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ANALYSIS OF SOIL - STRUCTURE INTERACTION ON RESPONSE OF TANKS FILLED WITH FLUID

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ABSTRACT

In the conventional analysis of tanks with fluid, the base of tank is assumed to be fixed and the flexibility of soil is not accounted in the analysis. However, it is well known that actual behavior of tank not only depends on the stiffness of tank but also on the stiffness of foundation and supporting soil system. In the proposed study, the tank resting on soil is analysed considering the effect of soil. The tank, fluid and soil are modelled using finite element method. Tank is subjected to one far field and one near fault ground accelerations and the displacement, base shear and the pressure in the fluid are obtained. Three types of soil with different flexibility are considered to study the soil structure interaction (SSI) effect. It is concluded from the study that the soil flexibility significantly affects the response of tank and the effect may be either beneficial or detrimental on the response of tank.

Key words: Finite Element Method, Fluid–Structure-Soil Interaction, Rectangular Tank, Far Field and Near Fault Earthquakes.

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1. INTRODUCTION

Liquid storage tanks have played a vital role in the distribution of water, liquid natural gas, chemicals etc. The dynamic performance of these tanks is a matter of special importance, since they are required to remain functional after a major seismic event. If forces on the tank are not estimated properly, it will lead to inappropriate design and may fail during a seismic event. Such inadequate designs have attributed to extensive damages to liquid filled tanks during past earthquakes [1]. Such failures created lot of interest in safeguarding these tanks against seismic forces. The dynamic response of tanks exposed to earthquake ground motion differs from the response of general structures [2]. This difference is caused due to the effect of pressure developed due to fluid on tank walls. In order consider the effect of fluid in the tank filled with fluid, Housner [3] proposed a simplified analytical solution in which hydrodynamic pressures induced by the ground motions are separated into two parts as convective and impulsive components and are modelled as lumped added masses. Later many studies considering the effect of fluid on tank [4 - 7] have also been conducted using the model proposed by Housner [3]. However, in all these analysis, the base of tank is assumed to be fixed and the flexibility of soil is not accounted in the analysis. It is well known that actual behavior of tank not only depends on the stiffness of tank but also on the stiffness of foundation and supporting soil [8]. Kim et al. [8] presented method for a cylindrical tank by considering the effects of the liquid and soil system in the frequency domain. Kianoush and Ghaemmaghami [9] also investigated the effect of SSI on a tank filled with fluid for six types of soil. In the proposed study, the influence of flexibility of the soil on a tank filled with fluid is studied. In order to consider the effect of flexibility of the tank wall, the tank, soil and fluid are modeled using finite elements. Similar investigation have been carried out by Chaithra et al. [10] to study the effect of SSI for Chi-Chi earthquake. However in this study two types of earthquakes one far field i.e., El Centro earthquake and one near fault i.e., Imperial Valley earthquakes have been considered to study the effect of type of earthquakes on SSI effect of tank.

2. METHODOLOGY

The tank, fluid and soil are modelled using finite elements.

Dynamic equation of equilibrium considering fluid structure interaction for the tank wall and soil is given by the equation

$$Kq + M\ddot{q} + C\dot{q} = f(t) + Fp \qquad (1)$$

Where,

K, M and C are the stiffness, mass and damping matrices respectively of tank and soil. q, $\dot{q}$ and $\ddot{q}$ are the vectors of displacement, velocity and acceleration respectively at the nodes. f(t) is the force due to ground acceleration and is given by the equation,

$$f(t) = -M\, I_V\, \ddot{u}_g(t) \qquad (2)$$

Where, 'I_V' is the influence vector and '$\ddot{u}_g(t)$' is the ground acceleration.

The fluid is modeled using the equation,

$$H\,p + G\,\ddot{p} - Fs = 0 \qquad (4)$$

H is the stiffness matrix and G is the mass matrix of the fluid. Fs and Fp are the forces resulted due to interaction between structure and fluid at the interface.

Equations (1) and (4) can be written in matrix form as,

$$\begin{bmatrix} K & -S \\ 0 & H \end{bmatrix} \begin{bmatrix} q \\ p \end{bmatrix} + \begin{bmatrix} C & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \dot{q} \\ \dot{P} \end{bmatrix} + \begin{bmatrix} M & 0 \\ \rho S^T & G \end{bmatrix} \begin{bmatrix} \ddot{q} \\ \ddot{p} \end{bmatrix} = [f(t)] \qquad (5)$$

Newmark's method is used to solve the above coupled equation of equilibrium considering soil-structure and fluid interaction. Constant average acceleration method is used by considering $\beta = \frac{1}{4}$ and $\gamma = \frac{1}{2}$.

3. NUMERICAL ANALYSIS

Two types of earthquake ground motions considered are El Centro earthquake with Peak Ground Acceleration (PGA) of 2.927 m/s^2 and Imperial Valley earthquake with PGA 4.31 m/s^2. It has been reported that El Centro earthquake has the characteristics of far filed earthquake whereas, Imperial Valley earthquake has the characteristics of near fault earthquake. The accelerogram of these two earthquakes are shown in figures 1and 2.

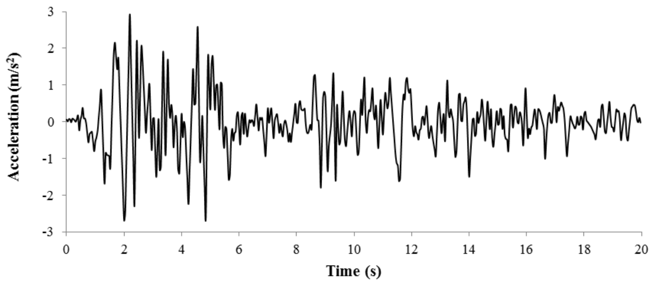

Figure 1 Accelerogram of El Centro earthquake

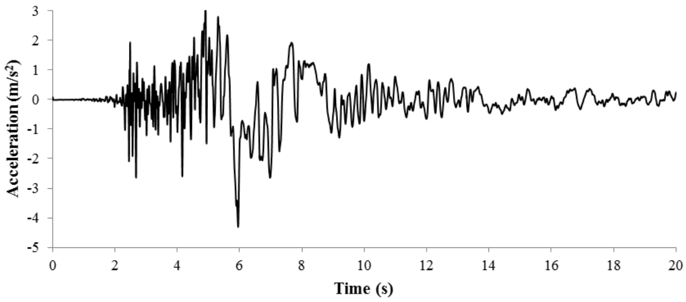

Figure 2 Accelerogram of Imperial Valley earthquake

3.1. Details of structure, fluid, and soil system considered for the analysis

The finite element discretization of tank, fluid and soil is shown in Figure 3. Material properties and geometric properties considered for the problem are as follows:

Tank:

Tank height = 3.0 m

Tank inner dimension = 3.0 m × 5.0 m

Mass Density = 2.4 $kN.s^2/m^4$

Modulus of Elasticity = 2×10^7 kN/m^2

Fluid:

Bulk modulus = 2.0684×10^6 kN/m^2

Mass density = 1.0 $kN.s^2/m^4$

Viscosity = 1.1×10^{-6} $kN.s/m^2$

Modulus of elasticity of Soil:

S_1 = 5000 kN/m^2

S_2 = 500000 kN/m^2

$S_3 = 5000000$ kN/m^2

Poisson's ratio = 0.3

The soil types S_1, S_2 and S_3 represent soft, medium and hard soil respectively. The tank is subjected to the above two types of earthquakes and response parameters such as the base shear, displacement of the tank and pressure in the fluid are obtained at various time interval. The peak values of base shear, displacement and pressure for the tank with SSI are compared with the tank without SSI to study the soil structure interaction effect.

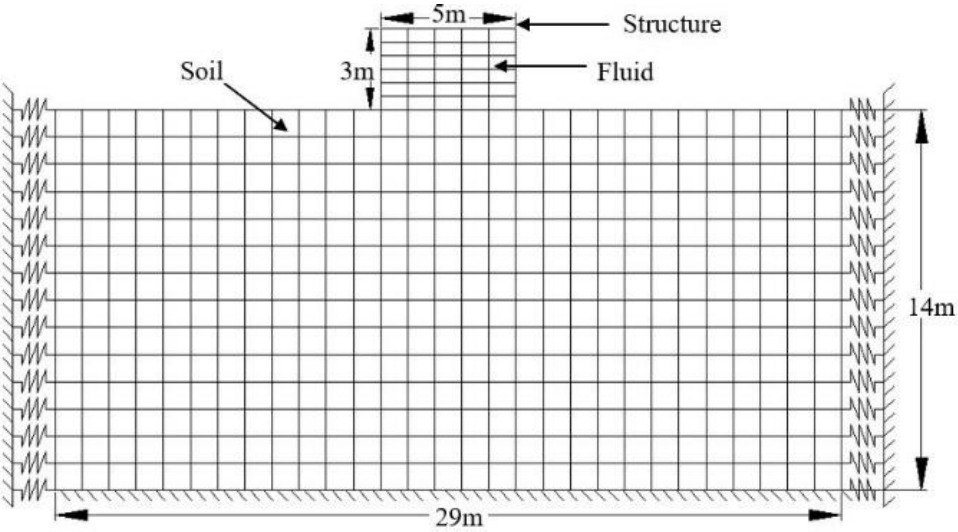

Figure 3 Finite element discretization of tank, fluid and soil

3.2. Time History Response

3.2.1. Top Displacement

Figures 4 and 5 shows the time history response of displacement at top of the tank resting on different type of soils obtained for two types of earthquake ground motions. From the figures, it can be observed that, the maximum displacement of the tank resting on S1, S2 and S3 soil types is 1.527 mm, 1.460 mm and 1.670 mm for El Centro earthquake whereas the displacement for Imperial valley earthquake is 1.899 mm, 2.662 mm and 3.052 mm for the tank resting on S1, S2 and S3 soil types respectively. This shows that, the displacement of the tank is influenced considerably due to SSI. The influence is significant for the tank on S1 type of soil and decreases as the stiffness of soil increases. It can also be observed that the influence of SSI on displacement is also affected by the type of earthquake i.e., for Imperial Valley earthquake, displacement increases as the soil stiffness increases, whereas for El Centro earthquake it is lesser for soil type S2 compared to S1 and S3 type.

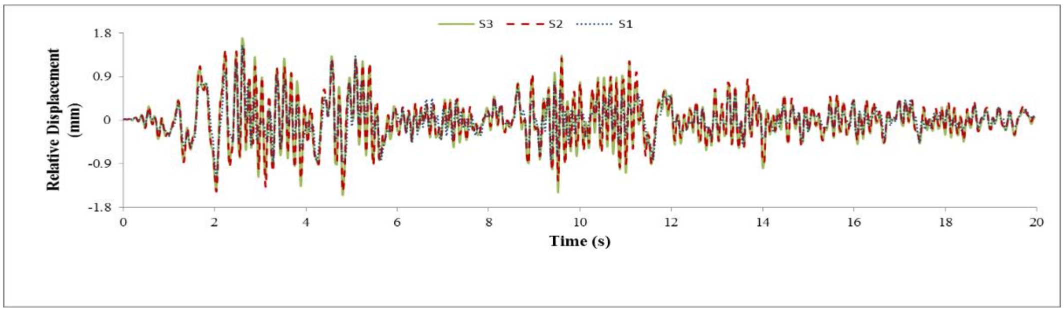

Figure 4 Time history response of displacement for El Centro earthquake

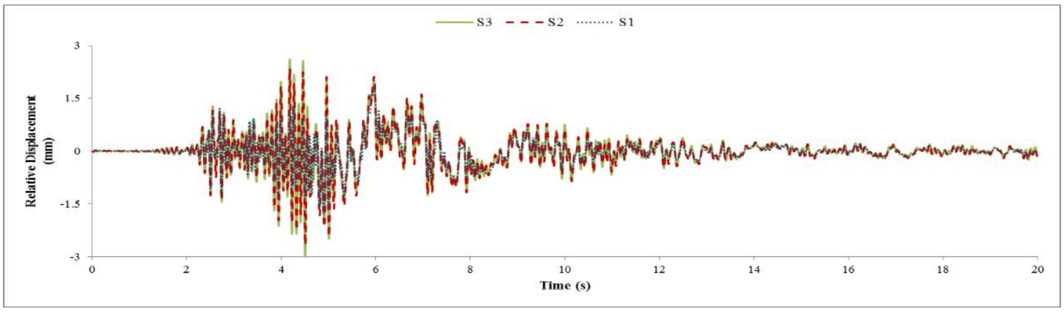

Figure 5 Time history response of displacement for Imperial Valley earthquake

3.2.2. Base Shear

The time history response of base shear of tank resting on different types of soil is shown in figures 6 and 7 for El Centro and Imperial Valley ground motions respectively. It can be observed from figures that, the maximum base shear of the tank resting on S1, S2 and S3 soil types is 19.263 kN, 26.704 kN and 26.062 kN for the tank subjected to El Centro earthquake, whereas the base shear for Imperial valley earthquake is 35.137 kN, 39.606 kN and 38.098 kN for the tank resting on S1, S2 and S3 soil types respectively. This shows that, the base shear of the tank is influenced considerably due to SSI. The influence is significant for the tank on S1 soil type and decreases as the stiffness of soil increases. The base shear is maximum for soil type S2 compared to S1 and S3 type for both earthquakes.

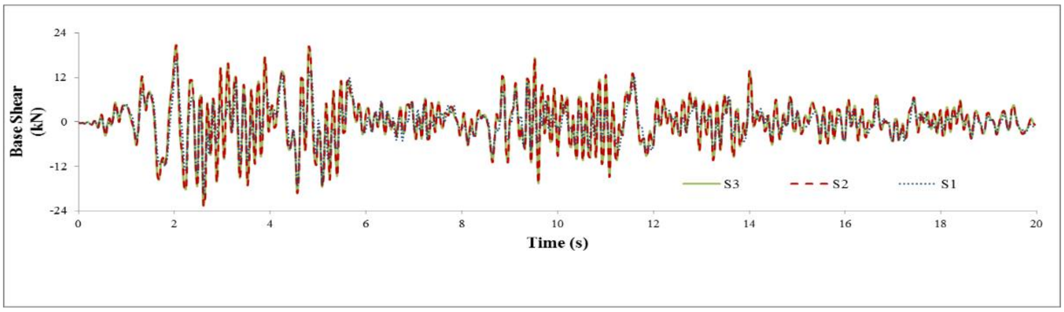

Figure 6 Time history response of base shear for El Centro earthquake

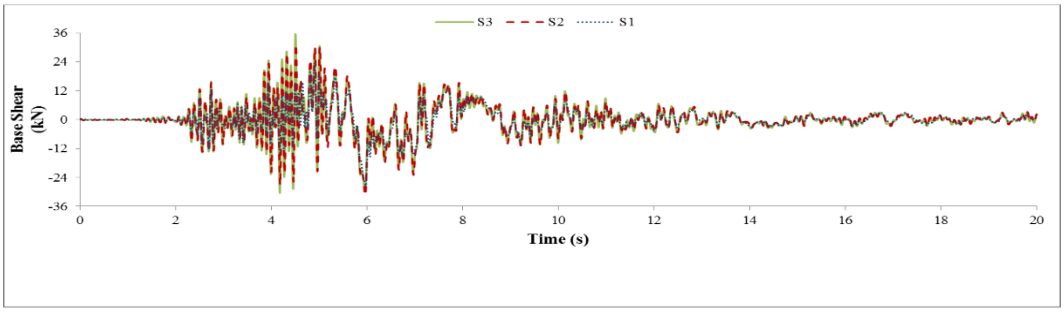

Figure 7 Time history response of base shear for Imperial Valley earthquake

3.2.3. Effect of SSI on pressure of fluid

Figures 8 and 9 shows the time history response of fluid pressure at base of the tank resting on different types of soil for El Centro and Imperial Valley earthquake ground motions respectively. From the figures, it can be observed that, the peak pressure of the tank resting on S1, S2 and S3 soil types is 5.864 kN/m2, 8.113 kN/m2 and 7.807 kN/m2 respectively when the tank is subjected to El Centro earthquake whereas, for the tank subjected to Imperial Valley earthquake, the response obtained for the tank resting on S1, S2 and S3 soil types is 10.607

kN/m2, 11.726 kN/m2and 11.270 kN/m2 respectively. This shows that, the fluid pressure is affected significantly due to SSI. The effect is maximum for the tank on S1 soil type, and it reduces as the soil stiffness increase. The pressure is maximum for soil type S2 compared to S1 and S3 type for both earthquakes

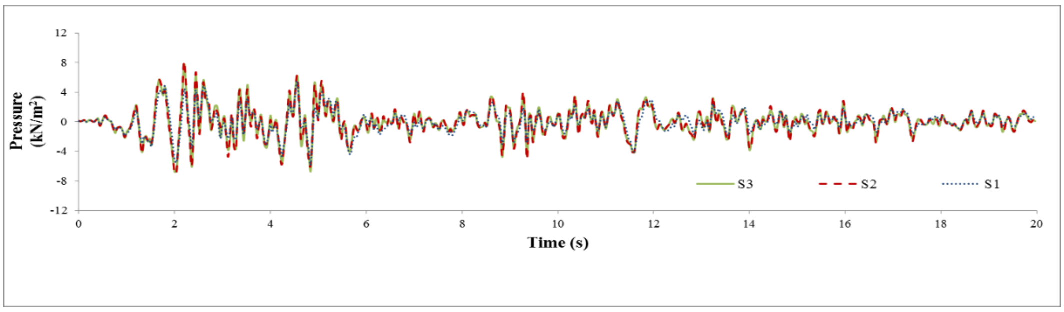

Figure 8 Time history response of Pressure of Fluid for El Centro earthquake

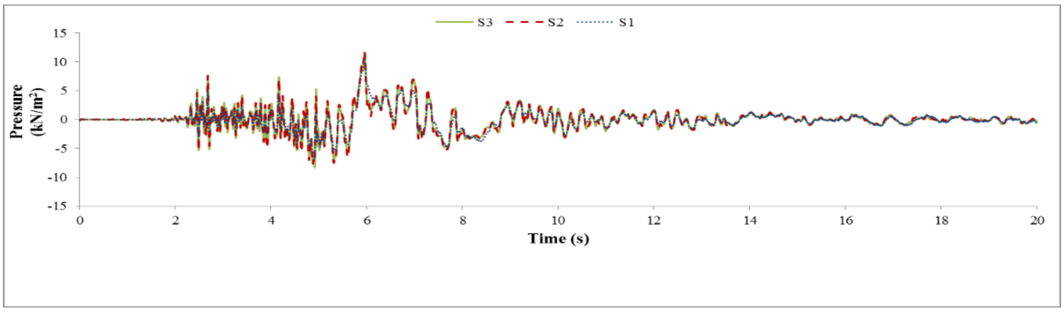

Figure 9 Time history response of Pressure of Fluid for Imperial Valley earthquake

It can be observed that the responses either decrease or increase due to SSI.

4. CONCLUSION

The effect of SSI on response of the tank containing fluid is investigated. In order to consider the flexibility of soil on SSI, three types of soils are considered for the analysis. The fluid is modeled using pressure formulation approach. The structure is subjected to two earthquake ground motions, one far field i.e., El Centro earthquake and one near fault Imperial Valley ground motions. From the study it is concluded that SSI has negligible effect on response of tank resting on hard soil. However, the SSI effect on the response of the tank and fluid is significant when resting on soft soil. In addition, the type of earthquake also affects the response of the tank when soil structure interaction effect is considered.

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