RESEARCH REPORT

VTT-R-00652-14

Variability of targets for component qualification with structural response

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Confidentiality: Public

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Variability of targets for component qualification with structural response	
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Summary

This report is deliverable for 2013 of Subproject 3 in the project SESA "Seismic Safety of Nuclear Power Plants – Targets for Research and Education", part of the SAFIR 2014 program on nuclear safety.

In 2013, in Subproject 3, the review task for an emergency diesel generator day-tank has been started according to the discussions in the Ad-Hoc group of SESA.

The day-tank has been one configuration supplied by Wärtsilä, and loads were provided by TVO according to a realistic scenario for placement of the day-tank. The aim was to carry out modeling of the day-tank, starting with simple models and ending with very sophisticated liquid interaction models, in order to understand the limitations of the analysis methods usually used in the qualification process. In this stage loads were predefined for the day-tank scenario, but in the next stage some variability of the loading will also be considered.

The main emphasis of Subproject 3 is in 2014 according to the multi-annual plan of the SESA project.

Confidentiality	Public

Espoo 25.2.2014

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Preface

The decisions to increase the number of nuclear power plants (NPP) in Finland, and especially the positioning of one NPP in the northern part of the country, called for reassessing the potential effect of earthquakes on plant safety requirements.

As a response to this need, the project SESA - ***Seismic Safety of Nuclear Power Plants – Targets for Research and Education*** was included in the Finnish Research Program on Nuclear Power Plant Safety, SAFIR 2014, under the umbrella of Reference Group 7 - Construction safety. SESA is in its first year of financing in 2011, and it has 3 Subprojects:

- Subproject 1. Earthquake hazard assessment,
- Subproject 2. Structural assessment,
- Subproject 3. Equipment qualification procedures,

This report is a deliverable of Subproject 3 for the 2013.

The work in SESA has been supervised by the Reference Group 7 and the Ad-Hoc group specifically named for the SESA project.

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1 Introduction

The design for earthquake loads is a challenging task. While design of buildings is a field interesting from a broad engineering perspective, qualification of components is a more specialised area.

Seismic qualification is more fragmented field compared to design of structures. The aim of the work in 2013 was to start developing a good practice example qualification for a commonly agreed equipment typology, which was fixed during the year to be a day-tank supplying an EDG.

2 Goal

The aim of this document is to present the/a procedure for seismic qualification of a day-tank. The work was planned to explore modelling techniques not usually used for such qualification by consultants, in order to understand the limitations of the traditional modelling techniques.

3 Modeling

The day-tank to be modelled is based on the portfolio usually supplied with Wärsilä emergency diesel generator (EDG) sets.

The scenario for deploying this day-tank was provided by TVO, with a realistic use scenario in the OL plant.

3.1 Configuration of the day-tank

VTT received the 3D geometry file of the day-tank in a meeting with Wärtsilä, 05.11.2013 (Figure 1).

It is important to state that the configuration is a generic tank, representing the standard project type not nuclear purpose specific configuration. If needed, several improvements can be implemented to this configuration to improve its seismic performance.

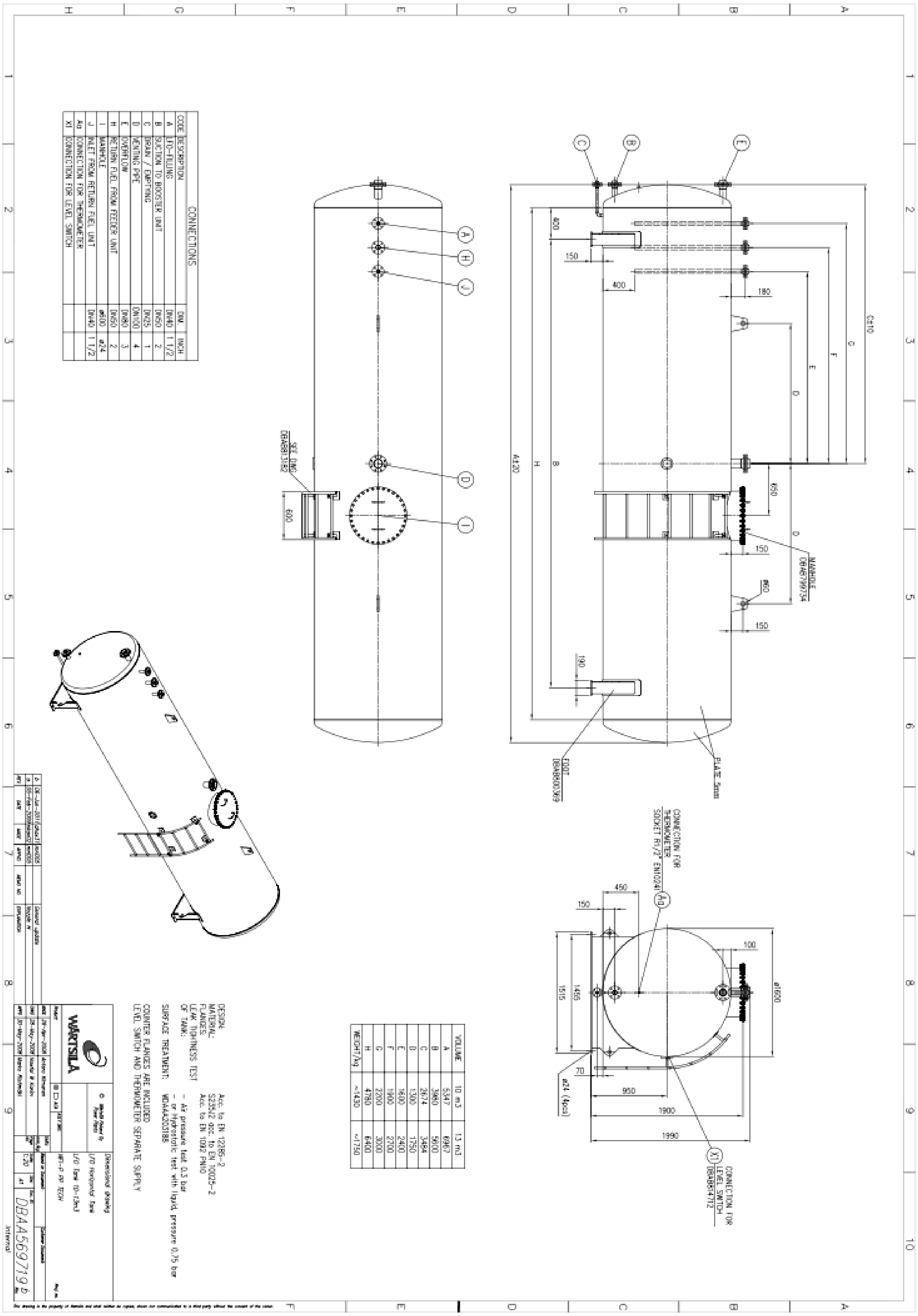


Figure 1. Design drawings of the tank

Modeling started, with Wärtsila's data (Figure 2). In this stage of the project there are still challenges to understand the functional requirements of the equipment.

Drafting the component list of such complex equipment is best done by the manufacturer's experts. In Wärtsilä's case the list of components has been drafted with the purpose of qualifying the EDG and its auxiliaries in normal operating conditions [1]. The component list states the role of each component and the consequence of failure, but it is also supplemented by assessment/classification on "Probability of Occurrence (PoO)", "Probability of Detection (PoD)" and "Severity" in case the component fails. The aggregation of the PoO, PoD and S classifies the component from the point of view of consequences in case of its failure.

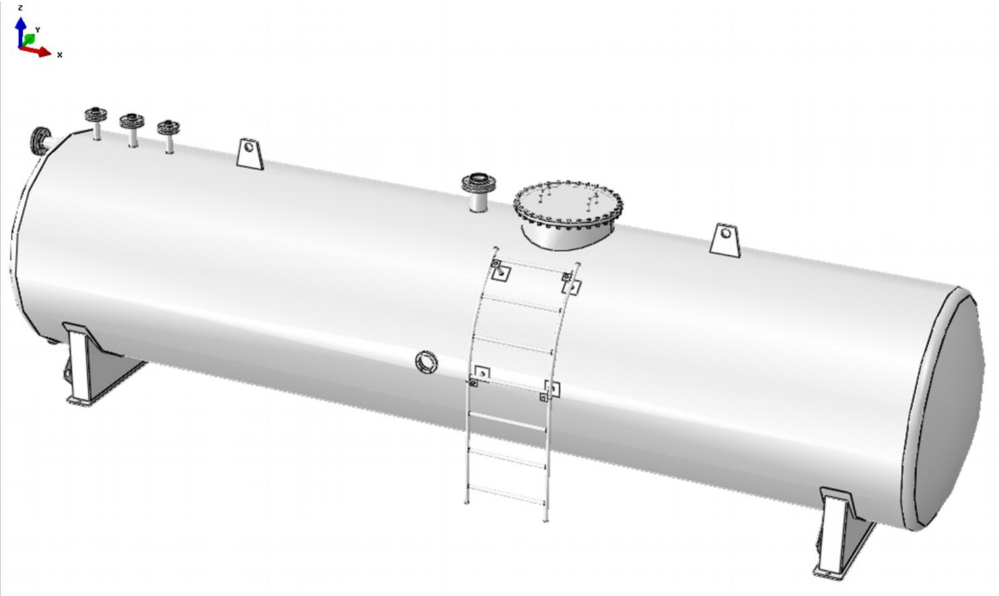


Figure 2. 3D render image of the analyzed day-tank

In the next stage, the component list has to be adapted for the specific requirements of seismic review, when the "Severity" in case of failure has the highest priority in classification [2]. Component review emphasizes "…meeting the performance requirements during and/or following the seismic event…" (e.g. [4], [5], [6]). For the few seconds seismic event PoO of the failure on the multiannual basis is not relevant. The PoD of the failure is also not useful, since repairing the component may not be an option in the conditions immediately following an earthquake.

Based on the data available to the research team, besides general checks concerning the anchoring and integrity of the reservoir, the components from Table 1 of the day tank are suggested for seismic review. It must be emphasized here, that the list in Table 1 is drawn up based on the description of failure consequences alone, so its purpose is to serve as example. Agreeing on such table should be done as teamwork, with experts from several disciplines.

Table 1. Components suggested for seismic review and failure modes for daytank sub-system of the EDG

2.	**Fuel oil day tank sub-system**					
2.2	Drainage of fuel oil day tank					SR
2.2.1	Drain valve	flow control of drain from tank	Valve total failure	Fuel from day tank flows to day tank basin.	Engine stops soon due fuel oil drain from day tank.	SR

2.2.2			pipe failure before valve	Fuel from day tank flows to day tank basin.	Engine stops soon due fuel oil drain from day tank.	SR
2.3	Fuel oil day tank controls					SR
2.3.3	Low level sensor/switch	low level indication, possible transfer pump start signal. Alarm for low level of day tank	Jam of float sensor. Other defect.	No correct level signal. Problem to start automatically transfer pump.	Possible risk that low level not noted. Limited time to operate engine	SR
2.3.4	Low low level sensor/switch	Low Low level switch	Jam of float sensor. Other defect.	No correct level signal. If Low level switch have been passed	If low level switch is passed and Low low do not work only limited time before engine stops.	SR
2.4	Fuel outlet					
2.4.1 a	Outlet connection	fuel outlet	leak of connection due to damage or failure	some leakage to tank basin.	some limited operation time due to loss of fuel.	SR
			total failure	day tank fuel flows to tank basin	very limited time to operate the Engine	SR
2.4.1 a	Outlet pipe	fuel flow outlet tank	leak of pipe due to damage or failure	some leakage out.	some limited operation time due to loss of fuel. Risk of fire increases	SR
			total failure	loss of pressure in pipe. Cavitation in feed pump	very limited time to operate the Engine	SR
2.4.2	Outlet valve	Fuel flow outlet control	leak of pipe due to damage or failure	some leakage out.	some limited operation time due to loss of fuel. Risk of fire increases	SR
			total failure	loss of pressure in pipe. Cavitation in feed pump	very limited time to operate the Engine	SR

There are two components with performance to be characterised by mechanical calculations – i.e. the “drainage of fuel oil day tank” sub-system and the “fuel outlet” subsystem. These are noted B and C in Figure 1. The third component, the “Fuel oil day tank controls” contains electronic equipment and its performance cannot be assessed based only on analytical measures. This is marked X1 in Figure 1. For all three components testing can be performed, once their loading is derived from the FE model of the day tank.

3.2 Loads

According to the information supplied by TVO, the day-tank could potentially be located on the +6.5m floor level of an auxiliary birdieing in OL2. The building sketches for the location are presented in Figure 3.

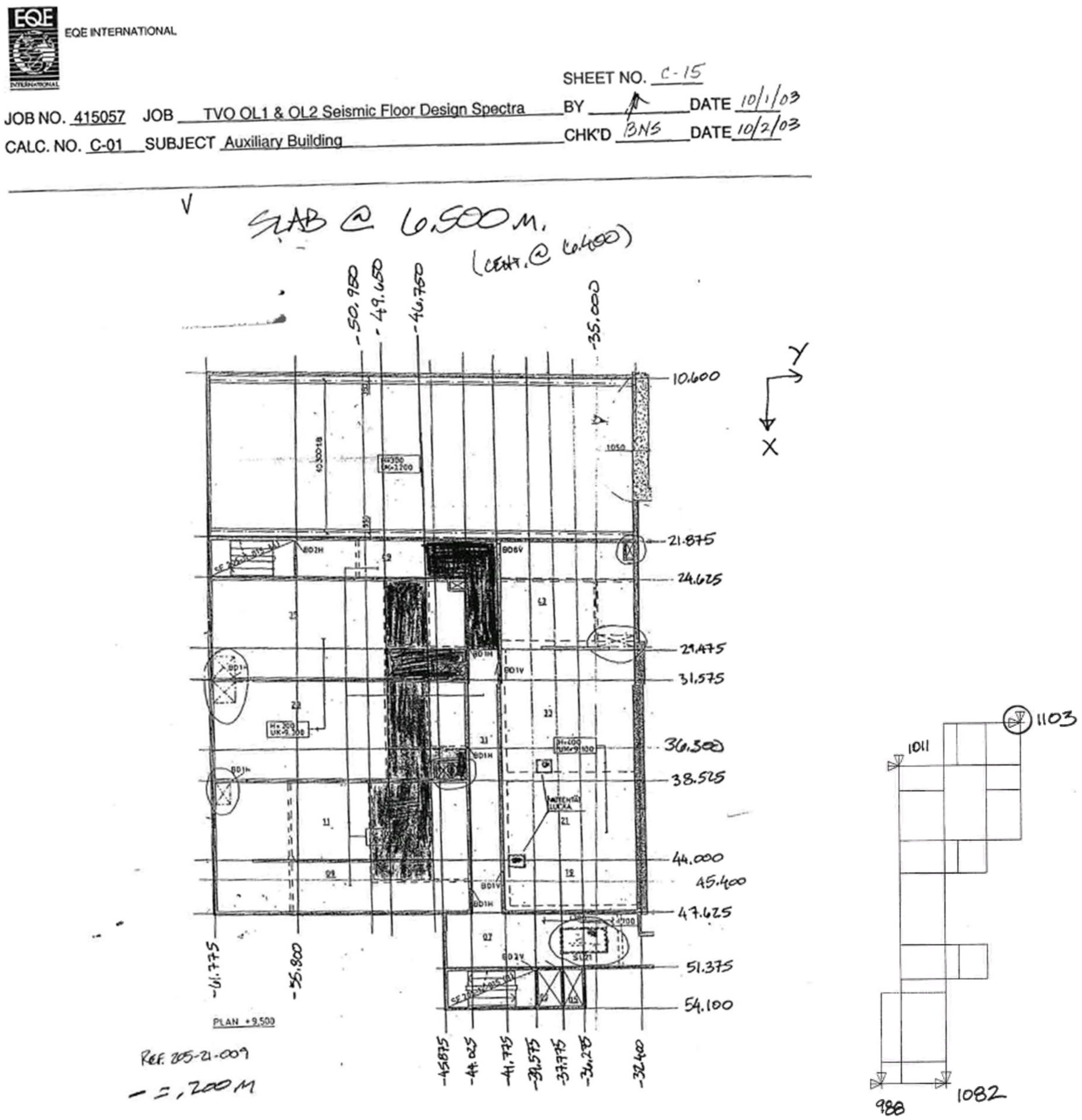


Figure 3. Sketch of the rooms with possible location of the day-tanks (a) and numbering of the nodes on the perimeter of the rooms (b)

The floor spectra corresponding to the 4 nodes presented in the sketch are given in Figure 4.

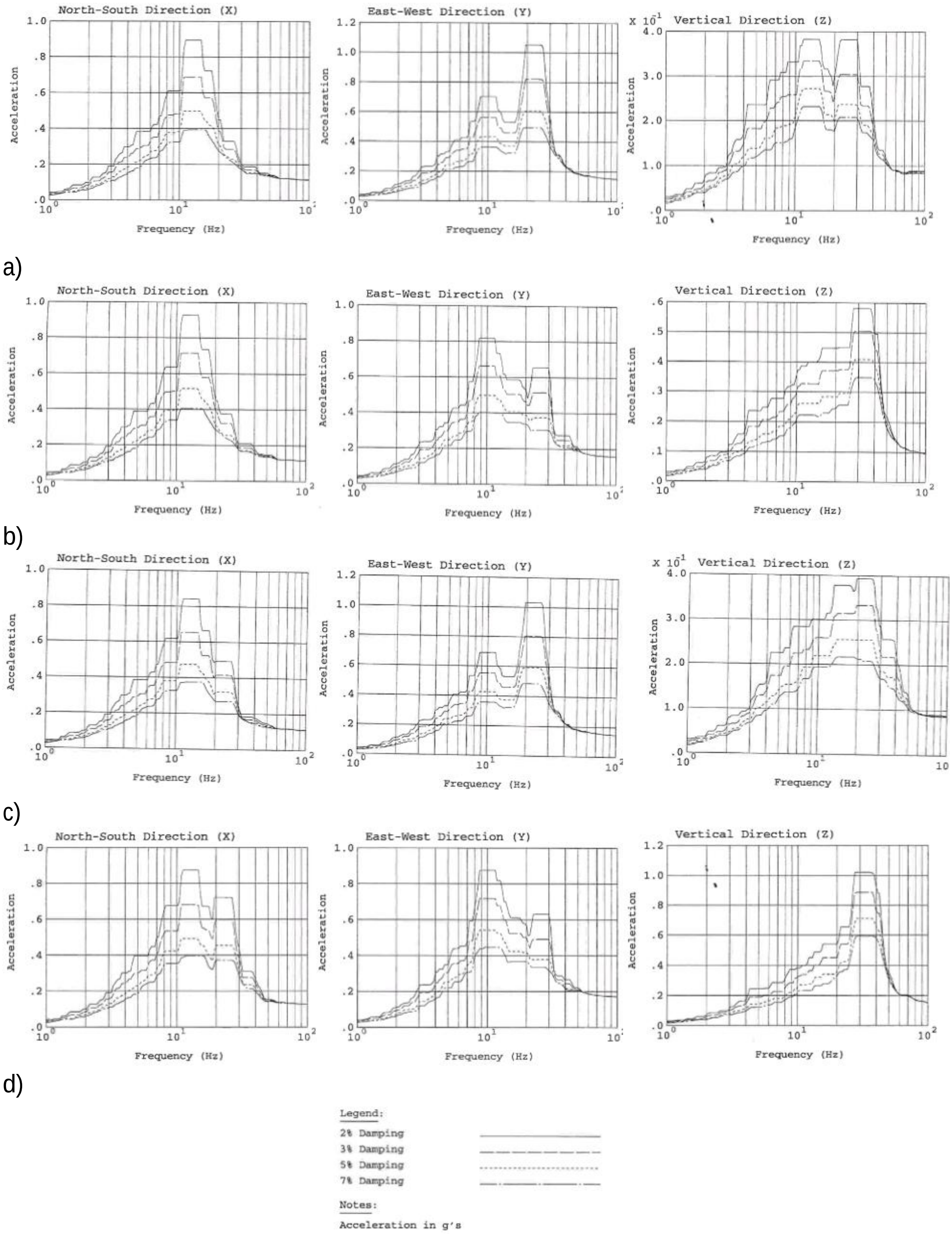


Figure 4. Floor spectra of node (a) 988, (b) 1011, (c) 1082 and (d) 1103

3.3 Qualification approached by modeling and testing

The scope of qualification guides like e.g. IEEE 344 is to give guidance on how to qualify equipment. In the framework of OL only shakings by a SSE (Safe

Shutdown Earthquake) shaking is required. Preliminary OBE (Operation Basis Earthquake) shaking is not used in Finland.

We acknowledge the requirements stated in IEEE 344 (§4.1) that earthquakes create at ground level:

- simultaneous shaking in all 3 directions of space
- the components of the shaking are statistically independent
- the strong motion part is 10-15s
- the significant frequency content is 1-33Hz

But, duration, independence and frequency content arriving to a component may be affected/changed by the filtering effect of its support, and we need to asses these possibilities in light of having only floor spectra as input as input. For the FE modeling, the seismic environment for a component will be specified as time history (shaking).

"Component qualifies" means that the component is able to perform its safety function during and/or immediately after the SSE events. Qualification is to be demonstrated by analysis and testing.

- In the first stage a FE model will be analyzed, focusing the assessment on integrity of the reservoir and the anchorages (mechanical assessment). The accelerations and displacement will be recorded to the location of the tree components to be qualified (see 3.1).
- Proposals will be sketched concerning the procedure leading to the qualification of the 3 components;

In the first stage a FE model will be built and subjected to shaking at the supports. Stresses, strains and forces are monitored in the tank's shell and other components of the system to ensure mechanical resistance. In the second stage, accelerations and displacement are collected from the connecting locations of the 3 components: 2.2 drainage of fuel oil day tank, 2.3 fuel oil day tank controls and 2.4 fuel outlet (Table 1), and a modeling or testing plan is presented for these components. Aging mechanisms have to be identified, and taken into account before the "seismic scenario" is applied.

3.4 Developed FE model

Coupled Lagrangian and Eulerian modelling techniques were employed in the simulation of the fuel sloshing in the day tank, due to a seismic excitation. Lagrangian domain is a classical finite element (FE) method where an element mesh describes deformation under a load. In Eulerian method the mesh is un-deformable but a single element could be occupied by a material. If fraction of the material occupancy in the element is 1.0 then this element full of material. In contrast, 0.0 fraction of the material occupancy implies void in the element.

As a first step, all ladders and the fuel inlet and outlet etc. were removed in order to simplify the FE model. The body and the legs of the day tank were modelled with shell elements (Figure 5). The material of the day tank was isotropic steel.

Table 2. Components suggested for seismic review and failure modes for daytank sub-system of the EDG

Steel density	8.0E-06	kg/mm^3
Diesel fuel density at 15°C	8.25E-07	kg/mm^3
Diesel fuel dynamic viscosity in 15°C	1.65E-06	kgs/mm

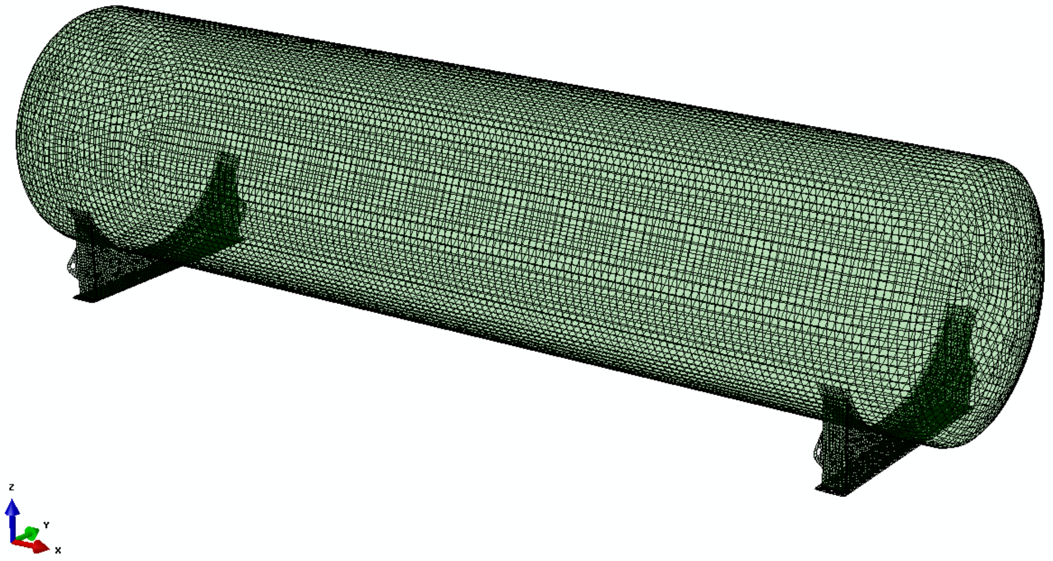


Figure 5. Lagrangian part of the day tank model

In the second stage, the Lagrangian model was embedded into Eulerian model (Figure 6). The diesel fuel was modelled with Eulerian domain. Rough contact was used between fuel and tank wall with option for no slipping. The fuel was modeled with 8 node linear brick element.

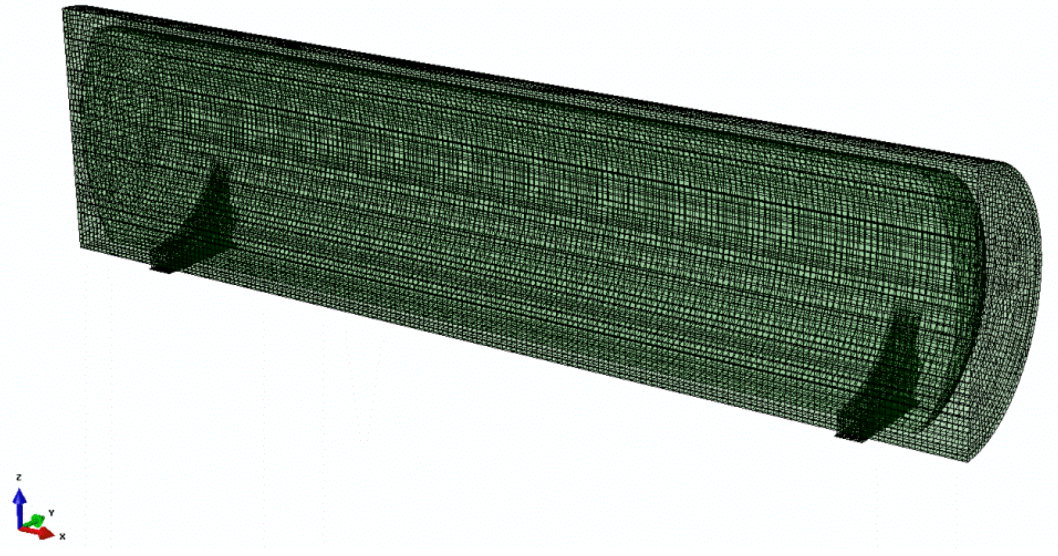


Figure 6. Lagrangian day tank model embedded in the Eulerian domain

The simulation was divided in two steps. In the first step gravity was applied in 3 second time span, and in the second step the earthquake acceleration signal was applied in 20s time span.

Concerning the acceleration signals applied to the base of the day-tank model, the following procedure was applied.

The spectra received from TVO were digitized and compared with each other in order to understand the behavior of the building (Figure 7). It can be noticed that the 4 floor spectra in the X direction are very homogeneous, almost identical. The most significant amplification occurs at around 13Hz. (Probably these are broadened spectra, so the plateau between 11-16Hz comes from a single peak at around 13Hz). Only node 1103 has a second amplification peak at 24Hz, probably resulting from a local softness of the structure, or the effect of the second vibration mode in X direction. In the Y direction, the spectra are grouped in two groups, nodes 988 and 1082 and nodes 1011 and 1103. All nodes show an amplification peak at around 10Hz, corresponding to the natural mode of the building in the Y direction. But nodes 988 and 1082 also have amplification at 22Hz. This is probably showing the 2nd mode in the Y direction, and hints to some torsion effect between nodes 1011/1103 and 988/1082. The largest differences can be seen in the vertical spectra (Figure 7) of the 4 nodes.

It was decided to use an overall envelope spectra for each of the 3 shaking directions (Figure 7). In the Y direction, since first mode peak of all four nodes are at 10Hz, this choice is still justifiable. However, in the vertical direction it is clear that out of phase motion will characterize the 4 nodes. It is also known that important variation can be observed in the vertical signals even within the area of a few floor spans [7]. So a deeper study of the vertical direction effects may be warranted at later stages of the modeling.

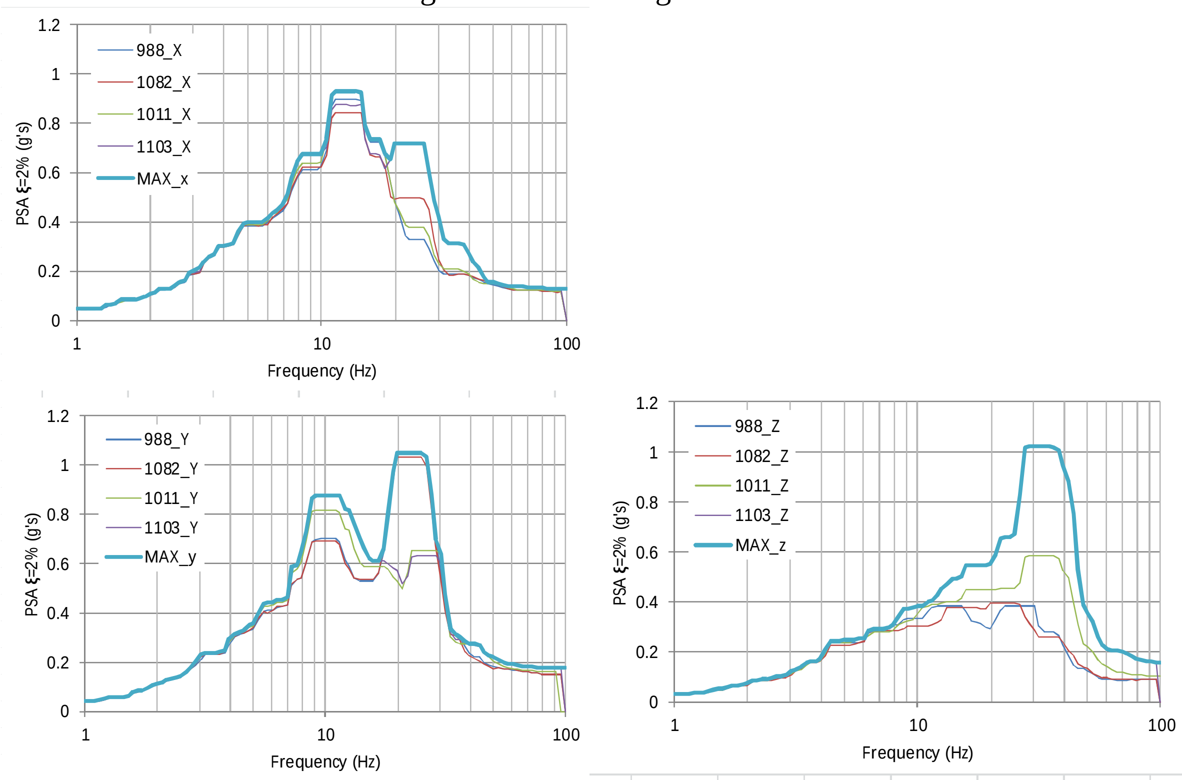


Figure 7. Envelope spectra of the four corner points for the location of the day-tank

- 3 statistically independent accelerograms were generated from the envelope spectra corresponding to the 3 shaking directions. The settings for the

ArtACC software are presented in Figure 8. Statistical independence was checked.

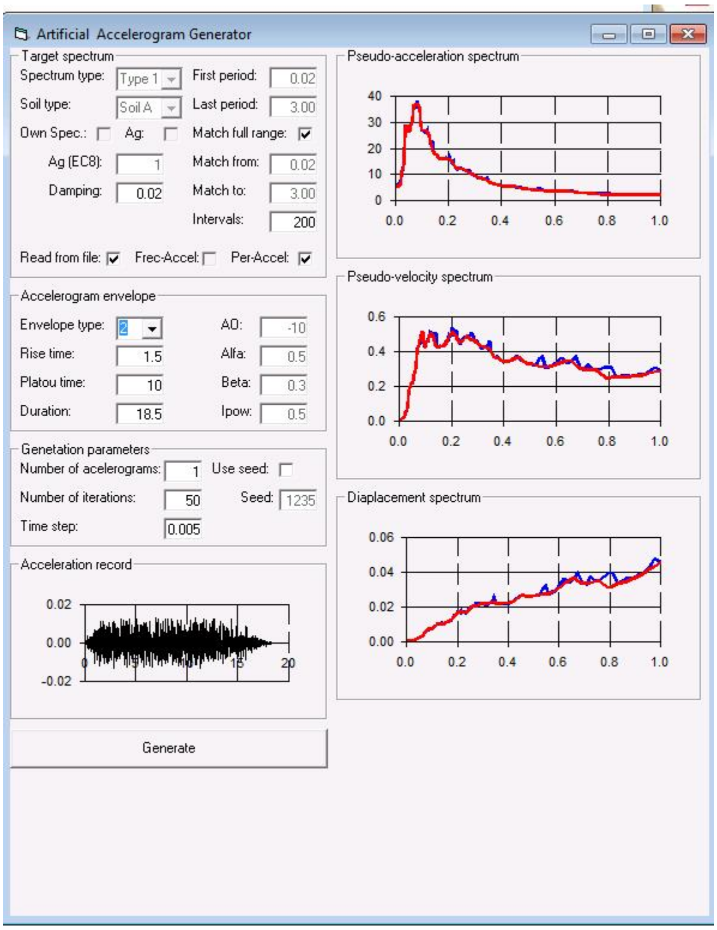


Figure 8. Settings for the artificially generated accelerograms (Damp=2%, $T_{plateau}$=10s, 200Hz), and example of spectral match for X direction shaking

The 3 accelerograms were simultaneously applied to the base of the day-tank model in the second loading step (after gravity).

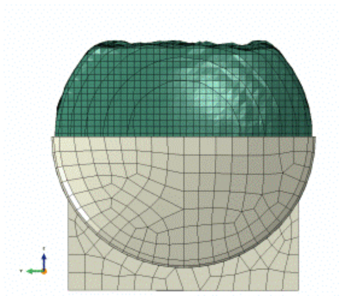
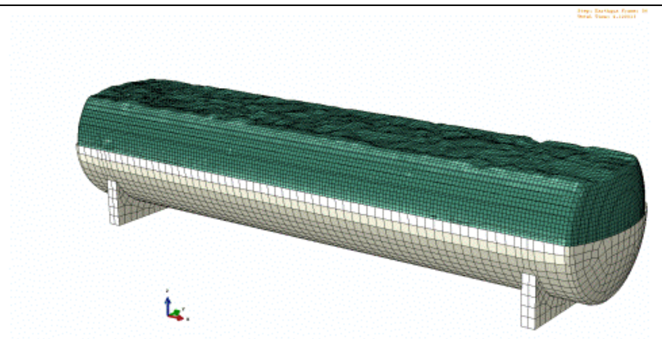
3.5 Preliminary FE results and discussion

The modelling is ongoing and only selected results obtained in 2013 are presented here. The sophisticated modelling of the fluid-solid interaction posed serious challenges to the project, driving the modelling effort to some delay. At this stage, convergence has been obtained in both steps of the modelling, but some parameter adjustments and results checks are necessary before quantitative results can be presented.

In Step 1 the liquid (diesel fuel) is materialized and gravity is applied in a 3 seconds timeframe. As the reservoir is filled 90%, and as consequence of the sudden appearance of gravitational forces the diesel drops to the bottom of the reservoir in the 3 seconds. The open surface of the liquid is formed, and as consequence of the raining” of droplets, some waving can be observed.

One adaptation of the current model needs to be done concerning the 3s. This period will be increased, because Step 1 is not sufficient for calming of the liquid surface. At the beginning of the seismic step (t=1.12s, t=3.32s, Table 3) there is still a gradual calming of the liquid surface.

Table 3. Sloshing of the diesel in the tank at different time steps of the seismic action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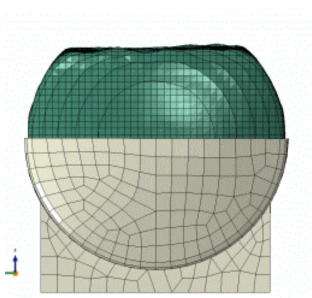
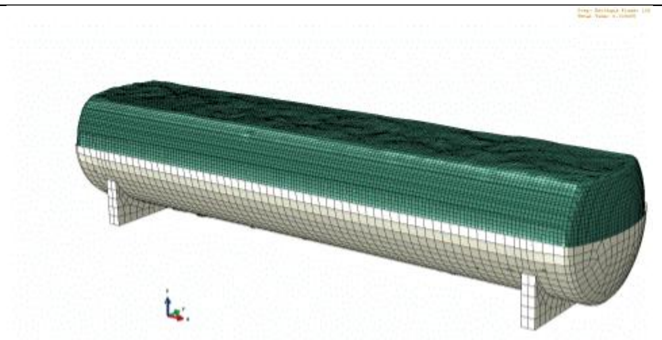
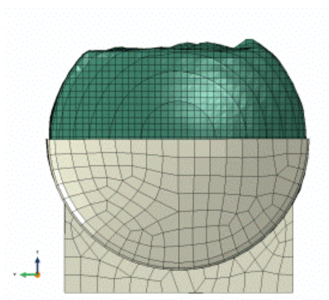
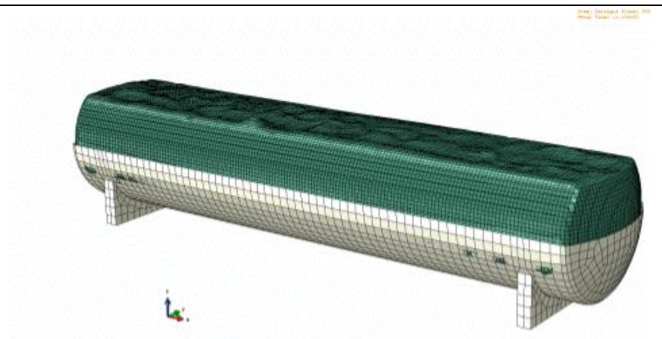
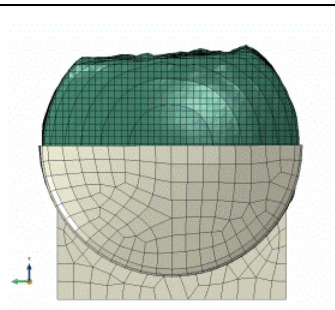
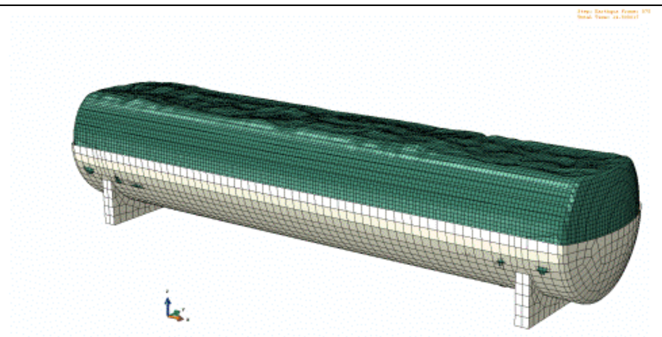
	
Time: 3.32 s	Time: 3.32 s
	
Time: 10.10 s	Time: 10.10 s
	
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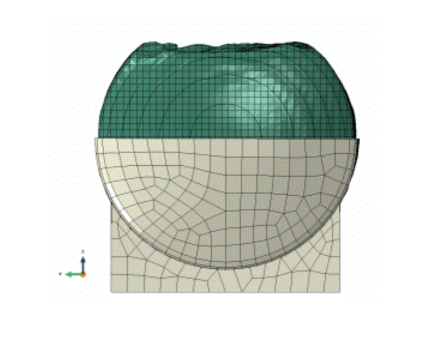	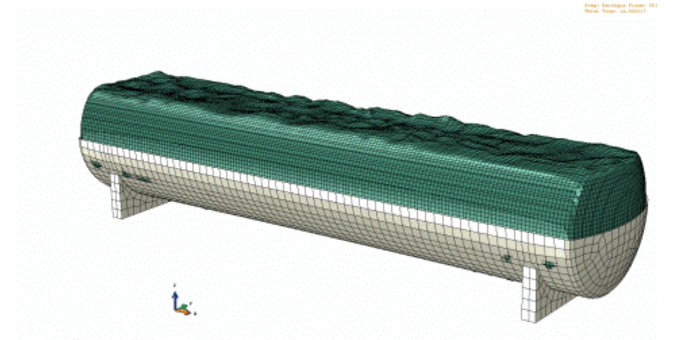
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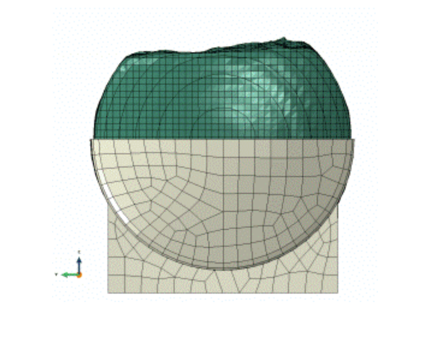	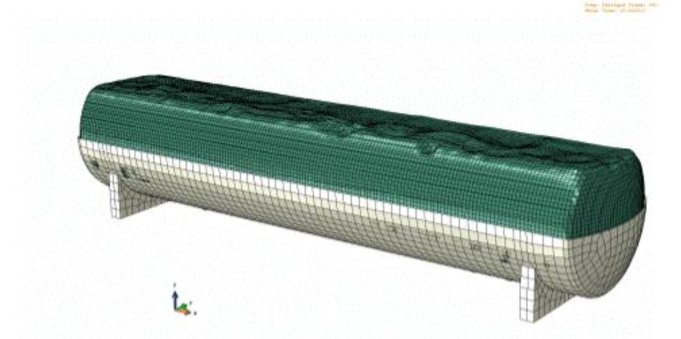
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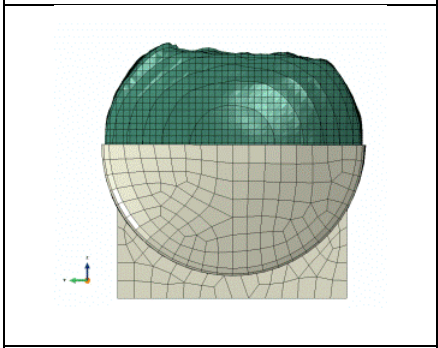	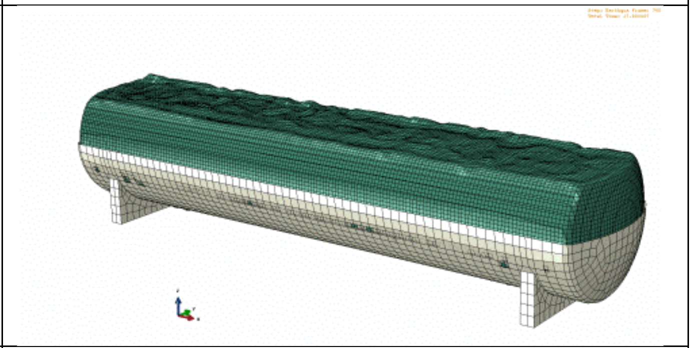
Time: 14.80 s	Time: 14.80 s

On the other hand, the seismic shaking is generating an increasing sloshing in the tank up until t=14.8s (Table 3). The sloshing is stronger in the transversal (Y) direction of the tank. This can be explained by the larger flexibility of the tank in this direction. But, a distinct longitudinal component of the sloshing is also present.

So far, only primary data extraction has been carried out on the model. It appears that using this modeling technique we are able to predict the complex liquid- solid interaction phenomena. However, some adjustments of the model are necessary before quantitative results can be confirmed.

3.6 Next steps of the modelling

In the next stage we plan to:

- Extract the reaction forces for the legs of the day-tank and confirm anchorage force values for the design;
- Assess stress levels in the shells steel elements;
- Assess stress fluctuations in the steel elements;

- Extract displacement and acceleration values corresponding to the locations of the “drainage of fuel oil day tank” sub-system, the “fuel outlet” subsystem and the “fuel oil day tank controls” (Figure 1), with the purpose of estimating amplifications of the acceleration compared to the base signal. Testing based qualification will be suggested for the 3 components.

  Test will be proof testing, since the location of the component is known/fixed. We have the 3 components of the 3D shaking in the location of the components, but only single axis shake table is available, so the 3D effect will have to be considered conservatively.

  The components do not need to be tested simulating operational conditions, but correct location/fixing/position need to be considered with the test setup. Operation is proven for the components after shaking.

  The components 2.2 drainage of fuel oil day tank and 2.4 fuel outlets may also be qualified analytically. For 2.3 fuel oil day tank controls testing is the suitable option, since one has to prove operation after the test.

The required response spectra (RRS) will be obtained from the aceelerograms of the 3 component locations. It is probably required to broaden the RRS, because of the uncertainty concerning the correctness of the dominating frequency. Only multiple-frequency signals are proposed for the testing, since activate all modes of the tested component simultaneously, and they are less conservative.

4 Conclusions

So far we can conclude that:

- It is possible, with reasonable effort (the runtime of the model is 4-5 days), to model the difficult liquid/solid interaction for the day-tank study. This will provide the opportunity to compare this sophisticated model with more simple methods used in everyday practice (e.g. single degree of freedom based models).
- The acceleration outputs corresponding to the locations of the different components will clarity the qualification requirements for these components.

However, the model still needs adjustments before it can yield useful quantitative results. Also, the different options of parameterization, e.g. level of liquid filling, deviation for base accelerations etc. needs to be decided in 2014.

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