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Demonstration of the Possibility to Replace the Seismic Isolation Laminated Rubber-Steel Bearings under the Full-Scale Occupied Buildings

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ABSTRACT
It is well-known that due to the scientific and engineering works of the author of this paper Armenia is currently the second country in the world after Japan by the total number of seismic isolated newly constructed or retrofitted buildings per the number of residents [1, 2]. In the same time Armenia is the world leader in implementation of the developed by the author low-cost seismic isolation technologies [3]. There is also another direction in seismic isolation where Armenia keeps its leadership in the world by showing the possibility of replacement of seismic isolation laminated rubber-steel bearings (SILRSBs) installed under the full-scale occupied buildings. This paper is dedicated to the author's unique woks, who together with his engineering and technical staff, has demonstrated how already installed in different buildings SILRSBs can be, if necessary, replaced without interruption of the use of these buildings.

I. INTRODUCTION

Armenia was experiencing extremely hard times in 1993 when the research works on seismic isolation systems and development of the relevant technologies were initiated by the author of this paper. However, it should be expressly underscored that the time was hard not only owing to complicated economic situation, but also because of the need for permanent struggle of the author with conservatism, malevolence, envy and other negative manifestations of the opponents, bureaucrats and decision-makers in the field, which lasted for several years. One of the main objections of those who were causing barriers on the way of development of seismic isolation in the country was the conviction that it is impossible to replace the SILRSBs in the retrofitted or newly constructed buildings. That is why the author has decided to develop and to demonstrate the technique of replacement on the very first newly constructed 4-story base isolated multi-apartment building in the city of Spitak [4]. Plan of location of SILRSBs in this building is shown in Fig. 1, from which it must be stressed that only one bearing locates on each foundation.

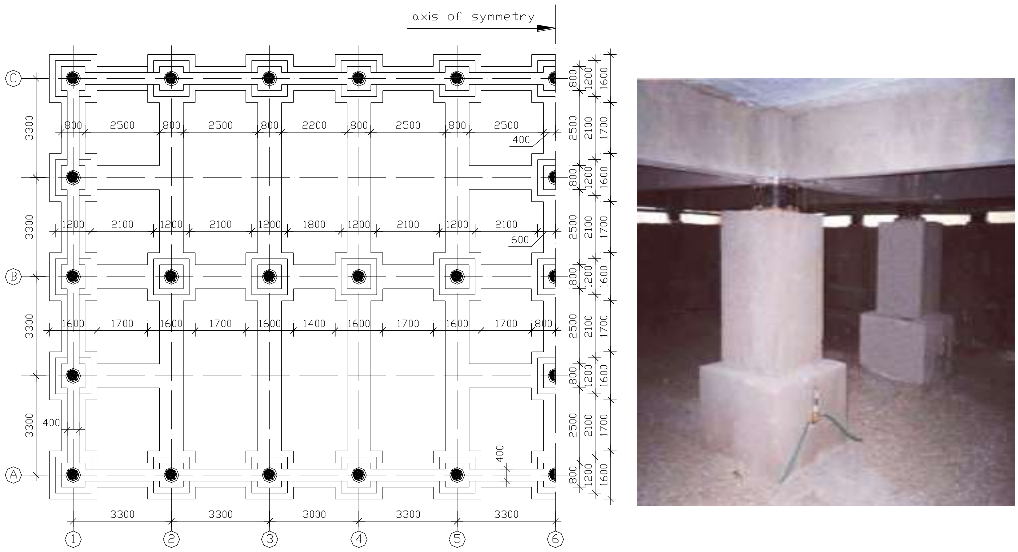

Figure 1. The foundation plan of the multi-apartment building with the location of seismic isolators and view of the fragment of seismic isolation system in this building

Then, together with further development of seismic isolation in Armenia the author suggested a method of creation of seismic isolation systems applying clusters of SILRSBs under the columns, shear walls or load bearing walls [5, 6]. With the increasing of the number of buildings where bearings are installed by clusters (Fig. 2) the author has decided to develop and to demonstrate the technique for replacement of SILRSBs also in these types of buildings.

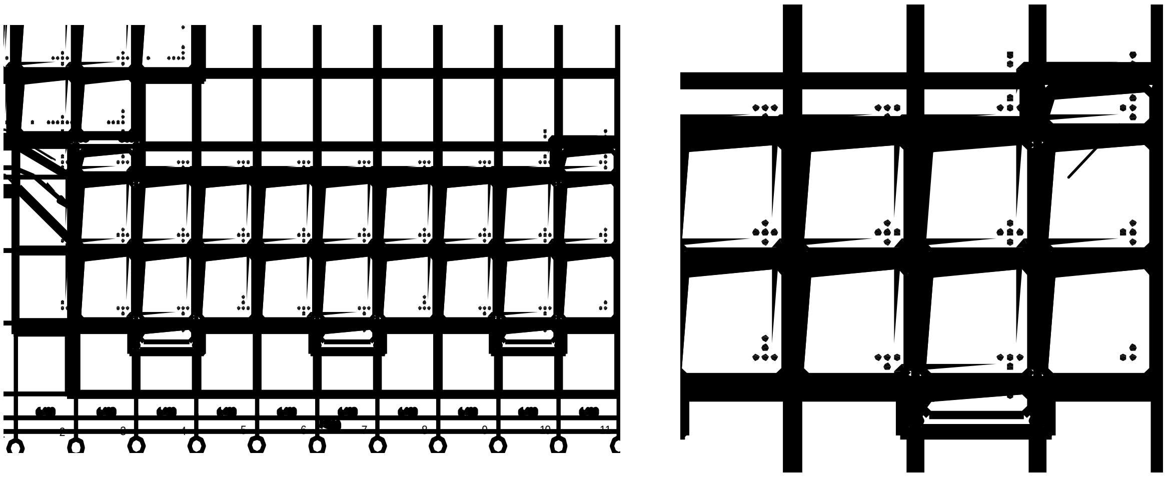

Figure 2. The plan of seismic isolation system of the 10-story multi-apartment building with the location of seismic isolators by clusters and the fragment of the seismic isolation system in this building where the arrow shows the cluster of SILRSBs to be replaced

Replacement of SILRSBs in both buildings was carried out in the presence of engineers, designers and researchers from different design, scientific and construction companies, as well as of those representing the Ministries of Urban Development and Emergency Situations invited by the author of this paper. It is worth noting that considered full-scale buildings were also tested under the action of the horizontal static loads to check the correlation of the design and actual parameters of the isolation systems. In essence, for the first time in the world rubber bearings replacement was demonstrated [2, 4]. It must be emphasized that the first unique operations on replacement of SILRSBs and testing of the full-scale building in the city of Spitak became possible thanks to the financial support provided by Dr. Sam Loo of Min Rubber Products Sdn. Bhd. (Malaysia).

Some part of this work was reported in Auckland, New Zealand during the 12th World Conference on Earthquake Engineering (Fig. 3).

Figure 3. The author of this paper Prof. Dr. Melkumyan (right) with Prof. Dr. William Robinson (New Zealand) and Dr. Sam Loo (Malaysia) at the 12th World Conference on Earthquake Engineering in the year 2000 in Auckland

The author notes with deep sorrow that the greatest scientist Prof. Dr. William Robinson and the famous manufacturer of seismic isolation bearings Dr. Sam Loo are no longer with us, but we will always remember their great contributions to the science and practice of seismic isolation.

II. DEMONSTRATION OF THE TECHNIQUE OF SILRSBS' REPLACEMENT IN THE 4-STORY BASE ISOLATED MULTI-APARTMENT BUILDING IN THE CITY OF SPITAK

After the destructive earthquake of December 7, 1988 [7], construction of buildings with more than two stories was disallowed in the city of Spitak. In the given case, thanks to the base isolation, for the first time after the mentioned earthquake, twice as high, i.e. a four-story building was designed. Plan of location of SILRSBs and view of the fragment of seismic isolation system in this building are shown above in Figure 1. All SILRSBs are of the same size; their geometrical dimensions, as well as physical and mechanical characteristics can be found in [2].

The superstructure of the building represents a system with reinforced concrete (R/C) monolithic load-bearing walls and slabs designed with application of precast hollow core panels of different width. The thickness of the exterior R/C walls is 40 cm and that of the interior walls – 20 cm. The precast panels are 22 cm thick. The floor height is equal to 3 m. Foundations consist of stepped footings connected to each other by wall footing along the exterior axes and by strips along the interior axes. Actually, the seismic isolation interface was designed within the premises of the basement. Continuous beams with a height of 60 cm were designed above the isolators, together with the slab that covers the basement. All vertical reinforcing bars of the superstructure's bearing walls were anchored in these beams. This building represents the case when the isolation interface is located above the outside ground level.

The SILRSBs in this building are located by upper and lower recesses provided by annular steel rings bolted to outer steel plates which are connected to the reinforcement in the upper continuous beams and lower foundations (stepped footings); the isolators themselves are not bolted to the structure (Fig. 4). This method of connection helps to minimize the cost of the isolators and simplifies their installation on site. Because the bearing is simply located in a recess, no tapped holes for bolted connections are needed in the endplate. The side, top and bottom rubber cover layers ensure the steel plates are protected from corrosion.

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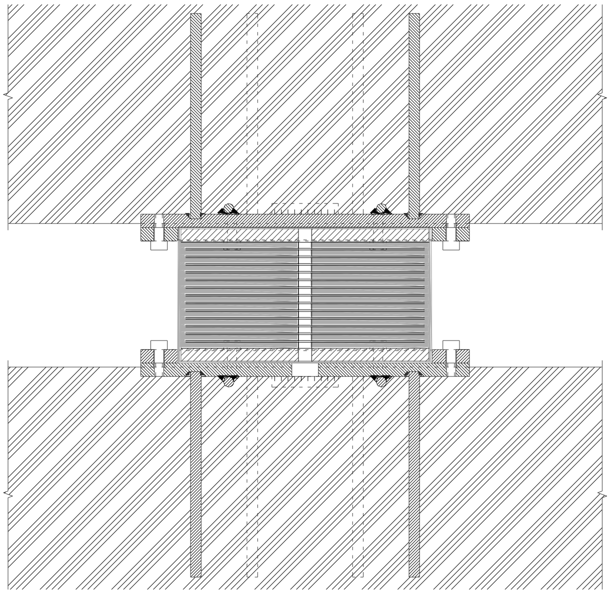

Figure 4. Location of SILRSB by upper and lower recesses provided by annular steel rings bolted to the outer steel plates connected to reinforcement in the upper continuous beam and lower foundation (stepped footing)

1.1. The First Demonstration of Replacement of SILRSBs Located One by One on Each Stepped Foundation in a Full-Scale Building

To perform this operation for the SILRSBs located, for example, along the exterior axes two pits were made in the basement walls of the building for installation of jacks from both sides of each previously installed SILRSB. Two jacks with a capacity of 1000 kN were used to lift the building on about 1.5-2.0 mm at each location (at this particular joint). Afterwards, the previously installed SILRSB was taken out (Fig. 5a) and installation of the new seismic isolator started to replace the previous one. First, the surfaces of the lower and upper steel plates, as well as of the new seismic isolator were cleaned. Then the lower and upper recess rings were placed around the new seismic isolator (Fig. 5b). The latter was gradually pushed to its design position together with the recess rings placed around it (Fig. 5c). Once the new seismic isolator reaches its design position the operation on fixation of the recess rings starts (Fig. 5d). At this stage the pressure in the jacks drops to zero. Finally, the two rings are bolted to the upper and lower steel plates (Fig. 5e).

a

b

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d

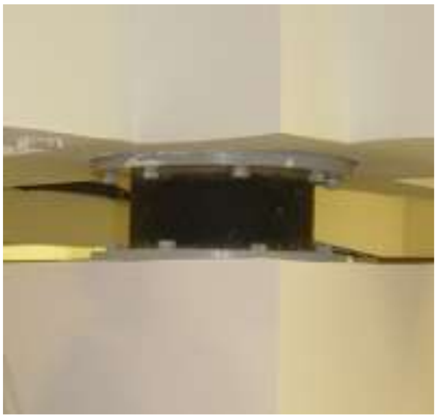
e

Figure 5. Demonstration of replacement of seismic isolators in a newly constructed full-scale occupied building pursuing scientific, engineering and public awareness goals
a – the joint of isolation system of the building is lifted using two 1000 kN capacity jacks by about 1.5-2.0 mm and a previously installed isolator is taken out from its design position;
b – the new isolator with the lower and upper recess rings (which were taken out from the previously installed isolator exactly on this stepped footing) placed around it, ready to be gradually pushed and installed in its design position;
c – by sliding on the lower plate the new isolator is pushed little by little to its design position on the given stepped footing;
d – view of the new isolator in its design location with the lower recess ring fixed (bolted) first and the moment of lifting the upper recess ring to its final position to be fixed by bolting to the upper plate;
e – final view (after replacing the previous isolator by the new one) of the isolator with bolted recess rings to the upper and lower steel plates.

By the described way it is demonstrated how the isolator located along the external axis of the foundation was replaced. The same way is not applicable in the case when the SILRSB to be replaced is located on the stepped footing along the interior axes. In this case two steel supports (short columns) must be temporarily installed and fixed by special devices at both sides of the stepped footing. After that two 1000 kN capacity jacks must be installed on the mentioned steel supports and all the above described operations must be carried out (repeated) at the selected joint. This was easily done in three locations of footings along the interior axes in the considered building.

Thus, the accomplished work showed that in essence, the worthwhile operation of replacing seismic isolators is neither complicated, nor expensive. It should be mentioned that using mainly manual labor and low-tech equipment it took 90 minutes to replace one SILRSB. The demonstrated trial confirmed that should the replacement of the isolators ever be necessary, it can be accomplished by a quick and simple operation. However, in reality there is no need to replace SILRSBs. Armenian Seismic Code in force states that the service lifetime of SILRSBs is warranted individually in accordance with the Armenian Standard “AST 261-2007” based on the specifications provided by the manufacturers. Currently there are four manufacturers of SILRSBs in Armenia and in specifications approved by them it is mentioned that the service lifetime of SILRSBs is not less than 150 years. Regarding this matter Technical Director, Earthquake Engineering, of BECA Richard Sharpe (New Zealand) rightly mentioned in one of the letters sent to the author in 2008: “You should be able to install the isolators and then forget about them”.

III. DEMONSTRATION OF THE TECHNIQUE OF SILRSBS’ CLUSTER REPLACEMENT IN THE 10-STORY BASE ISOLATED MULTI-APARTMENT BUILDING IN THE CITY OF YEREVAN

The plan of seismic isolation system of the 10-story multi-apartment building with the location of seismic isolators by clusters and the fragment of the seismic isolation system in this building where the arrow shows the cluster of SILRSBs to be

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replaced are shown above in Figure 2. This building represents the case when the isolation interface is located below the outside ground level. To provide the free movement of the isolation system accommodating its large horizontal displacement the gap covered by the cantilever slab was constructed along the perimeter of the building.

The superstructure of the building represents a R/C monolithic frame structure with shear walls in longitudinal and transverse directions constructed along the whole height of the building. The floor height in superstructure is equal to 3.3 m. There are shear walls also in the parking below the isolation interface. The columns and the shear walls of the parking floor are anchored in the strip foundations. The shear walls provide sufficient rigidity to the structures below and above the isolation plane so that effective performance of isolation systems in the event of strong ground motions is guaranteed. The beams below and above the seismic isolators are referred to herein as lower and upper beams, respectively. Lower beams with the cross section of 700×550(h) mm are connecting all columns of the parking floor and there is no slab at their level. SILRSBs are located immediately on the lower beams.

The clusters of SILRSBs are supporting the very strong upper beams with the cross section of 700×900(h) mm, in which the structural elements of superstructures are anchored. Upper beams are unified by rigid slab, thus creating stiff system in horizontal directions. The thickness of R/C slabs was set at 150 mm for all floors. All these structural elements, namely: the lower beams, the seismic isolation interface consisting of clusters of SILRSBs, the upper beams, and the slab make up the seismic isolation system of the given building. The isolators in this building are also located by upper and lower recesses provided by annular steel rings as was described above for the previous building. The difference here is that steel rings are bolted to outer steel plates which are connected to the reinforcement in the upper and lower beams. Here it should be mentioned again that SILRSBs themselves are not bolted to the structural elements. The same type of SILRSBs as was described above in Section 2 were also used in the clusters of the isolation system of this 10-story building [2, 5].

1.2. The Second Demonstration of Replacement of SILRSBs Located by Clusters Between the Lower and Upper Continuous Beams in a Full-Scale Building

To perform this operation for the four previously installed SILRSBs located in one cluster (see Fig. 2) the special loading system consisting of four 1000 kN capacity jacks was designed by the author of this paper to lift the building on about 1.5-2.0 mm at this location (at this particular joint). With this purpose the four steel supports in which the jacks are to be installed were designed, made, and then placed on the lower beams at initially defined positions (Fig. 6).

a b c

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d

e

Figure 6. Stages of replacement of the cluster of previously installed seismic isolators during the construction of a full-scale building pursuing demonstration, scientific, engineering and public awareness goals

a – fragment of the loading system consisting of four 1000 kN capacity jacks where the first jack is placed in the steel support and the latter is installed on the lower beam at one of its side. In this location there is a shear wall under the mentioned lower beam;

b – same fragment of the loading system but the second jack is placed in the steel support which is installed on the lower beam at its other side. The same shear wall under the mentioned lower beam can also be noticed;

c – the other two (third and fourth) jacks are fixed in the similar two steel supports installed on the lower beam, which is located in a perpendicular direction with respect to the previously mentioned lower beam. With the absence of shear wall under the lower beam special steel column is envisaged at this location to carry out vertical load from jacks;

d – previously installed cluster of SILRSBs is gradually taken out from its design position. At this stage the building at this joint supported only by jacks;

e - view of the new cluster of SILRSBs gradually pushed and installed in their design location and the process of fixation of the lower and upper recess rings is going on;

After that the following stages were performed. One of the steel supports together with the jack is installed on the lower beam at one of its side (Fig. 6a). It should be noted that there is a shear wall under the mentioned lower beam. The next steel support with the other jack is installed on the lower beam at its other side (Fig. 6b) in the same location. Then the other two jacks being fixed in the similar two steel supports are installed on the lower beam, which is located in a perpendicular direction with respect to the previously mentioned lower beam (Fig. 6c). There is no shear wall under the lower beam of this location and, therefore, a special steel column is envisaged here to carry out vertical load from jacks during the lifting of the building. At the next stage the previously installed cluster of SILRSBs was taken out (Fig. 6d) and installation of the new cluster of seismic isolators started to replace the previous one. The SILRSBs of the new cluster were gradually one by one pushed to their design position together with the recess rings placed around them (Fig. 6e). Once all the new SILRSBs reach their design position the operation on fixation of the recess rings starts. At this stage the pressure in the jacks drops to zero.

IV. CONCLUSIONS

For the first time in the world unique operations to demonstrate the possibility of replacement of SILRSBs in seismic isolation systems of two full-scale occupied buildings were performed in Armenia without interruption of the use of these buildings.

For each of the buildings two different loading systems were developed where the jacks with a capacity of 1000 kN were used to lift the buildings on about 1.5-2.0 mm at each location (at each particular joint). In the building where SILRSBs were installed one by one in seismic isolation interface two jacks were used. In the building where SILRSBs were installed by clusters in seismic isolation interface four jacks were used.

The demonstration of replacement of SILRSBs was carried out pursuing scientific, engineering and public awareness goals. The demonstrated trials for two full-scale buildings confirmed that should the replacement of the isolators ever be necessary, it can be accomplished by a quick, simple, and not costly operation. However, in reality there is no need to replace SILRSBs manufactured in Armenia.

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