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Division III

CALCULATIONS OF POTENTIAL LOSS OF WATER BASIN DUE TO NEW EARTHQUAKE DATA

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ABSTRACT

In the context of seismic safety revaluations of three nuclear power plants, EDF is designing new safety systems using existing water basins. This project leads EDF to evaluate the seismic behaviour of the water basin during strong seismic motion, and the volume of potentially spilled water that could reduce the water available in those basins.
Those evaluations have been performed using the Finite Point Method (FPM), considering the actual dimensions of the basins and a seismic action represented by acceleration time histories corresponding to a site-specific broadband design spectrum.

CONTEXT

Chosen Configurations And Earthquake Data

The three existing basins, hereafter called configuration A, B or C, are used for industrial water all-year long. EDF determined that these basins could also be used as a reserve of water for new systems that could increase the safety of the plants in case of an extreme seismic event, regarding local seismicity. To achieve this project, EDF had to evaluate the seismic behaviour of the water when submitted to a strong earthquake: 0.3g for site A and 0.25g for sites B and C. The different configurations and their corresponding models generated for the calculations are shown on the Figure 1.

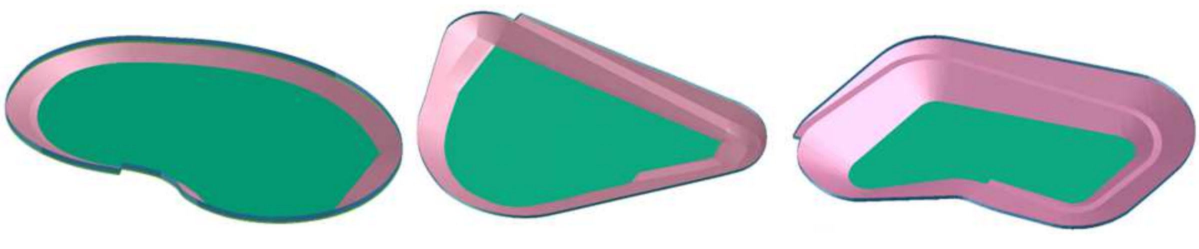

Figure 1: Three sites basins models (A, B and C)

The seismic action is represented by 5 sets of 3 acceleration time histories (for each direction). One set is illustrated in **Figure *2***.

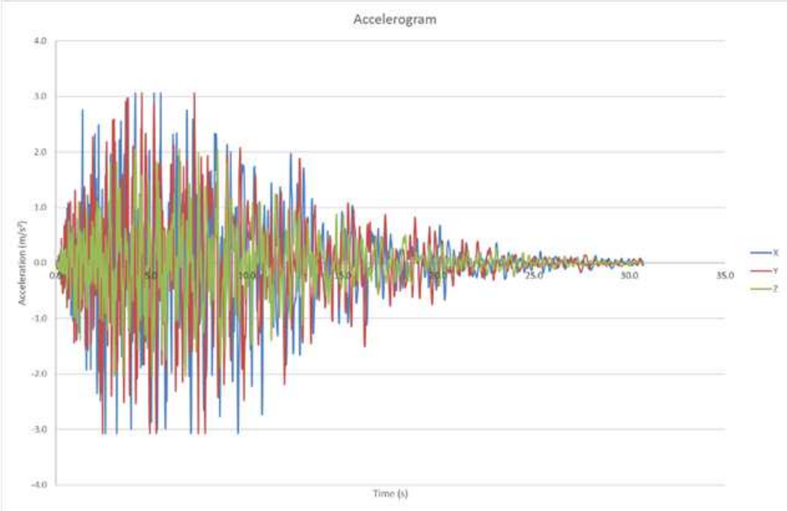

Figure 2: Example of a set of three acceleration time histories considered

This paper presents the method adopted to evaluate the amount of water potentially lost under seismic motion of interest, considered for each basin.

FINITE POINT METHOD

Simplified Methods Used Usually

Simplified Housner method could be used to estimate the height of the waves. Free surface basins can generally be modeled by masses and springs, connected to the walls. The basin shape is simplified and regarded as a rectangle. To estimate the maximum wave height for such a basin, the following formulas are used:

$$M_0 = M\frac{\mathrm{th}(1{,}7\ {}^{L}/_{H})}{1{,}7\ {}^{L}/_{H}}$$

$$M_1 = M\frac{0{,}83\ \mathrm{th}(1{,}6\ {}^{L}/_{H})}{1{,}6\ {}^{L}/_{H}}$$

$$H_0 = 0{,}38\ H\left[1 + \alpha\left(\frac{M}{M_0} - 1\right)\right]$$

$$H_1 = H\left[1 - 0{,}33\frac{M}{M_1}\left(\frac{L}{H}\right)^2 + 0{,}63\beta\frac{L}{H}\sqrt{0{,}28\left(\frac{L.M}{H.M_1}\right)^2 - 1}\right]$$

$$K = \frac{3.g.M_1^2.H}{M.L^2}$$

$$\eta = \frac{0{,}84\left({}^{K.L}/_{M_1.g}\right)}{1 - \left({}^{x}/_{L}\right)\left({}^{K.L}/_{M_1.g}\right)^2}$$

With the following notations:

- Height H : Liquid depth
- Mass M : Water mass contained in the basin
- Mass M_0 : Water mass rigidly connected to the basin (lower part)
- Mass M_1 : Moving water mass connected to the basin with springs (upper part)
- Height H_0 : Measure of the rigidly connected mass M_0
- Height H_1 : Measure of the flexibly connected mass M_1
- Stiffness K : Horizontal springs stiffness between M_1 and walls basin
- Length L : Basin half-length in the earthquake direction
- Acceleration g : Acceleration of gravity
- Displacement x : M_1 displacement range
- Height $\eta.x$: Wave height range

The results for the three different configurations A, B and C are given in **Table4**.

Modelling Hypotheses

Simplified methods are known to be severe and since only the maximal wave height can be used to estimate the volume of water potentially lost during the seismic event. An innovative method, named Finite Point Method (FPM), has been used in order to accurately estimate the amount of water eventually lost.

Navier-Stokes equations of fluid mechanics are solved without mesh, through a Lagrangian approach. The Finite Point Method is usually used for fluid-structure interaction, especially when the topology of the fluid is widely moving – and moving fast – such as airbag deployments or sloshing effects in a vessel.

In such a method, the system is considered as a set of particles, each one defined by its radius (called smoothing length) having all appropriate flow parameters (velocity, pressure and temperature). As classical Finite Elements Methods using mesh, each particle interacts with its neighbours within a sphere of radius h, as visible in Figure 3.

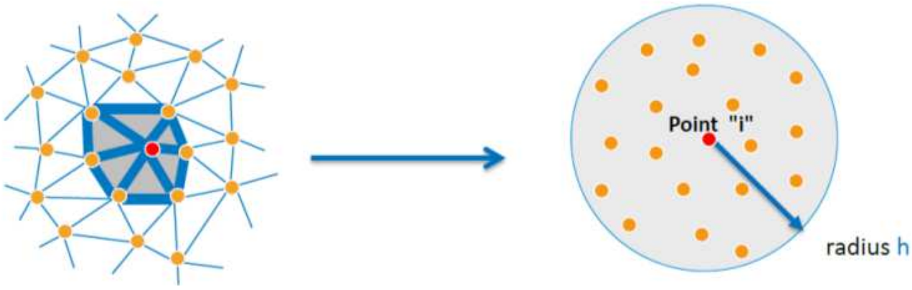

Figure 3: Sphere of influence containing particles

Radius h (smoothing length) is a leading parameter for resolution of such a problem. For each iteration, this parameter allows connectivities for all particles to be performed, to approximate Navier-Stokes equations.

Boundary conditions (free surface, escape conditions, center of gravity, etc.), smoothing length, time steps and number of particles are determined, so that the model shall be accurate enough (especially close to edges, where the number of escaped particles have to be estimated carefully) and can be performed in a reasonable delay.

Software Used

Here, the FPM module is coupling with the ESI-VPS^{TM} (Virtual Performance Solution) software, dedicated to solid mechanics. The software ESI-VPS^{TM} is an explicit Finite Element code, usually used for crash analysis. The FPM module is an add-on, integrated within ESI-VPS^{TM}, to deal with fluid-structure interaction. Thus, this software and its add-on module is the right solution to solve the considered problems. The software has been validated by comparing results with a previous EDF / ESI France study of water loss at the Kashiwazaki-Kariwa NPP.

CALCULATIONS

According to French regulator requirements (ASN guide 2/01), seismic non-linear time history analyses must be performed using at least 5 sets of acceleration time histories. Five sets of accelerograms, corresponding to each site specific broadband design spectrum, are considered in the seismic calculations of each basin configuration.

As explained before, smoothing length affects significantly results accuracy and computing time. Given that the desired outcomes are focused near the edges of the basin, a refined value is set in these zones whereas a larger one is preferred at the centre of the basin. Chosen parameters are summarised in the Table 1 for each configuration and the initial number of particles too.

Table 1: Numerical parameters chosen for the simulations

	Conf. A	**Conf. B**	**Conf. C**
Basin depth (m)	3.0	4.4	10.5
Initial volume of water (m^3)	17 842	17 680	76 100
Global smoothing length (m)	1.0	1.0	2.0
Refined smoothing length (m)	0.4	0.4	0.1 – 0.5
Initial number of particles	720 000	760 000	520 000

The configuration A basin filled by particles at initial time is visible in Figure 4 and Figure 5. Light blue particles stand for the free surface, dark blue ones stand for fluid domain in direct contact with the waterproof walls and pink ones stand fort fluid domain inside the basin.

The smoothing length evolution throughout the basin is in Figure 6.

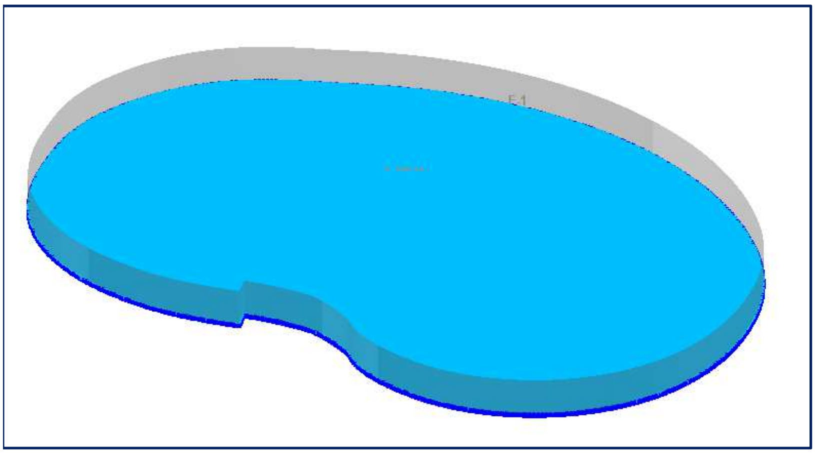

Figure 4: Display of the configuration A basin full of particles at initial time

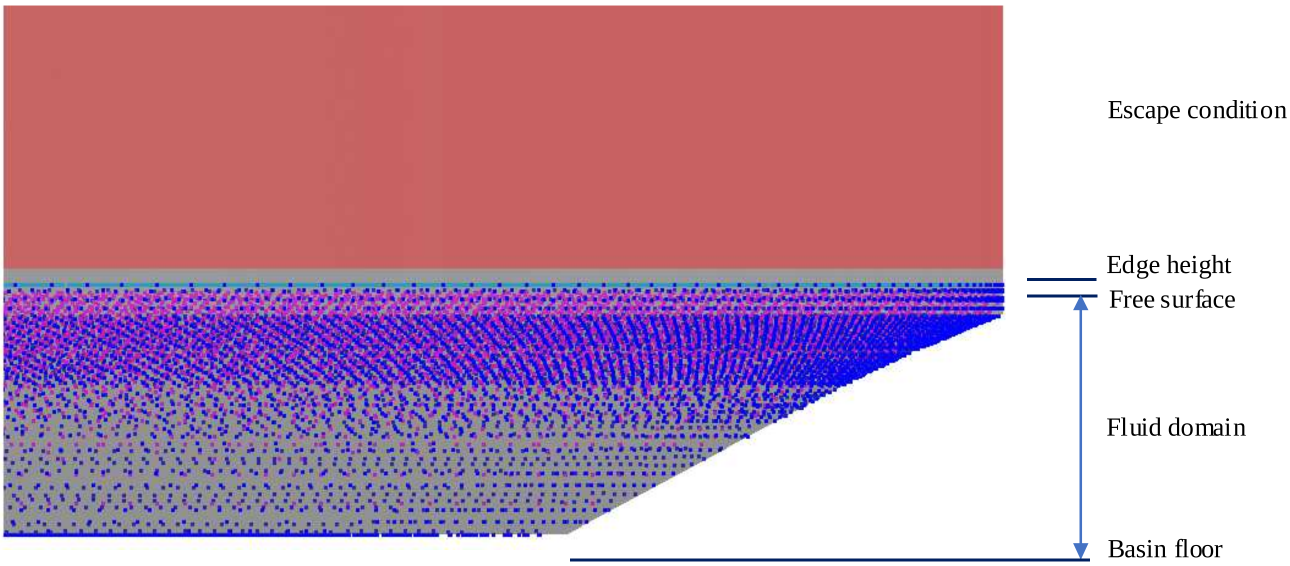

Figure 5: Sectional view of water level at initial time for the configuration A basin

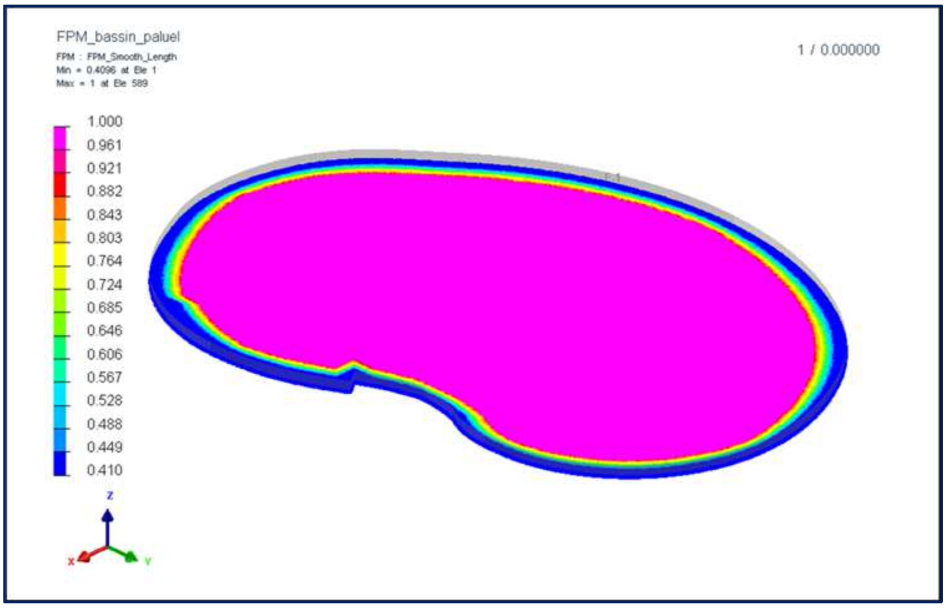

Figure 6: Smoothing length evolution throughout the basin

Another significant parameter is the time step, which is automatically calculated at each cycle by the software ESI-VPS™. However, a maximum time step is required and can be determined by the following formula:

$$\Delta t_{max} < \frac{h_{min}}{V_{max}}$$

Where h_{min} is the minimum smoothing length used in the model and V_{max} is the maximum particle velocity all along the simulation. Velocity time history is obtained by numerical integration of the acceleration time history, based on the trapezoidal scheme, on each elementary time range. The maximum acceptable time step is computed for each accelerogram and each configuration. The values are shown in Table 2.

Table 2: Maximum time step values

	Conf. A	**Conf. B**	**Conf. C**
Maximum velocity (m/s)	0.264	0.264	0.317
Minimum smoothing length (m)	0.4	0.4	0.1
Maximum time step (s)	1.51	1.51	0.31

RESULTS

Volumes And Displacements

The five different accelerograms are considered for at least 60 seconds for the three configurations A, B and C. It appears that no loss of water occurs for the three configurations even though the maximum wave heights for configurations A and B are higher than the edge height, but did not occur close to them.

Particles motion in a sectional view is displayed at the time at which the maximum wave height occurs, for the three configurations respectively in Figure 7, Figure 8 and Figure 9. Fluid motion is visible but does not exceed the edge (displayed in red).

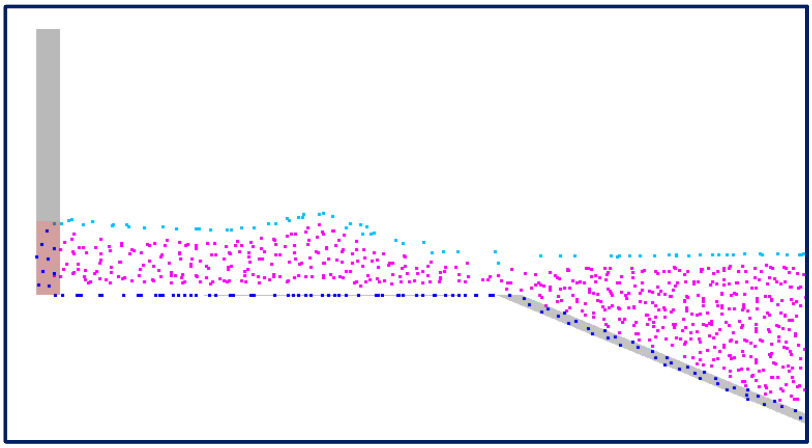

Figure 7: Maximum wave height during the whole simulation (configuration A)

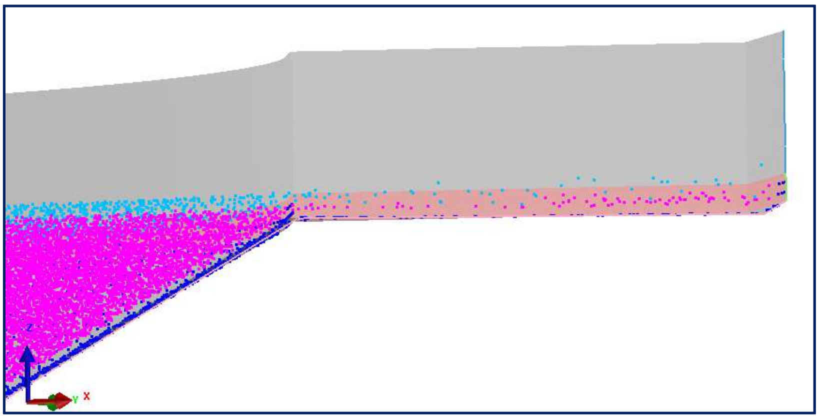

Figure 8: Maximum wave height during the whole simulation (configuration B)

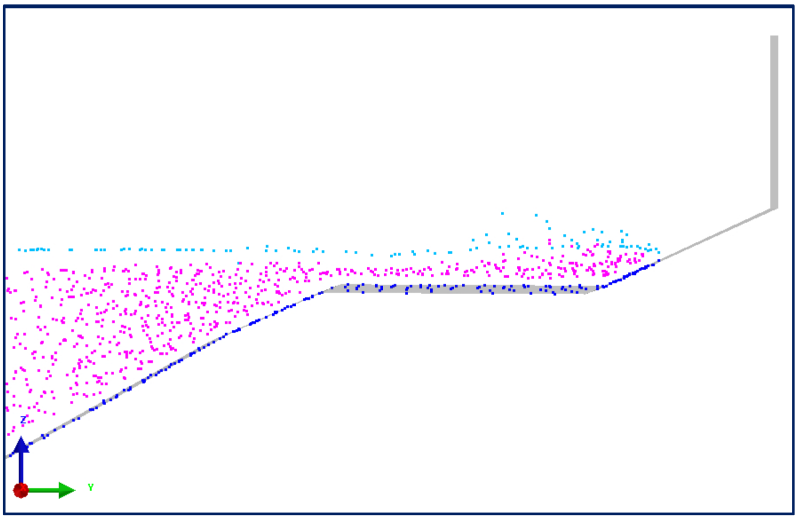

Figure 9: Maximum wave height during the whole simulation (configuration C)

Water Levels

In order to corroborate previous results, the maximum vertical coordinate is computed for all particles of the three basins and compared to the edge height. Maximum wave height exceeds the edge height for configurations A and B, but it never occurs close to the edges, which explains that no loss of water is found.

Time evolution results are shown in Figure 10, Figure 11 and Figure 12, respectively for configuration A, B and C and values of maximum wave height are given in Table 3.

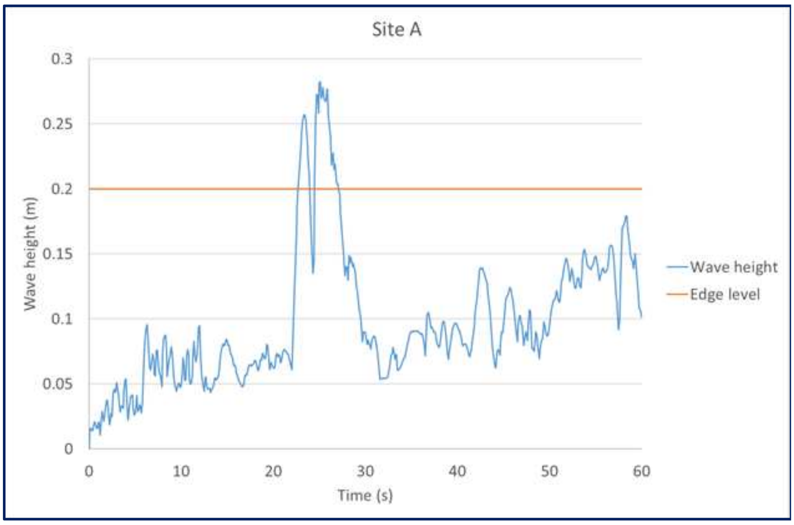

Figure 10: Time evolution of wave height for the most critical accelerogram (configuration A)

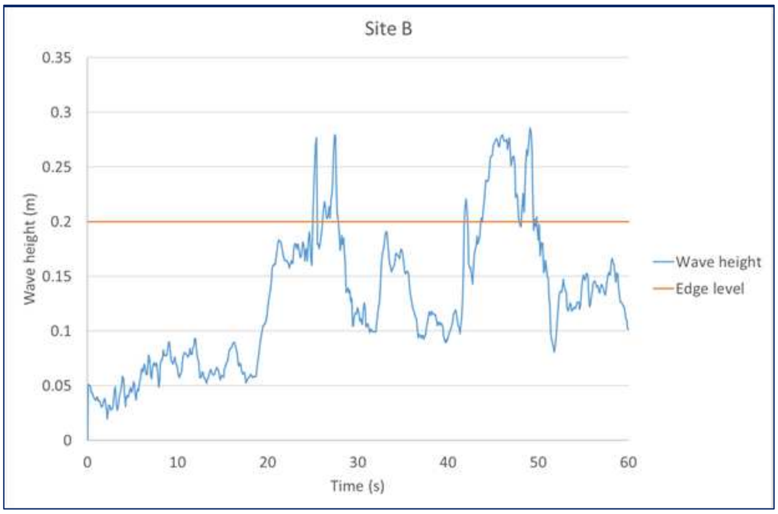

Figure 11: Time evolution of wave height for the most critical accelerogram (configuration B)

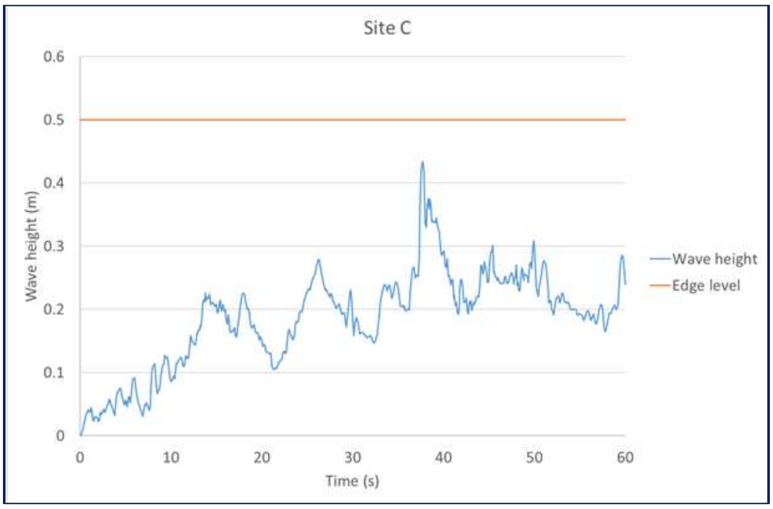

Figure 12: Time evolution of wave height for the most critical accelerogram (configuration C)

Table 3: Maximum wave height all along the simulation period

	Conf. A	Conf. B	Conf. C
Water volume (m^3)	~18 000	~18 000	~76 000
Height of edges (m)	0.20	0.20	0.50
Maximum wave height (m)	0.28	0.28	0.43

Analytical Methods

Analytical calculations based on the Housner method are performed. With such a simplified method, the maximum wave height is about few centimeters different for all three configurations, consolidating numerical results. The entire analytical values are available in **Table4**.

Table4: Analytical results calculated by Housner method

	Configuration A		Configuration B		Configuration C	
Housner parameters	direction X	direction Y	direction X	direction Y	direction X	direction Y
Basin half-length (m)	55	35	50	35	70	42.5
Basin height (m)	3.0	3.0	4.4	4.4	10.5	10.5
Moving mass M_1 (kg)	$1.91.10^7$	$1.91.10^7$	$2.54.10^7$	$2.52.10^7$	$1.02.10^8$	$9.86.10^7$
Associated stiffness (N/m)	$4.62.10^5$	$1.13.10^6$	$1.08.10^6$	$2.18.10^6$	$5.22.10^6$	$1.33.10^7$
Natural frequency (Hz)	0.0247	0.0388	0.0329	0.0468	0.0361	0.0585
Spectral acceleration (m/s2)	0.003	0.007	0.005	0.011	0.0061	0.0173
Horizontal displacement (m)	0.124	0.118	0.117	0.127	0.118	0.128
Wave height (m)	0.014	0.021	0.021	0.033	0.037	0.063

CONCLUSIONS

Under earthquake, numerical simulation with the software ESI-VPS™ highlights no water loss for the three basins and for all the time histories.

Maximum water height for each time history analysis is computed for all particles in the basins. Some exceedance of edge height are identified but they are not strictly located close to the edges. Therefore, no loss of water occurs for the three sites A, B and C.

Water volumes being unchanged after seismic solicitation, fuel cooling of stacked fuel in the fuel building is ensured in that context.

REFERENCES

Housner, G. W. (1963) - «The dynamic behavior of water tanks » – *Bulletin of the Seismological Society of America. Vol 53, N°2 pp 381-387.*

ASN Guide 2/01 - «Considering the risk of an earthquake when designing civil engineering structures of nuclear installations, excluding long-term storage of radioactive waste »