Replacement of the Old Rubber Bearings of the First Base Isolated Building in the World

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SUMMARY:
Base isolation has widely been applied for protection of structures and their contents in developed countries. Unlike these countries, this technique has not been applied in Macedonia, with the exception of the first structure in the World base isolated with rubber bearings, i.e., the Pestalozzi school building in Skopje donated to the city by the Swiss Government after the catastrophic earthquake of 26th July, 1963. Experimental investigations performed for this building have shown no significant stiffness degradation of the existing rubber bearings, but permanently propagating cracks due to ozone and fatigue has been observed. This has pointed to the fact that, the durability of the rubber has approached its design limit after 40 years of use. A project financed by NATO through the Science for Peace Programme involving development of low-cost, light weight rubber bearings, has therefore been proposed. The project has successfully been carried out, resulting in a complete replacement of the old rubber bearings of the above building by new, rubber bearings. The investigations and the results presented and discussed in this paper are related to the development, manufacturing and implementation of these natural rubber isolators. The stiffness characteristics of the new bearings have been obtained through dynamic analysis of three models. Presented further in this paper is a brief review of the conditions of the 40 year old bearings. Finally, the procedure of replacement of the old bearings of the Pestalozzi school building by new ones is presented.

Keywords:Base isolation, rubber bearings

1. INTRODUCTION

Republic of Macedonia along with the other Balkan countries is located in a zone of high seismic risk. The probability for occurrence of a catastrophic earthquake in Macedonia (having the intensity of the Skopje earthquake of 1963, M = 6.1, intensity of IX degrees according to the Mercalli scale) is very high in certain seismic regions. The level of economic development of R. Macedonia is very low so that possible occurrence of a catastrophic earthquake will not only result in a huge loss of human lives but also total economic collapse of the country. Therefore, we need to put a more attention in increasing the application of new technologies.

In the developed countries, base isolation is widely applied for protection of structures and their contents. Unlike these countries, this technique is seldomly applied or not applied at all in the developing countries. After the completion of the project, only one base isolated structure has been built in the Balkan countries, namely in Albania. In 1965, the first base isolated structure in the world, i.e., the Pestalozzi primary school building was constructed in Macedonia. However, since then, in Macedonia there hasn't been any other implementation of this technique. The minimal application of this technique in the Balkan is mainly due to the high price of the isolators in the highly developed countries and the fact that there haven't been any producers of isolators in the Balkan region.

For the purpose of increasing the interest in application of base isolation in R. Macedonia and the remaining countries in the Balkan, the Institute of Earthquake Engineering and Engineering

Seismology (IZIIS) proposed a project on development of low-cost rubber bearings. After adopting the production technology, 54 bearings were produced and installed in the Pestalozzi school building to replace the old bearings. The project was financed by NATO through the Science for Peace programme. In addition to IZIIS, the Civil Engineering Faculty of Tirana and the Earthquake Engineering Research Centre from Berkeley, California also took part in the project (Garevski, 2008).
This paper begins with a brief description of the base isolated structure and analysis of the new isolation system. The analysis of the isolation system involved optimization of structural performance under the effect of seven real earthquakes. The design parameters that the new isolation system had to satisfy were: (1) seismic gap of 20 cm and (2) bearing capacity of the structural elements. The stiffness characteristics of the isolators and the new period of the structure were defined through an iterative procedure where the two design parameters were checked.

The new rubber bearings were produced by a local firm in Macedonia which completely developed the technological process of production of such rubber bearings. The tests on the rubber isolators were carried out in the IZIIS' Dynamic Testing Laboratory, Skopje, Macedonia. The rubber bearing specimens were tested in axial and transverse direction. The tests in the transverse direction were carried out on two specimens (dual lap test). During the effect of the transverse excitation, the specimens were continuously exposed to axial load.

The last part of the paper displays details of the procedure of replacement of the old rubber isolators of the primary school "Pestalozzi". The procedure for replacement of the isolators was proposed by a design engineer, who elaborated it to the necessary details and it was carried out by a local company.

2. DESCRIPTION OF THE BUILDING AND DYNAMIC ANALYSIS OF THE STRUCTURE

The main school building consists of a ground floor and two storeys (Figure. 1a). The proportions of the stricture at plan are 13.0 m/61.5 m, while its height is 11.0 m. It represents a reinforced concrete box system. The bearing wall system is composed of shear walls with a thickness of 0.18 m. The floor slab is 0.20m thick. The building has a strip foundation forming a beam grid, which is sufficiently rigid to sustain all the effects from the upper structure without heavier deformations. The structure was totally base isolated by its placement on special rubber bearings (highly flexible elements) incorporated between the foundation structure and the first floor slab (Figure. 1b). There were a total of 54 (3D-full base isolators) bearings made of natural rubber which did not contain reinforcing steel plates. The bearings were with a square shape, a side of 0.7 m and a height of 0.35 m. They were fabricated by gluing together several (seven sheets) rubber layers vulcanized to the end steel plates. In addition to the rubber bearings, the isolation system also consisted of special prisms, the so called mechanical fuses (foam glass elements), made of porous and easily breakable material, whose basic purpose was to prevent unwanted possible vibrations of the structure due to the surrounding ambient, wind, traffic and alike. In the case of an earthquake with a defined intensity, i.e., intensity of 5 degrees MCS according to the design predictions, the stiff brittle elements were to be smashed so that the rubber bearings would be the only to affect the dynamic behaviour of the building.

a) Pestalozzi school building

b) Old isolation system

Figure 1. View of Pestalozzi primary school building

Prior to the beginning of replacement of the bearings of the considered structure, it was visually inspected, paying special attention to the state of the base isolation system. From the inspection of the old isolation system, it was concluded that the rubber elements were in a relatively good conditions (Garevski, , M.; Kelly, J. M. 2001). Some of the bearings were observed to have suffered separation of rubber layers at their ends, the upper and the lower part. As to the quality of material, i.e., rubber, it remained soft and elastic. The bearings, which were located at the ends of the structure and in the space which was more intensively exposed to external effects were in a worse condition than those situated inside the structure. In addition to the separation of the layers at the ends of the bearings, these bearings evidently suffered also vertical cracks in the rubber whose depth could not be reliably defined (Figure 2). The experimental results showed that failure of the isolator took place at its horizontal displacement of 25 cm. Due to the limitation of the seismic gap, it was clear that it could not be damaged since the experimental tests showed that, under horizontal displacements of 20 cm, there were no damages and that there was a linear force - deformation relationship.

Figure 2. Old rubber bearings

Although, in the preceding paragraph, it was mentioned that the old bearings still satisfied the design parameters, the afore mentioned NATO project anticipated replacement of the old bearings by new ones that were developed within the project. The need for installation of new bearings in this school building was justified by the following arguments:

- the experimental defining of the maximum displacement of the bearing at which it was torn was done for only one bearing, which was in a relatively good condition since it was inside the school. Many of the bearings, however, were placed along the perimeter (front) walls of the structure. These were more intensively exposed to atmospheric effects and had visible cracks due to the ozone effect. Because of these cracks, these bearings were expected to disintegrate at displacement which was less than the maximum allowed one (20 cm). Their tearing would have caused redistribution of the seismic forces over the remaining bearings, which would have been unable to sustain the seismic force in such conditions.
- the risk of loss of the necessary bearing characteristics of the isolators was to be constantly increased with the propagation of the cracks resulting from the ozone effect and the effect of tensile forces. The replacement of the old bearings by more sophisticated ones meant no need for other replacements to the end of the serviceability period of the school building.

To define the necessary stiffness characteristics of the new isolators, the structure was analyzed under two earthquake excitation levels (design and maximum capable earthquake). The stiffness of the new isolation system was selected through an iterative procedure which was performed for three different effective stiffness values of the isolators, i.e., three bilinear models of behaviour of the isolators were defined. The 3D finite element model of the Pestalozzi school building is shown in Figure 3.

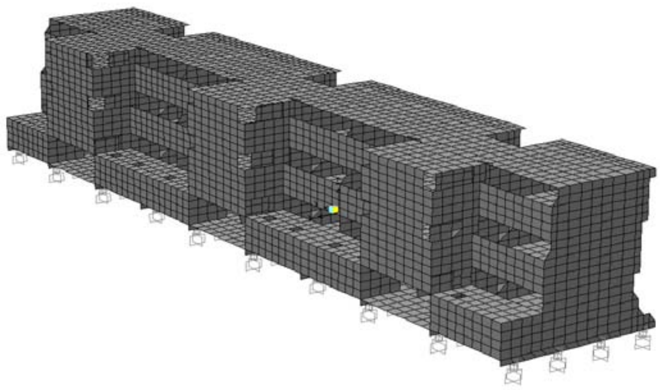
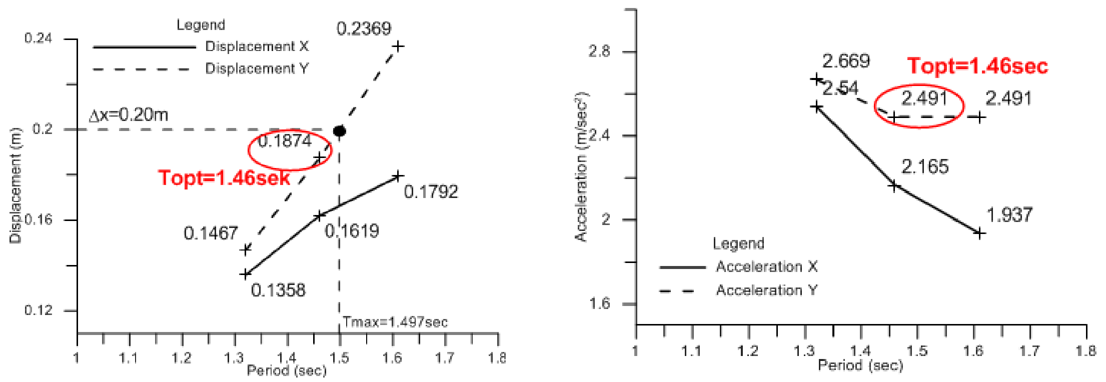


Fig. 3 3D Model of the Pestalozzi school building

All the analyses were performed assuming linear behaviour of the upper structure and bilinear behaviour of the isolation elements. The response of the structure isolated by three isolators was presented by peak horizontal displacement of the isolation system and by acceleration at the top of the structure. The maximal horizontal displacements of the node of the isolated level in both orthogonal directions under the effect of the three excitations are given in Fig. 4a. The bearing capacity of the superstructure was controlled for the effect of the design earthquake. The storey accelerations of the model with the old isolators and the model with the new isolators were also controlled. The maximal horizontal accelerations in both orthogonal directions for the node at the last level under the effect of the three excitations, are given in Figure 4b.

From the performed analyses, it was concluded that the isolation system with period T1=1.46sec represented the optimal solution for both design parameters.



a) Shear deformation at the isolation level b) Acceleration at the top of the structure

Figure 4. Results from FEM analysis of the Pestalozzi school building

3. REPLACEMENT OF BEARINGS

As it was stated previously, the final objective of this project was design and adoption of a technology for trial production of rubber bearings. Although assembly line production of bearings was not strictly required within the project, 64 large bearings were produced. Out of these, 54 were installed in the Pestalozzi school building as a replacement for the old ones. The entire trial and assembly line production of the bearings was carried out by a small company from Macedonia.

Due to lack of inner steel plates, the old bearings of the Pestalozzi school building had very large proportions and low vertical bearing capacity. This resulted in occurrence of large vertical and lateral deformations of these bearings. Due to the ozone effect the process of ageing of the rubber and occurrence of vertical fine cracks was also observed. The performed tests has been shown that the bearing capacity of the bearings in horizontal direction was not at all changed for the passed 40 years. The testing of a single bearing proved that failure of the bearings occurred at 25 cm in horizontal direction. In serviceability conditions, this deformation of the bearings could not have been achieved since the seismic gap of the school was 20 cm.

One of the benefits of the implementation of the new bearings is the increase of the damping of the isolation system. The rubber which was used for the production of the old bearings was not characterized by damping, i.e., it behaved in the linear-elastic. The new bearings are produced of natural high damping rubber with coefficient of hysteretic damping of 7–9 percents. The new isolators are with a circular form, with a diameter of Ø450mm and steel plates are inserted in them for the purpose of increasing their vertical stiffness. Although these bearings are considerably smaller than the old ones (Fig. 7), they can sustain 5 times greater vertical load. The characteristics of these bearings were defined by a series of vertical and horizontal tests carried out at the IZIIS' Dynamic Testing Laboratory, Macedonia.

Dismantling and mantling of 54 isolators bearing a vertical load of 20 000 kN is a very complex, responsible and sometimes unpredictable task. Since there was not much experience in mantling and dismantling of isolators, the task had to be performed slowly in the beginning in order to avoid heavy consequences. Prior to the beginning with the replacement of the bearings, it was planned to drill new holes in the beams and the foundation of the school building for fixation of the bearings, because the new isolators were smaller in size. Later, this was proved to be impossible due to the large deformations of the bearings. Therefore, a new way of mounting the bearings by using the old holes was elaborated. The second issue that needed a special treatment was the differences in the height of the bearings at corresponding locations (ranging from several millimetres to several centimeters). Therefore, it was necessary to prepare an enormous number of washers of different thickness for the purpose of precise (ideal) leveling of the bearings.

The entire process of replacement of the old bearings (54) by the new ones was carried out by only two workers within 27 days. The local lifting of the 20000 kN structure for the purpose of placement of the new bearings was done by means of ten manual hydraulic presses (Fig. 5). Because of the higher vertical stiffness of the new bearings, a considerably greater vertical force (from 100 to 150 kN) per bearing was used for their fixation. Hence, it was clear that the use of the old hydraulic presses to replace the bearings was not sufficient enough. For that purpose, additional six hydraulic presses were procured (Figure 5).

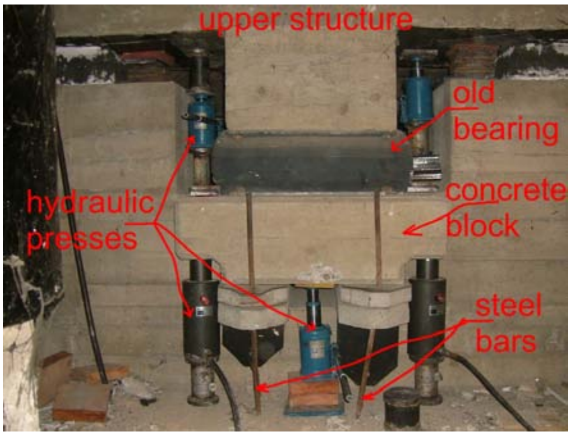
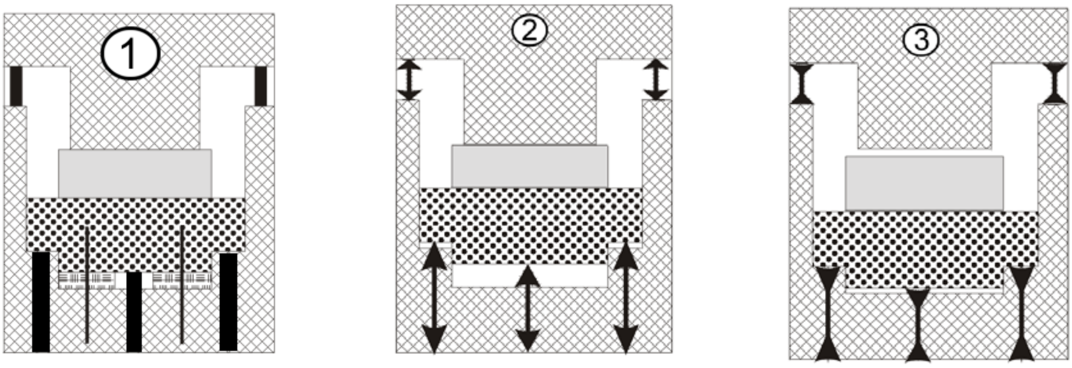


Figure 5. Placement of the hydraulic presses

The procedure for replacement of the bearings was as follows:

- Insertion of two temporary supports to the left and the right side of the bearing (Figure 6a);
- Removal of the steel bars from the concrete supports (Figure 6a);

- Elevation of the concrete block below the bearings by 6 presses (Figure 6b);
- Removal of the concrete beams below the concrete block (Figure 6b);
- Lowering of the concrete block and the bearing (Figure 6c);
- Replacement of the old bearing by a new bearing (Figure 6c);
- Insertion of additional steel washers to compensate for the difference in height of the bearings;
- Fixation of the concrete block below the bearing.



a) Insertion of the hydraulic presses b) Uplifting of the concrete block c) Lowering of the concrete block
Figure 6. Phases of dismantling of the bearings

The new bearings were fixed to the structure using the fixation points of the previous ones. End plates that thoroughly transfer the shear force from the structure to the isolator were specially constructed for that purpose (Figure 7).

Figure. 1 Installed new and old bearing

4. CONCLUSIONS

Although very complex and ambitious, all the goals of the project were achieved. The project contributed to mass production of rubber bearings in Macedonia and their implementation in the base isolated structure. The ample analytical and experimental investigations of the “Pestalozzi” primary school building have shown that, after 40 years, the bearings have been functioning perfectly even under the most severe earthquakes.
The old bearings of the Pestalozzi school building which were with much greater proportions and low vertical bearing capacity of 500 kN showed large vertical and lateral deformations due to absence of steel plates. The large lateral deformations and the ozone effect contributed to faster ageing of the rubber and occurrence of cracks. Due to this and also the end of the serviceability period of the old bearings, IZIIS in cooperation with a local company, succeeded to produce, test and implement rubber bearings.

It should be mentioned however that the removal of the bearings from the building did not cause any problems and was done within a relatively short time. The procedure was carried out by technicians trained for this specific task. Therefore, it may be concluded that one of the main tasks of the design engineer was successfully done, i.e., simple mounting and dismantling of the base isolators.

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