KARISMA BENCHMARK: FORTUM PARTICIPATION IN EQUIPMENT RESPONSE ANALYSES

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ABSTRACT

On 16 July 2007, the Niigataken-chuetsu-oki (NCO) earthquake affected the TEPCO Kashiwazaki-Kariwa NPS. Due to the large amount of data collected, the KARISMA benchmark, Kashiwazaki-Kariwa Research Initiative for Seismic Margin Assessment, was held. The benchmark consisted of studies on soil, structure and equipments. In this proceeding, our analyses of the residual heat removal (RHR) piping, spent fuel pool (SFP) and pure water tank (PWT) are presented. PWT and SFP analyses were carried out using Abaqus-6.9 software. The RHR piping calculations were done using Finnish finite element piping software FIPIPE-3.0a. In the RHR analysis piping model was analyzed using response spectrum method. Based on the calculations, most stressed piping areas could be identified. In addition to earthquake load also self weight and thermal expansion load cases were considered. In the SFP analysis an Abaqus/Explicit model of the pool was prepared. The pool was considered to be a Lagrangian rigid structure. The water was modeled as an Eulerian domain. Based on the analyses the spilled water amount could be estimated. Also the main sloshing frequencies could be determined from the pool support reactions. In the PWT analysis an Abaqus/Standard nonlinear time-history model was constructed. The model could capture realistic "elephant foot" buckling phenomena at the base of the tank. The model could not predict the slight diamond shape buckling behavior that was observed in real structure.

INTRODUCTION

This paper presents three tasks in the contribution of Fortum Nuclear Services in the benchmark related to the equipment response of the Kashiwazaki-Kariwa Nuclear Power Plant (K-K NPP) of Tokyo Electric Power Company (TEPCO) in Japan, during the 16 July 2007 Niigataken Chuetsu Oki earthquake (Niigataken Chuetsu-Oki earthquake). This benchmark is proposed in order to compare the analytical response to real measured responses and to evaluate the reliability and precision of secondary systems stress analysis. The main objective of the benchmark exercise is to conduct a comparison between different analytical techniques, as used in the usual engineering practice and the recorded response of a structure actually affected by an earthquake, in order to learn about the whole effectiveness of the available methodologies. The Unit 7 of the K-K NPP was selected for the benchmark exercise. The concerned equipment elements include: 1) The Residual Heat Removal piping system, 2) Fuel pool sloshing and 3) The pure water yard tank buckling. The scope of the benchmark as a whole was limited to three subject areas: Area 1: Seismic design basis of the plant and the corresponding design basis ground motions defined on the basis of the Niigataken Chuetsu Oki event are Area 1 of the research task at hand. Preliminary investigations of the actual earthquake and its ground motions and comparison with the design basis ground motions for the plant seismic design form this Area 1. Area 2: The plant response of structures, systems and components to the Niigataken Chuetsu Oki event is Area 2 of the research task. Observation of the damage that occurred as a consequence of the earthquake of 16 July 2007 to the seven units at Kashiwazaki-Kariwa nuclear power plant site on the basis of the information gathered. Area 3: Operational safety management of the K-K nuclear power plant on the basis of the Niigataken Chuetsu Oki event is Area 3 of the research task. Preliminary investigations of the operational safety management response and releases of radioactive material during and after the earthquake are also one topic of investigations. This paper concentrates on the equipment response of the Residual Heat Removal (RHR) piping system (Task 2.1), Fuel Pool Sloshing (SFP) (Task 2.2) and Pure Water Tank (PWT) buckling (Task 2.3).

Task 2.1: KK7 RHR PIPING SYTEM ANALYSES

Structural model and loads

The basic analysis of RHR piping was carried out by the model with Finnish FPIPE software [1]. The number of nodes in the model was 299 and the number of pipe elements was 299. The total mass of the model was 35.6 ton. The type of the analysis with FPIPE was Response spectrum analysis. The modal extraction part of the analysis consisted of 65 natural modes in the frequency range from 5.5 Hz up to 51.5 Hz. As the load the 2% damping floor response spectra were used. For combining the modal responses the USNRC 10% grouping method was used. For combining directional responses in x-, y- and z-directions square root of the sum of squares (SRSS) method was used. The following loads were considered in the FPIPE analysis: 1) Gravity load, 2) Internal pressure load, 3) Seismic load. The check of FPIPE analysis snubber loads was carried out by Abaqus time-history model. In the following Figure 1, the FPIPE model geometry is presented. The SPR notation in the Figure 1 is used for spring support, the SNB notation in Figure 1 is used for snubber support and the pipe diameters in Figure 1 are presented in scale.

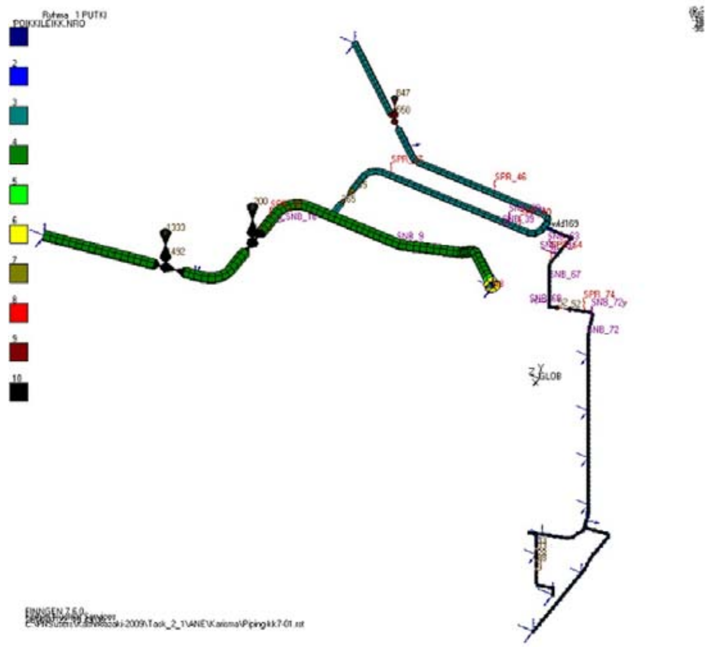
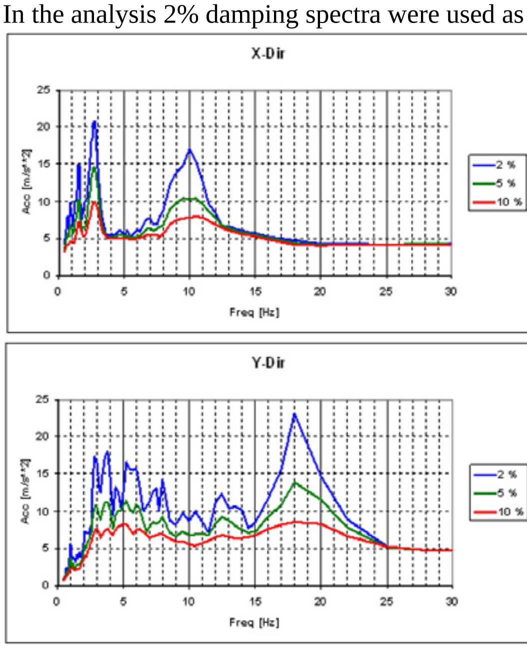


Fig.1: Task 2.1: Fpipe Model

The applied seismic load

The applied floor response spectra for RHR piping analysis are given in Figure 2. Three components of motion in x-, y- and z-directions are applied simultaneous in the model. In the spectra diagrams of Figure 2 2%, 5% and 10% damping spectra are shown. In the analysis 2% damping spectra were used as seismic load.



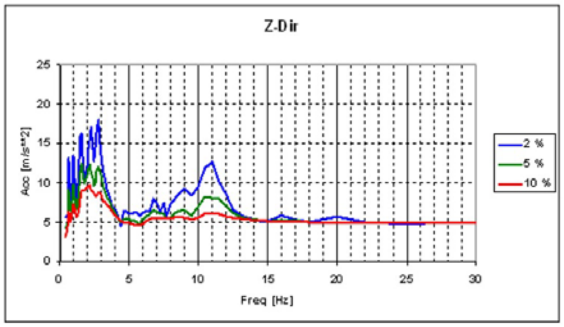


Fig.2: The seismic load spectra in three directions

The check of the snubber reactions was carried out with the aid of ABAQUS time history method. In the ABAQUS model the spring hangers were not modeled. The valves in RHR piping system were modeled as rigid links. The load applied in the ABAQUS time history model consisted of the seismic load only. For the snubber SNB9 the FPIPE reaction force was 100.3 kN and the ABAQUS reaction force was 80.7 kN. For snubber SNB16 the corresponding results were 126.8 kN for FPIPE and 104.8 kN for ABAQUS. The displacement results for RHR piping obtained from FPIPE analysis are given in Figure 3.

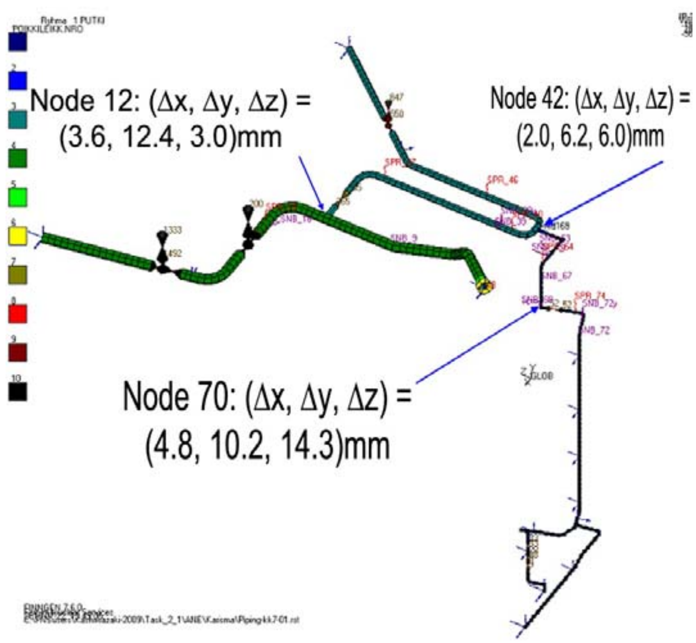


Fig.3: FPIPE Displacement Results

The equivalent stresses in FPIPE analysis calculated according to ASME NC-3600 Level C code procedure. The calculated FPIPE stresses and utilization coefficients are given for two locations in the model in Figure 4. The ASME allowable at the temperature of T = 276 °C is σ_{allow} =162 MPa.

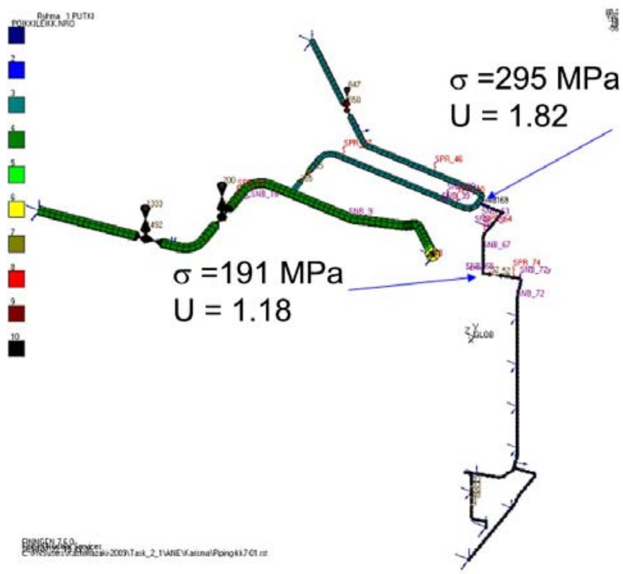


Fig.4: FPIPE Stress Results

TASK 2.2: KK7 SLOSHING OF SPENT FUEL POOL

The spent fuel pool sloshing analysis was carried out with ABAQUS-6.9 and with the explicit solver [2]. Coupled Euler-Lagrangian modeling method with direct integration time-history analysis was carried out. The pool walls ans bottom slab were modeled as a Lagrangian rigid body and the water in the pool was modeled as an Eulerian domain. The number of Eulerian elements in the model was 83044. The length of used excitation time histories in X-, Y- and Z-directions was 15 seconds. The following water physical properties at the temperature T=52 °C were used. The water density was taken to be 987 kg/m^3. The speed of sound in the water was taken to be 1541 m/s and the viscosity of water was taken to be 0.000528 Ns/m^2. The analysis model with initial water elevation is shown in the Figure 5.

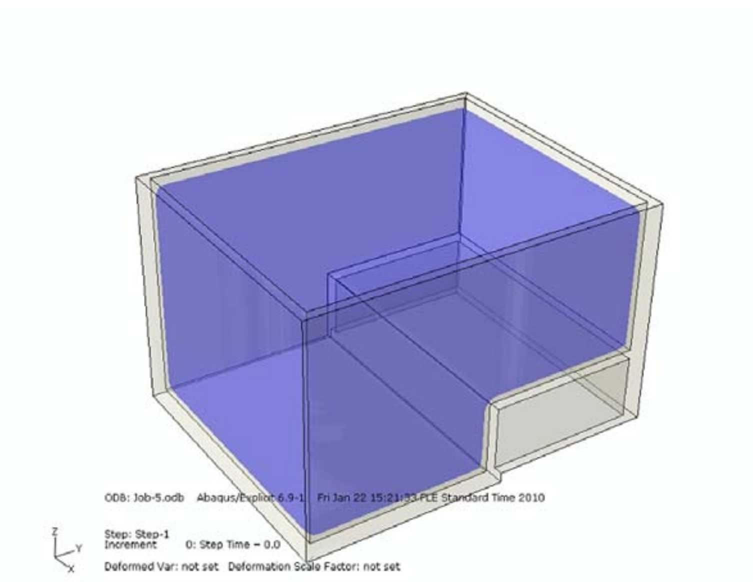


Fig.5: Initial Water Assignment in the spent fuel pool sloshing analysis

The applied acceleration time histories in the spent fuel pool sloshing analysis

The three component seismic excitation acceleration time histories were applied as a load to the combined model of Lagrangian and Eulerian domains. The length of excitation time histories in NS-, EW- and UD -plant coordinate directions was 15 seconds. The plots of these histories in g units are shown in Figure 6.

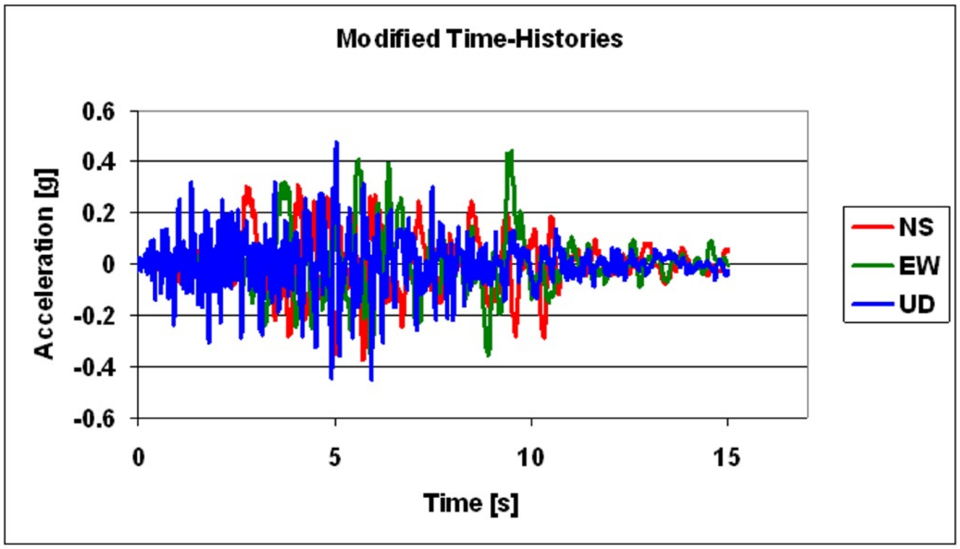


Fig.6: Acceleration Time-Histories for Spent Fuel Pool sloshing analysis

RESULTS OF SPENT FUEL POOL SLOSHING ANALYSIS

In the following still image the elevation of the sloshing of the spent fuel pool is shown at the time point of 6.3 seconds during the 15 second time history analysis. The estimated maximum sloshing wave height was about 1 meter and the estimated amount of spilled water was 376 m^3.

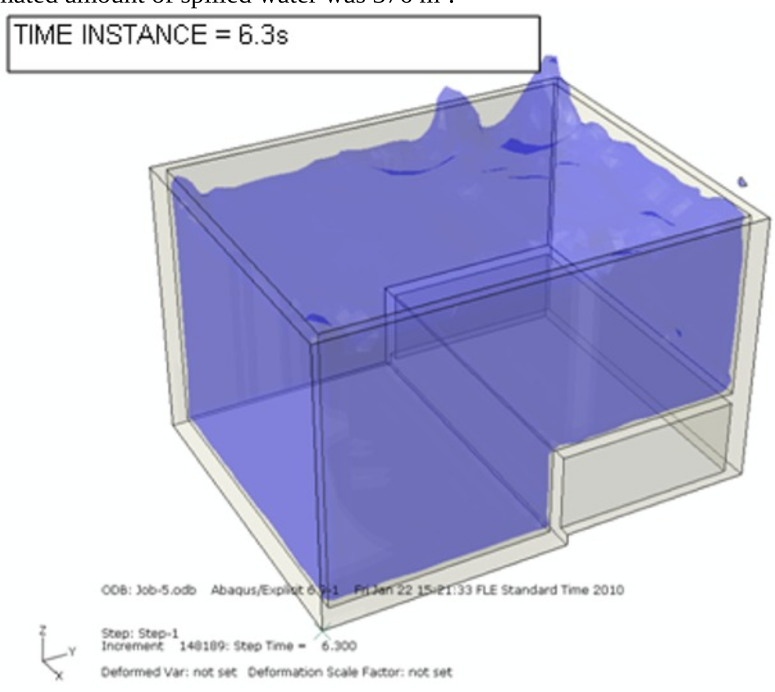


Fig.6: Still figure of the spent fuel pool sloshing at time point 6.3 seconds

TASK 2.3: KK7 PURE WATER TANK ANALYSIS

The Pure Water Yard Tank analysis was carried out with Abaqus/Standard-6.9. Number of nodes in the model was 2958 and number of elements in the model was 3077. The element used in the modeling was four node shell element. The stiffeners were modeled with 2-node Timoshenko beam elements. Water mass was modeled as nonstructural mass and this mass was distributed evenly on the cylinder up to height of 8.6m. The water pressure was applied as hydrostatic pressure distribution on cylinder. The displacements were fixed at the 12 anchor bolt locations at the bottom of the tank. The own weight steel tank was excluded from the analysis. Time-history analysis with implicit time-integration and with Δt_{max} of 0.005 seconds was carried out. The Rayleigh damping with alpha coefficient of 0.123 and beta coefficient of 0.0003105 was applied in the time history analysis. These values have been chosen according to ASCE4-98 code specification [3]. Steel properties of the tank material were chosen to be as follows: 1) Young's modulus = 200 GPa, 2) Poisson's ratio = 0.3, 3) Density = 7850 kg/m^3, von Mises elasto-plastic material model yield stress of 215 MPa was applied in the analysis. The nalysis model of the pure water yard tank is shown in Figure 7.

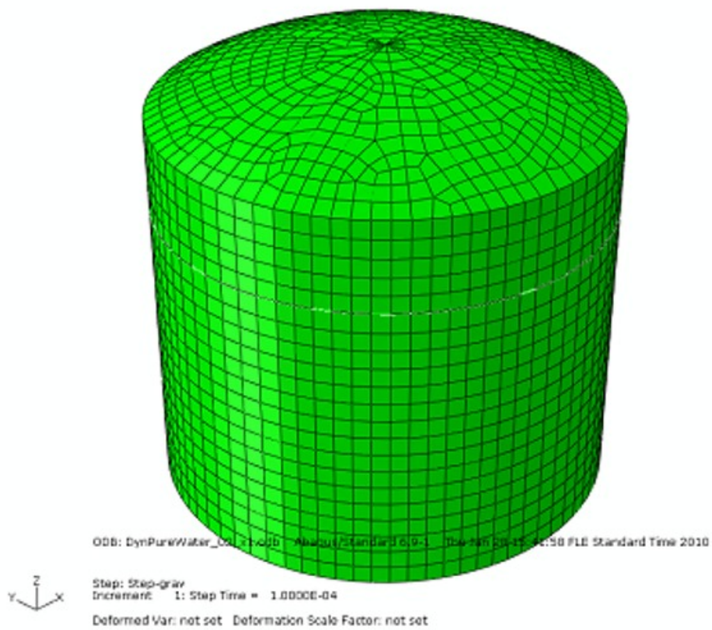
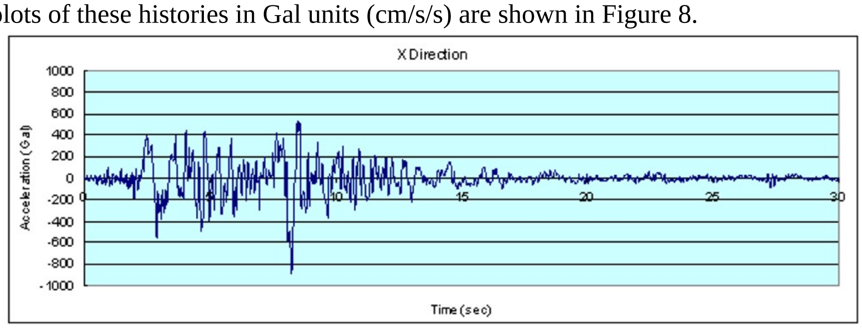


Fig.7: Pure Water Tank Analysis FEM - model

The applied acceleration time histories in the pure water yard tank analysis

The three component seismic excitation acceleration time histories were applied as a load to the pure water yard tank analysis. The length of excitation time histories in NS (x)-, EW(y)- and UD(z) -plant coordinate directions was 30 seconds. The plots of these histories in Gal units (cm/s/s) are shown in Figure 8.



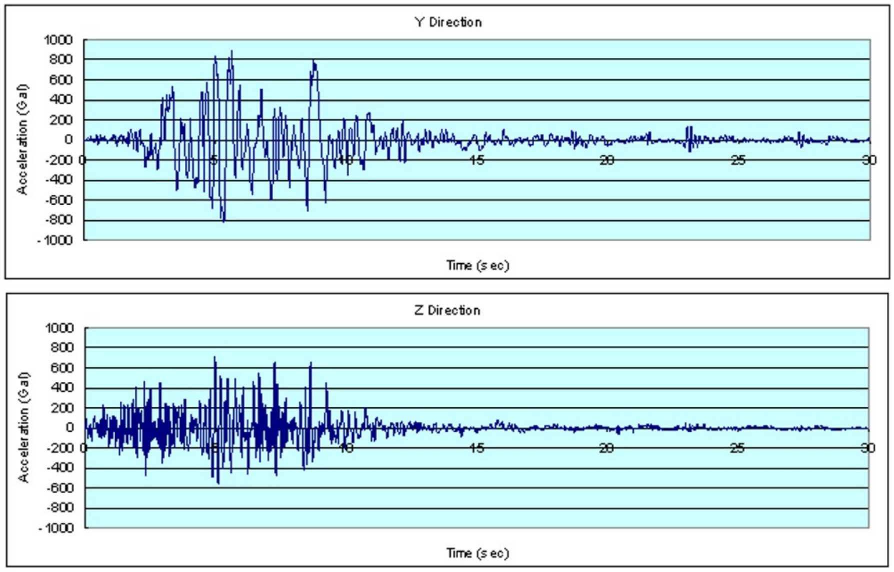


Fig.8: Acceleration Time Histories in Pure Water Tank analysis

BUCKLING PREDICTION OF THE PURE WATER YARD TANK

The displacement time histories of the apex of the pure water yard tank were calculated for scaled excitations of 50%, 60%, 70%, 80%, 90% and 100% of time histories given in Figure 8. The results of these analyses are shown in Figure 9.

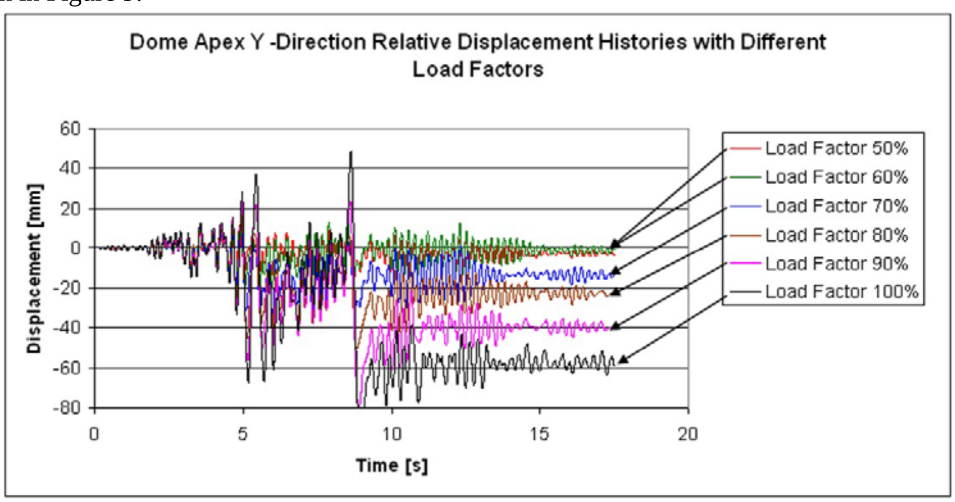


Fig.9: Buckling prediction for pure water yard tank

It can be seen from the Figure 9 that according to simulation the tank buckling occurs when load factor is between 60% and 70% of the full Niigata-ken-Chuetsu-oki excitation. This los of stability occurs at time point 9 seconds from the beginning of the acceleration time history. At this point the apex response acquires the new position and the vibration dampens out and the permanent displacement approaches to this new position.

CONCLUSIONS

In this paper the Fortum participation in the KARISMA benchmark for simulating Kashiwazaki-Kariwa plant unit 7 equipment response was presented. The exercise consisted of three analyses, namely, Residual Heat

Removal piping response, Spent Fuel Pool sloshing and Pure Water Yard tank buckling. The used modeling techniques were presented. The major results in the form of displacements and stresses or sloshing heights and amount of spilled water or in the form of load factor for the estimated buckling load were given.

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REFERENCES

[1] FPIPE, User's Manual, FEM data, Espoo, Finland, 2010.
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[3] ASCE STANDARD 4-98, "Seismic Analysis of Safety Related Nuclear Structures", American Society of Civil Engineers, September 1998.