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SHAKING TABLE TEST OF EFFICIENCY OF ALSC BASE-ISOLATION SYSTEM

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SUMMARY

Almost Lifted Structure Concept ("ALSC") is a specific solution which belongs to the well known "sliding concept", where the main structure is split from the supporting structure, thus allowing the main structure to slide, when forced. The sliding force is controlled by means of system for lifting of the main structure. The efficiency of the "ALSC" system has been demonstrated on 1/3 scale model of liquid storage tank, tested on two-component seismic shaking table at IZIIS dynamic testing laboratory. It was proved that the "ALSC" system produce significant reduction of energy transmission from supporting to the main structure within the broad frequency range, for different intensity of ground shaking. Because of its high efficiency, relatively simple installation, low cost and simple maintenance, the ALSC system is highly recommended by authors to be applied on reservoirs, special industrial structures(turbo-generator foundations, chemical laboratories), public structures(schools, hospitals, libraries, administrative buildings), residential houses, buildings etc.

INTRODUCTION

The experience from the recent catastrophic earthquakes shows human losses and heavy damage of the structures. Many of them have been designed in accordance to the actual official codes, but still not sufficient to resist earthquake because of higher intensity of ground motion than expected or unfavorable predominant frequency. That is a very clear message for earthquake engineering scientists, that a new approach in aseismic design and construction of the structures, such as control of structural behavior should be considered. The "ALSC" system belongs to above mentioned new approach, based on sliding base isolation concept, offering an opportunity for remarkable reduction of earthquake effects, using the new original "almost lifted structure concept"(ALSC).

DESCRIPTION OF ALSC SEISMIC BASE ISOLATION SLIDING SYSTEM

The friction force at the contact surface of base isolation sliding systems is defined by the following simple equation:

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$F_r = \mu N$ (1)

Classical sliding: N=G, L=0 (2)

ALSC sliding: $N = G - L, G > L >> N, N \geq 0$ (3)

where F_r = friction force transmitted to the main structure; μ = friction coefficient in the contact surface, N = compression force at the contact surface, L = lifting force, G = gravity force (weight of the main structure).The classical sliding base isolation concept is well known in earthquake engineering practice.

The main efforts in this case are oriented to reduction of friction coefficient μ by using special sliding surface (teflon pads etc) or sliding bearings. Sometimes it is expensive solution, because of high cost of the low friction materials and sliding devices. The ALSC concept improves the said sliding concept, offering a possibility to use standard sliding surface materials, such as epoxy resin or cement mortar, but still having low friction force as well. The reduction of the friction force is achieved by reduction of compression force N, on the manner that the main structure is subjected to vertical lifting force L, up to the state near lifting (before loosing the contact). Namely, the structure becomes "lighter", and according to above expressions: (1) and (3), the friction force could be significantly reduced. This lifting system is applicable on the buildings as well as on many industrial and special facilities. In this research study, the results of experimental investigations of a base isolated liquid storage tank by "ALSC" system is presented. The main parts of the system applied on the tested model are presented in Figure 1.

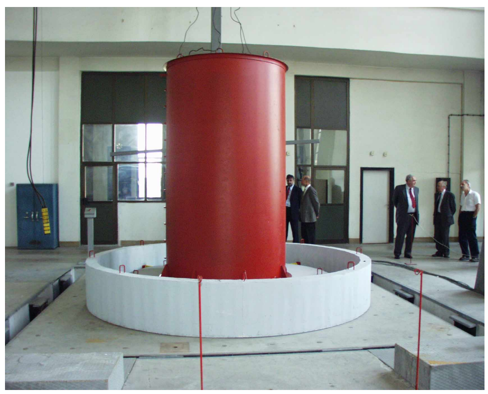

Figure 1. " ALSC" system applied on steel liquid storage tank model

The main structure is supported over flat supporting base without any interface connection. The base should be smooth in order to reduce the friction in the contact and to prevent the leakage of the liquid, which is under pressure. The bottom plate of the main structure and supporting structure are designed to resist pressure produced by liquid. The soft rubber tube fixed peripherally by metal ring, prevents the leakage of the liquid under the structure. The "working pressure" is obtained by infilling of the empty space under supporting structure by liquid, producing pressure:

$p = \gamma h$

which acts at the bottom and tends to uplift the structure. Low friction epoxy resin placed on the flat supporting structure reduces friction force. Finally, the centering devices such as springs, located around the tank and connected as shown in Figure 1, keep the structure in centered position always when sliding starts. The springs are designed as much flexible as possible, but stiff enough to resist the wind effects.

EXPERIMENTAL TESTING OF 1/3 SCALE MODEL ON SEISMIC SHAKING TABLE

Description of the model

The model was designed and built in scale 1/3, consisting of three main parts as shown on Fig.1 and Fig. 2: 1.-steel tank infilled by water; 2- sliding RC plate serving as a base for fixing the tank by steel bolts simulating upper foundation structure; 3-RC supporting base fixed to the shaking table, simulating the foundation supported to the ground. The model mass in total was 17.0 tons. The contact surface between two RC plates was specially smoothed by epoxy mortar. The hole under sliding plate was designed to accept a liquid layer to produce negative pressure and to "lightening the model" and to keep it in almost lifted position. Eight steel springs symmetrically distributed around circular sliding plate were placed in order to keep the sliding plate in centered position during vibration. The piezo-metric plastic tube has been installed in order to control visually the level of the hydraulic pressure.

Instrumentation set-up

The instrumentation set-up is shown on Fig.2. Seventeen channels have been instrumented by 9 accelerometers, 3 LVDT transducers, 3 linear potentiometers and 2 strain gauges. The absolute displacement of the RC plates as well as steel tank, relative displacement between two RC foundation plates, horizontal and vertical acceleration of the RC plates as well as steel tank, stress in two point at the bottom of steel tank have been monitored for any performed test. Two resonant indicators at each RC plate have been installed in order to show transmissibility of the sliding plate i.e. effectiveness of ALSC base isolation system.

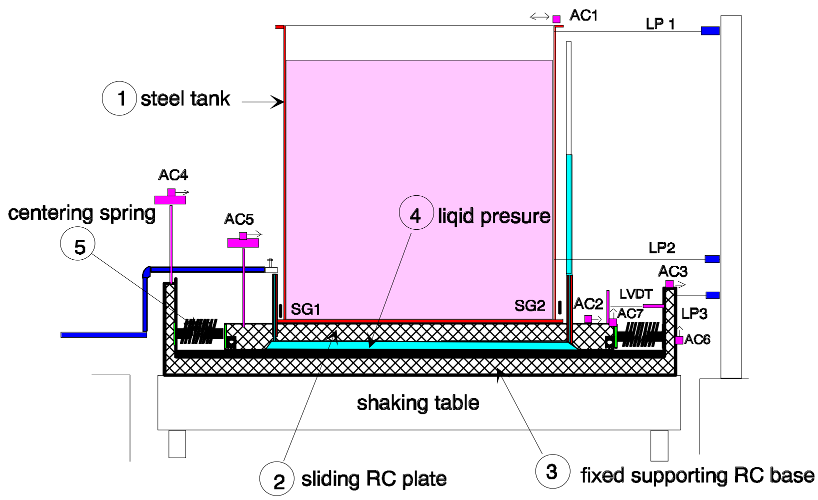

Fig.2. Instrumentation set-up

Testing program

The objective of the testing program was to verify the efficiency of a base isolation system "ALSC". First step of the program was to investigate the sliding-friction force at the contact between RC plates under static and dynamic conditions, considering different springs and liquid pressure conditions. The sliding-friction force in static conditions without springs was measured first, than the sliding-friction force with participation of the springs. The efficiency of the liquid pressure in reduction of sliding-friction force was also investigated under static and dynamic conditions. Three series of tests have been conducted for different type of dynamic excitations produced by shaking table. First of all, the resonant frequency of the model has been defined by random excitation test. In the next step, a series of harmonic excitations has been applied within the frequency range of 0.5-15.0 Hz, producing an acceleration of the shaking table within the range of 0.1-1.25g in horizontal and 0.1-0.5g in vertical direction. A series of earthquake excitations has been applied in the last phase of testing program in horizontal as well as by-axial, h-v direction.

Test results

The resonant frequency of the system was obtained by performing of random excitation tests within the frequency range of 0.1-30 Hz. The frequency f = 3.4 Hz was considered as a first sliding-friction frequency. In practice, the resonant frequency of the structure base isolated by ALSC system, should have a resonant frequency lower than predominant frequency of designed earthquake which can be controlled by adjusting of centering springs stiffness. This property is very important, because in case of earthquake, the structure practically can not be excited in resonance, i.e. it will not move, while the base move.Figs. 3 and 4 show the performance of the model base isolated by ALSC system under harmonic and earthquake excitation respectively

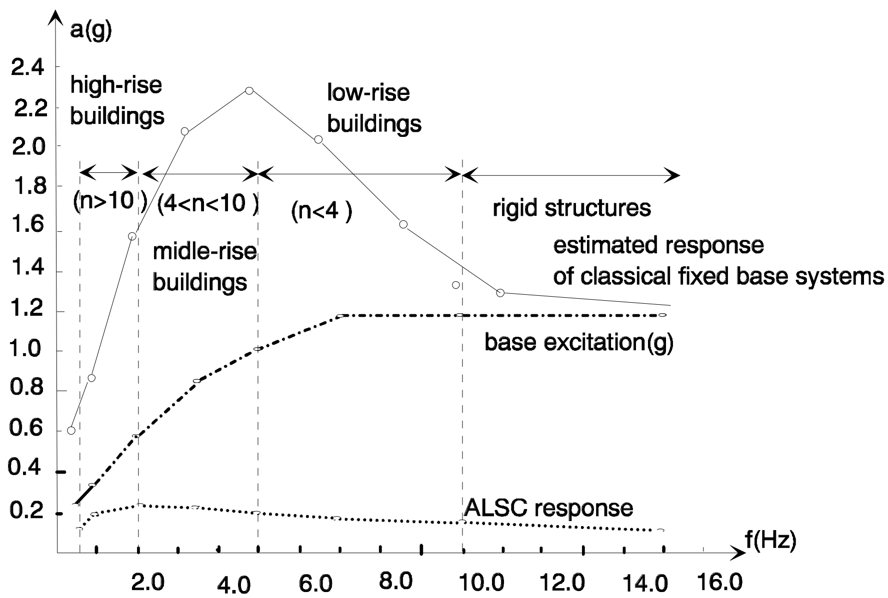

Fig. 3 Performance of the model isolated by ALSC system under harmonic excitation

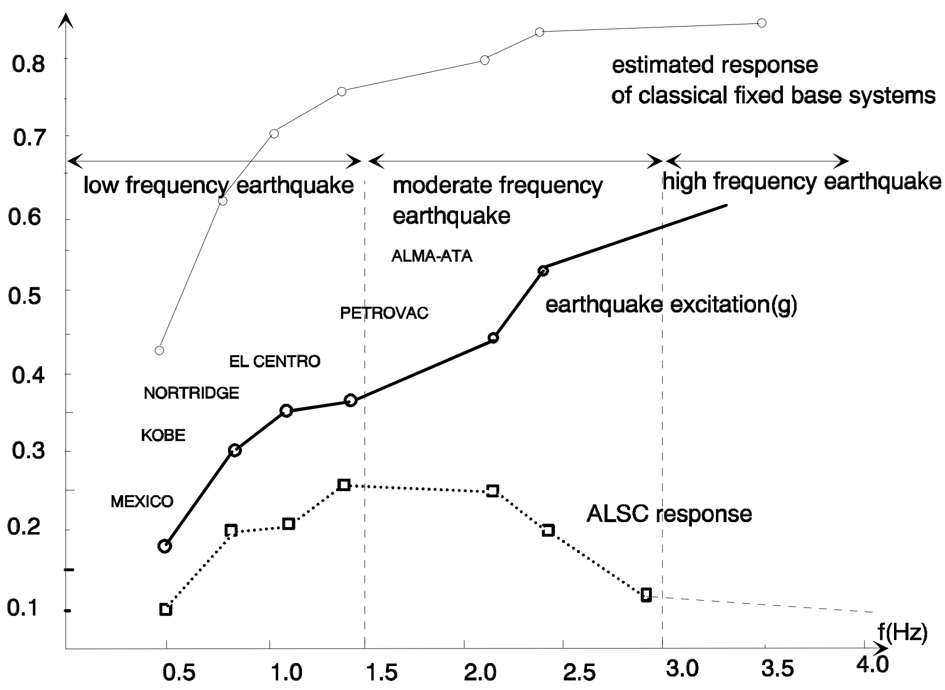

Fig.4 Performance of the model isolated by ALSC system under earthquake excitation

For harmonic excitation, series of tests within the frequency range of 0.5-15.0 Hz has been performed in order to check effectiveness of the ALSC system. Significant reduction of the input acceleration(2-6 times) is obtained as shown fig.3. Comparing to the classically designed(fixed base) structures, the maximum structural response is reduced 5-15 times depending of resonant frequency of estimated structure. Fig. 4 shows the same comparison for the earthquake excitation. As can be seen, the same reduction factors are valuable within the lower frequency range (0.5- 3.0 Hz). Ones again should be pointed out that this reduction factor could be increased if stiffness of the centering springs is reduced. In this particular case, the sliding-friction force is limited to 0.2g and it was not exceeded even the input acceleration was increased up to 1.2 g. The tabular presentation of response parameters are given in Table1. Besides response acceleration of the sliding plate, the absolute displacement, relative displacement to the fixed plate, vertical displacement of the sliding plate, top displacement of the model, top acceleration of the model, acceleration response of resonant indicators are given as peak numerical values obtained from time history response plots. The plots show nonlinear behavior of sliding ALSC plate during earthquake excitation because of the centering springs keeping the model out of the resonance during table shaking. After stopping the shaking, the position of the model was checked. The central position was always kept. It proves the effectiveness of the springs. The tests with vertical earthquake component show very stable behavior of the model without loosing the contact and changing the working pressure under the sliding plate. The same results are obtained in by-axial tests by horizontal and vertical components of Montenegro earthquake. In this case the model reacts with dominating sliding effect without up-lifting of the sliding plate.

CONCLUSIONS

- Model testing of a liquid storage tank, base isolated by the ALSC system, showed very effective reduction of input energy transmission by sliding of the reservoir over smooth surface, lightened by pressurized liquid layer. This simple and original solution, keep the structure out of the resonant within broad frequency range of the excitation force.
- The bending and shear forces in the main structure, and consequently, relative story drifts, are almost eliminated
- The ALSC system is controlled by two parameters: sliding-friction force and up-lifting force. The first parameter depends of smoothness of the contact surface and springs stiffness, while the second one depends of hydraulic lifting pressure. The control of above mentioned parameters was passive in this case, which doesn't require any external electric source. Next research activities will be oriented to automatic control of the friction force and automatic regulation of hydraulic pressure.
- The sliding range of the ALSC system during earthquake is not limited as in case of rubber base isolation system
- The system is not sensitive to vertical excitation component
- In case of by-axial excitation(vertical and horizontal) the system react by horizontal sliding only, which is not case of rubber base isolation system
- The system offers a possibility for easy displacement and /or rotation of the main structure, if required.
- Because of its high efficiency, relatively simple installation, low cost and simple maintenance, the ALSC system is highly recommended by authors to be applied on reservoirs, special industrial structures(turbo-generator foundations, chemical laboratories), public structures(schools, hospitals, libraries, administrative buildings), residential houses, buildings etc.

Table 1: Response parameters of the model for harmonic and earthquake excitation

N	Record	fr. hz	Input parameters		Maximum response values								
					Acceleration response (g)					Displacement response (mm)			
			Displ of table (mm)	Acc. of table (g)									
					AC 3,6	AC 2,7	AC1	AC4	AC5	LV DT	LP 3	LP 2	LP 1
			CH 1,3	CH 2,4	CH 21, 17	CH 20, 18	CH 19	CH 22	CH 23	CH 24	CH 25	CH 26	CH 27
1	RAND-H	3.4	1.6	1.80	1.50	0.22	0.66	1.26	1.03	2.2	1.5	1.9	1.7
2	RAND-V	15.3	0.6	0.26	0.27	0.22	0.38	0.17	0.66				
3	HARM-H	3.5	4.3	0.27	0.21	0.12	0.11	0.40	0.31	6.2	3.9	2.2	1.7
4	HARM-H	3.5	6.4	0.41	0.34	0.12	0.12	0.57	0.25	11.2	6.0	5.8	4.0
5	HARM-H	3.5	8.5	0.61	0.50	0.13	0.19	0.75	0.30	11.9	7.9	4.6	2.8
6	HARM-H	0.5	46.7	0.18	0.14	0.07	0.11	0.38	0.25	2.4	45.7	47.6	45.9
7	HARM-H	1.0	34.8	2.70	0.21	0.16	0.19	0.41	0.21	15.9	33.8	43.1	43.3
8	HARM-H	2.0	22.1	0.55	0.45	0.23	0.89	0.70	0.58	36.8	21.0	2.5	9.9
9	HARM-H	3.5	11.7	0.86	0.71	0.17	0.23	1.11	0.32	15.2	11.4	4.5	2.6
10	HARM-H	5.0	6.7	1.04	0.86	0.16	0.17	2.72	1.09	8.1	6.4	0.8	0.7
11	HARM-H	7.0	4.3	1.21	1.02	0.16	0.23	1.67	0.28	0.2	3.8	0.2	0.2
12	HARM-H	10.0	2.3	1.23	1.01	0.99	0.19	0.69	0.08	0.1	1.7	0.2	0.2
13	HARM-H	15.0	1.0	1.18	0.99	0.04	0.12	0.37	0.23	0.1	0.6	0.1	0.1
14	HARM-V	1.0	0.1	0.08	0.07	0.07	0.03						
15	HARM-V	5.0	2.7	0.31	0.31	0.28	0.10						
16	HARM-V	10.0	0.8	0.35	0.36	0.37	0.26						
17	HARM-V	15.0	0.2	0.26	0.24	0.39	0.56						
18	IZMIT -H	1.71	53.0	0.29	0.22	0.17	0.24	0.78	0.65	2.74	52.3	54.3	52.6
19	IZMIT -H	1.71	51.6	0.11	0.09	0.13	0.20	0.54	0.30	6.64	50.2	53.5	52.5
20	IZMIT -H	1.71	76.7	0.17	0.14	0.18	0.27	0.88	0.54	16.3	75.3	81.4	79.9
21	IZMIT -H	1.71	109.7	0.22	0.18	0.23	0.32	1.20	0.69	35.3	108	121	119
22	KOBE-H	0.83	51.3	0.12	0.10	0.14	0.23	0.13	0.23	4.6	50.1	54.2	52.1
23	KOBE-H	0.83	102.3	0.28	0.23	0.21	0.27	0.39	0.62	39	100	115	110
24	ELCENTRO-H	1.46	68.7	0.25	0.20	0.23	0.35	0.78	0.81	23.9	65.6	78.9	78.4
25	ELCENTRO-H	1.46	97.1	0.35	0.28	0.25	0.37	0.88	1.21	31.5	95.5	113	107
26	PETROVAC-H	1.46	71.7	0.45	0.38	0.48	0.79	0.84	1.33	76.5	71.2	97.9	95.5
27	NORTHRIDGE	1.07	73.4	0.34	0.29	0.20	0.37	0.85	10.7	64.2	48.3	103	101
28	MEXICO-H	0.48	77.9	0.22	0.19	0.11	0.17	0.43	0.54	4.5	76.1	77.9	74.4
29	ALMA ATA-H	2.39	10.0	0.17	0.14	0.17	0.32	0.69	0.97	16.4	9.1	19.1	18.5
30	ALMA ATA-H	2.39	24.5	0.42	0.37	0.24	0.44	1.45	1.48	53.4	23.5	54.9	52.8
31	ALMA ATA-H	2.39	29.6	0.52	0.44	0.26	0.43	1.66	1.5	67.6	25.7	66.9	65.7
32	PETROVAC-V	25.0	26.7	0.12	0.13	0.11							
33	PETROVAC-H,V	2.17	72.1	0.46	0.40	0.62	0.81	0.76	1.61	77.7	7.8	71.3	99.0
		25.0	31.7	0.15	1.45	1.66							

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