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SHAKING TABLE TEST OF KEY LOCK SYSTEMS PRODUCTS OF HEERUM- GERMANY UNDER SEISMIC AND RESONANT CONDITIONS

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ABSTRACT

.The subject of this paper is testing of five electro-mechanical components (key lock systems) products of HEERUM, Germany, under simulated earthquake and resonant conditions by means of the shaking table at the Dynamic Testing Laboratory at IZIIS, Skopje, Macedonia. The main objective of the testing is to check the functioning of the components under the earthquake conditions existing in Central and Eastern Europe Countries.

This is the second test related to the HEERUM treasure lock system performed at the Dynamic Testing Laboratory at IZIIS during the last week of October 1994. The first test was performed in July 1994 and it was related to the treasure locks which would be incorporated in the National Bank in Alma-Ata, Republic of Kazakstan. The results were very reliable even for an intensity twice as high the expected one. The objectives of the second test was to investigate the dynamic behavior of the HEERUM key lock systems not only under seismic conditions existing in different regions in Europe, but also under resonant conditions, which is a more strong requirement. Further more, destructive test was also performed in order to define the limit state under which the functioning of the key lock system would be affected.

KEYWORDS

Key lock systems, shaking table tests, seismic and harmonic excitations

TESTING METHOD

In order to check the resistance of the key lock systems under real earthquake excitations, valuable for various European countries, and its functional security during and after the earthquake, five samples have been fixed on the shaking table and excited by different earthquakes within the estimated frequency and amplitude range, according to the expected seismic conditions

The testing of the key lock systems has been performed in each orthogonal direction, separately. The measuring points have been determined with the assistance of the representative from the producer. Accelerations at the selected points have been measured during the test. After each test run, the functioning of the lock systems has been checked. On the basis of the visual, instrumental and functional control, acceleration of the selected earthquakes rangeş between 0.13 (Vranchea) to 0.7 g (Alma Ata). All the above mentioned records have been reproduced in full scale using the IZIIS biaxial shaking table.

For resonant tests, the harmonic excitation was defined based on the obtained resonant frequencies of the tested components. The resonant tests have been performed in transversal and vertical direction. Two frequencies have been used (30 and 50 Hz), which were close to the fundamental frequencies of the lock systems. The considered input acceleration was a=0.6 g, in transversal, and 0.4 g, in vertical direction, which corresponded to the peak acceleration value of the used earthquakes.

For destructive tests, the harmonic excitation was defined according to the resonant frequency of EL-2 element in transversal direction, i.e. 30 Hz. Starting from 0.9 g, the intensity was gradually increased in each test up to 1.7 g. These severe conditions correspond to considerably higher intensity of excitation than the strongest earthquake.

RESULTS

Testing of the key lock systems under earthquake conditions, is not regulated by any particular standard procedure. Therefore, the general recommendations for testing of electrical and mechanical equipment under seismic and other vibrating conditions have been used in this particular case.

All the components have been fixed to steel plates, which were in turns fixed to the shaking table. These fixing conditions do not quite correspond to the original ones, but still, they are sufficiently effective to simulate the rigid body conditions. It should be pointed out that main objective of the test was to check the global behavior of the components, not their constitutive parts. By checking the functionality after each test, the constitutive parts were indirectly checked too.

Frequency response test

Following the testing program , in the first phase, the components were tested by random noise and impulse excitation in order to define the resonant frequencies within the range of 0-250 Hz. For this purpose, the components have been exited in each of the three orthogonal directions separately. Tabular presentation of the fundamental resonant frequencies is given in Table 1. Obtained transfer function spectra showed that in transversal direction EL-1, EL-2 and EL-3 have resonant frequencies lower than 60 Hz, while the other three components, in the range of 80-140 Hz. In longitudinal direction, only EL-1 and EL-2 have the resonant frequencies below 60 Hz, while in vertical direction only EL-1 has a sharp resonance, below 60 Hz. Based on these data, resonant tests have been performed by harmonic excitation with frequencies f=30 Hz and f=50 Hz, as the closest ones to the resonant frequencies of the tested components. The frequencies higher then 50 Hz are not related to the earthquake conditions. Therefore, the influence of the higher frequencies has not been investigated in this case.

Table 1. Fundamental resonant frequencies of the tested key lock systems

	Resonant frequency (Hz)		
Element	Transversal	Longitudinal	Vertical
EL1	56.0	62.0	52.8
EL2	28.0	48.0	40.0
EL3	80.0	114.0	38.4
EL4	92.8	152.0	52.8
EL5	39.2	158.0	84.0
EL6	138.0	134.0	87.2

conclusions about the locks reliability have been drawn. All the results have been presented in tabular and graphic form.

The testing steps are listed below:

1. Definition of the resonant frequencies for three orthogonal directions.
2. Testing of the components under various real earthquakes, relevant to different European countries.
3. Testing of the components under resonant conditions with harmonic motion.
4. Destructive test of EL-2 component under resonant conditions

The resonant frequencies have been defined on two ways: by impulse test and random excitation test. The seismic tests have been performed by different earthquakes that correspond to the expected ones. Two testing positions (closed and opened) have been considered for each of the selected earthquakes. Five earthquake time histories were simulated for each of the three orthogonal directions.

The resonant tests have been performed after the seismic test series. They gave the information how the components behave under resonant conditions. Many Eastern European countries consider this kind of test as a proof test of the proper functioning of the systems under seismic conditions.

The destructive tests have been performed only for EL-2 under harmonic motion with the frequency close to the resonance of the element. The tests were repeated several times with a higher intensity comparing to the previous one. The functioning of the systems was checked after each test run for both closed and opened position.

The testing of the components has been performed by means of biaxial shaking table. All five elements have been fixed to the table and tested together (Fig.1).

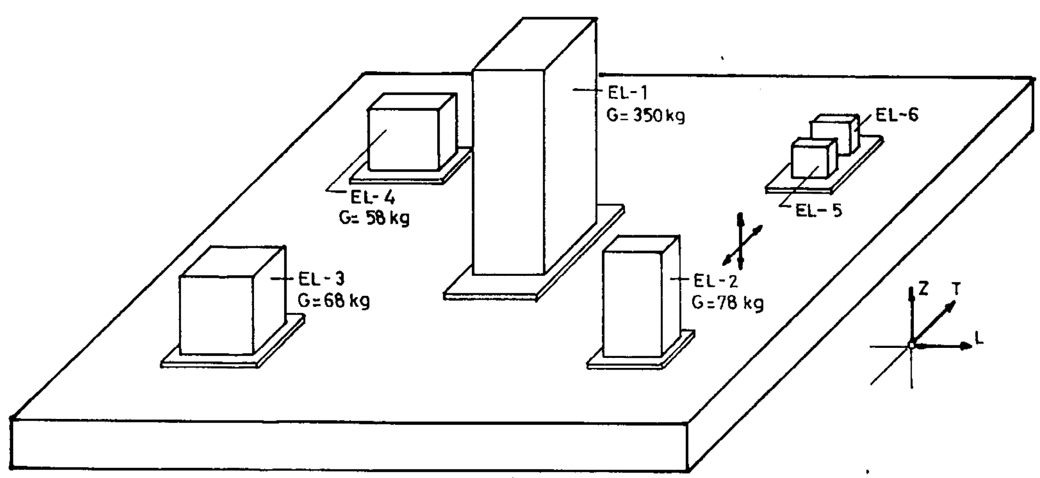

Fig. 1. Disposition of the key lock systems on biaxial shaking table at IZIIS laboratory

SEISMIC INPUT AND HARMONIC EXCITATION

On the basis of the HEERUM request, that the seismic input should correspond to the seismic conditions existing in the European countries, five earthquake time histories have been selected as representative ones: El Centro 1940 (USA) as a reference one, Friuli 1976 (Italy), Petrovac 1979 (Montenegro), Vranchea 1977 (Romania) and synthetic time histories relevant to the Alma -Ata region (Kazakstan). The average peak

Earthquake excitation test

The most important part of this investigation was the earthquake excitation test. The key lock systems have been subjected to five selected earthquakes with full scale intensity, in each of the three orthogonal directions respectively, in opened and/or closed position of the lock. Thirty tests in total have been performed in this phase. The functioning of the locks has been checked every time after the test run. The electronic part of EL-5 was not functioning since the beginning of the test, therefore it was not included in the next tests.

The test results obtained for Friuli earthquake excited in transversal direction are presented in Fig. 2 and 3.

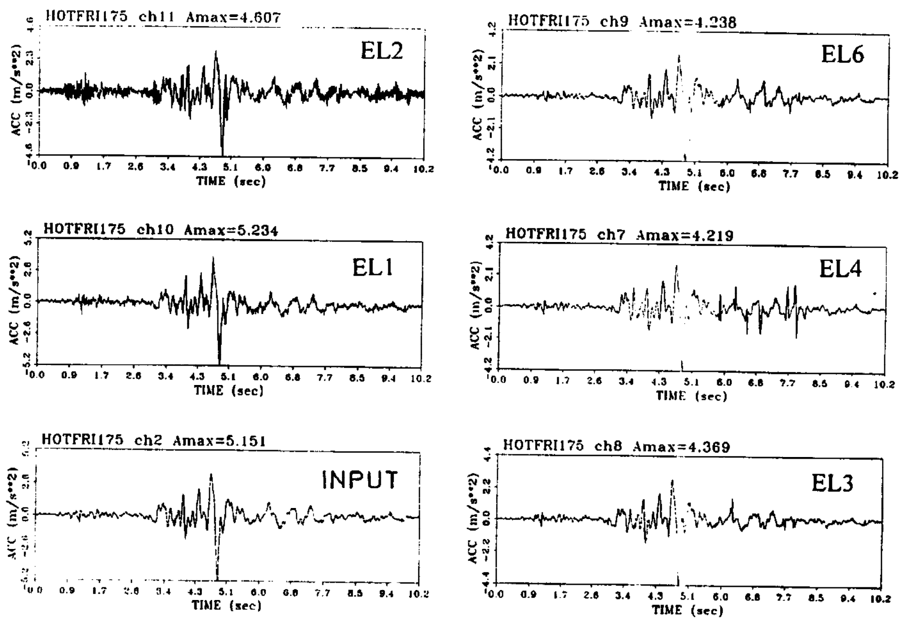

Fig. 2. Acceleration time histories of the tested key lock systems in transversal direction - Friuli earthquake

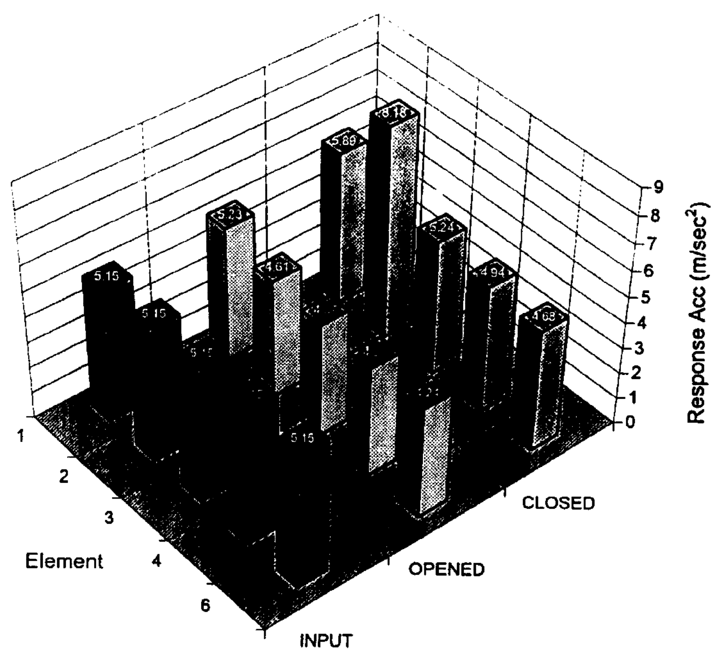

Fig. 3. Friuli earthquake - transversal direction

Tabular presentation of the results is given on Tables 2.

Table 2. Test results obtained from earthquake excitation tests in transversal direction

Earthquake	Test code	Position of the lock	Input acc (m/sec^2)	Response acc (m/sec^2) EL1	EL2	EL3	EL4	EL6
El Centro	HOTELC850	opened	3.56	3.68	5.07	5.50	2.59	3.46
USA	HZTELC850	closed	3.36	3.65	4.70	5.00	2.65	2.94
Friuli	HOTFRI176	opened	5.15	5.23	4.61	4.37	4.22	4.24
Italy	HZTFRI175	closed	5.98	5.89	8.18	5.24	4.94	4.68
Petrovac	HOTPET700	opened	5.47	4.90	8.22	4.03	4.10	4.58
Montenegro	HZTPET700	closed	5.14	4.96	7.47	4.52	4.61	4.77
Vranchea	HOTVRA800	opened	1.24	1.45	1.66	1.22	1.60	1.10
Romania	HZTVRA800	closed	1.25	1.38	1.66	1.13	1.20	1.11
Alma-Ata	HOTATA500	opened	7.44	7.35	7.70	5.90	6.10	6.50
Kazakstan	HZTATA500	closed	7.26	6.81	15.30	6.81	5.00	7.19

The general conclusion is that all the tested key lock systems resist very successfully any of the simulated earthquake. In transversal direction, the peak ground acceleration ranges between 0.12 - 0.75 g (1,2 to 7.5 m/sec 2), depending on the type of the earthquake. The response amplitudes, within the frequency range of 0.1 - 50 Hz, do not exceed the values 1.5 times larger than the input peak value, which follows to the conclusion that the key lock systems are out of the resonant conditions for any of the excited earthquake. For longitudinal and vertical direction the response intensity is even smaller than in transversal one. These conclusions provide a reliable prediction of the proper functioning of HEERUM key lock systems even under severe earthquake conditions.

Concerning the influence of the type of the earthquake upon the dynamic behavior of the key lock systems, the Friuli, Montenegro and Alma Ata earthquakes produce more intensive response than the others, especially for the elements EL-1 and EL-2, in transversal direction.

Testing under resonant conditions

Another important testing phase was resonant testing of the key lock system. Every researcher, familiar with the dynamic problems, knows that resonant conditions could produce many problems in functioning of any mechanical or electrical equipment. It was a challenge for HEERUM to test their key lock systems even under resonant conditions. They could occur in practice at locations where high vibration working conditions exist. Another reason for performing the resonant test is to check the resistance of the key lock systems according to the Eastern European countries requirements. Namely, the resonant test is most frequently applied for electro-mechanical equipment installed in nuclear power plants. The seismic input, i.e. the peak acceleration, in that case, is based on the floor response spectra, according to the location of the particular equipment.

The resonant test has been performed considering two frequencies of the harmonic excitation: f = 30 Hz and f = 50 Hz, which are close to the fundamental resonant frequencies of the tested components. Table 1 show that EL-1 has the resonant frequencies f =56.0 Hz, in transversal direction, f = 62.0 Hz, in longitudinal direction and f = 52.0 Hz, in vertical direction. EL-2 has the resonant frequency f = 28.0 Hz, in transversal direction, f =48.0 Hz, in longitudinal direction, and f = 40 Hz, in vertical direction. EL-3 has a resonant frequency f = 38.4 Hz, in vertical direction, while EL-5, f = 39.2 Hz, in transversal direction. The other resonant frequencies are higher than 50 Hz and they are not considered in relation to this investigation.

The test results obtained form the resonant test with a harmonic sinusoidal motion in transversal direction, considering, first, an excitation frequency of 30 Hz and an input acceleration of 0.6 g, than, an excitation frequency of 50 Hz and an input acceleration of 0.4 g. It is obvious from the results that under sinus excitation of 30 Hz, the response of EL-2 is most intensive in transversal direction (amplification factor AF=5.5), while of El-1, EL-2 and EL-3, under the sinus excitation of 50 Hz.(AF1=6.2, AF2=2.3, AF3=3.3) In all the above mentioned cases, the response is more intensive when the locks are in closed position.

The resonant test in vertical direction shows that EL-1 responds more intensively than the other elements (amplification factor 3.9),.but still less intensively than in transversal direction. This was the reason for performing destructive tests in transversal direction.

Destructive test

In the final phase, destructive tests were performed on EL-2 by a sinus force with a frequency of f = 30 Hz, in transversal direction. This type of test was not included in the programme, but it was performed on the request of the HEERUM representative in order to check the behaviour of the key lock system EL-2 under extremely high dynamic excitation. Starting from an input acceleration of 0.9 g , the component was subjected to strong vibrations up to 1.7g. in eight test runs.(Table 3).

Table 3. Test results obtained from destructive tests with harmonic excitation in transversal direction

Type of excitation	Test code	Position of the lock	Input acc (m/sec^2)	Response acc (m/sec^2) EL2
SINUS	HZTS30010	closed	9.21	70.42
30 Hz	HOTS30010	opened	9.15	63.00
SINUS	HZTS30013	closed	11.29	83.37
30 Hz	HOTS30013	opened	11.34	75.64 *
SINUS	HZTS30016	closed	13.44	111.58 *
30 Hz	HOTS30016	opened	13.36	< 41.94
SINUS	HZTS30021	closed	17.38	< 49.50
30 Hz	HOTS30021	opened	17.40	55.63

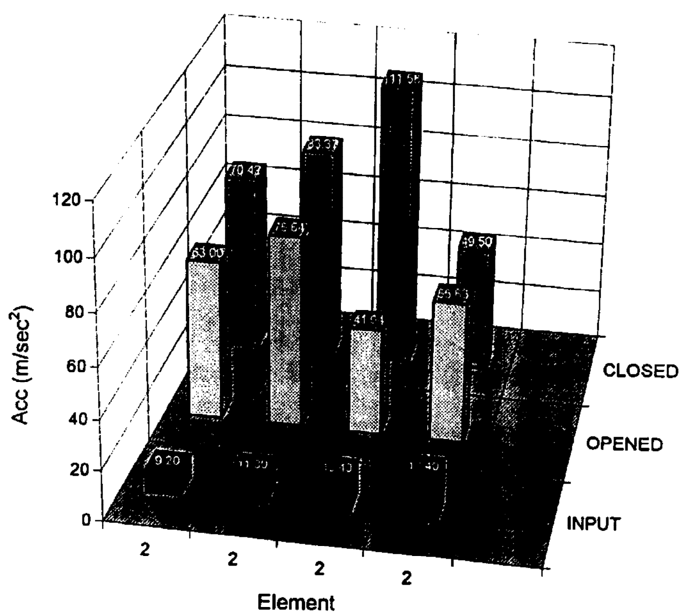

Fig. 4. Destructive test with harmonic excitation 30 Hz in transversal direction

After each run, the functioning of the lock has been checked and careful visual inspection has been performed. The tested component shows excellent behavior, without loosing the function and without any visible damage. After the test with an intensity of 1.1 g in opened position and 1.3 g in closed position, nonlinear response of the component occurs, without affecting its function. It is probably a consequence of nonlinearity occurred in the fixing plate. The maximum amplification factor, before the occurrence of nonlinearity, ranged between AF=7.5 to 8.3, for closed position, and AF=6.6 to 6.9, for opened position. After that, the amplification factors decrease, having the values: of AF=3.1, for opened, and AF= 2.8, for closed position.

At the end of the testing, in order to check the resonant frequency of EL-2, random noise excitation test was performed. Comparing the Fourier spectra a slight decrease of the frequency was observed (from f = 28.5 Hz to f = 26.0 Hz), which is about 10%.

CONCLUSIONS

After the occurrence of many catastrophic earthquakes, besides human and structural losses, significant loss in mechanical and electrical equipment have been observed, too. Such an experience should be considered as a message to the engineers, to pay more attention in the design of the electro-mechanical equipment to ensure its necessary resistance and to keep its functionality during and after the earthquake.
Based on the results obtained from this investigation, the following important conclusions should be pointed out:

- The five tested key lock systems show proper functioning after excitation of the considered earthquakes, without any damage. This conclusion is valuable for the tests in all three orthogonal directions.
- The resonant test performed by harmonic motion with frequencies of 30 and 50 Hz, and an input acceleration of 0.6 g , shows that even under resonant conditions, the key lock systems do not lose their proper functioning.
- Destructive test applied on EL-2, was performed in order to define the limit capability of the key lock system. Even for very high intensity of input (1.7 g) in the resonant stage, the component was still functioning., but some slight nonlinear behaviour occurred, after which the test was stopped.

REFERENCES

Jurukovski D., Taskov Lj., Mamucevski D., Dojcinovski D., (1994). Shaking table test of treasure lock products of HEERUM-Germany, *IZIIS Report 94/5/1*.

Taskov Lj., Jurukovski D., Mamucevski D., Rakicevic Z., Stamatovska S., (1994). Shaking table test of key lock systems of HEERUM-Germany under seismic and resonant conditions, *IZIIS Report 94/5/2*.