NUCLEAR CONTAINMENT DESIGN

Computation of necessary pre-stress tendons

Paul Ionescu
Group NUC1

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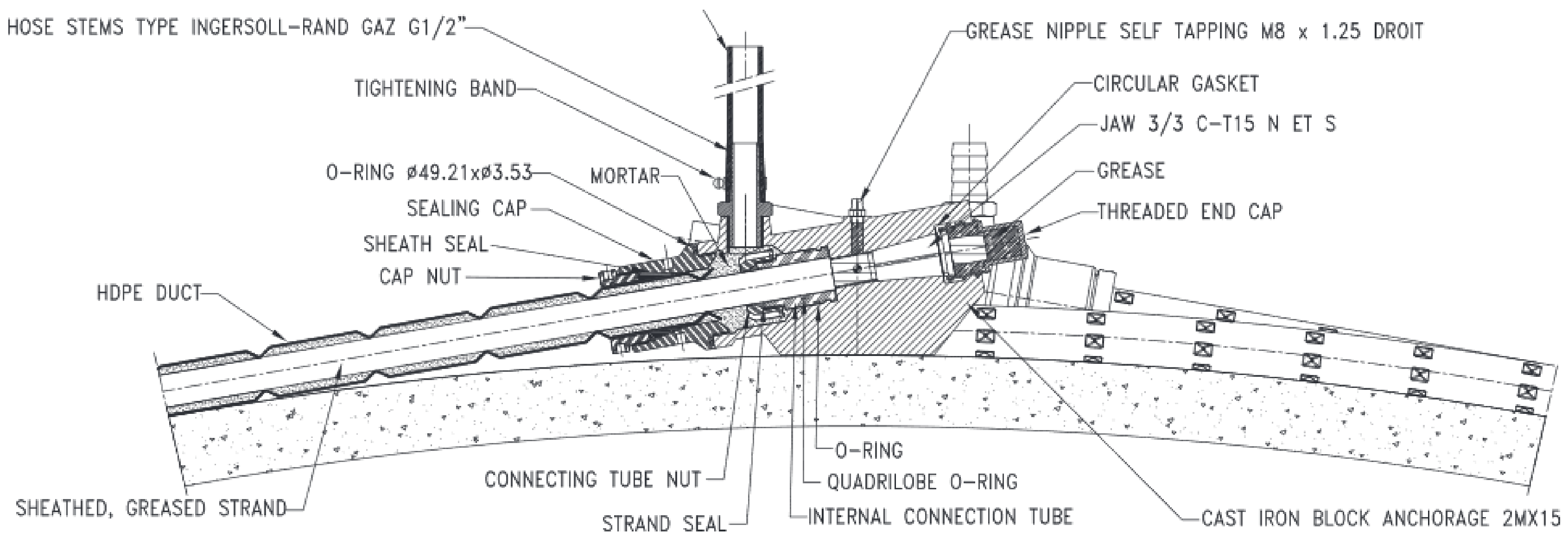
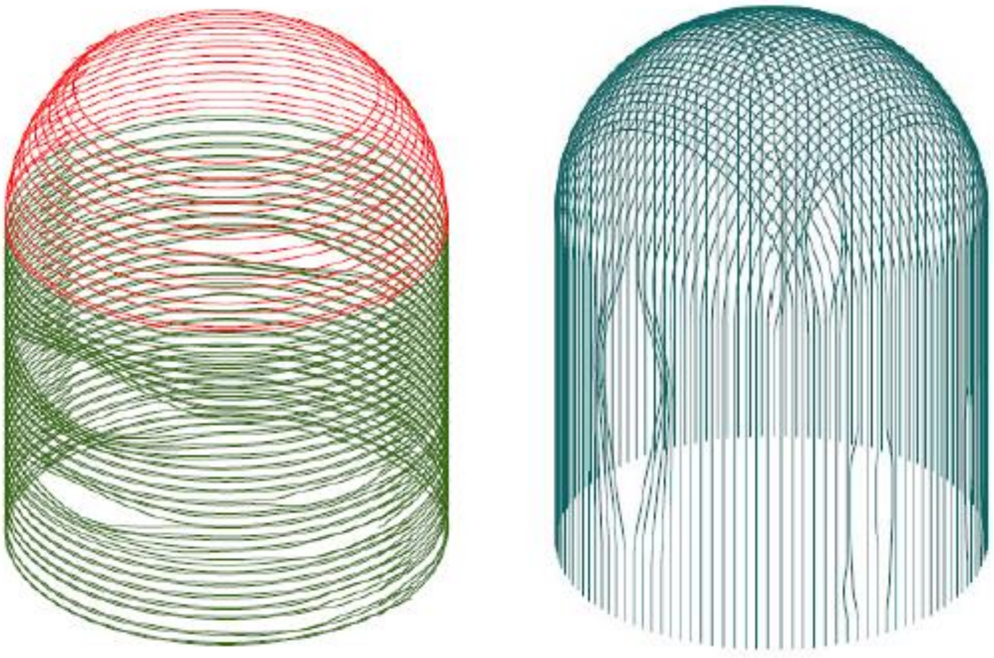
Pre-stress system - Cement grouted tendons
55 strands T15
Duct diameter Φ160 mm
Guaranteed ultimate strength f_{pk}=1860 MPa



Geometry of the structure

- Cylindrical shell:
  - Inner radius 22 meters
  - Thickness 1,20 meters
  - Height 41,6 meters

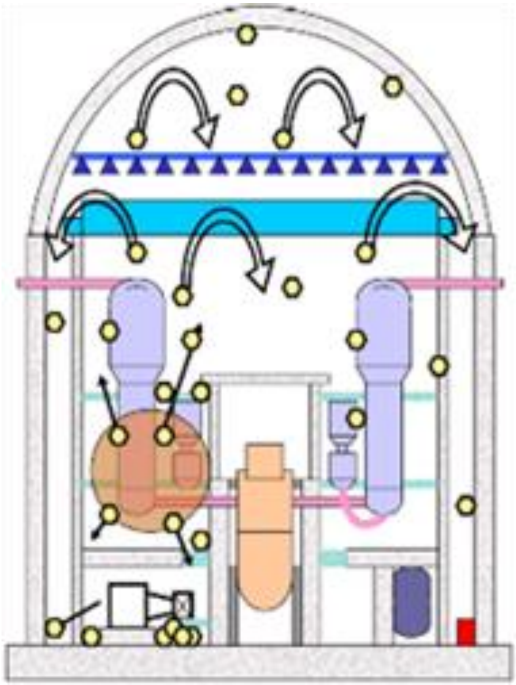
- Hemispherical dome:
  - Inner radius 22 meters
  - Thickness 1 meter



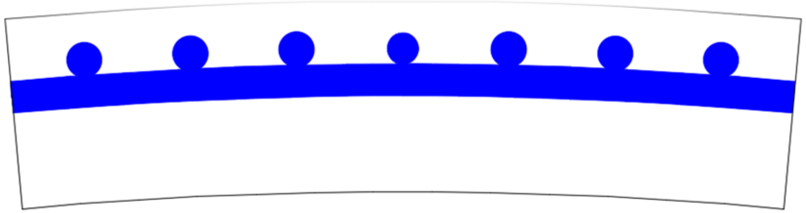
Tendons layout

Strength requirements

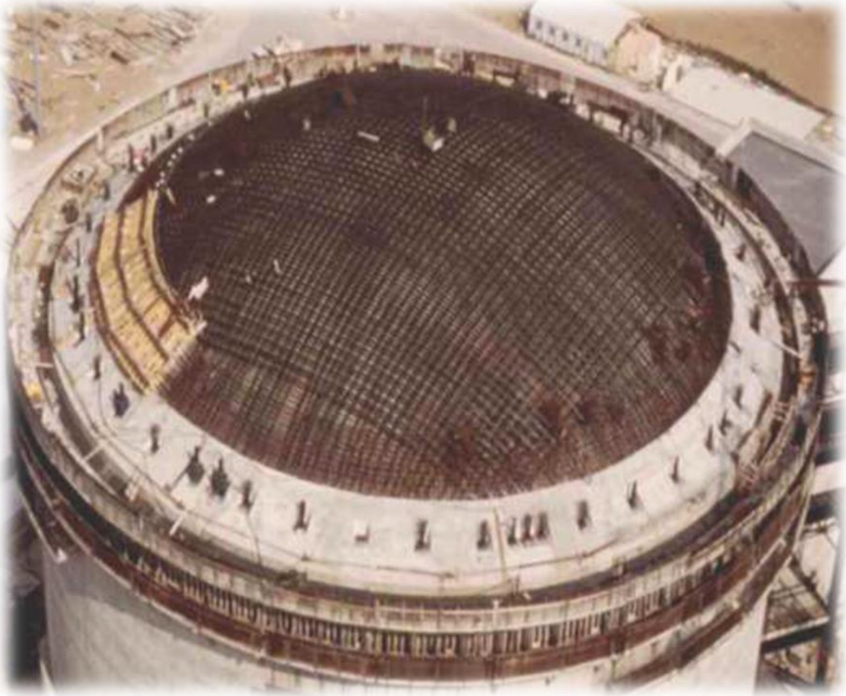
- The structure is designed to resist 60 years to:
  - Severe accident – LOCA which will lead theoretically to a relative pressure of 4 bars inside and to a temperature that plastifies the metallic liner
  - Containment test related to a relative pressure of 4,6 bars



Vertical tendons



- Necessary vertical pre-stress
  - 9,815 $\frac{MN}{m}$
  - obtained using the force given by LOCA pressure along with maximum traction forces in the liner and passive reinforcement
  - Tendons will be tensioned at $0{,}8f_{pk}$
  - The maximum spacing between tendons will be determined for LOCA and containment test pressure supposing that it will occur 60 years after construction
  - Minimum concrete covering equal to Φ_{duct}= 160 mm. The tendons from different directions are in contact.



Pre-stress tension losses:

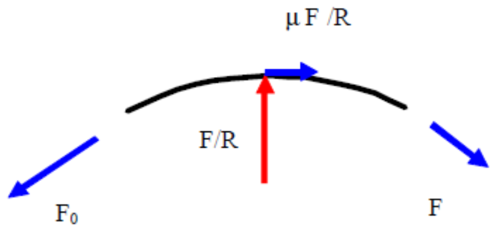
1. Friction between tendons and concrete
2. Elastic losses
3. Relaxation of steel
4. Concrete differed strain losses
   - Shrinkage
   - Creep

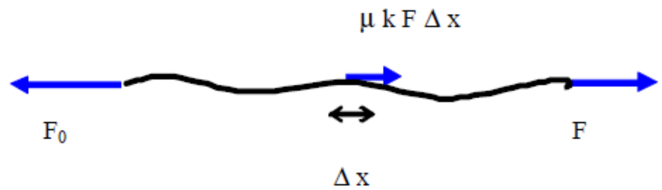
1. Friction losses

- ❖ due to relative high friction coefficient for the solution with cement grout
- ❖computed at middle length (▯=▯/2)

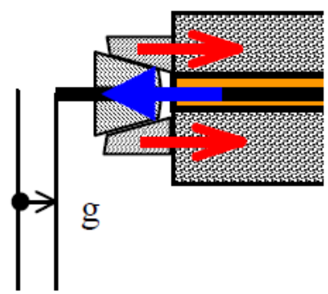
Friction losses:

$$\Delta\sigma_{frot}(x) = \sigma_0 \cdot \exp(-\mu \cdot \alpha - k \cdot \mu \cdot x)$$





The slip losses

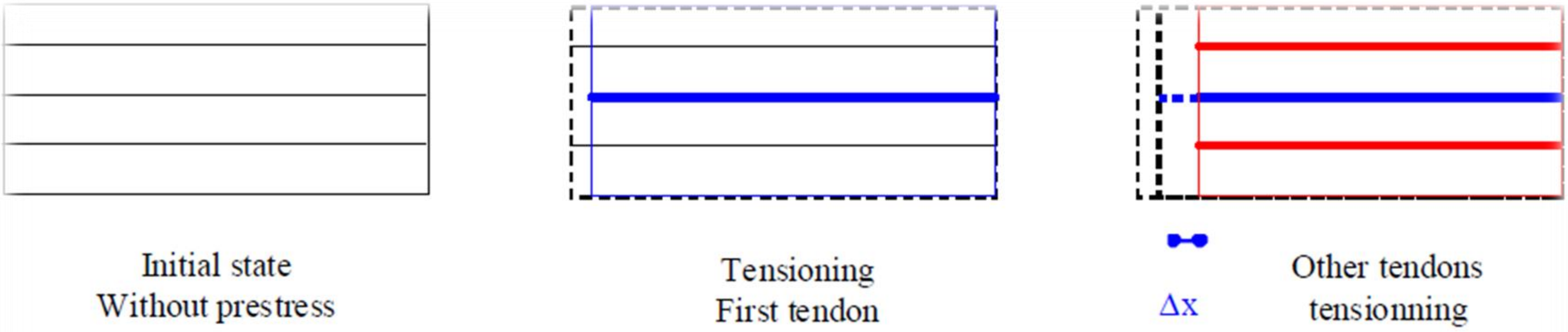


The anchorage slip is neglected as it doesn't have any effect at the middle length

After the initial pre-stress of 0,8f_{pk} (1488 MPa) it will remain only 1088 MPa of tension into the tendons.

2. Elastic losses

- The first tendons are submitted to a shrinkage due to the tensioning of the last tendons

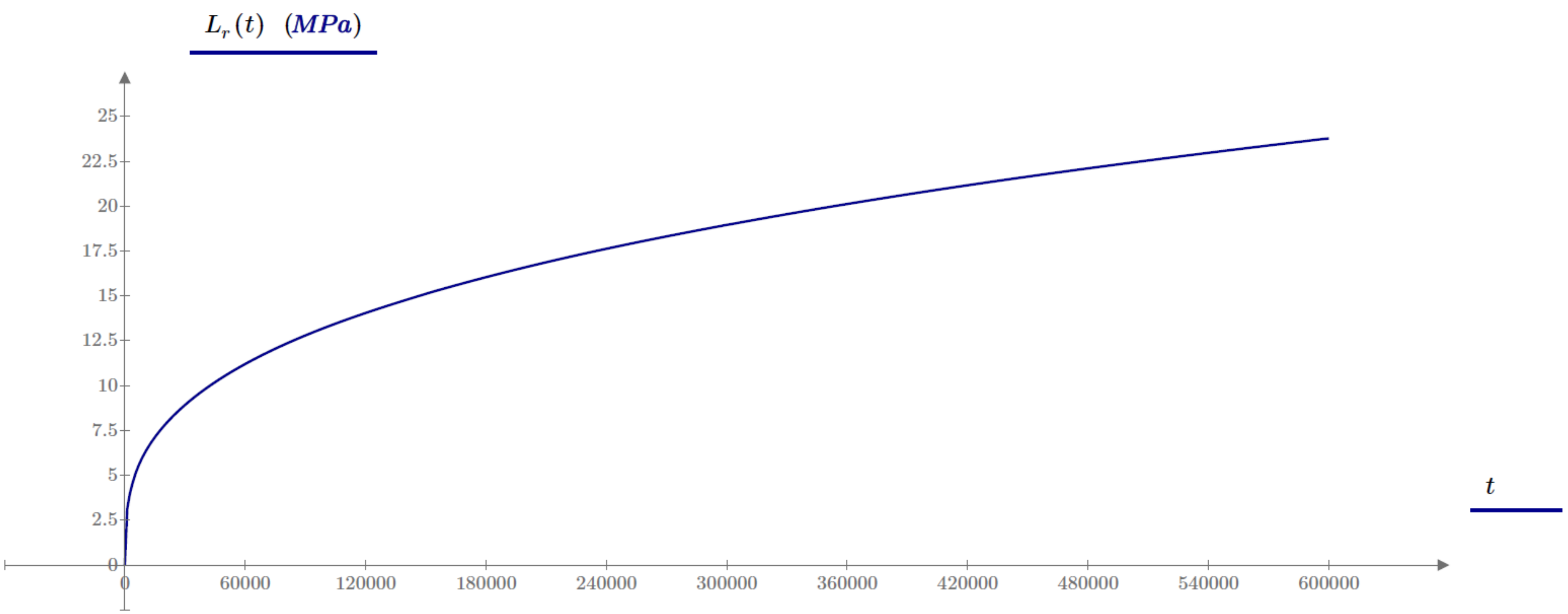


$$\Delta\sigma_{elast} = \frac{1}{2}\cdot\frac{\sigma_c}{E_c}\cdot\left|E_p\right.$$

Obtaining an elastic loss of 39 MPa the stresses after construction will be 1049 MPa

3. Relaxation losses

- Class 2 – Low relaxation strands
- 2,5% relaxation at 1000 hours and 20℃
- 22,8 MPa loss in 30 years (526320 hours)



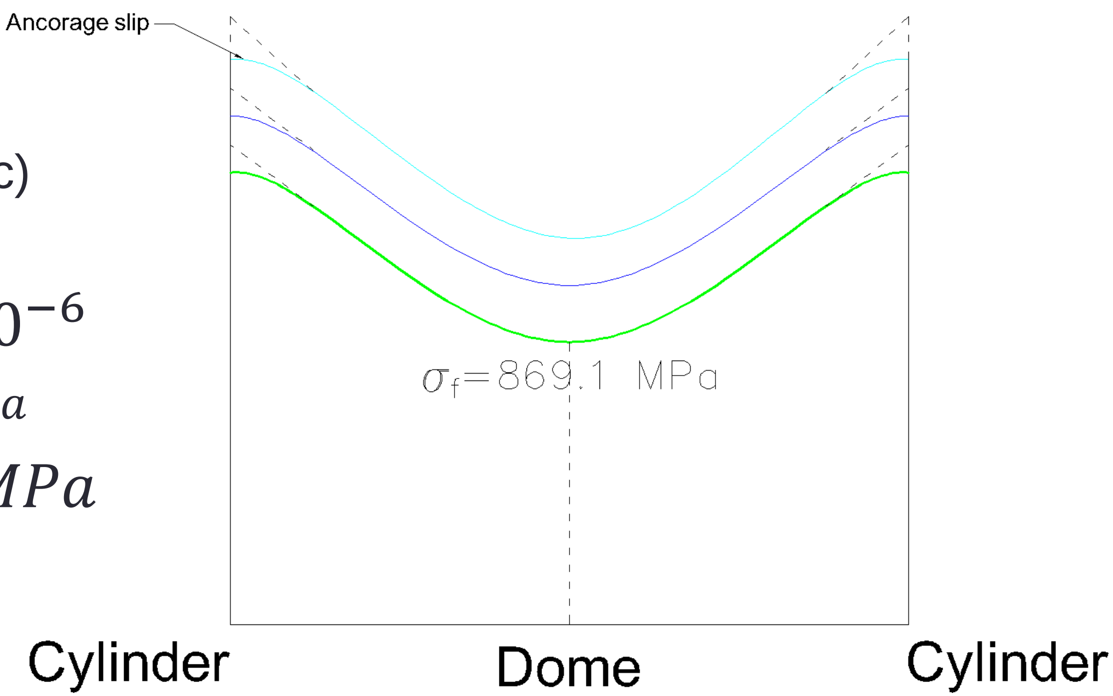
4. Concrete differed strain losses

- Shrinkage

  Desiccation shrinkage during 60 years (concrete without silica fume)

  Autogenous shrinkage neglected

- Creep
  - Basic creep (anisotropic)
  - Desiccation creep (isotropic)



Total strain: $852{,}897 \times 10^{-6}$

$\Delta\sigma = 162{,}05\ MPa$

Final tension: $\sigma_f = 891{,}1\ MPa$

Minimum spacing: $e_d = 731\ mm$

Pressure test

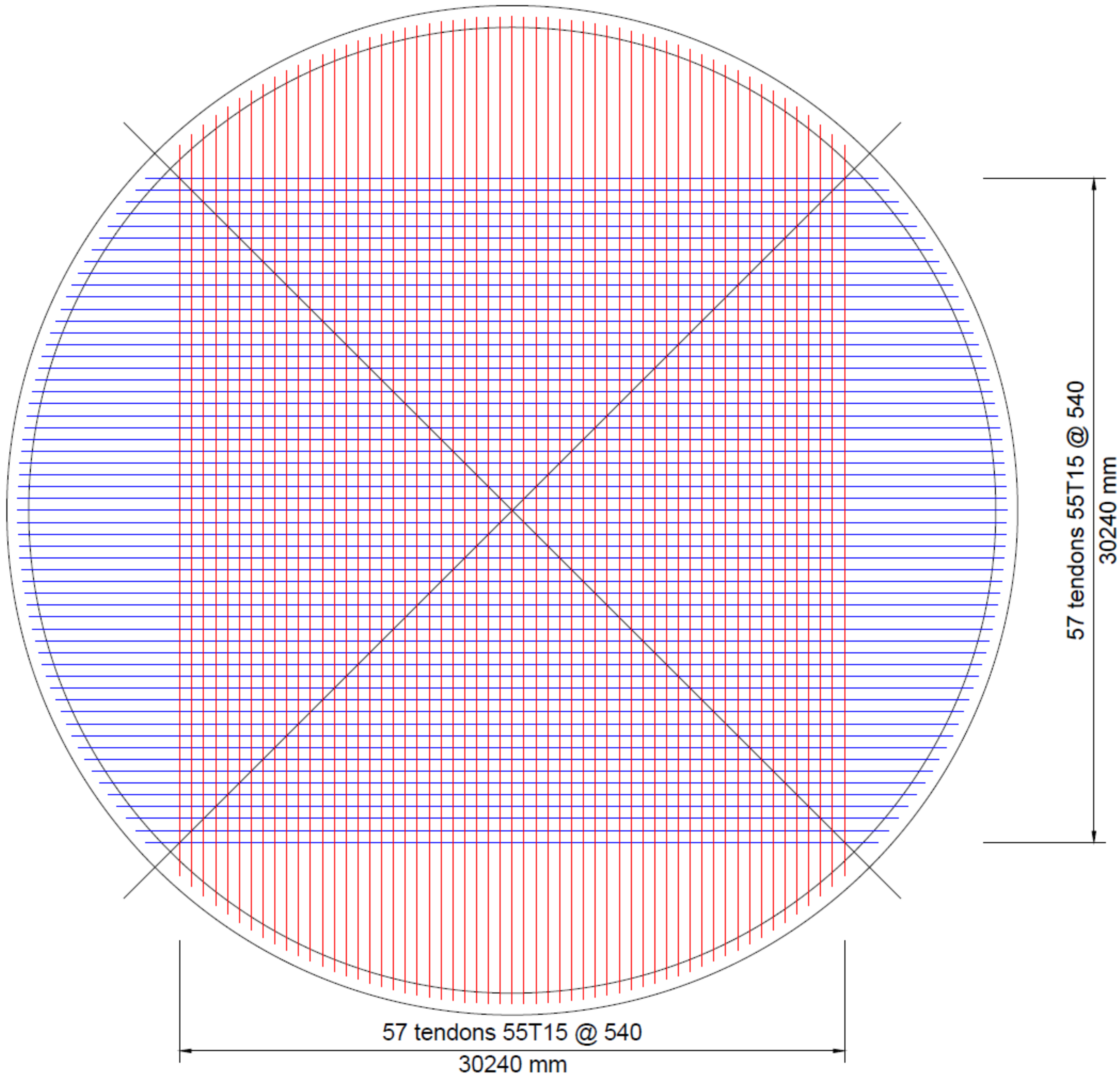
When the test is performed (at 4,6 bars) the tension force in concrete is given by tangential force due to inner pressure on the sphere and the differed strains in concrete applied to reinforcement and liner ($852{,}897 \times 10^{-6}$).

Pressure test force: $F_{test} = 7{,}78 \frac{MN}{m}$ instead of

$$F_{LOCA} = 9{,}815 \frac{MN}{m}$$

Minimum spacing: $e_d = 922\ mm$

After preliminary trials on the FEM model we decided to continue the analysis with a spacing of 540 millimeters due to high tensions in the concrete.



57 tendons 55T15 @ 540
30240 mm
57 tendons 55T15 @ 540
30240 mm

Ultimate pressure assessment

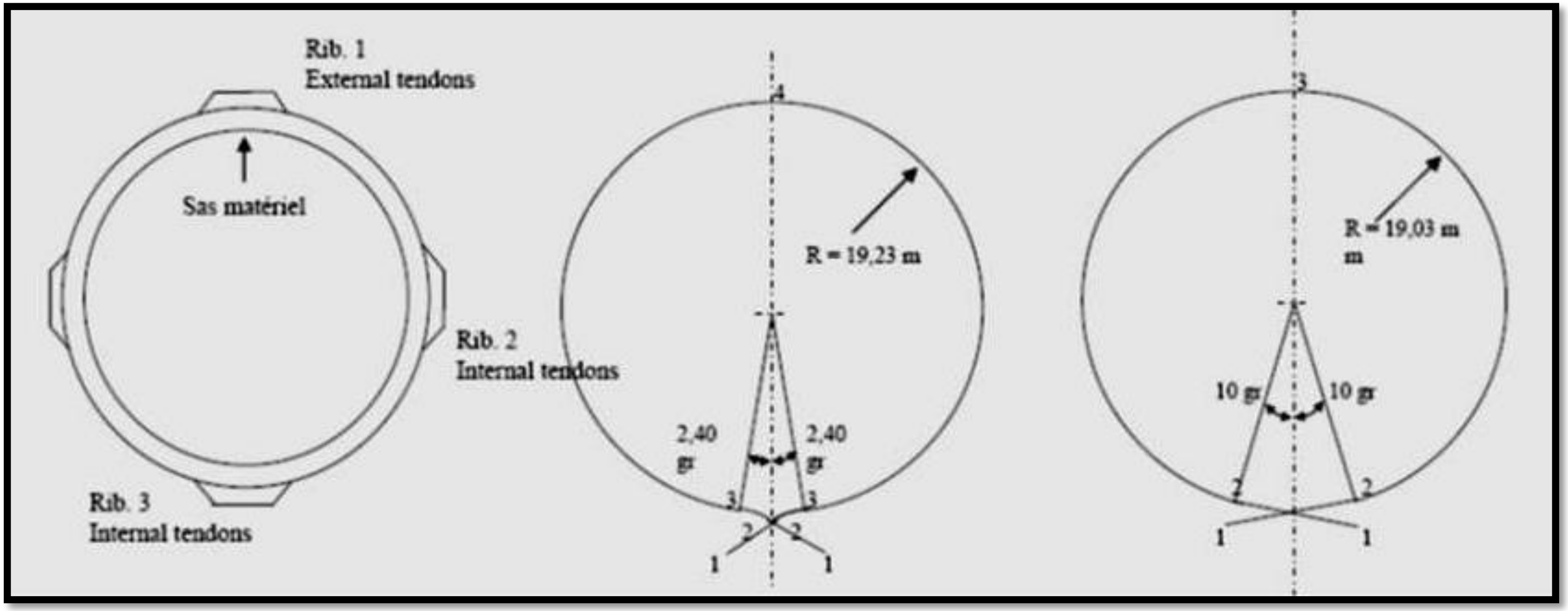
The ultimate force is obtained assuming the rupture occurs when the most “brittle” element fails i.e. tendons when they reach 3% tensile strain.

Thus the stress in the tendons will be 1888 MPa in the same time with 279 MPa in the liner and 419 MPa in rebars.

Hence the force at rupture $N_{Rupture} = 33{,}128\ \frac{MN}{m}$ associated with the ultimate pressure $P_{ultimate} = 1{,}506 MPa$ having 50% confidence (determined with median values for strength of components).

Horizontal pre-stress tendons

- The cylinder tendons are of two types – exterior (R=22,753m) and interior (R=22,588m) spaced vertically at $_{duct}$.
- Necessary pre-stress
  - 13,575 $\frac{MN}{m}$



Tension losses:

1. Tension after friction loses $\sigma_{\frac{\pi}{2}} = 1058\ MPa$ on the opposite side of the corresponding rib.
2. Elastic losses - 44 MPa $\sigma_c = 1014\ MPa$
3. Relaxation of steel - 20,2 MPa
4. Concrete differed strain losses
   - Shrinkage
   - Creep -138,15 MPA $\sigma_f = 859{,}5\ MPa$

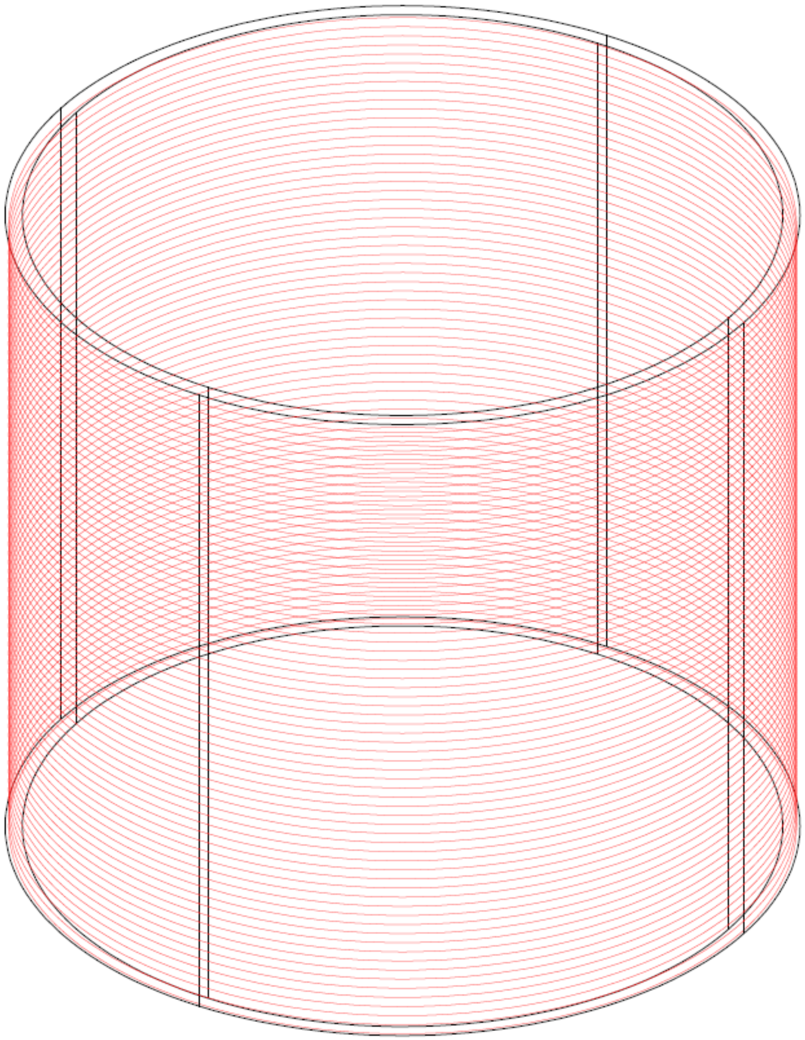
Minimum spacing for LOCA: $e_d = 722\ mm$

Pressure test

Pressure test force: $F_{test} = 12{,}13\,\frac{MN}{m}$

instead of

$$F_{LOCA} = 13{,}575\,\frac{MN}{m}$$



Minimum spacing: $e_d = 584\,mm$

Thus we will proceed the analysis with 580 millimeters between horizontal tendons.

Ultimate pressure assessment

Hence the force at rupture $N_{Rupture} = 31{,}532\ \frac{MN}{m}$ associated with the ultimate pressure $P_{ultimate} = 1{,}433MPa$ having 50% confidence (determined with median values for strength of components).

Recalling the ultimate pressure for the vertical tendons failure of 1,549 MPa we can conclude that the structural failure will occur at **14,33 bars** and the horizontal cables will fail first using this configuration.

Conclusions

Because the 55T15 tendons could bear high tension forces the minimum required spacing between them is relatively large (500-600 mm). Although, with the current ratio of passive steel on intrados and extrados face $(in\ total\ 55\frac{cm^2}{m})$ the concrete is not able to carry the stresses between the tendons. Maybe it is better to use 15T15 tendons spaced at 200 millimeters and have less tension in concrete between them.

Nevertheless a smaller number of tendons will decrease considerably the time needed in the actual construction project.