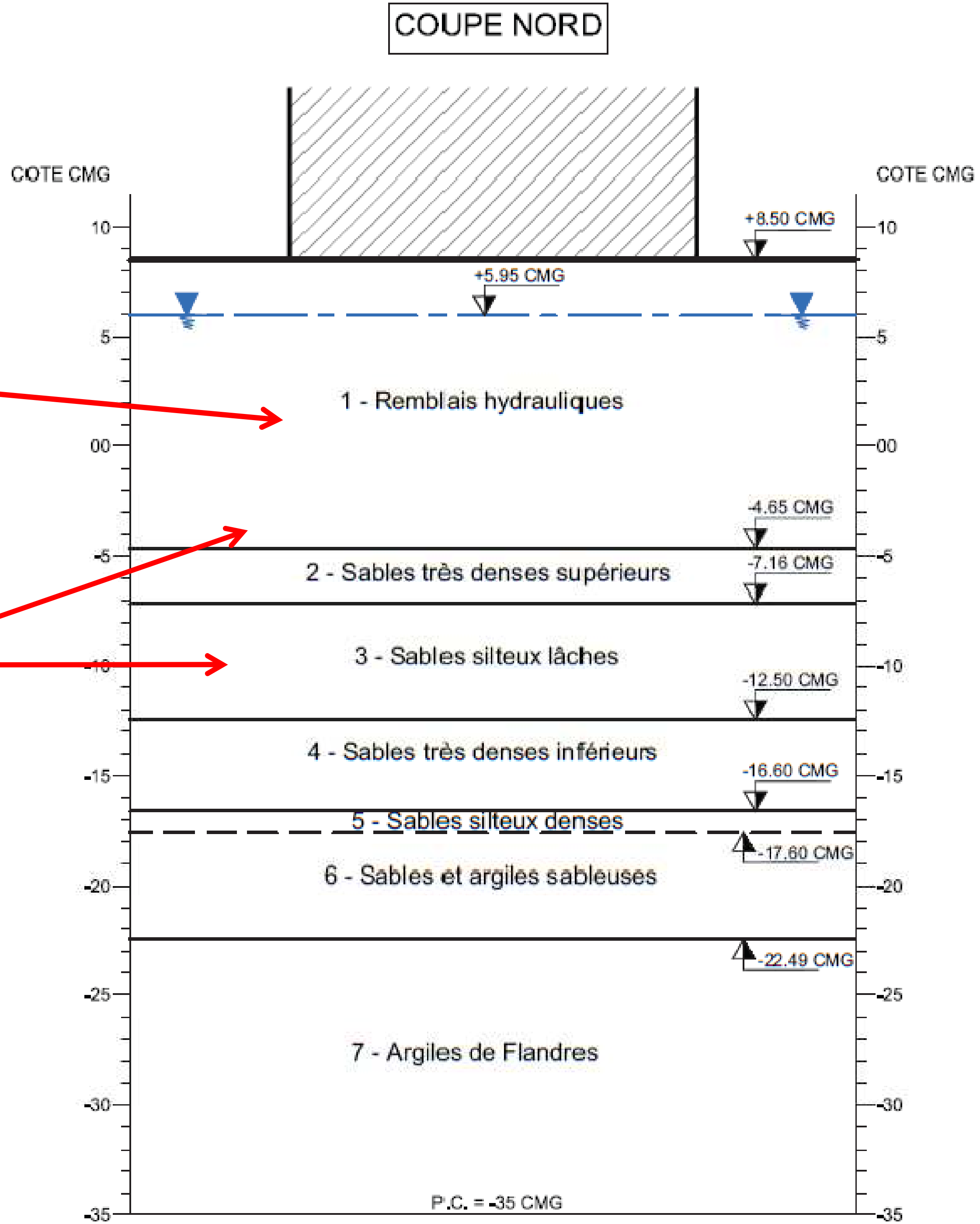
- Soil improvement

heterogeneous

→ **Vibroflottation:**

objective = minimum density

liquefiable



Structural problematics and mc

Geotechnical models

- Soil improvement

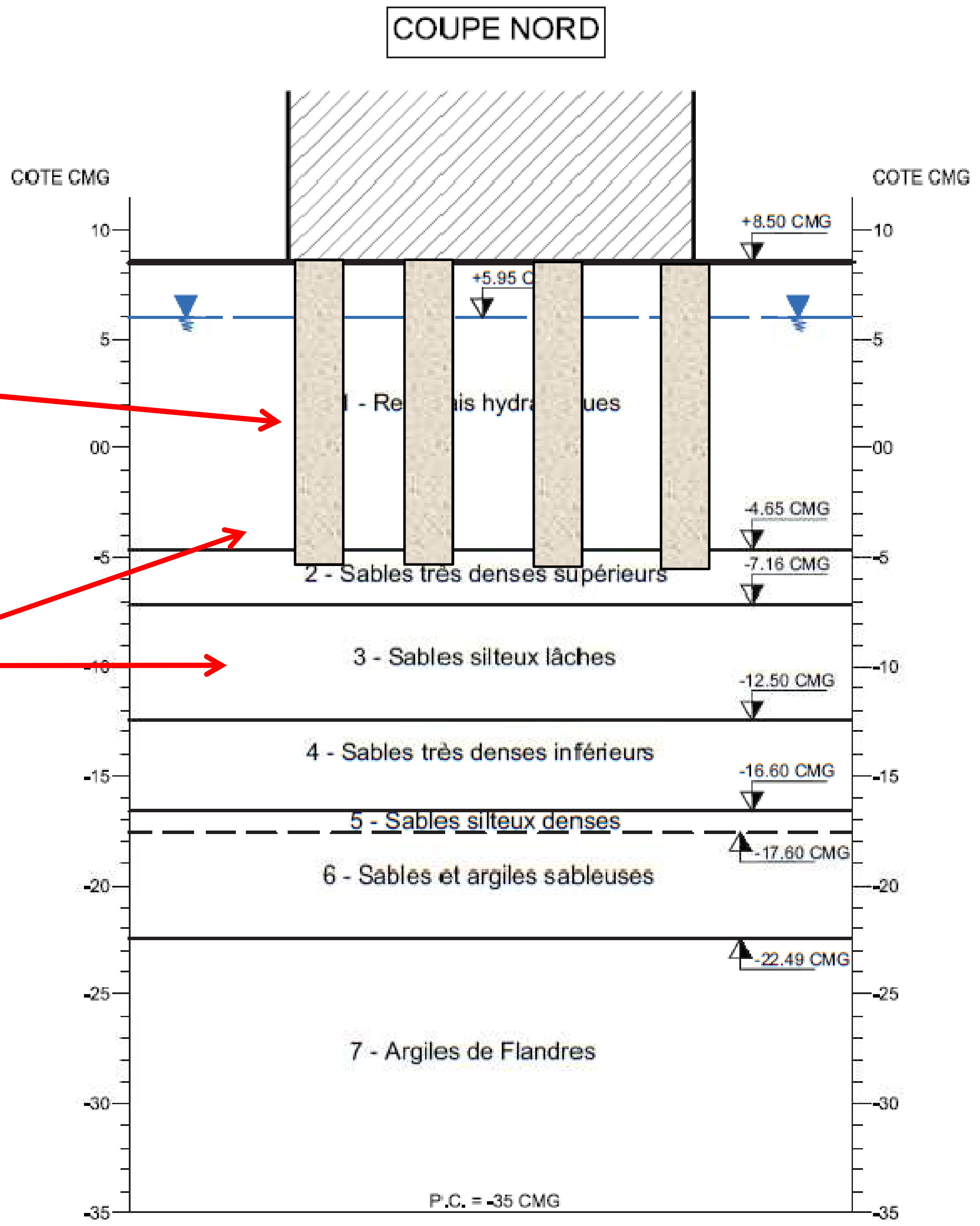
heterogeneous

➔ **Vibroflottation:**

objective = minimum density

liquefiable

➔ **stone columns**



Structural problematics and mc

Geotechnical models

- Soil improvement

heterogeneous

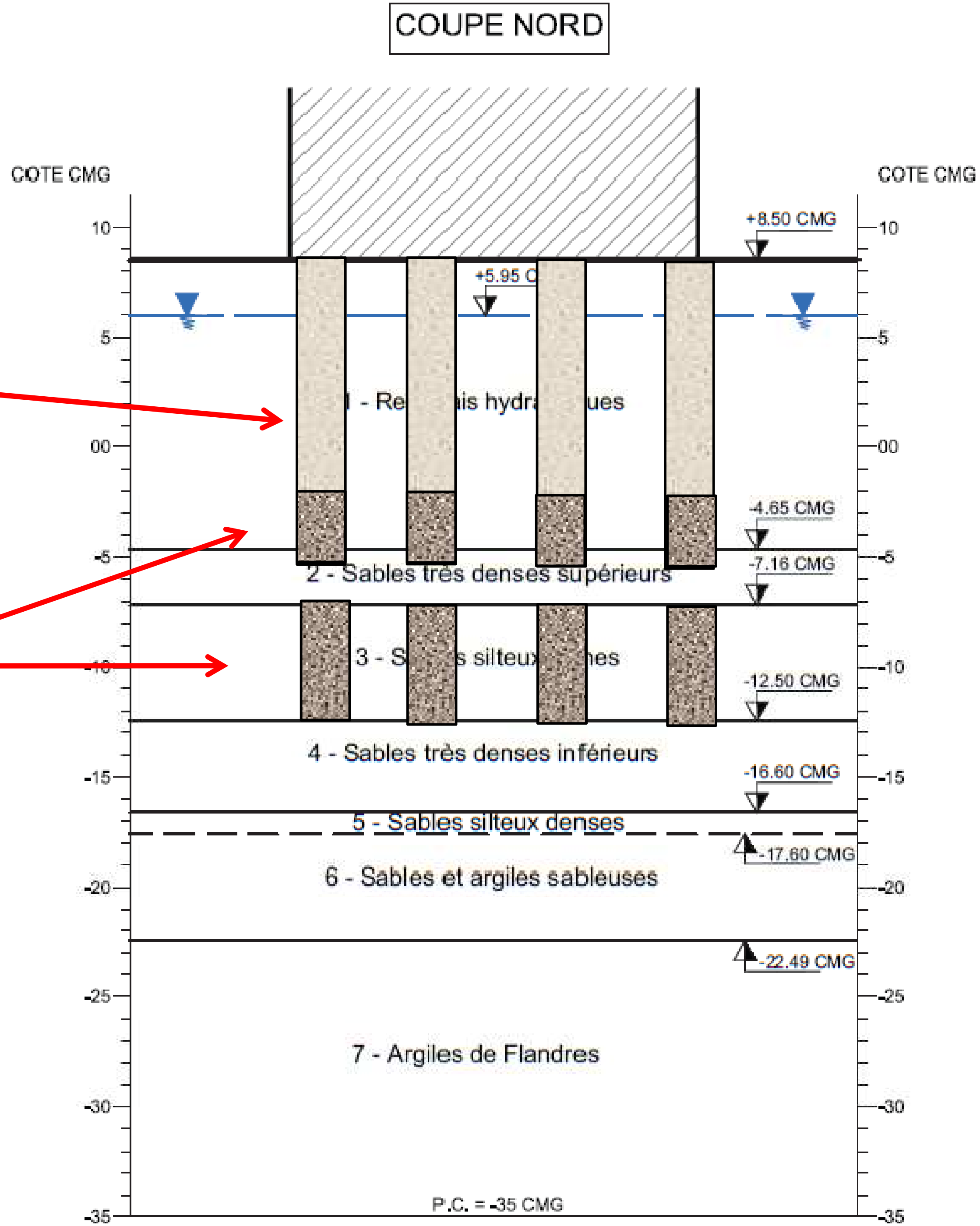
➔ **Vibroflottation:**

objective = minimum density

liquefiable

➔ **stone columns**

- Adequacy of soil improvement: pilot tests



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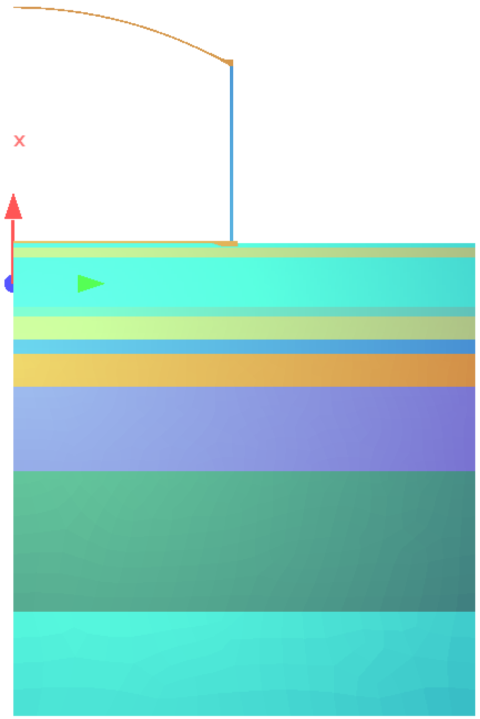
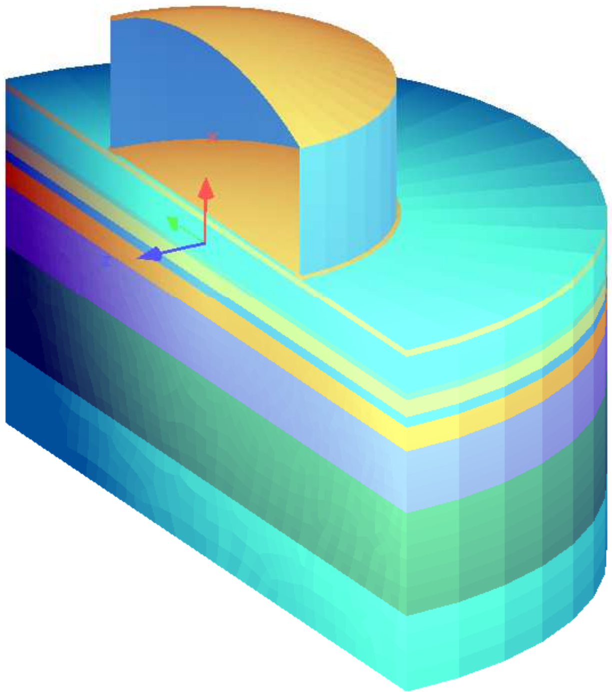
Static models

3D axi-symmetrical model

- Tank = axi-symmetrical structure
- axi-symmetrical loads : self weight, prestress, LNG weight, service or test gas pressure, temperature, axi-symmetrical construction and service live loads

→ axi-symmetrical 3D linear elastic model in plane deformations





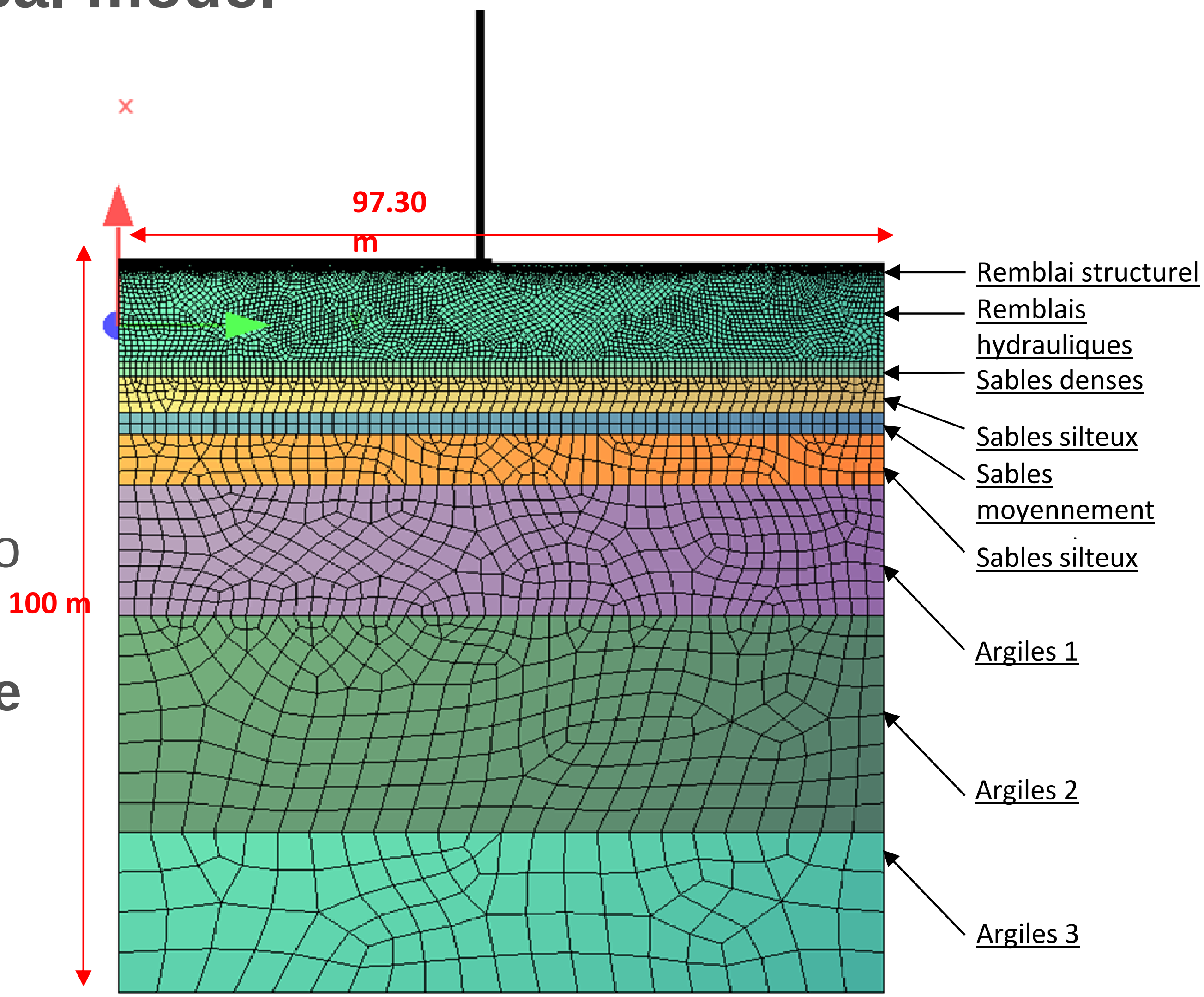
Static models

3D axi-symmetrical model

Soil

- Elastic linear properties
- Particular situations : imposed displacements applied to raft (fictive temperature field applied to soil)

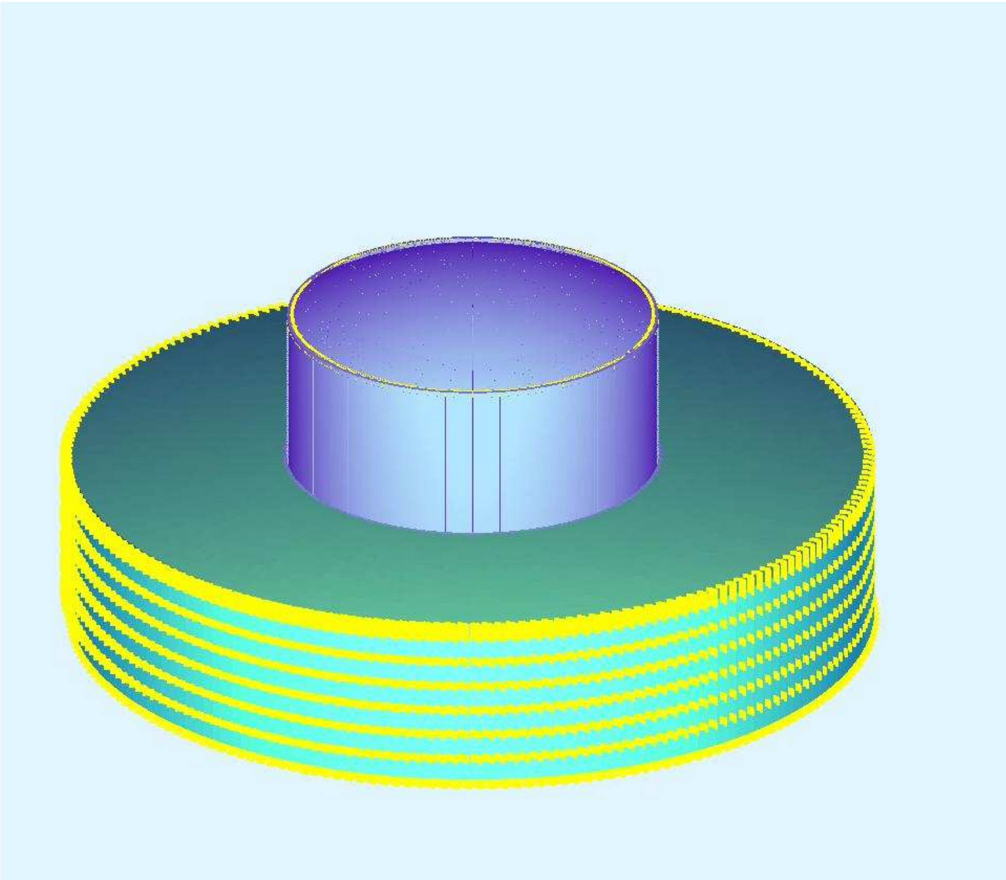
➔ **actual settlement profile**

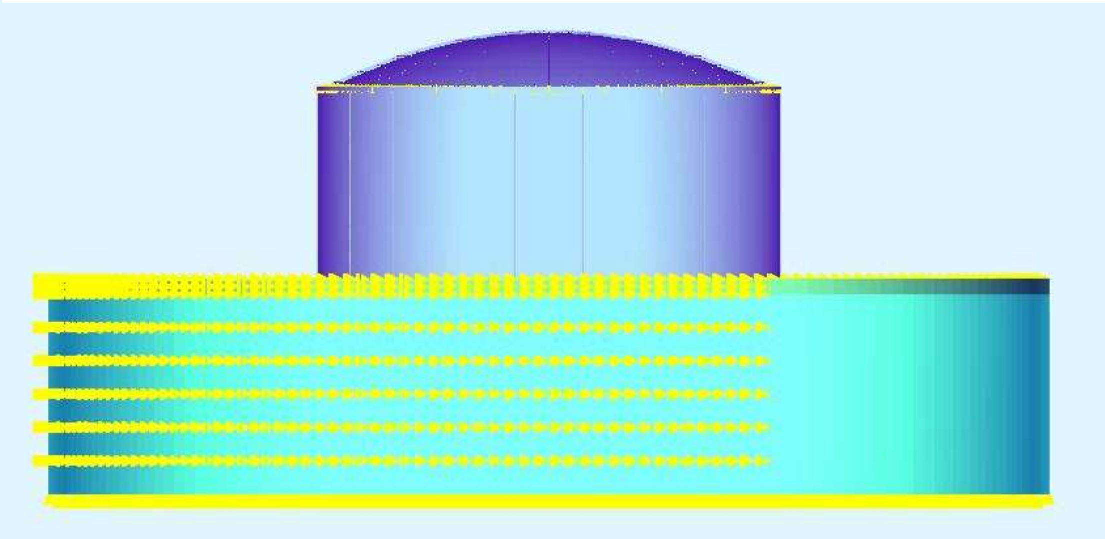


Static models

Full 3D model

- used for calculations of internal forces under non axi-symmetrical loads: wind, blast, snow, earthquake, missile and plane impacts





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Dynamic models

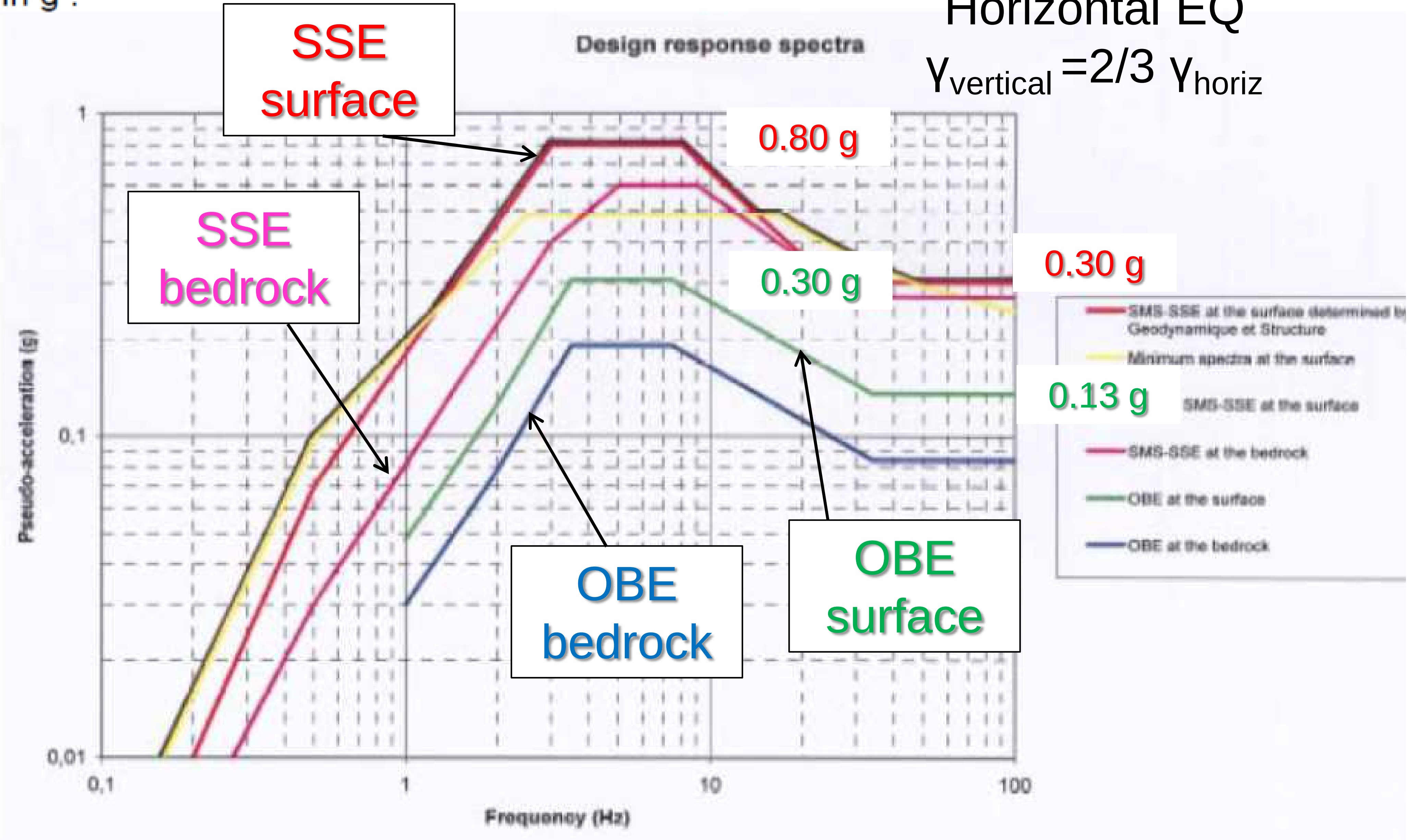
Seismic loads:

- Operating Basis Earthquake (OBE):
  - no damage
  - restart and safe operation can continue.
  - return period = 475 years.
  - pga : amax = 0.134 g
- Safe Shutdown Earthquake (SSE) :
  - essential fail-safe functions and mechanisms preserved.
  - return period = 5,000 years.
  - pga: amax = 0.30 g

In g :

Horizontal EQ

$\gamma_{vertical} = 2/3\ \gamma_{horiz}$



Dynamic models : 4 models

- 3D soil model
- 3D Global “skewer” model
- 3D Model “ground + raft (shells) + skewer”
- 3D “parasol” model

Dynamic models : 4 models

3D soil model (GDS)

- Purpose: determination of soil dynamic impedances (stiffness and damping) of the tank foundation
- input data : for each layer :
  - the soil density ρ,
  - Shear wave propagation velocity V_{s0} (or shear modulus G_{max}) $V_{s0} = \sqrt{\frac{G_{max}}{\rho}}$
  - compression wave propagation velocity V_p (or Poisson's ratio ν)
- Two sets of soil characteristics:
  - underestimated characteristics, without soil treatment
  - increased characteristics, which takes into account soil treatment.

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Dynamic models : 4 models

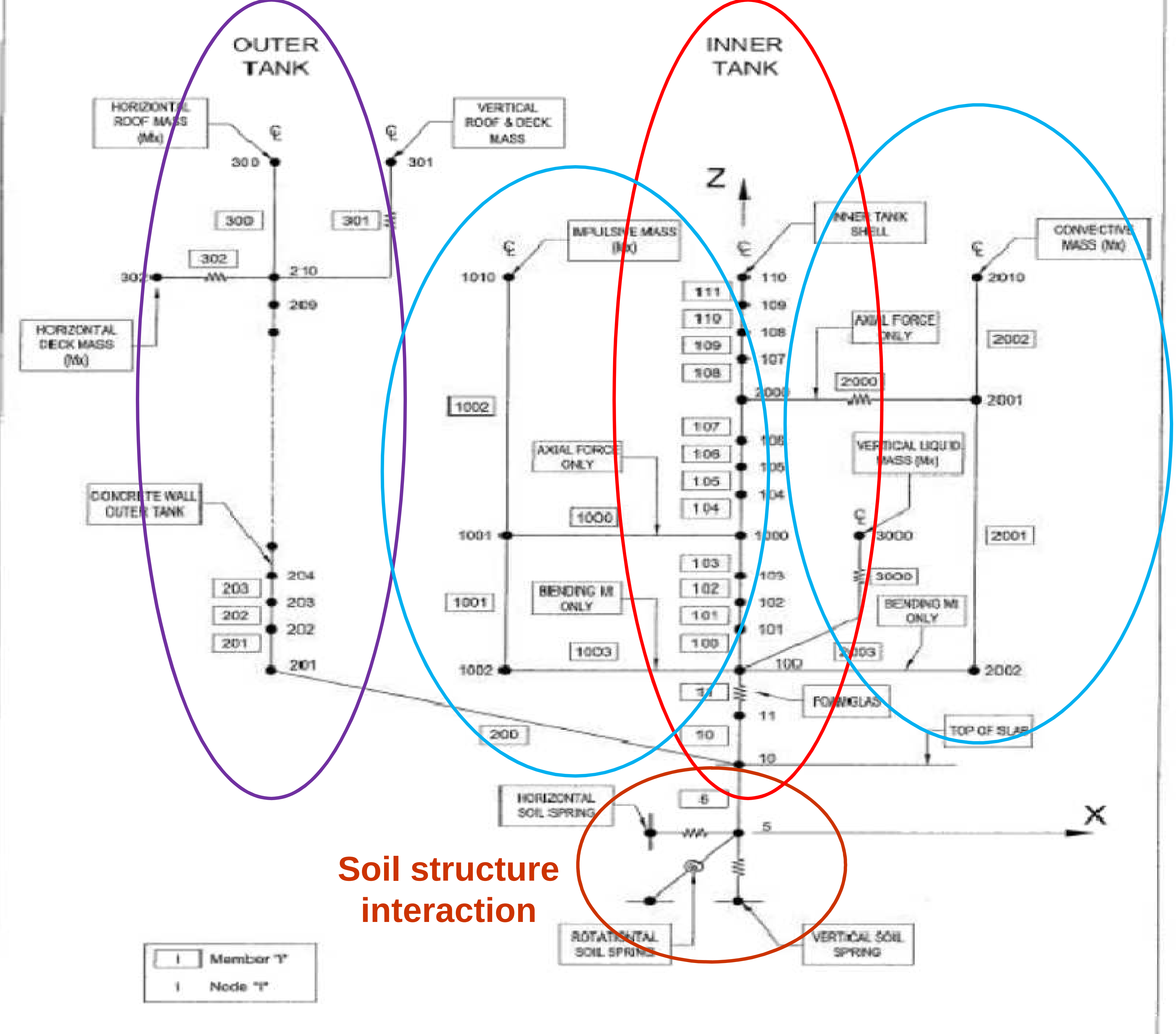
3D Global "skewer" model

- Purpose: determination of the global seismic answer of the structure, coping with the interactions between inner tank, liquid, outer tank, suspended deck, foundation and soil, in a single composite model.
- "skewer" model:
  - multi degree of freedom lumped masses
  - computer code SOFISTIK Version 2010.
- modal spectral analysis, under horizontal and vertical spectra,

➔ global forces, moments and accelerations for each modeled component (inner tank, foundation, outer tank).

Structu

- Dyna
  - 3D



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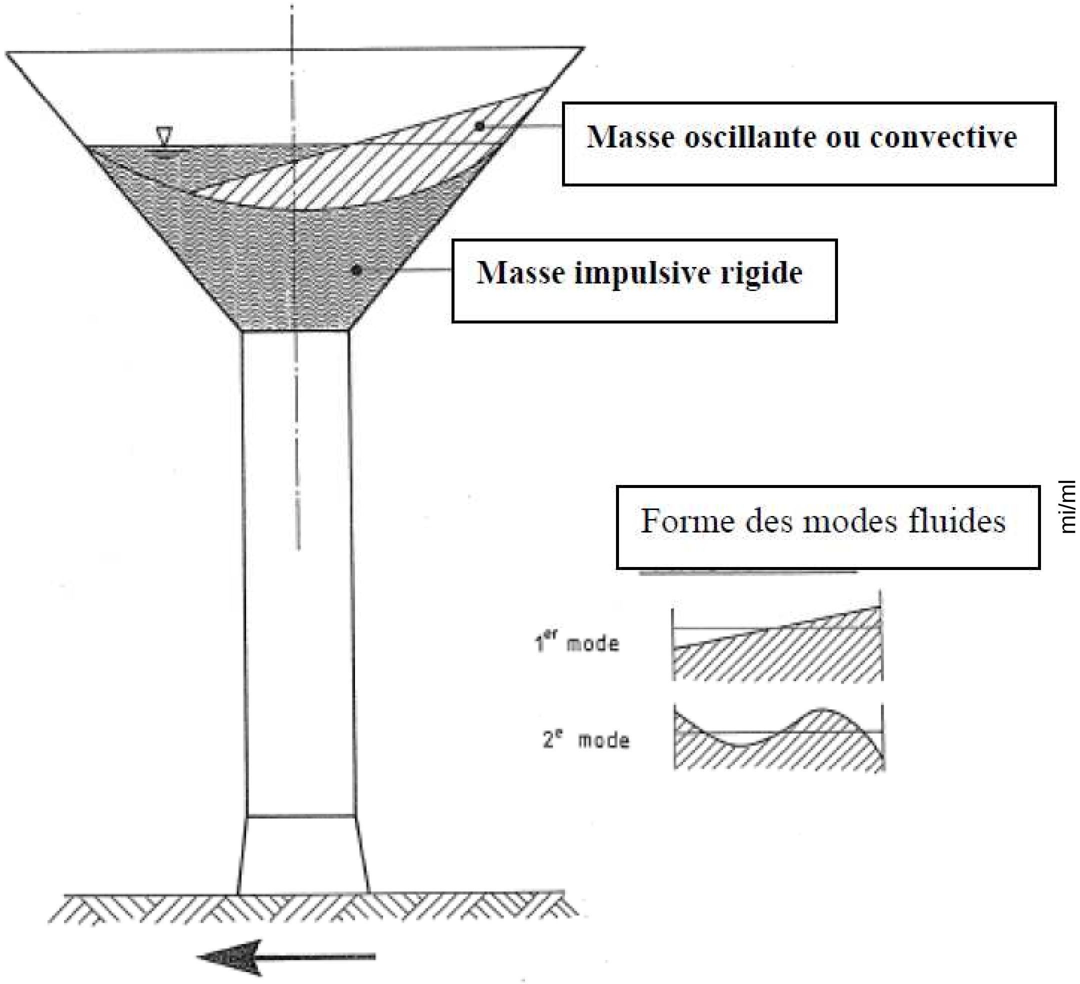
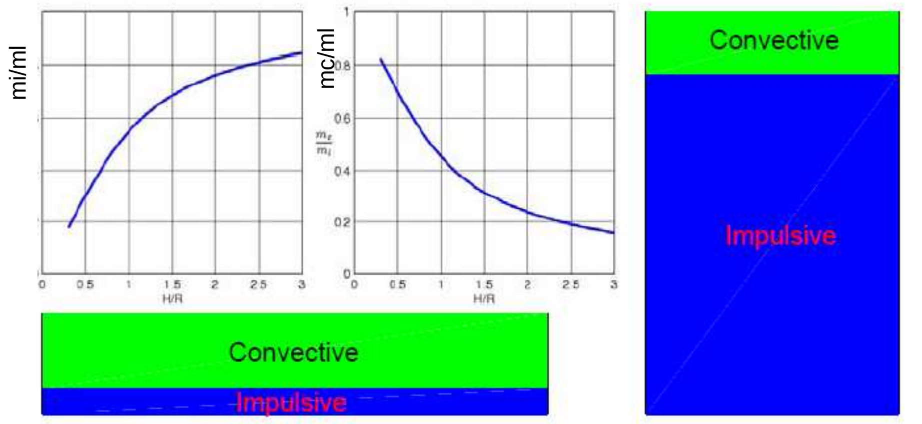


Impulsive and Convective Masses



P. K. Malhotra, 2006

Dynamic models : 4 models

3D Global “skewer” model

- 8 load configurations studied, combining :
  - filled / empty tank,
  - OBE/ SSE,
  - weak / stiff soil.

Dynamic models : 4 models

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- 3D Model “ground + raft (shells) + skewer”
- 3D “parasol” model

Dynamic models : 4 models

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- **3D Model “ground + raft (shells) + skewer”**
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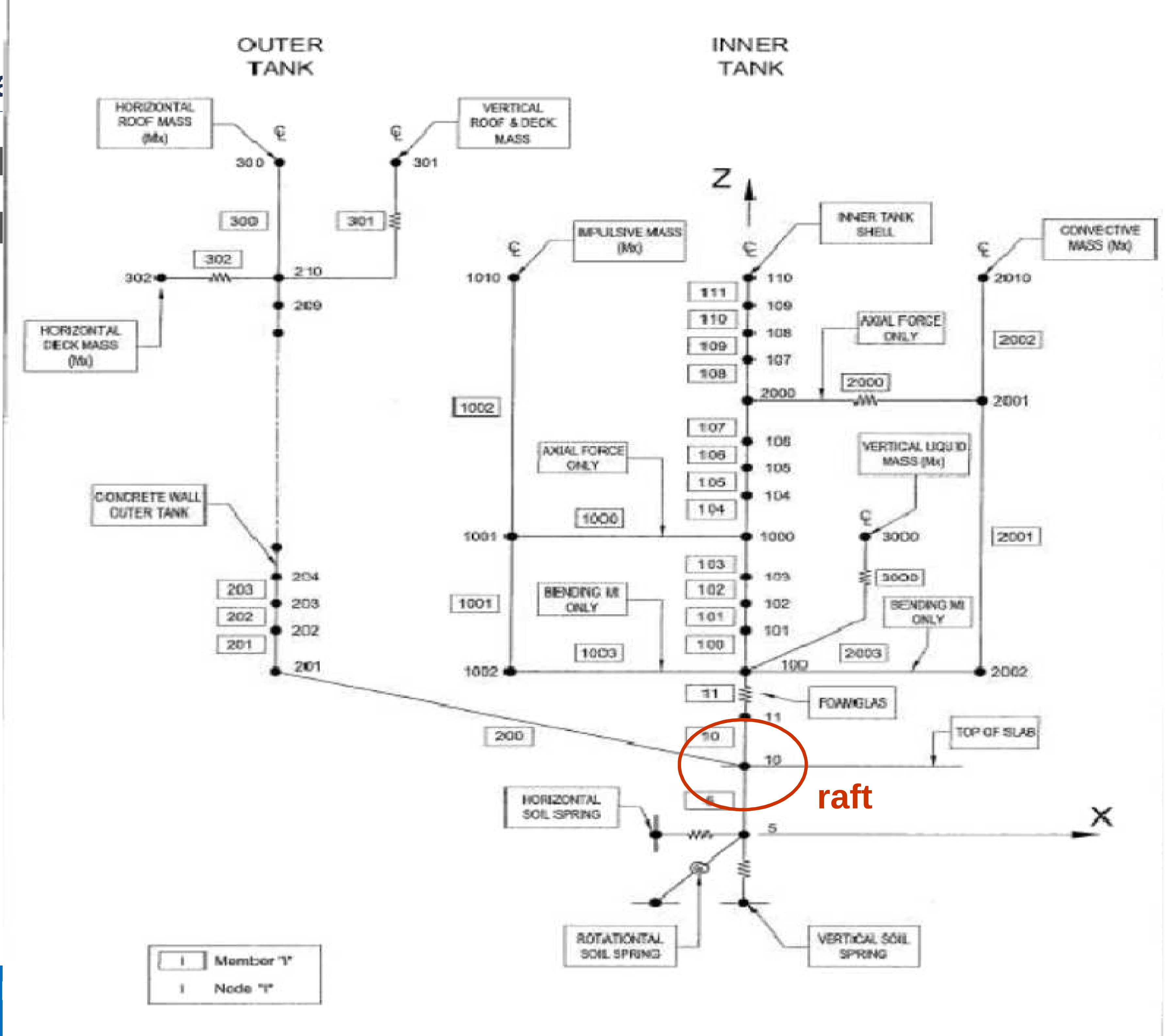
Structura

Dynai

3D I



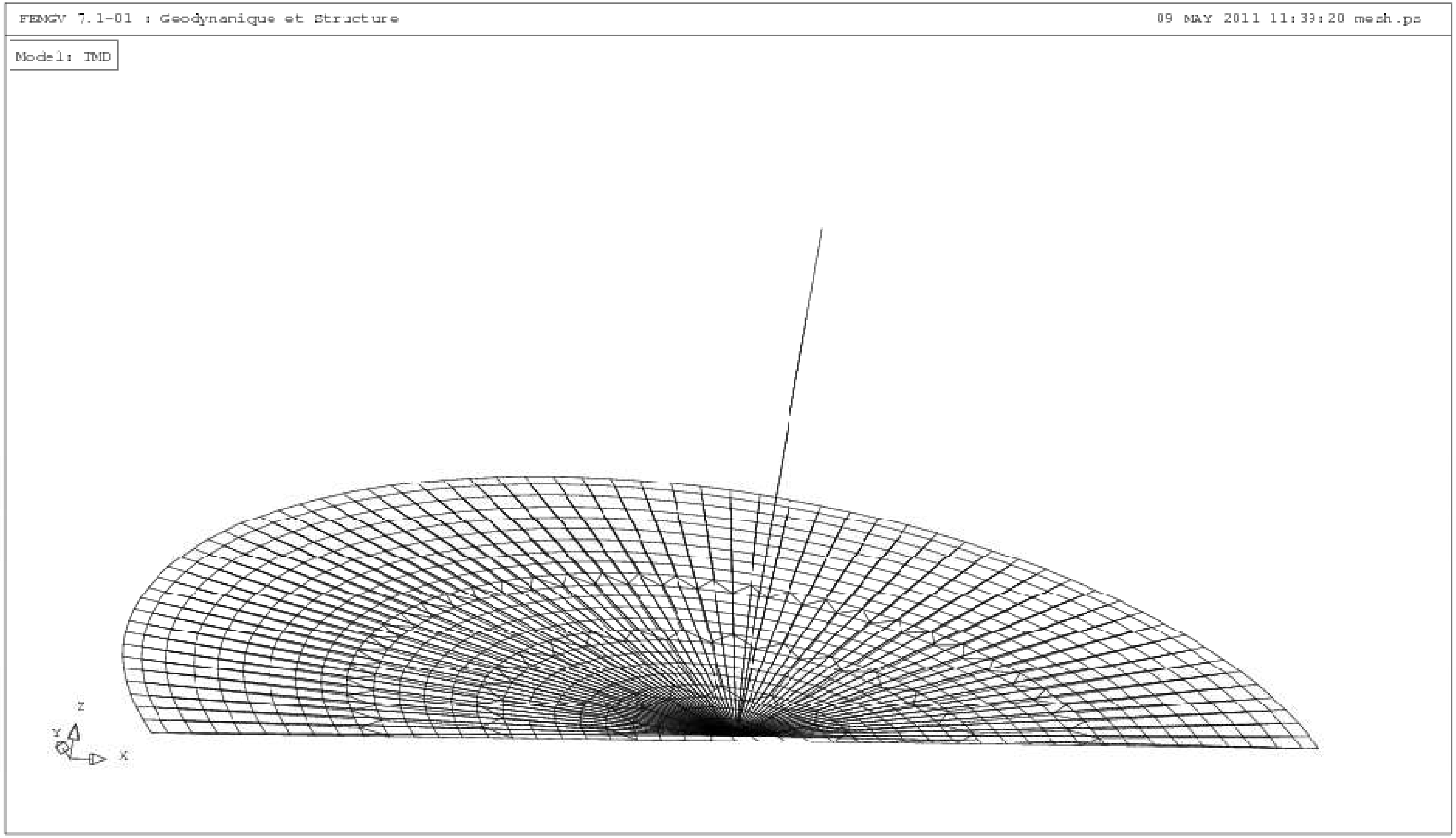
Dynamic models : 4 models

3D Model “ground + raft (shells) + skewer”

- Purpose: zoom of the lower part of skewer model ➔correct determination of seismic loads in the foundation raft, which cannot be done from the skewer model (raft not perfectly rigid)
- obtained by introducing into SASSI time history soil model the skewer model and a model of the raft, made up of shell elements, with their real thicknesses in the central part and rigid ones for the external circular ring located under the wall.
- Skewer connected by rigid connections to the external ring of the raft.

Dynamic models : 4 models

3D Model “ground + raft (shells) + skewer”



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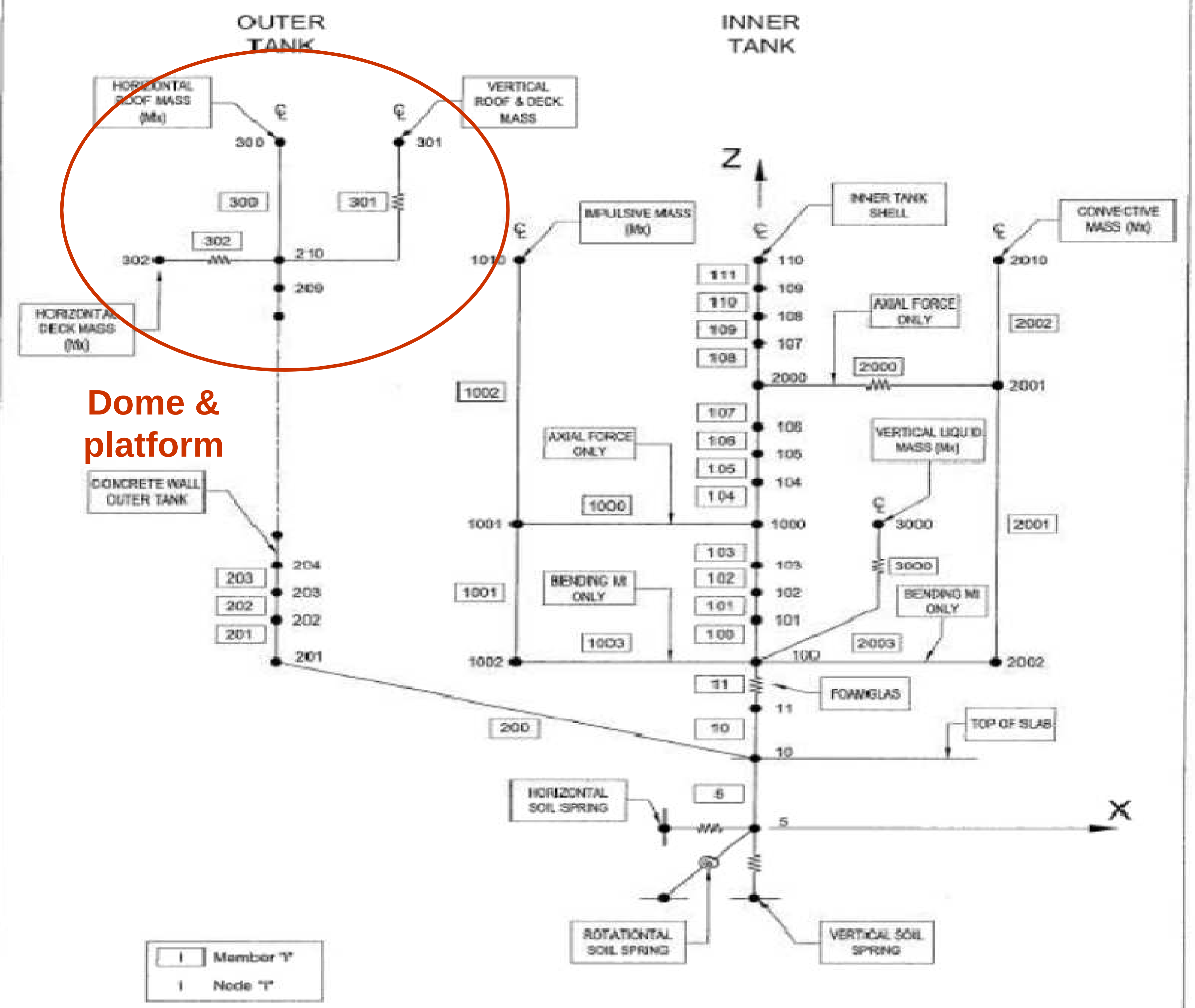
Structu

- **Dyna**
  - **3D**



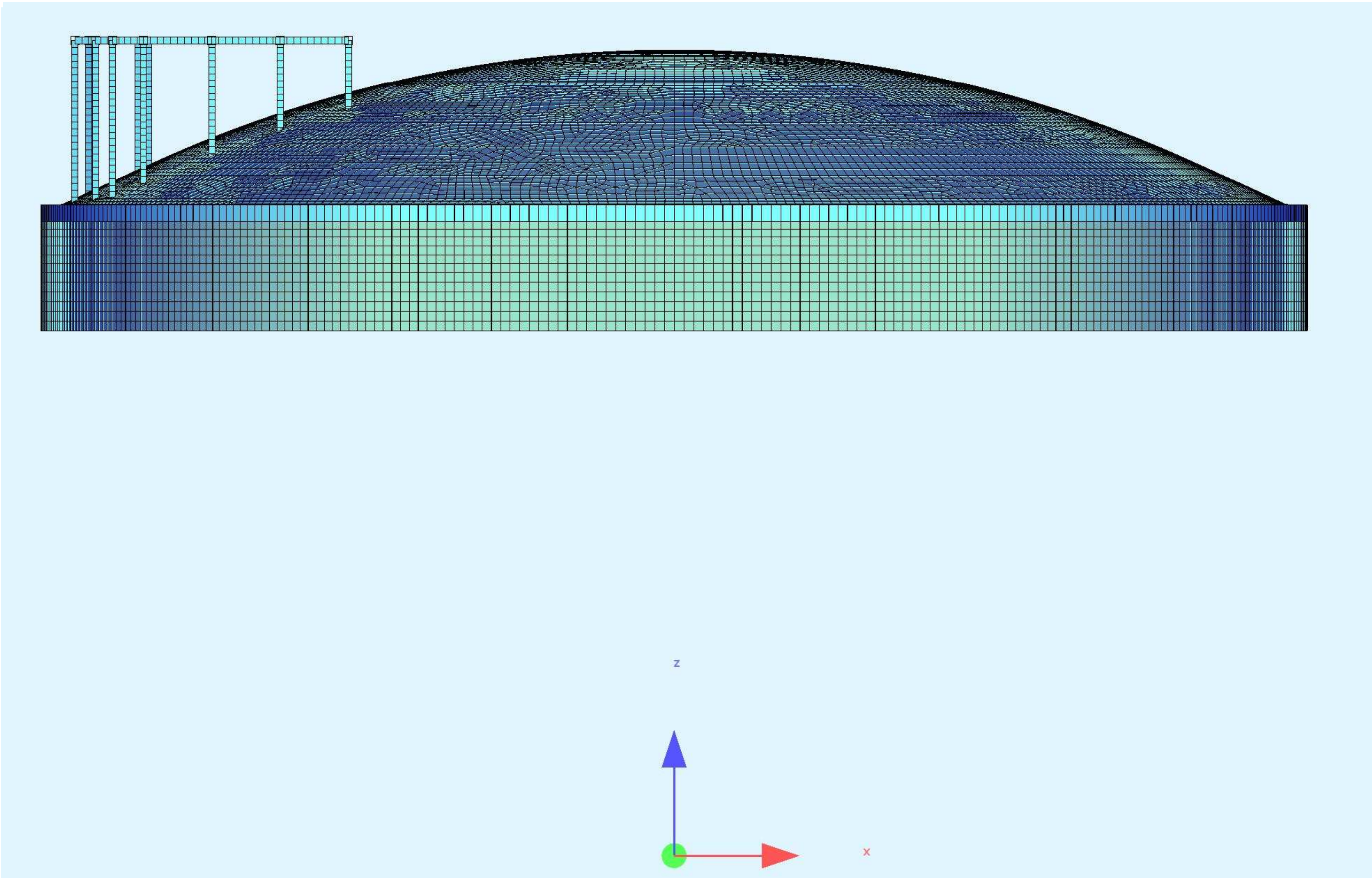
Dynamic models : 4 models

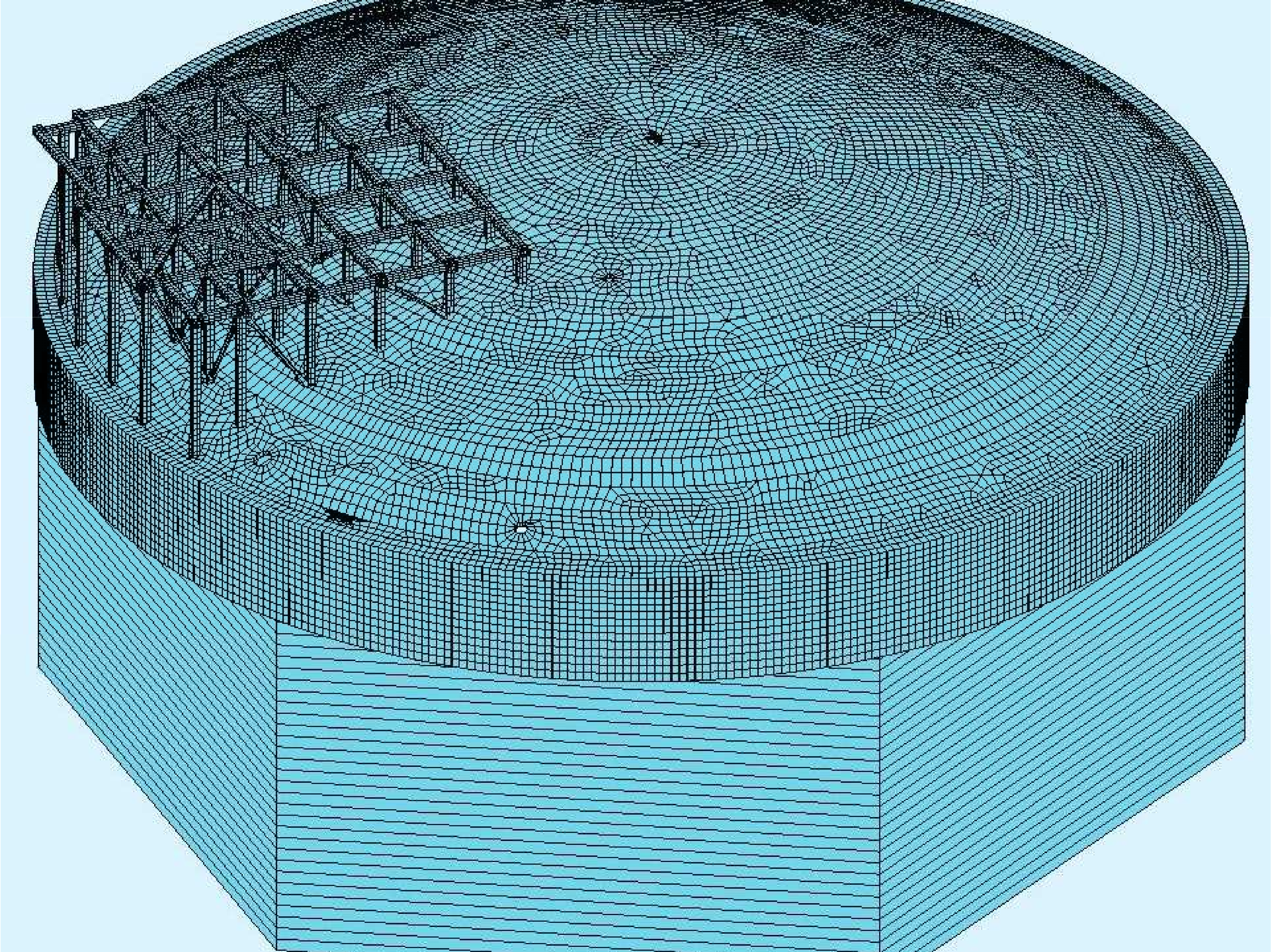
3D “parasol” model

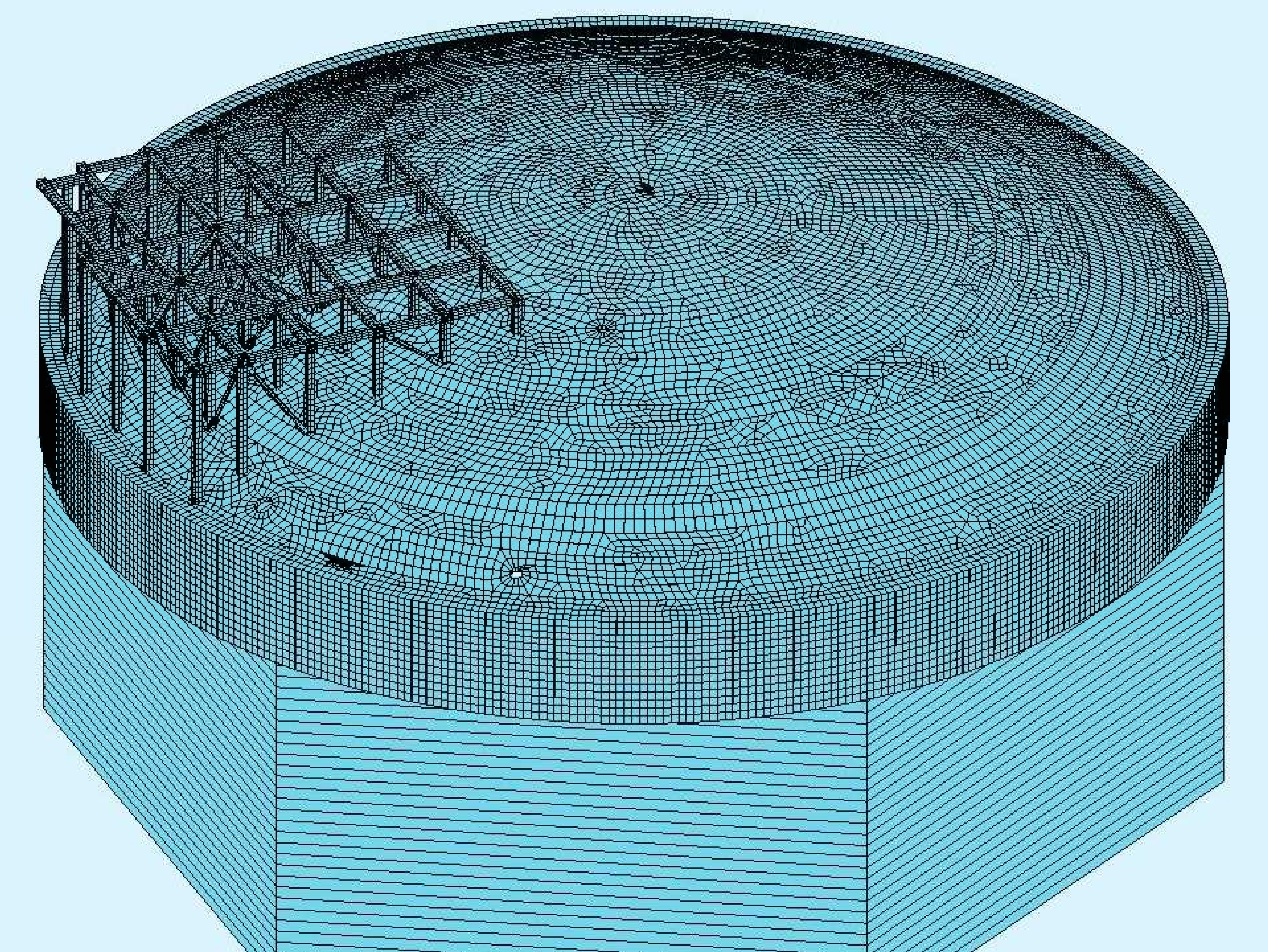
- Purpose: zoom of the upper part of skewer model ➔correct determination of seismic loads in the dome and the platform
- gathers elements from the skewer model and elements of the general 3D model.

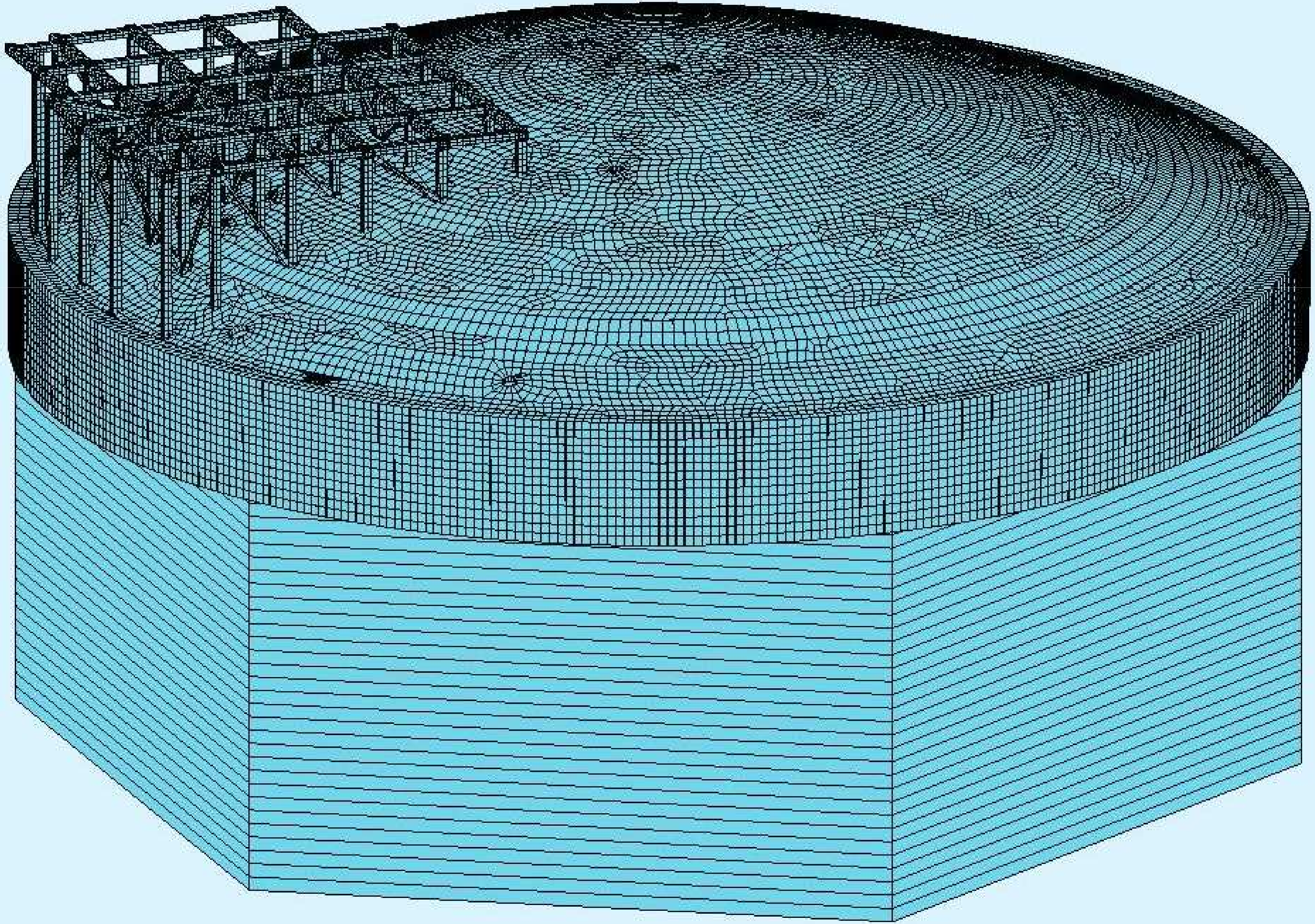
Dynamic models : 4 models

3D “parasol” model









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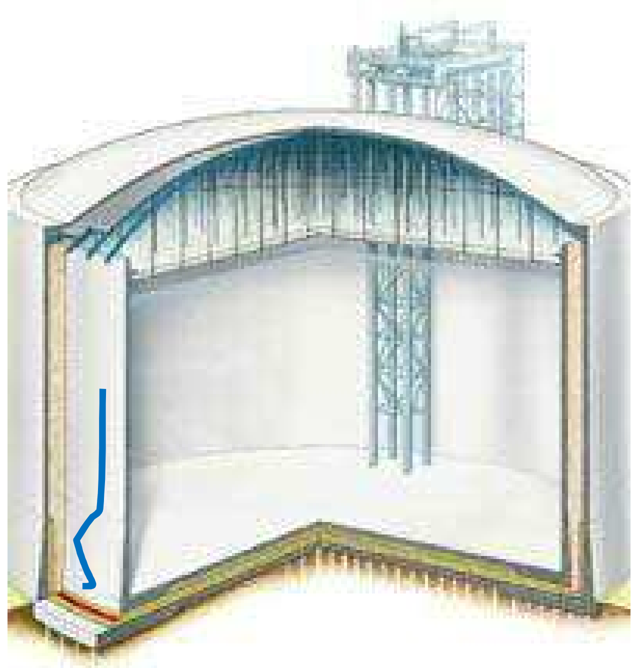
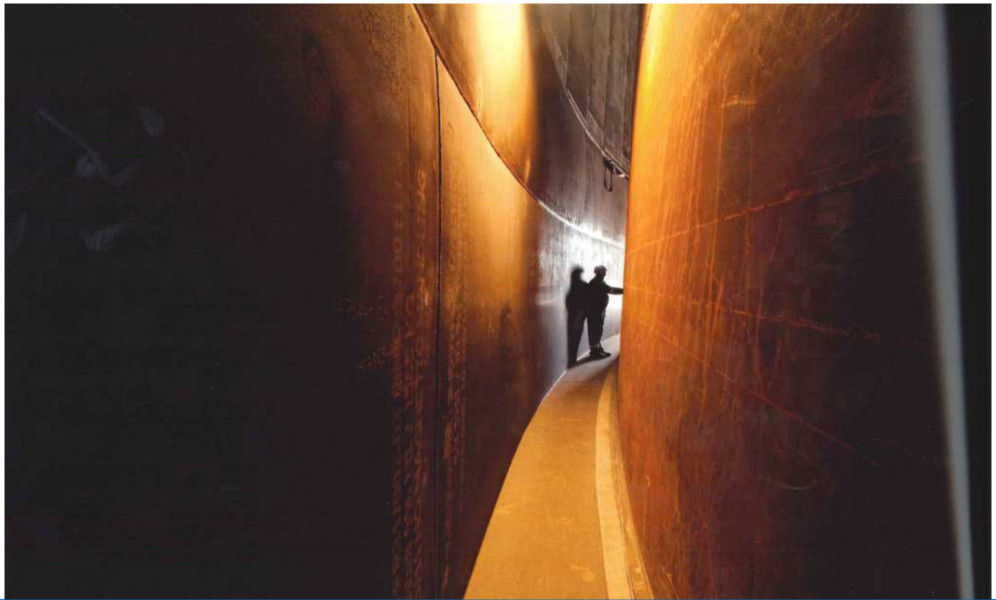
Thermo mechanical models

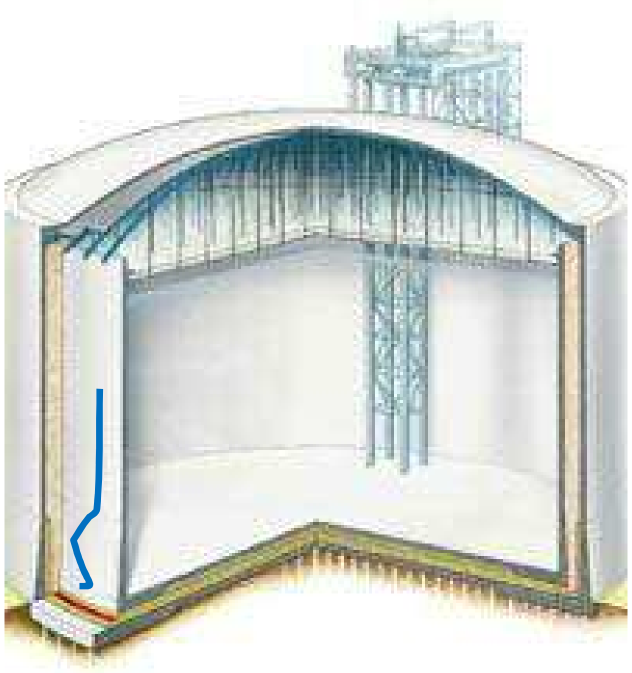
- Purpose : consequences of an important leakage in the inner metallic tank.
- entirety of the LNG transferred in the concrete outer tank.
- prestressed concrete wall in direct contact with LNG at -165℃ and bears the hydrostatic pressure.





Thermo mechanical models (ADDL)

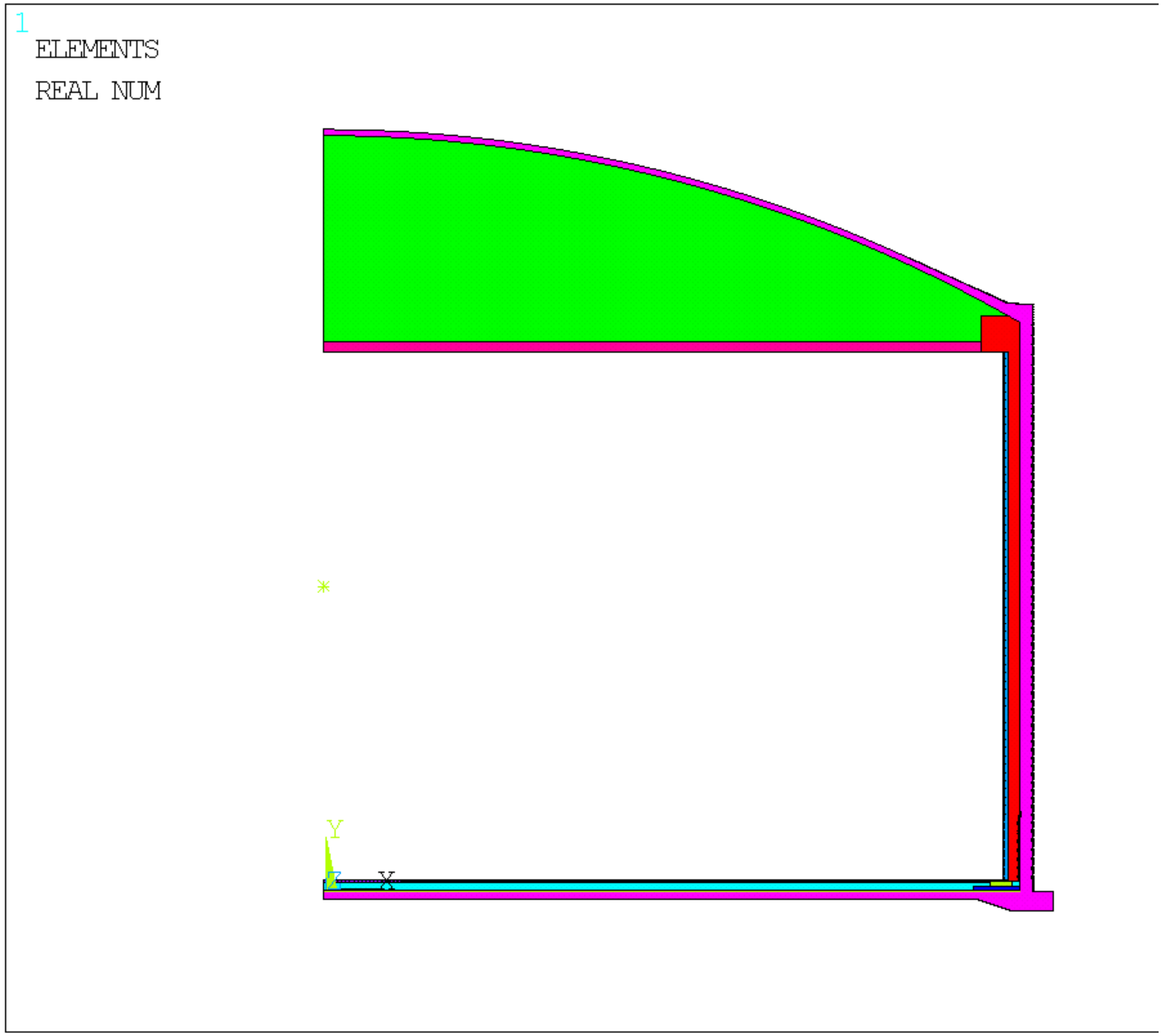
- ANSYS code
- 2 phases:
  - A thermal calculation, which determines temperature distribution.
  - a mechanical calculation, which integrates temperature distribution and mechanical loads.
- Purpose: check of the tightness of the outer wall : minimum compression zone of 100 mm in concrete section



Thermo mechanical models

Thermal model:

- 2D axi-symmetrical
- Non linear calculation: thermal properties depend on temperature

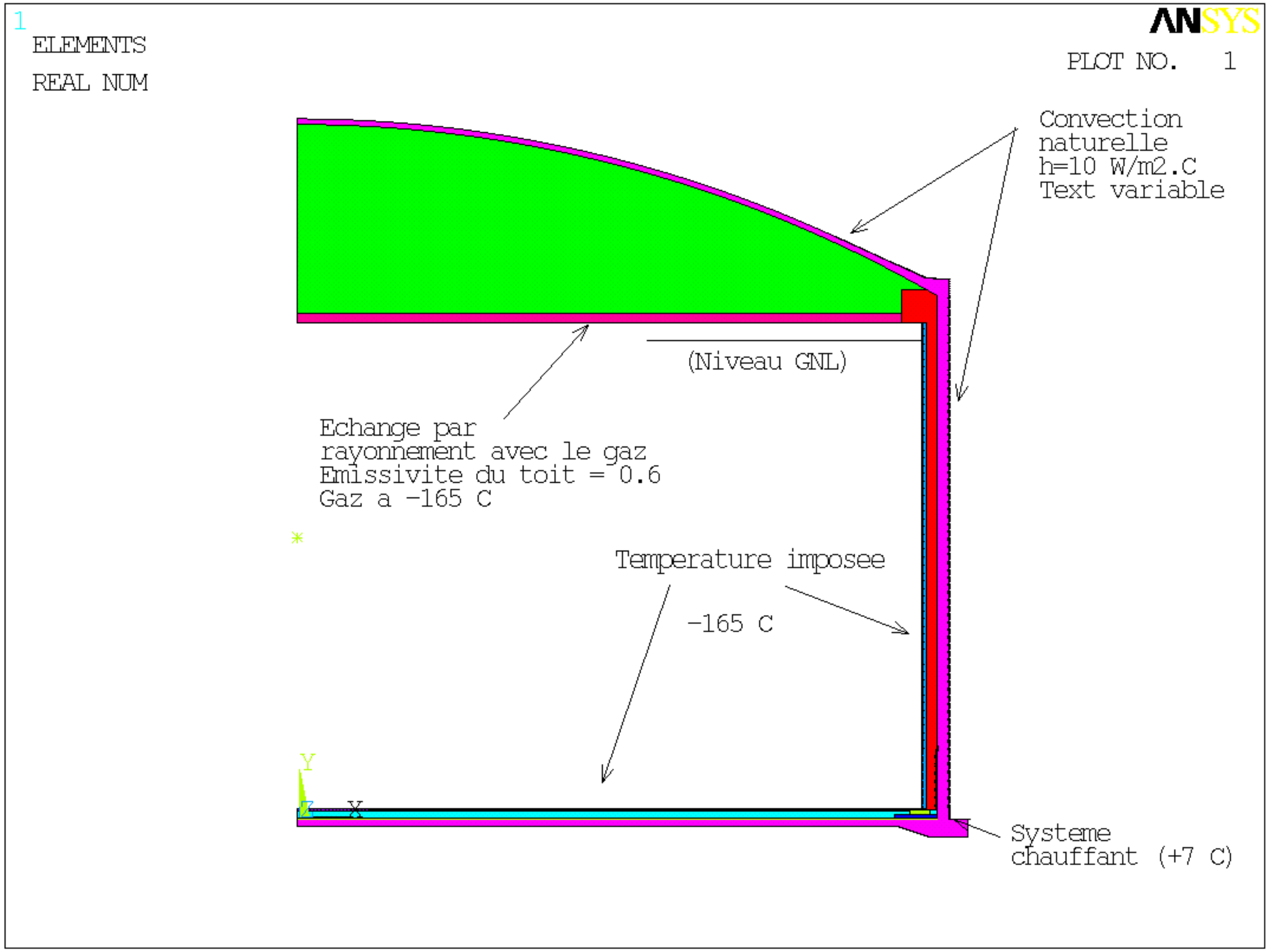


Thermo mechanical models

Thermal model:

– 2 analyses:

- **Service configuration:**
  - LNG contained by inner tank;
  - efficient insulation

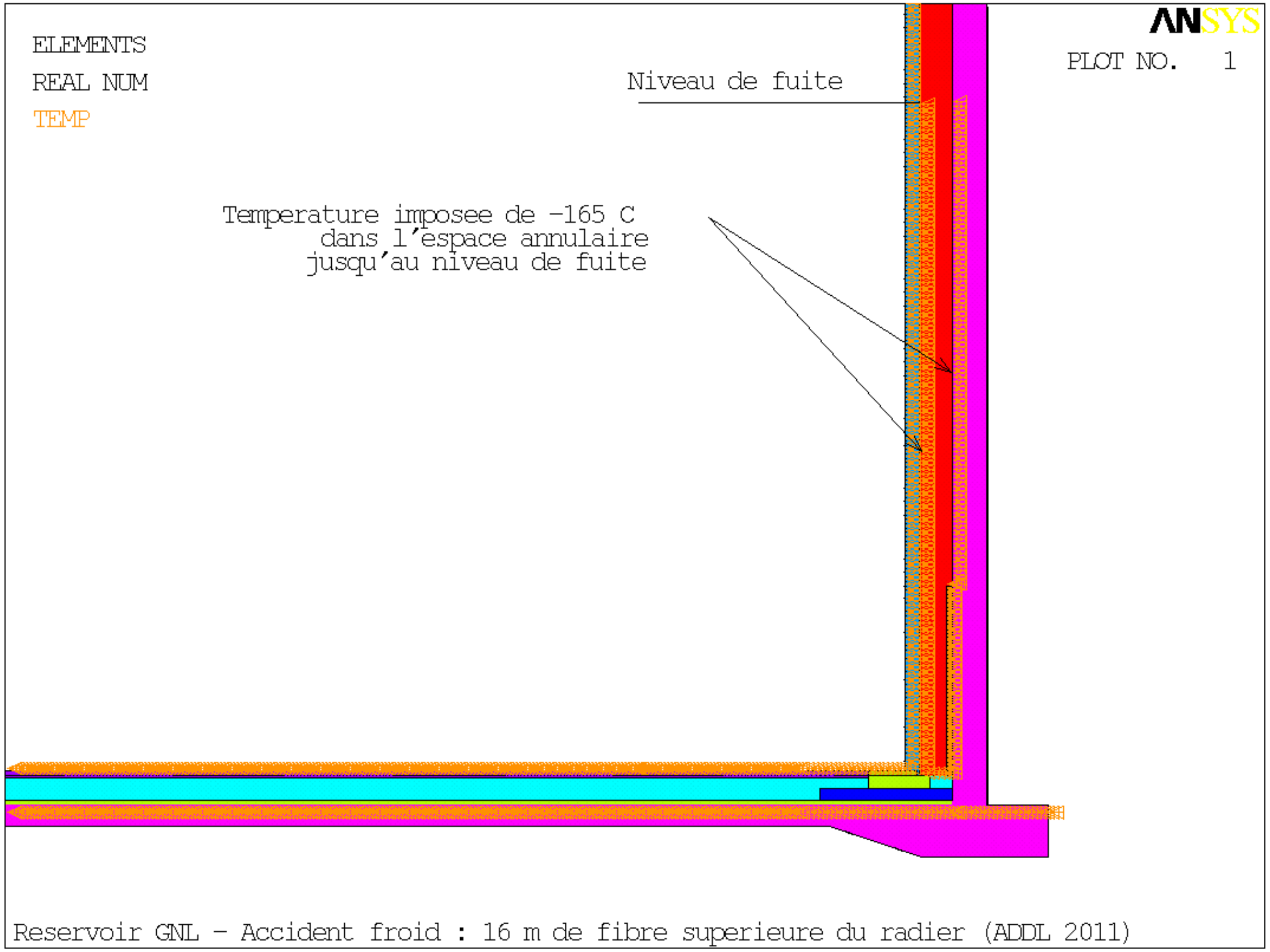


Thermo mechanical models

Thermal model:

– 2 analyses:

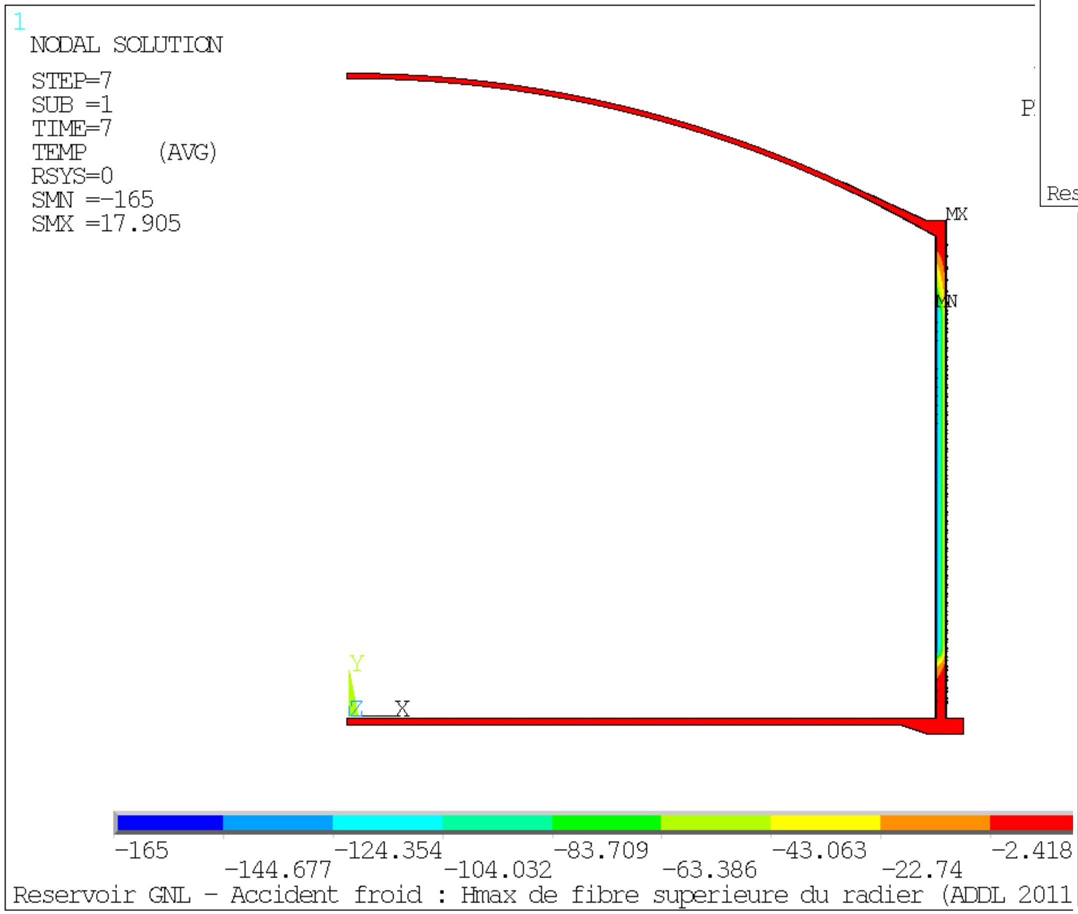
- **Accidental scenario**;
  - LNG in annular space;
  - insulation unefficient except raft / corner protection
  - 6 levels of outer tank filling

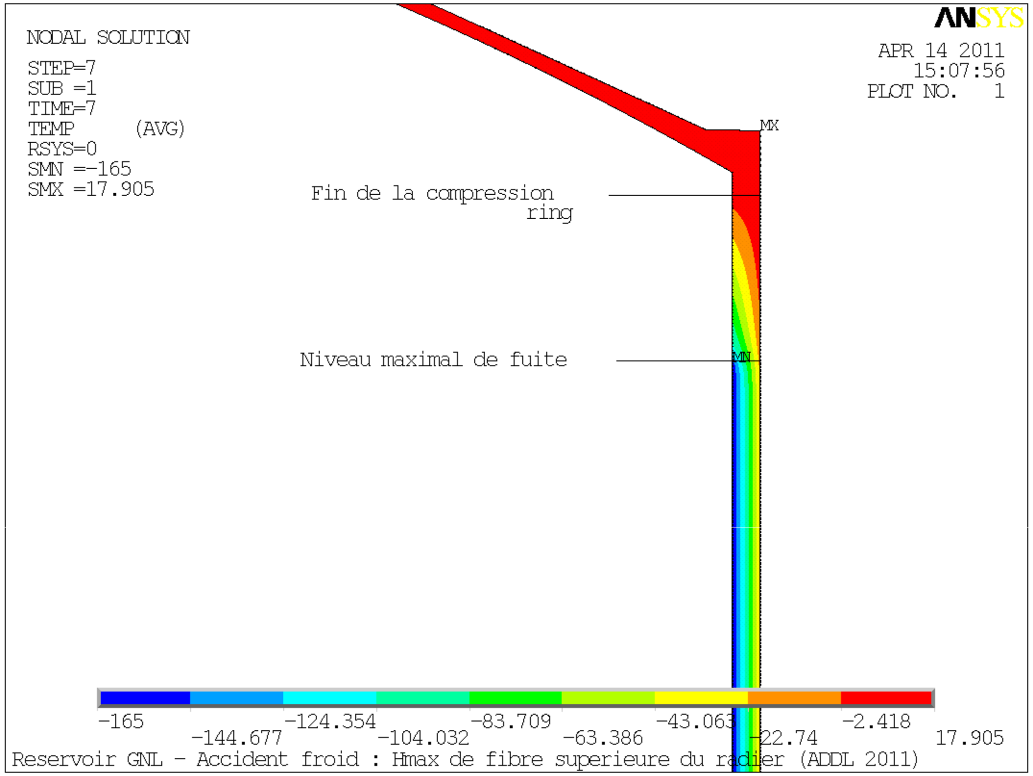


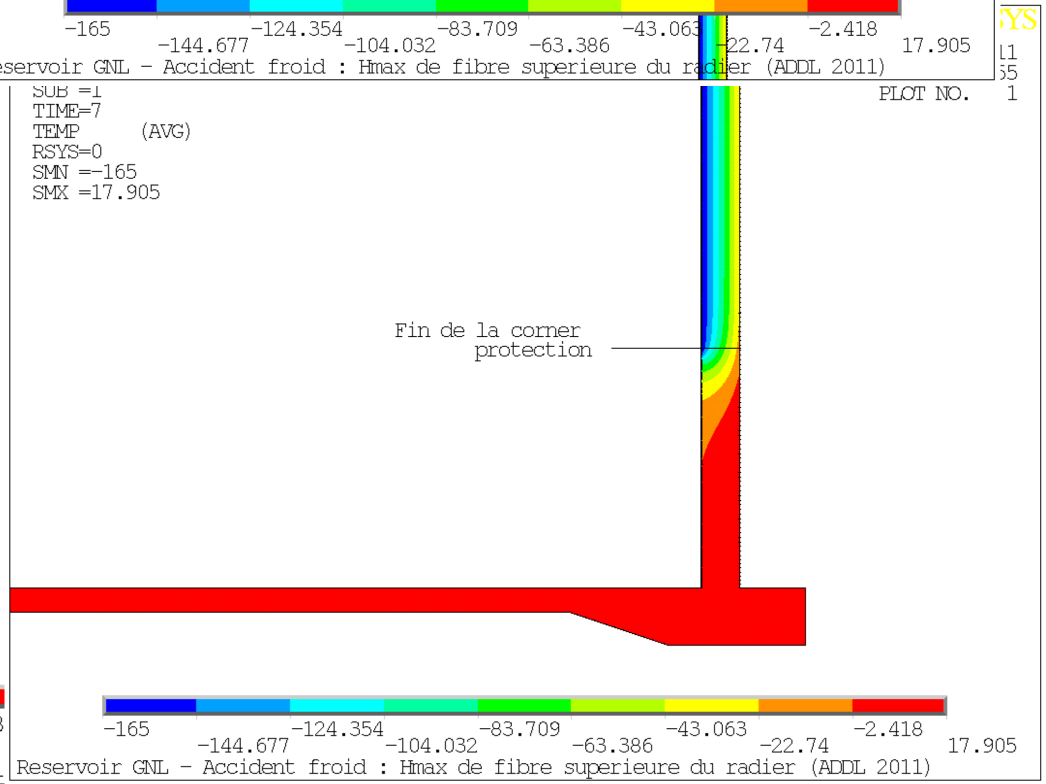
Structural problematics and mode

Thermo mechanical mo

- Thermal model: results:
  - 31 m leakage



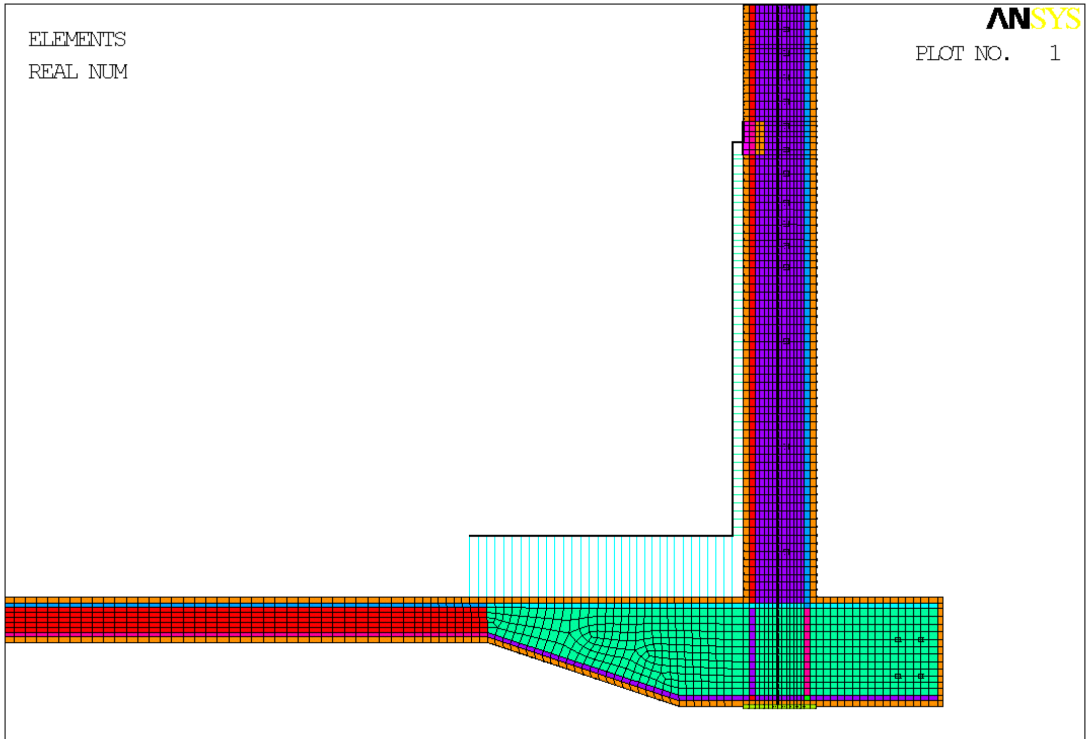




Structural problematics and mod

Thermo mechanical m

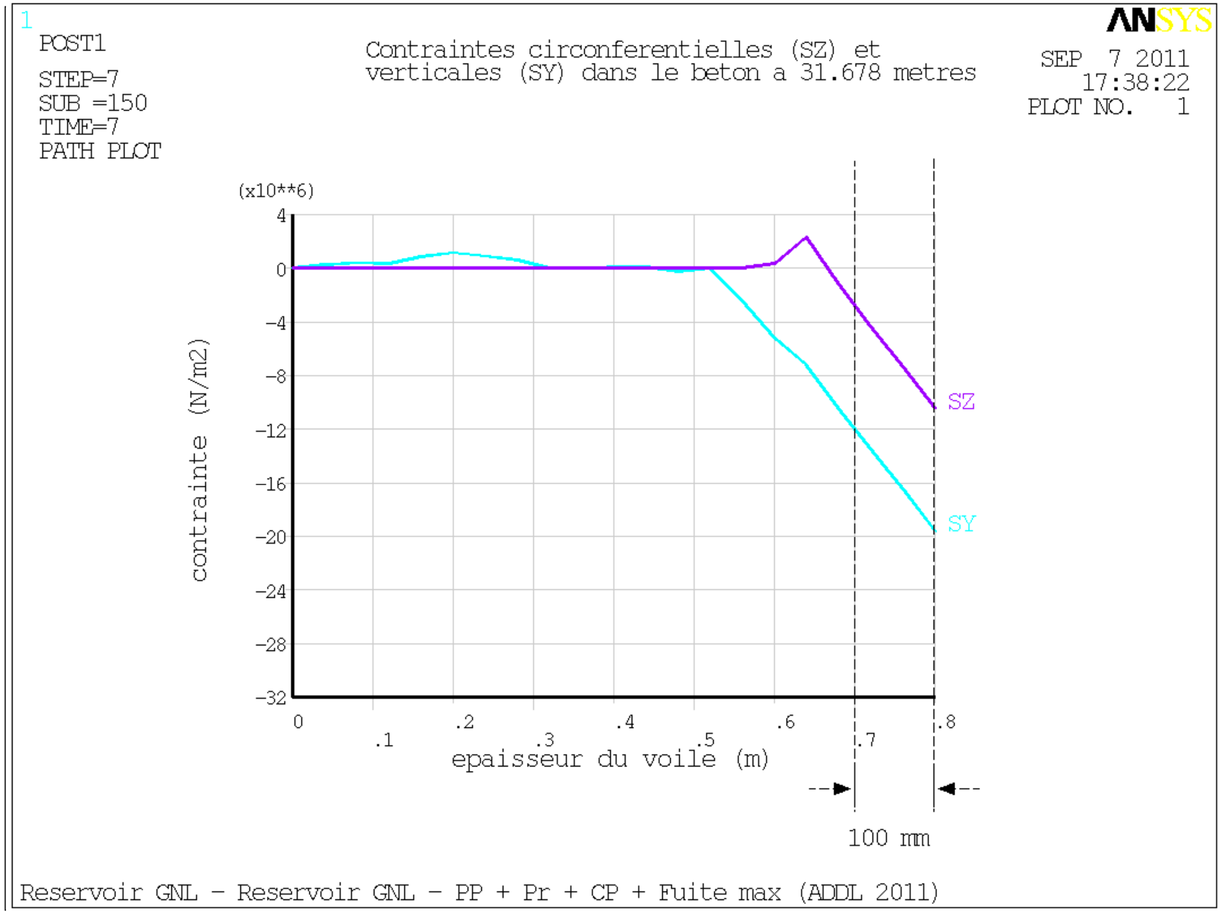
- Mechanical model:
  - 2D axi-symmetrical
  - Non linear calculation:
    - fck(θ), E(θ)
    - fp(θ), Ep(θ)
    - fy(θ), Es(θ)
    - Plasticity / cracking of concrete
    - Reinforcement = equivalent steel densities
    - Steel plasticity
  - P=290 mbarg



Thermo mechanical models

Mechanical model: results

- check of the tightness of the outer wall : minimum compression zone of 100 mm in concrete section
- Governs horizontal and vertical prestress



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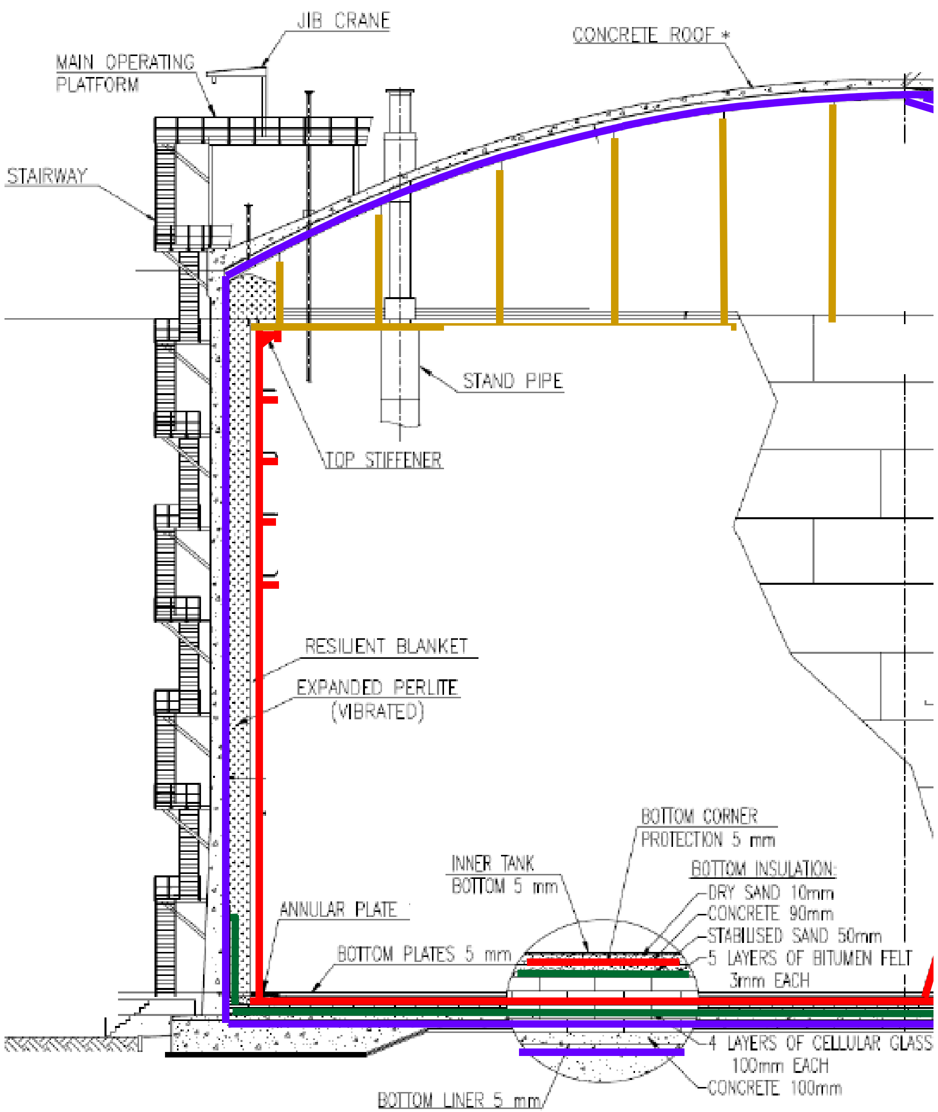
Overfilling scenario

- accidental overfilling of the tank
- LNG flow =14000 m^3/h during 30 minutes
- LNG overflows the inner tank and progressively invades the annular gap between inner and outer tank, filled with perlite.
- internal gas pressure increases quickly following partial evaporation of the LNG in contact with the warmer elements of the annular gap.
- Frangibility : damage of the roof under the corresponding over pressure will occur in the first place enabling the over pressure to be dissipated and the containment of LNG still being ensured by the outer concrete wall and raft.

Overfilling scenario



Cuve Primaire
Acier 9%Ni
Contient le liquide en opération normale

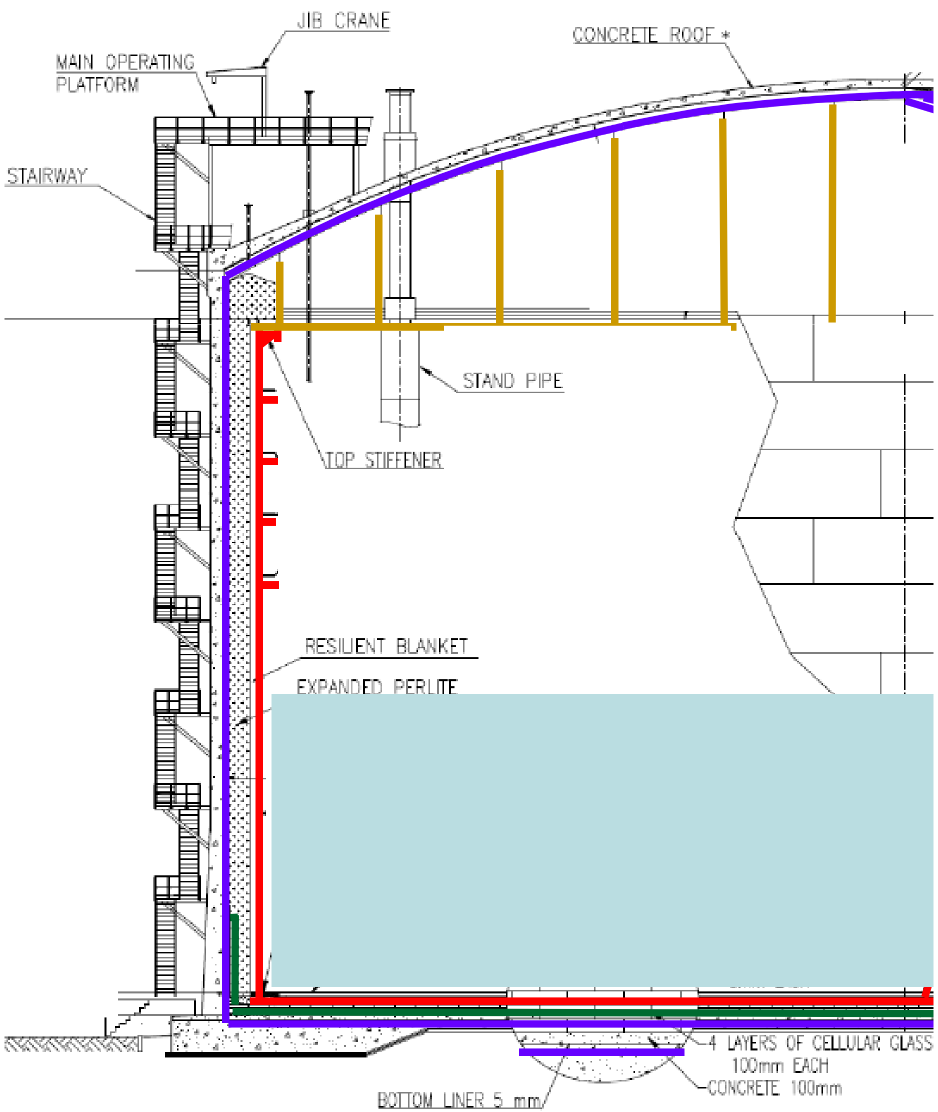
Cuve Externe
Contient le liquide en cas de fuite de l'enceinte primaire
Protège l'ouvrage des scénarii accidentels

Fond Secondaire
Acier 9%Ni
Contient le liquide en cas de fuite mineure

Barrière Vapeur
Acier carbone
Contient la vapeur en opération normale

Plafond Suspendu
Aluminium
Supporte l'isolation supérieure

Overfilling scenario



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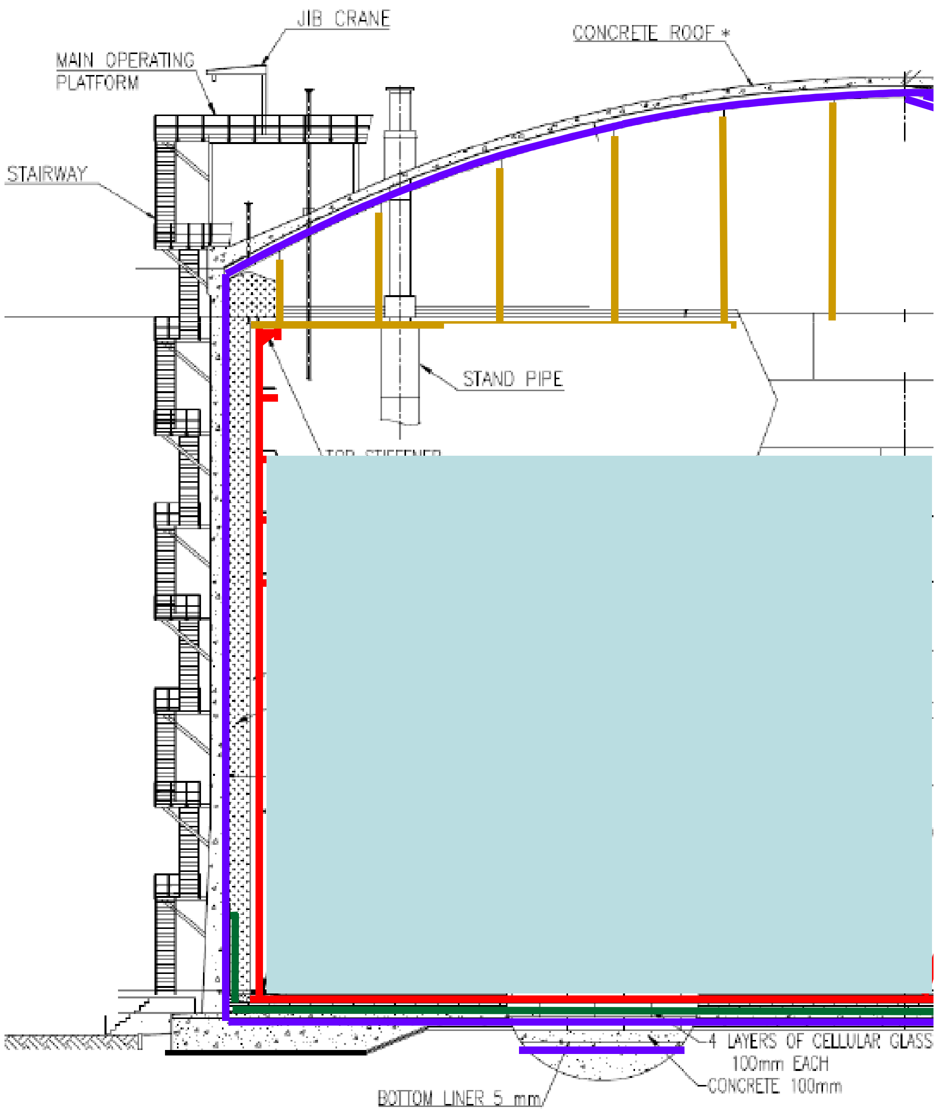

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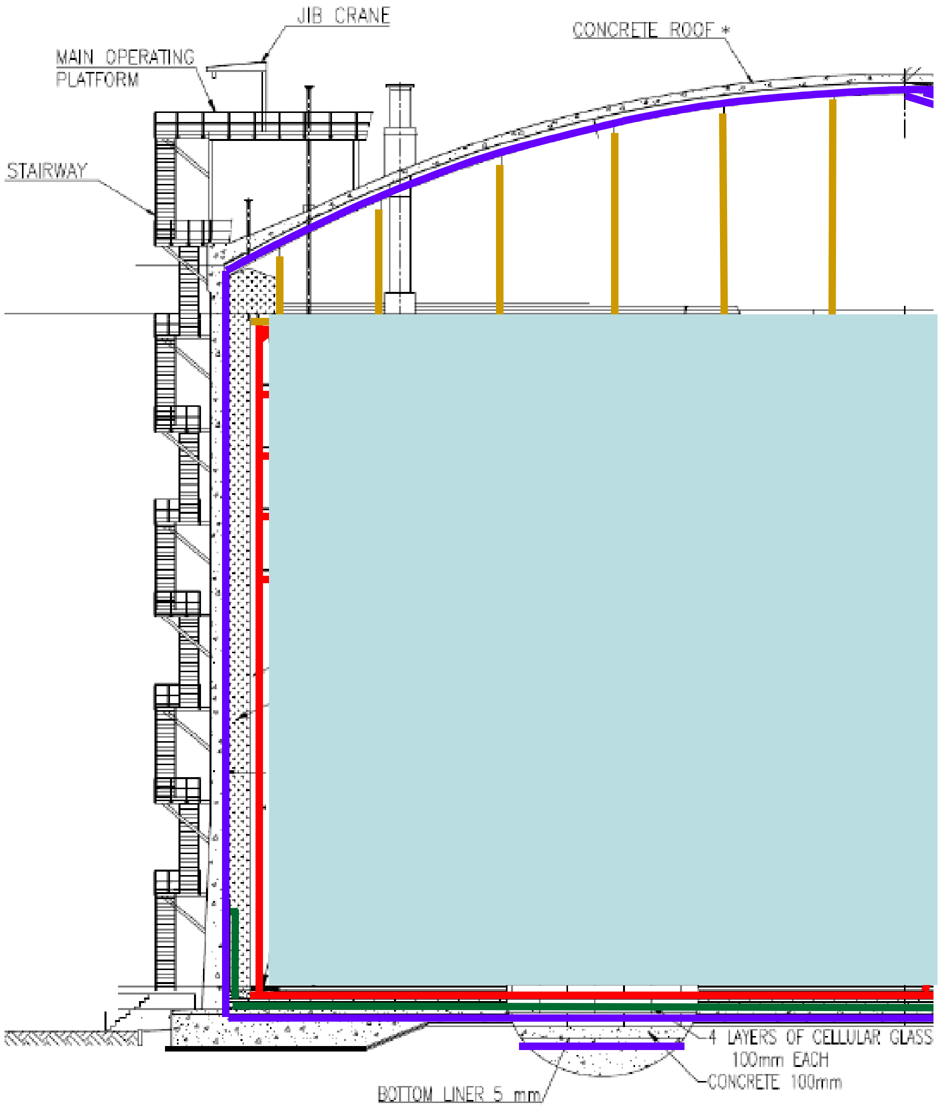

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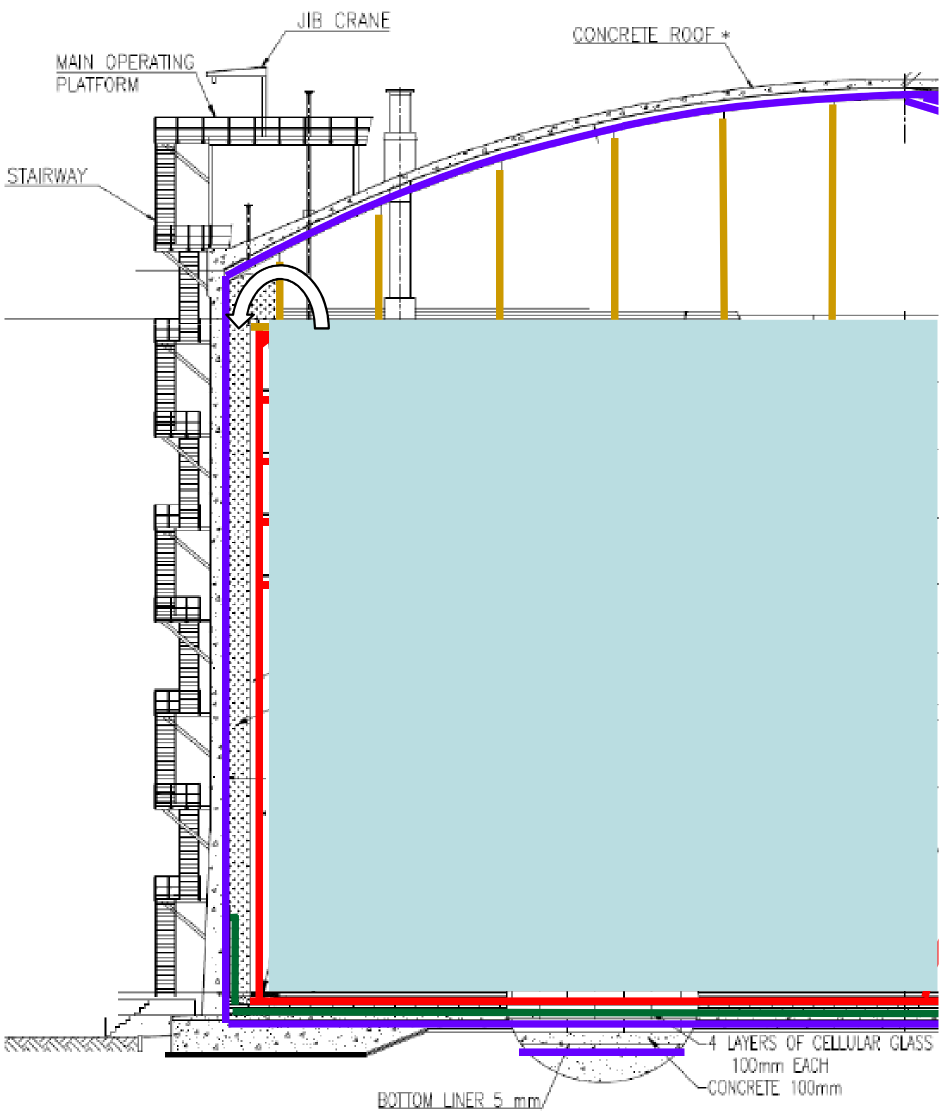

•t=0: start of overflow

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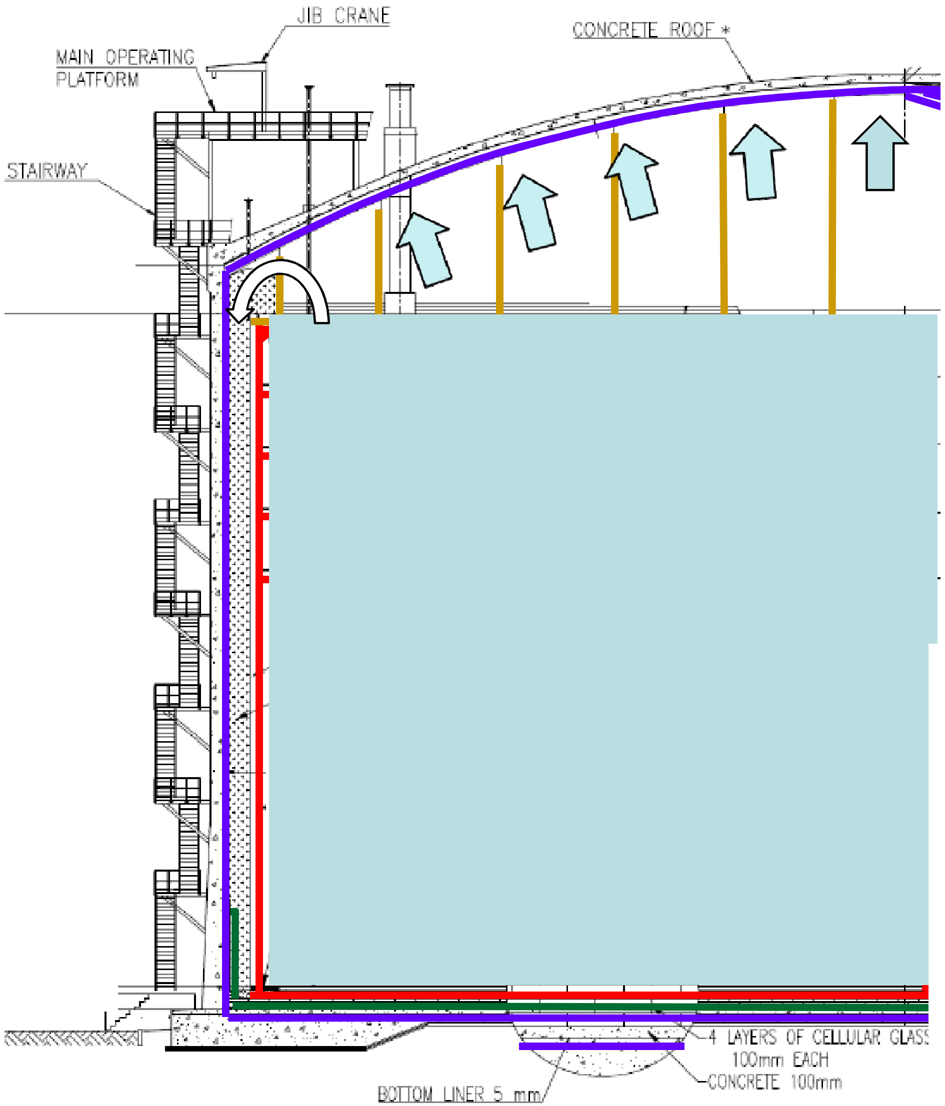

- t=0: start of overflow

Cuve Primaire
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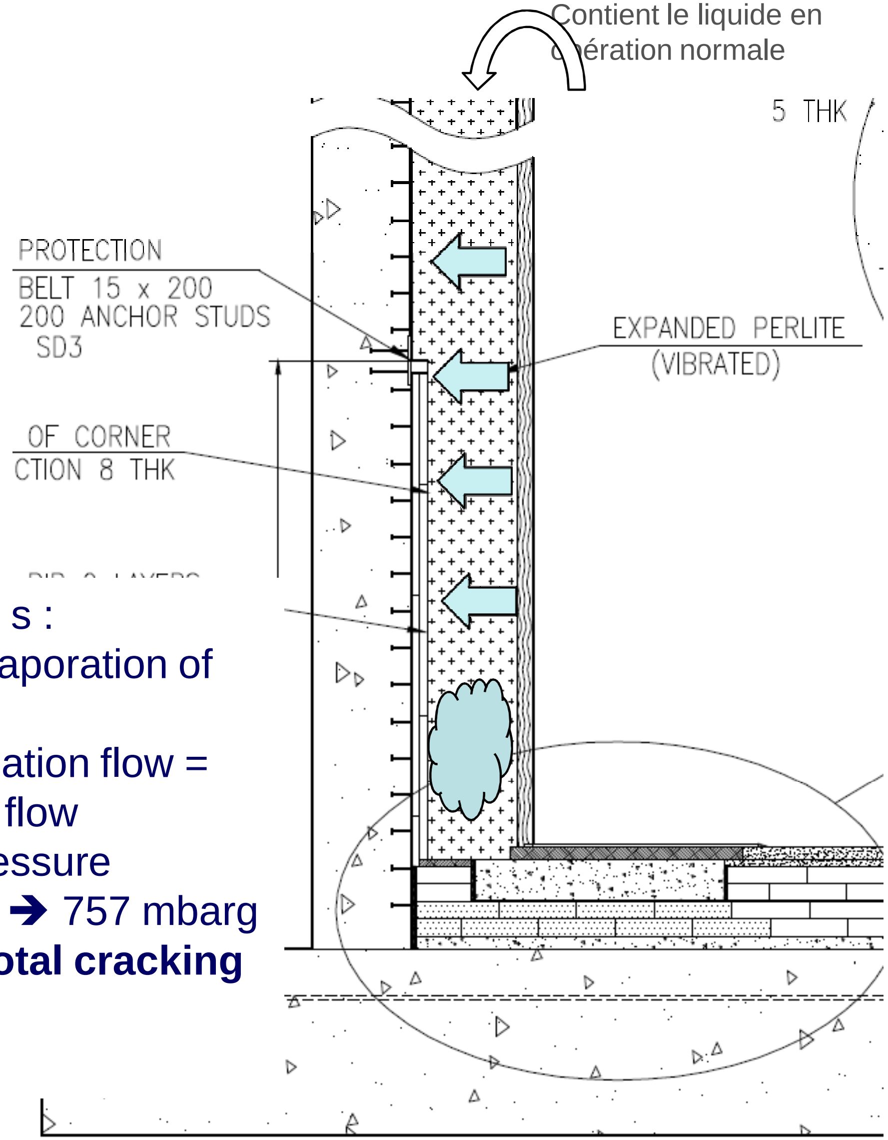
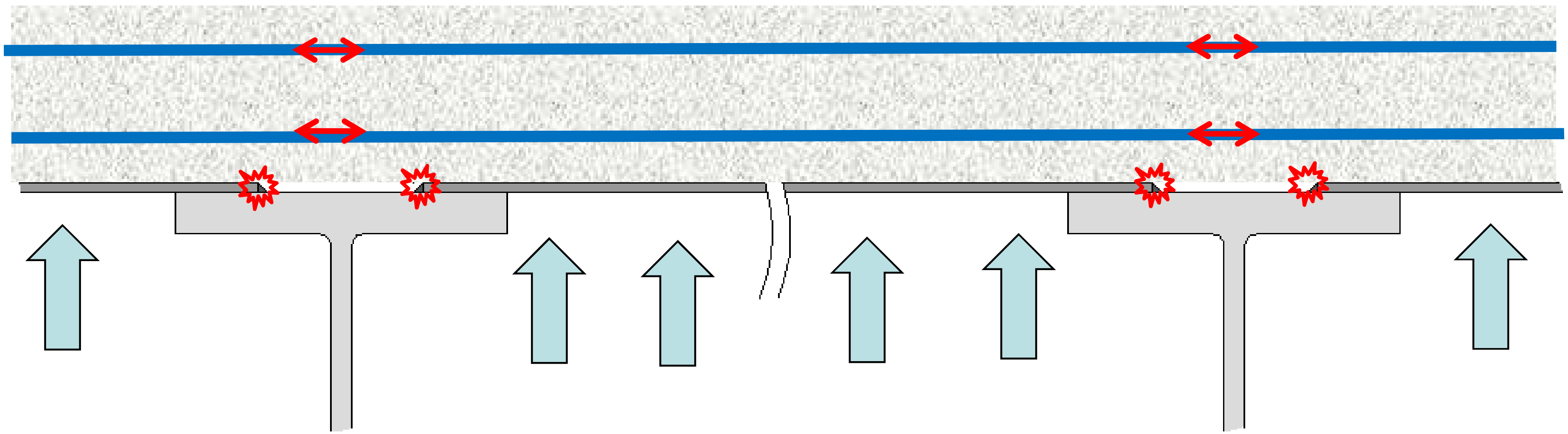
Contient le liquide en opération normale



- t=0 to t=40 s :
  - ➢ total evaporation of LNG
  - ➢ Vaporization flow = overfilling flow
  - ➢ Gas pressure increases ➔ 757 mbarg = **dome total cracking**

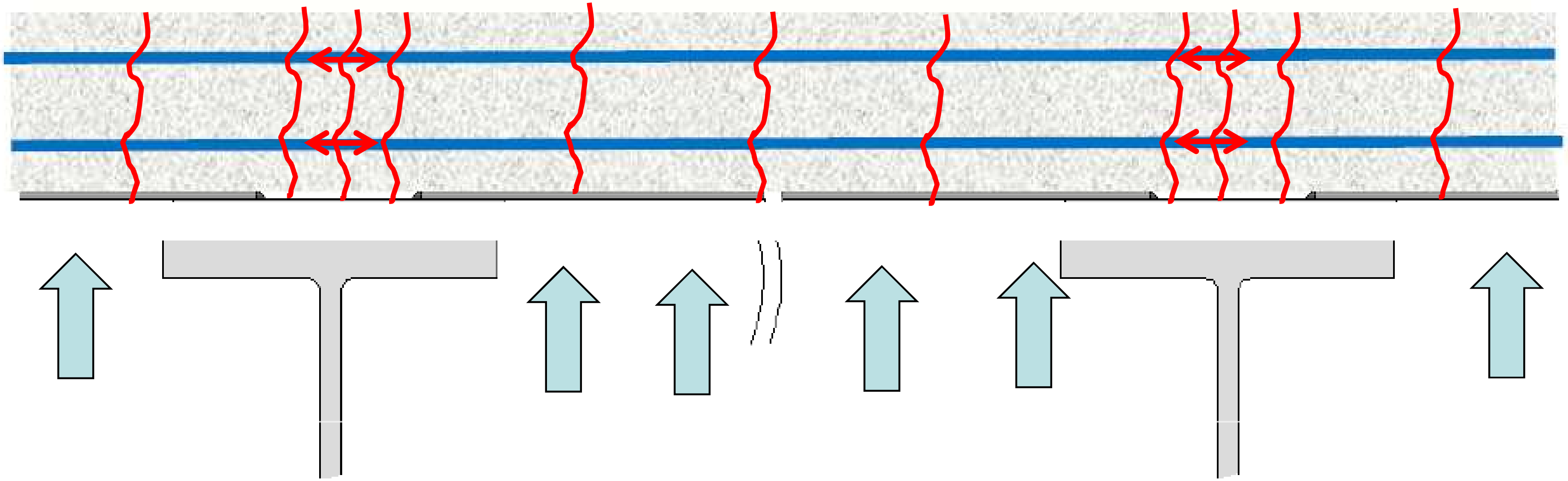
Dome cracking pressure



- P2=757 mbarg → weld failure
- Tension redistributed in rebars
- Rebar plastification; large rebar deformation
- Separation dome / rafter

Overfilling scenario

▶Dome cracking pressure



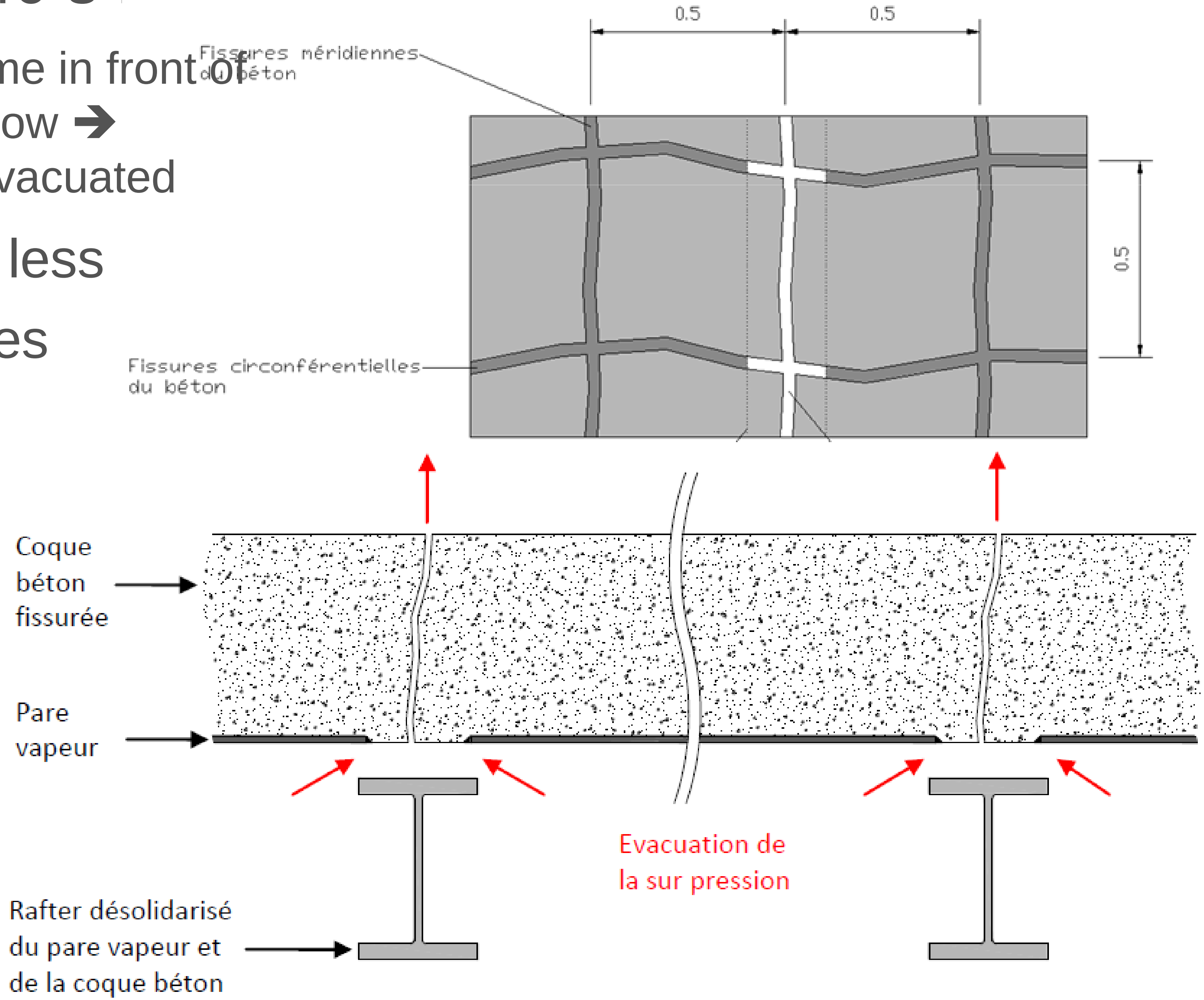
- ▶P2=757 mbarg → weld failure
- ▶Tension redistributed in rebars
- ▶Rebar plastification; large rebar deformation
- ▶Separation dome / rafter
- ▶Cracking of dome

Overfilling scenario

- t=0 to t=40 s :

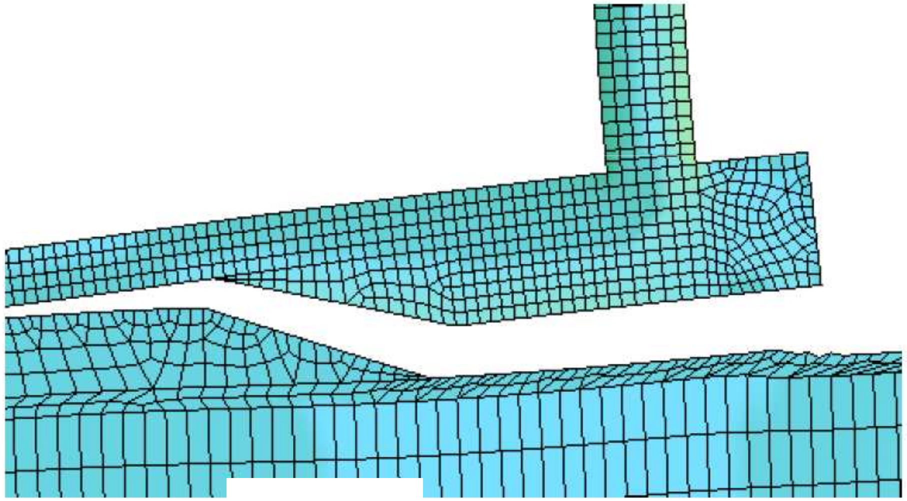
- Cracking of dome in front of rafters ➔ gas flow ➔ overpressure evacuated

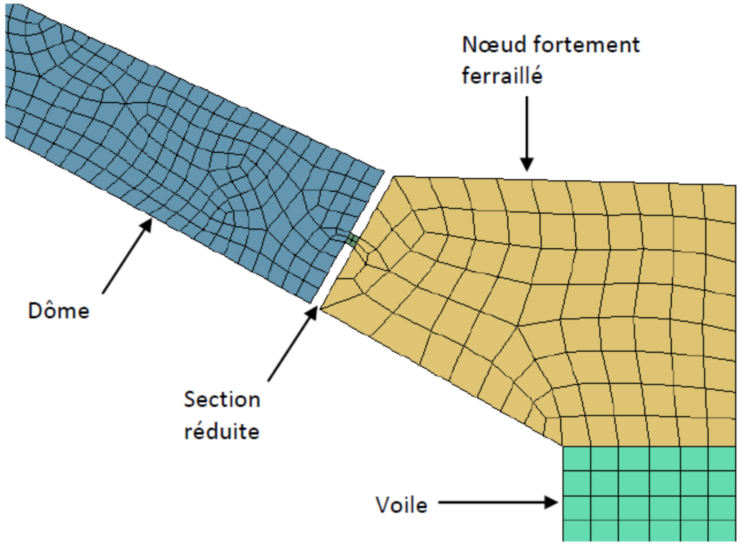
- t > 40 s : less critical phases



Dome frangibility

- integrity of outer concrete wall and raft ensured during the accident.
- 3D axisymmetrical used with modifications:
  - dome : totally cracked; section of the dome = section of passive reinforcement
  - sliding and uplift at the interface between raft and soil
  - Hinge between dome and gusset at 620 mbarg



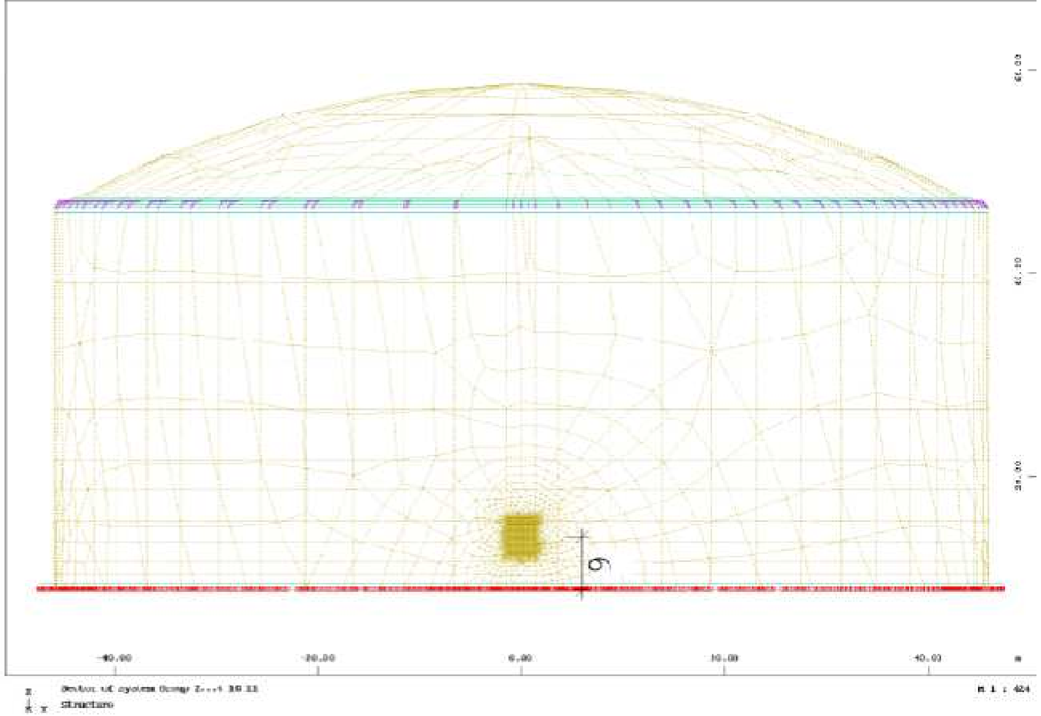


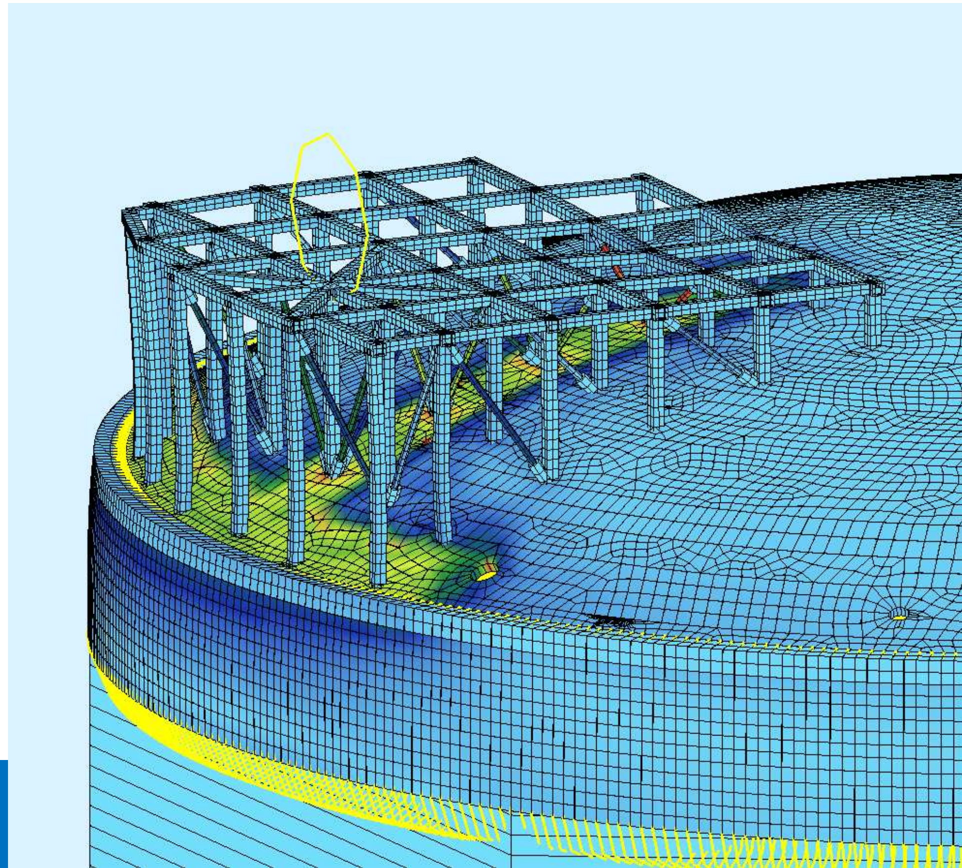
Dome frangibility

- elasto plastic calculations
- 1st set: dome cracking pressure
  - initial stage :
    - LNG at maximum level in the inner tank
    - design gas pressure of 290 mbarg.
  - Accidental overpressure applied till 757 mbarg
- 2nd set: end of the overfilling scenario:
    - maximum LNG level in the annular gap;
    - dome, completely cracked, suppressed in the model.
    - pressure = atmospheric pressure.
- integrity of wall and raft during overfilling scenario demonstrated.

Other situations

- Construction phases
- Accidental situations
  - Cold spot
  - fire hazard,
  - LNG leakage on the dome
- Platform study





Conclusion

- Various situations → Different models; most specific :
  - geotechnical context (compressible and liquefiable soil, conception of soil improvement),
  - seismic behaviour (interactions between inner tank, liquid, outer tank, suspended deck, foundation and soil)
  - accidental scenarios (major leakage, overfilling).
- Partnership with Entrepose

Conclusion