SIMULATION OF TSUNAMI INTERACTION WITH ON-LAND STRUCTURE

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1. INTRODUCTION

Tsunami can be identified as a catastrophic event which can cause vast amount of damage, in term of causalities as well as in distortion of infra-structure. Specially, considering the devastation caused by the 2004 Indian Ocean tsunami, 2011 Tohoku tsunami and the subsequent events, questions has been raised and still remain regarding the safety, preparation and minimizing the damage against this destructive wave. Since the coastal structures like oil storage tanks tend to become much more critical under tsunami loading, it has a great importance in understanding interaction between tsunami and such structures.

In the study, a finite element model was developed considering Arbitrary Lagrangian-Eulerian (ALE) approach, available with the 3-Dimentional nonlinear finite element code LS-DYNA. The paper discusses the modeling results for the interaction of on-land propagating tsunami bore with a cylindrical tank structure and the results are compared with the experimental modeling results by Sakakiyama et al. (2009). Primary objective of the study is to check the applicability of the ALE methodology to tsunami-structure interaction modelling.

2. NUMERICAL SCHEME

2.1 ALE Formulations

ALE method has the combined advantages of the Lagrangian and Eulerian formulation. In case of Lagrangian description mesh and material move exactly together, whereas materials been tracked when flow through a mesh which is fixed in the space for the Eulerian description. Combination of the behavior of these two descriptions in a single analysis provides an ability to predict the interaction between fluid and structural elements. The material derivative for the ALE description can be introduced as [Souli et al. (2000)],

$$\frac{\partial f(X_i,t)}{\partial t}=\frac{\partial f(x_i,t)}{\partial t}+w_i\frac{\partial f(x_i,t)}{\partial x_i} \tag{1}$$

where X is Lagrangian coordinate and x is Eulerian coordinate. $w_i=v_i-u_i$ is introduced as relative velocity where, v is the velocity of the material and u is the velocity of the mesh. Governing equations for the ALE formulation can be described as follows,

Equation for the mass conservation,

$$\frac{\partial \rho}{\partial t}=-\rho\frac{\partial v}{\partial x_i}-w_i\frac{\partial \rho}{\partial x_i} \tag{2}$$

Navier-Stokes equation for fluids, which governs the motion,

$$\frac{\partial v}{\partial t}=-\left(\frac{\partial \sigma_{ij}}{\partial x_j}+\rho b_i\right)-\rho w_i\frac{\partial v_i}{\partial x_j} \tag{3}$$

Stress tensor σ_{ij} in Eq. (3) can be introduced as,

$$\sigma_{ij}=\ -p\delta_{ij}+\mu\left(\frac{\partial v_i}{\partial x_j}+\frac{\partial v_j}{\partial x_i}\right) \tag{4}$$

where, ρ is the density of fluid, μ is the coefficient of kinematic viscosity and p is the pressure.

2.2 Finite Element Model

The model arrangement shown in Fig.1 consists of 17828 nodes, 13600 solid elements and 1000 shell elements. A tank structure is modeled with shell elements as a Lagrangian cylindrical mesh while air and water domains are modeled with 0.02 × 0.02 × 0.02 m cubic solid elements which behave as ALE mesh. The water element set is expected to be act like a reservoir which is continuously supplying the inflow to the domain. Physical parameters of the incoming flow at the entrance are prescribed and decided according to the experimental study observations by Sakakiyama et al. (2009). Such type of inflow mechanism was applied in aim of reducing the large computational cost which makes a significant influence to the effectiveness of the analysis. Tank diameter is set to 0.654 m and the inundation depth and the flow velocity in the ‘x’ direction at the source are initialized as 4 cm and 40 cm/s, respectively. The size of the whole computational domain is 0.9 × 1.0 × 0.12 m and the slip boundary condition is applied at the side and bottom boundaries.

Keywords: Tsunami-Structure Interaction, Arbitrary Lagrange-Euler, Tsunami Force

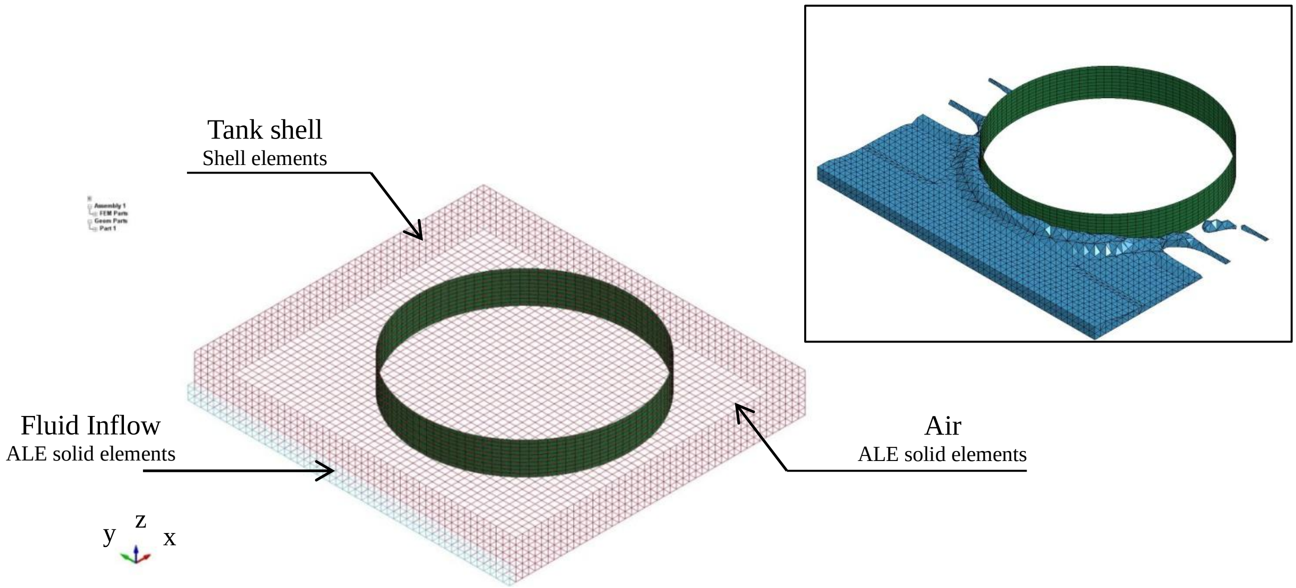

Fig. 1 Finite element domain for the analysis and deformed mesh during the simulation

3. CONCLUSIONS

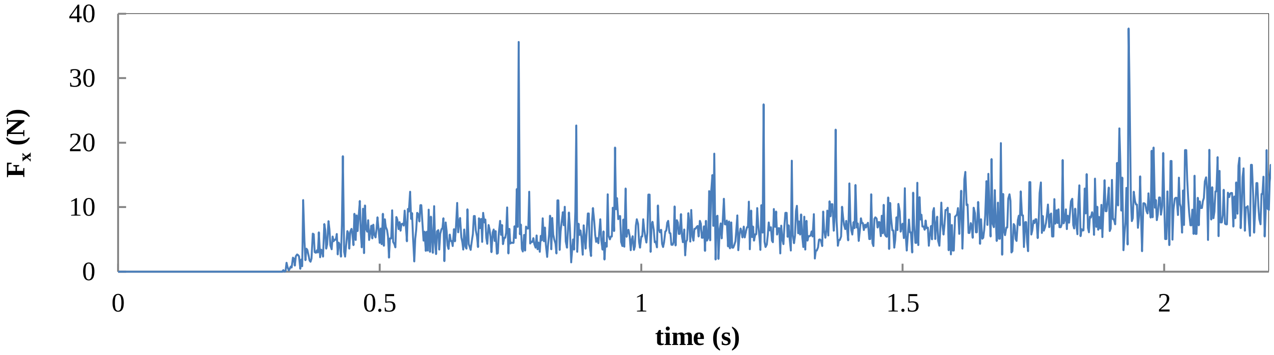

Fig. 2 Variation of the Horizontal component of the force

The observed temporal variation of the Horizontal force in flow direction (F_x) acting on the cylindrical tank is shown in Fig. 2. It is highlighted that the simulation time interval considered is not sufficient to predict loading over long duration. However, in the simulation, since the flow conditions achieve the maximum velocity and the maximum inundation depth of the experimental flow conditions fairly quickly, it can be clearly observed that the acting horizontal force by simulation results also reaches the experimental maximum (10 N) within a short time period (Fig.2). Slight increment of the force is observed in the latter part of the force variation due to the reflection of the flow from the side boundaries. As the results reveal, the approach can be applied to simulate the tsunami-structure interaction and further studies should be carried out in order to improve the accuracy of the results as well as to identify the limitations.
Simulation was conducted under compressible flow conditions since the incompressible flow solver of the LS-DYNA is still going under basic development. There is a high possibility of achieving accurate results within relatively low computational cost with the use of incompressible flow solver.

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