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NEW APPLICATION OF ROOF ISOLATION SYSTEM IN THE FORM OF AN ISOLATED UPPER SLAB FOR SEISMIC PROTECTION OF AN EXISTING 12-STORY OFFICE BUILDING

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ABSTRACT

In Armenia the number of already constructed and retrofitted buildings, where seismic base and roof isolation technologies developed by the author of this paper were applied, has reached to 40. This number per capita in Armenia is one of the highest in the world. The paper describes a new structural concept of earthquake protection designed for application in the existing 12- story reinforced concrete office building. Its upper floor is an attic, the slab of which is envisaged to be separated from the columns then lifted up and seismic isolators installed between them. The mentioned slab is converted into an isolated upper slab (IUS) which will be acting as a tuned mass damper providing earthquake protection for building by reducing response accelerations 1.65 times in average. Results of Seismic Code and time histories analyses confirm that IUS is an effective tool for protecting buildings from strong seismic events.

KEYWORDS

Roof Isolation Systems, Protection of Existing Buildings, New Structural Concept, Earthquake Response Analysis, Modes of Vibrations

1. INTRODUCTION

One of the main features of anti-seismic design of buildings is the possibility to control inertial load values depending on the structural concept of the buildings. In the 1950s, when the spectral theory of seismic stability was developed, the flexible ground floor was regarded as the basic approach for reducing the seismic action level. However, the consequences of strong earthquakes such as the 1963 Skopje, the 1988 Spitak or the 2008 Sichuan Earthquakes, etc. have shown that in this case the bearing structures (mainly columns) of the ground floors were severely damaged and further use of buildings was impossible despite the upper floors were well preserved. Therefore, continuing efforts are made by researchers to determine the most efficient methods of seismic protection of buildings for their practical application. One of these methods is the application of tuned mass damper (TMD), a passive vibro-protecting device, known as a single-degree-of-freedom appendage of the primary structure [1]. Dampers have been widely investigated in connection with seismic protection problems [2, 3, 4, and 5].

The natural frequency of TMD (with the damping neglected) should be equal to the forced vibration frequency of the structure to be protected, which as a rule is represented in a form of a single-degree-of-freedom system. However, during earthquakes, forced vibrations are neither harmonic, nor have a preset frequency and buildings are not single-degree-of-freedom systems. As mentioned in [6], in spite of the chaotic nature of the ground motion, accelerations time histories of linear oscillator are similar to harmonic vibration processes with the period equal to that of linear oscillators. Therefore, if the first mode of vibration is assumed to be the most significant during earthquakes, then the natural frequency of the damper should be equal to the first mode frequency of structure vibration. When seismic loading is formed due to superposition of inertial loadings of the first three oscillation modes, then three dampers should be used instead of one, with natural vibration frequencies tuned correspondingly to frequencies of the first three modes of building's free vibrations. The application of three dampers is a more efficient means for increasing the earthquake resistance of structures.

When analyzing any building with TMDs, the number of vibration modes that should be taken into account is equal to the number of TMDs, with addition of at least the next three modes [7, 8]. Thus, for the buildings with three dampers at least six vibration modes should be encompassed in the analysis. The multi-version analyses of such structure allowed concluding that in this case such optimal stiffness and mass correlations of dampers could be found to enable significant reduction of shear forces and displacements (for about 2 times) compared to the building without TMDs. It has to be noted that these results are obtained by linear analyses of the building with and without TMDs. However, non-linear analyses were also carried out, proving that consideration of non-linearity for both the building and TMD structural elements significantly increases the effectiveness of the TMD [6, 8].

Thus generally the application of several dampers is expedient in terms of reducing the seismic action level in buildings. However, it is technologically difficult to design and make them in the traditional way, in the form of a mass properly fixed to the building. Particularly, even one such damper (for the first vibration mode) in a 10-12 story building possesses considerable mass and its practical realization is impossible. Therefore, an additional upper floor for the building has been proposed as a vibration damper [6].

As the mass of the upper floor is approximately equal to the mass of other floors of the building, this additional floor should exhibit a stiffness considerably smaller compared to that of the other floors. Thus, a building with a flexible upper floor would be analogous to the one with flexible ground floor. However, there is an essential difference between the two, since after the seismic event residual deformations in the flexible upper floor are not as disastrous for the building as a whole. A flexible upper floor (TMD) could be erected on the existing buildings to increase their seismic resistance, without requiring the tenants to leave the building. Also TMD could be widely applied in new construction.

Reduction of lateral forces and displacements in the building with TMD takes place due to increase of vibration period of the whole system (building plus the TMD) and decrease of the first mode vibration coefficients (participation factors). However, a new type of second vibration mode appears in the system; its participation factors are increasing significantly and together with the factors of the first mode of vibration they even become greater than the first mode participation factors of the building without TMD. This new type of second mode becomes prevailing, which results in the TMD oscillations in anti-phase relative to the building along the whole duration of the earthquake [9, 10].

The author of this paper has suggested providing flexibility to the damper using laminated rubber bearings (LRBs) [6, 8]. Obviously, in such case the above mentioned flexible upper floor will turn into an additional isolated upper floor (AIUF). This earthquake protection system was implemented in the city of Vanadzor for two existing buildings (Figures 1 and 2) within the framework of the Armenia Earthquake Zone Reconstruction Project financed by the World Bank [11]. It was decided to conduct dynamic tests of these buildings in two stages: first without AIUF, and then with AIUF in resonance regime, using unprecedented by its power vibration machine, which provided excitation of inertial horizontal loads allowing imitation of the design level seismic impact [10]. The testing was held in the resonance regime in two vibration modes: AIUF and the building oscillate in the same phase (mode I/1), and AIUF oscillates in the anti-phase to the building (mode I/2). Comparison of the obtained shear forces at the ground floor level and displacements at the level of 9th floor slab has shown that thanks to the AIUF shear force and displacement are reduced by factors of 1.97 and 2.2, respectively. If the influence of I/2 vibration mode is considered as well, shear force will decline by a factor of 1.76. At the same time the drift of AIUF, or specifically the LRBs displacement, exceeds the maximum drift of a story in the building by a factor of 4.3 [6, 10]. However, this does not prevent using the AIUF space for various purposes, since its structures remain almost un-deformed.

Figure 1. General views of the two existing 9-story apartment buildings with the R/C bearing frames and shear walls protected by AIUF

Figure 2. Steel rigid trusses constructed on the top of 9-story building and at the bottom of AIUF providing its reliable connection with the building by LRBs

2. STRUCTURAL CONCEPT OF THE 12-STORY OFFICE BUILDING WITH R/C BEARING FRAMES AND SHEAR WALLS PROTECTED BY AN ISOLATED UPPER SLAB

Successful experience accumulated in Armenia in protecting of existing buildings against seismic impacts by using AIUF systems acting as a TMD has created a good basis for further development and application of such systems in the country. They may play a critical role for the country situated in high seismic activity zone and living through the hard transition period of its economic development. Hence, conventional earthquake resistance upgrading techniques applied for existing buildings most probably are not acceptable in Armenia insofar as they require interruption of the use of the buildings and/or re-settlement of residents, and, consequently, providing them with temporary shelters, that in turn entails additional investments. The new modification of the earthquake protection system in the form of an isolated upper slab (IUS) developed for an existing 12-story building is presented.

The considered building has standard structural concept and buildings of this type had been erected in all regions of Armenia. This building was constructed in 1989 on rocky soils with the inclination along its longitudinal direction of about 14.5˚ so that the first transverse frame of the building has 12 floors and the last frame - 8 floors. The structural plan of this building has the main dimensions of 39×15m with the distances between the columns in transverse (short) direction equal to 6-3-6m. In longitudinal direction the distance between the columns in the first span is equal to 3m and in the other six spans - to 6m. The spatial horizontal stiffness of the building in transverse direction is provided by frames with strong beams and shear walls. In the other direction– it is provided by moment resisting frames with strong beams along the exterior longitudinal axes, as well as by frames with weak beams and shear walls along the interior longitudinal axes. Some shear walls have door openings.

The design of these buildings incorporates precast R/C elements. Precast columns have the height of three floors, whereas precast strong and weak beams are of one span. All column-to-column or beams-to-column joints are welded. The precast shear walls' panels are also welded to the frame elements. The slabs were designed using precast R/C hollow core panels of different widths. Foundations were designed in the form of R/C strip footings. The 30cm thick non-structural exterior precast walls are made of lightweight concrete and are attached to the frames by welding. Interior walls - partitions with thickness of 6cm are also made of lightweight concrete small plates with dimensions of 40×60cm. The upper floor of this building is an attic with a height of 2.32m, which is envisaged to be separated from the columns then lifted up and seismic isolators installed between them. By doing so the mentioned slab is converted into an isolated upper slab which will be acting as a tuned mass damper thus protecting the building from strong seismic events. The proposed new solution of roof isolation system for an existing R/C building is illustrated in Figure 3.

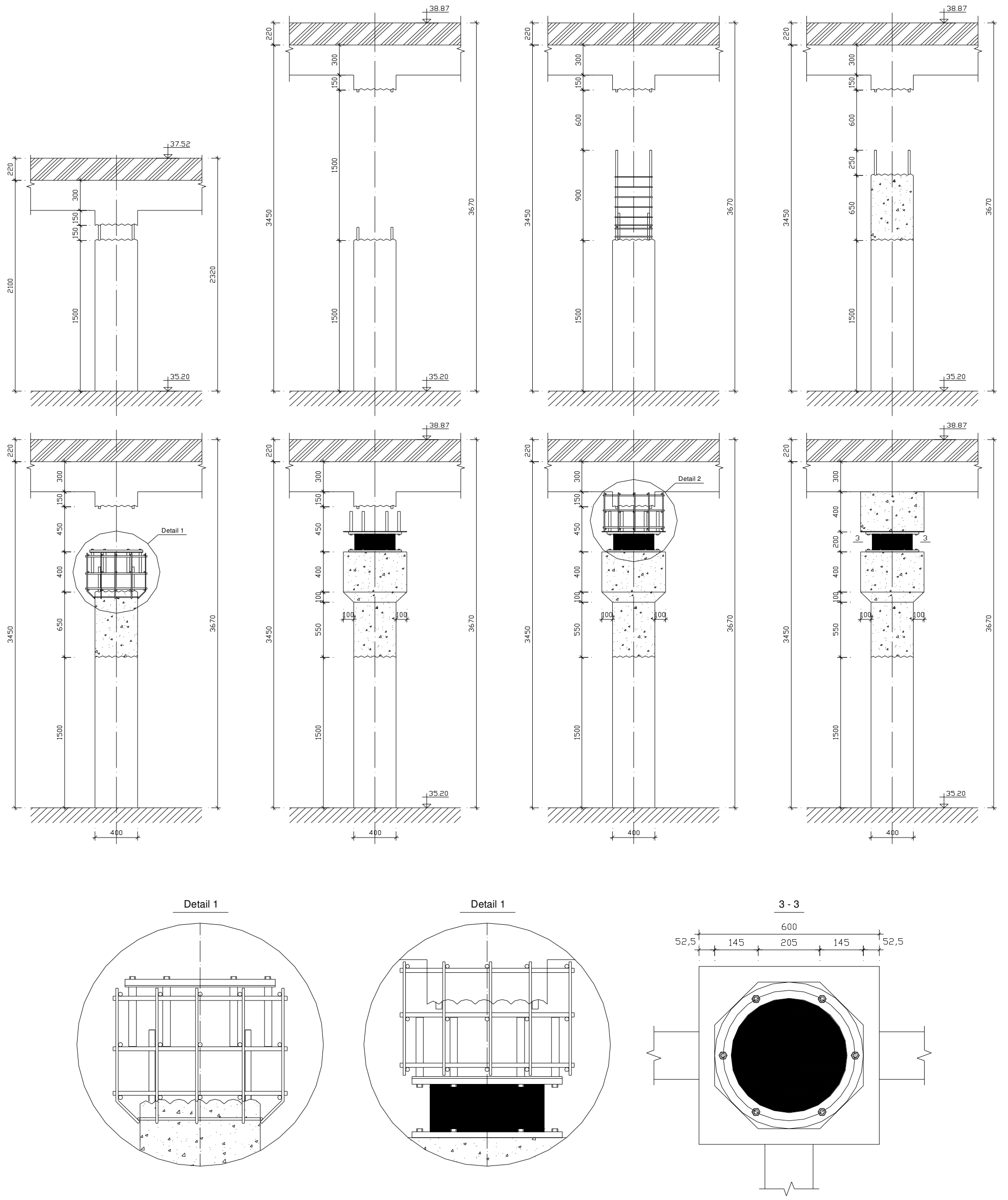

Figure 3. Sequence of placing the rubber bearings in the columns of attic of the existing 12-story office building with R/C bearing frames and shear walls

Before starting the works on separating of the existing columns, their surfaces should be cleaned from plaster and thoroughly washed. This is needed to ensure a good contact between the fresh concrete of the new R/C short walls, which will be constructed around the existing columns, and the concrete surfaces of these columns. The new R/C walls have the thickness of 160mm and height of 2.55m and will be constructed using reinforcing steel bars with diameters from 8 to 12mm, which will be anchored in the body of the existing columns as shown in Figure 4.

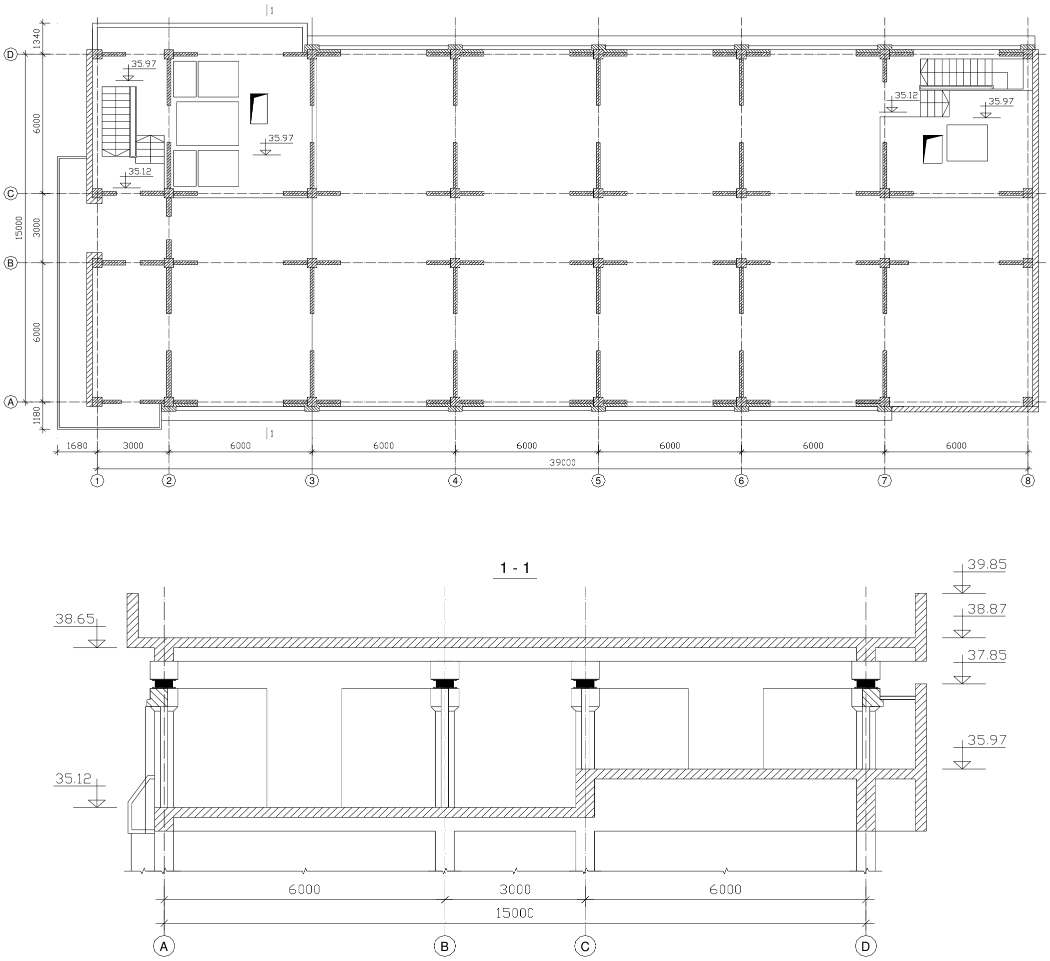

Figure 4. Plan and vertical elevation of the 12th floor with indication of the new R/C short walls to be constructed around the existing columns

These walls will provide sufficient horizontal stiffness for the existing columns, reliable interaction of the isolated upper slab with the building and transfer forces from this slab to the building. Then by specially developed technique the existing columns will be cut and using the mechanisms prepared in advance the slab above them will be gradually lifted by 1.35m preserving its horizontality. Operations on cutting of the columns and lifting of the slab should be performed in a special order stipulated in the design. Thus, the height of the attic under the isolated upper slab will be increased significantly and the newly created space will become usable. This was envisaged following the order of the client. When all operations illustrated in Figure 3 are accomplished the mechanisms used for the lifting of the slab could be removed and the slab will be settled on rubber bearings.

3. RESULTS OF ANALYSIS OF THE 12-STORY BUILDING PROTECTED BY AN ISOLATED UPPER SLAB BASED ON THE PROVISIONS OF THE ARMENIAN SEISMIC CODE AND THE TIME HISTORIES

Based on the results of analyses carried out for different structures protected by the TMD [6, 12, 13] the mass ratio factor $\nu=Q_{IUS}/Q_B$ was determined. The total weight of the building is equal to Q_B=89,000kN and the weight of the isolated upper slab is equal to Q_{IUS}=5,600kN, which means that $\nu=0.063$ (6.3%). In order to find the needed horizontal stiffness of all rubber bearings to be installed in 32 columns of the 12th floor the first mode micro vibrations periods of the building before starting any construction works were measured on site. They were equal to T_{trans}=0.550sec and T_{long}=0.541sec. It is well known that real vibrations periods of the buildings are larger than their micro vibrations periods by about 20% [14] and, therefore, for the considered existing building the vibrations period in both directions was accepted equal to T=0.66sec. This is actually the value of the period to which the system of the isolated upper slab should be tuned (T_{IUS}=T). Consequently, using this value the total horizontal stiffness of all the 32 rubber bearings can be determined as:

$$A_{ht}=(4\times\pi^2\times Q_{IUS})/(10\times T^2_{IUS})=(4\times3.14^2\times5600)/(10\times0.66^2)\cong50701\text{kN/m}.$$

Thus, the horizontal stiffness of one rubber bearing is equal to 1.58kN/mm and this parameter together with the magnitudes of vertical load on each rubber bearing (not more than 1000kN) and horizontal displacement were used for its design. Table 1 summarizes the design parameters and details of the laminated rubber-steel bearings. The rubber shear strain at the design displacement is chosen to be 100%. The simple recess connection detail for these bearings was chosen, see Figure 3. Earthquake response analysis of the considered building was carried out using SAP 2000 non-linear program. The design model (Figure 5) was developed using different types of finite elements for shear walls, floor slabs, columns and beams, as well as for seismic isolators.

Table 1. Design parameters and details of laminated rubber-steel bearings to be used in the system of the isolated upper slab.

Parameters and details of rubber bearings	**Values**	**Parameters and details of rubber bearings**	**Values**
Horizontal stiffness, kN/mm	1.55±0.05	Thickness of internal metal plates, mm	2.5
Vertical stiffness, kN/mm	≥400	Radius of internal plates, mm	180
Horizontal displacement, mm	160	Load for internal plate yield, kN	4800
Rubber shear modulus, MPa	0.97±0.1	Thickness of steel end-plates, mm	18
Shore A hardness, points	70±5	Radius of steel end-plates, mm	187
Damping factor, %	15±1	Thickness of side cover layer, mm	10
Number of rubber layers	30	Thickness of end cover layer, mm	2
Thickness of rubber layers, mm	3	Overall height, mm	202.5
Number of internal metal plates	29	Overall diameter, mm	380

As mentioned above the soil conditions of the site where the considered building is located are rocks and in accordance with the Armenian Seismic Code they correspond to category I, for which the soil conditions coefficient is $k_0=0.9$ and the prevailing period of vibrations $T_0\leq0.3$sec. The site is located in zone 3, where the expected maximum acceleration is equal to 0.4g. There are different allowable damage coefficients stipulated in the Code. For this particular case of building with R/C bearing frames and shear walls it is required to apply allowable damage coefficient (reduction factor) of $k_1=0.4$ for the building itself and $k_1=0.8$ for seismic isolators and the structures below the isolation plane within the 12th floor. Results of calculations regarding the periods of vibrations are given in Table 2.

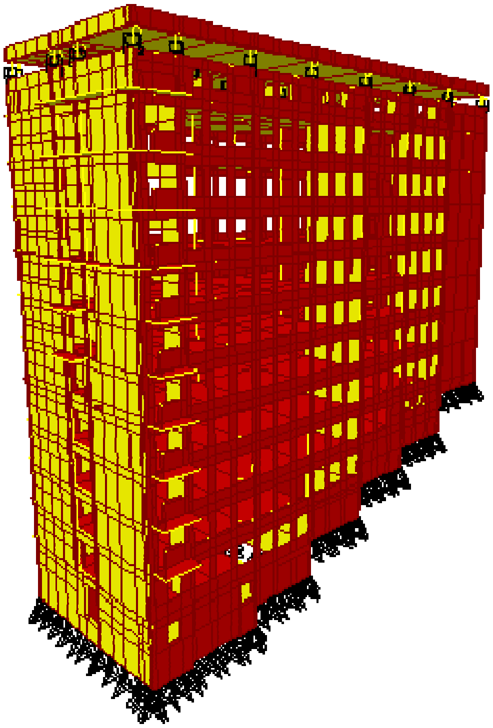

Figure 5. Design model of the 12-story office building with R/C bearing frames and shear walls protected by an isolated upper slab

Table 2. The values of the periods of vibrations of the 12-story office building without and with the isolated upper slab.

Modes of vibrations	**Periods of vibrations, sec**	
	Transverse direction	**Longitudinal direction**
Building without the isolated upper slab		
I	0.656	0.668
Building protected with the isolated upper slab		
I/1	0.771	0.785
I/2	0.497	0.520

The following 8 time histories recorded in Armenia (7.12.88 Spitak, EW and NS directions), Iran (20.06.90 Manjil, NE direction), Japan (17.12.87 Chiba, NS direction), USA (09.03.49 Hollister, 20.12.54 Eureka, NE direction and 17.10.89 Loma Prieta), and former Yugoslavia (15.04.79 Bar, EW direction) were selected for calculations and were scaled to 0.36g (0.4g×0.9) acceleration. Also the building was analyzed based on the provisions of the Armenian Seismic Code.

It follows from the obtained results that the vibrations' periods of I/1 and I/2 modes of the building protected by the isolated upper slab are almost symmetrical in relation to the periods of the building without it. Indeed: (0.771+0.497)/2=0.630sec and (0.785+0.520)/2=0.653sec. The average difference comprises about 3% and this means that the tuning of the system of the isolated upper slab is done correctly. With no consideration of damping the tuning in transverse direction is equal to f^2_{trans}=2.29/2.32=0.98 and in longitudinal – f^2_{long}=2.29/2.24=1.02. With consideration of damping [15] the optimal tuning is determined by the following formula:

$$f_{op}^2 = \frac{1}{1+\upsilon} = \frac{1}{1.063} = 0.94$$

Thus, the f^2_{op} differs from the $f^2_{trans,\ long}$ values for about 6% in average. Figure 6 shows the I/1 and I/2 modes of vibrations of the building protected by the isolated upper slab as well as the Ist vibration mode of the building without it.

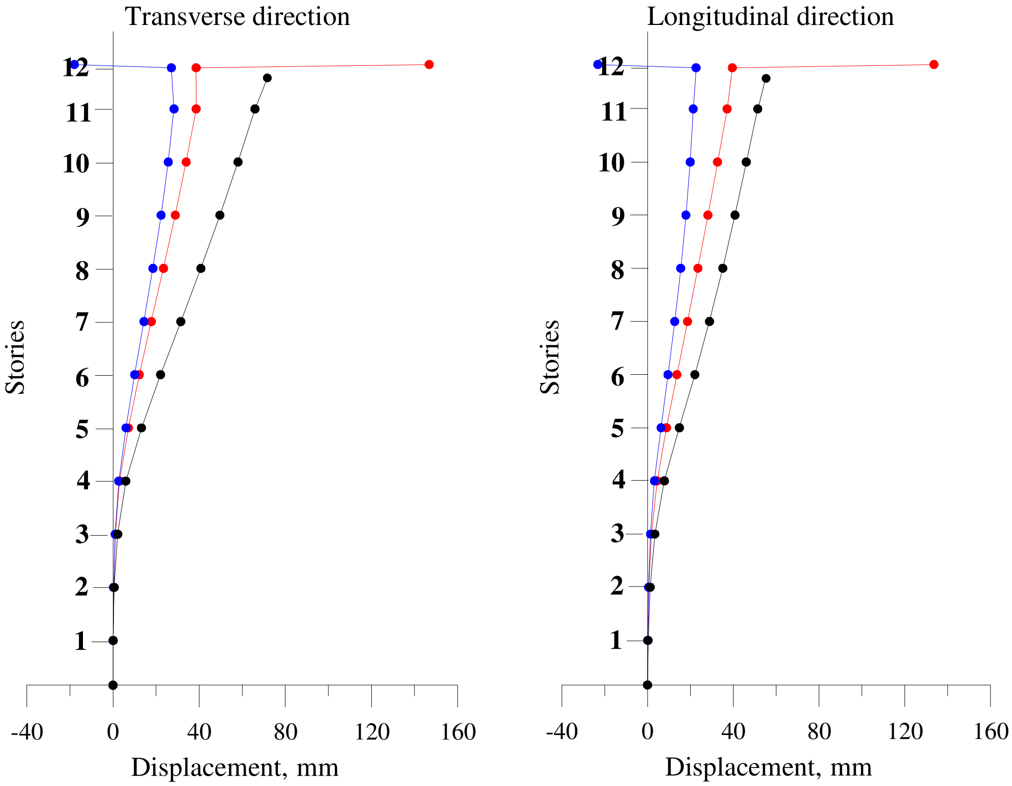

Figure 6. Modes of vibrations of the 12-story office building with R/C bearing frames and shear walls protected by the isolated upper slab (the red line is the mode I/1, the blue line is the mode I/2); the black line is the vibration mode of the building without the isolated upper slab

The horizontal displacements at the level of the building's 11th floor slab calculated for cases with and without isolated upper slab are shown in Figure 7. It can be stated that application of the isolated upper slab brings to reduction of the displacement at the mentioned level by 1.39 times based on the calculations using the provisions of the Armenian Seismic Code and by 2.88 times in average based on the time history analyses. Other results of calculations are given in Table 3 from which it is clear that according to the Code based calculations horizontal shear forces decrease by 1.47 times in average and according to the time history analyses – in average by 2.09 times. Correspondingly, inter-story drifts decrease by 1.30 times and 2.83 times in average. There is a significant difference (by about 4.1 times in average) in the magnitudes of displacements at the level of the isolated upper slab depending on the Code or time history analysis.

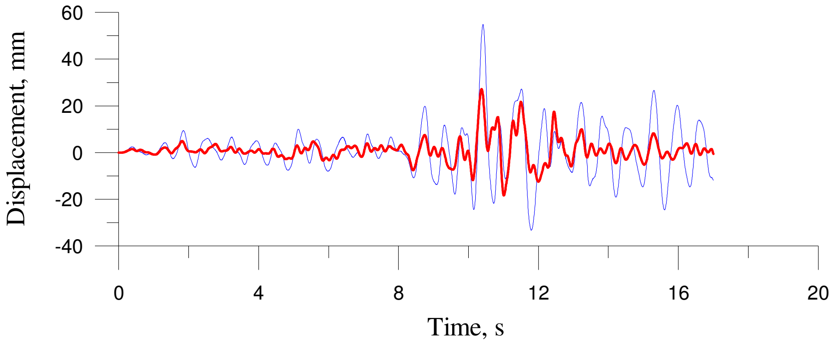

Figure 7. Horizontal displacements at the level of the building's 11th floor slab received from the analysis by the 7.12.1988 Spitak Earthquake, X direction Ashotsk accelerogram, for two cases: with (the red thick line) and without (the blue thin line) the isolated upper slab

Table 3. Some results of analysis of the 12-story office building with R/C bearing frames and shear walls with and without the isolated upper slab.

Design parameters	**Obtained using provisions of the Armenian Seismic Code**			
	for building with the isolated upper slab in the direction:		**for building without the isolated upper slab in the direction:**	
	transverse	**longitudinal**	**transverse**	**longitudinal**
Horizontal shear forces at the level of foundation, kN	20754	19184	30654	28084
Displacements at the level of the 11th floor slab, mm	47.87	42.81	65.91	59.97
Displacements at the level of the isolated upper slab, mm	117.38	104.86	-	-
Inter-story drifts, mm	7.14	6.94	9.41	8.89
	Average by the time histories			
Horizontal shear forces at the level of foundation, kN	19754	18541	45508	34764
Displacements at the level of the 11th floor slab, mm	28.81	31.60	86.52	86.86
Displacements at the level of the isolated upper slab, mm	25.97	28.43	-	-
Inter-story drifts, mm	4.23	4.50	12.45	12.18
Accelerations at the level of the 11th floor slab, g	0.52	0.53	0.85	0.89
Accelerations at the level of the isolated upper slab, g	0.45	0.47	-	-

It also can be stated based on the time history analyses that application of the isolated upper slab brings to reduction of accelerations at the level of the building's 11th floor slab by 1.65 times in average. It should be emphasised that accelerations at the level of the isolated upper slab are smaller (by about 1.14 times in average) than accelerations at the level of the building's 11th floor slab. This, as well as the mentioned difference in displacements at the level of the isolated upper slab calculated by Code and time histories, is most probably conditioned by the fact that the time history analyses are taking into account the damping factor (25%) in the isolated upper floor system. In Table 1 the damping factor for the designed laminated rubber-steel bearings is given as 15%. It is envisaged in the design to add more 10% by installation next to every bearing a simple device (damper) presented by a steel rod connected with its upper end to the isolated upper slab. The lower end of this rod will be moving in the cup filled up with the viscous material and fixed to the new R/C short walls.

4. CONCLUSIONS

Seismic protection of existing buildings by application of the TMD is discussed. The statement is made that in comparison with a single mass damper the application of three dampers tuned correspondingly to frequencies of the first three modes of building's free vibrations is a more efficient means for increasing the earthquake resistance of structures.

Providing flexibility to the damper using laminated rubber bearings (LRBs) converts the system of an ordinary TMD into the system of an additional isolated upper floor - AIUF, which actually is a roof isolation system. Its effectiveness is stressed in the paper.

The non-linear seismic response analysis proves that with AIUF, acting as a TMD, seismic loads (the strain-stressed state level) experienced by the building could be reduced along the height of the building by about 2.5 times in average. Dynamic testing of the existing 9-story building before and after erection of AIUF allows to conclude that the proposed AIUF method leads to upgrading of earthquake resistance of buildings and brings to reduction of shear force at the ground floor level by a factor of 1.76, at the same time decreasing the displacement at the 9th floor slab level by 2.2 times.

Based on the efficiently implemented concept of AIUF the new application of roof isolation system in the form of an isolated upper slab - IUS for seismic protection of an existing R/C 12-story office building is proposed. The bearing structure of this building, the site of its location and the soil conditions are briefly described. By the developed structural solution it is suggested to separate the slab of the attic floor from the columns then to lift it up and install the seismic isolators between them, thus converting the mentioned slab into an isolated upper slab acting as a tuned single mass damper.

Some provisions of the Armenian Seismic Code used in the analyses of the 12-story building for two cases, namely, without and with the IUS are given and explained, as well as the list of the selected 8 time histories scaled to 0.36g to carry out the earthquake response analyses of the same building for both cases is mentioned.

Application of the IUS brings to reduction of the displacement at the level of the building's 11th floor slab by 1.39 times based on the calculations using the provisions of the Armenian Seismic Code and by 2.88 times in average based on the time history analyses. Correspondingly, inter-story drifts decrease in average by 1.30 times and 2.83 times and horizontal shear forces decrease in average by 1.47 times and 2.09 times. It also can be stated based on the time history analyses that application of the isolated upper slab brings to reduction of accelerations at the level of the building's 11th floor slab by 1.65 times in average. These results confirm that being properly tuned the IUS is an effective tool for protecting buildings from strong seismic events.

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Authors

Mikayel G. Melkumyan was born on June 10, 1951. He started his scientific and practical activity in 1973, immediately after graduation from the Civil Engineering Department of Yerevan Polytechnic Institute, carrying out both design works and experimental-theoretical research to study the behavior of various reinforced concrete structures under seismic actions. In 1983 he defended his thesis for the degree of Candidate of Engineering Sciences and began to lead the Department of Earthquake Resistant Construction at the Armenian Scientific-Research Institute of Construction and Architecture. After the Spitak earthquake of December 7, 1988 in Armenia, Dr. Melkumyan dedicated himself to the deep analysis of consequences of this and other earthquakes and reasons for widespread destructions of various buildings and structures.

From April 1990 through March 1991 he conducted research at the Institute of Industrial Science (IIS), University of Tokyo, where he was invited by Prof. Tsuneo Okada, Director of the Institute. On the basis of his experimental research works he created a new hysteresis model to describe the shear behavior of reinforced concrete structures (walls, diaphragms). As it is indicated in the Certificate granted to him by the IIS, this model and the formula proposed by him for calculation of horizontal stiffness of diaphragms were accepted in Okada and Nakano laboratory, and the model was incorporated in the computational software for earthquake response analysis of multistory frame buildings with predominance of shear deformation. It is also mentioned in the Certificate that this research work will have a considerable contribution to earthquake resistant construction and earthquake damage mitigation in the world.

After his return from Japan, from 1992 through 1996 he was a teaching Professor at the College of Engineering of the American University of Armenia, giving lectures on non-linear behavior of reinforced concrete structures and design principles thereof in earthquake resistant construction. At the same time he led the Earthquake Engineering Center of the National Survey for Seismic Protection under the Government of Armenia. From 1993 through 1997, having been approved by the Government for the position of Director, he managed the Spitak Earthquake Zone Reconstruction Project, financed by the World Bank. From 1993 he started his work on development and application of seismic isolation systems for buildings and structures in Armenia, in the meanwhile defending his thesis for the degree of Doctor of Engineering Sciences in 1997 on the subject “Formation of the Dynamic Design Models for Seismic Response Analysis of Reinforced Concrete Buildings and their New Structural Solutions”.

During a short period of time in 1995-1996, devoting himself to the challenge of increasing earthquake resistance of existing buildings, he developed two unique methods of protecting existing buildings from earthquakes through base isolation and isolated upper floor without interrupting exploitation of the buildings. His new technologies were successfully implemented in Armenia, where for the first time in the world a 5-story stone apartment building and over 60 years old 3-story stone school building, which had a historical and architectural value, were retrofitted by base isolation without evacuation of inhabitants and interruption of school functioning. Besides, for the first time seismic resistance of two existing 9-story apartment buildings was enhanced by application of the isolated upper floor. These works are unprecedented in the world practice of earthquake resistant construction of the time. Later on, his technology for seismic isolation of existing stone buildings (Patent of the Republic of Armenia № 579) was successfully applied in Russia during retrofitting by base isolation of a 100 years old bank building in Irkutsk city. Afterwards, the Government of Romania ordered a design for retrofitting about 180 years old municipality building in Iasi city, which he accomplished using the same technology.

His works in the fields of both non-linear behavior of reinforced-concrete structures and seismic isolation are well known to the international professional community by the weighty contribution to the science and practice of earthquake resistant construction. He has authored and co-authored 192 scientific works, including 15 books, 10 normative documents, and 12 inventions. As a principal structural engineer he has designed 87 earthquake resistant residential, civil, and industrial buildings. 116 of his scientific works have been published in international journals and proceedings of the World, European, and National Conferences in 27 countries of the world.

He is the President of the Armenian Association for Earthquake Engineering, the Vice-President of the International Association of CIS countries on Seismic Isolation, a Founding Member of the of *A*nti-*S*eismic *S*ystems *I*nternational *S*oc*i*ety (*ASSISi*), a Member of the Saint-Petersburg Arctic Academy of Sciences, a Corresponding Member of Engineering Academy of Armenia, International Expert in Seismic Protection of Buildings and Structures of the Professional League of Experts of the CIS countries' Commission on Earthquake Resistant Construction and Disaster Reduction, an overseas Member of the Research Center of Earthquake Resistant Structures of the IIS, University of Tokyo.