PARAMETRIC STUDY OF BASE ISOLATION SYSTEM FOR ELEVATED WATER TANK

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ABSTRACT
For improvement of seismic performance of the structures base isolation technique is generally used, in which base isolators are placed between foundation and the base soil. In this paper comparative study of three types of base isolations viz. elastomeric bearing, laminated rubber bearing and friction pendulum system for elevated water tank is carried out to study impact of various base isolators on seismic behavior of elevated water tank. Elevated water tanks of three different capacities with tank full, tank partially full and tank empty coditions are considered. The dynamic characteristics of the base-isolated elevated water tanks are obtained for parametric study. It is found that the partially full condition is critical, due to sloshing effect. Moreover it is worthy to note that for the maximum period of time the tank is in partially full condition. The seismic performance of elevated water tank without base isolation and with base isolation systems are evaluated and compared. The effectiveness of isolation system on different capacities of the water tanks is presented. From the present study it is concluded that the laminated rubber bearing base isolator gives better performance for the elevated water tank.

KEYWORDs: Base Isolation, Bearing, Elevated water tank etc.

I. INTRODUCTION

In the past several decades the technique of base isolation has been increasingly accepted for providing seismic protection to structures and their contents. Base isolation as a technique for the seismic retrofit of historic structures, designing buildings containing motion sensitive equipment (such as computer systems facilities), high risk buildings (such as nuclear power plants), buildings of special importance after earthquakes (hospitals, disaster management centres) etc. In the latter approach, the horizontal decoupling of the structure achieved through insertion of bearings at the foundation level, transfers it in to lower frequency range where seismic energy acting on the structure is beyond that if resonance and disputes the energy through damping the technique is known as base-isolation. Therefore, under the aforementioned circumstances, base isolation does indeed have advantages over traditional approaches by providing much higher protection from extreme earthquake events. Base isolations systems are believed to provide solutions for a wide range of design situations. M.B Jadhav, et.al.[1] derived the governing equations of motion of the isolated tank and solved iteratively. The frictional forces mobilized at the interface of the sliding system are assumed to be velocity dependent and their interaction in two horizontal directions is duly considered. Vasant A Matsagar,et.al. [2] Explained the isolated building modelled as a shear type structure with lateral degree-of-freedom at each floor. The coupled differential equations of motion for the isolated system are solved and derived in the incremental form using New-mark's step-by-step method of integration. Vasant A. Matsagar,et.al. [3] done the numerical study using analytical model of the base isolated building under consideration for calculation of response quantities of interest viz. top floor absolute acceleration and relative bearing displacement. The problem of sliding structures is discontinuous and these different sets of equations of motion with varying forcing functions are required for the sliding and non-sliding phases.

II. THEORETICAL FORMULATION

A. THEORETICAL BACKGROUND OF BASE ISOLATION SYSTEM.

Seismic base isolation can be adopted to improve the seismic performance of strategically important building such as schools, hospitals, industrial structures, elevated water tanks, residential house etc. in addition to places where sensitive equipments are intended to protect from the hazardous effects during earthquake. The need of seismic isolation includes the ability to significantly reduce the structural and non-structural damage to reduce the seismic design forces. The concept of base isolation date backs to 1974 {William Robinson 1974}. Base isolation is one of the most important concepts for earthquake engineering which can be defined as separating or decoupling the structure from its foundation. In other words, base isolation is a technique developed to prevent or minimise damage to structures during an earthquake. The dynamic model of structure with support motion is shown in figure 1.

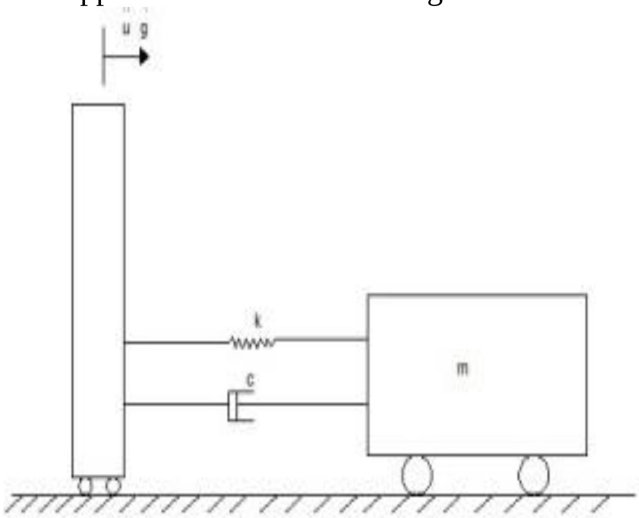

Figure.1 Basic Dynamic model of structure with support motion

The Governing equations of motion are given below. The equations of motion of elevated liquid storage tank subjected to unidirectional earthquake ground motion are expressed in the matrix form as:

$$[m]\{\ddot{x}\}+[c]\{\dot{x}\}+[k]\{x\}=-[m]\{r\}\ddot{u}_g \quad \text{……………..……2.1}$$

Where {x} is the displacement vector; [m], [c] and [k] are the mass, damping and stiffness matrix of the system, respectively; {r} is the influence coefficient vector; and $\ddot{u}_g$ is the earthquake acceleration. The displacement vector for non-isolated tank is given by:

$$\{x\}=\{x_c, x_i, x_t\}^T \quad \text{…………………………………2.2}$$

$x_c = u_c - u_t$ is the relative displacement of the sloshing mass,
$x_i = u_i - u_t$ is the displacement of the impulsive mass;
$x_s = u_t - u_g$ is the tower displacement relative to ground (i.e. tower drift).

The Typical configuration and design stipulations for ESR'S which are studied in this research is given in fig 2.

1) Capacity = 15 lakh liters
2) Safe bearing capacity. = 200 kN/m^2
3) Depth of foundation below G.L = 1.5m
4) Height of staging above G.L. = 9m
5) Free board = 0.3m
6) Diameter of Container = 20m
7) Height of water = 5.3m
8) Cylindrical wall thickness = 200mm
9) Brace to Brace height = 3m

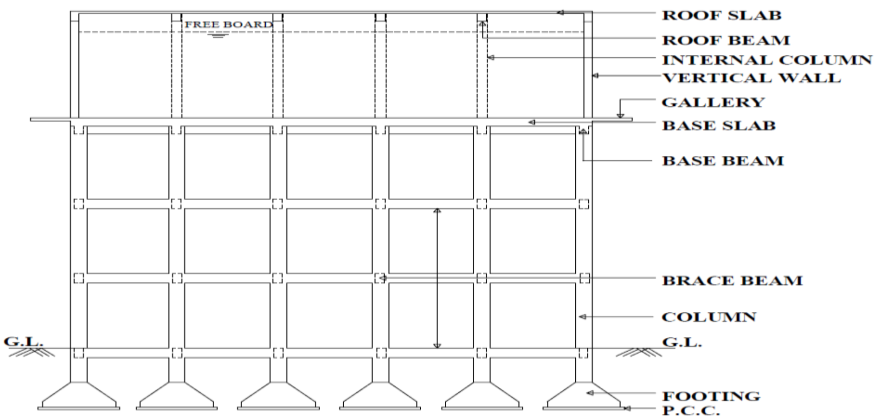

Figure. 2. Circular elevated water tank with flat roof & base

III. PROBLEM FORMULATION

The present work aims to study the effect of provision of base isolation system for elevated water tank. The research is the design of liquid retaining structure with base isolation systems. The analysis is carried out using application software.

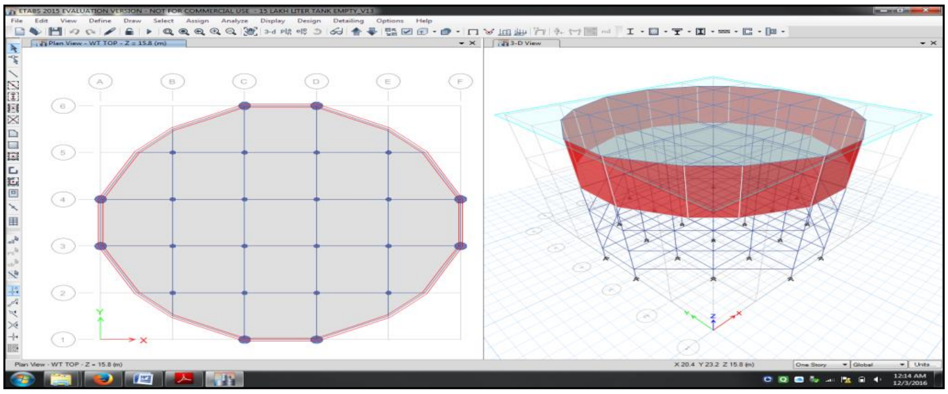

Figure 3 Analytical model of elevated water tank.

IV. PARAMETRIC SUTDY

The elevated water tank of flat top and flat bottom shape is used for the study. The elevated water tank with 10 lakh litres, 12.5 lakh litres and 15 lakh litres capacity are considered for parametric study. These three capacities are analyzed and designed for tank full, tank partially full, tank empty conditions. The staging arrangement is same for all cases. Every capacities tank is designed without base isolator. There after base isolation system viz. Elastomeric bearing (EMB), laminated rubber bearing (LRB) and Friction pendulum system (FPS) are incorporated for every tank. The displacement of tank, storey displacement of staging, acceleration of tank and acceleration induced at storey level are studied and comparison is made. Tank partially full is found to be critical in comparison to other two loading conditions and thus it is considered for further analysis.

CASE	ELEVATED WATER TANK	TANK CONDITION
I	10 lakh litres capacity	Tank Full
II	10 lakh litres capacity	Tank Partially full
III	10 lakh litres capacity	Tank Empty
IV	12.5 lakh litres capacity	Tank Full
V	12.5 lakh litres capacity	Tank Partially full
VI	12.5 lakh litres capacity	Tank Empty
VII	15 lakh litres capacity	Tank Full
VIII	15 lakh litres capacity	Tank Partially full
IX	15 lakh litres capacity	Tank Empty

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V. RESULT AND DISCUSSION

4.1 Displacements at top of tank for 10 lakh litres capacity (partially full) with-out base isolator and with different types of base isolator.

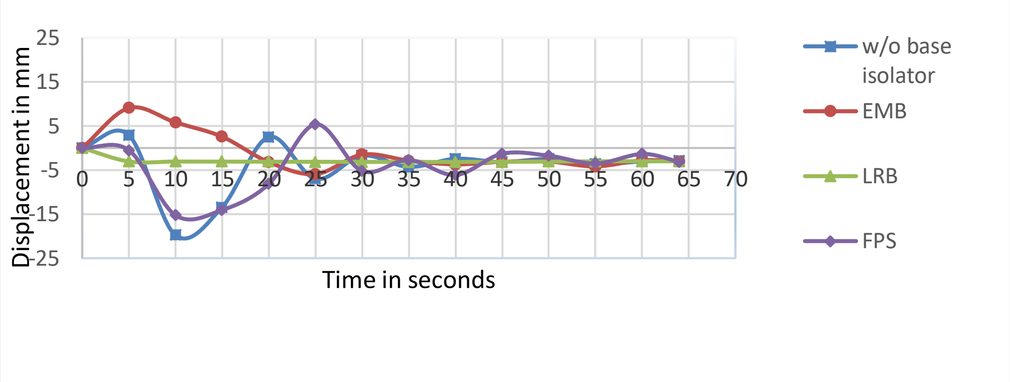

Figure 4.1: Displacement -time graph of 10 lakh litres tank (partially full) without base isolator and with different types of base isolator.

Figure 4.1 shows the variation in displacement of tanks at top of ESR with respect to time in seconds during the vibration. The severe displacement for all cases is observed during initial thirty seconds after which displacements are diminishing with increase in time. The higher displacement is observed for tank with-out base isolation followed by tank with Friction pendulum system (FPS) and tank with Elastomeric bearing (EMB). However for the tank with laminated rubber bearing (LRB) system shows continuous reduction in displacement with increase in time for initial five seconds. There afterwards for laminated rubber bearing (LRB) system displacement nearly remains same with increase in time. The displacement induced for the tank is lower by 22% using Frictional pendulum system (FRS) type isolator, is lower by 71 % for Elastomeric bearing (EMB) type isolator and is lower by 81% for laminated rubber bearing (LRB)type isolator respectively in comparison with those displacement produced for water tank without base isolator. The reduction in displacement has been observed 40% from Friction pendulum system (FPS) to Elastomeric bearing (EMB) & 65% from Elastomeric bearing (EMB) to laminated rubber bearing (LRB) respectively.
Laminated rubber bearing (LRB) has given nearly same displacement during vibration period where as other systems have given detrimental results of displacements.

4.2 Storey Displacement of 10 lakh litres capacity (partially full) with-out base isolator and with different types of base isolator.

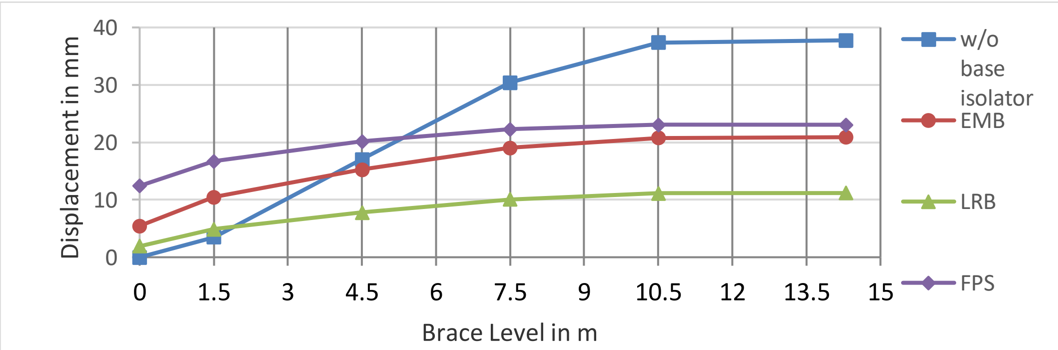

Figure 4.2: Storey Displacement of 10 lakh litres tank for (partially full) without base isolator and with different types of base isolator.

It is revealed from above graph (Figure 4.2) that the storey displacement is increasing with increasing number of brace levels. In case of tank with-out base isolation initially the increase in displacement is mild up to first brace level (plinth level) i.e. 1.5m, afterwards it increases at a steeper rate up to a brace level of 7.5m. Again, there after it becomes milder from 7.5m to 10.5m brace level. Further it is remaining nearly same with increase in brace level up to 14.3m. Eventhough initially the displacement produced by tank without base isolator is observed to be less, storey displacement above 4.5 m brace level of tank without base isolator is observed to be the highest, followed by Friction pendulum system (FPS), Elastomeric bearing (EMB) and laminated rubber bearing (LRB) system. For all type of base isolated systems initially the increase is steeper up to brace level 1.5m, there afterwards it becomes milder up to brace level 7.5m. The storey displacement is found to remain nearly same for further increase in brace levels.

The storey displacement induced for the tank is lower by 38% using Frictional pendulum system (FPS) type isolator, is lower by 44 % for Elastomeric bearing (EMB) type isolator and is lower by 70% for laminated rubber bearing (LRB) type isolator respectively in comparison with those displacement produced by tank without base isolator. The displacement of Elastomeric bearing (EMB) is observed 9% lower in comparison with displacement of Friction pendulum system (FPS) and the displacement of laminated rubber bearing (LRB) is observed 47% lower in comparison with Elastomeric bearing (EMB). However the gentle slope of curve up to 7.5m brace level is observed for laminated rubber bearing (LRB) after which, it is nearly remaining same. The displacements at different brace levels are controlled by laminated rubber bearing (LRB) system leading to reduction in moments.

4.3 Maximum Acceleration at top of tank for 10 lakh litres capacity (partially full) with-out base isolator and with different types of base isolator.

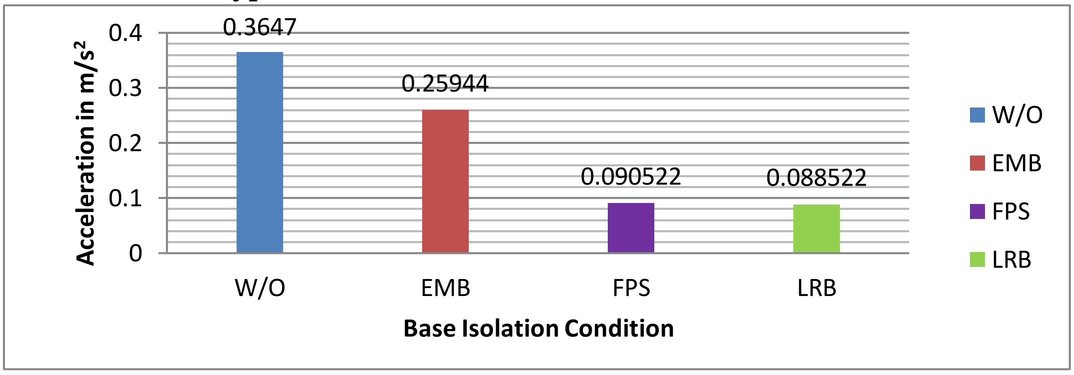

Figure. 4.3: Maximum Acceleration of 10 lakh litres tank: partially full without base isolator and with different types of base isolator.

The maximum value of acceleration (Figure 4.3) is observed for the tank with-out base isolation followed by Elastomeric bearing (EMB), Friction pendulum system (FPS) and laminated rubber bearing (LRB). The laminated rubber bearing (LRB) system produces lowest acceleration. The acceleration induced for the tank is lower by 28.8% using Elastomeric bearing (EMB) type isolator, 75 % using Frictional pendulum system (FRS) type isolator and is lower by 76% by using laminated rubber bearing (LRB)type isolator respectively in comparison with acceleration for the tank without base isolator. The reduction in acceleration observed is 65% from Elastomeric bearing (EMB) to Friction pendulum system (FPS) & 2.2% from Friction pendulum system (FPS) to laminated rubber bearing (LRB) respectively. The incorporation of laminated rubber bearing (LRB) leads to reduce inertial forces due to minimal induced acceleration.

4.4 Storey Acceleration of 10 lakh litres capacity (partially full) with-out base isolator and with different types of base isolator.

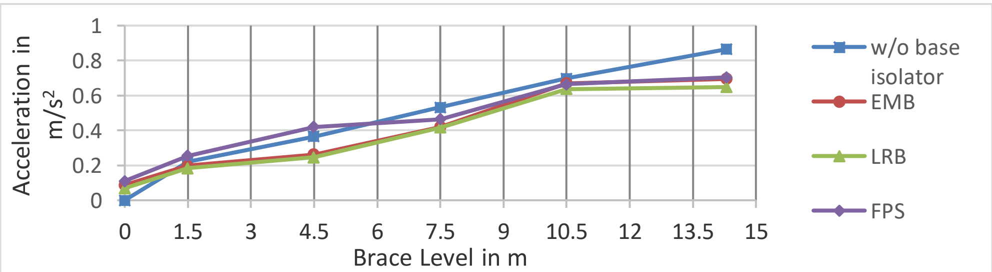

Figure 4.4 Storey acceleration of 10 lakh litres tank (partially full) without base isolator and with different types of base isolator.

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The storey acceleration graph with respect to brace level (Figure 4.4) is nearly linear with steep variation for with-out base isolator. The variation of storey acceleration for laminated rubber bearing (LRB) & Elastomeric bearing (EMB) is almost similar in nature, with initially increasing at a steeper rate up to 1.5m brace level, there afterwards it increases at moderate rate from 1.5m to 4.5m, further again acceleration increases at steeper rate between 4.5m to 10.5m. Beyond 10.5m it is remaining nearly same. The storey acceleration induced for the tank using Frictional pendulum system (FPS) is observed to be higher and of similar nature of Elastomeric bearing (EMB) & laminated rubber bearing (LRB) type isolator. The acceleration is lower by 20% for Friction pendulum system (FPS), 21 % for Elastomeric bearing (EMB) type isolator and 27% for laminated rubber bearing (LRB)type isolator respectively in comparison with storey acceleration observed for without base isolator. The reduction in storey acceleration observed is 1.38% from Friction pendulum system (FPS) to Elastomeric bearing (EMB) & 7% from Elastomeric bearing (EMB) to laminated rubber bearing (LRB) respectively.

4.5 Displacements at top for tank 12.5 lakh litre capacity (partially full) with-out base isolator and with different types of base isolator.

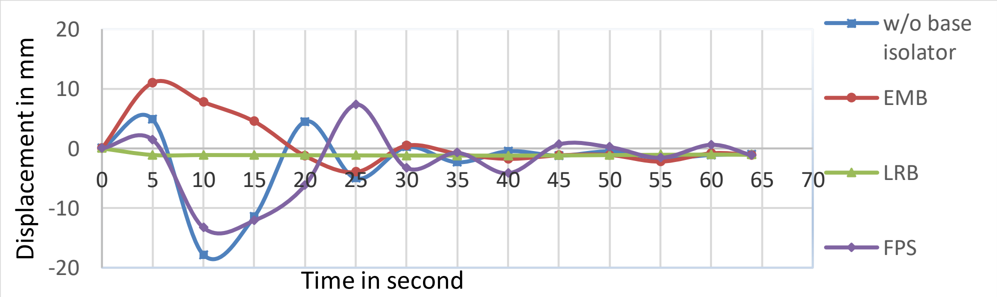

Figure 4.5: Displa1cement -time graph of 12.5 lakh litres tank (partially full) without base isolator and with different types of base isolator.

Figure.4.5 shows the variation in displacement of tanks at top of ESR with respect to time in seconds during the vibration. The severe displacement for all cases is observed during initial thirty seconds after which displacements are diminishing with increase in time. The higher displacement is observed for tank with-out base isolation followed by tank with Friction pendulum system (FPS) and tank with Elastomeric bearing (EMB). However the tank with laminated rubber bearing (LRB) system shows continuous reduction in displacement with increase in time for initial ten seconds. There afterwards displacement is nearly same with increase in time. The displacement induced for the tank is lower by 26% using Frictional pendulum system (FRS) type isolator, is lower by 41 % for Elastomeric bearing (EMB) type isolator and is lower by 67% for laminated rubber bearing (LRB)type isolator respectively in comparison with those displacement produced by without base isolator. The reduction in displacement is observed 17% from Friction pendulum system (FPS) to Elastomeric bearing (EMB) & 89% from Elastomeric bearing (EMB) to laminated rubber bearing (LRB) respectively.

Laminated rubber bearing (LRB) has given nearly same displacement during vibration period where as other systems have given detrimental results of displacements.

4.6 Storey Displacement of 12.5 lakh litres capacity (partially full) with-out base isolator and with different types of base isolator.

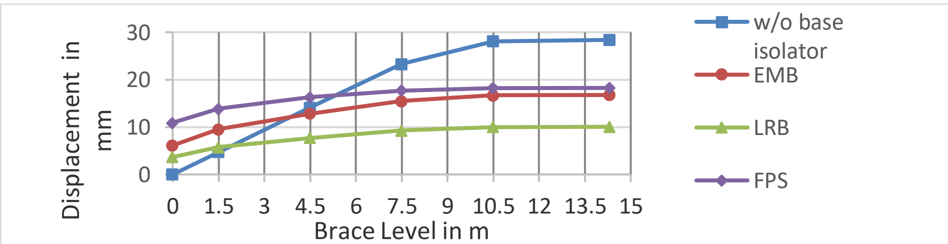

Figure 4.6: Storey Displacement of 12.5 lakh litres tank for (partially full) without base isolator and with different types of base isolator.

It is revealed from above graph (figure 4.6) that the storey displacement is increasing with increasing number of stories. In case of tank with-out base isolation initially the increase in displacement is mild up to first brace level (plinth level) i.e. 1.5m, afterwards in increases at a steeper rate up to a brace level of 7.5m. Again, there after it becomes mild from 7.5m to 10.5m brace level. Further it is remaining constant up to next brace level 14.3m. Eventhough initially the displacement produced by tank without base isolator is observed to be less, storey displacement above 4.5 m brace level of tank without base isolator is observed to be the highest, followed by Friction pendulum system (FPS), Elastomeric bearing (EMB) and laminated rubber bearing (LRB) system. In case of base isolated systems initially the variation is steep up to brace level 1.5m after which it has become milder up to storey height 7.5m. The storey displacement is found to remain nearly same from 7.5m to 14.3m.
The storey displacement induced for the tank is lower by 32% using Frictional pendulum system (FRS) type isolator, is lower by 42.6 % for Elastomeric bearing (EMB) type isolator and is lower by 67% for laminated rubber bearing (LRB)type isolator respectively in comparison with those displacement produced by without base isolator. The trend of reduction in displacement has been observed 9% from Friction pendulum system (FPS) to Elastomeric bearing (EMB) & 43% from Elastomeric bearing (EMB) to laminated rubber bearing (LRB) respectively. However the gentle slope of curve up to 7.5m brace level is observed for laminated rubber bearing (LRB) after which it is nearly same. The displacements at different brace levels are controlled by laminated rubber bearing (LRB) system leading to reduce the moments.

4.7 Maximum Acceleration at top of tank for 12.5 lakh litres capacity (partially full) with-out base isolator and with different types of base isolator.

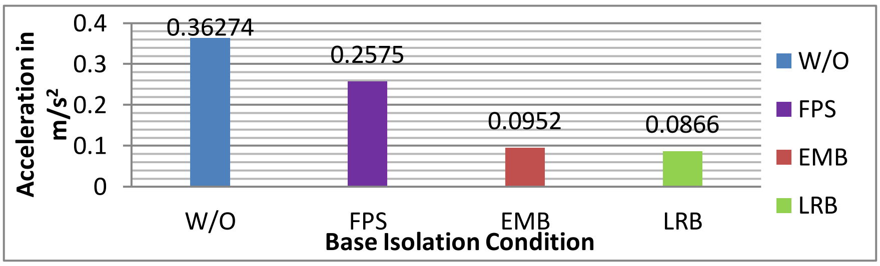

Figure 4.7: Maximum Acceleration of 12.5 lakh litres tank: partially full without base isolator and with different types of base isolator.

The maximum value of acceleration (figure 4.7) is observed for the tank with-out base isolation followed by Friction pendulum system (FPS), Elastomeric bearing (EMB) and laminated rubber bearing (LRB). The laminated rubber bearing (LRB) system has given lowest magnitude of acceleration. The acceleration induced for the tank is lower by 29% by using Frictional pendulum system (FRS) type isolator, is lower by 74% for Elastomeric bearing (EMB) type isolator and is lower by 76% for laminated rubber bearing (LRB)type isolator respectively in comparison with acceleration for the tank without base isolator. The reduction in acceleration observed is 63% from Friction pendulum system (FPS) to Elastomeric bearing (EMB) & 9% from Elastomeric bearing (EMB) to laminated rubber bearing (LRB) respectively.
The incorporation of laminated rubber bearing (LRB) leads to reduce inertial forces due to minimal induced acceleration.

4.8 Storey Acceleration of 12.5 lakh litres capacity (partially full) with-out base isolator and with different types of base isolator.

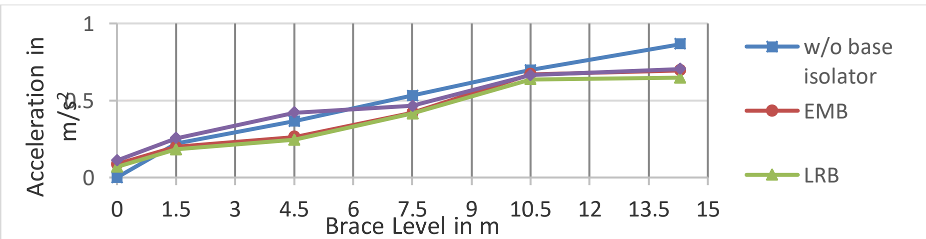

Figure 4.8 Storey acceleration of 12.5 lakh litres tank (partially full) without base isolator and with different types of base isolator.

The storey acceleration graph with respect to brace level (Figure 4.8) is linear with steep variation for with-out base isolator. The variation of results for laminated rubber bearing (LRB) & Elastomeric bearing (EMB) is almost similar with steep slope up to 1.5m storey, moderate from 1.5m to 4.5m, further steep slope from 4.5m to 10.5m. After 10.5m it is remaining constant. The storey acceleration is lower by 18% for Frictional pendulum system (FRS) type isolator, is lower by 20 % for Elastomeric bearing (EMB) type isolator and is lower by 25% for laminated rubber bearing (LRB)type isolator respectively in comparison with those storey acceleration produced by without base isolator. The reduction in storey acceleration observed is 1.5% from Friction pendulum system (FPS) to Elastomeric bearing (EMB) & 6.6% from Elastomeric bearing (EMB) to laminated rubber bearing (LRB) respectively.

The incorporation of laminated rubber bearing (LRB) & Elastomeric bearing (EMB) leads to reduce storey shear forces due to controlled acceleration.

4.9 Displacements at top of tank for 15 lakh litres capacity (partially full) with-out base isolator and with different types of base isolator.

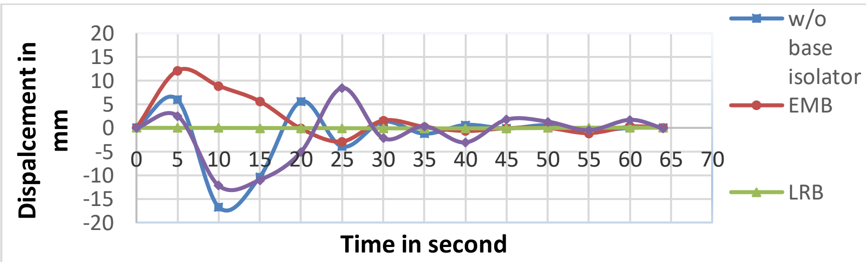

Figure 4.9: Displacement -time graph of 15 lakh litres tank (partially full) without base isolator and with different types of base isolator.

Figure 4.9 shows the variation in displacement of tanks at top of ESR with respect to time in seconds during the vibration. The severe displacement for all cases is observed during initial twenty five seconds after which displacements are diminishing with increase in time. The higher displacement is observed for tank with-out base isolation followed by tank with Friction pendulum system (FPS) and tank with Elastomeric bearing (EMB). However the tank with laminated rubber bearing (LRB) system shows continuous reduction in displacement with increase in time for initial ten seconds. There afterwards displacement is nearly same with increase in time. The displacement induced for the tank is lower by 27% using Frictional pendulum system (FRS) type isolator, is lower by 28 % for Elastomeric bearing (EMB) type isolator and is lower by 99% for laminated rubber bearing (LRB)type isolator respectively in comparison with those displacement produced by without base isolator. The reduction in displacement has been observed 1% from Friction pendulum system (FPS) to Elastomeric bearing (EMB) & 99.12% from Elastomeric bearing (EMB) to laminated rubber bearing (LRB) respectively. Laminated rubber bearing (LRB) has given nearly same displacement during vibration period where as other systems have given detrimental results of displacements.

4.10 Storey Displacement of 15 lakh litres capacity (partially full) with-out base isolator and with different types of base isolator.

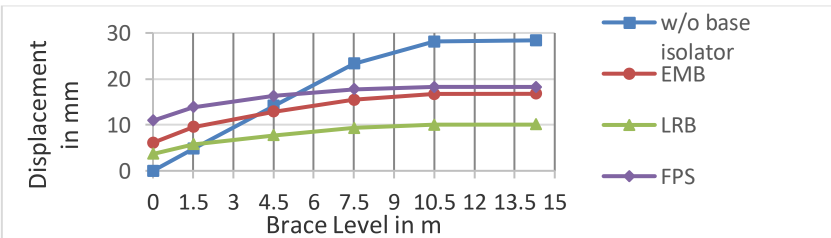

Figure 4.10: Storey Displacement of 15 lakh litres tank for (partially full) without base isolator and with different types of base isolator.

It is revealed from above graph (Figure 4.10) that the storey displacement is increasing with increasing number of stories. In case of tank with-out base isolation initially the variation of displacement is mild up to first brace level (plinth level) i.e. 1.5m, afterwards in increases at a steeper rate up to a brace level of 7.5m. Again, there afterwards it becomes mild from 7.5m to 10.5m brace level. Further it is remaining constant up to next brace level 14.3m. Eventhough initially the displacement produced by tank without base isolator is observed to be less, storey displacement above 4.5 m brace level of tank without base isolator is observed to be the highest, followed by Friction pendulum system (FPS), Elastomeric bearing (EMB) and laminated rubber bearing (LRB) system. In case of base isolated systems initially the variation is steep up to storey height 1.5m after which it has become milder up to brace level 7.5m. The storey displacement has remained nearly same from 7.5m to 14.3m.The storey displacement induced for the tank is lower by 36% using Frictional pendulum system (FPS) type isolator, is lower by 40 % for Elastomeric bearing (EMB) type isolator and is lower by 64% for laminated rubber bearing (LRB)type isolator respectively in comparison with those displacement produced by without base isolator. The reduction in displacement has been observed 8% from Friction pendulum system (FPS) to Elastomeric bearing (EMB) & 40% from Elastomeric bearing (EMB) to laminated rubber bearing (LRB) respectively.

However the gentle slope of curve up to 7.5m brace level is observed for laminated rubber bearing (LRB) after which it is nearly same. The displacements at different brace levels are controlled by laminated rubber bearing (LRB) system leading to reduce the moments.

4.11 Maximum Acceleration at top for 15 lakh litres capacity (partially full) with-out base isolator and with different types of base isolator.

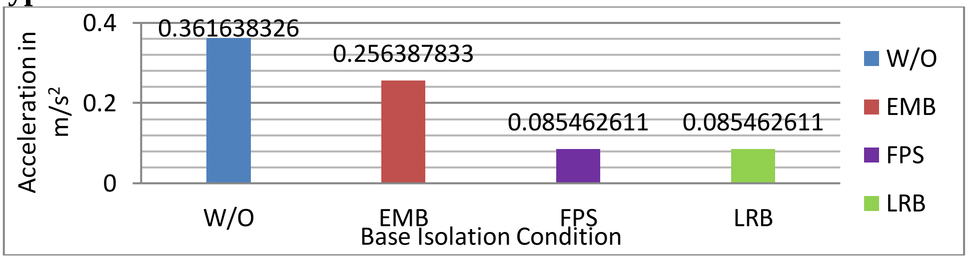

Figure 4.11: Maximum Acceleration of 15 lakh litres tank: partially full without base isolator and with different types of base isolator

The maximum value of acceleration (figure 4.11) is observed for the tank with-out base isolation followed by Elastomeric bearing (EMB), Friction pendulum system (FPS) and laminated rubber bearing (LRB). The laminated rubber bearing (LRB) system has given lowest magnitude of acceleration. The acceleration induced for the tank is lower by 29% using Elastomeric bearing (EMB) type isolator, is lower by 76 % for Frictional pendulum system (FRS) type isolator and is lower by 76% for laminated rubber bearing (LRB) type isolator respectively in comparison with acceleration for the tank without base isolator. The reduction in acceleration has been observed 66% from Elastomeric bearing (EMB) to Friction pendulum system (FPS) & 0 % from Friction pendulum system (FPS) to laminated rubber bearing (LRB) respectively. The incorporation of laminated rubber bearing (LRB) leads to reduce inertial forces due to minimal induced acceleration.

4.12 Storey Acceleration of 15 lakh litres capacity (partially full) with-out base isolator and with different types of base isolator.

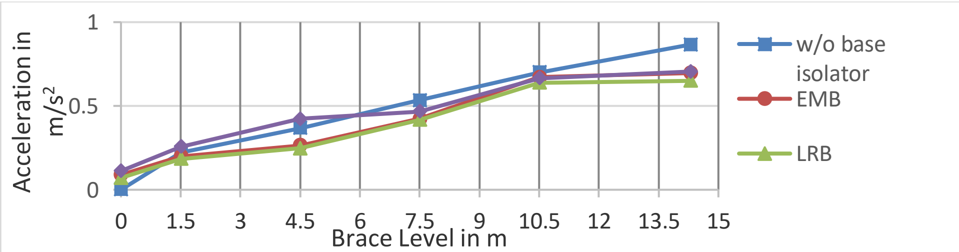

Figure 4.12 Storey acceleration of 15 lakh litres tank (partially full) without base isolator and with different types of base isolator.

The storey acceleration graph with respect to brace level (Figure 4.12) is linear with steep variation for with-out base isolator. The variation of results for laminated rubber bearing (LRB) & Elastomeric bearing (EMB) is almost similar with steep slope up to 1.5m storey, moderate from 1.5m to 4.5m, further steep slope from 4.5m to 10.5m. After 10.5m it is remaining constant. The storey acceleration induced for the tank is lower by 19% using Frictional pendulum system (FRS) type isolator, is lower by 20 % for Elastomeric bearing (EMB) type isolator and is lower by 25% for laminated rubber bearing (LRB)type isolator respectively in comparison with those storey acceleration produced by without base isolator. The reduction in storey acceleration observed is 1% from Friction pendulum system (FPS) to Elastomeric bearing (EMB) & 6% from Elastomeric bearing (EMB) to laminated rubber bearing (LRB) respectively.The incorporation of laminated rubber bearing (LRB) & Elastomeric bearing (EMB) leads to reduce storey shear forces due to controlled acceleration.

V. CONCLUSIONS

On the basis of parametric study carried out for the elevated water tank with different capacities viz. 10,12.5 and 15 lakh litres and for various loading conditions viz. Tank full, tank partially full and tank empty. The comparative study of water tank with-out base isolation and elevated water tank with various base isolator viz. Elastomeric bearing (EMB), laminated rubber bearing (LRB) and friction pendulum system (FPS) has been done. On the basis of study presented, the following conclusions are drawn:

1. For all type of elevated water tank with-out and with base isolator, the partially full is most severe condition due to sloshing effect.
2. Incorporation of base isolations improves seismic performance of elevated water tank, since all seismic responses are not transferred to superstructure as it is.
3. The seismic effect becomes increasingly severe with increasing height of brace levels. This is due to the fact that the cantilever behaviours of the structure.
4. Laminated rubber bearing (LRB) system is found to be most efficient in controlling seismic response of structures. Also the elastomeric bearing (EMB) and friction pendulum system (FPS) system controls seismic responses in comparison with the tank with-out base isolator.

Overall it is beneficial to use base isolation system for elevated water tank as it reduces the transfer of seismic responses to superstructure. This will assist in improving dynamic performance of structure even for the lower structural configuration. In all types of base isolation system tried, the laminated rubber bearing (LRB) system is most efficient.

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