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TESTING OF A FULL SCALE BASE ISOLATED FOUR STORY APARTMENT BUILDING IN THE CITY OF SPITAK, ARMENIA

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SUMMARY

In 1996 for the first time in Armenia a seismic isolation system was designed and developed by Earthquake Engineering Center (EEC) of the National Survey for Seismic Protection (NSSP), for the construction of a new building in the center of the old Spitak, which was almost completely destroyed during the Earthquake of December 7, 1988. Thirty-nine high damping rubber bearings manufactured in Malaysia by Min Rubber Products Sdn. Bhd. were used for the building in Spitak. The seismic isolators were designed in collaboration with TARRC-MRPRA (UK) to give a horizontal displacement of 13 cm. It was decided to carry out two unique tests in 1997, when construction of the building was almost completed. The purpose of the first one was the trial of the technology of replacement of seismic isolators. The purpose of the other one was to check the correlation of the design and actual parameters of the isolation system. Description of tests and their results is given in this paper.

INTRODUCTION

The investigations on seismic isolation systems had started in Armenia at the EEC of NSSP in 1992. At that time the first attempt had been made to design, manufacture and test a laminated rubber bearing of seismic isolation. After a successful start new technologies, using seismic isolation systems for upgrading the earthquake resistance of existing buildings were developed, which have already attracted international professional attention. They allow to upgrade the earthquake resistance of existing buildings without interruption of their functioning. The technology of seismic isolation of an existing building [Melkumyan 1994], in essence allows to make vulnerable buildings practically safe from the seismic point of view. Based on that technology a unique project was developed at EEC on seismic isolation of an existing five story stone masonry apartment building without evacuation of tenants. It was implemented in 1996 for the first time in the world in the city of Vanadzor. This building was gradually cut from its foundation and between them on the level of the upper edge of the foundation 60 seismic isolators manufactured in UK and Malaysia were placed [Fuller et al. 1997].

Along with that seismic isolation systems were developed and designed for the construction of different new buildings and structures. In 1995 a one-story bath-house project in cooperation with Engineering Research Center of the American University of Armenia has been introduced in three cities of the country - Giumri, Vanadzor and Spitak [Melkumyan et al. 1997]. The next design using seismic isolation was developed for the construction of a new building in the center of old Spitak, which was destroyed during the earthquake of December 7, 1988. After this tragedy buildings with more than two stories were not erected here. In the given case, thanks to the base isolation, for the first time after the mentioned earthquake, a building was designed two times higher, i.e. four story. All together 39 high damping rubber bearings manufactured in Malaysia were used for the building in Spitak. In this paper the tests of this particular building are described and the results are given.

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GENERAL INFORMATION ON SEISMIC ISOLATION SYSTEM AND TRIAL OF THE TECHNOLOGY OF REPLACEMENT OF SEISMIC ISOLATORS

The structure of the building represents a system with monolithic bearing walls and prefabricated slabs. The foundation plan with the location of seismic isolators is shown on Fig. 1. The seismic isolators were designed in collaboration with TARRC-MRPRA (UK) to give a horizontal displacement of 13 cm. They are located in recesses formed by two steel rings rather than being bolted to the structure. Sixteen bolts fix the recess rings to steel plates which are in turn connected to the foundation beam reinforcement. In this building one type of seismic isolators was used. Their design parameters are given in the Table 1.

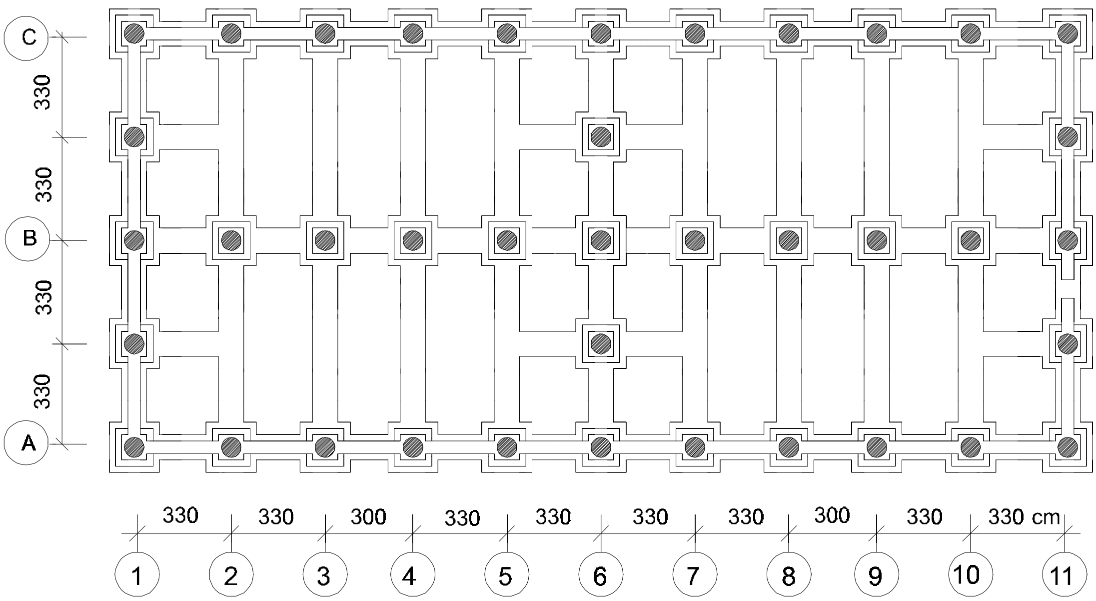


Fig. 1. The foundation plan with the location of seismic isolators

During the construction the 9 dummy isolators, made from the steel pipe, were installed in certain positions instead of rubber bearings. At the final stage of construction all dummy isolators were replaced. In order to do that operation two pits for installation of the jacks from both sides of each dummy isolator were made in the foundation wall along the external axis of the building. Two jacks with the capacity of 100t were used to lift the building at each location by about 0.5mm. After that the dummy isolator was taken out and installation of the real seismic isolator started. First of all the surfaces of the lower and upper steel plates, as well as of the seismic isolator were cleaned. Then the lower and upper recess rings were placed around seismic isolator. The latter was gradually brought into its design position with the recess rings placed around it. Finally the two rings were bolted to the upper and lower steel plates.

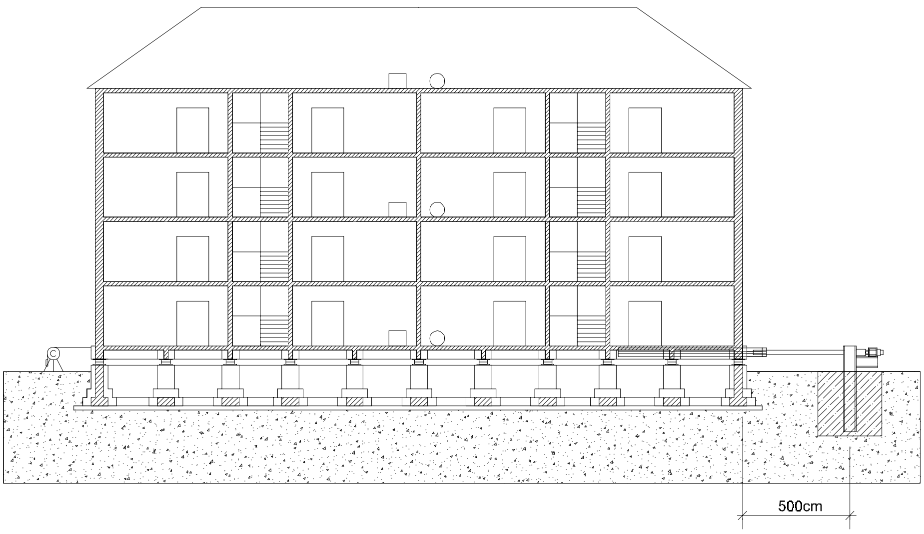
By the described way the dummy isolators located along the external axis of the foundation were replaced. The same was not possible to realize for dummy isolators located along the middle axis of the foundation, as the foundation wall along the middle axis was absent. Therefore, in this case, in order to replace the dummy isolator, two steel columns were installed and fixed by special devices from both sides of stepped footing. On the top of these columns the jacks were installed. After that all operations as described above were realized and dummy isolator was easily replaced. Thus, in the result of accomplished work it was shown, that in essence, being very meaningful operation, the replacement of seismic isolators is not complicate and not expensive. It should be mentioned that 90 minutes were spent to replace one dummy isolator when mainly hand power and low tech equipment were used. Certainly, using high tech equipment this time can be shortened 2-3 times. The trial confirms that replacement of the isolators, should this ever be necessary, can be accomplished in a quick and simple operation.

Table 1: Parameters of seismic isolators

Name of parameter	Symbol of unit	Value
Overall height	mm	202
Overall diameter	mm	380
Number of rubber layers		14
Thickness of rubber layer	mm	9
Number of steel layers		13
Thickness of steel layer	mm	2
Diameter of steel layer	mm	360
Thickness of rubber cover layer (side)	mm	10
Thickness of two steel endplates	mm	23
Thickness of end cover layers	mm	2
Shear stiffness	kN/mm	0.81
Vertical load	kN	820

DESCRIPTION OF THE LOADING SYSTEM AND RECORDING INSTRUMENTS FOR THE TESTING OF THE ISOLATION SYSTEM

In order to carry out the second test, a special loading system by which a horizontal static or dynamic force could be applied to the building at the level of the upper beams of the isolation system was designed and constructed near the building. The testing scheme and location of the recording instruments is shown on the Fig. 2.



○ - seismometer to record displacements during dynamic test;

□ - accelerometer to record acceleration during dynamic test;

◎ - instrument to record displacements during static test

Fig. 2. The testing scheme and location of the recording instruments

Four channels No 16 were placed into a beam of the upper level of the isolation system during construction to create the possibility to apply the horizontal force along the middle longitudinal axis of the building. The length of the channels in the beam was equal to 600 cm and they came out from the building by 90 cm. The channels were located above each other and were connected by a strong steel beam, through which the loading bar was installed. The other end of the loading bar passed through the second strong steel beam which was under the pressure of two 100 t jacks. The latter were placed into the specially constructed support at the distance of 500 cm from the building, using two channels No 60. Support also consisted of a reinforced concrete part constructed in the ground, and its deepness was 300 cm and the sizes in plan 200x300 cm.

It was assumed that the loading system will allow to pull the building applying static force up to 2000 kN. In case of applying the dynamic force, the same loading system was used with the difference, that another additional bar with smaller diameter was connected to the loading bar. Diameter of that additional bar was calculated so, that at the horizontal force of 700 kN it will be destroyed. In the result of destruction the dynamic impact will be created to identify the dynamic characteristics of the isolation system.

The vibrations of building were registered by oscillographs H-O85, located in the special room near the building. Recordings of vibrations were realized by seismometers and accelerometers located on the floors of the building according to the scheme on Fig. 2. Static horizontal displacements of the isolation system were registered by instruments which were installed at the other side of the building, opposite to the loading system in three positions at the axis A, B and C (see Fig. 1). This was necessary, as only using such type of location of instruments is possible to register the rotation.

THE RESULTS OF TESTS OF ISOLATION SYSTEM AND THEIR ANALYSIS

Four cycles of loading and unloading were performed under displacement control during the static tests of the isolation system up to a maximum horizontal displacement of 20% of the design value. The results are given in Table 2.

Table 2: Results of the static tests of the building with isolation system

Cycles of loading							
1		2		3		4	
Displ., mm	Force, kN	Displ., mm	Force, kN	Displ., mm	Force, kN	Displ., mm	Force, kN
2	670	5	700	10	840	13.5	600
4	850	7	1040	13	1170	15.5	1000
6	1000	9	1140	15	1390	17.5	1200
4	100	11	1240	17	1450	19.5	1400
3	0	13	1330	19	1510	21.5	1590
		11	540	17	800	23.5	1640
		9	240	14	380	25.5	1700
		7	0	10.5	0	23.5	1080
						21.5	750
						19.5	500
						17.5	290
						14.8	0

By this results the relationship between the horizontal force and horizontal displacement was drawn (Fig. 3). From the obtained data it follows, that the initial stiffness of the whole isolation system was equal to 335 kN/mm. So, the initial stiffness of one seismic isolator will be equal to 335:39=8.59 kN/mm. This value is 10.6 times higher than the shear stiffness of seismic isolator at the design displacement (see Table 1). Passing into the non-linear stage of the behavior of isolation system at the first cycle it is easy to see that the tangent stiffness has decreased and was equal to (1000-670) : (6-2)=82.50 kN/mm. At the second cycle it was equal to (1330-1040) : (13-7)=48.33 kN/mm, at the third - (1510-1390) : (19-15)=30.00 kN/mm and at the fourth cycle - (1700-1590) : (25.5-21.5)=27.5 kN/mm. Above was mentioned that the loading system allowed to reach the 2000 kN horizontal force. But during the tests the 1700 kN horizontal force was reached, after which the tests were stopped because a crack appeared and started to intensively develop in the reinforced concrete massive of the support. At this very moment the horizontal displacement of the isolation system was equal to 25.5 mm.

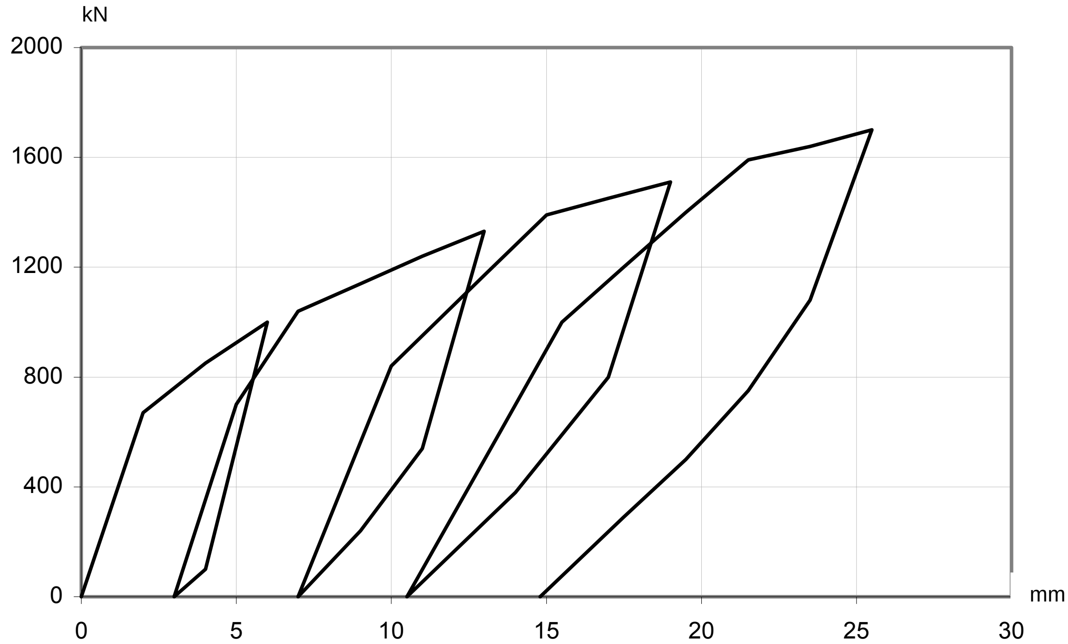


Fig. 3. "Horizontal force - horizontal displacement" relationship for the whole isolation system

From the obtained data it follows, that non-linear behavior of the isolation system causes significant degradation of its stiffness starting from the first cycle, when the displacement exceeded 2 mm. At the third and fourth cycles the tangent stiffness corresponding to the maximum displacements were approximately equal to each other. This gives the basis to suppose that in case if would be possible to continue the tests and reach, for example, the design displacement, the degradation of stiffness from cycle to cycle would not be as big, as it was for the first two cycles. Apparently, the average tangent stiffness at the third and fourth cycles of loading, which is equal to about 29 kN/mm, can be accepted with some assumption as the stiffness of the isolation system at the design displacement. If it is so, then the actual stiffness of one seismic isolator will be equal to 29:39=0.74 kN/mm, which is about 9% less than the design stiffness. Thus, the static tests allowed to reveal pretty good correspondence between design and real characteristics of the isolation system.

During the dynamic tests the records of free vibrations of the building with isolation system were obtained at the destruction of the additional loading bar when horizontal force reached 670 kN. The records obtained by the instruments located on the first and third floors and the roof are shown on Fig. 4. Using the obtained records the period of free vibrations of the building with isolation system was defined. It was equal to 0.48 sec. This value is corresponding to the initial stiffness of isolation system equal to 335 kN/mm. Taking the latter as the basis, lets calculate the period of vibrations of the building having in mind, that at the time of carrying out the tests the total weight of the building was equal to 21200 kN.

Consequently: $T=2\times\pi\sqrt{}21200/(10\times335000)\approx0.5$ sec. As it is seen, the difference between the calculated period of vibration using real values of the stiffness and weight of the building, and the period defined by direct measurement of vibrations, is negligibly small. This proves, that the results of static and dynamic tests are reliable and well correspond to each other. The records of vibrations also allow to state, that the displacements, as well as the accelerations on the level of the roof are bigger, than that of on the level of the third and first floors 1.03 and 1.06 times, respectively. During the design of this building with the isolation system, it was obtained that the displacements, as well as the accelerations on the level of the roof are bigger, than that of on the level of the third and first floors 1.01 and 1.02 times, respectively. So, the experimental and design values practically coincide, which also proves the reliability of the obtained data. Based on the experimental records the decrement of vibrations of the building with the isolation system was also calculated and was equal to 0.55, which corresponds to 8.8% of critical damping.

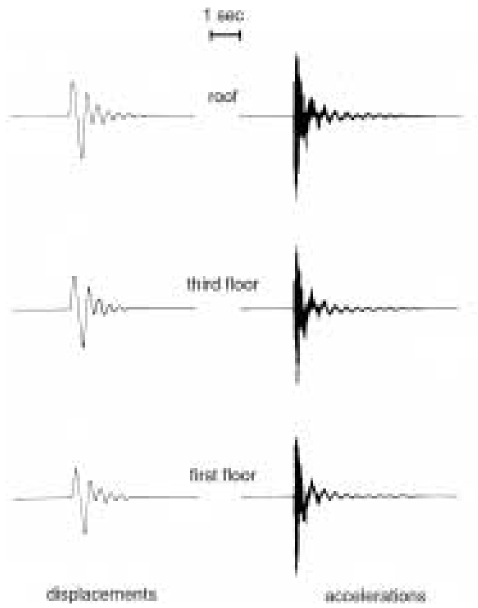


Fig. 4. Records of the displacements and accelerations obtained during dynamic tests on the level of the first and third floors and the roof of the building with isolation system

AKNOWLEGEMENT

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CONCLUSIONS

Technology of replacement of seismic isolators is described and it is shown that this operation in real buildings and structures can be easily realized and does not require big investments.

The loading system designed for carrying out static and dynamic tests on full-scale building with the isolation system is described.

At the static tests four cycles of loading and unloading were accomplished and the following results were obtained:

- the initial stiffness (at 0.2cm displacement) of the isolation system is more than 10 times higher than its expected stiffness at the design displacement; the ability of the system to provide an intrinsic restraint against wind loading is confirmed;

- the non-linear behavior of the isolation system is close to that observed in tests on rubber samples;

- at a deformation equal to about 20% of the design value the observed stiffness of the overall isolation system correlates well with the stiffness expected at that deformation from the design calculations and the quasistatic test results on individual isolators.

The dynamic tests were carried out by releasing the isolation system at the displacement of 0.2cm and allowing the building to oscillate freely. The following conclusions are made:

- the experimental value of the period of vibrations is virtually identical with the value calculated on the basis of initial stiffness of the isolation system and actual weight of the building;

- the displacements and accelerations at the third floor and the roof are respectively 1.03 and 1.06 times those at the first floor, figures agreeing well with the design analysis;

- the damping of the isolation system is equal to 8.8% of critical damping at small displacements (<0.2cm).

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