SUMMARY REPORT

"PREVENTING DISASTER LOSES AND REDUCING VULNERABILITY OF CHILDREN IN ARMENIA" PROJECT

This report was developed by the "Preventing Disaster Loses and Reducing Vulnerability of Children in Armenia" project, implemented with financial support from the Office of U.S. Foreign Disaster Assistance (OFDA) under the U.S. Agency for International Development (USAID) and with technical support from the United Nations Children's Fund (UNICEF).

"APPROVED BY"

"Western Survey for Seismic

Protection" SNCO executive director

__________________ S. MARGARYAN

«____»«____» 2015

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CONTENT

TERMS AND DEFINITIONS

Magnitude - measurement unit of the amount of energy (power) released by an earthquake.

Seismogenic zone - a probable area of origination of earthquake.

Soil category - the characteristic of a soil stratum seismic properties.

Horizontal ground acceleration - the value of a soil stratum acceleration on earth surface in horizontal direction during an earthquake.

Predominant period-o/the ground - the largest period of a ground stratum free oscillations.

Seismic zoning map - breakdown of a country's territory by the seismic hazard.

Seismic load - the value of the inertial force acting on any level of a building or structure during an earthquake.

Earthquake resistance - buildings' and structures' capability to resist earthquake impact.

Permissible damage - earthquake induced damage of buildings and structures that is neither lifethreatening, nor hampering their serviceability.

The main principles of earthquake resistance - principles that must be adhered to while designing andconstructing earthquake resistant buildings and structures.

Anti-seismic joint - space that separates the compartments of a building or structure

Anti-seismic belt - a closed-loop reinforced concrete belt at the floor slab level.

Special systems of seismic protection - non-traditional systems, application of which ensures earthquake resistance of buildings and structures.

Extents of damage - the level of an earthquake-caused building damage assessed by a certain number.

Strengthening -Group of actions ensuring the enhancement of loadcarrying capacity and operating abilities of the building construction or building and structure altogether, including soils relative to the actual state or project target value.

INTRODUCTION

The Spitak 1988 Earthquake has shown that the level of seismic resistance of the majority of buildings and structures in Armenia is considerably lower than the level of seismic hazard and practically all its territory is located in the zone of high seismic risk.

Beginning from 1989 large-scalework has been carried out for seismic risk reduction for the Armenian North region, damaged from the earthquake. The level of seismic hazard of the region was evaluated again, the inventory-taking of buildings and structures,influenced under the Spitak earthquake, was finished and the buildings and structures damaged as a result of the earthquake were strengthened to the level of seismic resistance according to the requirements of Earthquake ResistantConstruction Codes established in Armenia after the Spitak earthquake.

Presently the seismic risk in Armenia has reached its peak which is conditioned by the new cycle of seismic activity, the low seismic resistance of buildings and structures, the high level of urbanization, the lack of attention paid to important technical structures (e.g. the nuclear station, hydroelectric stations, storage pools, healthcare centers, etc.), the low level of awareness of the population and the social-economic state.

According to the Armenian history, there were a number of destructive earthquakes such as Dvin (1319, 1840), Garni (1679) and Tsakhkadzor (1827).

The Garni July 4, 1679 destructive earthquake with a seismic intensity of 9-10 points destroyed Nork, Kanaker, Noragavit, Noragyugh, Dzoragyuz and many other settlements of Yerevan. The village of Garni was totally destroyed and 7600 people died. And 1230 people died in Kanaker. As a result of the earthquake a great number of churches and monasteries were destroyed, among them St. Sargis, St. Hovhannes and Zoravor in Yerevan.

The Parakar seismogenic source group includes 9 earthquakes, 7 of which took place in 1937. The most intensive of them with a seismic intensity of 7 points took place on January 7, 1937 in the south-western outskirts of Yerevan city. As a result of the shakings a lot of structures received different degrees of damage and separate houses were destroyed.

Since 1976 in the vast area of the Greater Caucasus and the Armenian Highland, the territory of Armenia being part of them, the seismic activity has been characterized by catastrophic earthquakes such as Chaldran (1976, M=7.3, Intensity-10, Turkey); Norman (1988, M=6.7, Intensity-8, Turkey); Spitak (1988, M=7.0, Intensity-10, Armenia); Rudbar (1990, M=7.7, Intensity-11, Iran); Rachin (1991, M=7.1, Intensity-9, Georgia); Erzijan (1992, M=6.8, Intensity-9, Turkey); Barisakho (1992, M=6.4, Intensity-8, Georgia); Ardebil (1997, M=6.9, Intensity-9, Iran); Izmit (1999, M=7.4, Intensity-10, Turkey); 32 km SE from Baku (2000, M=6.8, Intensity-9, Azerbaijan); 215 km SW from Tehran (2002, M=6.5, Intensity-8-9, Iran); Van (2011, M=7.1, Intensity-10, Turkey); Ahar (2012, M=6.4, Intensity-8-9, Iran).

From the above-mentioned data, one can see that the seismicity of the region has changed in recent years. If in the past one major earthquake occurred once 50 years, since 1976 the intervals have been as follows - 7, 5, 2 and 1 year and 1992 was marked with two events. Thus, it is evident that the increase of seismic activity in the region poses a serious threat to Armenia. This treat is particularly serious in view of the high vulnerability of structures that are likely to be subjected to earthquakes stronger than those in the past.

There are 1434 secondary schools in the Republic of Armenia. Most of them were built before the devastating Spitak earthquake, and it is obvious that they do not conform to the modern requirements of seismically resistant construction.

Before 1988 was mostly built on buildings and structures designed for ground acceleration 0.1-0.2g corresponding to seismic hazard level of 7-8 on the MSK-64 scale.According to MSK-64 scale for horizontal direction, the following values were accepted as equivalent acceleration (cm/sec^2) values for seismic intensity of 7,8 and 9 points:

- 7 seismic intensity -(61÷120) cm/sec^2(0.061÷0.120)*g*
- 8 seismic intensity -(121÷240) cm/sec^2(0.12÷0.24)*g*
- 9 seismic intensity -(241÷480) cm/sec^2(0.21÷0.480)*g*.

It is evident that in case of a possible major earthquake (with a magnitudeof M>5.5)a large number of buildings or their separate parts will be destructed which will result in a high death toll and huge material damage.

It is worth mentioning that after the 1988 devastating Spitak earthquake, results of macro-seismic examinations on the behavior of schools can be said to be absent or very limited in number. The reason for that can be considered the fact that the schools totally collapsed in the disaster zone, or they were damaged in such a way that later even their reconstruction was impossible. Another fact that points to this is that in the book "The Spitak Tragedy Should Not Be Repeated", dedicated to the devastating Spitak Earthquake of 1988, there is no analysis of either constructive peculiarities of the school buildings, or their seismic resistance, or their behavior during the earthquake.

This problem is in the focus of attention of the Government of the Republic of Armenia. In 1999 two decisions were adopted aimed at implementing the state projects on seismic risk reduction in the territory of Armenia and Yerevan city (the decisions No. 392 of 07.06.1999 and No. 429 of 10.06.1999 of the RA Government). The RA agency “National Survey for Seismic Protection” (NSSP) is responsible for implementing and coordinating the projects.

This report has been prepared based on the agreement signed between the "Western Survey for Seismic Protection" SNCO of the Ministry of Emergency Situations and the

United Nations Children's Fund in 02.06.2014 within the framework of the "Project for Disaster Damage Prevention and Reduction of Children's Vulnerability in Armenia.

The report is made in the Armenian and the English languages.

1. THE PURPOSE AND METHODOLOGY OF THE PROJECT

Based on the aforementioned, a memorandum of understanding was signed between the Ministry of Urban Development, Ministry of Education and Science, Ministry of Emergency Situations and UNICEF aimed at establishing cooperation among the parties within the framework of implementation of 2005-2015 Hyogo Framework for Action, particularly Priority 4 (reducing the underlying risk factors). Its main aim is the significant reduction of human, social, economic and environmental asset losses as a result of disasters in countries and communities, and cooperation within the framework of the "Project for Disaster Damage Prevention and Reduction of Children's Vulnerability" in order to support the RA Government in the task of implementing a comprehensive assessment of the safetyof schools and preschool institutions. The summary analytical report of the evaluation project will support the RA Government in developing a National Program and Activity Plan aimed at rehabilitation, reconstruction and modernization of secondary educational institutions, which will include the revealed priority schools, necessary activities, sources of funding and timeline. It will also contribute to the integration of sponsorships revealed by the project into the RA Education Development State Program for 2016-2020.

The work carried out within the framework of the project is aimed at prevention of disasters in Armenia and intends to increase the seismic safety of school-aged children, within the framework of which special attention is given to works of seismic vulnerability assessment of school buildings and structures as an important stage in activities aimed at seismic risk reduction.

The main tasks of the project are the following:

1. Acquisition of designs of each type of school building from the National Archive or other respective structure for documentation and for carrying out analysis during the next stage;

2. Evaluation of all the prototypical school designs in Armenia to determine their compliance with the current building codes considering the group they belong to;

3. Identification of the most “at-risk” schools in Armenia through carrying out the detailed observation and instrumental inspection of schools in the most “at risk” areas and provide estimates of their recovery, reconstruction and modernization;

4. Preparation of final assessment reports based on prototypical school designs, field research and feedback from counterparts;

Development and submission of recommendations to inform the GoA National Program and Action Plan aimed at recovery, reconstruction and modernization of school.

The tasks of project performed according to the schedule presented below:

	Activity	2014						2015	
		1	2	3	4	5	6	7	8
1	Analysis and digitalization of the prototypical school designs								
2	Evaluation of all the prototypical school designs in Armenia to determine their compliance with the current building codes considering the group they belong to.								
3	Identification of the most “at-risk” schools in Armenia through carrying out the detailed observation and instrumental inspection of schools in the most “at risk” areas and provide estimates of both retrofitting and replacement								
4	Preparation of final assessment reports based on prototypical school designs, field research and feedback from counterparts								
5	Development of recommendations to inform development of a GoA seismic retrofitting and replacement plan for schools								

Methodology of Project Implementation

Based on a preliminary review of the structural design and regional distribution, the school buildings have been divided into 3 main groups by the Earthquake Engineering Center of WSSP SNCO in 2010.

Group 1: 2-4-floor masonry buildings constructed before 1960 based on individual design, and many of them have great architectural and artistic value. The school buildings have been constructed by complex design, by non-uniform distribution of heights, stiffness and mass, without seismic measures. 30% of the schools fall in this category and nearly 20% of all the schoolchildren attend these schools.

Group 2: 2-3-floor buildings constructed during 1960-1970 with longitudinal and transversal bearing walls and internal reinforced concrete frame and with the seismic measures of that time period. About 35% of all secondary school buildings belong to this category and 30% of the school children attend those schools. In contrast to the first group, these buildings have rectangular shape in the plan and some defects, and do not comply with the modern seismic resistance codes.

Group 3: 2-4-floor frame skeleton buildings constructed during 1970-1988 (before the Spitak earthquake) made from precast reinforced concrete (series IIS-04). About 35% of all schools belong to this group and 50% of the students attend them.

From the point of view of proper planning of activities there has been close cooperation with the Ministry of Urban Development, Ministry of Education and Science, Ministry of Emergency Situations and other interested agencies and organizations.

In order to improve the quality and effectiveness of the activities, prominent scientists who are well-known in this field were involved in the activities, namely T. Margaryan, Doctor of Engineering, assistant professor at the chair of “Building constructions”, A, Arzumanyan, PhD, director of “ARSEA” LLC, academic S.Nazaretyan and S. Simavoryan.

In order to carry out the digitization of the designs, two organizations were invloved having respective licenses for working out urban development documents.

The seismic calculation and 3D modeling of the buildings were carried out with LIRA software package, version 9.

The visual studies of 60 school buildings were carried out by three SNCOs which have respective licences for carrying out the works.

In the Northern regions of the RA, studies were carried out by NSSP SNCO, in the central regions – by WSSP SNCO, and in the Southern regions – by SSSP SNCO. All the groups were equipped with video cameras, photographic cameras and laser range finders that make linear measurements.

The instrumental studies were carried out by the Earthquake Engineering Center and the Seismic Hazard Assessment Complex Center of WSSP SNCO. The respective specialists of other SNCOs were also involved in the works. Instrumental studies were carried out in parallel with visual studies.

The activities of checking the soils of the building area and dynamic characteristics of the building itself were carried out with the help of SMACH and GURLAP type three-component seismometers. The analysis of the records was done via Fourier spectrum with the use of a relevant software package.

For specifying the geological data of the territories of school buildings and for getting the necessary additional data, “Yerkraban-Utiq” LLC was involved in the works.

2. DIGITIZATION AND ANALYSES OF THE TIPICAL DESIGN OF THE SCHOOLS BUILDINGS

2.1 Analyses of typical school designs

With financial and practical support of the UN Children's Fund the structural and engineerring parts of design documents of 20 typical schools have been obtained from the archive of "Haynakhagits" OJSC, total 550 printed pages of A1 format. The 20 typical designs have conditionally been designated by us with the numbers 1-20.

Table 2.1.1

N/N	Type	Date of Design	Number of Students (Design)	Number of buildings	Volumetric-design solutions	Constructive solutions	Design seismic resistance	Design seismic resistance
					Number of floors, high (m))	Sizes plan (m)		
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	A2-02-04	1961	320	EB	3 (3.3m)	12.4x39.0	Exterior RC frame and internal precast RC bearing walls,	7-8
				CH	1 (3.3m)	12.4x33.3		
				ԴՄ	1 (3,7m)	9.0x18.0		
2	27-66	1967	320	EB-CH	2 (3,3m)	9,5x51.0	Exterior RC frame and internal precast RC bearing walls,	7-8
				EB	2(3,3m)	9.5x30.0		
				MB	2 (3,3m)	9.5x15.0		
				ՄM	1(5,6m)	9.0x21.0		
3	**-**	1974	320	EB	2 (3,3m)	36.0x36.0	Precast RC frame (IIS-04 seria	7-8
4	22-72	1973	392	EB	2 (3,3m)	12.0x36.0	Precast RC frame (IIS-04 seria	7-8
				EB	2 (3,3m)	12.0x36.0		
				CH -GYM	2 (3,3,4,8m)	18,0x30.0		
5	222-1-270c	1976	392	EB	2 (3,3m)	12.0x30.0	Precast RC frame (IIS-04 seria	7-8
				EB	2 (3,3m)	12.0x30.0		
				CH -GYM	2 (3,3,4,8m)	18.0x30.0		
6	26-66	1967	480	EB	2(3,3m)	12.0x54.0	Exterior RC frame and internal precast RC bearing walls,	7-8
				EB	2 (3,3m)	12.0x36.0		
				GYM	1 (4,8m)	9.0x18.0		
				MB	2 (3.3m)	9.0x21.0		
7	A2-02-06	1961	640	EB	3 (3,3m)	12.4x60,0	Exterior RC frame and internal precast RC bearing walls,	7-8
				EB	1 (3,3m)	12.4x30.0		
				GYM	1 (3,3;4.8m)	18.0x30.6		
8	225-1-170C	1969	640	EB	2 (3.3m)	12.9x48.0	Exterior RC frame and internal precast RC bearing walls,	7-8
				EB	2 (3.3m)	12.9x48.0		
				GYM	2(3.3-5.6m)	12.0x40.9		
				CH	2(3.3-5.6m)	33.0x40.9		
9	222-1-205c	1973	784	GYM	1(4.8m)	12.0x30.0	Precast RC frame (IIS-04 seria	7-8
				EB	2(3.3m)	12.0x36.0		
				EB-CH	3-4 (3.3;4.2m)	12.0x30.0		
				EB	2(3.3m)	12.0x36.0		
				EB	2(3.3m)	12.0x30.0		
10	A2-02-15	1961	964	EB	3 (3.3m)	12.4x72,0	Exterior RC frame and internal precast RC bearing walls,	7-8
				EB	2 (3.3m)	12.4x36,0		
				CH -GYM	1 (3.3m; 4.8m)	18.0x36,0		
11	222-1-107c/73	1973	1176	EB-CH	1-2(3.3m-4.2m)	12.0x36.0	Precast RC frame (IIS-04 seria	**7-8**
				EB	2 (3.3m)	12.0x36.0		
				Manuf	2 (3.3m)	12.0x36.0		
				EB	2 (3.3m)	12.0x36.0		
				EB	2 (3.3m)	12.0x36.0		
				EB	2 (3.3m)	12.0x36.0		
				GYM	1(6.6m)	12.0x36.0		

12	-	1979	1176	EB	3 (3.3m)	15.0x27.0	Precast RC frame (IIS-04 seria	7-8
				EB	3 (3.3m)	15.0x27.0		
				EB	3 (3.3m)	15.0x27.0		
				CH -ՄԴ	1-2 (3.3-6.6m)	36.0x42.0		
13	222-1-196c	1974	1568	EB	2 (3.3m)	12.0x33.0	Precast RC frame (IIS-04 seria	
				EB	2 (3.3m)	12.0x33.0		
				EB	2 (3.3m)	12.0x33.0		
				EB	2 (3.3m)	12.0x33.0		
				EB	2 (3.3m)	12.0x33.0		
				EB	2 (3.3m)	12.0x33.0		
				GYM-CH	1-2 (3.3-6.6m)	36.0x37.2		
14	229-9-169c	1979	1568	EB	3(3.3m)	12.0x66.0	Precast RC frame (IIS-04 seria	7-8
				EB	3(3.3m)	12.0x66.0		
				GYM-CH	2-3 (3.3-6.6m)	42.0x54.0		
15		1977	1568	EB	3(3.3m)	12.0x66.0	Precast RC frame (IIS-04 seria	7-8
				EB	3(3.3m)	12.0x66.0		
				GYM-CH	2-3 (3.3-6.6m)	42.0x48.0		
16	222-1-266c	1975	624	GYM-CH	1-2 (3.3-6.6m)	24.0x24.0	Precast RC frame (IIS-04 seria	7-8
				EB	2(3.3m)	12.0x36.0		
				EB	2(3.3m)	12.0x36.0		
				EB	2(3.3m)	12.0x36.0		
17	14-75	1968	784	EB	2 (3.3m)	12.0x27.0	Precast RC frame (IIS-04 seria	7-8
				EB	3 (3.3m)	12.0x75.0		
				EB	2 (3.3m)	15.0x18.0		
				GYM-CH	1 (6.6m)	12.0x24.0		
18	26-67	1968	192	EB	2 (3.3m)	9,60x41,70	Exterior RC frame and internal precast RC bearing walls,	7-8
				CH	1 (3.3m)	12.90x16.0		
				GYM	1 (5.6m)	9.0x18.0		
19	A2-02-13	1961	330	EB	3 (3.3m)	12.4x51.0	Exterior RC frame and internal precast RC bearing walls,	7-8
				EB	3 (3.3m)	12.4x51.0		
				GYM-CH	1(3.3; 4.8m)	18.6x39.0		
20	-	1978	192	EB	2(3.3m)	18.0x42.0	Precast RC frame (IIS-04 seria	7-8

EB- eductional building, MB – main building
GYM, CH –ceremonial holl:

Analysed the main indicators of the 20 typical schools designs, for example volumetric specifications, constructive solutions and unconformities with the requirements of valid RA RABC II-6.02-2006 codes “Earthquake resistant construction. Design codes” [1]. The summary results presented in the Appendix 1. As an example below presented the analys of second typical design.

Typical design number 2 (27-66)

The design was developed by the Institute “Haypetnakhagits” in 1966 and is designed for 320 pupils.

The composition of the school is realized by three buildings with a rectangular layout which are connected to each other with a two-storey corridor where the staircase is located with two stairs(see fig. 2.2.1; 2.2.2; 2.2.3). The main entrance of the school is organized in the vestibule. The buildings are rectangular in the layout and have the following marginal axes sizes and number of storeys:

- educational building – 9.5x51.0m, two storeys,
- additional building - 9.5x30.0m, two storeys,
- gym building – 9.5x21.0m, one storey,
- corridor – 9.0x15.0m, two storeys.

The height of the storeys of educational and additional buildings is 3.3m, and that of the gym – 5.6m, up to the inner point of the cover farm. All the buildings are separated from each other with anti-seismic joints. The entrance to the buildings is ensured with the two-storey corridor which is also the main administrative building.

All the buildings are calculated to have seismic resistance of 7-8 points.

The constructive solutions of the buildings

a) Educational and additional building:

The constructive solution of the main and educational buildings is given with external longitudinal bearing walls and internal monolithic RC frame and horizontal rigid discs of the covers. The inner transverse walls are placed at a step of 9.0m and 15.0m and areinterrupted by the corridor and connect with the longitudinal walls with monolithic RC frames (see fig. 2.1.1). The constructive elements have the following characteristics:

- The type of the stone masonry is complex (see fig. 2.1.4). The RC kernels used in the RC walls of the educational and additional buildings and the frame columns have a 30x30cm square cross section. The foundations under the walls are strip, and under the columns – pointed (see fig. 2.2.2).
- The bearing beams of the RC frame have a T-shaped cross section with an inner belt. The width of the inner belt is 40cm, and the height is 25cm; the total height of the cross section of the beams is 50cm, and the side width at the upper part of the section is 20cm.
- The interfloor covers and the upper cover are realized with precast reinforced concrete 200mm-thick round-hole slabs.
- The stairs are made withstringer boards and beams with number 20 steel rolled channel bars, with monolithic reinforced concrete platforms and precast reinforced concrete stair steps.

- The partitions are made with 6cm-thick pumice concrete tiles and partly with 20cm-thick block masonry.
- The roof is pitched with external water removal and is made with wooden bridle and bracing constructions and is covered with corrugated asbestos sheets.
- The paving is of asphalt concrete.

b)Gym building:

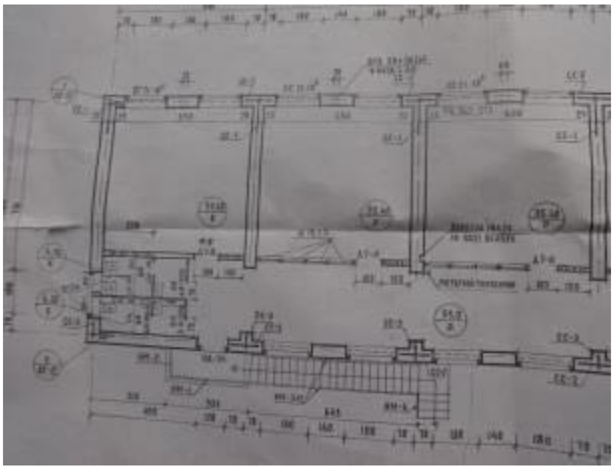
The constructive solution of the gym is given with 2 longitudinalbearing walls and 2 transverse connecting walls and with a horizontal rigid disc of the cover (see fig. 2.1.3). The constructive elements of the gym have the following characteristics:

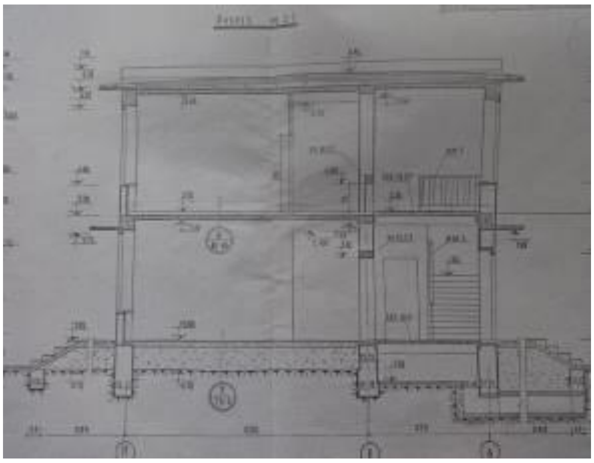
- the foundations are strip and made with rubble concrete.
- The walls are laid with a tuff stone masonry with regular shaped section, with the use of sand cement mortar, and have a thickness of 45-60cm. The width of the piers is 110cm, and the opening width of the windows is 195cm. On the longitudinal walls, at the cover level a monolithic reinforced concrete belt with a 60x40(h)cm rectangular cross section was realized, on which the upper cover slabs lean.
- The cover was made with precast RC 9.0m-long side panels.
- The partitions are made with the masonry of 6cm-thick pumice concrete tiles and partly with 20cm-thick blocks.
- The roof is pitched with external water removal and is made with wooden bridle and bracing constructions and is covered with corrugated asbestos sheets.
- The paving is of asphalt concrete.

As a result of analysis of the constructive solutions of the buildings it was revealed that there are unconformities with the requirements of valid RA RABC II-6.02-2006 codes "Earthquake resistant construction. Design codes":

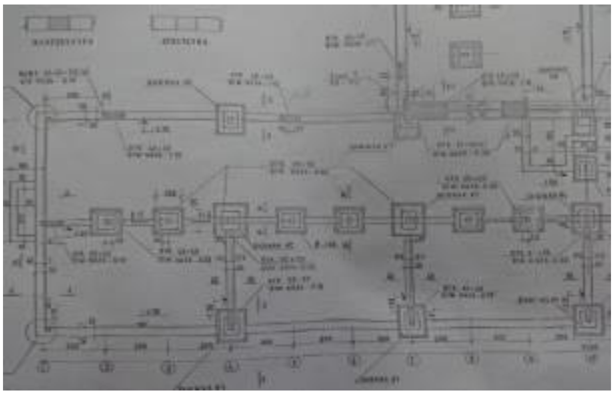
1. The constructive solutions of the educational and additional buildings do not comply with the requirements of paragraph 7.1.2 of the codes, namely: "*The spatial and planning, as well as structural solutions of buildings and structures shall meet the conditions of symmetry and uniform distribution of masses and rigidities".*
2. The factual axial distance between the transverse walls of the gym building is 21.0m which exceeds the maximal permissible values specified in Table 13 of paragraph 7.9.6 of the codes.
3. Piers width to opening width ratio in the longitudinal walls of the gym building is less than 0.8 which is the minimal permissible value specified in point 3 of Table 14 of the codes.
4. The RC single-piece stair steps in the staircases factually are not connected to the metal stringer boards as specified in paragraph 7.6.2 of the codes.
5. The pier width of the gym building is 0.8-1.0m which is less than the value of 1.2m specified for the 3rd seismic zone by the codes.

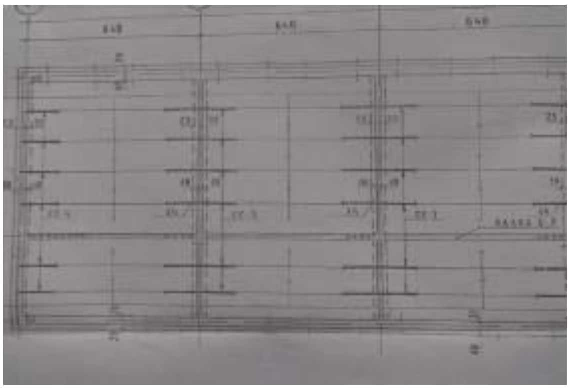
6. The storey height of the gym building is 5.6m, which exceeds the values of 4.5m and 4.0m specified for the 2nd and 3rd seismic zones by the codes.



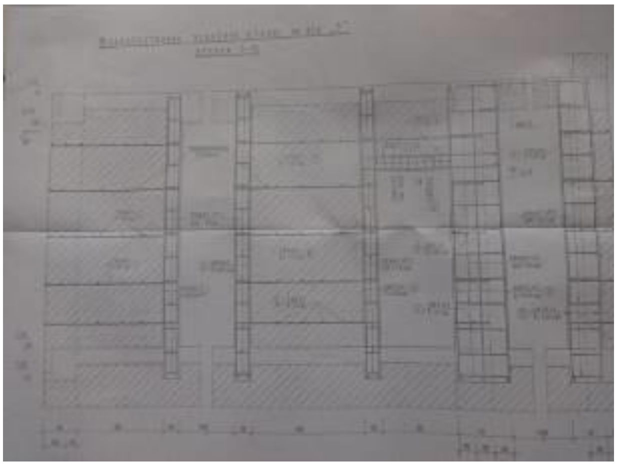


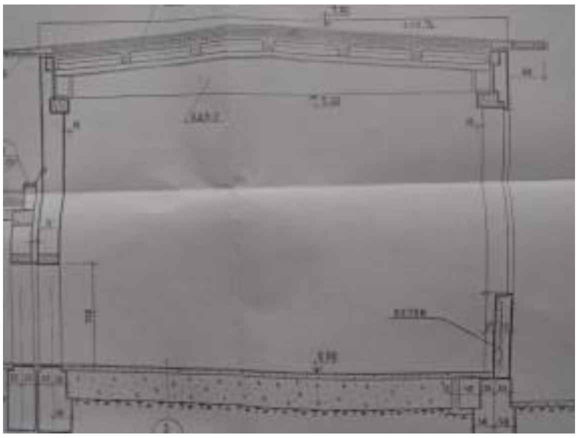
2.1.1 Episode from the educational building layout and the transverse section



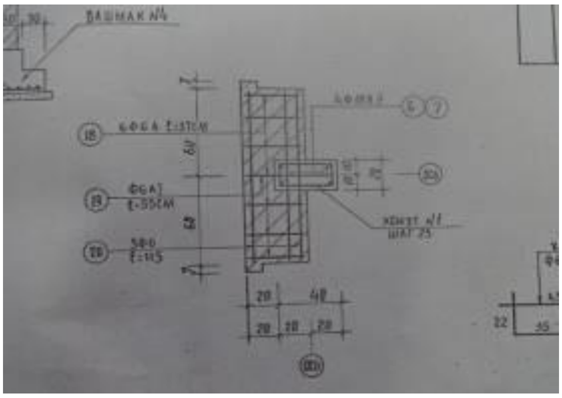


2.1.2 Episode from the layouts of bases and interfloor cover slab





2.1.3 Episode from the RC frame and the transverse section of the gym builing



2.1.4 Connection joints of the walls with stone masonry and of the RC constructions

By summing up the design indicators of 20 typical schools and considering mainly the volumetric-design and constructive solutions of the educational buildings of schools and the number of storeys, the designs of 20 typical schools have been classified by us into the following 5 main types:

A. Bearing walls of stone masonry, complex construction

B. External bearing walls, internal RC precast or monolithic frame

C. External RC frame, internal precast RC bearing walls

D1. Precast two-storey RC frame (IIS-04 series)

D2. Precast three-storey RC frame (IIS-04 series).

Table 2.1.2 below summarizes the classification of the 20 school typical designs according to the above-mentioned groups, besides, the main design indicators are given. The number of educational buildings of 1-20 types included in each group numbered by EEC is brought as an indicator, and the design capacity – the number of pupils and the sizes are brought in the layout.

Table 2.1.2

Classification by constructive solutions	Classification by EEC	Number of buildings	Number of Students(Design)	Sizes plan (m), Number of floors,
1	2	3	4	5
A	2	2	192-640	9.5 x51.0; 2 story
				9.5x30.0m; 2story
	8	1		12.9x48.0; 2story
	18	1		9.60x41.70; 2story
B	6	3	480	12.0x54.0; 2story
				12.0x36.0; 2story
				9.0x21.0; 2story
C	1	1	320-964	12.4x39.0; 3story
	7	2		12.4x60.0; 3story
				12.4x30.0; 1story
	10	2		12.4x72.0; 3story
				12.4x36.0;2story
	19	2		12.4x51.0; 3story
D1	3	1	320-1568	36.0x36.0; 2story
	4	2		12.0x36.0; 2story
	16	3		12.0x36.0; 2story
	11	6		12.0x36.0; 2story
	5	2		12.0x30.0; 2story
	13	6		12.0x33.0; 2story
	20	1		18.0x42.0; 2story
D12	9	2	680-1568	12.0x30.0; 2-4 story
		2		12.0x36.0; 2story
	12	3		15.0x27.0; 3story
	14	1		12.0x66.0; 3story
	15	2		12.0x66.0; 3story
	17	1		12.0x27.0; 2story
		1		12.0x75.0; 3story
		1		15.0x18.0; 2story

2.2 Digitization of Typical School Designs

The layouts and facades of all the 20 typical buildings have been digitized by AutoCAD and ArchiCAD programs, and are presented in 2D and 3D formats. The digitization results of typical School N2 are given below as an example (see pic. 2.2.1-2.2.4). The full results of the study are presented in the attached Appendix 2 in electronic version. Besides, an evacuation plan has been developed for each typical school (Appendix 3).

Fig. 2.2.1 The 3D view of the 2nd typical school

Fig. 2.2.2 The 2D view of the 2nd typical school

Fig. 2.2.3 The 3D view of the 2nd floor of 2nd typical school

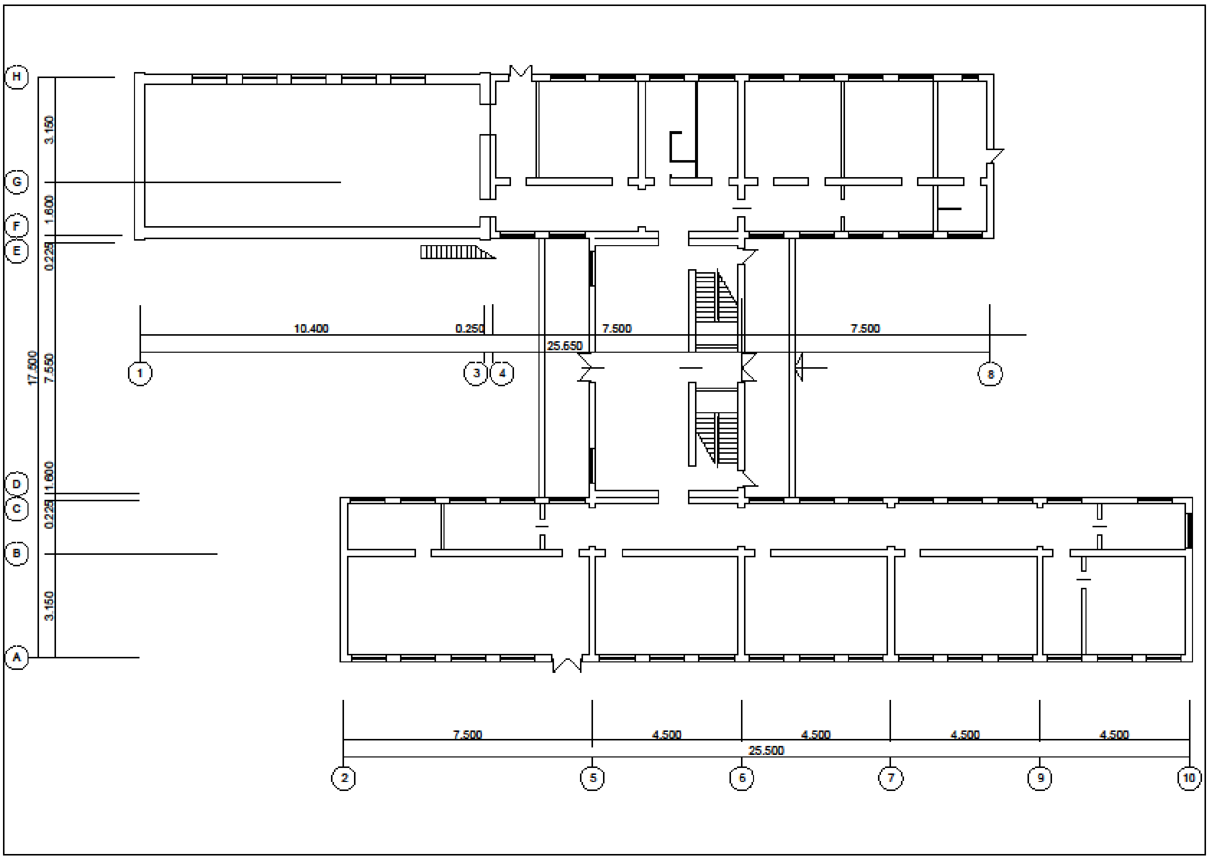


Fig. 2.2.4 The schematic plan w of the 2nd floor of 2nd typical school

3. SEISMIC CALCULATION OF TYPICAL SCHOOLS AND SEISMIC VULNERABILITY ASSESSMENT

3.1 Seismic calculation of typical schools

Seismic calculation of typical schools has been performed by LIRA "Computation Complex intended for structure strength analysis by the method of super-elements", version: 9.6, software package developed in Kiev Construction Automation Research Institute. Software package considers criteria accepted in Armenian Seismic Codes, particulary:

- **Paragraph 6.4.1:** The design value of the horizontal seismic load S_{ki}, applied at a point k, which corresponds to the i^{th} mode of the building's or structure's free oscillations, is determined by the following formula:

$$S_{ki}= k_1k_2k_3S_{0ki}$$

Where:

S_{0ki} is the horizontal seismic load by the ith mode of the structure's natural oscillations, determined assuming elastic deformation of structures, by the formula:

$$S_{oki} = Q_k A K_0 \eta_{ki} \beta_i$$

where:

Q_k is the weight that induces inertial force, and is deemed to be concentrated at the point k and determined with consideration of the Table 5 herein;

A is the dimensionless coefficient of seismicity indicating the ratio of a given settlement's

design ground acceleration (paragraph 5.2.2) to the gravitational acceleration (Table6);

k_1 - is the building and structure permissible damage coefficient;

k_2 - is the buildings and structures importance coefficient (Table 8, by School buildings k_2=1.3):

k_3 is the soil-structure interaction coefficient;

k_o is the dimensionless coefficient of soil conditions (Table 4);

β_i is the dimensionless dynamic coefficient corresponding to the ith mode of a given building's or structure's free oscillations;

η_{ki}, is a dimensionless coefficient depending on the ordinates of the free oscillation mode X_{ki} and concentrated weights values Q_k (oscillation mode coefficient).

- **Paragraph 6.2.1:** When determining the values of horizontal seismic loads, the static design load values shan be multiplied by combination coefficients:

  Dead load - 0.9

  Live load: long-term - 0.8; short-term - 0.5

- **Paragraph 6.4.3:** The maximum values of horizontal displacements X_{ki} of the kth storey by the its mode of free oscillations, and the storey drifts L1ki are determined by the following formulas:

$$x_{ki} = Agk_0\eta_{ki}\beta_i(T_i/2\pi)^2$$
$$\Delta_{ki} = x_{k+1i} - x_{ki}$$

- **Paragraph 6.4.4:** The values of dynamic coefficient β_i depending on soil category and ith mode free oscillations period Ti (in seconds) are determined according to the graphs or by the following formulas (for damping n=5%)

For soils of Category I:

β_i = 1+15T_1, when 0<$T_i \le$ 0.1

β_i = 2.5, when 0.1≤$T_i \le$ 0.4

β_i = 1/T_1 , when T_i ≥0.4

For soils of Category II:

β_i = 1+7.5 T_i , when0<$T_i \le$ 0.2

β_i = 2.5, when0.2 ≤$T_i \le$ 0.6

β_i = 1.66/$T_i^{4/5}$, when $T_i \ge$ 0.6

For soils of Category III:

β_i = 1+5 T_i , when 0<$T_i \le$ 0.3

β_i = 2.5, when 0.3 ≤$T_i \le$ 0.8

β_i = 2.15/$T_i^{2/3}$, when $T_i \ge$ 0.8

- **Paragraph 6.9.1:** The design values of shear forces and bending moments, nonnal and tangential stresses, displacements and drifts of structures at the point k induced by seismic loads, with consideration of higher modes of oscillation, are detennined by the following formula:

$$N_k^p = \sqrt{\sum_{i=1}^{\nu} N_{ki}^2 + \sum_{\substack{j,i=1 \\ i\neq 1}}^{\nu} N_{ki}\rho_{ij}N_{kj}}$$

Where:

N_{ki} and N_{kj} - are the values of forces and stresses, as well as displacements and drifts in a considered section k, induced by seismic loads of i^{th} or j^{th} oscillation mode;

ν - is the number of oscillations modes;

ρ_{ij} - are the coefficient values depending on the ratio of free oscillations periods (for critical damping coefficients of 5% for all oscillations mode).

- **Paragraph 6.11.1** In the building and structure seismic impacts analysis, in addition to the horizontal and vertical seismic loads it is necessary to consider the torsional impacts caused by rotary ground motions relative to the vertical axis and those due to disalignment of a building's mass center and rigidity center.

  6.11.2 The design torque value M_k^t at the k^{th} storey level is determined by the formula:

$$M_k^t = P_k(e_k + e),$$

where:

P_k -is the lateral force value at the k^{th} storey level (multiplied by the k_1,k_2,$k_3$coefficients);

e_k -is the factual eccentricity between the k^{th} storey's mass center and rigidity center;

e -is the additional design value of eccentricity caused by rotary ground motions, depending on the period T_1 of the fundamental mode of oscillations and the soil category as follows:

For buildings and structures where $T_1 \leq 0.5$ sec:

e=0.03b for Category I soils

e=0.06b for Category II soils

e=0.08b for Category III and IV soils

For buildings and structures where $T_1 \geq 0.5$ sec:

e=0.02b for Category I soils

e=0.04b for Category II soils

e=0.05b for Category III and IV soils

where **b** is the **k^{th}** storey size in plan in the directon perpendicular to the action of the **P_k** lateral force.

- **Paragraph 7.1.7**: In the columns of reinforced concrete multistory frame buildings, the value of compression dead load and other vertical static loads in the most loaded section (usually at the foundation edge level) shall not exceed $0.9N_R$, $0.8N_R$ and $0.7N_R$ for Seismic Zones 1, 2 and 3 respectively, where N_R is the bearing capacity design value.

According to the project tasks, a seismic calculation has been carried out for separate buildings (academic, sport and concert halls) of 20 typical schools based on the operating norms. The calculation has been done for 3 types of etalon soils. The analyses of the calculation results are presented in the form of tables, where all the quantitative indicators related to seismic calculation are given (sum of bearing forces in the upper part of the bases, the maximum drift of the storey, the values for natural periods of vibrations, and etc.) depending on soil category (Appendix 4).

As an example, the seismic calculation done for 15 typical designs is given below for three soil types.

The constructive point of view the building consists of four identical three-storey educational buildings with a basement floor and one two-storey general building (gym building), the seismic calculation below has been done for one educational building: According to our classification, the academic building is of D2 type.

Seismic calculation of the educational building

In figure 3.1.1 the 3D calculation model of the educational building and in figure 3.1.2-3.1.5 and in table 3.1.1 the main results of calculation are presented.

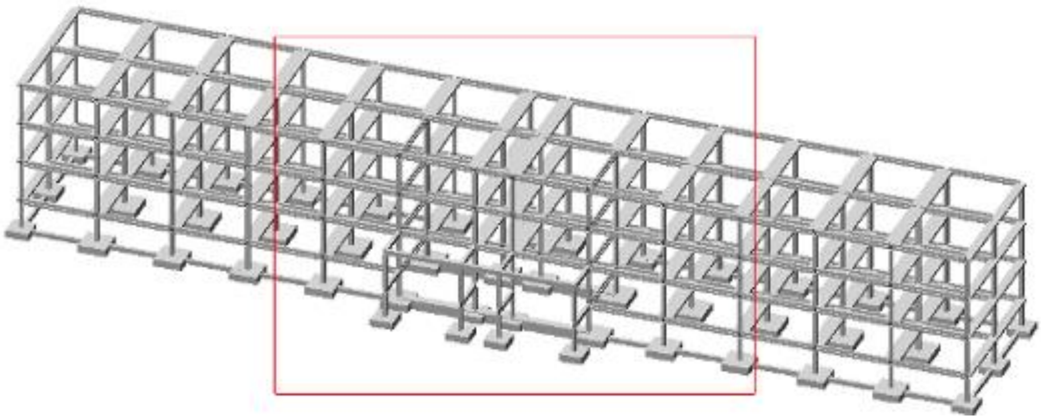


Fig.3.1.1Calculation model of the educational building

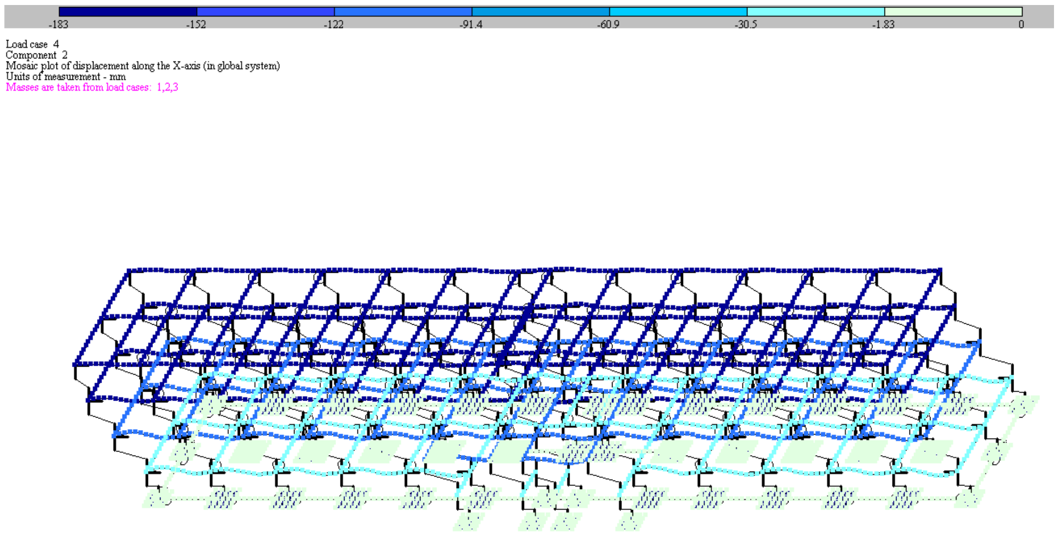


Fig. 3.1.2 Displacements from seismic load in the longitudinal direction (soils of Category II)

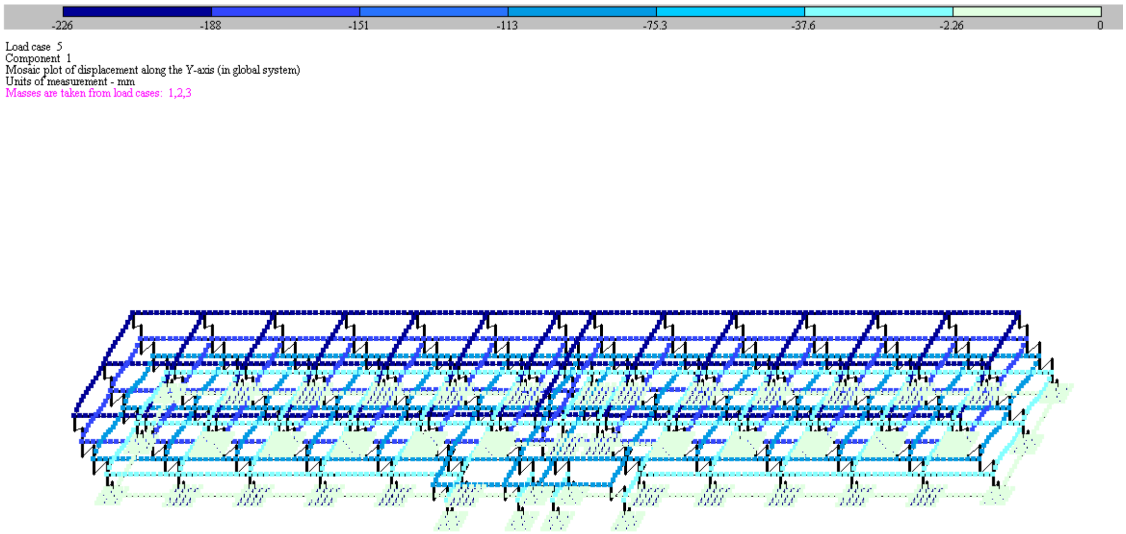


Fig. 3.1.3 Displacements from seismic load in the latitudinal direction (soils of Category II)

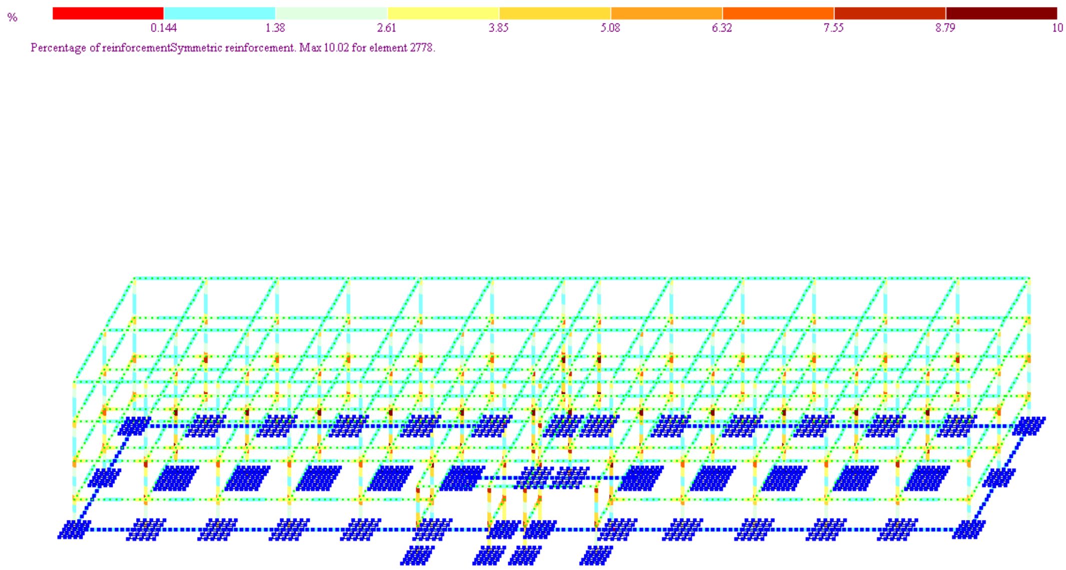


Fig. 3.1.4 The mosaic of maximal reinforcement percent for the base with II class seismic properties.

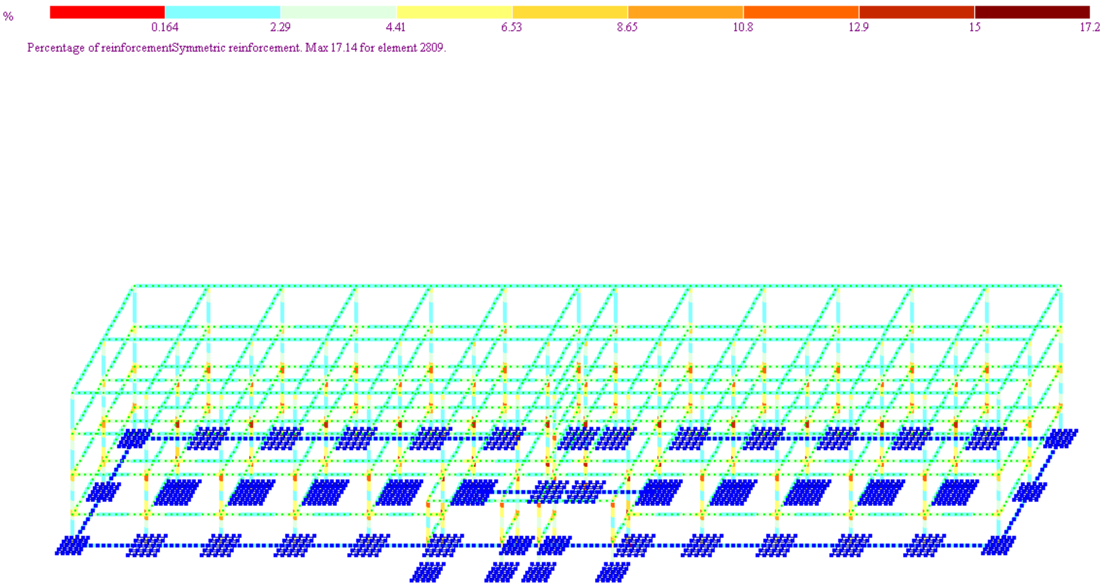


Fig. 3.1.5 The mosaic of maximal reinforcement percent for the base with III class seismic properties.

Table3.1.1

No	Calculated value	Unit of measurement	Latitudinal (Y)			Longitudinal (X)		
			Ground category					
			I	II	III	I	II	III
1	Calculative mass of the buliding	ton	367,8					
2	The sum of seismic forces in the upper level of the foundation (∑Q)	ton	399.0	714.0	1011.0	469.0	828.0	1156.0
3	The period of the first two modes of free oscillations	sec.	1.065 0.348	1.075 0.351	1.140 0.368	0.901 0.298	0.907 0.300	0.931 0.306
4	Mass/ ∑Q		0.922	0.515	0.364	0.784	0.444	0.318
5	Maximal drift of the storey (storeys) • basement • 1st storey • 2nd storey • 3rd storey	mm	15.1 42.9 39.7 23.3	28.1 80.0 73.9 44.0	40.2 114.9 105.9 62.9	14.7 38.9 31.1 16.3	26.6 70.1 56.0 30.0	37.3 98.4 78.6 42.7
6	Maximal principal stress	%	5.56	10.0	17.2	5.56	10.0	17.2
7	Maximal number of necessary reinforcements	cm^2	65.5	119.0	180.0	65.5	119.0	180.0

The analysis of the calculation results shows that the values of the first mode of the educational building's own vibration period in the longitudinal (X) and latitudinal (Y) directions are respectively:

$$T_x = 0.907 \text{ sec}; \qquad T_y = 1.07 \text{ sec}.$$

As it is seen from the given numbers the values of the first mode of the building's own vibration period (T1x=T1y=0.26sec.) are 3 time greater than the RABC II-6.02-2006 codes 6.5 point for public reinforced concrete frame buildings defined T1=0.0085xn=0.085x4=0.34sec. criteria. This fact once again proves that the building in the two directions hasn't necessary rigidity.

It should be mentioned that according to Table 7 of the RABC II-6.02-2006 codes the value of storey drifts of RC frame buildings should not be more than the 1/200 part of the storey height, in this case 3300mm/200=16.5mm:

The analysis of the results from table 3.1,1 shows the maximal drift value of the educational building all three cases of the type of soil is exceed the normative standards. Furthermore, the maximal drift value is in the latitudinal and longitudinal directions of the building at the level of the first storey cover accordingly equal to 114.9mm and 98.4mm which exceeds the normative criterion for about 6.0-7.0 times (114.9/16.5=7.0, 98.4/16.5=6.0).

Besides, the percentage of reinforcement required by calculation in the latitudinal and longitudinal directions of the building is maximal 17.2% for III category of soil cat, which also exceeds the 4% stipulated by paragraph 7.8.3 of valid RABC II-6.02–2006 building codes. It means that the surface of the column section of the frame of the building is not sufficient, and the number of necessary reinforcements exceeds what was provided for in the design.

At the Appendix 4 presented the main results of 20 typical schools seismic calculation.

The main results of seismic calculations need for calculating the vulnerability corvey by types (A,B,C,D1,D2) in the future.

According to the definition of "Seismic protection" law the assessment of vulnerability buildings and structures is the prediction of the behavior of buildings and structures in case of earthquakes.

According to order 957-A as of 23.10.2014 approved by the Ministry of Emergency Situations “Methodological instructions for estimating the level (degree) of seismic vulnerability of buildings and structures” defined the following levels of vulnerability.

High:i.e. in case of a potential earthquake with a seismic intensity value of up to 8 points on MSK-64 scale (with maximal expected ground acceleration A_{max}=0.2g) major damages can occur in the constructions of the building with the 4^{th} damage degree according to Table 24 of RABC II-6.02-2006 codes.

Averege: i.e. in case of a potential earthquake with a seismic intensity value of up to 8-9 points on MSK-64 scale (with maximal expected ground acceleration Amax=0.3g) major damages can occur in the constructions of the building with the 3th damage degree according to Table 24 of RABC II-6.02-2006 codes.

Low: i.e. in case of a potential earthquake with a seismic intensity value of up to 9 points and more on MSK-64 scale (with maximal expected ground acceleration Amax=0.4g) moderate damages can occur in the constructions of the building with the 2nd damage degree according to Table 24 of RABC II-6.02-2006 codes.

Taking into account the above mentioned and based on the results of the seismic calculation, Table 3.1.2 below illustrates the levels of vulnerability according to the types – A, B, C, D1, D2.

Table 3.1.2

Project Type	Soil category		
	I	II	III
	Levels of vulnerability		
A	**High**	**High**	**Averege**
B	**High**	**High**	**Averege**
C	**Averege**	**High**	**High**
D1	**Averege**	**High**	**High**
D2	**Averege**	**High**	**High**

3.2 Seismic vulnerability assessment

The vulnerability curve or function shows the connection between the ratio of building damage and seismic intensity. In international practice, loss is accepted as a vulnerability indicator expressed in percentage (0-100%), or a value up to one point (0-1). Picture 3.2.1 shows the damage degrees (1-5) of the building depending on seismic intensity (0-12 points).

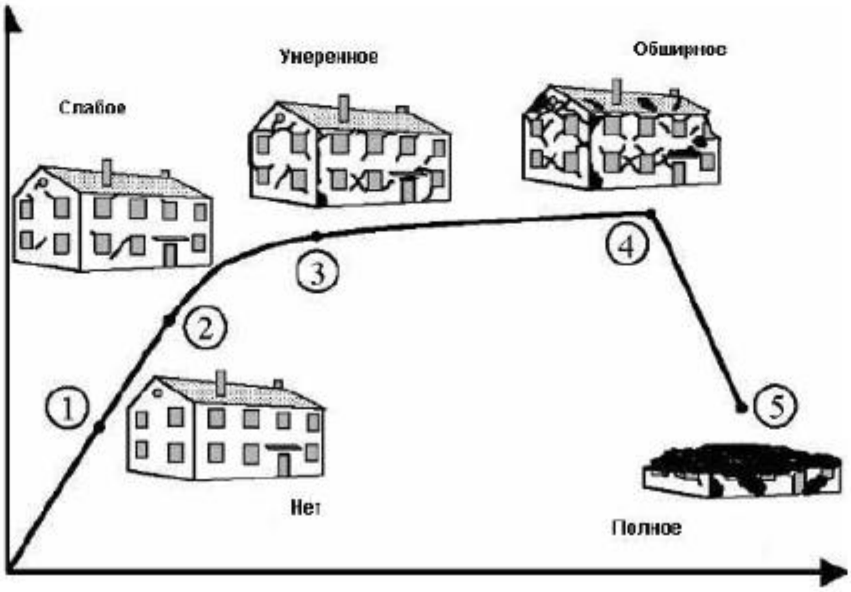


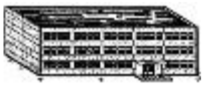
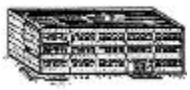
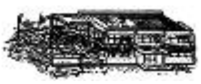
Fig. 3.2.1 The level of damage depends on earthquake intensity

The quantitative and qualitative indicators of damage degrees defined by the European MSK-98 scale and RABC building codes are presented below for stone buildings (A, B) and buildings with reinforced concrete frame skeleton (C,D1,D2).

Classification of damage to masonry buildings

Damage level		Europen codes	Armenian codes
0	-	-	**No damage,** • whitewash flakes chalking
1		**Negligible to slight damage (no structural damage, slight non-structural damage)** • Hairline cracks in very few walls. • Fall of small pieces of plaster only. • Fall of loose stones from upper parts ofbuildings in very few cases.	**Light damage of non-bearing elements** • small cracks (up to O.Smm) in plasterwork; • spalling pieces of plasterwork; • Thin cracks along the edges of partitions and panels.
2		**Moderate damage (slight structural damage, moderate non-structural damage)** • Cracks in many walls. • Fall of fairly large pieces of plaster. • Partial collapse of chimneys.	**Moderate damage of structures** • small cracks (O.S-I mm) in stone lintels, piers,walls; • spalling large pieces of facing and plasterwork, • damaged chimneys, cornices, concrete pipes, parapets
3		**Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** • Large and extensive cracks in most walls. • Roof tiles detach. Chimneys fracture at theroof line; failure of individual non-structural elements (partitions, gable walls).	**Significant damage of structures** • through, inclined and diagonal cracks (1.0-10.0mm)in stone walls; • disintegration of masonry in some elements that do not affect the spatial rigidity of the building; • displacement of some floor slabs; • some cracks on exterior and interior wall abutments; • chimney failure or tilt, collapse of some parapet parts
4		**Very heavy damage (heavy structural damage, very heavy non-structural damage)** • Serious failure of walls; partial structuralfailure of roofs and floors.	**Severe damage of structures** • collapse of exterior self-bearing walls and partial collapse of bearing walls; • anti-seismic belts breaking, and detachment of exterior walls from the interior ones; • substantial displacements of floors slabs and resting areas, falling panels; • concrete destruction, exposure of reinforcements, buckling of longitudinal reinforcements of columns, detachment of embedded fittings.
5		**Destruction(very heavy structural damage)** • Total or near total collapse.	**Collapse** • full or partial destruction of the building

Classification of damage to buildings of reinforced concrete

Damag level		Europen codes	Armenian Codes
0	-	-	**No damage,** • whitewash flakes chalking
1		**Negligible to slight damage** **(no structural damage,** **slight non-structural damage)** • Fine cracks in plaster over frame members or in walls at the base. • Fine cracks in partitions and infills.	**Light damage ofnon-bearing elements** • small cracks (up to O.Smm) in plasterwork; • spalling pieces of plasterwork; • thin cracks along the edges of partitions and panels.
2		**Moderate damage** **(slight structural damage,** **moderate non-structural damage)** • Cracks in columns and beams of framesand in structural walls. • Cracks in partition and infill walls; fall ofbrittle cladding and plaster. Falling mortarfrom the joints of wall panels.	**Moderate damage of structures** • up to 0.5mm cracks in bearing reinforced concrete elements and concrete slivering near the column bases;
3		**Substantial to heavy damage** **(moderate structural damage,** **heavy non-structural damage)** • Cracks in columns and beam column joints of frames at the base and at joints ofcoupled walls. Spalling of conrete cover, buckling of reinforced rods. • Large cracks in partition and infill walls,failure of individual infill panels.	**Significant damage of structures** • disintegration of masonry in some elements that do not affect the spatial rigidity of the building; • displacement of some floor slabs; • some cracks on exterior and interior wall abutments; • local spalling of concrete and crushing of concrete in joggles; • up to 0.5mm cracks and spalling of concrete, exposed reinforcement of columns;
4		**Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** • Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. • Collapse of a few columns or of a single upper floor.	**Severe damage of structures** • anti-seismic belts breaking, and detachment of exterior walls from the interior ones; • substantial displacements of floors slabs and resting areas, falling panels; • significant number of destructed lintels, piers, and partially destructed wall panels in large-panel buildings, destructed walls parts of cast-in-situ buidings; • concrete destruction, exposure of reinforcements, buckling of longitudinal reinforcements of columns, detachment of embedded fittings.
5		**Destruction(very heavy structural damage)** Collapse of ground floor or parts (e. g.wings) of buildings.	**Collapse** • full or partial destruction of the building

The European MSK-98 scale, RABC codes, the joint work with JICA OYO [8] in 2010, the results of seismic calculation carried out by us and the following two factors have served as a basis for building the curves for A,B,C,D1,D2 types of typical designs:

1) Damage data at the Spitak earthquake in 1988
2) Natural period of buildings and soil category

Damage data at the Spitak earthquake in 1988

Damage data about schools owned by Armenian side is very limited, and data of reports by researchers of USA and Japan was used. Observed damage ratio of multi-story residential buildings at the Spitak earthquake in 1988 by the EERI report [10] and estimated ground acceleration by the Japanese report [11]. It is noted that the relation of soil type and buildingperiod affected the damage ratio of buildings.

Vibration period of buildings and soil category

Response spectrum is shown in Armenian Building Code, RABC II-6.02-2006. Figure 3.2.2 shows seismic response of buildings (Dynamic Coefficient β x Coefficient of Soil Conditions ko) for each type of soil and natural vibration period of typical structural types by the Code. Difference of response by soil category is relatively big for the range of longer period.

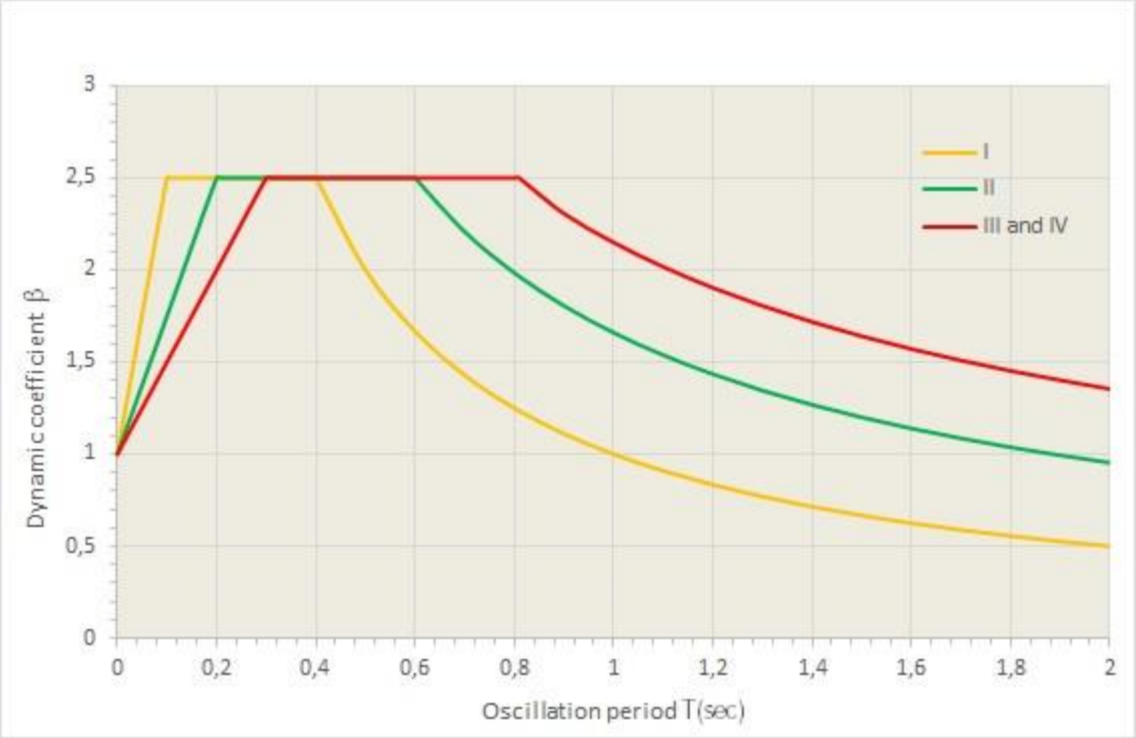


Fig 3.2.2 Response coefficient by soil type and vibration period of buildings

Based on above mentioned below presented the 5 types (A,B,C,D1,D2) curves , which were built by using the following formula.

$$\mathbf{D=50.0[1+tanh(\frac{I+6.25V_i-13.1}{\alpha})]}$$

where`

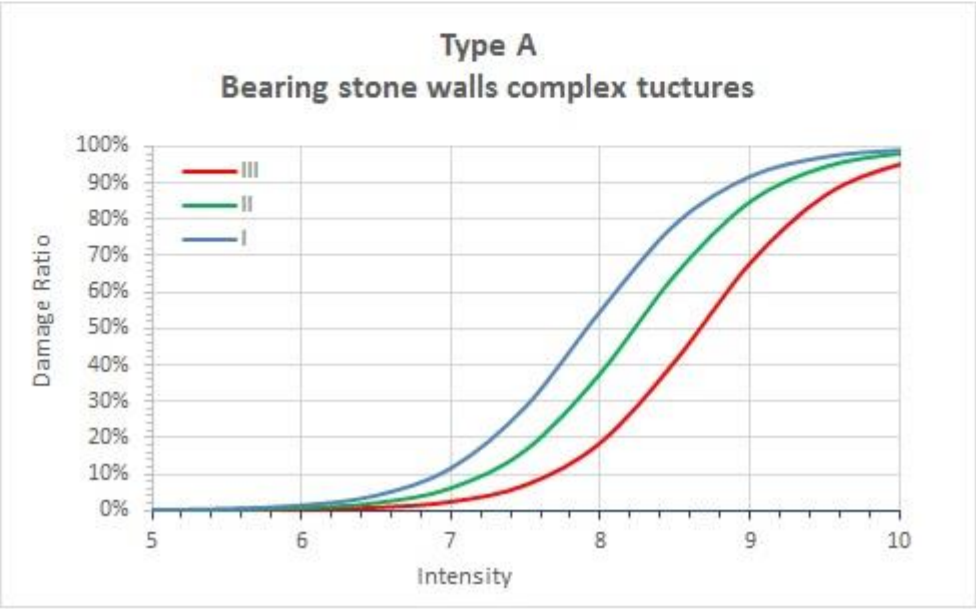
D- demage level (0-100%),

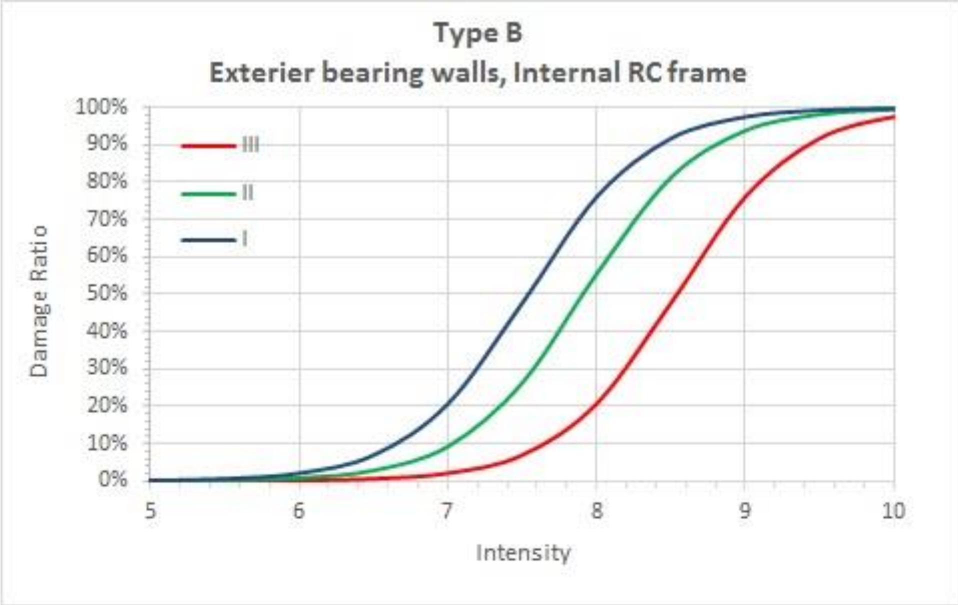
α- abstract oefficient, depend of the type od building,

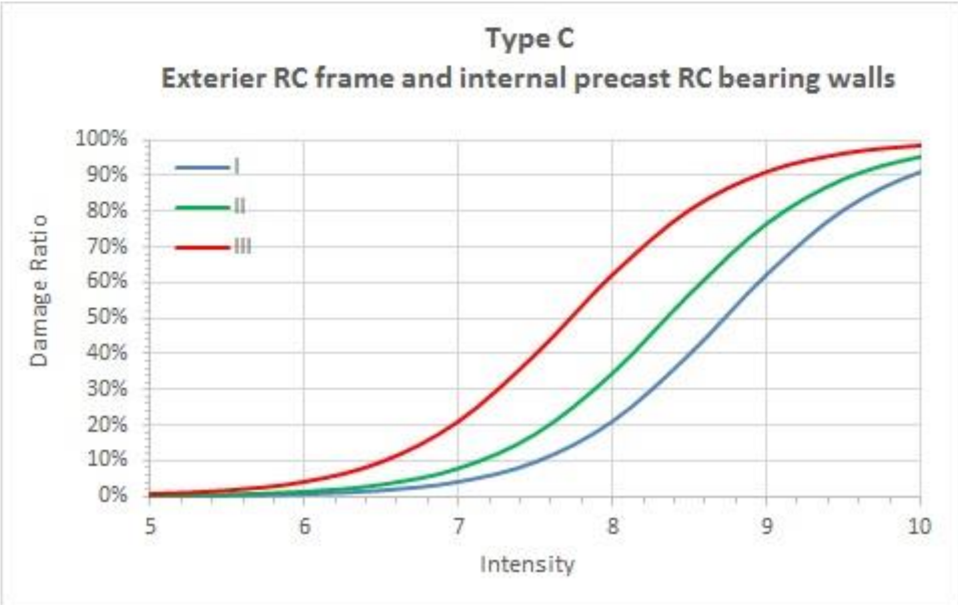
I – The intensity of earthquake (5-10),

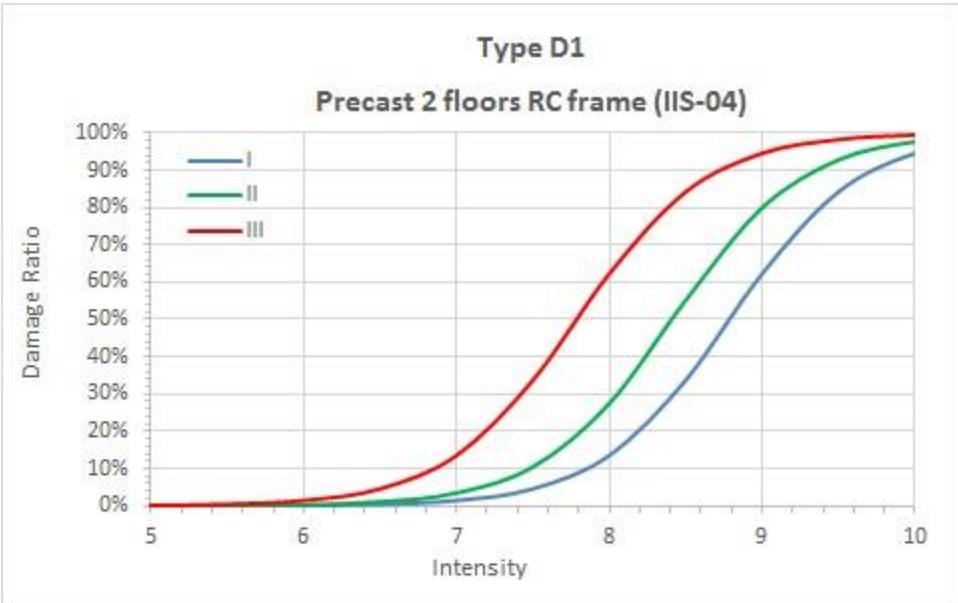
V_I- Vulnerability Index, depend of the type od building and soil category.

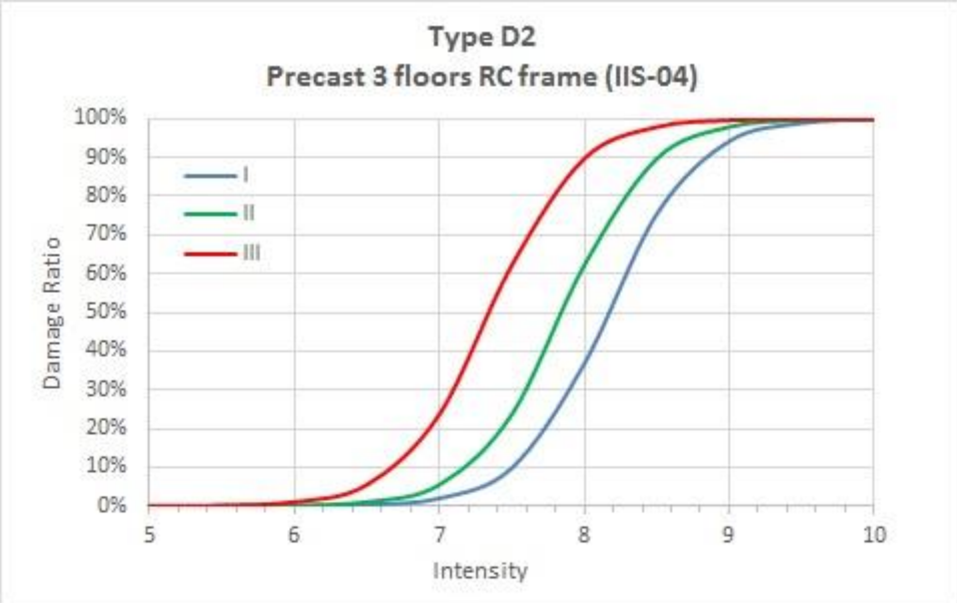
Type	Vulnerability Index (V_i)			□
	Soil category			
	I	II	III	
A	0,83	0,78	0,71	0,9
B	0,8	0,83	0,73	0,8
C	0,7	2,48	0,86	1,1
D1	0,69	0,75	0,85	0,85
D2	0,79	0,84	0,92	0,6




Type B
Exterier bearing walls, Internal RC frame
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Damage Ratio
III
II
I
5
6
7
8
9
10
Intensity


Type C
Exterier RC frame and internal precast RC bearing walls
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Damage Ratio
I
II
III
5
6
7
8
9
10
Intensity


Type D1
Precast 2 floors RC frame (IIS-04)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Damage Ratio
I
II
III
5
6
7
8
9
10
Intensity


Type D2
Precast 3 floors RC frame (IIS-04)
Damage Ratio
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
I
II
III
5
6
7
8
9
10
Intensity

4. IDENTIFICATION OF THE MOST “AT-RISK” SCHOOLS IN ARMENIANIA AND OBSERVATIONAL-INSTRUMENTAL STUDY

4.1 Identification of the most “at-risk” schools in Armenia

There are 1440 secondary schools in the Republic of Armenia. Most of them were built before the devastating Spitak earthquake, and it is obvious that they do not conform to the modern requirements of seismically resistant construction.

Taking into account the circumstance that there is no accurate database on the secondary school buildings in the republic from the point of view of seismic risk assessment (purely in terms of seismic resistence), the aim of the initial phase of the project implementation was to create a respective database. For that purpose, preliminary visual studies were implemented by the EEC working groups in the RA regions and in Yerevan.

In particular, the visits to Ria Taza, Alagyaz, Jamshlu, Tsil Kar and Gegharot communities of the RA Aragatsotn region revealed that thetwo-storey school building of Ria Taza community got moderate damage from the devastating Spitak Earthquake and was renovated with partial strengthenings in 2002 (see picture 4.1.1): In all the remaining 5 communities, the school buildings were strongly damaged by the devastating Spitak Earthquake and their rehabilitation was not considered expedient. Currently, new buildings have been built in all these communities (see picture 4.1.2).

In contrast to Aragatsotn region, the picture is different in Sevan basin, Armavir and Ararat regions and Yerevan.

Fig 4.1.1 School outside and inside views

Fig. 4.1.2 Views of strengthened constructive elements

Fig. 4.1.3 New building schools

Taking into account the aforementioned, the analysis results for typical school designs, a preliminary selection of seismically hazardous schools has ben done as a result of comparison and analysis of collected database. The following documents have served as a base for the selection:

1. The list formed by the RA Ministry of Urban Development (1264 schools) and the information provided by the National Center for Education Technologies,

2.The list of RA settlements by seismic zone determined by the RABC II-6.02-2006 codes,

3.The 1:750000 scale geological map of the RA territory (the Atlas published by the "Center of Geodesy and Cartography" SNCO of the State Real Estate Cadaster under the RA Government in 2007, page 27),

4. The 1:1000000 scale landslide map of the RA territory (the Atlas published by the "Center of Geodesy and Cartography" SNCO of the State Real Estate Cadaster under the RA Government in 2007, page 38),

5.The school database of southern, western and northern SNCOs of the Service for Seismic Protection of the Ministry of Emergency Situations,

6.Designs of 20 typical buildings.

For the purpose of selecting the most seismically hazardous schools, an evaluation scale has been developed based on the list developed by the RA Ministry of Urban Development and the lists provided by the National Center for Education Technologies, as well as based on numerous discussions between team leaders, advisors and representatives of the UN Children's Fund. The scale includes the following 7 main indicators:

1. The seismic hazard level of the area,
2. Vulnerability degree of the typical building,
3. Number of students,
4. The date of construction of the school,
5. The technical state (according to the existing database),
6. The existence of secondary hazards in the school area (landslide, rockfall, mudflows, flood, etc.),
7. The existence of buildings, structures, objects with high vulnerability adjacent to the school.

Seismic Safety Evaluation Scale

1. The Seismic Hazard Level of the Area						
I seismic zone 20	II seismic zone 30	III seismic zone 50	0.30 Weight coefficient	I seismic zone 6.00	II seismic zone 9.00	III seismic zone 15.00
2.Vulnerability Degree of Typical School						
Low 10	Medium 30	High 60	0.30 Weight coefficient	Low 3.00	Medium 9.00	High 18.00
3.Number of Students						
Up to 200 20	200-400 30	More than 400 50	0.10 Weight coefficient	Up to 200 2.00	200-400 3.00	More than 400 5.00
4. Date of Construction of the School						
Until 1960 35	1960-1970 25	1970-1988 40	0.10 Weight coefficient	Until 1960 3.50	1960-1970 2.50	1970-1988 4.00
5. Technical State (According to the Existing Database)						
Good 10	Satisfactory 40	Unsatisfactory 50	0.10 Weight coefficient	Good 1.00	Satisfactory 4.00	Unsatisfactory 5.00
6. ExistenceofSecondaryHazardsintheSchoolArea(Landslide, Rockfall, Mudflows, Flood, andetc.)						
Not existent 0	Medium 20	High 80	0.06 Weight coefficient	Not existent 0.00	Medium 1.20	High 4.80
7.ExistenceofBuildings, Structures, ObjectswithHighVulnerabilityadjacenttotheSchool						
Not existent 0	Medium 30	High 70	0.04 Weight coefficient	Not existent 0.00	Medium 1.20	High 2.80
95	**205**	**400**	1.00	**14.25**	**29.75**	**56.00**

Based on the analysis results of the Table, the following evaluations are given from the perspective of seismic safety:

- Schools having high level of safety-14.25
- Schools having medium level of safety -14.25-29.75
- Schools having low level of safety -29.75-56.00

Each indicator of the scale has its weight which is based on the following considerations:

1. Taking into consideration the high level of seismic hazard in the territory of Armenia, the seismic hazard indicator has 0,3 weight only in 1,0 weight. Moreover, taking into account that the seismic hazard in the RA territory is divided into three zones according to Armenian norms (1st zone – 0,2g or 7-8 points, 2nd zone – 0,3g or 8-9 points, and 3rd zone – 0.4g or 9 and higher), each zone is also estimated as 1st zone – 20%, 2nd zone – 30%, and 3rd zone – 50%.

2. The next important indicators are the peculiarities of constructive solutions and seismic vulnerability of the typical school.As a whole, this indicator is also estimated by 0,3 coefficient or 30% representation, and the vulnerability degrees are respectively estimated as low – 10%, medium – 30%, high – 60%.

3. As the seismic safety of schools is directly related to the number of students studying at the school, that indicator is also considered to be important and its weight has been accepted as 0,1. That indicator is also characterized by three levels. Up to 200 students – 20%, 200-400 students – 30%, and more than 400 students – 50%.

4. The analysis of consequences of the devastating Spitak Earthquake has shown(Spitak Tragedy Should Not Happen Again), that buildings constructed during different periods have different seismic resistance indicators. This factor is also important for the evaluation of seismic safety of schools and it has resulted to be 0,10 weight in the scale. Moreover, the buildings constructed before the 1960s have been considered by 35% representation, 1960-1970 – 25%, and 1970-1988 – 40%.

5. Taking into account the fact that the factual seismic resistance of the school building is directly related to the factual technical state of the school as well, this indicator has also been taken into account and its weight has been accepted as 0.10. This indicator is also characterized by three levels:

- good (first degree) 10%, that is, there are no deformations, there are separate mnor defects which can be eliminated during ongoing repairs and which do not affect the exploitation of constructive elements.

- satisfactory (second degree) 30%, that is, constructive elements are generally fit for use, but they require some capital repair which is the most necessary at the moment.

- unsatisfactory (third degree) 60%, that is, the exploitation of constructive elements is possible only after capital repair.

6. It is known that other secondary hazards are generated during earthquakes (rockfall, landslide, flooding because of reservoir collapse, etc.). Thus, this factor has also been considered for seismic safety evaluation of the school and its weight has been accepted as 0,06.

7. The seismic vulnerability of existing buildings, objects and other structures is also an important factor which has been estimated by 0.04 weight in the general scale.

Based on discussions and analyses, 60 “most vulnerable“ schools (Appendix 5, page 2) were finally selected from the pre-selected 132 schools (Appendix 5, page 1). The schools having low safety level have been included in the schools list taking into account the high level of landslides in the area (schools in Tavush region).

EEC head of WSSP SNCO, the project leader Zaven Khlghatyan, together with the head of DRR programs from UNICEF T. Tovmasyan and S. Kalantaryan, participated in the meetings with principals of schools subject to study in the RA Gegharkunik, Armavir, Ararat, Syunik, Kotayk, Vayots Dzor regions and Yerevan city. The methodology developed by the Western Survey of Seismic Protection, the works to be carried out at schools and their importance were discussed during the meetings.

4.2 Observational-instrumental study

In total,carried outobservational-instrumental studyof the "most at risk" 60 schools buildings and structures within a framework of this program. The observational-instrumental study included the solution of the following problems.

- Clarification of the volumetric-design and constructive solutions of the buildings,
- Observational study of the school buildings,
- Instrumental study of the school buildings,
- Determination of concrete strength of reinforced concrete constructions of the buildings by the instrumental method,
- Collection of information on the ground conditions of the school territory
- Determination of dynamic properties of the school territory by the instrumental method,
- Determination of dynamic properties of the school from microtremors,
- Determination of the degree of physical depreciation of the school building,
- Assessment of the seismic vulnerability of the School buildings,
- Summaries and recommendations for rehabilitation and strengthening of the school buildings.

For the purpose of revealing the factual volumetric-design and constructive solutions of the school buildings, as well as for their technical state assessment a detailed study of the reinforced concrete (RC) frames (columns, beams, connecting beams), interfloor covers and upper cover RC slabs, perimeter walls, lintels, staircases and other constructive elements has been carried out; besides, measurement and photography works have been done. For the purpose of on-site study of RC frame junctions, joints of longitudinal operational reinforcements, joints of precast RC floor slabs, as well as junctions attaching self-bearing perimeter walls to the RC frame, coreesponding junctions have been opened. The existence of damages, cracks and deformations of the constructive elements of the buildings has been revealed, the thickness and factual condition of the concrete protective layer of the reinforcements have been assessed, the specification of locations of eroded sections and cracks of the concrete protective layer of the reinforcements has been made, the existence of corrosion in the reinforcements and steel supplementary elements has been revealed, the factual condition of the reinforcements has been assessed, and with this regard qualitative and quantitative assessments have been made [13-15]. The nature and degree of damage to the RC constructions and other constructive elements have been determined. The existence of displacements of the supporting parts of the constructive elements has been revealed, their locations and sizes have been determined (see fig. 4.2.1-4.2.8 episodes fromvisual study).

Fig. 4.2.1 Episodes of research of schools in Ararat marz


Fig. 4.2.2 Episodes of research of schools in Tavush




Fig. 4.2.3 Episodes of research of schools in Vayoc Dzor marz



Fig. 4.2.4 Episodes of research of schools in Ghegarkunik




Fig. 4.2.5 Episodes of research of schools in Yerevan



Fig. 4.2.6 Episodes of research of schools in Armavir marz


Fig. 4.2.7 Episodes of research of schools in Kotayq marz




Fig. 4.2.8 Episodes of research of schools in Yerevan

➢ The factual concrete strength of the reinforced concrete frame was determined by the non-destructive method with the help of “Schmidt-Hammer” (serial number 2P0003). The instrument “Schmidt-Hammer” operates by the method of elastic rebound. This work was performed according to the requirements of RA national standard “Concrete. Determination of strength by mechanical methods of non-destructive testing” (GOST 22690-80) [2]. The measurements were carried out in different storeys and different axes of different school buildings (see fig. 4.2.9).

Fig. 4.2.9 Episodes of determination of factual concrete strength of reinforced concrete frame of Secondary school #14 after Nar-Dos at Yer. Kochar 12/1, Yerevan with “Schmidt-Hammer”

➢ According to paragraph 5.3.3 of the RABC II-6.02-2006 Codes if the soil profile at the construction site is not uniform as is the case with the soil of Aremenian territory, the soil category is assigned by their dynamic characteristics, as per Table 3. According to this table from the ground categories obtained on the basis of the T_0 free oscillation value the next higher number is taken as the design category. The predominant period of the ground T_0 is determined theoretically or experimentally (on the basis of microseismic measurements) according to these codes. Respective instrumental measurements have been done to determine the natural periods of vibration for soils of 60 most risky schools in the school areas and in the buildings (see pic. 4.2.10).

Fig 4.2.10 Episode from instrumental record of soil own vibrations of Secondary school #14 after Nar-Dos at Yer. Kochar 12/1, Yerevan.

Records of soil vibration have been carried out using GURALP 6TD(made in Britain) broadband digital seismometer which incorporates a three-component velocity measuring sensor. The device allows to record oscillation within 0.01-50Hz frequency range. Before making a spectral analysis, records of velocity were modified into acceleration.

The vibrations were recorded in the period of 40-140sec.

As an example figures 4.2.11 and 4.2.12 show the records made, and fig. 4.2.13 and 4.2.14 show the record analysis in the two (X-latitudinal and Y-longitudinal) horizontal directions of the bulding.

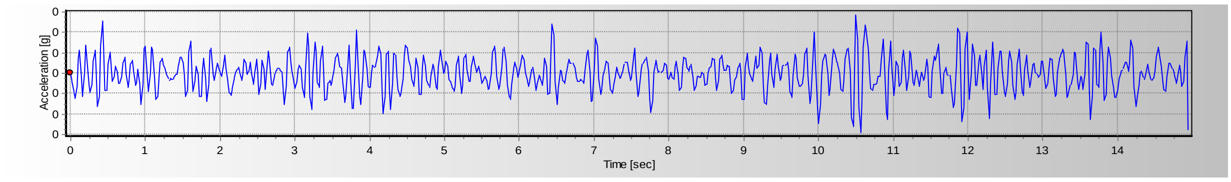


Fig. 4.2.11 Record of acceleration in axis X

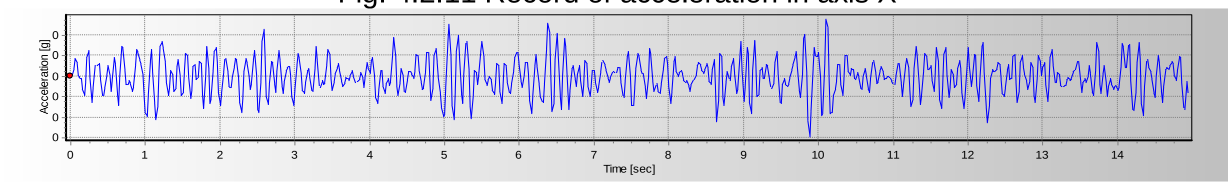


Fig. 4.2.12 Record of acceleration in axis Y

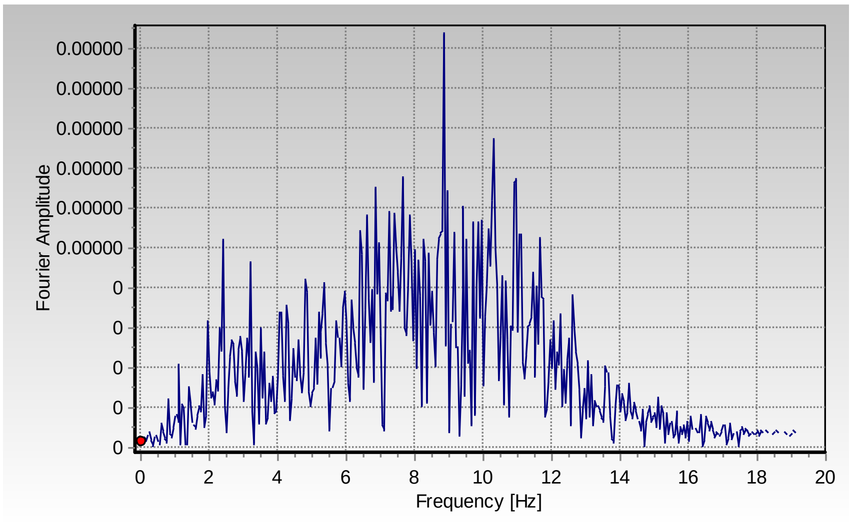


Fig. 4.2.13 The Fourier spectrum in axis X (latitudinal)

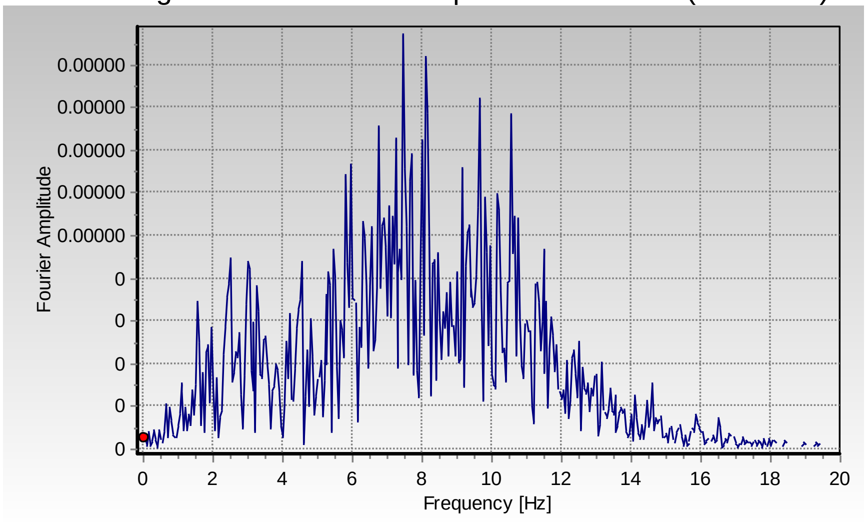


Fig. 4.2.14 The Fourier spectrum in axis Y (longitudinal)

Analysis of records has been made with the method of Fourier. The prevailing frequencies of the soil own horizontal vibrations of the site have been determined through the obtained spectrum (see fig. 4.2.13, 4.2.14). They are in the 2.3Hz ÷ 3.3Hz range. From here we obtain the period range:

$$T_{01}= 1/(3.3+2.3)/2 \approx 0.36\text{sec.}$$

According to paragraph 5.3.3. of the RABC II-6.02-2006 Codes 1.3T_0 is taken as the design value (0.36x1.3=0.47sec.). Under such conditions according to table 3 of the codes the soil category of the school territory is considered to be second category.

- In order to obrain reliable information during the evaluation of the seismic resistance of buildings it is necessary to take into consideration a row of factors defining their behavior during earthquake, one of which is the factual periods of their own vibration[16-18]. Instrumental determination of own vibration periods of structures is a basis for the specification of their computing schemes and assessment of the damage level according to paragraph 6.5 of RABC II-6.02.2006 “Earthquake Resistant Construction: Design codes”. It is essential for the assessment of the vulnerability level of buildings.

Thus, the actual values of own vibrations of prevailing periods of buildings allow to assess their vulnerability level and to take relevant measures with the aim of assuring the seismic resistance of the structure.

As an example below presented determining the own vibration period of the buildings of Secondary school #14 after Nar-Dos at Yer. Kochar 12/1, Yerevan instrumental measurements. Vibration records of the buildings have been carried out using Guralp-6TDseismometer.

The measurements have been carried out at the level of the second floor cover of the educational building of the school (see fig. 4.2.15).

:

Fig. 4.2.15 Episode from the instrumental record of own vibrations of the educational building of Secondary school #14 after Nar-Dos at Yer. Kochar 12/1, Yerevan

The filtered records in the range 0.1-10Hz are illustrated in figures 4.2.16 and 4.2.17 and the analysis of those records in two horizontal (X, Y) directions is illustrated in figures 4.2.18 and 4.2.19 X direction was taken in the latitudinal direction of the building.

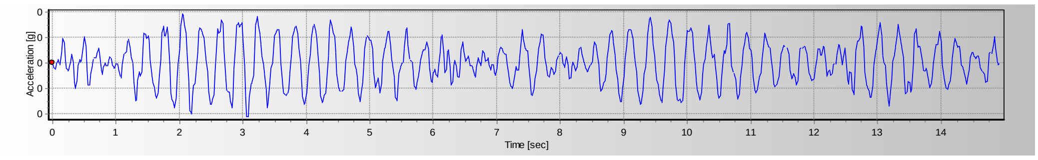


Fig. 4.2.16 Record of acceleration in axis X (latitudinal)

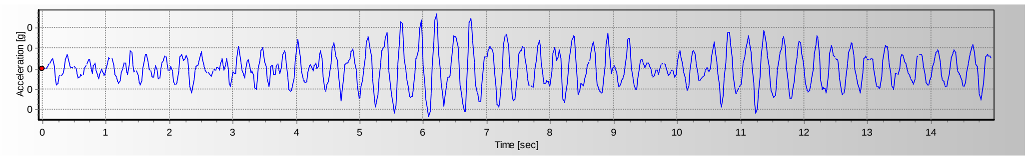


Fig. 4.2.17Record of acceleration in axis Y (longitudinal)

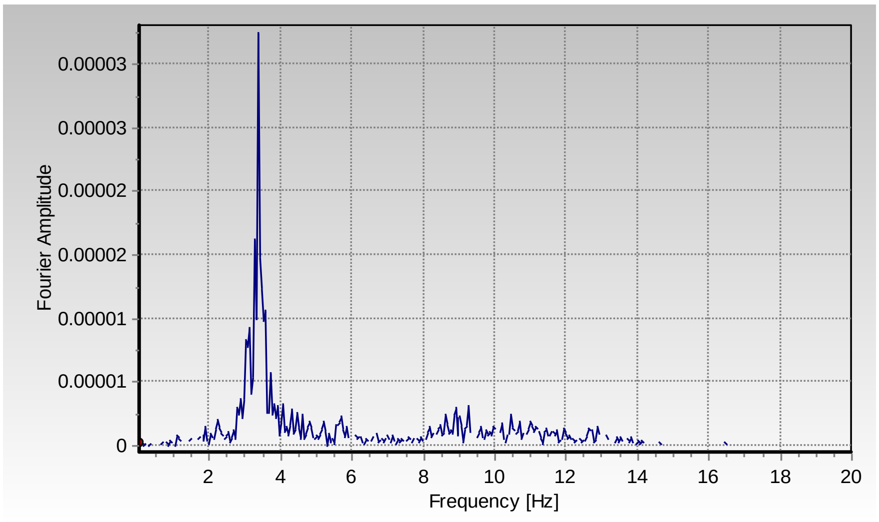


Fig. 4.2.18 The Fourier spectrum in axis X (latitudinal)

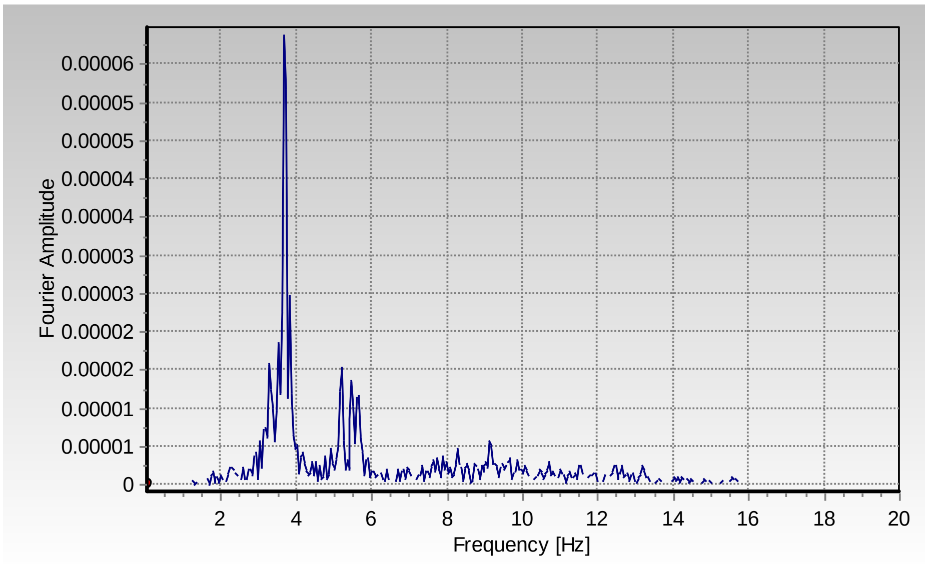


Fig. 4.2.19 The Fourier spectrum in axis Y (longitudinal)

The analysis of the records was carried out with the method of Fourier and it shows that the vibration periods of the building in the latitudinal and longitudinal directions are close to each other and equal 3.3Hz and 3.7Hz respectively:

$$T_x = 1/3.3\text{Hz} \approx 0.30 \text{ sec.}$$

$$T_y = 1/3.7\text{Hz} \approx 0.27\text{sec.}$$

Comparing the prevailing period value T_0=0.47sec. of site soil vibrations determined by instrumental measurements with the free oscillation values of the first mode T_1=0.35÷0.39sec. of the educational building, we see that $1.5T_1 < T_0$ requirement of paragraph 7.1.8. of RABC II-6.02.2006 codes are met (1.5x0.30sec.=0.45sec.<0.47sec.):

➢ Relevant notifications have been provided by "Erkraban-Utiq" LLC on the soil conditions of the 60 riskiest schools of RA., below in table are given geological structure of the site, a brief description of the soil and the value of their physical and mechanical properties.

As an example below presented the references given by the Secondary school N14 after Nar-Dos at 12/1 Er. Kochar.

layer number	Average thickness of the layer	Soil name	Brief description of the soil	values of the physical and mechanical properties of the soils					
				ρ (g/sm^3)	φ (^{0})	C (KPa)	E_0 (MPa)	R_0 (MPa)	c_1 t/m^3
1	0.1-0.3	Asphalt-bituminous cover	On preliminary gravel foundation	1.75	—	—	—	—	—
2	1.0-1.1	Filling ground, no rammed	Of rubble and gruss ground composition with clayey and sandy materials up to 30%	1.70	—	—	—	—	—
3	2.0-2.2	Rubble and gruss ground	Of volcanic rocks with blocks, with clayey sand filling up to 20-30%	1.90	32	2	32	0.30	5000
4	3.0	Basalt, andesite-basalt	Gray color, with multi-colored hues, fissured with big lumpy generations	2.50	—	—	—	0.50	30000

where:ρ- density, φ- inner friction angle, grad, C- specific coherence, E_0 - deformation modulus, R_0 - Conventional calculated resistance, c_1- coefficient of subgrad.

By the hydrogeological point of view, the ground waters are associated with non-differentiated complexes of Neogen- Quaternary volcanic formations: In accordance with archival datac, ground waters is located deeper than 15.0 meters.

The territory and the area of the schools have favorable geotechnical, hydrogeological and climatic conditions.

➢ The physical depreciation of schools buildings were determined according to valid RA “Methodological instructions for examining the technical state of residential, community and industrial buildings and structures” [3].

The physical depreciation of a construction, an element or a system that have varied degrees of depreciation in different segments is determined by the following formula:

$$\Phi_{ц} = \sum_{i=1}^{n} \Phi_i \frac{P_i}{P_{ц}}$$

where

$\Phi_{ц}$ - is the physical depreciation of the construction, element or system, %,

Φ_i - is the physical depreciation of Segment i of the construction, element or system, %,

P_i - denotes the sizes of the affected segment (area or length), m^2 or m,

n - is the number of damaged segments,

$P_{ц}$ - denotes the sizes of the whole construction, m^2 or m

The physical depreciation of the building has been determined by the following formula:

$$\Phi_2 = \sum_{i=1}^{n} \Phi_{цi} L_i / L$$

Where:

Φ_2 -is the physical depreciation of the building, %,

$\Phi_{цi}$ -is the physical depreciation of an individual construction, element or system, %,

L_iL- is the correlation between the value of an individual construction, element or system and the value of the whole building,

n - is the number of individual constructions, elements or systems inside the building.

Drawn up reports for selected 60 schools, where are presented technical condition, physical depreciation, compliance with the current seismic codes, the value of seismic vulnerability. Recommendations given on Improved seismic capacity, rehabilitation and reconstruction (Appendix 8). Besides, respective seismic safety passports have been formed for each of the building of the school according to methodical instructions (Appendix 6).

The main results of the study are presented in the summary form in the table 4.2.1 below.

:

Table 4.2.1

	The names of schools in residential areas.	Type	Averaged values of the concrete compressive strength (kgs/cm^2)	The predominant period of the ground of the site T_0	Soil category	Values of the vibration periods two horizontal (X, Y) directions		Physical depreciation of the school building	The technical state estimate/ the degree of damage	Estimating the level (degree) of seismic vulnerability	Level of reconstruction
						Tx	Ty				
1	2	3	4	5	6	7	8	10	11	12	13
	Yerevan										
1	Yerevan primary school № 50	no typical	200-250	0.39sec.	2nd	0. 26sec.	0.30sec.	49%	insufficient/ third degree	High	Change functional
2	Yerevan primary school № 187	15	300-400	0.47 sec.	2nd	0. 26sec.	0. 26sec.	42%	insufficient/ third degree	High	Improved seismic capacity
3	Yerevan primary school № 135	10	300-400	0.38 sec.	2nd	0.25sec.	0.24 sec.	42%	insufficient/ third degree	High	Improved seismic capacity
4	Yerevan primary school № 11	15	300-400	0.30 sec.	2nd	0.29sec.	0.30sec.	34%	satisfactory/ second degree	High	Improved seismic capacity
5	Yerevan primary school № 124	no typical	300-400	0.35sec.	2nd	0.21sec.	0.18sec.	45%	satisfactory/ second degree	High	Improved seismic capacity
6	Yerevan primary school № 14	15	300-400	0.36sec.	2nd	0.30sec.	0. 27sec.	37%	satisfactory/ second degree	High	Improved seismic capacity
7	Yerevan primary school № 162	11	300-400	0.43sec.	2nd	0.19sec.	0.19sec.	32%	satisfactory/ second degree	High	Improved seismic capacity
8	Yerevan primary school № 117	no typical	300-400	0.40sec.	2nd	0.21sec.	0.29sec.	22%	satisfactory/ second degree	High	Change functional
9	Yerevan primary school № 153	10	300-400	0.37sec.	2nd	0.25 sec.	0.26 sec.	37%	satisfactory/ second degree	High	Improved seismic capacity
10	Yerevan primary school № 132	10	300-400	0.33sec.	2nd	0.20 sec.	0.22 sec.	29%	satisfactory/ second degree	High	Improved seismic capacity
11	Yerevan primary school № 156	11	300-400	0.30sec.	2nd	0.24 sec.	0.28 sec.	32%	satisfactory/ second degree	High	Improved seismic capacity
12	Yerevan primary school № 158	11	300-400	0.27sec.	1st	0.20 sec.	0.18 sec.	32%	satisfactory/ second degree	High	Improved seismic capacity
13	Yerevan primary school № 122	no typical	150-200	0.33sec.	2nd	0.33 sec.	0.28 sec.	47%	insufficient/ third degree	High	Change functional
	Armavir region										
14	Nalbandyan secondary school	no typical	275-350	0.25sec.	2nd	0.25sec.	0.22 sec.	33%	satisfactory/ second degree	High	Improved seismic capacity
15	Aygeshat secondary school	no typical	150-200	0.25sec..; 0.37sec.	2nd	0.40sec.	0.37 sec.	30%	satisfactory/ second degree	High	Improved seismic capacity
16	Armavir primary school № 6	7	75-100	0.29 sec.	2nd	0.23sec.	0.19 sec.	31%	satisfactory/ second degree	High	Improved seismic capacity
17	Paraqar secondary school	7	75-100	0.32sec.	2nd	0.35sec.	0.26sec.	45%	insufficient/ third degree	High	Change functional
18	Haytax secondary school	no typical	100-150	0.40–0.33 sec.	2nd	0.16sec.	0.14sec.	30%	satisfactory/ second degree	High	Improved seismic capacity
	Ararat region										
19	Artashat secondary school № 1	no typical	100-150	0.37 sec.	2nd	0.29 sec.	0.29 sec.	27%	satisfactory/ second degree	High	Improved seismic capacity
20	Avshar secondary school	10	75-100	0.33 sec.	2nd	0.29 sec.	0.31 sec.	31%	satisfactory/ second degree	High	Improved seismic capacity

21	Masis primary school № 4	17	300-400	0.48sec.	2nd	0.30sec.	0.30sec.	42%	insufficient/ third degree	High	Improved seismic capacity
22	Shahumyan secondary school	19	75-100	0.33sec.	2nd	0.22sec.	0.21sec.	27%	satisfactory/ second degree	High	Improved seismic capacity
23	Masis secondary school	10	75-100	0.29sec.	2nd	0.27sec.	0.37sec.	24%	satisfactory/ second degree	High	Improved seismic capacity
24	Norashen secondary school	no typical	150	0.40sec.	2nd	0.24sec.	0.20sec.	24%	satisfactory/ second degree	High	Improved seismic capacity
25	Ararat primary school № 1	no typical	75-100	0.37 sec.	2nd	0.27sec.	0.33sec.	41%	insufficient/ third degree	High	Improved seismic capacity
26	Vedi primary school № 1	no typical	200-250	0.40sec.	2nd	0.27sec.	0.27sec.	46%	insufficient/ third degree	High	Improved seismic capacity
27	Nor Kharbert secondary school № 2	10	300-400	0.43sec.	2nd	0.24sec.	0.21sec.	51%,	insufficient/ third degree	High	Improved seismic capacity
28	Artashat secondry school	no typical	100-150	0.40sec.	2nd	0.26 sec.	0.26 sec.	35%,	satisfactory/ second degree	High	Improved seismic capacity
29	Artashat secondary school № 5	no typical	125-150	0.31sec.	2nd	0.29sec.	0.29sec.	30%,	satisfactory/ second degree	High	Improved seismic capacity
30	Artashat primary school № 2	no typical	100-150	0.40sec.	2nd	0.23sec.	0.29sec.	26%	satisfactory/ second degree	High	Improved seismic capacity
	Gexarquniq region										
31	Tsovasar secondary school	no typical	200-300	0.27sec..	2nd	0.14 sec.	0.18 sec.	27%	satisfactory/ second degree	High	Improved seismic capacity
32	Martuni primary school № 1	11	300-400	0.32 sec.	2nd	0.22sec.	0.20sec.	32%,	satisfactory/ second degree	High	Improved seismic capacity
33	Sarukhan secondary school № 1	no typical	300-400	0.40sec.	2nd	0.20sec.	0.22sec.	35%,	satisfactory/ second degree	High	Improved seismic capacity
34	Gavar Basic School №2	10	75-100	0.33sec.	2nd	0.21sec.	0.33sec.; 0.15sec.	41%	insufficient/ third degree	High	Change functional
35	Mets Masrik secondary school	11	300-400	0.40 sec.	2nd	0.22sec.	0.21sec.	43%	insufficient/ third degree	High	Improved seismic capacity
	Lori region										
36	Alaverdi secondary school № 12	11	300-350	0.29sec.	2nd	0.12sec.	0.11sec.	43%	insufficient/ third degree	High	Improved seismic capacity
37	Vanadzor primary school № 4	10	250-300	0.14sec.	2nd	0.24 sec.	0.24 sec.	12%	good / first degree	Intermediate	Improved seismic capacity
38	Odzun secondary school № 1	10	250-350	0.40sec.	2nd	0.24 sec.	0.18 sec.	30%	satisfactory/ second degree	High	Improved seismic capacity
	Kotayq region										
39	Garni Basic School N1	no typical	200-250	0.31sec.	2nd	0.22 sec.	0.18 sec.	37%	satisfactory/ second degree	High	Improved seismic capacity
40	Hrazdan Basic School N11	11	300-400	0.30sec.	2nd	0.22 sec.	0.19 sec.	35%	satisfactory/ second degree	High	Improved seismic capacity
41	Abovyan Basic School N8	16	300-400	0.25sec.	2nd	0.25 sec.	0.25 sec.	43%	insufficient/third degree	High	Improved seismic capacity
	Shirak region										
42	Shirakavan Secondary School	4	300-350	0.37 sec.	2nd	0.17 sec.	0.17 sec.	30%	satisfactory/ second degree	High	Improved seismic capacity
43	Gyumri Basic School N4	no typical	-	0.43 sec.	2nd	0.33 sec.	0.37 sec.	22%	satisfactory / first degree	Intermediate	Improved seismic capacity
	Syuniq region										
44	Kapan Basic School N7	10	270-340	0.23 sec..	2nd	0.15sec.	0.21sec.	40%	satisfactory/	High	Improved seismic capacity

									second degree		
45	Synuik Secondary School	typical	270-350	0.24sec..;	2nd	0.15sec.	0.19 sec.	42%	insufficient/ third degree	High	Improved seismic capacity
46	Lernadzor Basic School	typical	-	0.14sec.	2nd	0.15sec.	0.19 sec.	42%	insufficient/ third degree	High	Improved seismic capacity
47	Shinuhayr Secondary School	typical	270-360	0.20sec..	1st	0.14sec.	0.15sec.	9%	good / first degree	Intermediate	Improved seismic capacity
48	Meghri Secondary School N2	no typical	-	0.16sec.	1st	0.15sec.	0.15sec.	35%	satisfactory/ second degree	High	Improved seismic capacity
49	Tashtun Basic School	typical	-	0.16sec.	1st	0.15sec.	0.15sec.	49%	insufficient/ third degree	High	Improved seismic capacity
50	Alvank Secondary School	4	280-340	0.22sec..; 0.16sec.	2nd	0.21 sec.	0.19 sec.	41%	insufficient/ third degree	High	Improved seismic capacity
51	Kajaran Secondary School N1	no typical	130-200	0.28sec..	2nd	0.30 sec.	0.30 sec.	27%	satisfactory/ second degree	High	Improved seismic capacity
52	Dastakert Secondary School	no typical	-	0.33sec..	2nd	0.15sec.	0.19 sec.	47%	insufficient/ third degree	High	Improved seismic capacity
	Tavush region										
53	Ijevan Basic School N3	typical	100-150	0.29sec..	2nd	0.20 sec.	0.28 sec.	29%	satisfactory/ second degree	High	Improved seismic capacity
54	Haghartsin Secondary School	typical	100-150	0.31sec..	2nd	0.22 sec.	0.29 sec.	30%	satisfactory/ second degree	High	Improved seismic capacity
55	Berd Basic School N1	no typical	100-150	0.25sec..	2nd	0.17sec.	0.18sec.	11%	satisfactory/ second degree	Intermediate	Improved seismic capacity
	Vayots Dzor region										
56	Yegheghadzor Basic School N1	10	100-150	0.27 sec..	2nd	0.22 sec.	0.19 sec.	28%	satisfactory/ second degree	High	Improved seismic capacity
57	Arpi Secondary School	typical	200-250	0.16 sec.	1st	0.17 sec.	0.21 sec.	30%	satisfactory/ second degree	High	Improved seismic capacity
58	Aghavnadzor Secondary School	no typical	200-250	0.192 sec.	1st	0.20 sec.	0.17 sec.	29%	satisfactory/ second degree	High	Improved seismic capacity
59	Yegheghadzor Basic School N2	no typical	150-200	0.24sec.	2nd	0.22 sec.	0.19 sec.	30%	satisfactory/ second degree	High	Improved seismic capacity
60	Martiros Secondary School	2	75-100	0.31 sec.	2nd	0.17 sec.	0.17 sec.	41%	insufficient/ third degree	High	Improved seismic capacity

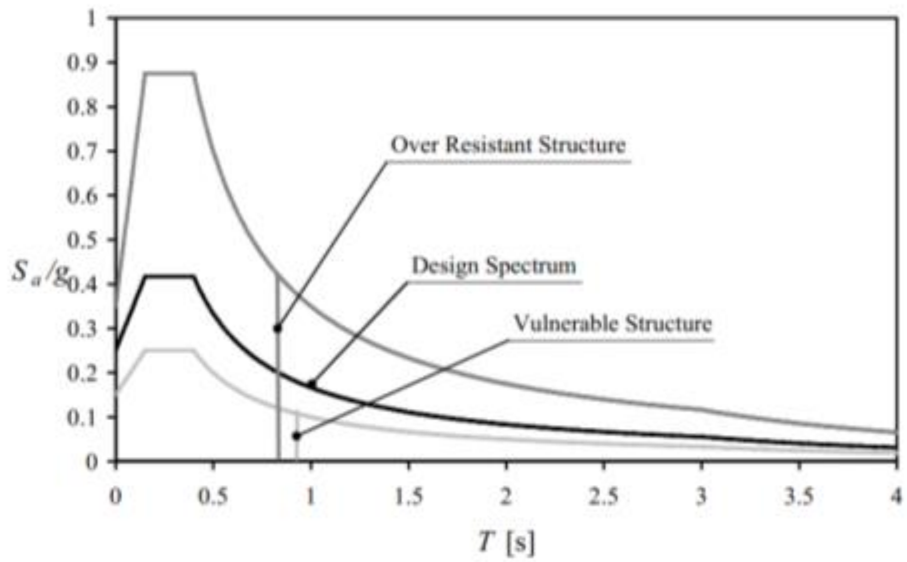
5. BEST METHOD OF REHABILITATION FOR BUILDINGS OF SCHOOLS. CONSOLIDATED COPST ESTIMATE

5. 1 Best method of rehabilitation for buildings of schools

To select the best method of rehabilitation study of the international practice has been carried out. The general strategy of strengthening of existing buildings and the international and the Amenian practice are given in this chapter**.**Both the traditional and innovative methods of retrofitting of structures are represented below.

5.1.1 Seismic resistance and vulnerability

Because it is necessary to retrofit only constructions vulnerable to the design earthquake, a vulnerability evaluation is obviously needed before attempting any seismic retrofitting. In the following, a definition of seismic resistance is provided and the corresponding vulnerability of a construction to the design earthquake is also defined. As has been seen, the design earthquake is specified by means of a design spectrum which depends on the energy dissipation capacity through the structure behaviour factor. Assuming that the structure behaviour factor for the structure being considered can be evaluated, the design spectrum can be drawn. An example of such a spectrum is shown in Figure 5.1.1.1.



Figur 5.1.1.1 Comparison between seismic resistance and seismic demand

If a structure exhibits seismic resistance larger than that required by the design earthquake, it obviously possesses an over-resistance and therefore is not vulnerable. This is the case shown by the longer ordinate in Figure 5.1.1.1.A structure with the resistance specified by such an ordinate is capable of withstanding an earthquake with an anchoring acceleration larger than that associated with the design earthquake. Instead if the seismic resistance of the structure corresponds to the shorter ordinate in Figure 5.1.1.1, it is obvious that the resistance capacity is smaller than the demand that the earthquake places on it and the structure is vulnerable to the design earthquake. In this second case the structure can only withstand an earthquake with an anchoring acceleration smaller than the design one. It is, therefore, necessary to retrofit the structure to allow for the satisfaction of the design inequality (Capacity > Demand).

The design inequality above must be satisfied not only in terms of strength or resistance, but also in terms of stiffness. The stiffness capacity of the building must not be less than the stiffness demanded of it by the earthquake. If it were not so, displacements would be too large, especially inter-story drifts, and damage could result to non-structural components. The stiffness control is usually performed indirectly by checking the inter-story drifts.

5.1.2 Traditional methods of seismic retrofitting

Traditional methods of seismic retrofitting fall essentially into two categories, one based on the classical principles of structural design which requires an increase of strength and stiffness, and the other based on mass reduction. Thus the first one tends to satisfy the design inequality by an increase of the capacity while the second one achieves the same result by a reduction of the demand. Since seismic design is different from ordinary design, both techniques may turn out to be quite ineffective as is shown in the following.

With reference to the first method, that is increase of strength and stiffness, the concept involved in its application can be understood using Figure 5.1.2.1. Suppose that the fundamental period of the structure is *Tnr,* to which corresponds a demand *Sanr* in pseudo-acceleration terms, which the structure cannot satisfy. On applying a strength and stiffness increment, the fundamental period will shorten from *Tnr* to *Tr*, to which corresponds a demand *Sar* much larger than the original one. It is, therefore, possible that the structure will be less safe in the new condition than in the original one.

Only after stiffness and strength have been increased up to a level where the fundamental period corresponds to the constant branch of the design spectrum, is it possible to achieve a condition where the design inequality is satisfied. It is, therefore, evident that an attempt to increase the seismic resistance capacity in this way only results in an increase of the seismic demand. When, in the end, the procedure converges, it is at the expense of a considerable expenditure of resources.

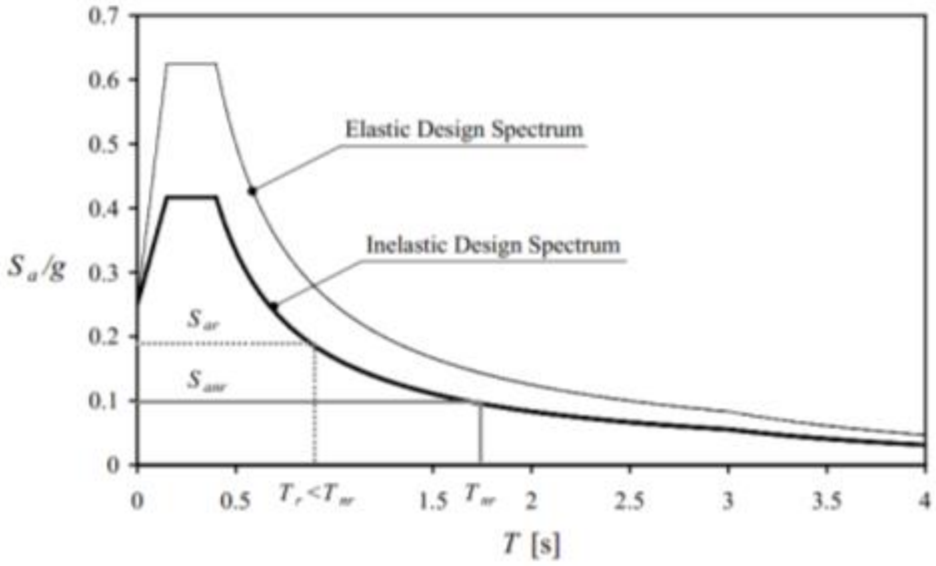


Fig. 5.1.2.1 Increase of the seismic demand following an increase of seismic resistance

A similar situation occurs with reference to mass reduction. In this case it is evident that the removal of the mass will lead to a decrease in the period, i.e. *Tr<Tnr*, which will lead to an increase in the required strength, i.e. *Sar > Sanr*. Therefore the advantage acquired by the mass reduction is partially cancelled by the period shortening through the increase in the demand as shown in Figure 5.1.2.2.

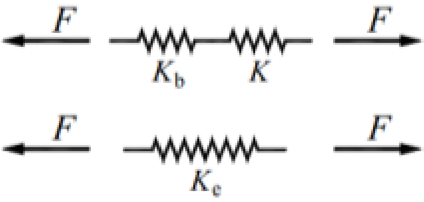
In conclusion, both of the traditional methods of seismic retrofitting, although effective, are rather expensive. It must however be pointed out that, as in the case of low buildings, the fundamental period may already fall within the constant branch of the design spectrum and a period shortening may not result in an increase of the seismic action. Another situation when traditional methods of seismic retrofitting may be rather effective is in the case of soft soil conditions, where higher spectral ordinates occur at relatively longer periods.

5.1.3 Innovative approaches to seismic retrofitting

The main innovative methods of seismic retrofitting may be grouped into the following classes:

- Stiffness reduction (seismic isolators)
- Ductility increase
- Damage controlled structures
- Structures that increase damping
- Passive and Active control.

Stiffness reduction: For equal mass the 'stiffness reduction' produces a period elongation and a consequent reduction of the seismic action and therefore of the seismic strength demand. The stiffness reduction may be achieved by the principle of springs in series whereby the equivalent stiffness of two springs in series is smaller than either of the single springs as shown in Figure 5.1.3.1.



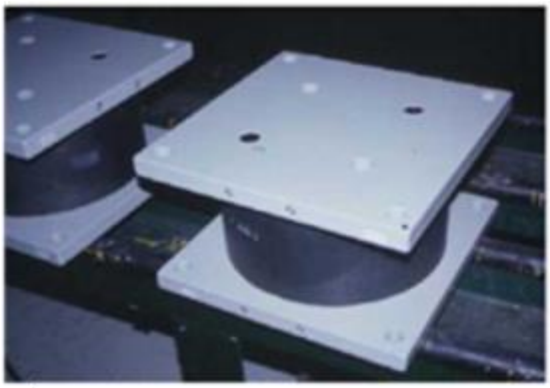
$$\frac{1}{K_e} = \frac{1}{K_b} + \frac{1}{K}$$

$$K_e < K_b \qquad K_e << K$$

Figure 5.1.3. Stiffness reduction by the principle of springs in series

Seismic isolation is carried out with the help of laminated rubber bearings. Laminated Rubber bearings (LRB) consist of alternate layers of rubber and steel plates of limitedthickness bonded by vulcanization, being able to support vertical loads with limited deflection, due to very high vertical stiffness (see fig. 5.1.3.1, 5.1.3.2):

Նկ. 5.1.3.1. Գյումրի քաղաքում սեյսմամեկուսիչներով շենքի և ՌՄՀ-ի տեսքերը



Elastomeric Bearing Devices (seismic isolators) Low-Friction Bearing Devices

Fig. 5.1.3.2 LRB using for the seismoisolation of the building

Ductility increase: A 'ductility increase' may be achieved locally by confinement of reinforced concrete flexural as well as compressed structural members. Although this method has a long history, it may now be applied easily using new materials such as fibre reinforced polymers (FRP). These materials are distinguishable by the type of fibre and the most common are denoted by CRP, GRP, ARP, indicating respectively reinforcement with carbon (C), glass (G) and aramidic (A) fibres (see Fig.5.1.3.3, a): For ductility increase of the structure another widespread method is the so-called DC-90 system, which represents metal connections having great damping (see fig. 5.1.3.3, b).

a)


b)


Fig. 5.1.3.3 Episodes of construction retrofitting

a) by fibre reinforced polymers (FRP), b) DC-90

Damage controlled structures: One of the most important developments to surface in earthquake engineering in the last 10 years is the introduction of the concept of designing 'damage controlled structures'. According to this concept the structural system consists of two parallel structures as shown in Figure 5.1.3.4, 5.1.3.5:

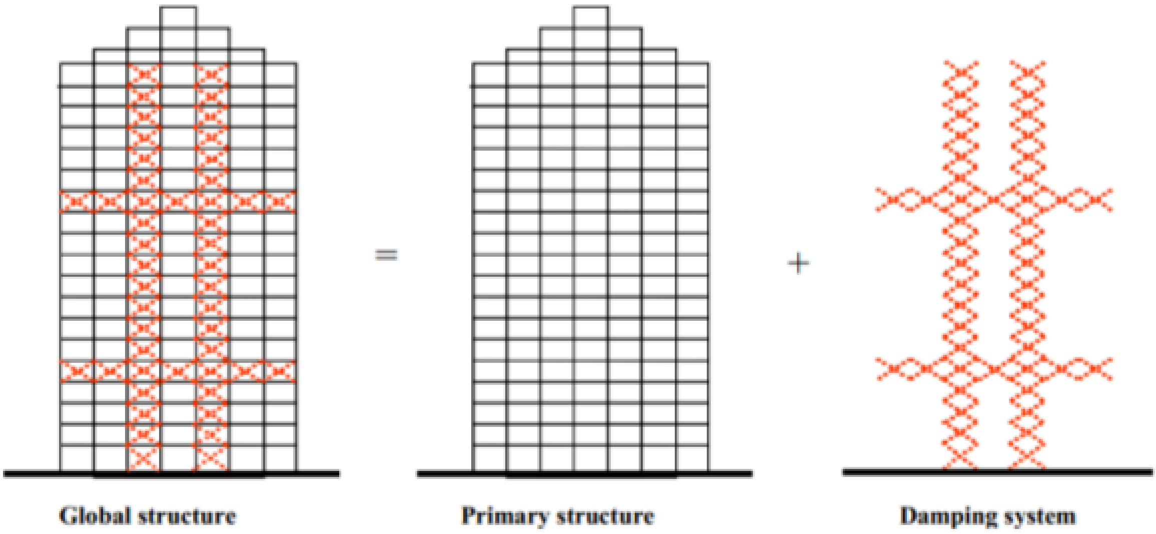


Fig. 5.1.3.4 Damage controlled structure

Fig. 5.1.3.5 Reinforced concrete apartment retrofitted by exterior frame method

The primary structure will behave elastically under the most severe design earthquake while the auxiliary structure, shown by the damping system in Figure 5.1.3.4-will respond to the seismic action. The concept is applicable to new as well as to old buildings. The auxiliary structure introduces a stiffness increment and a large energy dissipation capacity.

Damage occurs only in the auxiliary structure in which damaged elements may be replaced after the earthquake. It is important to realize that, with this seismic design criterion, the structure remains operative even under the most severe design earthquake. A comparison of the behaviour of a traditional system and of a damage controlled system is shown in Figure 5.1.3.6.

In the traditional system, elastic deformations of beams and columns and plastic deformations occur in series, so that the total deformation is the sum of the two. The total deformation, measured as an angular inter-story drift, may be larger than 1/200 and therefore too large to be tolerated without serious damage (see explanatory graph in fig 5.1.3.6).

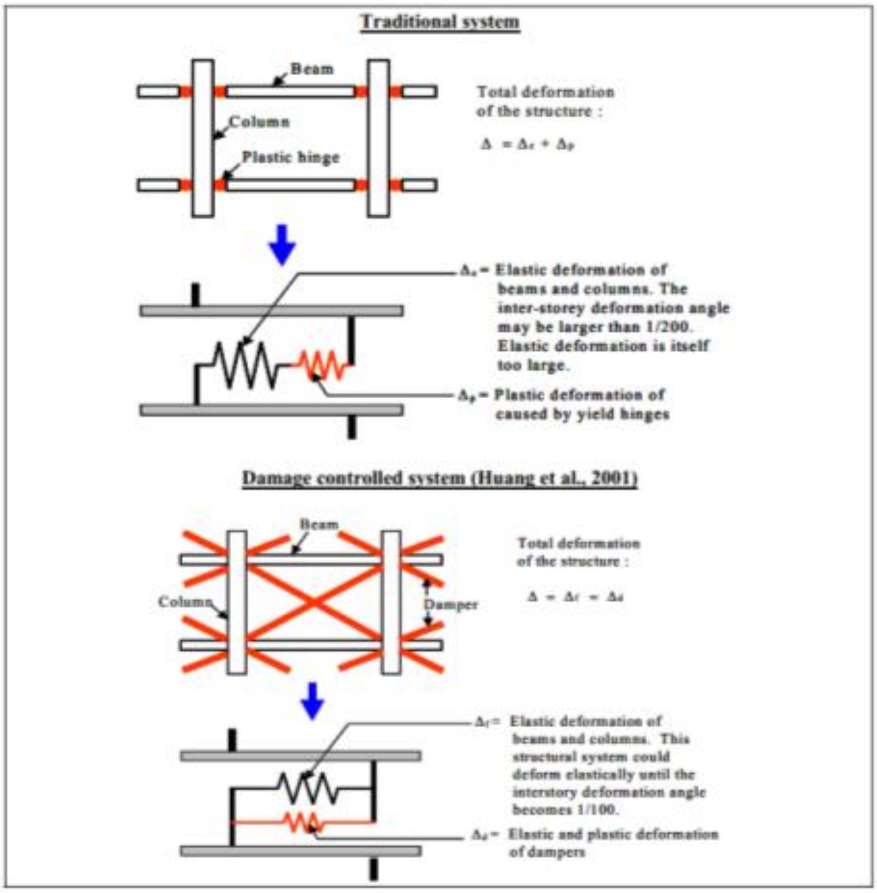


Fig. 5.1.3.6 Comparison of a traditional system and a damage controlled system

In the damage controlled system, the primary structure and the damping system are in parallel, so that the total deformation is the same for both. In this system the primary structure can deform elastically until the angular inter-story drift is as large as 1/100. Plastic deformations occur in devices specially designed for such a purpose without affecting the primary structure.

Under a small or moderate earthquake the traditional system behaves elastically, while under a severe earthquake it undergoes large elastic and plastic deformations and the structure as a whole may be so damaged as to be no longer operative. With the damage controlled system, even under small or moderate earthquakes, while the primary structure remains elastic, the auxiliary structure reacts to the seismic action by dissipating an amount of energy proportional to the deformation amplitude. Under a severe earthquake the primary structure continues to behave elastically while the auxiliary structure dissipates a much larger amount of energy than in the previous cases. After the earthquake the primary structure will continue to be operational and at most it might be necessary to replace damaged elements in the auxiliary structure.

Structures that increase damping: Research and development of energy dissipation devices for structural applications haveroughlyover a 50-year history. Consequently, serious and long efforts have been provided to maturethe concept of passive energy dissipation or supplemental damping into a feasible technologyable to better protect structures, along with their occupants and contents, from the damagingeffects of destructive environmental actions. The innovative design notion of structural protectionresponds to the basic idea of incorporating into a structure high performance energy dissipationdevices able to absorb or consume a considerable portion of the input energy, thereby reducingenergy into structural members and minimizing possible structural damage.

Another interesting approach of increasing damping of the structures is the application of Tuned Mass Damper (TMD) systems (dynamic damper of vibrations as specified by paragraph 7.15.1 of RABC II-6.02.2006).

Tuned Mass Damper (TMD) systems are often considered as a practical solution in the area of structural response control for flexible structures and buildings. However, the main disadvantage of a TMD system is the sensitivity related to the narrow band control and the fluctuation in tuning the TMD frequency to the controlled frequency of a structure. The limitation of a TMD is usually set by the size of the mass. Compared to regular control devices that are connected to structural elements or joints, the TMD involves fairly large mass and large displacements.To overcome the limitations of the TMD mass ratio, it has been suggested to use a portion ofthe building itself as a tuned mass damper. Pan et al. (1995), Pan and Cui (1998) and Charng (1998) sought to evaluate the effect of using segmental structures where isolation devices are placed at various heights in the structure, as well as at the base, in order to reduce the displacements imposed on each of the devices. Each segment may comprise a few stories and is interconnected by additional vibration isolation systems. To increase the performance of the TMD without incurring the problem of increasing structural weight, semi-active (SA) control is emerging as an effective method of mitigating structural damage from large environmental loads over active and passive solutions. SA systems are also strictly dissipative and do not add energy to the system, guaranteeing stability. Bobrow and Jabbari (1997), and Jabbari and Bobrow (2002) have previously focused on the basic analytical techniques needed to characterize structural systems that use a resetable SA device for vibration suppression. Various researchers(Hunt, 2002; Barroso et al. 2003; Chase et al. 2004) have presented an investigation of the ability of SA control methods utilizing resetable devices to mitigate structural response in the presence of hysteretic, geometric and yielding nonlinearities under various intensity level seismic hazard suites to define control efficiency and seismic hazard statistics. Meanwhile, Abe (1996) presented the performance of SATMD with initial TMD displacement and variable dampingsubject to earthquake excitation. He found that the SATMD system gave higher reduction of structural response than conventional passive TMD.

It should be mentioned that in paragraph 7.15.1 of the Code of the Republic of Armenia RABC II-6.02.2006 “Earthquake Resistant Construction: Design codes” the following systems of seismic protection are specified. The design of earthquake resistant buildings and structures and strengthening of the existing buildings may include use of special systems of seismic protection, such as: dynamic dampers of vibrations; interactive ties; structures that increase damping; seismic isolation by means of laminated rubber steel bearings; tying the existing structure to a newly constructed extension.

The following methods were applied in the Republic of Armenia: dynamic dampers of vibrations, seismic isolation by means of laminated rubber, tying the existing structure to a newly constructed extension (see fig. 5.1.3.7, 5.1.3.8, 5.1.3.9):

Before After

Fig. 5.1.3.7 The view of the hotel complex of Shoushi city before seismic preparedness enhancement with an upper flexible floor and after it

Fig. 5.1.3.8 The building construction wih the method of additional “upper flexible storey” and seismic isolation by means of laminated rubber

Before

After

Fig. 5.1.3.9 Five-storey building reinforcementwith the method oftying the existing structure to a newly constructed extension

Before the devastating Spitak Earthquake, the first theoretical and experimental studies on TDM-s in Armenia were carried out in 1980s in a laboratory led by E. Khachiyan, a prominent academician in the field working in §HayShinChartGHI¦. Besides, the increase of seismic resilience by TDM or the so called “upper flexible floor” method won a prize in TEPARM-90 International open contest (authors E. Khachiyan, Z. Khghatyan, M. Melkumyan) [21-23]. The “upper flexible floor” method was applied both in the disaster zone – in Vanadzor city, and during enhancing the seismic resilience of 10-storey hotel complex building in Shoushi town. Later another version of TDM was applied in Vanadzor city by M. Melkumyan, which received the name “isolated floor” by the author.

It is worth mentioning that in Armenia, seismic isolation with the application of laminated rubber bearings was done during enhancement of seismic resilience of existing buildings, as well as the construction of new buildings. Besides, laminated rubber bearings with 380mm diameter and 202.2mm height are produced in Armenia in accordance with Armenian standards (LRB, AST 261-2007). In this respect, the research and practical works of professor, Doctor of Engineering M. Melkumyan are irreplaceable [24].

5.1.4 Best method selection

Summing up the above mentioned and taking into consideration the volumetric design and constructive solutions of the schools, the following main approaches are suggested for improving seismic capacity of the 5 types (A,B,C,D1,D2) classified by us:

1. Stone and reinforced stone constructions (A, B, C)

As the best option of retrofitting for these types we suggest the option of the so-called involved RC frame, which received an award in the open international competition TEPARM-90 after the Spitak destructive earthquake (authors A. Arakelyan, Z. Khlghatyan, E. Tovmasyan). In its nature this method is similar to the concept of constructions protecting from damage.

The essence of the method lies in the fact that in the transverse and longitudinal directions the existing building is supplemented with new monolithic RC frames (see fig. 5.1.4.1):

Moreover, the columns and beams of the frame are realized in the outside and inside of the bearing walls.And in the angular parts the columns are triple-branched. For the purpose of ensuring the combined operation of the separate branches of the columns and beamsthey are connected to each other with rigid connections with the help of short RC beams. In order to ensure the integrity and combined operation of the cover slabs they are anchored to the new beams. In such conditions there is no need to make an additional RC upper layer on the cover slabs. This technique was applied in the disaster zone too. The advantage of the technique (see fig. 5.1.4.2)is that it allows preserving the initial appearance of the building maximally.

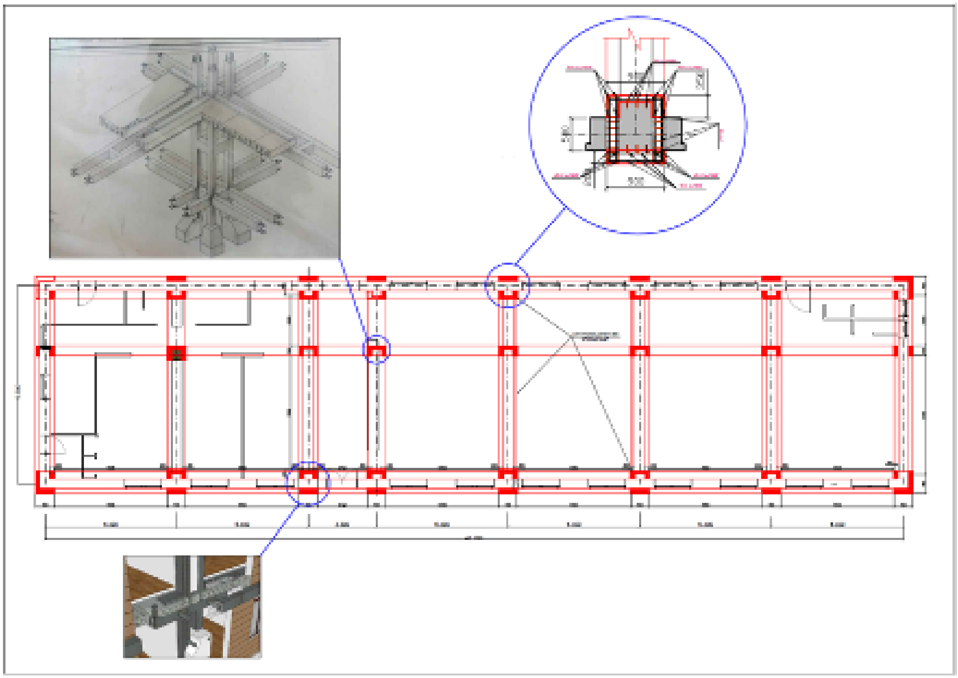


Fig. 5.1.4.1 Typical scheme for A type building

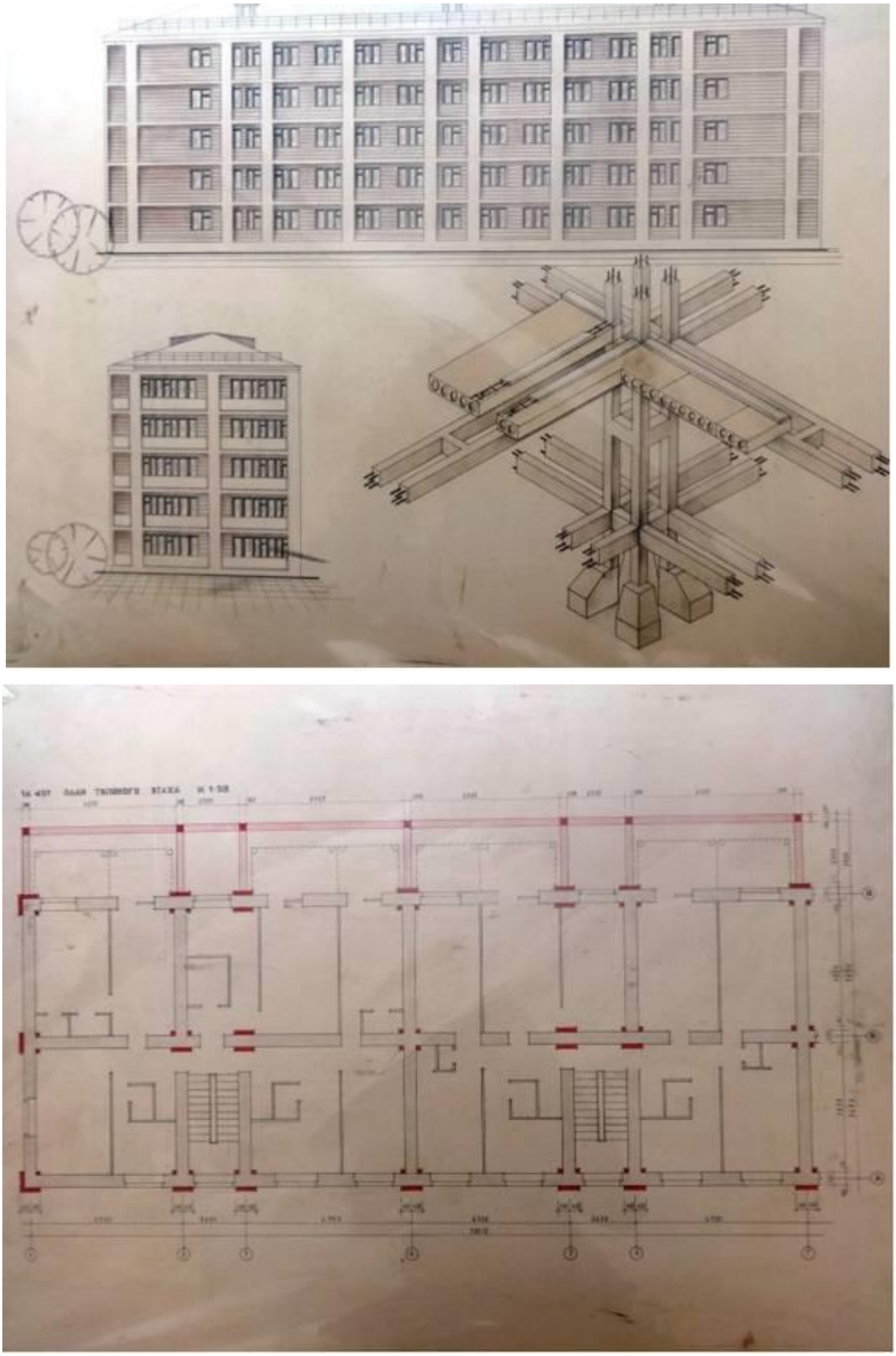


Fig. 5.1.4.2 The strengthening version for stone buildings (ТЕПАРМ-90)

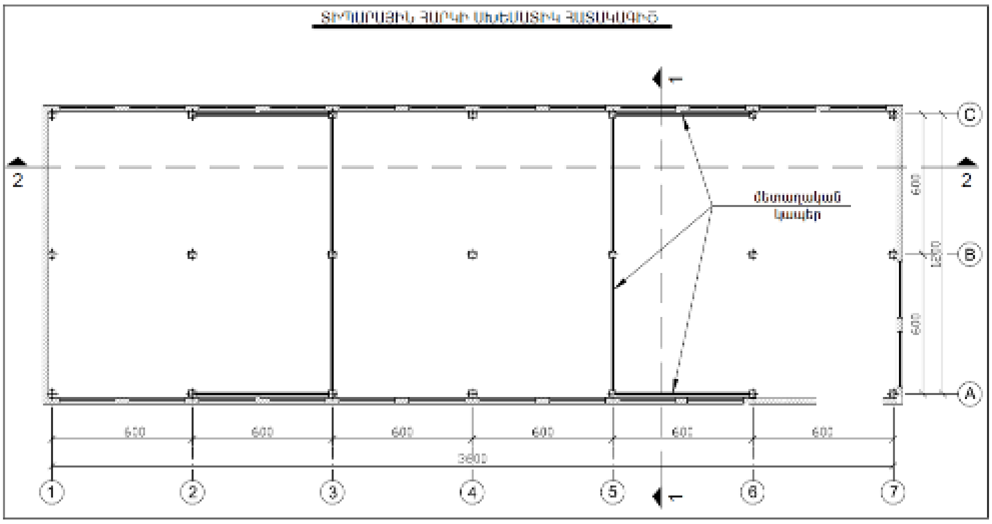
2. ***Frame buildings (D1, D2)***

For these types of buidings unlike the methods used in the past, instead of reinforced concrete stiffness shear walls it is suggested supplementing the frame of the building with steel connections that must simultaneously ensure increase of rigidity and a great possibility of damping of energy. The number of steel connections, their rigidity and elasticitymust be determined by a relevant calculation and must meet the reqirements of paragraph 7.11 of RABC II-6.02-2006 codes. In order not to interferewith the internallayout solutions of the sections itisdesirable to place the shearwalls or connections in the marginal axes (see fig. 5.1.4.3). In any case the connections must beplacedsymetricallytowards the main geometrical axes of the section and must becontinuousalong the wholeheight of the building.

Unlike the monolithic reinforced concrete stiffness shear walls the steel connections canbeplaced in any flight of the building (e.g. in the corridors, near the windowopenings). Besides, the connections can be regarded as part of the interier. (see fig. 5.1.3.3, b)) :

Besides the above mentioned, in the retrofitting and reconstruction working drafts of this type of schools it is required to include also the casting of reinforced concrete upper layer on the interfloor cover and upper cover slabs in order to get rigid discs operating in the horizontal plane.

It should be mentioned that the suggested methods do not require additional expenses during further operation and can fully ensure the necessary level of seismic resistance.



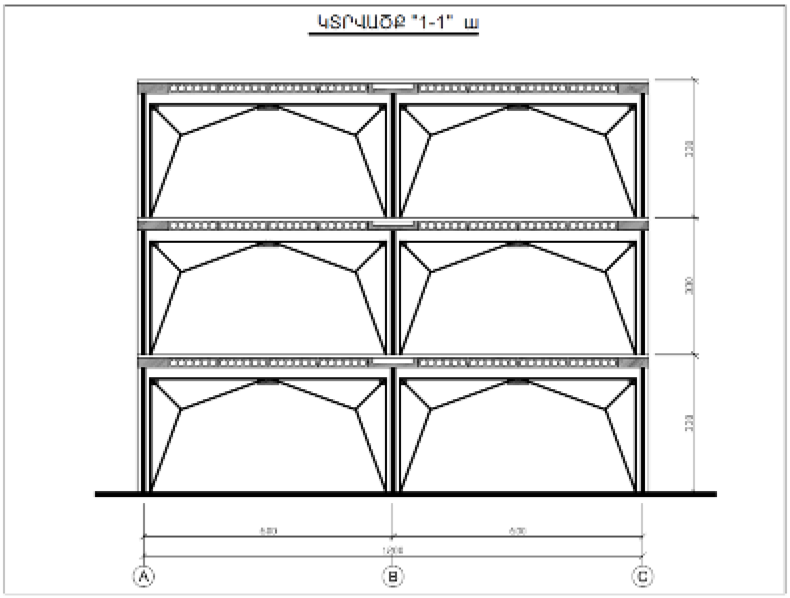


Fig. 5.1.4.3 Strengthening scheme of framework frame buildings

Reconstruction and reabilitation works design for all types of schools should be included in the constructive solutions envisaged by the design.

Taking into account the fact that the factual constructive solutions of jointing the partitions with the bearing constructive elements of the all types ofbuildings do not meet the requirements of RABC II-6.02-2006 codes, as well as the fact that there are considerable damages, cracks and deformations in the partitions, it is recommended dismantling all the partitions and realizing new partitions instead of them, following all the normative requirements.

This suggestion is also based on the point of view that the actual inner layout solutions of the school buildings do not conform with modern normative requirements made to schools, and it is necessary to do replanning of the buildings.

As in fact segmented reinforced concrete stairs are not fastened with metal bridgeboards, as it is envisaged by point 7.6.2 of RABC II-6.02-2006 codes, hence it is necessary to eliminate this defect and fasten the stairs to metal bridgeboards. At the same time, based on the requirements of fire prevention norms, all the steel beams and bridgeboards of staircases should be covered with fire-protective concrete cover strengthened with fine steel fabric. If desired, the disassembly of existing stairs and their substitution with monolithic reinforced concrete can be applied as an alternative variant, in case of which the existing steel bridgeboards can also be removed, as well as included inthe new structure.

3. During the replanning of inner layout solutions of schools buildings, it is mandatory to take into account the following requirements of RABC 31-03.01-2014 'Buildings of General Education Purpose' codes [7]:

- During the design of general education institutions, it is necessary to take into account the disabled people, including people that use wheelchairs and other auxiliary facilities, the possibility of their use, with the application of requirements made to approaches to the buildings, entrances and doors, ramps, staircases and stairs, handrails, elevators, windows, furnishing of sanitary units and auxiliary facilities that form part of them, following the requirements of RABC IV-11.07.01 building codes.:

4. Remove all thoseanti-seismic joints (separating schools buildings from each other) that are filled with concrete or other construction materials so that they don't hamper the free oscillation of school buildings as separate structures during seismic impacts.

5. Create dry conditions on basement floors for the safe operation of constructive elements by ensuring the sufficient ventilation of the basement floors and excluding the leakage of water from the school waterlines and inner sewerage system to the basement floor.

6. For energy-saving purposes, it is suggested to apply a heat-insulating layer from the inner side of the enclosing walls of the school buildings with modern light construction materials.

7. Part of the doors leading from the buildings to the inner yard are closed by decorative covers, which creates evacuation problems and contradicts other fire and emergency normative requirements. Hence, the doors should be freed from decorative covers for organizing quick evacuation.

8. All the reconstruction and rehabilitation works should be implemented based on the design developed and approved by defned order. At the same time taking into account the following requirementsof the RABC 20-06-2014 normes [4].

Urban development problems related to planning of neighborhood site-building;

• Architectural role of the building or construction in site-building;
• Operational purpose of building or construction;
• Planning-spatial concept and structural solutions;
• Quality of construction and assembly works;
• Primary seismic stability of building or construction;
• Degree of damage of building or construction;
• Period of further exploitation of building or construction;
• Rehabilitation measures implemented after the previous damage and their nature;
• Engineering and geological conditions of the plot;
• State of bearing structures and level of significance.

5.2 Consolidated cost estimate

The analiz of international practice has shown that in case of using constructions increasing damping (as for example DC-90 systems) the retrofitting for 1m^{2}can comprise 60-100 Euros. For the stading the Armenian practice the design-and-estimate documents of retrofitted schools in RA through 2010-2013 have been acquired from the office of Project implementation of the Ministry of Urban Development. These documents have been analyzed, and the costs have been calculated for 1m^2.

Below is an example of the analysis of the reconstruction design of the secondary school of Tsovinar village, Gegharkunik district of RA, which was developed by “STEM” LLC in 2013.

The design type of the secondary school of Tsovinar villagecorresponds to type number 11 (D1) analyzed by us. It is comprised of 7 two-storey buildings with a basement floor, with rectangular layout of marginal axes sizes of 12.0x36.0m. The constructive solution of the buildings is frame type, and the frame is made with precast RC constructions ofIIS-04 series. The total design cost of retrofitting and reconstructing one 12.0x36.0m building of the school comprised approximately 112.44 million AMD, which includes the works listed in the table below.

nn	Name of works	Construction installation works (thousand AMD)	Equipment (thousand AMD)	Total (Thousand AMD)
1	3	4	5	6
1	Co-construction works	76601,02		76601,02
2	Heating works	4888,24	531,74	5419,98
3	Ventilation works	7353,98	1765,24	9119,22
4	Plumbing work	3328,58		3328,58
5	power supply	6315,40	225,00	6540,40
6	Fire alarm of the buildings	908,55	338,57	1247,12
7	Video surveillance and calls system	586,79	105,60	692,39
8	Furniture distribute works	117,90	9374,39	9492,29
	Total	**100100,45**	**12340,54**	**112440,99**

The estimate was made as of December 2013 according to the order established by the resolution 879/N-Նas of January 23, 2011 by the RA Government.

According to the table below the co-construction works comprise 76.6 million or about 68 percent of total works. It should be mentioned that the co-construction works include the following main operations: demolition and land works, those of monolithic reinforced concrete constructions, walls and partitions, doors and windows, floors, finish and roof. The overall cost of the co-construction works for 1m^{2}comprised about 90000.0 AMD.

In 2013 the Institute “Haynakhagits” developed a reconstruction project for school N 18 of Vanadzor city. The school design type corresponds to type number 11 (D1) analyzed by us, and it consists of 7 separate two-storey buildings with the sizes of 12.00x36.0m. The school was retrofitted in 1989 after the Spitak earthquake. Partial retrofitting of bearing constructions of the buildings was carried out, particularly:

- All the 30.0x30.0cm columns of the buildings were strengthened with 65.0x65.0x6.0cm metal angles, metal mesh and guniting.
- One storey 35.0cm-thick RC shear walls are placed along the internal longitudinal axis (except the gym) in two flights , and in the transversedirection (except the gym and event hall) one-storey separate support columns are placed opposite the external columns.
- The flat roof and the upper cover of the gym building and event hall building are replaced with 12.0m-flightmetal farms and metal profile plate, and the flat roof of the other buildings is replaced with a dual pitched cover of corrugated asbestos sheets and with wooden bearing constructions.

The retrofitting design considered increase of seismic capacity of the school constructions (the coefficient of seismic capacity k=0,7).

As a retrofitting option separate two-storey 80,0x50,0cm RC support columns were realized opposite the external columns (except the first and the last columns) along the longitudinal facades of the buildings, which were anchored to the existing columns in two places in each storey according to height, and in the upper point in the longitudinal directionthe support columns are connected to each other with RC beams. Besides, in order to increase the horizontal rigidity of the covers of the buildings a 5cm-thick RC covering layer was realized, which had a 1.0m-width in the marginal axes, and a 2.0m-width in the middle axis.

The cost estimate of total retrofitting and reconstruction works planned in the buildings comprised about 1263.0 million AMD, from which the co-construction works – about 1033.5 million AMD, or about 82 percent of the total works. The cost of the overall co-construction works for 1m^{2}comprised about 171thousand AMD.

Taking into account the above mentioned we can conclude that the average cost of retrofitting of 1m^2 of reinforced concrete frame buildings comprises 90-170 thousand AMD, depending on the chosen techniques of retrofitting and the volume of reconstruction works.

The total cost estimate of the new school construction project of Mush-2 block of Gyumri city comprised 20100000 (two milliard one hundred thousand) AMD, and for 1m^2 - 240 000.0 AMD (the calculation was done according to the 2012 prices).

This shows that the cost of school retrofitting and co-construction works comprises up to 80 percent of the cost of building a new school.

For each method suggested by us a sketch design has been developed based on which the volumes and consolidated cost estimates of retrofitting and reconstruction works have been calculated. The estimates were made as of November 2014 according to the order established by the resolution 879/N-Ն as of January 23, 2011 by the RA Government.

Appendix 7 shows the estimates where the following co-construction works have been included: demolition and land works, those of monolithic reinforced concrete constructions, walls and partitions, doors and windows, floors, finish.

By summarizing the results of the estimates, the cost of co-construction works for 1m^2 per the types has comprised:

A - 45000 (forty five thousand) AMD/m^2,

B, C - 65000 (sixty five thousand) AMD/m^2,

D1,D2 - 85000 (eighty five thousand) AMD/m^2:

The expenses directed to only retrofitting for 1m2 comprise 25-45 thousand AMD or about 50 percent of total co-construction works, depending on the constructive peculiarities of the school building (stone, RC frame).

It should also be mentioned that engineering and other parts (water, sewage, ventilation, heating, territory improvement, school furniture) of the estimates were not included in it. Based on the data obtained from the Office of Project Implementation of the Ministry of Urban Development and taking into consideration our calculations, the consolidated cost estimates of retrofitting and reconstruction of 60 schools are summed and presented in the Appendix 5, page 3. The table additionally includes such expenses as the installation of ramps and elevators for invalids, as well as children moving with the help of wheelchairs and other additional facilities.

As an example the summery schedule of the schools of Armavir marz presented below:

	School names	Type	Names of branches (Academic Sport, Main)	Stores	Total area	Technical condition	Seismic preparedness level	Reinforcement costs (1000 AMD)	Restoration costs` engineering network, decoration work (1000 AMD)	Ramps and elevators costs (1000 AMD)	Total costs (1000 AMD)
1	2	3	4	5	6	7	8	9	10	11	12
Armavir Marz											
2	Nalbandyan Secondary School	no typical	Main building	3	2630	2	Improve seismic capacity	105200,0	39450,0	12000,0	259500,0
			Acad. buildin	3	1870	2		74800,0	28050,0		
			Sport building	1	200	3	Demoletion	0,0	0,0		
3	Aygeshat Secondary School	no typical	Main building	2	1585	2	Improve seismic capacity.	63400,0	23775,0	12000,0	147025,0
			Acad. buildin	2	870	2		34800,0	13050,0		
5	Armavir Basic School N6	10	Acad. buildin	3	2850	2	Improve seismic capacity.	171000,0	42750,0	12000,0	366000,0
			Acad. buildin	2	960	2		57600,0	14400,0		
			Sport building	1	910	2		54600,0	13650,0		
6	Parakar Secondary School	10	Acad. buildin	3	2850	3	Change the significance, build a new one	0,0	0,0	0,0	0,0
			Acad. buildin	2	960	3					
			Sport building	1	900	3					
7	Hayatagh Secondary School	no typical	Acad. buildin	2	1210	2	Improve seismic capacity	48400,0	18150,0	12000,0	282250,0
			Acad. buildin	2	1210	2		48400,0	18150,0		
			Sport building	1	650	3		26000,0	16250,0		
			Acad. buildin	2	1460	3		58400,0	36500,0		
							Total	**658200,0**	**264175,0**	**48000,0**	**1054775,0**

6. RECOMMENDATIONS TO INFORM THE GOA NATIONAL PROGRAM AND ACTION PLAN AIMED AT REHABILITATION, RECONSTRUCTION AND MODERNIZATION OF SECONDARY SCHOOLS

Z. Khlghatyan discussed the National Program and Action Plan aimed at rehabilitation, reconstruction and modernization of secondary educational institutions with the RA Deputy Minister of Urban Development A. Ghukaryan, and head of Department of Construction Policy A. Nazaretyan. The results of studies carried out within the framework of this project should be taken as guidelines to form basis of the National Program.

The National Program should also include the following main principles:

1. Based on the requirements of RABC 20-06-2014 “Rehabilitation, Reconstruction and Strengthening of Buildings and Structures. Main Provisions” codes currently operating in the RA, a mandatory condition is carrying out the reconstruction works of secondary schools with absolute consideration of strengthening measures.
2. Starting reconstruction works of secondary schools with the 60 schools included in this project.
3. Develop working design-estimate documents for different types (A, B, C, D1, D2) of schools, where the main provisions and results of this project should be taken into account.
4. Develop a timeline for reconstruction of 60 most risky schools or construction of new ones. Consider the current technical condition of the school and the nature and volume of works done before in the timeline. As a preliminary version a table was developed which is presented on page 4 of Appendix 5. The reconstruction of the schools has been divided into three main stages in the table, and includes revealed prioritized schools, as well as the necessary amount of funding.

5. As a state strategy and necessity, it is advised to create a single database of all the schools in a short time, which should by all means include school passports in formats determined by the codes.

6. The urgent need of strengthening of schools requires that they be included in the RA 2016-2020 education development state programs. Besides, it is suggested to apply in parallel to donor organizations, as well as search other sources of funding, particularly in the form of crediting.

SUMMARY AND CONCLUSIONS

1. Based on the aforementioned, a memorandum of understanding was signed between the Ministry of Urban Development, Ministry of Education and Science, Ministry of Emergency Situations and UNICEF aimed at establishing cooperation among the parties within the framework of implementation of 2005-2015 Hyogo Framework for Action, particularly Priority 4 (reducing the underlying risk factors). Its main aim is the significant reduction of human, social, economic and environmental asset losses as a result of disasters in countries and communities, and cooperation within the framework of the "Project for Disaster Damage Prevention and Reduction of Children's Vulnerability" in order to support the RA Government in the task of implementing a comprehensive assessment of the safetyof schools and preschool institutions.

2. The work carried out within the framework of the project is aimed at prevention of disasters in Armenia and intends to increase the seismic safety of school-aged children, within the framework of which special attention is given to works of seismic vulnerability assessment of school buildings and structures as an important stage in activities aimed at seismic risk reduction.

3. For the purpose main indicator of typecal schools with financial and practical support of the UN Children's Fund the structural and engineerring parts of design documents of 20 typical schools have been obtained from the archive of "Haynakhagits" OJSC. The layouts and facades of all the 20 typical buildings have been digitized by AutoCAD and ArchiCAD programs, and are presented in 2D and 3D formats. Evacuation plans in case of earthquake have been developed for each typical school. The main peculiarities of the 20 typical schools designs and volumetric specifications, constructive solutions and unconformities with the requirements of valid RA RABC II-6.02-2006 codes “Earthquake resistant construction. Design codes” have been analyzed.

4. By summing up the design indicators of 20 typical schools and considering mainly the volumetric-design and constructive solutions of the educational buildings of schools and the number of storeys, the designs of 20 typical schools have been classified by us into the following 5 main types:

C. Bearing walls of stone masonry, complex construction

D. External bearing walls, internal RC precast or monolithic frame

C. External RC frame, internal precast RC bearing walls

D1. Precast two-storey RC frame (IIS-04 series)

D2. Precast three-storey RC frame (IIS-04 series).

5. Seismic calculation of typical schools in form has been performed by LIRA “Computation Complex intended for structure strength analysis by the method of super-elements”, version: 9.6, software package developed in Kiev Construction Automation

Research Institute. The calculation has been done for 3 types of etalon soils. The analyses of the calculation results are presented in the form of tables, where all the quantitative indicators related to seismic calculation are given (sum of bearing forces in the upper part of the bases, the maximum inclination in the upper point of the building, the values for natural periods of vibrations, and etc.) depending on soil category.

6. The European MSK-98 scale, RABC codes, the joint work with JICA OYO in 2010, the results of seismic calculation carried out by us, damage data at the Spitak earthquake in 1988, natural period of buildings and soil category have served as a basis for building the curves for A,B,C,D1,D2 types of typical designs.

7. For the purpose of selecting the most seismically hazardous schools, an evaluation scale has been developed based on the list developed by the RA Ministry of Urban Development and the lists provided by the National Center for Education Technologies, as well as based on numerous discussions between team leaders, advisors and representatives of the UN Children's Fund. The scale includes the following 7 main indicators:

- The seismic hazard level of the area,
- Vulnerability degree of the typical building,
- Number of students,
- The date of construction of the school,
- The technical state (according to the existing database),
- The existence of secondary hazards in the school area (landslide, rockfall, mudflows, flood, etc.),
- The existence of buildings, structures, objects with high vulnerability adjacent to the school.

8. Overall, visual-instrumental study of 60 most risky RA school buildings and constructions has been carried out within the framework of this project, the results of which have been summarized in the form of separate reports. Besides, the reports for Yerevan city and the regions have been summarized in the form of separate books. The reports include the technical state of the schools, physical depreciation, the conformity with the RA operating seismic codes, degree of seismic vulnerability. Suggestions have been made related to increase of seismic resilience, rehabilitation and reconstruction of schools. Besides, respective seismic safety passports were formed for each building of the school according to methodical instructions.

9. For stone and reinforced stone constructions (A, B, C) as the best option of retrofitting for these types we suggest the option of the so-called involved RC frame, which received an award in the open international competition TEPARM-90 after the Spitak

destructive earthquake (authors A. Arakelyan, Z. Khlghatyan, E. Tovmasyan). In its nature this method is similar to the concept of constructions protecting from damage.

The essence of the method lies in the fact that in the transverse and longitudinal directions the existing building is supplemented with new monolithic RC frames.

10. For frame (D1, D2) type of buidings unlike the methods used in the past, instead of reinforced concrete stiffness shear walls it is suggested supplementing the frame of the building with steel connections that must simultaneously ensure increase of rigidity and a great possibility of damping of energy. The number of steel connections, their rigidity and ductility must be determined by a relevant calculation and must meet the reqirements of paragraph 7.11 of RABC II-6.02-2006 codes. In order not to interfere with the internal layout solutions of the sections it is desirable to place the shear walls or connections in the marginal axes. In any case the connections must be placed symetrically towards the main geometrical axes of the section and must be continuous along the whole height of the building.

Unlike the monolithic reinforced concrete stiffness shear walls the steel connections can be placed in any flight of the building (e.g. in the corridors, near the window openings). Besides, the connections can be regarded as part of the interier.

11. For each method suggested a sketch design has been developed based on which the volumes and consolidated cost estimates of retrofitting and reconstruction works have been calculated. The estimates were made as of November 2014 according to the order established by the resolution 879/N-Ն as of January 23, 2011 by the RA Government.

The estimates have included the following co-construction works: demolition and land works, those of monolithic reinforced concrete constructions, walls and partitions, doors and windows, floors, finish.

By summarizing the results of the estimates, the cost of co-construction works for 1m^2 per the types has comprised:

A - 45000 (forty five thousand) AMD/m^2,

B, C - 65000 (sixty five thousand) AMD/m^2,

D1,D2 - 85000 (eighty five thousand) AMD/m^2:

12. Estimates where, besides co-construction works, have been included engineering and other costs and such expenses as the installation of ramps and elevators for invalids, as well as for children moving with the help of wheelchairs and other additional facilities, have been presented for all the schools subject to retrofitting in the form of tables.

13. Based on the requirements of RABC 2014 “Rehabilitation, Reconstruction and Strengthening of Buildings and Structures. Main Provisions” codes currently operating in the RA, a mandatory condition is carrying out the reconstruction works of secondary schools with absolute consideration of strengthening measures.

14. Start reconstruction works of secondary schools with the 60 schools included in this project.

15. Develop working design-estimate documents for different types (A, B, C, D1, D2) of schools, where the main provisions and results of this project should be taken into account.

16. Develop a timeline for reconstruction of 60 most risky schools or construction of new ones. Consider the current technical condition of the school and the nature and volume of works done before in the timeline. As a preliminary version it is suggested that the works be divided into three main stages starting from the schools requiring priority.

17. As a state strategy and necessity, it is advised to create a single database of all the schools in a short time, which should by all means include school passports in formats determined by the codes.

18. The urgent need of strengthening of schools requires that they be included in the RA 2016-2020 education development state programs. Besides, it is suggested to apply in parallel to donor organizations, as well as search other sources of funding, particularly in the form of crediting.

19. The results of studies carried out within the framework of this project should be taken as guidelines to form basis of the National Program and Action Plan aimed at rehabilitation, reconstruction and modernization of secondary educational institutions.

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SUMMARY REPORT
“Preventing Disaster Loses and Reducing Vulnerability
of Children in Armenia” project

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