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Seismic Response mitigation of Liquid Storage Tank Isolated by SMARB and NZ Isolation under Near Fault Ground Motions

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Abstract:- The seismic response of liquid storage tanks isolated by SMARB isolation and N-Z type isolation was studied under unidirectional near-fault earthquakes, focusing on a slender liquid storage water tank. The continuous liquid mass was modelled as a lump mass, comprising convective (sloshing), impulsive, and rigid mass, with corresponding equations of motion solved using the Newmark's method. The effect of shape memory alloy rubber bearing base isolation was identified by comparing the tank's earthquake response with that of the tank isolated with an N-Z isolator. Results indicated that the shape memory with rubber bearing isolation mode effectively controlled convective and isolator displacement, with slender tanks enhancing seismic performance and safety as compared to normal isolation.

Introduction

Liquid storage tanks have always been an important part of water distribution systems, factories, and nuclear power plants. They are used to store drinking water, dangerous and flammable liquids, nuclear fuel, and oil products. The seismic performance of these tanks is very important, even more so than the building's economic value, because they need to keep working after a big earthquake. Immediately after a major earthquake, it is very important to provide water so that fires can be put out and disease outbreaks can be stopped. Another reason is the risk that comes with tanks breaking down that hold highly flammable materials. This could lead to uncontrolled fires that spread quickly, and leaks of these materials could hurt the environment and affect areas with a lot of people. In the past, some ground-supported liquid storage tanks have failed. These kinds of failures made a lot of people interested in keeping these tanks safe from seismic pressures. Conventional reinforcement of tanks does not ensure total safety during intense seismic activity; consequently, engineering researchers have developed alternative methods, such as base isolation, to protect liquid storage tanks.

Haroun and Housner (1981) and Haroun (1983) introduced the basic behavior of liquid storage tank under seismic loads behavior and they identified the important parameters such impulsive and convective (sloshing) liquid components that govern tank response, with that Mokha et al. (1991) and Wang et al. (2001) demonstrated significant reductions in structural demand using friction and sliding bearings. Furthermore, Shrimali and Jangid (2002, 2004), jangid and Panchal (2010) Soni et al (2011) demonstrated that sliding bearings efficiently reduce transmitted earthquake accelerations, but near-fault ground motions, which have high-energy, long-period velocity pulses, are a special problem that standard isolation systems may not be able to handle. Even though traditional systems like N-Z (Lead Rubber Bearings) have good damping, they often cause displacements at the base when there are strong pulses, to overcome such problem Hybrid systems were introduced that use smart materials. Mishra et al. (2015) were the first to use the shape memory alloy rubber bearing (SMARB) for bridges. They showed that shape memory alloy better at controlling displacements and self-centering thanks to the superelastic effect of SMA wires. Although base isolation is effective at controlling tank displacements, the incorporation of shape memory alloy rubber bearing isolation systems for liquid storage tanks remains largely undiscovered.

The specific objectives of current study are: (i) to identify and compare the earthquake response of liquid storage tanks with N-Z isolators versus smart SMARB isolators. (ii) to evaluate the performance of both systems under unidirectional loading (x-component), particularly focusing on their behavior during near-fault ground motions. (iii) to determine the effect of smart isolation on

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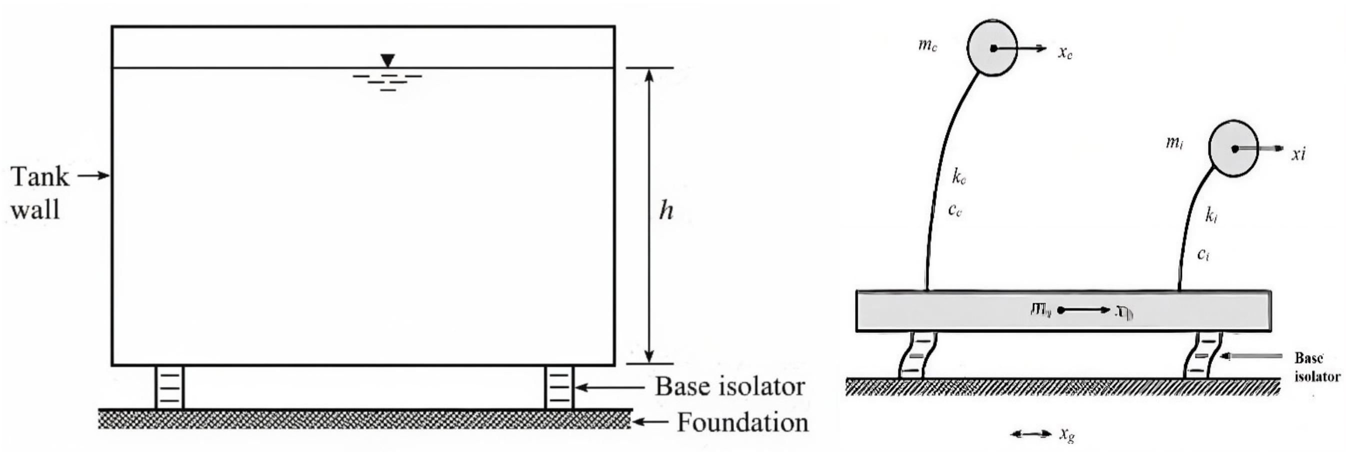
critical parameters, including isolator displacement, convective (sloshing) displacement, and impulsive displacement.

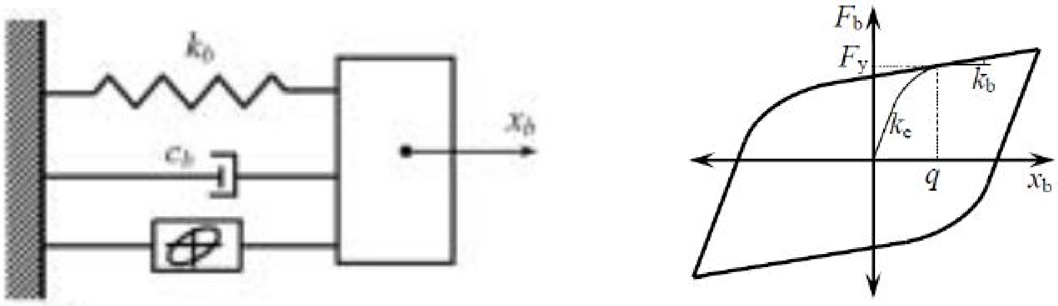
Model of Ground supported liquid storage tank



(a) (b)

Figure. 1: - Base-isolated liquid storage tank's structural model [7]

Figure 1 (a) and (b) illustrates the structural model of a base-isolated circular cylindrical liquid storage tank. The isolation bearings are positioned between the base and the foundation to separate the tank. The base excitation induces vibrations in the tank liquid in three unique modes: convective or sloshing mass (i.e the upper liquid mass changing the free surface), impulsive mass (the intermediate liquid mass oscillating with the tank wall), and rigid mass (the lower liquid mass moving in unison with the tank wall). Sloshing and impulsive masses exhibit multiple vibrational modes; nevertheless, the reaction can be anticipated by analysing the primary sloshing mode and the initial impulsive mode. The sloshing, impulsive, and rigid masses are designated as m_c, m_i, and m_r, respectively [7]. The sloshing and impulsive masses are linked to the tank wall by analogous springs with stiffness constants k_c and k_i, respectively. [10] The damping constants for the sloshing and impulsive masses are denoted as c_c and c_i, respectively. The system possesses three degrees of freedom in response to unidirectional seismic ground motion. The degrees of freedom are represented by x_c, x_i, and x_b, which define the relative displacements of sloshing, impulsive, and stiff mass, respectively [11], additionally, the self-mass of the tank is considered negligible compared to the effective mass of the tank's liquid. The ratio of height of tank to radius of tank is called aspect ratio $S = H/R$. Depending on aspect ratio, tank is classified as either Slender or Broad. For slender tank aspect ratio S = 1.85 and S = 0.86 tank is classified as broad. For current study, aspect ratio is considered as 1.85 m and height is 10 meters, hence the radius of tank is 5.40 m.



(a) (b)

Figure 2: - (a) Mathematical modelling of N-Z isolator, (b) Force deformation behaviour of N-Z isolator

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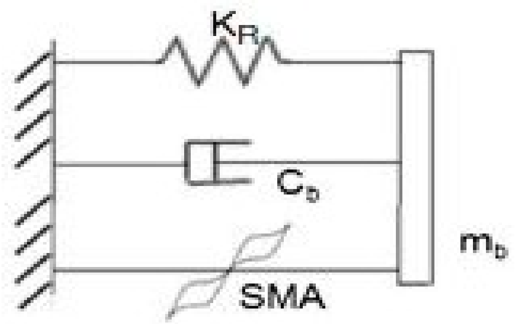
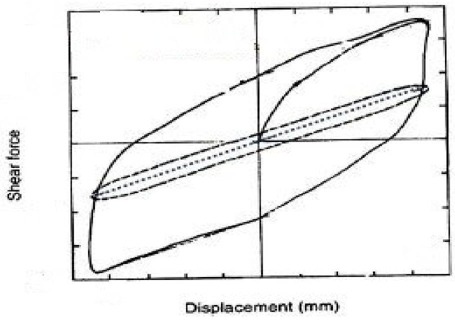
Figure 2 (a) depicts mathematical model where k_b is stiffness of rubber where c_b is damping of rubber bearing (N-Z) and isolator and symbol suggests bilinear plasticity, e.g., lead core that yields under force and m_b is mass of structure subjected to displacement x_b. The hysteresis loop of a bearing is generally modelled by bi-linear force-deformation Behaviour expressed by the Wen's equation.





(a) (b)

Figure 3:- (a) Mathematical modelling of SMARB isolator, (b) Force deformation behaviour of SMARB isolator [12]

Figure 3 (a) shows mathematical model of base-isolated system that includes a Shape Memory Alloy Rubber Bearing (SMARB). mathematical model of SMARB where m_b is mass of structure, Kr is stiffness of rubber bearing, c_b is damping and SMA is Shape memory alloy. Figure 3 (b) Shows hysteresis behaviour of SMARB (Shape Memory Alloy Rubber Bearing) plot of displacement (mm) vs Base Shear (K_n) [12].

Numerical Study

In current study liquid storage tank isolated with N-Z type isolator and SMARB (shape memory alloy rubber bearing) is carried out under five near-fault ground motion. Computational tools are developed for both types of isolators and responses such as convective displacement, impulsive displacement, isolator displacement and Base Shear is evaluated. For the tank, the modulus of elasticity is taken as E = 200 GPa and the mass density = 7900 kg/m3. T_b Isolation time period is 2.5 sec and damping is 10%.

Sr. No.	Earthquake	Station	PGA(*g*)
1	Imperial valley	El Centro Array #7	0.46
2	Northridge (1994)	Rinaldi	0.89
3	Northridge (1994)	Sylmar	0.73
4	Kobe (1995)	KJMA	0.83
5	Kocaeli (1999)	Yarimca	0.27

Table 1: - Ground Acceleration data for current study

Table 1 shows near fault ground motions considered for current study, only *x*-component of each of five ground motions was considered for comparison of results of both isolation modes.

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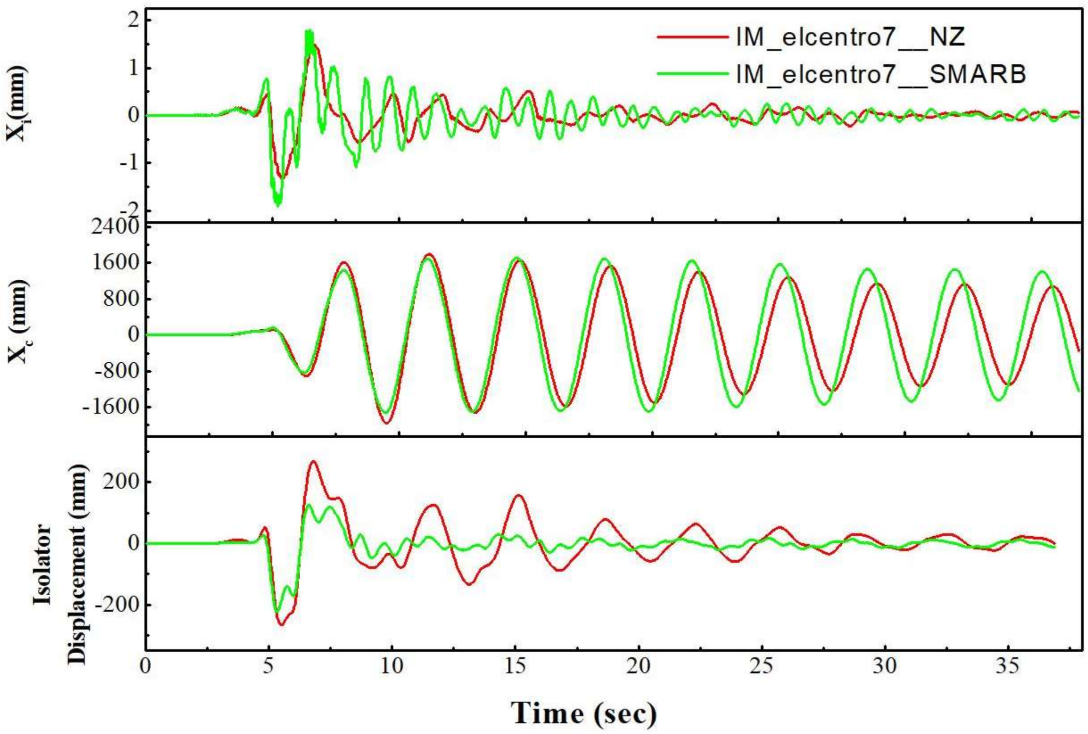

Figure 4: - Seismic Response of slender tank isolated with N-Z and SMARB isolator Imperial valley earthquake (1979) Electro Array #7

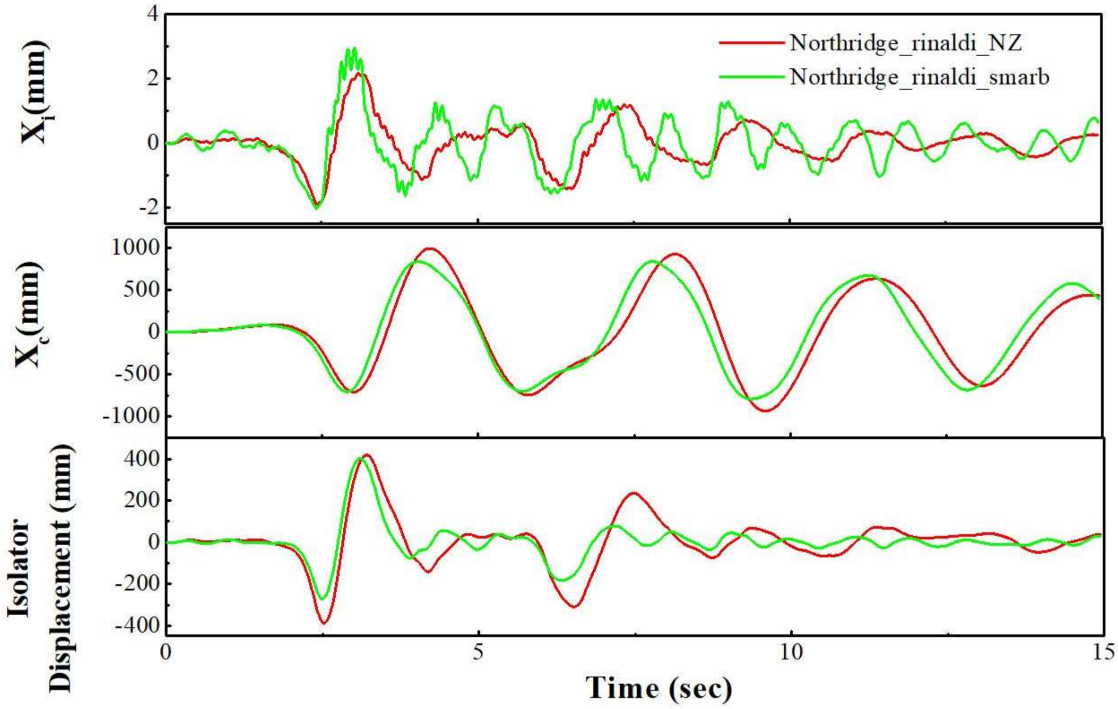

Figure 5: - Seismic response of slender tank isolated with N-Z and SMARB isolator under Northridge earthquake (1994)

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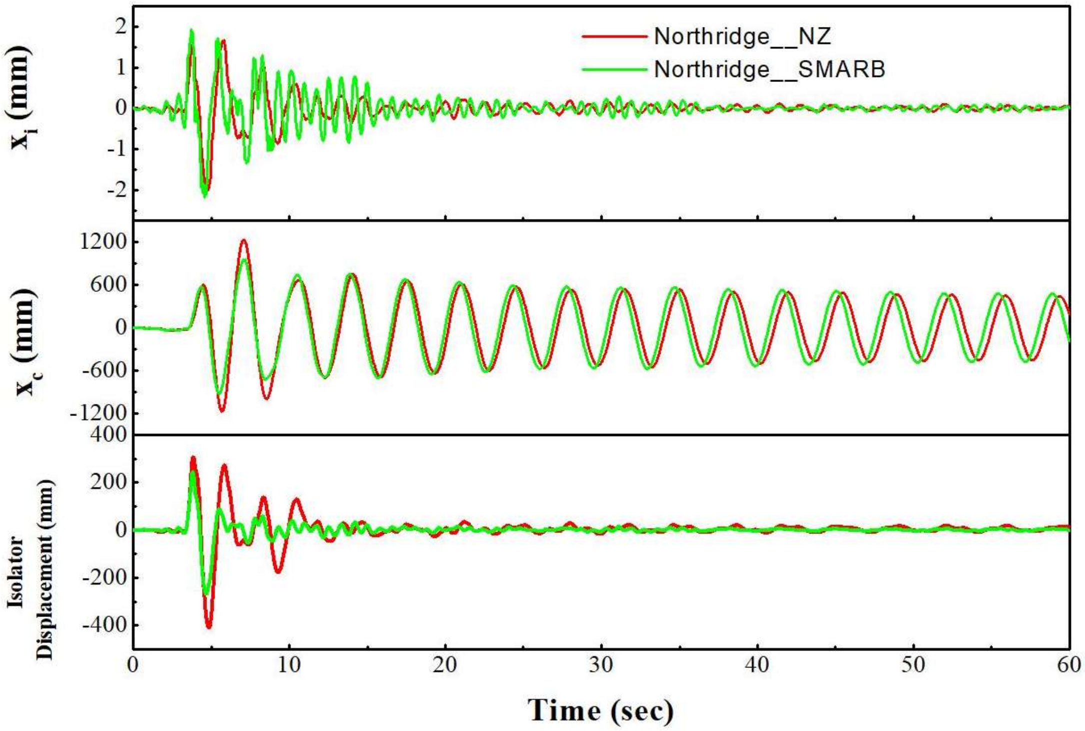

Figure 6: - Seismic response of slender tank isolated with N-Z and SMARB isolator under Northridge Sylmar earthquake (1994)

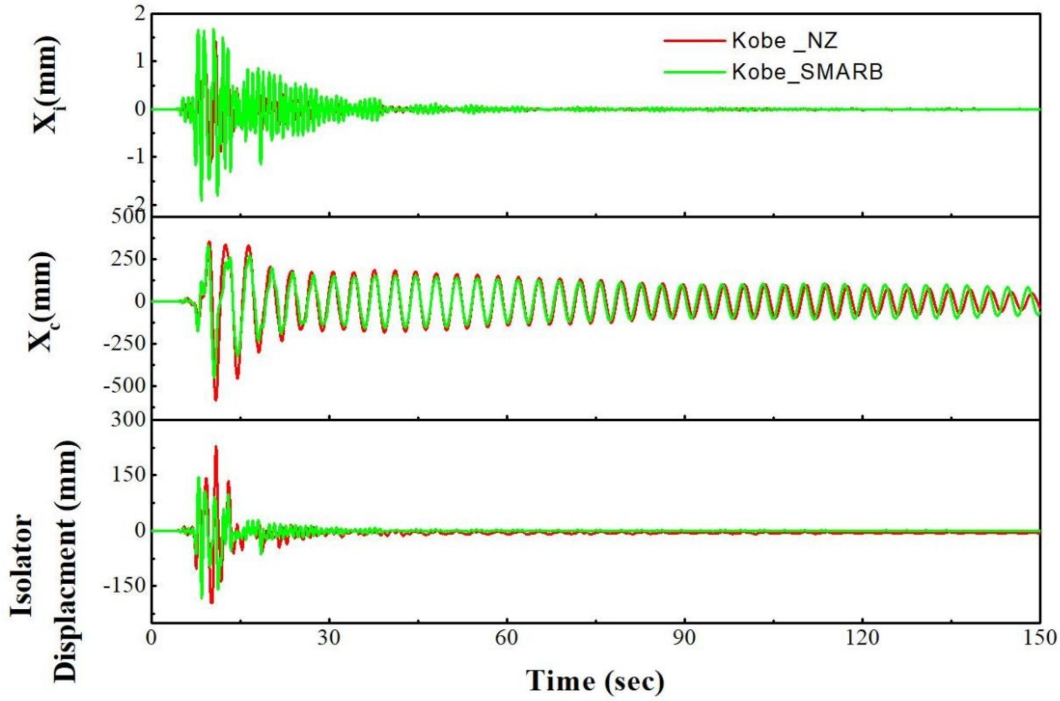

Figure 7: - Seismic response of slender tank isolated with N-Z and SMARB isolator under Kobe earthquake (1995)

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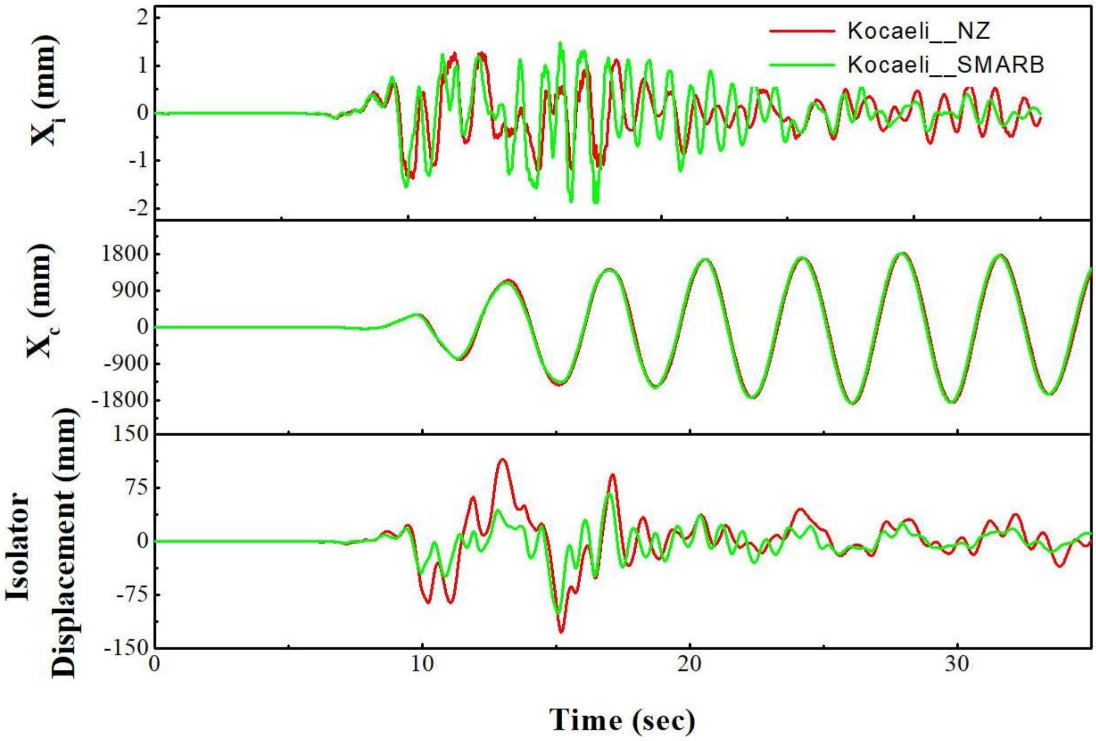

Figure 8: - Seismic response of slender tank isolated with N-Z and SMARB isolator under Kocaeli earthquake (1999)

Under the set of above five near-field ground motions, liquid storage tank isolated with N-Z and SMARB isolators and their responses have been recorded and plotted as shown in figures 4 to 8, involving various parameters such as isolator displacement, convective displacement, and impulsive displacement, respectively. The line marked in red are responses with N-Z isolators, whereas the line in green depicts the response of the shape memory alloy rubber bearing. The graphical representation shows isolator displacement reduces in smart isolation in all cases as a comparison with the N-Z isolation mode; also, convective displacement of the tank reduces when in isolation with smart as compared to N-Z isolation. The Northridge-Sylmar earthquake shows the highest reduction in isolator displacement, whereas the Kobe earthquake shows a major reduction in sloshing displacement.

Table 2 depicts variation of different parameters for N-Z isolator and Smart isolator, with that percentage variation (i.e., N-Z) also shown in comparison to shape memory alloy rubber bearing; it can be confirmed from numerical values displayed in tabular form that convective and isolator displacement are on higher side in N-Z isolator, visibly in percentage variation. A column where a positive value denotes N-Z isolation variation is on the higher side, whereas a negative value suggests N-Z isolation is on the lesser side in comparison to the smart isolation mode.

Sr. No.	Name of Earthquake	Parameters	N-Z	SMARB	Variation (%)
GM-1	Imperial Valley -1979 El Centro #7	x_c (mm)	1952.9	1724.4	11.7
		x_i (mm)	1.48	1.91	-29.05
		x_b (mm)	268.49	223.7	16.68
GM-2	Northridge -1994 Rinaldi	x_c (mm)	994.43	840.07	15.52
		x_i (mm)	2.17	2.96	-36.41
		x_b (mm)	418.2	401.5	3.99
GM-3	Northridge -1994 Sylmar	x_c (mm)	1224.3	954.9	22.03
		x_i (mm)	2	2.18	-9.22
		x_b (mm)	408.67	268.63	34.22
GM-4	Kobe -1995 KJMA	x_c (mm)	586.78	450.98	23.14
		x_i (mm)	1.49	1.91	-28.19
		x_b (mm)	228.43	182.98	19.9
GM-5	Kocaeli-1999 Yarimca	x_c (mm)	1885.2	1880.4	0.25
		x_i (mm)	1.36	1.9	-39.71
		x_b (mm)	127.08	100.51	20.91

Table 2: - Comparison of results in terms of percentage for N-Z isolator with SMARB

Summary and Conclusions

This study investigates the seismic response of a liquid storage tank isolated by two different systems: a conventional N-Z (Lead Rubber Bearing) and an advanced SMARB isolation. The main aim of the current study was to identify earthquake behavior of the tank and compare various isolation modes under high-energy pulses from near-fault ground motions with respect to different parameters. The liquid's impulsive and convective (sloshing) behaviours were modelled using a mechanical two-mass model. Time history was carried out under five distinct near-fault ground motion records to assess essential performance criteria such as isolator, convective (sloshing), and impulsive displacement. The generalized conclusion that can be drawn is as follows:

- Overall average in reduction Convective displacement is 15 % for all the earthquakes (all of five earthquakes) and Isolator displacement reduction is around 20 % in SMARB isolator as compared to N-Z isolator for present study.
- On contrary, Impulsive component increase by 21% in case of SMARB in comparison with N-Z (i.e. Lead Rubber Isolator). In current case, slender tank is considered in which failure is generally due to sloshing SMARB isolation is more effective option than tank in isolation with normal isolation (i.e N-Z) in which generally failure occurs in sloshing mode, hence SMARB is more suitable for slender tanks as compared to N-Z isolator.
- Incorporation of SMA provides more balanced performance by reducing displacements over normal isolation mode

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