Structural aspects related to the vacuum vessel of the SHIP Project

Research Group at University of Naples Federico II

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Draft date: November 24, 2016
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Structural problem

The Vacuum Vessel has a behavior similar to underground tunnels due to its geometry and main static loading which is characterized by a radial pressure, constant along the longitudinal development.

Pressure is here due to internal depression corresponding to vacuum conditions.

The pressure considered for following calculations has been (1.013 bar = 10330 kg/m²), very close to atmospheric pressure.
Load pattern used for the calculations

Applied Load = 1 atm = 1,013 bar

Design data (from CERN)
Internal pressure = 10 – 100 mbar = 0,01 – 0,1 bar

Optimal shape to counteract radial pressure would be circular cross-section

Calculations and checks have been conducted in terms of strength (flexural) and deformability under the above permanent loading conditions
Material properties

FOR STEEL PROFILE:
STEEL S355JO(J2)WP
CORTEN TYPE STEEL

FOR REINFORCED CONCRETE
CLS C40/50 SELC-COMPACTING CONCRETE - STEEL BARS B450
Analyzed solutions

0) **Steel-concrete composite structure**  
Steel profiles + concrete slab (slab connected to profiles by means of connectors)

1) **Steel-concrete composite structure with a composite slab**  
Steel profiles + steel-concrete slab (slab connected to profiles by means of connectors).

**NOTE:**  
0) has not been further considered because of a large thickness of the concrete slab (40-50cm) governed by cracking checks; if we managed to reduced the spacing between transverse steel rings below 1 mt, the rationale of the solution had no sense anymore.  
Therefore, different solutions have been explored.
DETAIL CONNECTION RC SLAB-STEEL BEAM

LONGITUDINAL CROSS SECTION

TRANSVERSE CROSS SECTION

CROSS SECTION OF STEEL BEAM

RC SLAB 15cm with steel sheet type HI-BOND

HE340B

IPE330

IPE330

HE340B

steel sheet type HI-BOND

Thickness 1,2mm
Atmosphere pressure = 100,03 kN/ml

Lateral displacement max = 12.4 mm

Bending moment max = 380 kNm
Lateral displacement max = 15mm

Bending moment max = 770kNm
Assemblage of steel sheet and RC slab

Reinforced concrete (RC)

Steel sheet

HE300B

IPE300

Detail of top side

Detail of bottom side
## Preliminary Estimate of Structural Costs

<table>
<thead>
<tr>
<th>Solution</th>
<th>Steel Profiles</th>
<th>Slab thickness Scl</th>
<th>Hb</th>
<th>d1</th>
<th>d2</th>
<th>Total Weight</th>
<th>Max lateral displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>HE340B + IPE 330</td>
<td>15 cm</td>
<td>34 cm</td>
<td>2,6 m</td>
<td>1 m</td>
<td>464 ton</td>
<td>12.4 mm</td>
</tr>
<tr>
<td>1b</td>
<td>HE400B + IPE400</td>
<td>17 cm</td>
<td>40 cm</td>
<td>2.0 m</td>
<td>2 m</td>
<td>463 ton</td>
<td>15 mm</td>
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### Longitudinal Cross Section

#### Solution 1a e 1b
- **Transverse Cross Section**
- **Slab thickness (Scl)**
- **Height (Hb)**
- **Depth (d1)**
- **Total Weight**: 464 ton
- **Max Lateral Displacement**: 12.4 mm

#### Solution 2a e 2b
- **Transverse Cross Section**
- **Slab thickness (Scl)**
- **Height (Hb)**
- **Depth (d1)**
- **Total Weight**: 463 ton
- **Max Lateral Displacement**: 15 mm

**Preliminary Estimate of Structural Costs**: 1,200,000 Euro
Analyzed solutions

0) **Steel-concrete composite structure** – Steel profiles + concrete slab (slab connected to profiles by means of connectors)

1) **Steel-concrete composite structure with a composite slab** – Steel profiles + steel-concrete slab (slab connected to profiles by means of connectors).

2) **Steel structure with coupled profiles** – Steel profiles calendered and coupled by means of welding – Stepped longitudinal profiles of the vessel
RATIONALE BEHIND Solution 2a and Solution 2b

NO RC SLAB!

Welding of profiles

HE300B

Detail of bottom side

Detail of top side
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<tr>
<td>2a</td>
<td>HE300B</td>
<td>---</td>
<td>30 cm</td>
<td>---</td>
<td>0 cm</td>
<td>360 ton</td>
<td>5,8 mm</td>
</tr>
<tr>
<td>2b</td>
<td>HE300A</td>
<td>---</td>
<td>29 cm</td>
<td>---</td>
<td>0 cm</td>
<td>280 ton</td>
<td>8,5 mm</td>
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Schematic view of vessel
Analyzed solutions

0) **Steel-concrete composite structure** – Steel profiles + concrete slab (slab connected to profiles by means of connectors)

1) **Steel-concrete composite structure with a composite slab** – Steel profiles + steel-concrete slab (slab connected to profiles by means of connectors).

2) **Steel structure with coupled profiles** – Steel profiles calendered and coupled by means of welding – Stepped longitudinal profiles of the vessel

3) **Steel structure based on assemblage ensured by welding**
**SOLUTION 3**

*Steel structure based on assemblage ensured by welding*

– *Steel structure with a calendered sheet coupled with welded stiffening elements.*
SOLUTION 3
Steel structure based on assemblage ensured by welding
– Steel structure with a calendered sheet coupled with welded stiffening elements.

1. Internal steel sheet (calendered and welded) – thickness of 30 mm

2. T profile, height of 320mm and spacing of 800mm

3. Transverse stiffening elements, thickness of 10 mm and spacing of 1500 mm
SOLUTION 3

Steel structure based on assemblage ensured by welding
– Steel structure with a calendered sheet coupled with welded stiffening elements

Deformability
\[ d = 8.4 \text{mm} \]

Ultimate limite state - strength
SOLUTION 3

Steel structure based on assemblage ensured by welding
– Steel structure with a calendered sheet coupled with welded stiffening elements
SOLUTION 3

Steel structure based on assemblage ensured by welding
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END LIDS

Bolted joint
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<td>0 cm</td>
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<td>8,5 mm</td>
</tr>
<tr>
<td>3</td>
<td>Sheet 30mm + T320</td>
<td>-----</td>
<td>35 cm</td>
<td>---</td>
<td>0 cm</td>
<td>300 ton</td>
<td>8,4 mm</td>
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**Preliminary cost estimate:**
about 3,000 euros/tons, total cost ranging between 1 and 1,5 millions
This cost does not include foundations and other non structural components
PROCEDURE CERTIFICATE DELLE LAVORAZIONI

La saldatura
La Castaldo SpA riconosce il processo della saldatura come processo speciale, attesa la rilevanza strutturale. Pertanto, tutte le attività inerenti tale processo sono eseguite in accordo ai requisiti richiesti dalla UNI EN 3834-2, certificata dall’Istituto Italiano della Saldatura. Il coordinamento delle attività di saldatura è affidato a Personale con competenze adequate e rispondenti alla UNI EN 719.
L’esecuzione dei controlli non distruttivi sulla saldatura è demandata a personale interno qualificato in conformità alla UNI EN 473.

Il taglio
Il taglio delle lamiere, fino a grossi spessori, avviene mediante ossitaglio e taglio al plasma. Il metallo non viene tagliato per fusione, bensì per asportazione degli ossidi indotti dall’apporto termico, che si formano a temperature più basse di quelle di fusione dell’acciaio.
Feasibility and constructability

Special devices and tools

CAPABILITY OF MOVING HUGE WEIGHTS AND DIMENSIONS
Feasibility and constructability
Feasibility and constructability
Feasibility and constructability
The structural analysis can be completed upon final definition of:

- **Geomtry** (cross-section, longitudinal development, end libs, etc.)
- **Actions** (in addition to static loads, define dynamic loads as well as others such as fire, chemical attack, and so for);
- **Allowable limits for deformability and number of cycles** (loading and unloading);
- **Interaction with other structures and with pipelines, non-structural components, etc.**;
- **Foundation system**;
- **Connection of vacuum vessel to foundation**;
- **Temporary loading conditions during moving operations and installation**

Further checks to be done