International Journal of Engineering Research
Volume No.5 Issue: Special 3, pp: 770-776

ISSN:2319-6890)(online),2347-5013(print)
27-28 Feb. 2016

Earthquake Response of Secondary Systems in Fixed-Base and Base-Isolated Primary Structures

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Abstract In this paper, investigations are reported for the seismic response of the secondary systems (SS) housed on the floors of the fixed-base (FB) and base-isolated (BI) primary structures (PS). Various SS serves as lifeline systems in civil structures such as nuclear power plants, aerospace industries, hospitals and several important public utility buildings/ structures. After the earthquake events proper functioning of these SS is always anticipated to avoid social and economic chaos. The primary structure considered in the current study is a real-life reinforced cement concrete (RCC) framed structure. The structure is isolated with a combination of lead rubber and sliding type of isolation devices. Numerical model of the RCC framed structure with and without base-isolation devices is developed and study is performed by attaching the SS at different floor levels of both the fixed-base and base-isolated structures under the excitation of seismic loadings. It is observed that in case of the base-isolated structure seismic performance of SS is enhanced and it is concluded that in the base-isolated structure, acceleration response and thereby seismic design forces acting on the SS reduces in comparison with fixed-base conditions of PS. Comparative assessment for performance of the SS housed in a fixed-base and base-isolated PS is carried out through the parametric numerical investigations for various dynamic properties of the SS. The information obtained from the parametric studies gives an idea for design of the SS in considered range of the dynamic properties of the SS.

Keywords Base Isolation, Earthquake, Primary Structure, Secondary System

1. Introduction

Seismic base isolation is a well established and widely accepted passive structural vibration control technology used for improving the seismic performance of important buildings such as tall buildings, public utility buildings, nuclear reactor plants etc. apart from safeguarding sensitive equipments from disastrous effects of earthquake. The basic mechanism of a base-isolator is to decouple the entire structure from the ground and arrest seismic forces at isolation level by means of a flexible interface between foundation and base of the structure. In base-isolated structures fundamental time period of the structure increases with reduced floor accelerations along with better energy dissipation through damping.

Secondary systems generally comprise of equipments or mechanical machines, either be fully anchored to the primary structures or they are free standing on the floors of the primary structures. Safety of the SS is vital for proper functioning of power plants, industrial facilities, hospitals and other important structures; since, they have to play vital role in regard to the safety and proper functioning of the PS and to keep the facilities functioning after the events of earthquakes, post-disaster. Damages to the secondary systems may result in significant social chaos, costly economic losses, possible death and injury to the occupants. The estimated economic loss from failure of secondary systems can be many folds of the construction cost of the building, because of loss of equipment, loss of inventory and loss of use of facility until it can regain its operational capabilities. Seismic performance of the secondary systems can be improved and those also can be safeguarded effectively from the disastrous effects of earthquake vibrations by using the seismic base isolation technology.

Chen and Soong (1988) provided a comprehensive review and assessment on seismic response of secondary systems,

doi : 10.17950/ijer/v5i3/054

which are attached to primary structures. Singh (1988) described the evolution of the methods which have been used to analyze the secondary systems in the past two decades. Fan and Ahmadi (1992) presented results of a series of numerical simulation studies on seismic responses of secondary systems in base-isolated structures including equipment-structure interaction and investigated analytical seismic response of multi-storey buildings isolated by lead-rubber bearings (LRB) under near-fault motions. Chaudhuri and Gupta (2002) studied a mode acceleration formulation to investigate the variability in the response of a secondary system which is supported on a flexible-base primary structure at multiple attachment points. Khechfe et al. (2002) discussed feasibility and behavior of base isolation for seismic protection of non-structural secondary system such as sensitive instrumentation, computer equipment, communication network, HVAC facilities, and power transmission systems housed in non-isolated primary structures. Matsagar and Jangid (2004) studied the influence of base-isolator characteristics on the base-isolated structure.

Herein this paper, the seismic response of the secondary systems (SS) housed on various floors of the fixed-base (FB) and base-isolated (BI) primary structures (PS) is studied under different real earthquake ground motions. The specific objectives of this study are: (i) performance of SS in fixed base and base-isolated building, (ii) influence of housing position/ elevation on performance of SS, (iii) effect of dynamic property of SS on its performance.

2. Numerical Modeling

2.1. Modeling of Fixed-Base and Base-Isolated PS

Figure 1 shows the typical floor plan and sectional elevation of the real-life building structure under study. The structure considered in the present study is a base-isolated, reinforced cement concrete (RCC) structure. This structure is constructed in seismic zone IV of India, which is one of the severe earthquake zones of India. In the present study numerical model of this structure is developed as per the details provided in Table 1. In the current modeling process, effect of infill wall is ignored from the structure. The structure is base-isolated with combination of lead rubber bearing (LRB) and sliding bearings. In total, 106 numbers of isolators are placed below the structure in order to decouple it from receiving the seismic forces generated during earthquake events. The details of the isolators along with their properties considered in modeling are described in Table 2. After provision of the base isolation devices it is observed that, the time period (T) of the base-isolated structure is enhanced to 1.5986 sec from its original time period of 0.9817 sec in fixed-base condition. Top floor absolute acceleration values in case of the base-isolated structure are comparatively lower than those in case of the fixed-base structure.

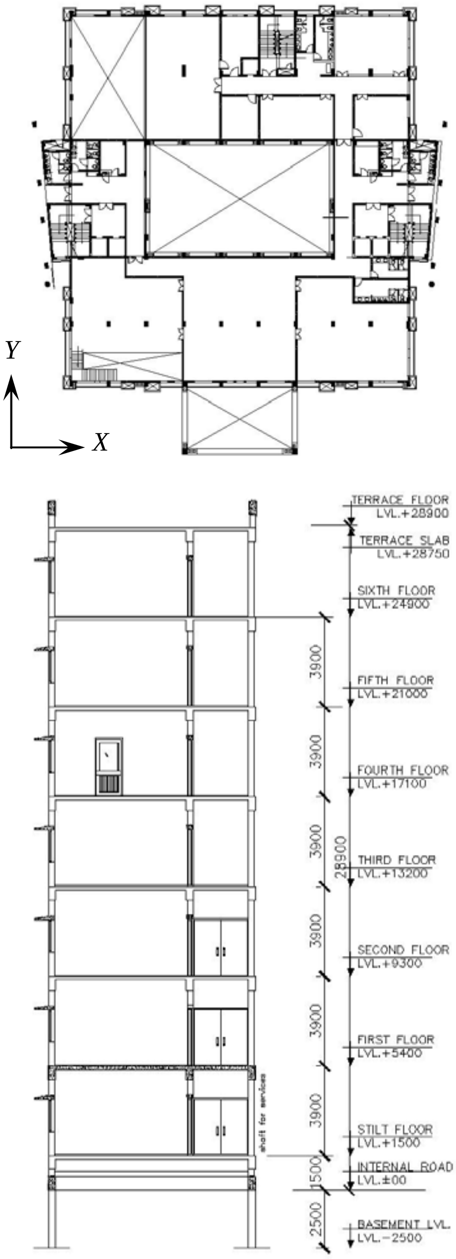

Figure 1. Typical Floor Plan and Sectional Elevation of the Real-Life Building

Table 1. Real-Life Building Details

Sr. No.	Description	Remark
1	Plan Dimensions	45 m × 49 m
2	Number of Stories	Basement + Stilt + 6
3	Grade of Concrete	M35
4	Grade of Steel	Fe500
5	Basement Storey Height	2.50 m
6	Stilt to Sixth Floor Height	3.90 m

7	Sixth to Terrace Floor Height	3.85 m
8	Sizes of column	450 mm × 750 mm

Table 2. Isolator Details

Sr. No.	Isolator Type	Quantity in Numbers	Effective Horizontal Stiffness, K_{Heff} (kN/m)	Effective Vertical Stiffness, K_{Veff} (kN/m)	Horizontal Damping Coefficient, C_{H} (kN-sec/m)	Vertical Damping Coefficient, C_{V} (kN-sec/m)
1	LRB A	58	2678.9	1928180	620.4	334.1
2	LRB B	45	3574.4	2943550	810.2	711.2
3	LRB C	1	4676.2	4174760	1142.5	1283
4	Slider D	2	1408.1	1368560	553.3	129

2.2. Modeling of the Fixed-Base SS.

SS are modeled on stilt, fourth and terrace floor of the both FB and BI buildings. The housing location of the SS is hypothetically considered at 7.35 m and 8.00 m respectively along X and Y axis of the building. Constant mass is lumped at top floor of the SS and for performing the parametric studies of SS, their dynamic properties are varied by changing the horizontal stiffness value. The details of the SS considered in present study are described in Table 3.

Table 3. SS Details

SS Type	Time Period, T (sec)	Mass, M (kg)	Stiffness, K kN/m
SS1	0.05	1000	15791.37
SS2	0.20	1000	986.96
SS3	0.50	1000	157.91
SS4	0.60	1000	109.66
SS5	1.20	1000	27.42
SS6	1.40	1000	20.14

Mass of the SS is assumed as 1000 kg; since, several heavy equipments installed in the public utility structures have a mass ranging around 1000 kg. Time period of the SS is assumed in such a way that, the SS1 and SS2 lies in the acceleration sensitive zone, the SS3 and SS4 lies in the velocity sensitive zone, and the SS5 and SS6 lies in displacement sensitive zone of the response spectrum.

3. Numerical Study

Earthquake response of the SS housed in FB and BI building is investigated under different earthquake time histories. The numerical study is carried out using the developed numerical model for calculation of the response quantities such as, absolute acceleration and relative displacement response histories at top floor of the SS, which are of deem importance in design of the SS. The displacement responses at top floor of the SS are relative to the corresponding floor displacement response at which the SS is fixed. The selected earthquake responses for conducting the parametric study are; (i) N00E component of 1989 Loma Prieta earthquake recorded at Los Gatos Presentation Center; (ii) N90S component of 1994 Northridge earthquake recorded at Sylmar station, and (iii) N00S component of 1995 Kobe earthquake recorded at JMA. The peak ground acceleration (PGA) of Loma Prieta, Northridge and Kobe earthquake motions are 0.57, 0.6 and 0.86g, respectively. The displacement and acceleration spectra of the above ground motions are shown in Figure 2.

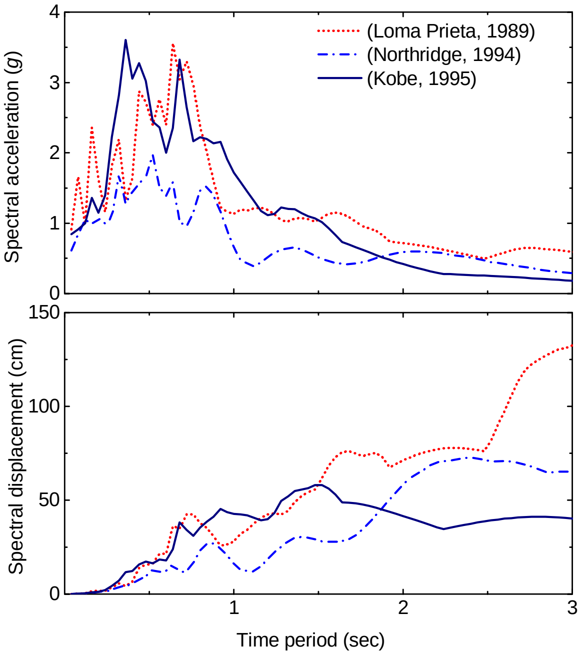

Figure 2. Response Spectrum for Loma Prieta, 1989, Northridge, 1994 and Kobe, 1995 Earthquakes

As described in Table 3 parametric studies are conducted by modeling the six different types of SS at various floor locations of the PS. The modeled SS behaves as a single-degree-of-freedom (SDOF) system under the excitation of earthquake force. Mass of the SS is kept constant and the stiffness values are calculated in such a way to obtain the decided time period of the SS based on acceleration, velocity and displacement sensitive zones of the response spectrum.

The comparative performance of the SS housed in both the

FB and BI structure is evaluated for the mentioned earthquake time histories. Moreover, the effectiveness of isolation for response control of SS in a BI structure is studied through the parametric study. Figures 3, shows the comparison of acceleration and displacement response time histories of the SS housed at fourth floors of the FB and BI structures. Figure 3 illustrates the effectiveness of isolation in reducing the acceleration and displacement of the SS. Results obtained from the parametric study are plotted in Figure 4, where it is observed that the accelerations and displacements at top floor level of the SS housed in BI structure are much lower than those housed in FB structure. It is observed that the acceleration and displacement responses of the SS lying in acceleration and velocity sensitive zone are more controlled in BI structure than those lying in displacement sensitive zone. Table 4 and 5 summarizes the peak values of absolute acceleration and relative displacements of the SS for the three different earthquake ground motions. These values are corresponding to low to high frequency range of SS considered in this study, which gives an idea of behavior of these SS in both FB and BI structure and role of isolation in safeguarding the high frequency equipments housed in structures.

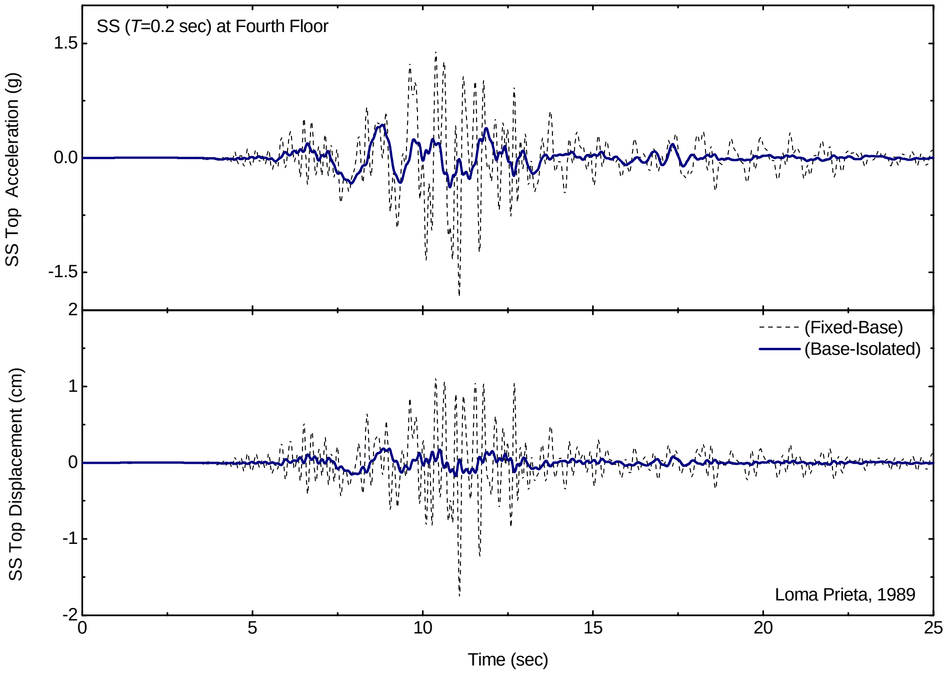

Figure 3. SS Top Floor Acceleration and Displacement Time History, T = 0.2 sec, Loma Prieta, 1989 Earthquake

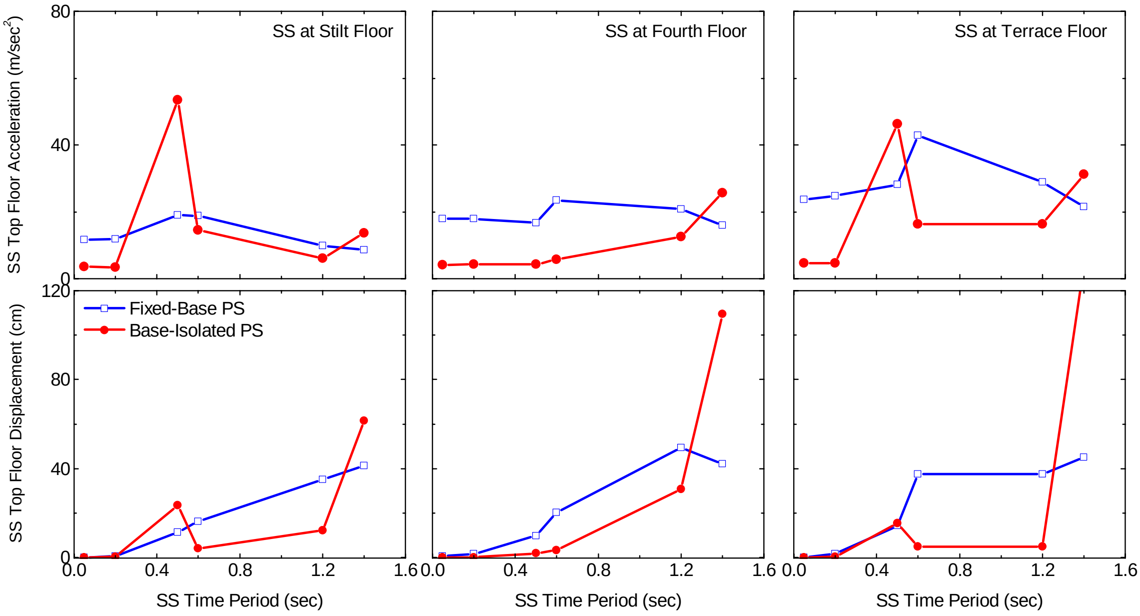

Figure 4. Top Floor Acceleration and Displacement Response of Various SS Housed at Stilt, Fourth and Terrace Floor of the PS, Loma Prieta, 1989 Earthquake

Table 4. Peak Absolute Acceleration Response of SS Top Floor Housed in Fixed-Base and Base-Isolated PS

Observation Quantity		Loma Prieta, 1989		Northridge, 1994		Kobe, 1995	
SS Type and Location		SS in FB Structure (m/sec^2)	SS in BI Structure (m/sec^2)	SS in FB Structure (m/sec^2)	SS in BI Structure (m/sec^2)	SS in FB Structure (m/sec^2)	SS in BI Structure (m/sec^2)
SS1	Stilt Floor	11.57	3.60	6.25	3.00	8.35	5.01
	Fourth Floor	17.98	4.13	10.91	3.14	15.41	3.90
	Terrace Floor	23.67	4.60	14.49	3.76	25.74	4.63
SS2	Stilt Floor	11.86	3.42	9.09	3.39	10.48	5.14
	Fourth Floor	17.85	4.25	11.44	3.38	19.32	4.11
	Terrace Floor	24.84	4.67	14.31	3.99	27.98	4.61
SS3	Stilt Floor	19.07	53.37	13.15	4.21	20.85	53.68
	Fourth Floor	16.77	4.26	12.73	3.69	22.48	6.00
	Terrace Floor	28.24	46.20	27.22	40.39	50.78	4.97
SS4	Stilt Floor	18.79	14.49	11.92	10.00	15.88	12.70
	Fourth Floor	23.50	5.82	16.51	4.24	26.49	5.07
	Terrace Floor	42.83	16.24	30.52	11.70	51.33	16.01
SS5	Stilt Floor	9.94	6.04	4.77	3.24	9.09	5.23
	Fourth Floor	20.77	12.64	12.71	6.28	28.00	11.87
	Terrace Floor	28.81	16.33	17.69	8.12	38.90	15.43
SS6	Stilt Floor	8.55	13.60	5.12	7.87	9.08	16.48
	Fourth Floor	15.90	25.63	11.61	14.44	17.78	30.74
	Terrace Floor	21.48	31.26	15.01	17.49	23.44	36.68

Table 5. Peak Relative Displacement Response of SS Top Floor Housed in Fixed-Base and Base-Isolated PS

Observation Quantity		Loma Prieta, 1989		Northridge, 1994		Kobe, 1995	
SS Type and Location		SS in FB Structure (cm)	SS in BI Structure (cm)	SS in FB Structure (cm)	SS in BI Structure (cm)	SS in FB Structure (cm)	SS in BI Structure (cm)
SS1	Stilt Floor	0.1	0.06	0.14	0.05	0.23	0.05
	Fourth Floor	0.5	0.15	0.4	0.12	0.72	0.12
	Terrace Floor	0.15	0.03	0.11	0.03	0.1	0.02
SS2	Stilt Floor	0.61	0.21	0.53	0.07	11.73	0.09
	Fourth Floor	1.759	0.17	0.64	0.16	0.62	0.18
	Terrace Floor	1.72	0.34	1.12	0.23	2.36	0.23
SS3	Stilt Floor	11.46	23.47	7.83	18.44	12.13	35.19
	Fourth Floor	9.72	2.09	7.29	0.88	13.12	1.64
	Terrace Floor	14.47	15.4	16.68	14.97	23.41	32.39
SS4	Stilt Floor	16.35	4.1	10.34	0.86	13.82	8.13
	Fourth Floor	20.19	3.33	13.81	3.46	22.22	3.25
	Terrace Floor	37.58	4.91	23.95	3.33	37.24	12.41
SS5	Stilt Floor	35.04	12.24	16.82	7.11	31.66	18.51
	Fourth Floor	49.47	30.81	18.78	17.15	54.16	37.46
	Terrace Floor	56.49	39.95	22.17	21.92	65.68	49.06
SS6	Stilt Floor	41.19	61.64	24.32	36.16	43.44	65.64

	Fourth Floor	42	109.5	27.52	67.48	42.8	1.06
	Terrace Floor	45.05	131.9	29.31	82.06	42.19	0.39

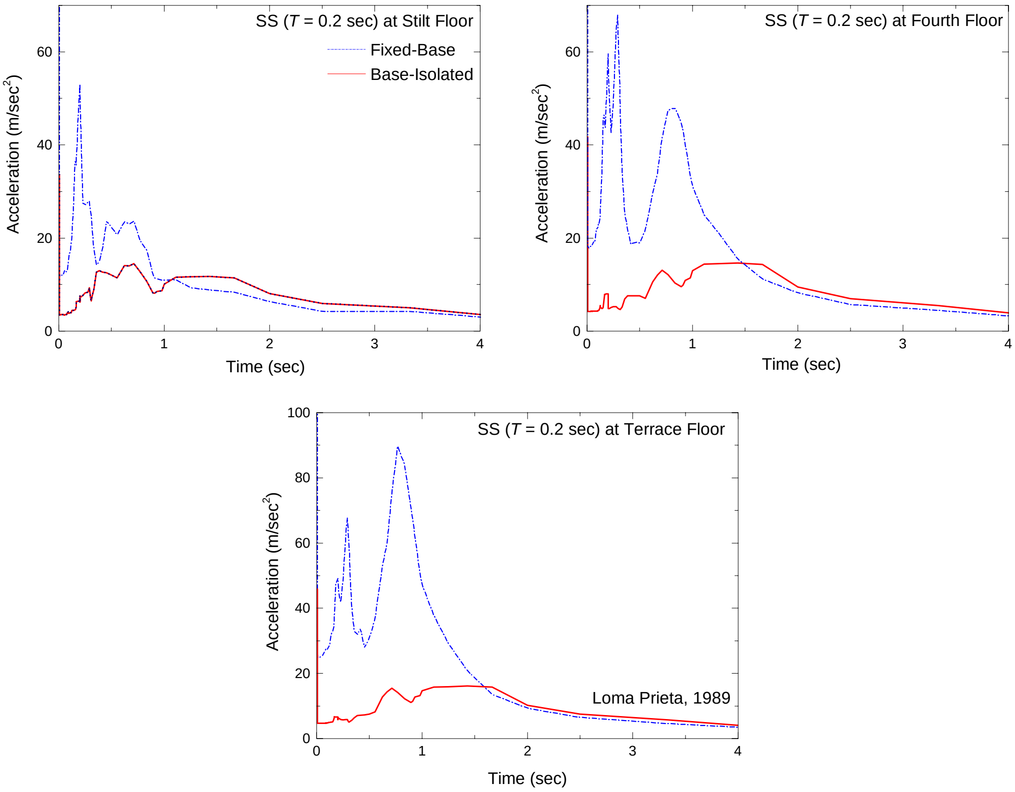

Figure 5. Floor Response Spectra of SS Housed at Stilt, Fourth and Terrace Floor of the PS, Loma Prieta, 1989 Earthquake

Figure 5, shows the floor response spectra of the SS housed at stilt, fourth and terrace floor of FB and BI structure. From the figure it is observed that the amount of acceleration entering into the SS in case of BI structure is drastically reduced and hence the SS will be safeguarded from earthquake events.

4. Conclusions

In this paper, seismic response of the SS housed in FB and BI structure is investigated. The comparative performance of the SS in FB and BI real-life building is studied under three different real earthquake ground motions. Parametric studies are conducted for different frequency range of SS located at different floors of the considered PS. Specific conclusions derived from this study are listed below.

1. Performance of SS housed in BI structure is improved in comparison with those housed in FB structure.

2. Base isolation is observed more effective in reducing the acceleration and displacement responses of the SS lying within the acceleration and velocity sensitive zone of the response spectrum.

3. Base isolation is observed less effective for the SS lying in displacement sensitive zone of the response spectrum.

4. Due to provision of base isolation a drastic reduction in acceleration entering into the SS is observed, hence base isolation is found effective in protection of the SS during the seismic events.

REFERENCES

i. Chen, Y. and Soong, T. T. (1988) "State-of-the-art review: seismic response of secondary systems", Engineering Structures, Vol. 10, pp. 218-228.

ii. Singh, M.P. (1988) "Seismic design of secondary systems", Probabilistic Engineering Mechanics, Vol. 3, No. 3, pp. 151-158.

iii. Fan, F. G. and Ahmadi, G. (1992) "Seismic responses of secondary systems in base-isolated structures", Engineering Structures, Vol. 14, No. 1, pp. 35-48.

iv. Chaudhuri S. R. And Gupta V. K. (2002) "Variability in seismic response of secondary systems due to uncertain soil properties", Engineering Structures, Vol. 24, No. 12, pp. 1601-1613.

v. Khechfe, H., Noori, M., Hou, Z., Kelly, J. M., Ahmadi, G. (2002), “An experimental study on the seismic response of base-isolated secondary systems”, Journal of Pressure Vessel Technology, Vol. 124, pp. 81-88.

vi. Matsagar, V. A. and Jangid, R. S. (2004) “Influence of isolator characteristics on the response of base-isolated structures”, Engineering Structures, Vol. 26, pp. 1735-1749.