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ASSESSMENT OF THE SEISMIC RISK IN THE CITY OF YEREVAN AND ITS MITIGATION BY APPLICATION OF INNOVATIVE SEISMIC ISOLATION TECHNOLOGIES

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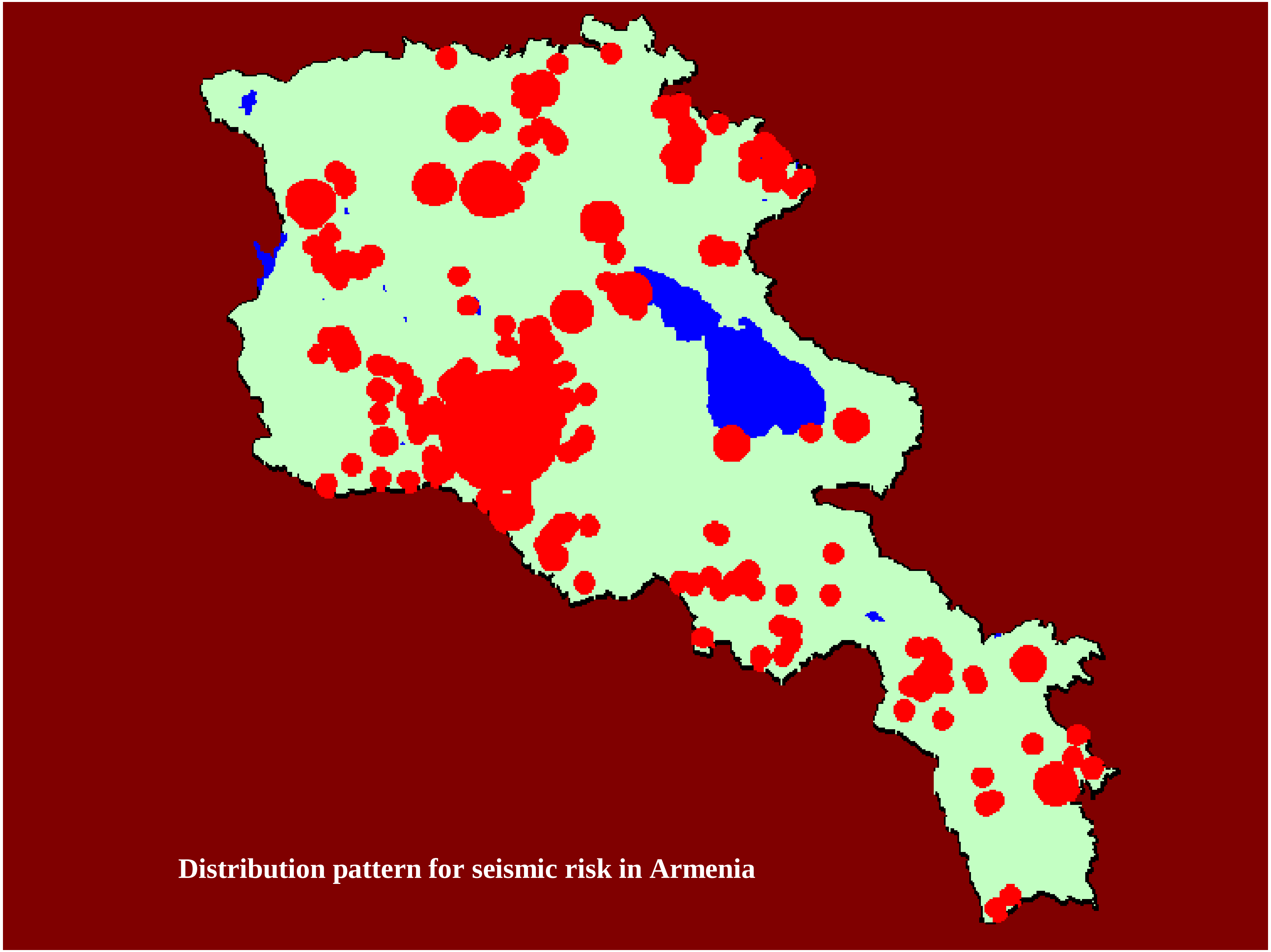
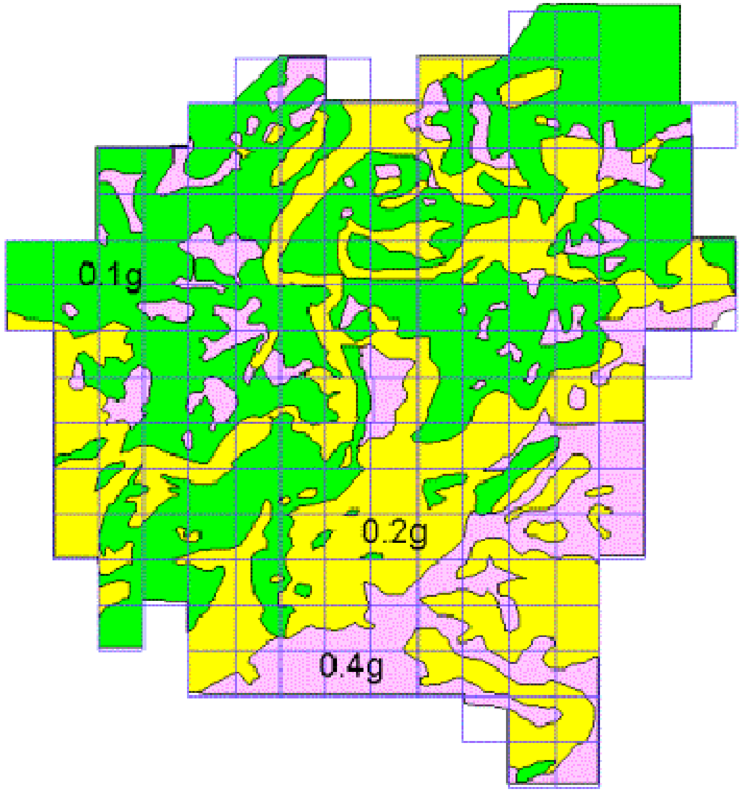
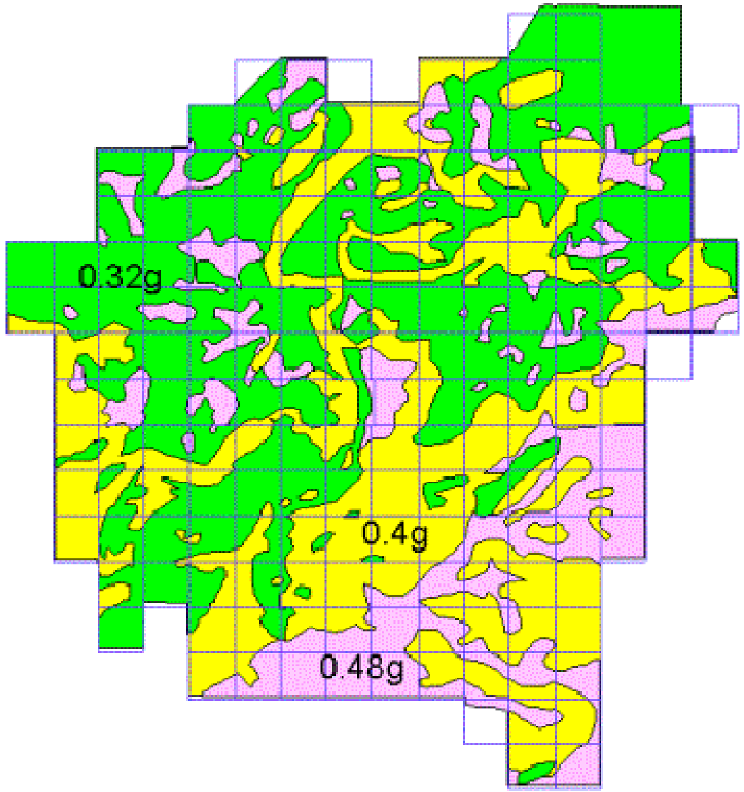


Distribution pattern for seismic risk in Armenia



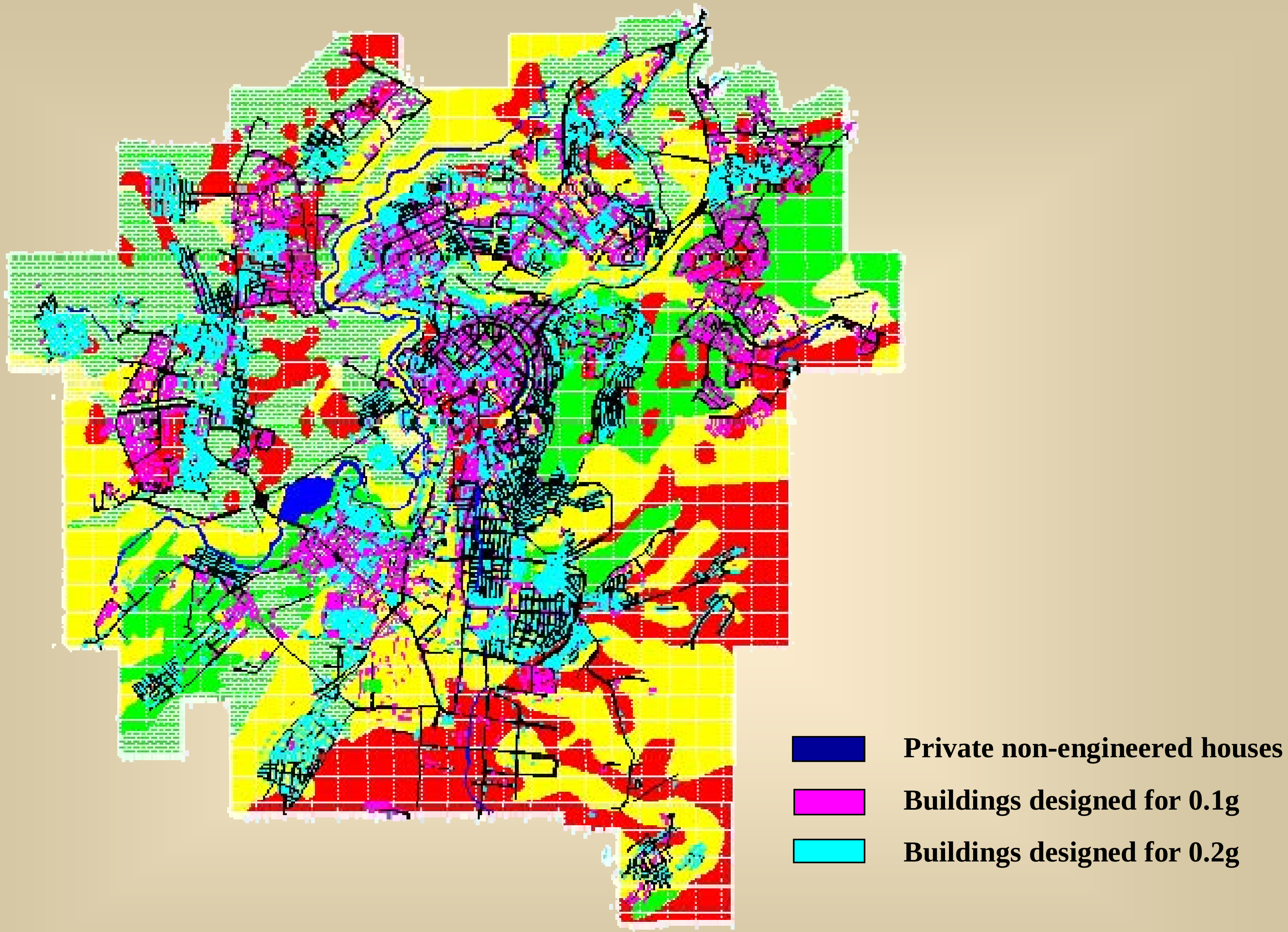
Corresponding to the former Soviet Union Seismic Code II-7-81



Corresponding to the Armenian National Seismic Code in force II-6.02-2006

Scheme of the Yerevan City indicating soil conditions and expected accelerations

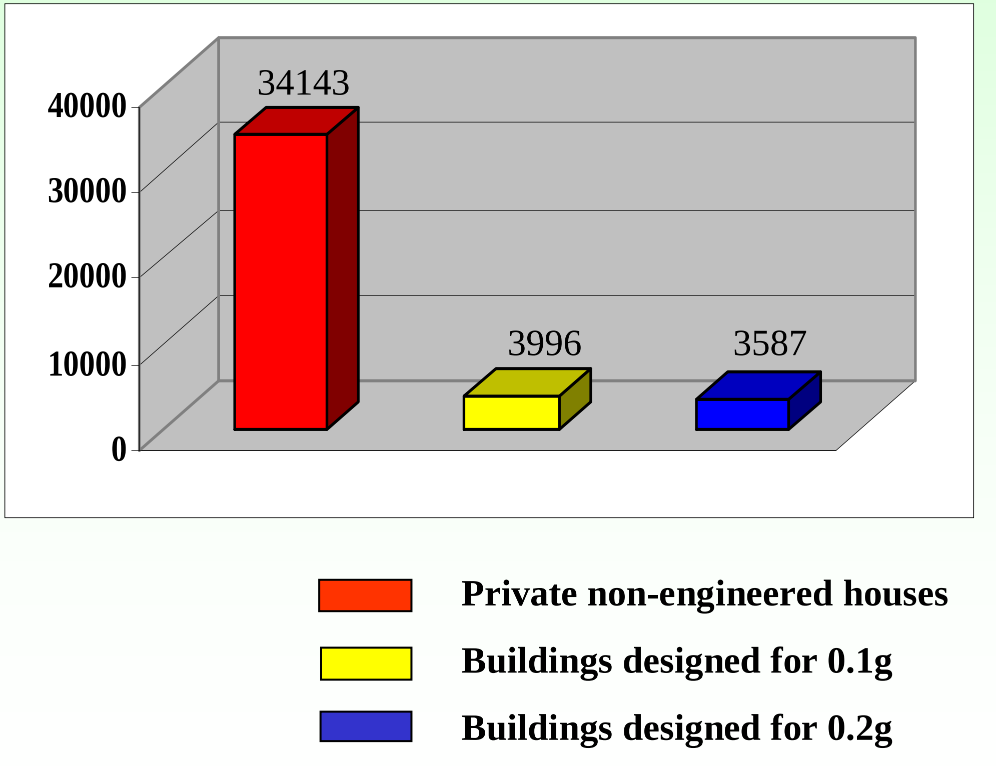
rocky and large disintegrated rocks **rocky weathering; coarse sand** **sandy unconsolidated**

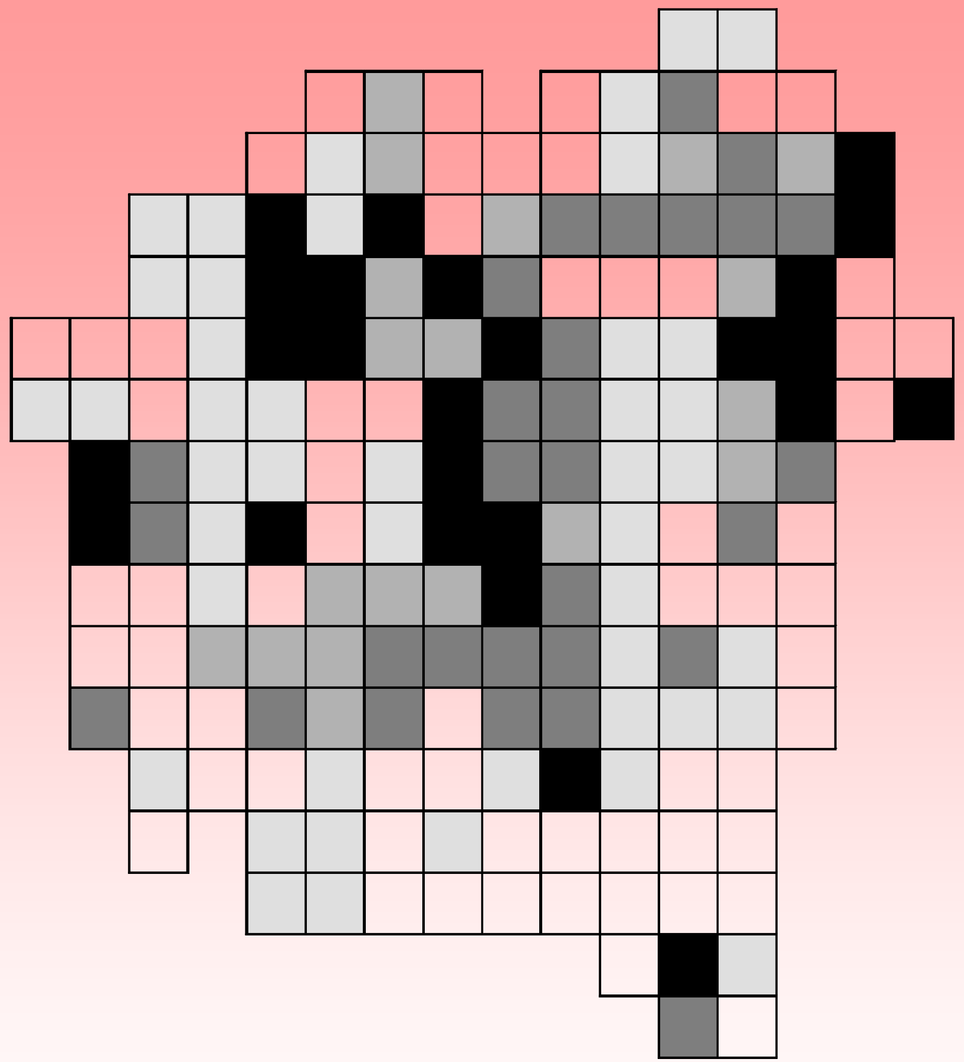


Existing buildings and structures in the Yerevan City and the design level of their earthquake resistance

The principle of seismic risk assessment is based on the definition of the seismic risk coefficient: $K_r = A_{exp}/A_{design}$, where A_{exp} – expected acceleration at the site, where the given building is located, and A_{design} – the design acceleration of the ground of that site. The analysis of the 1988 Spitak Earthquake, as well as non-linear earthquake response analyses show that at the loading, which exceed the design values by up to 2 times, buildings and structures are still able to resist seismic impact. Therefore, if $K_r > 2$ it is assumed that seismic risk of destruction is high, if $1.2 < K_r < 2$ – the seismic risk is moderate, and if $K_r < 1.2$ – there is no risk practically.

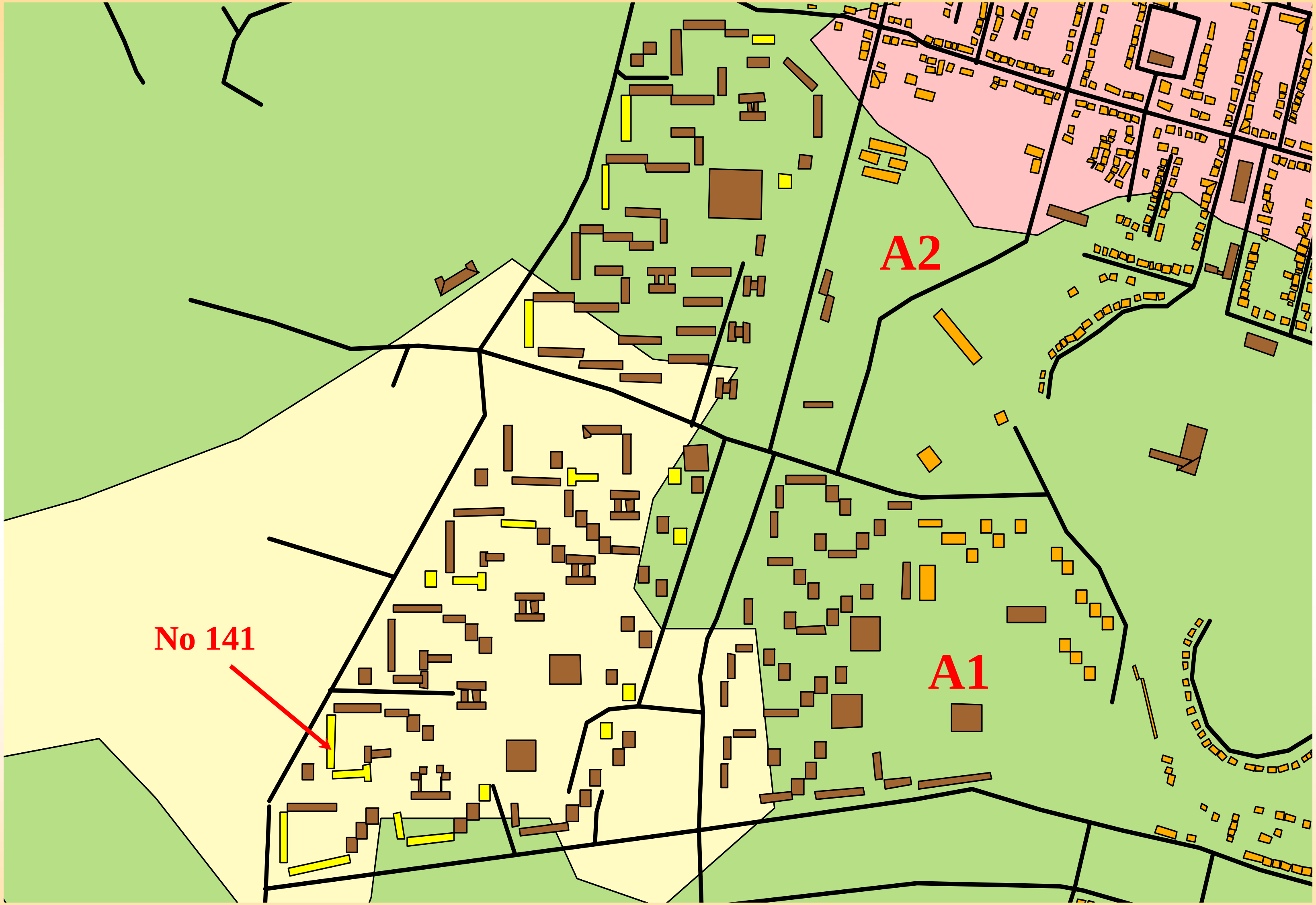
The analysis of data obtained has shown that about 26 km^2 of the zones of high seismic risk represent city area, that comprises 15% of the total area. About 5,389 buildings have been constructed here. Together with that 44 km^2 (24%) of the city area is occupied by 34,143 low-storied stone private non-engineered houses and also should be considered as a high seismic risk area. The remaining 2,185 buildings have a moderate risk of destruction.





Map of distribution of seismic risk by sectors with one square kilometer area on the territory of Yerevan City

very high risk **high risk** **moderate risk** **low risk** **no risk practically**



A1 and A2 microdistricts of the southwestern massive of the city of Yerevan where 20 buildings were selected

Some data on the building N141 in the A1 Microdistrict of the Southwestern Massive of the City of Yerevan

Design acceleration		0.2g
Type of the building		apartment building
Structural concept		reinforced concrete frame
Stories		9
Series		111
Vibration period T_x, sec in transverse direction	design	1.013
	experimental	0.56
Vibration period T_y, sec in longitudinal direction	design	1.631
	experimental	0.62
Average strength of concrete by stories, N/cm^2	1	2400
	2	2550
	3	2600
	4	2460
	5	2550
	6	2450
	7	2650
	8	2500
	9	2340

For the quantitative assessment of the seismic resistance of an existing building the actual bearing capacity (A) shall be compared with the required one (R). It is obvious that the relation of A/R must be more or equal to unit, to say for sure that the building's seismic resistance is secured. And, this relation must be checked for each story of the building. R is the value of the total shear force at each story of the building during the design earthquake. If horizontal stiffness of all structures is defined, it is recommended to obtain the A of the given story by the following formula:

$$A = \Delta \cdot K \cdot \sum_{i=1}^{n} C_i$$

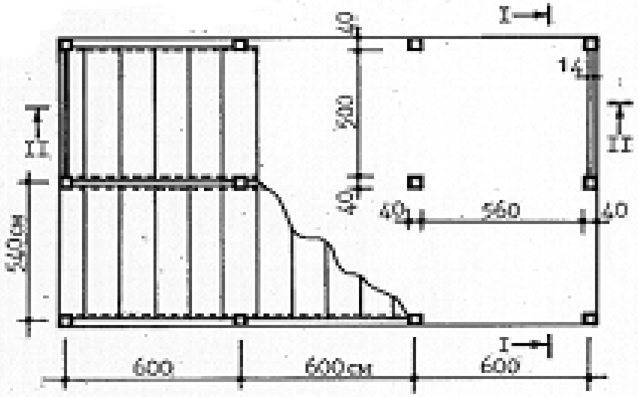
where C_i – horizontal stiffness of the i vertical bearing element of the given story; Δ - ultimate displacement for the elastic stage, which is defined in the Table below; K – stretch coefficient, which is determined in the same Table; n – number of the vertical bearing structures.

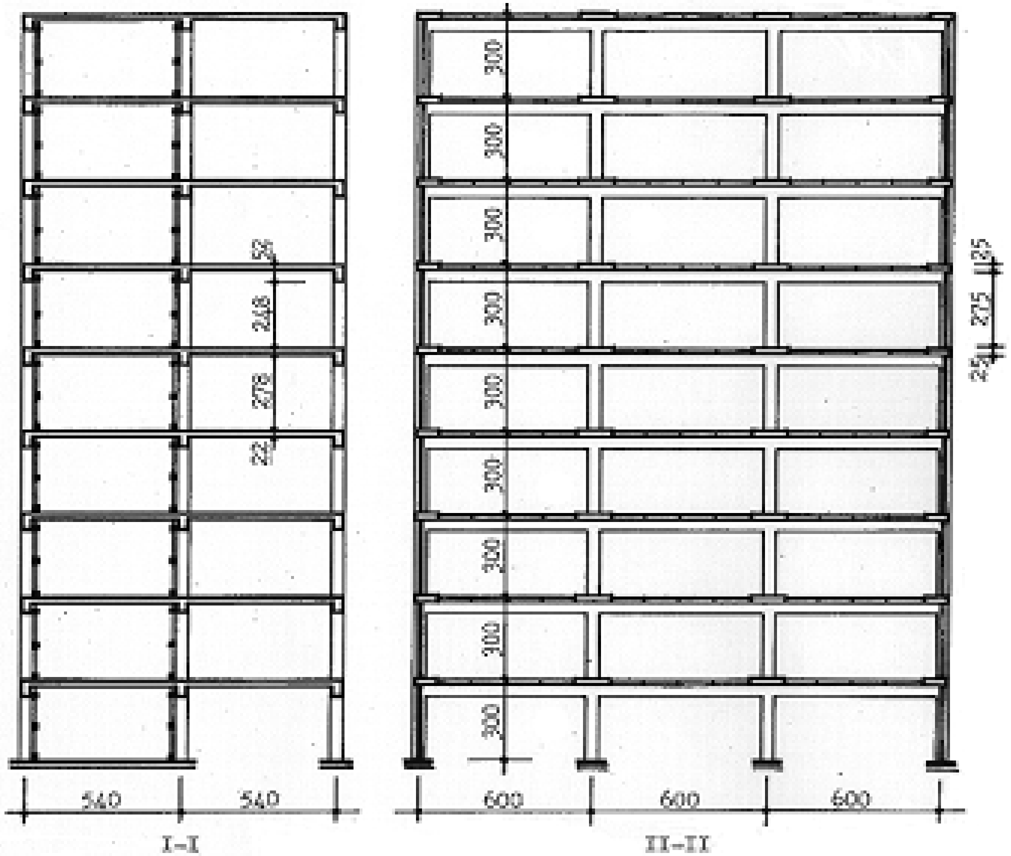
Data to obtain A of stories of the reinforced concrete buildings of various structural systems

Building's structural system	Δ	K
Frame with weak beams	h/1250	4,5
Frame with strong beams	h/1500	4,2
Braced frame with solid reinforced concrete shear walls or a system with solid bearing walls	h/2000	4,0
Braced frame with shear walls or bearing walls, having openings	h/3150	3,7

h – story's height

The general geometrical dimensions of the frame of the 9-story building N141





The values of the required and actual bearing capacities calculated for the 9-story existing R/C building

Required bearing capacity, kN (Code II-7-81)		Required bearing capacity, kN (Code II-6.02-2006)		Actual bearing capacity, kN	
x	y	x	y	x	y
Q_1^R=1183	Q_1^R=1091	Q_1^R=4593	Q_1^R=3691	Q_k^A=1860	Q_k^A=1115
Q_2^R=1176	Q_2^R=1067	Q_2^R=4573	Q_2^R=3615		
Q_3^R=1150	Q_3^R=1013	Q_3^R=4476	Q_3^R=3432		
Q_4^R=1100	Q_4^R=930	Q_4^R=4276	Q_4^R=3152		
Q_5^R=1016	Q_5^R=821	Q_5^R=3949	Q_5^R=2782		
Q_6^R=895	Q_6^R=688	Q_6^R=3477	Q_6^R=2332		
Q_7^R=734	Q_7^R=535	Q_7^R=2849	Q_7^R=1814		
Q_8^R=531	Q_8^R=366	Q_8^R=2061	Q_8^R=1242		
Q_9^R=186	Q_9^R=186	Q_9^R=1116	Q_9^R=632		

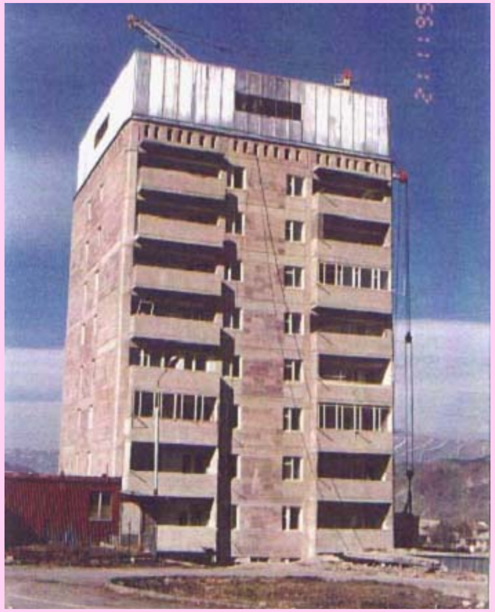
x – transverse direction of the building

y – longitudinal direction of the building

Q_k^R – seismic shear forces corresponding to the required bearing capacity

Q_k^A – seismic shear forces corresponding to the actual bearing capacity

The project on upgrading seismic resistance of nine-storey RC frame buildings by means of roof isolation / additional isolated upper floor (AIUF) pioneered the applications of seismic isolation structures to the top part of the buildings and was implemented in 1995-1997. The project was financed by the World Bank.

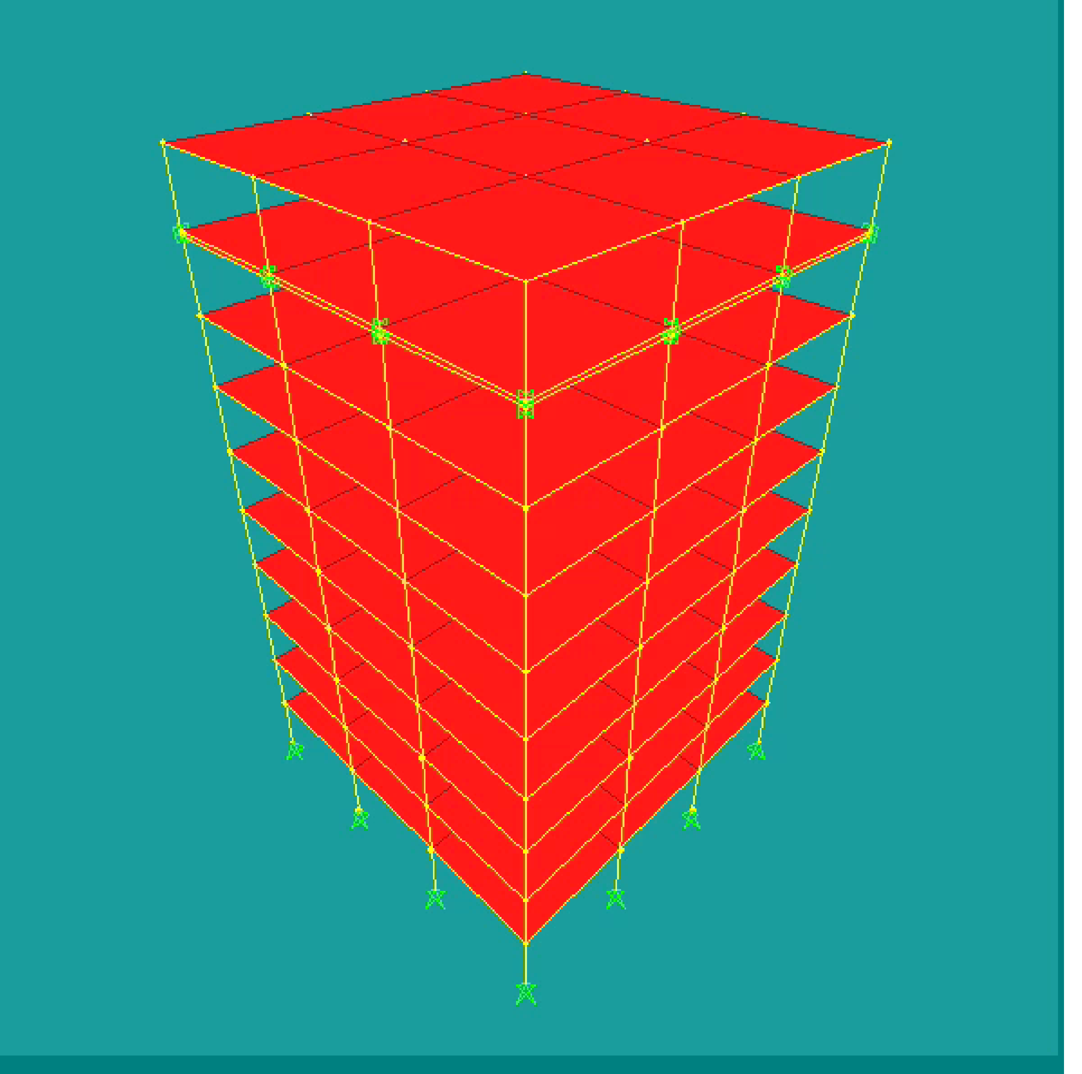


There are 16 columns in the plan of the buildings. All columns pass through the slab of the ninth floor into the space of the attic floor and are taken into steel jackets. The assembling of AIUF over the building starts after dismantling the attic floor. The connection of AIUF to the building was designed by means of high damping rubber bearings (HDRB). The steel jackets of all 16 columns were connected to each other by means of steel trusses. Thus, a rigid structure is created to transfer the forces from AIUF to the building.

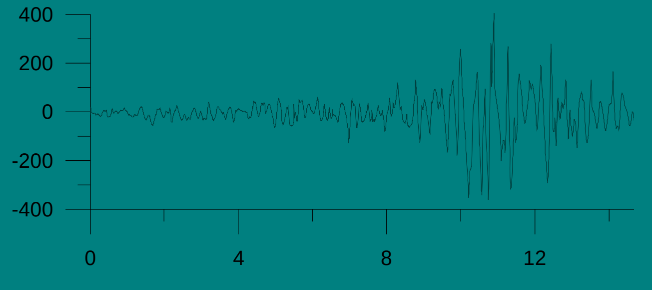
Under the earthquake impact AIUF, acting as vibration damper, reduces the stress-deformed state of the building and increases earthquake resistance, on average by a factor of 1.6.

It is worth noting that the isolated upper floor allows not only upgrading the earthquake resistance of a building, but enlarging its useful space as well. The most distinctive feature of this earthquake resistance upgrading method, however, is that there is no need to re-settle the occupants of the building during construction.

Earthquake response analysis of the building protected with the roof isolation system



December 7, 1988 Spitak Earthquake accelerogram recorded at the Ghoukassian station and scaled to 0.4g



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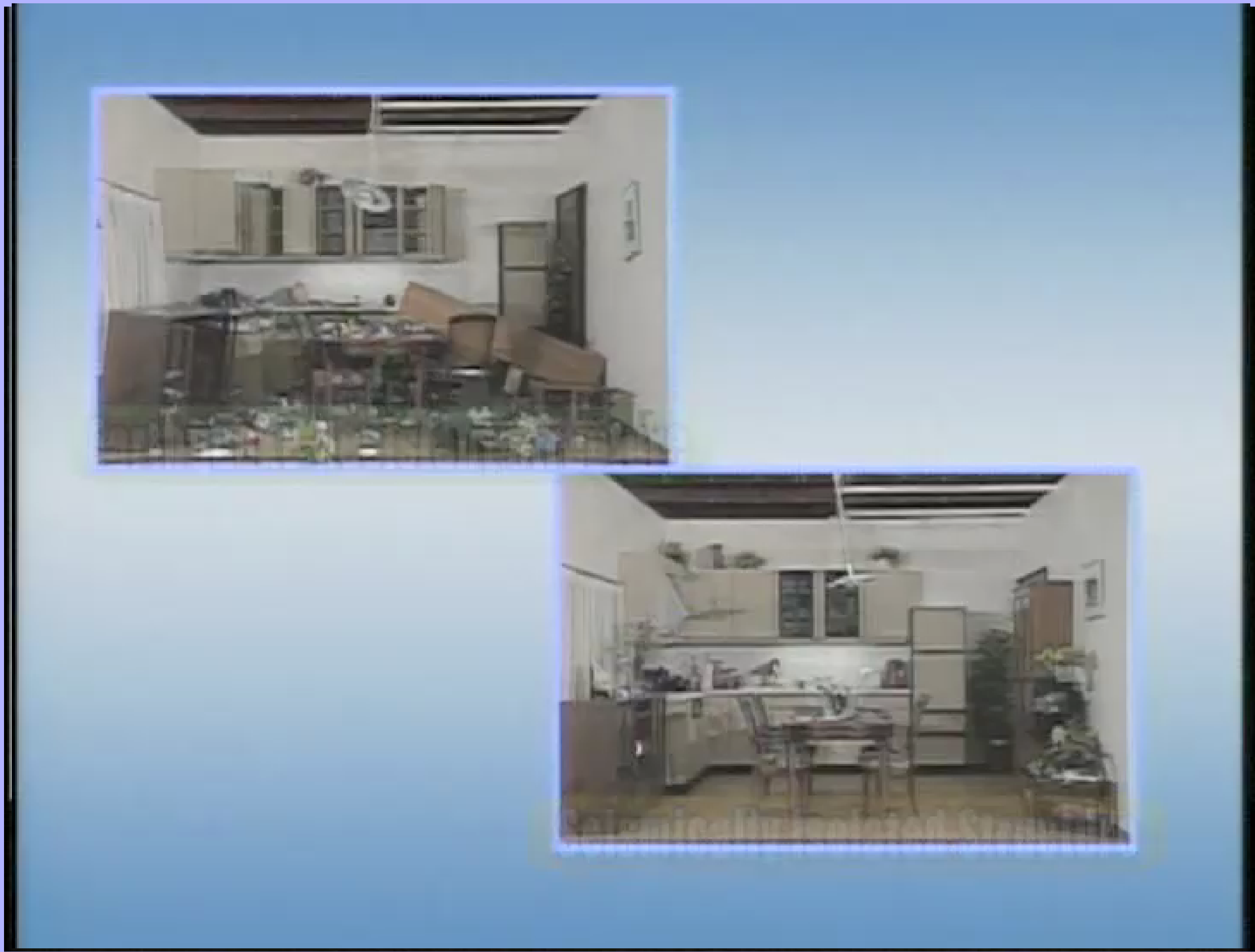


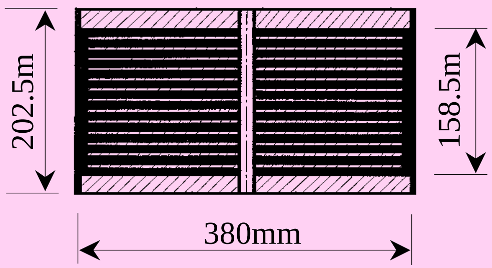
movie

The structural concept developed in 1994 (M.G. Melkumyan, Patent of the Republic of Armenia No 579) aims to retrofit an existing building by means of seismic isolation, using simple working technology. This is a unique, pioneering seismic isolation project introduced in 1995-1996 for an existing five-storey stone building.
The project was financed by the World bank.

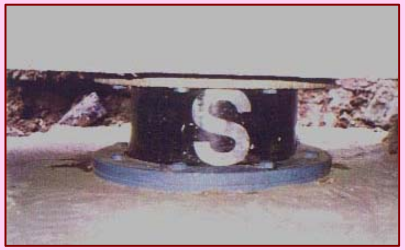
The idea is to supply this building with seismic isolation by gradually cutting it from its foundation and installing the isolators at the level of upper edge of the foundation between a two-stage system of RC beams. The operation is made without resettlement of the occupants. World practice provides no similar precedent in retrofitting of apartment buildings.

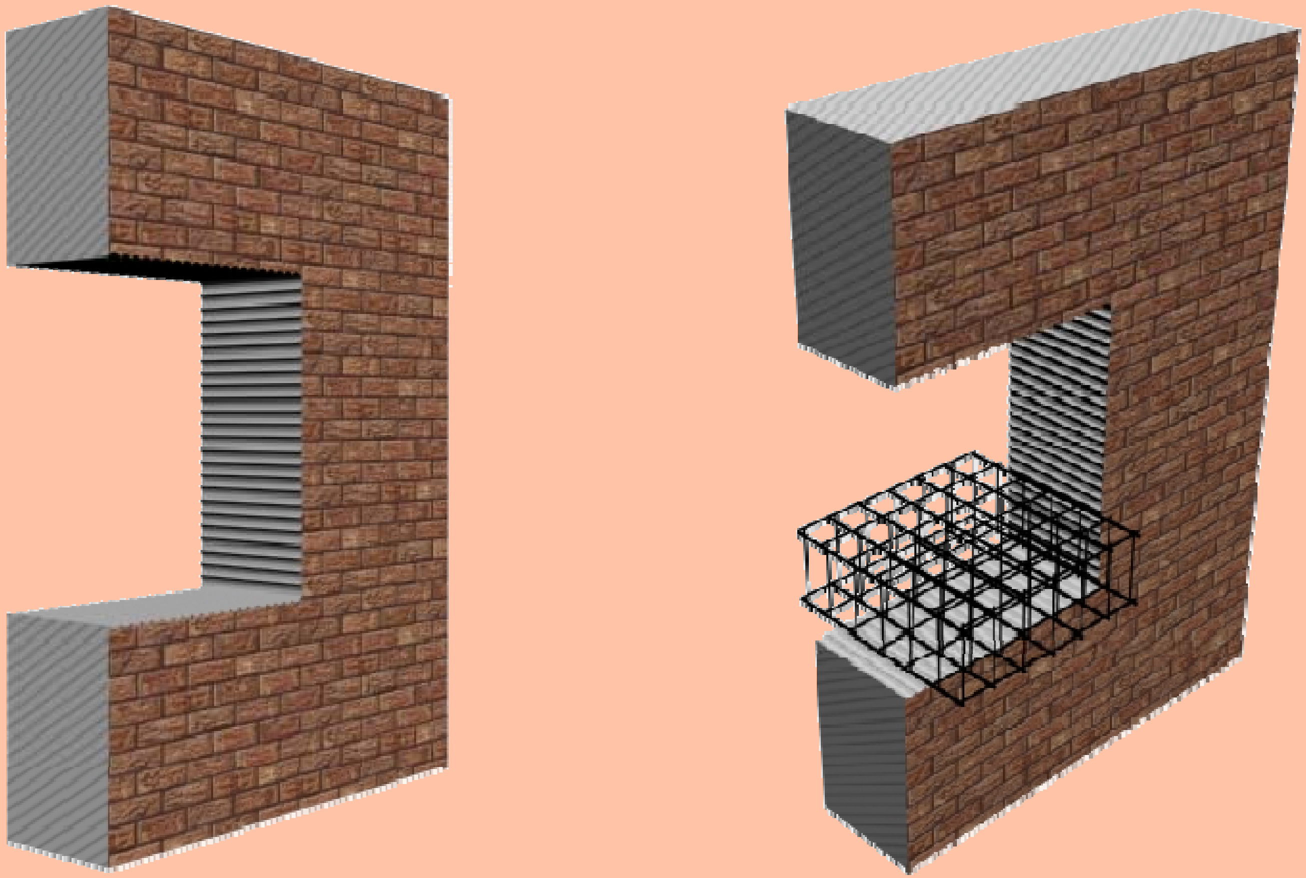
In addition, this technique was shown to be much cheaper than conventional strengthening methods. Conventional strengthening involves fitting a reinforcing steel mesh to the bearing walls and spraying on concrete. For rehabilitated building the cost would have been about US$ 340,000. The cost of seismic isolation is only about US$ 200,000, a substantial saving.

The HDRB for seismic isolation were designed in collaboration with TARRC (UK). As the range of the static vertical loads on each bearing is quite high, it was decided to have two types of bearings Soft -"S" and Hard -"H", differing only in the shear modulus of the rubber. The design horizontal displacement was 130 mm. The bearings were to operate safely up to 1.5 times the design displacement.

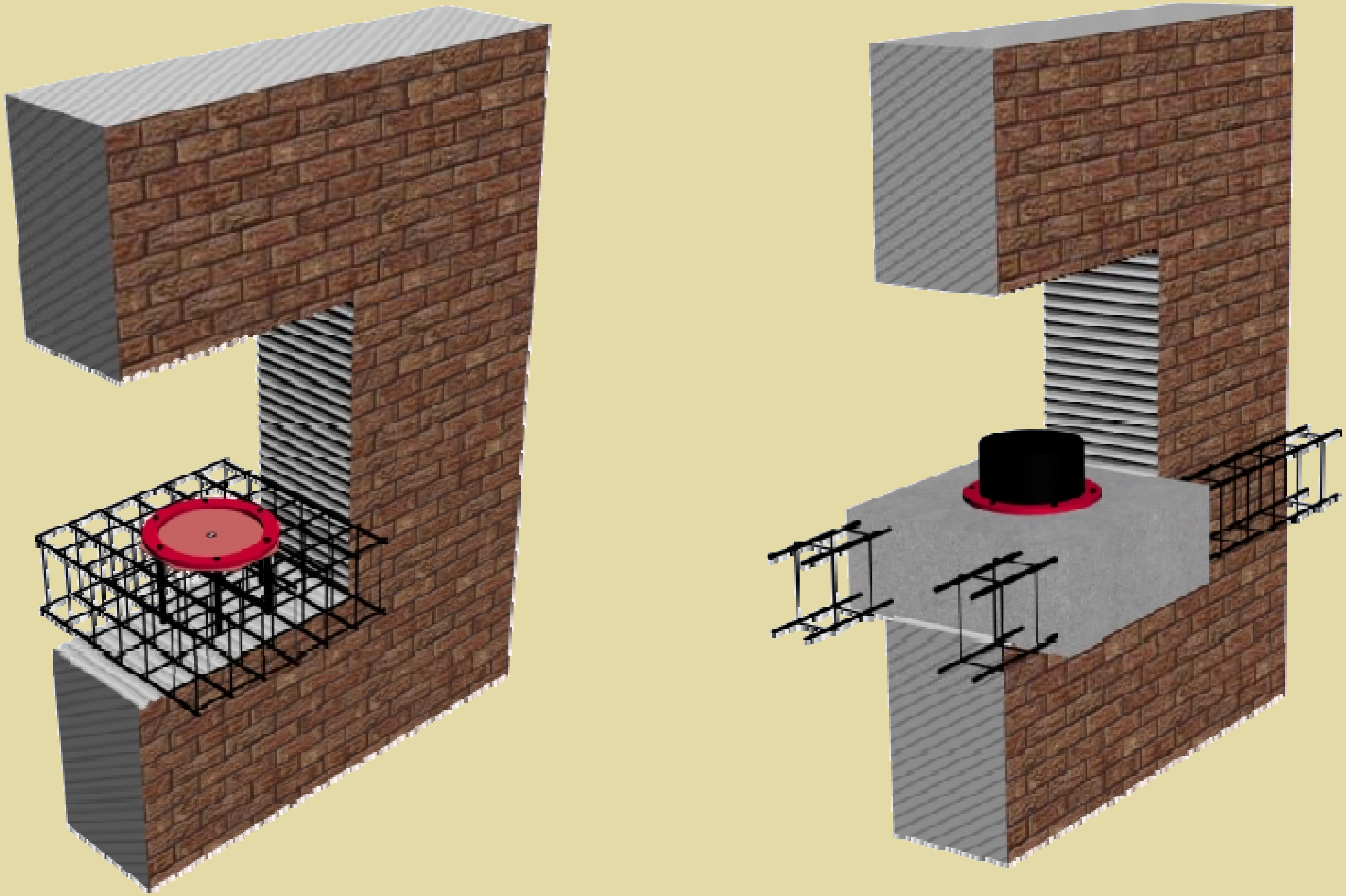


The bearings were tested at TARRC, using a single bearing facility. Under the design vertical load and the maximum horizontal displacement of 195 mm there was no sign of an approach to the displacement capacity of the isolators.





Stages of installation of seismic isolation in the existing buildings with bearing walls



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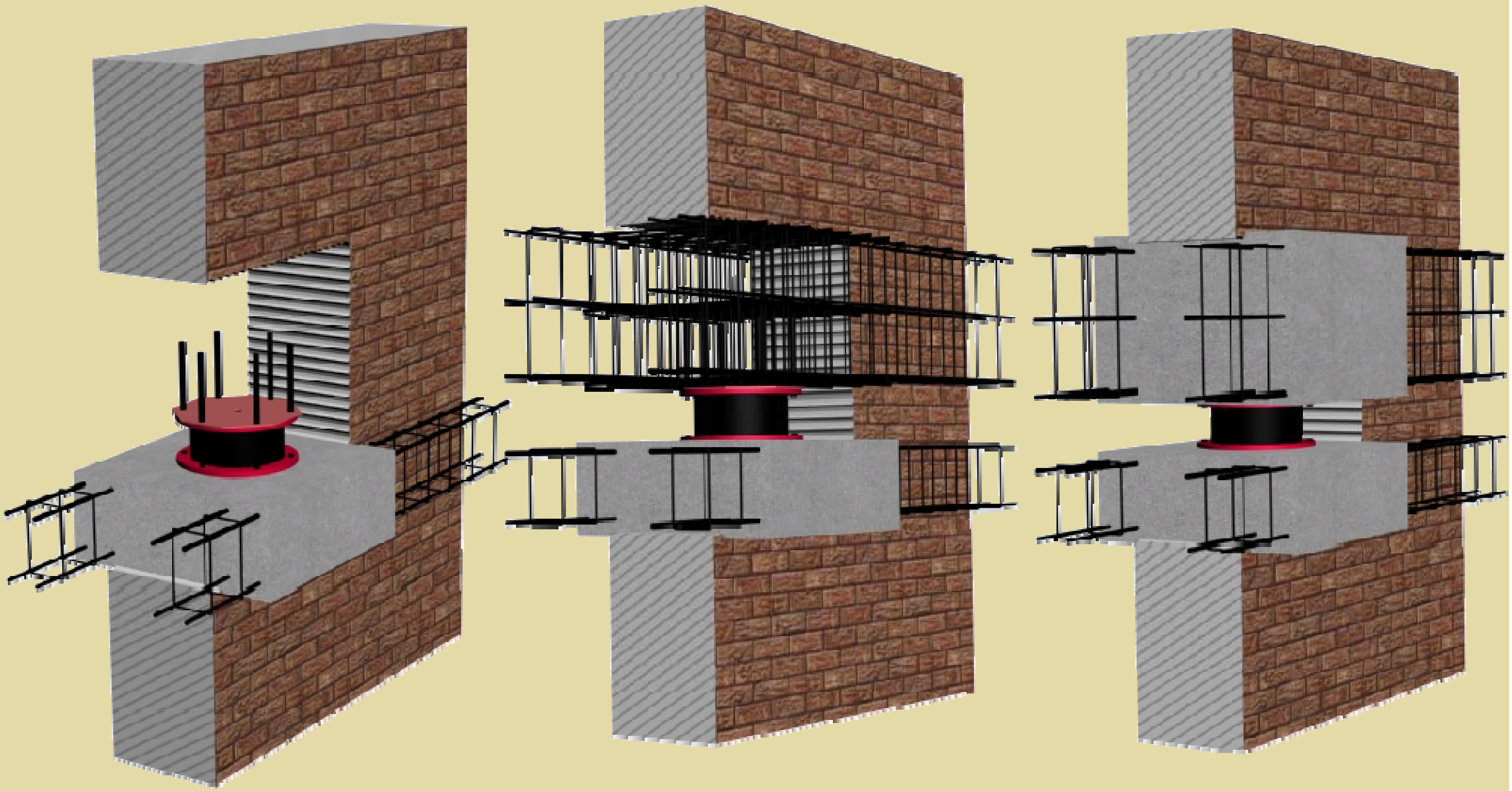

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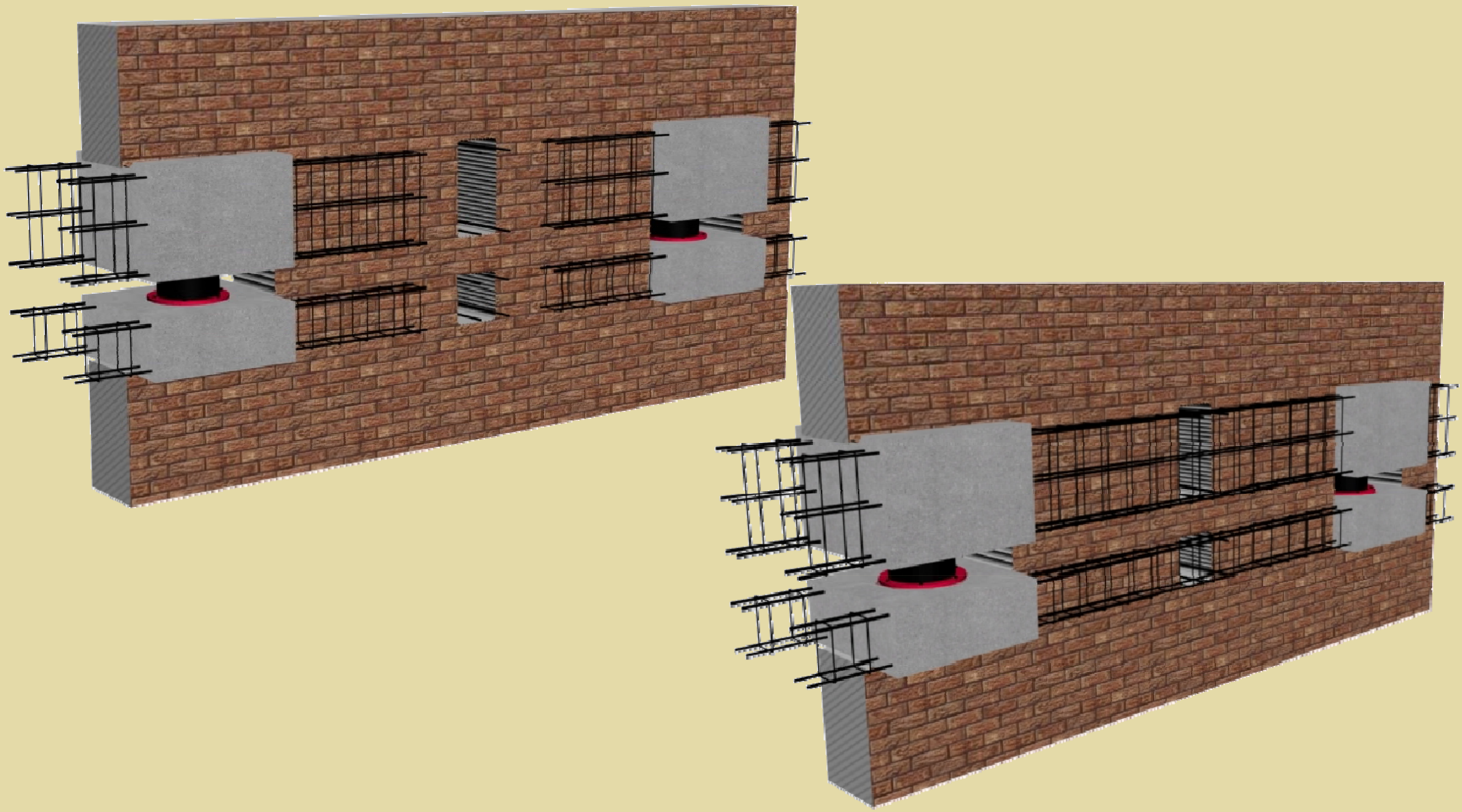

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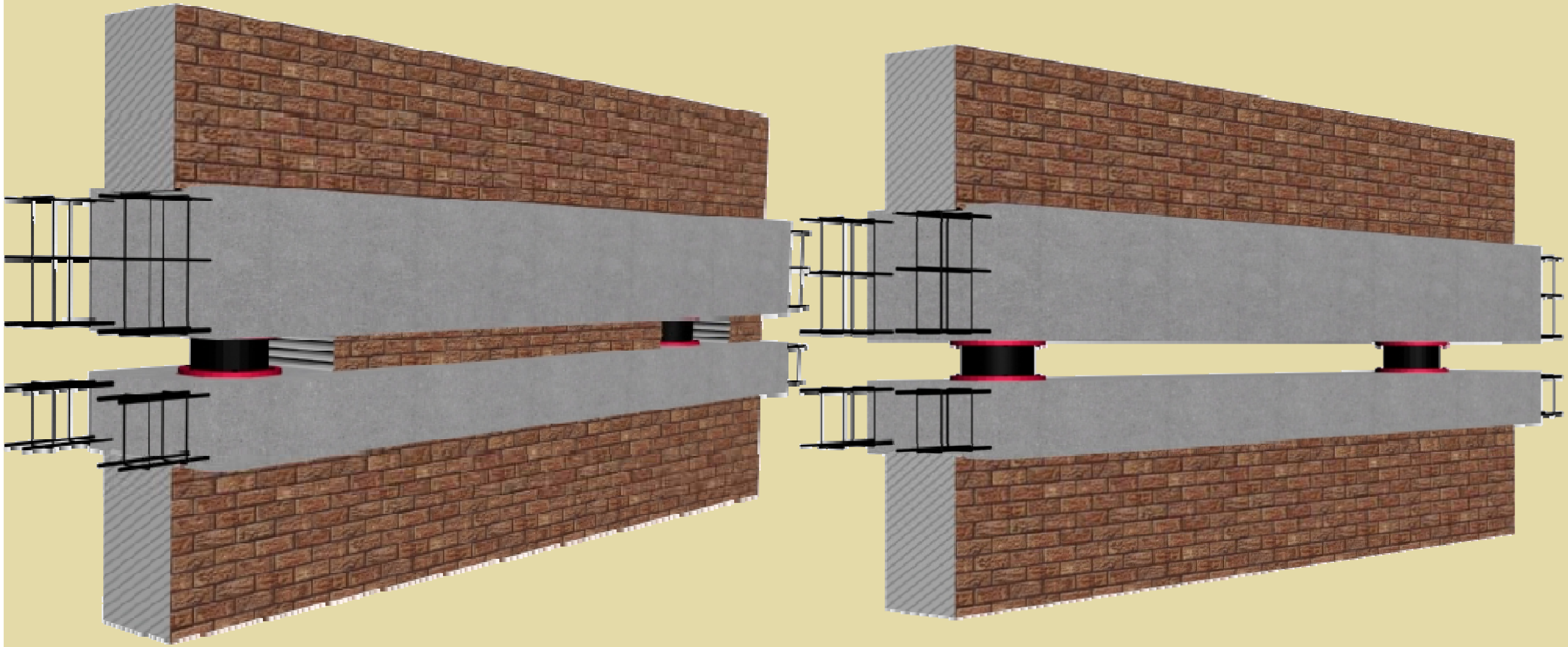
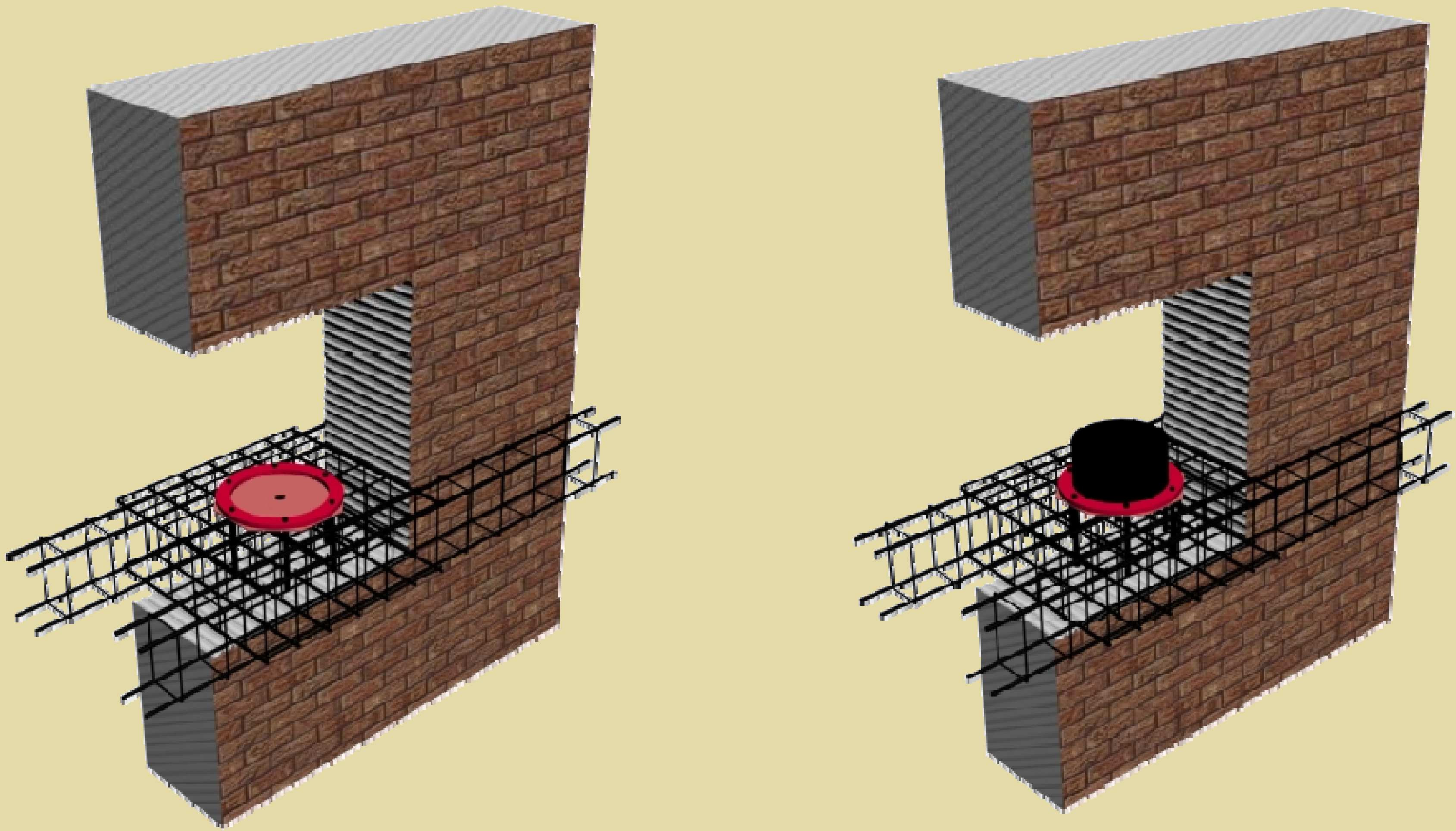


Stages of installation of seismic isolation in the existing buildings with bearing walls



Stages of installation of seismic isolation in the existing buildings with bearing walls

Retrofitted by base isolation existing 3-story building of school #4 in Vanadzor.
Project financed by "CARITAS Switzerland" in 2002

The case when the opening has the part of the existing wall above it

The view of the lower reinforcement frames installed in the opening together with the isolator socket

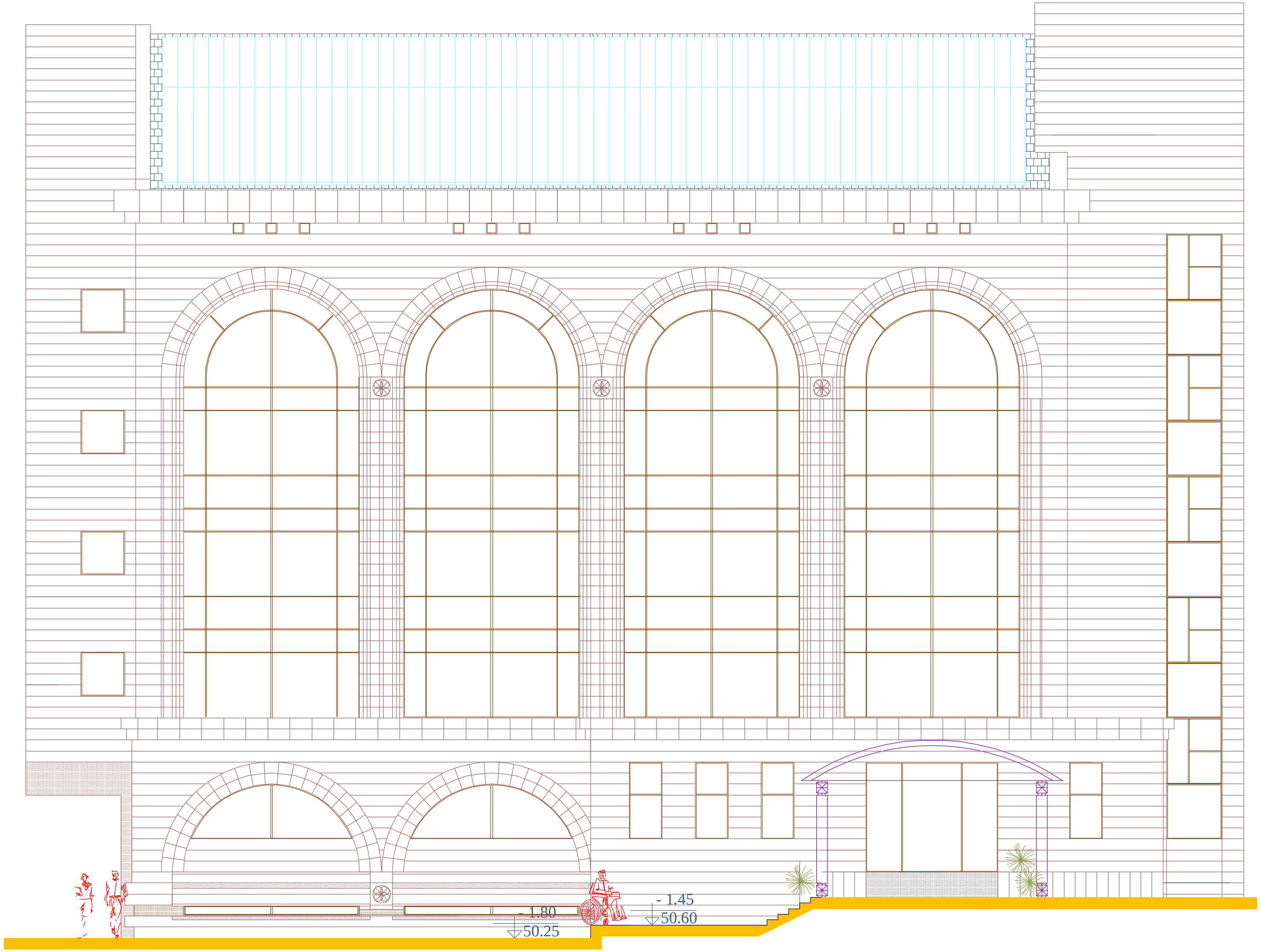
The view of the upper reinforcement frame installed in the opening together with the isolator upper socket after casting the concrete of the lower pedestal

The view of a two-stage system of R/C continuous beams, which separate the building from its foundation and create the seismic isolation system

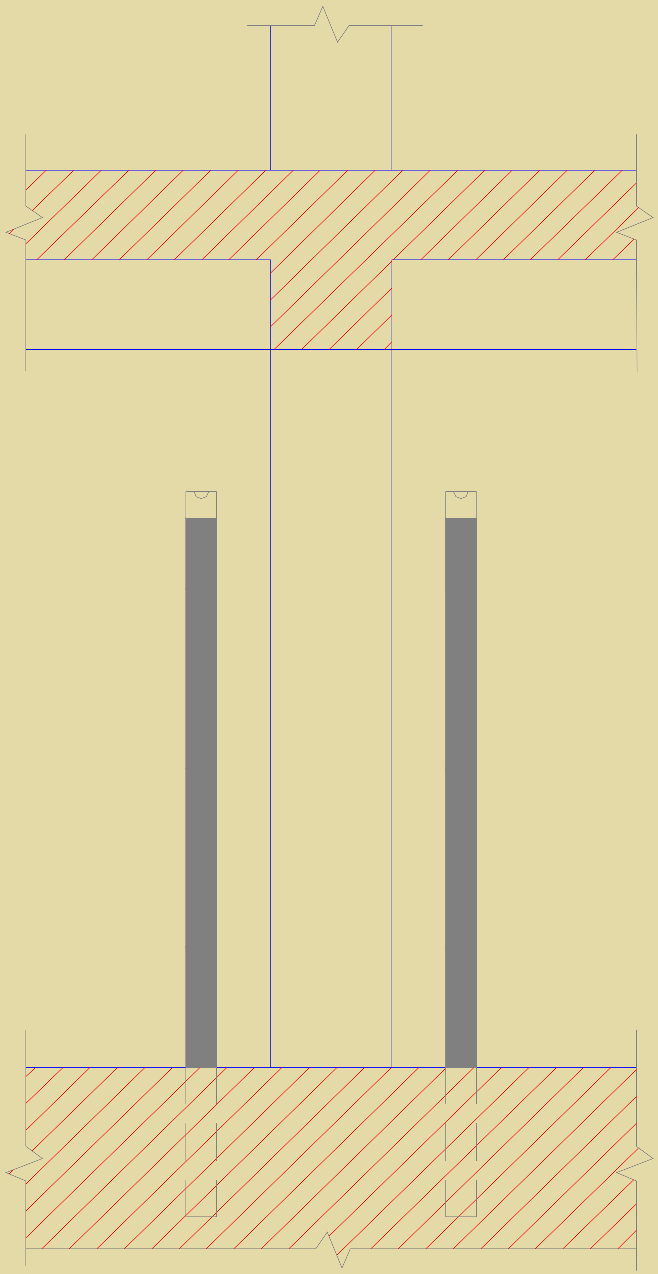
The existing beam
is crossing the space
of the opening and
supported by temporary
columns

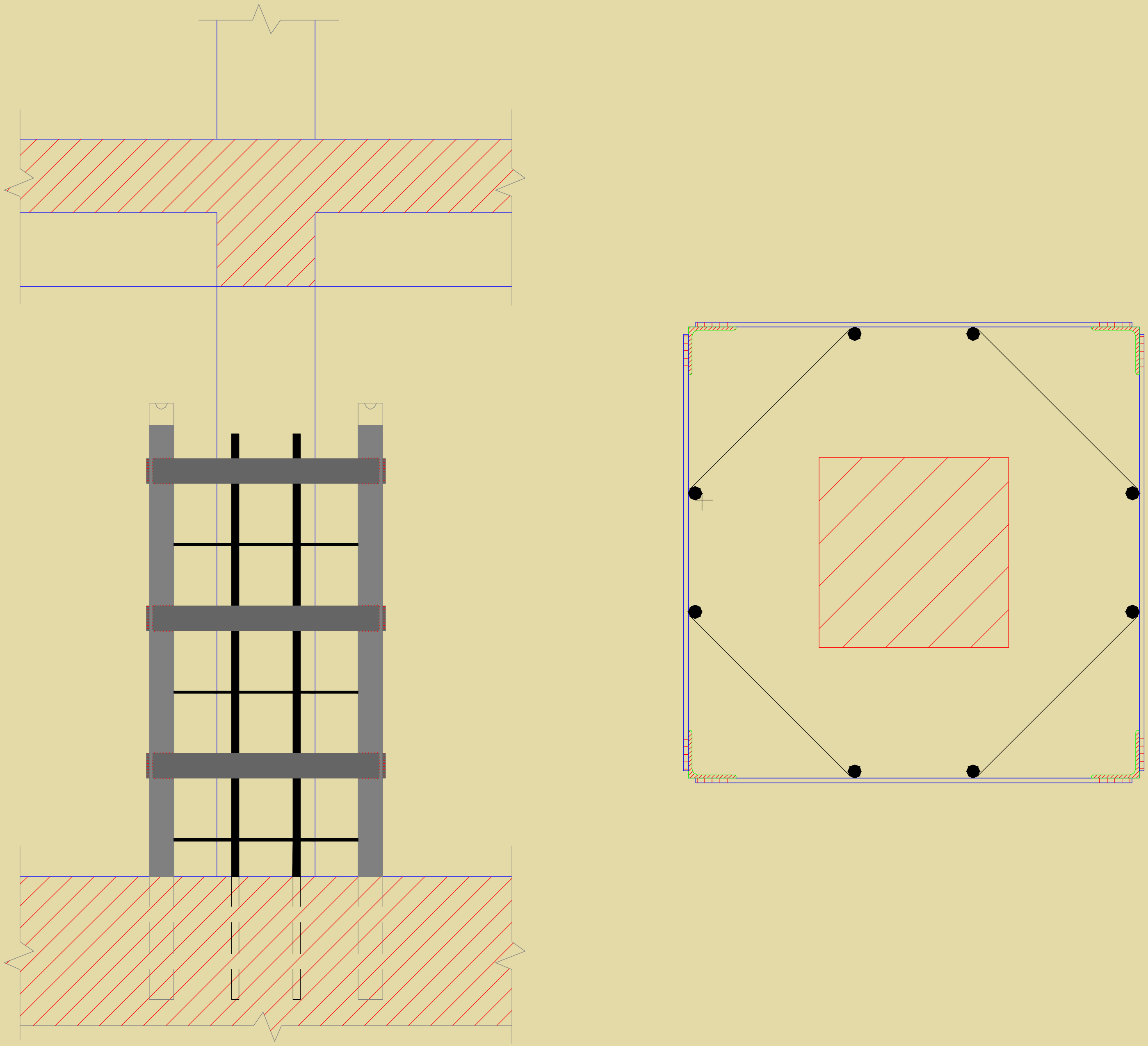
Temporary support under the existing arches

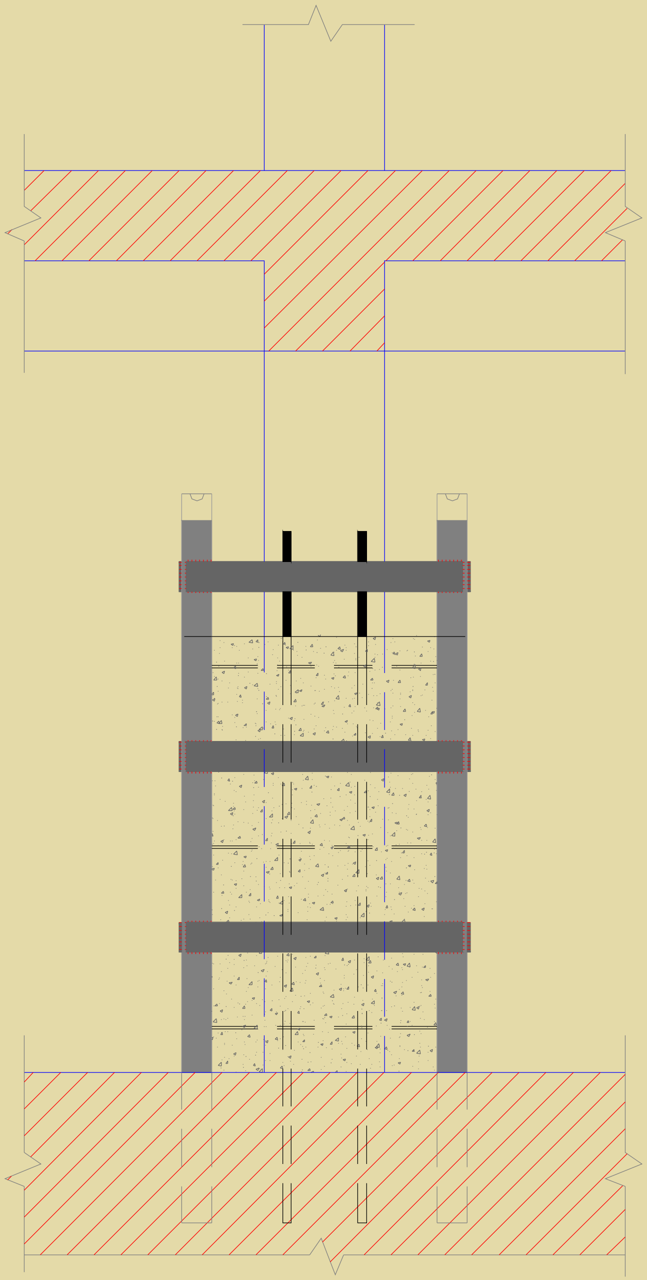
Existing column and the wall behind it are supported temporarily and the reinforcement frame of the upper pedestal is installed

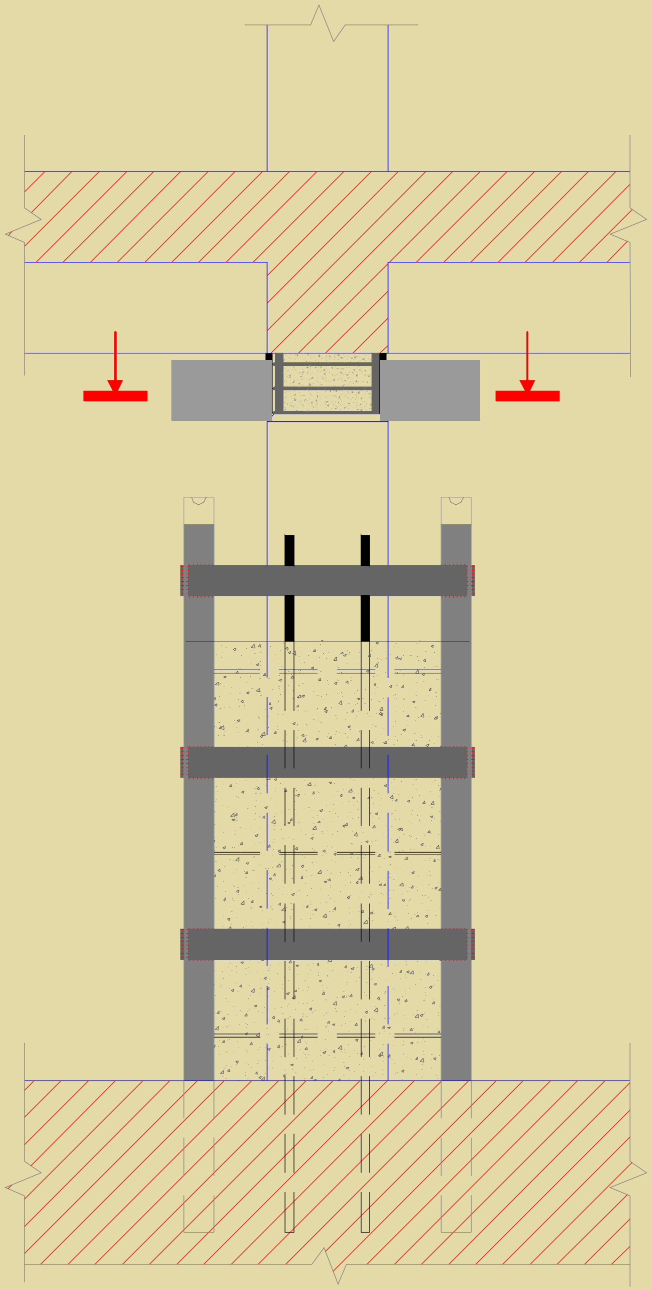


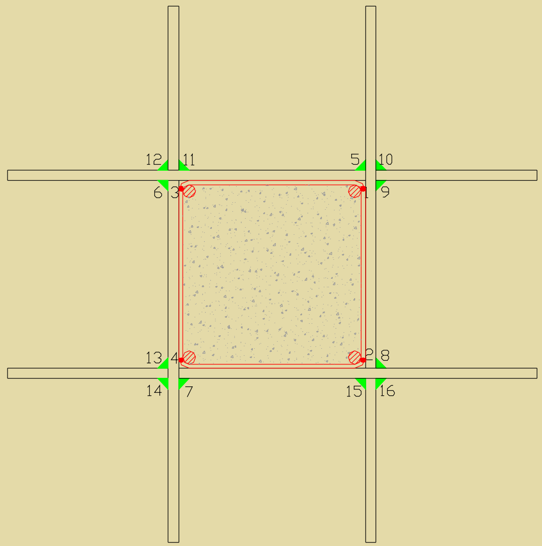
Existing RC frame building of Armenian-American Wellness Center (AAWC)







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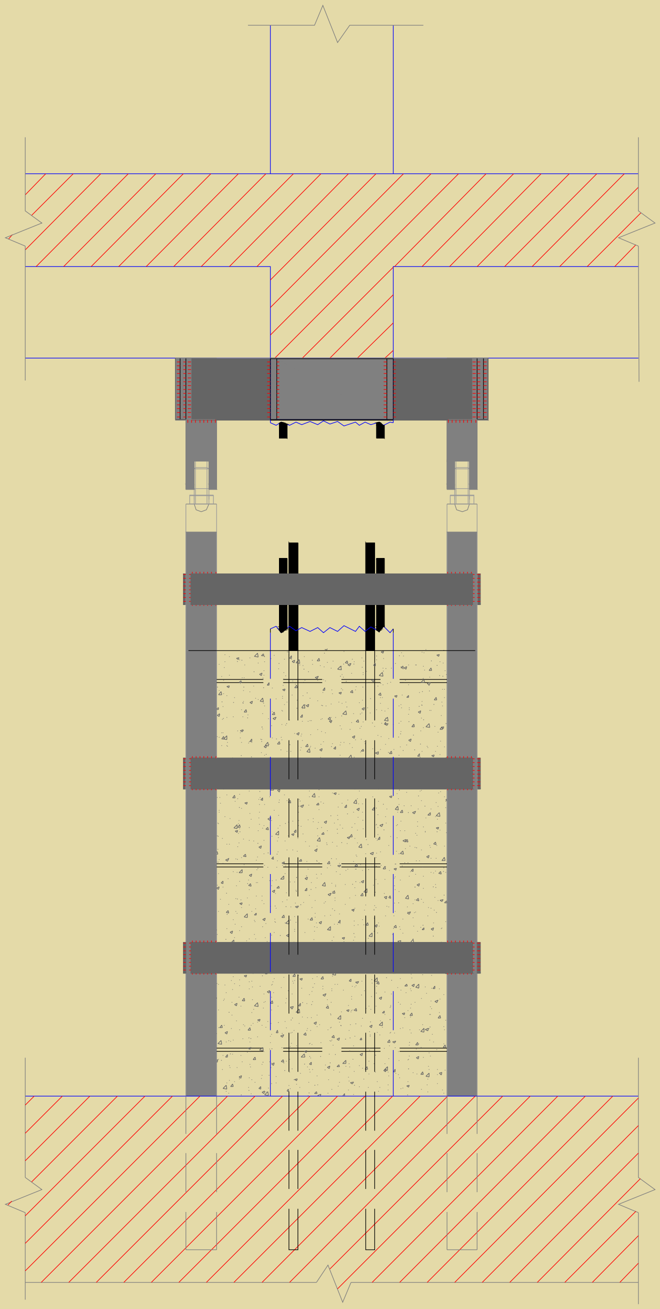
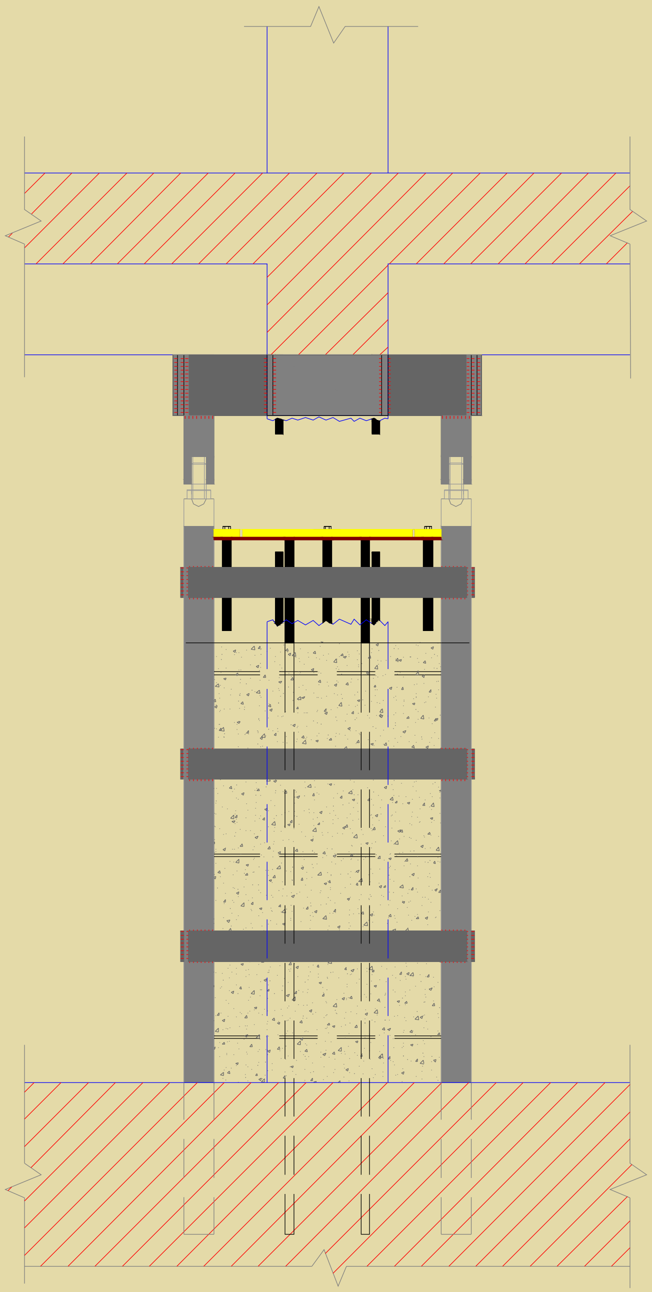
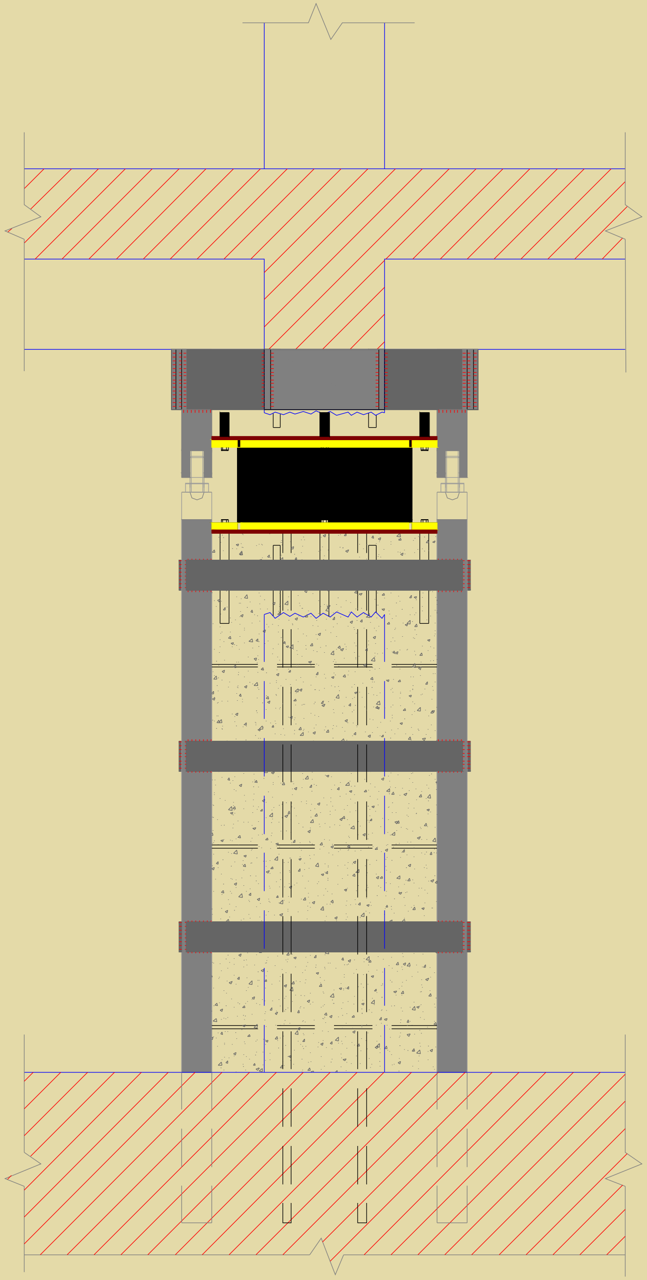
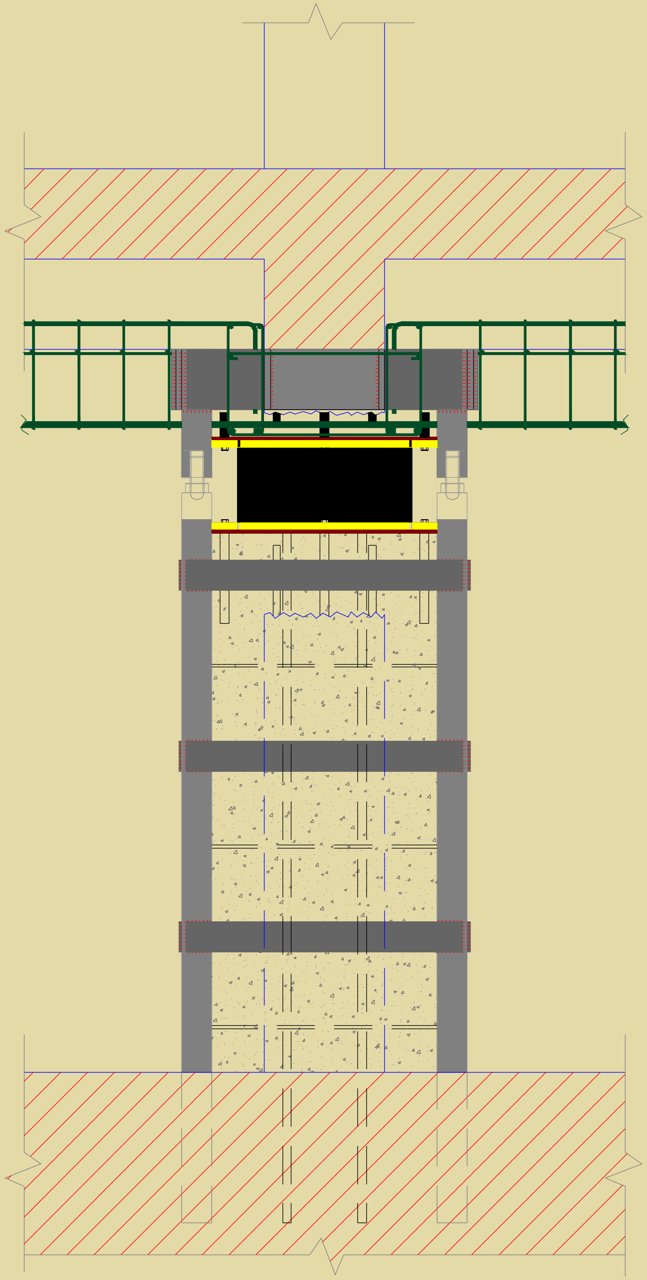
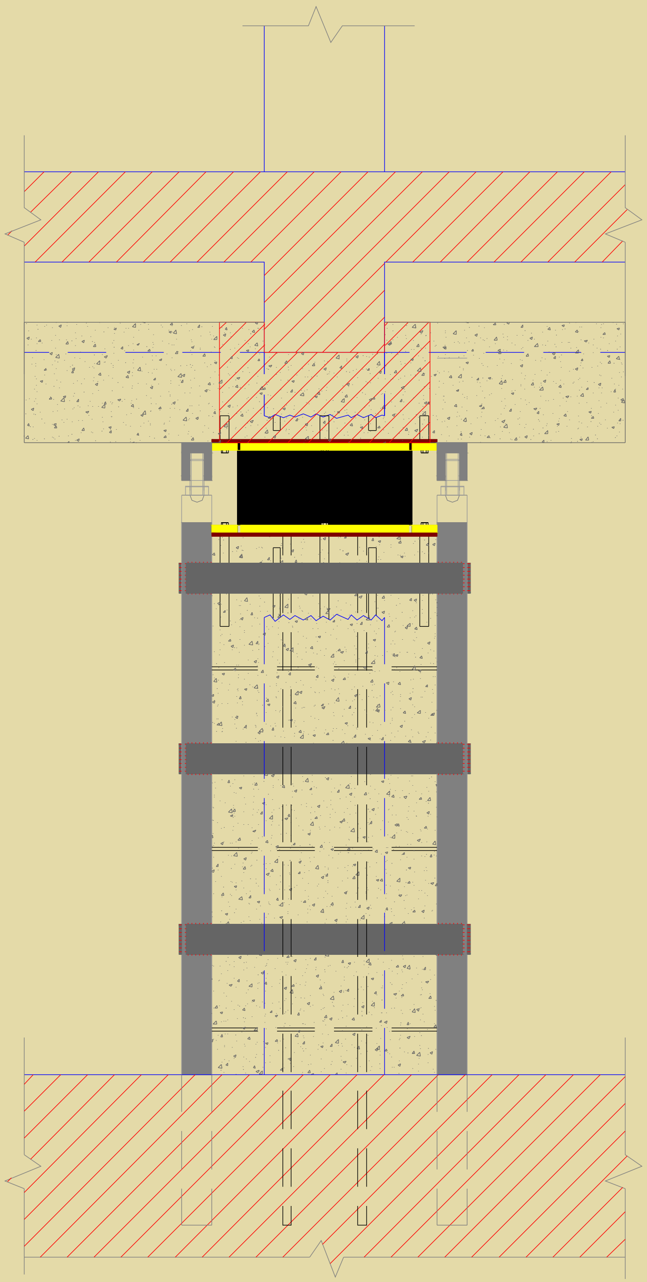
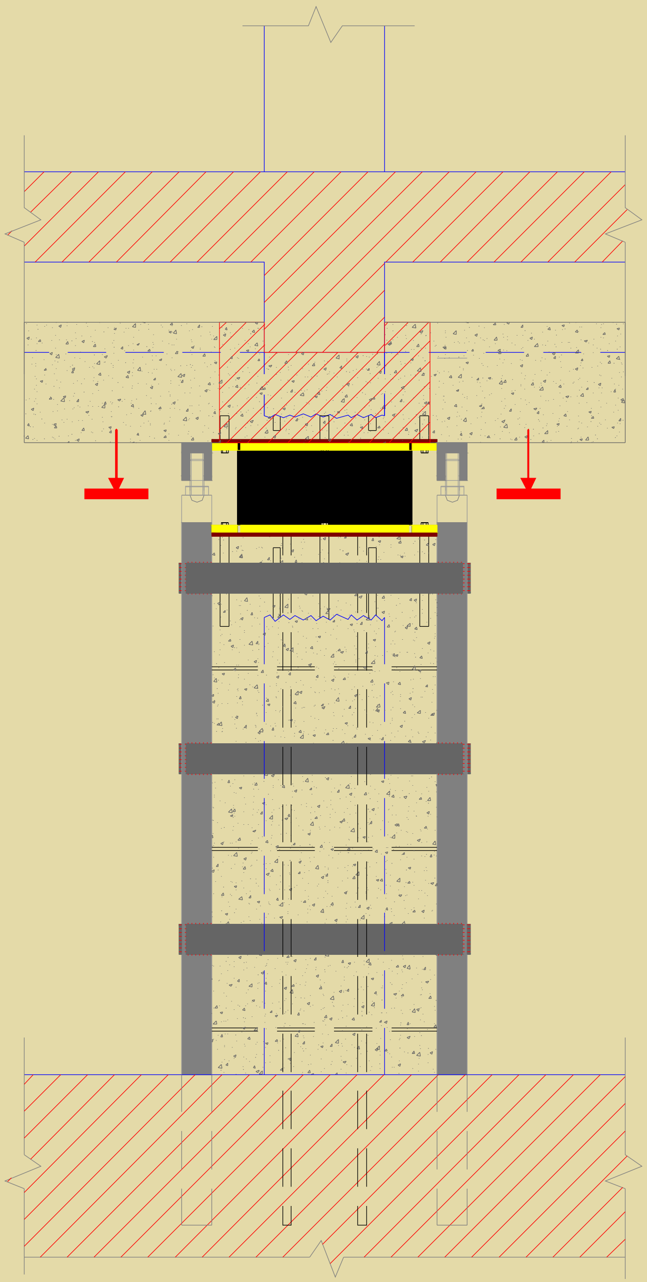


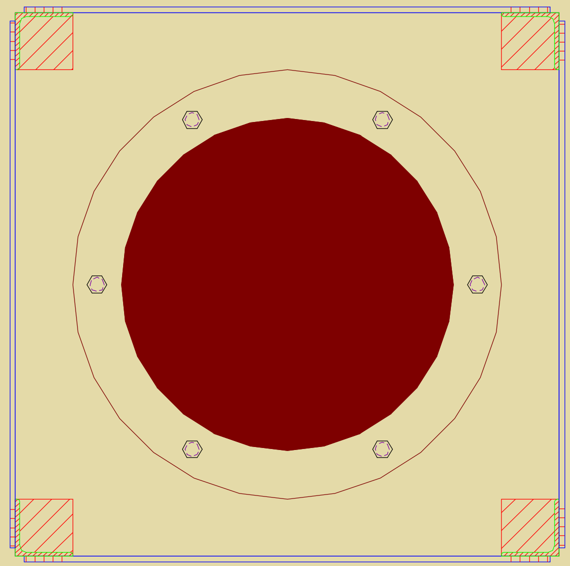


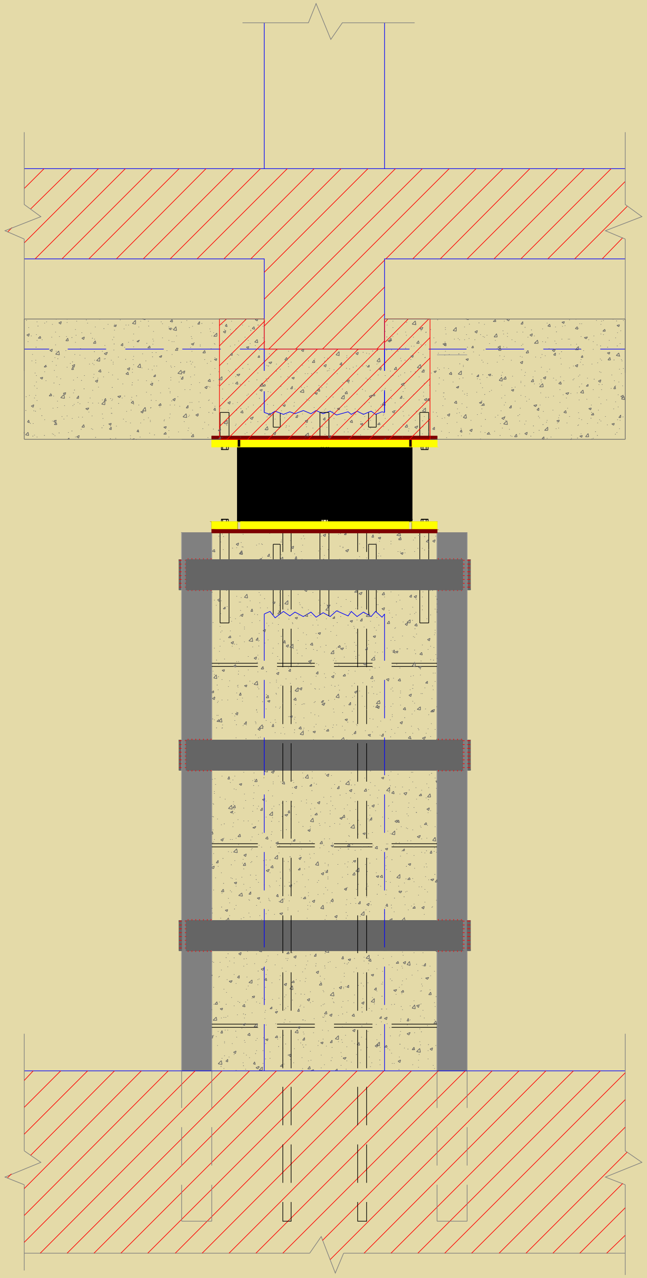








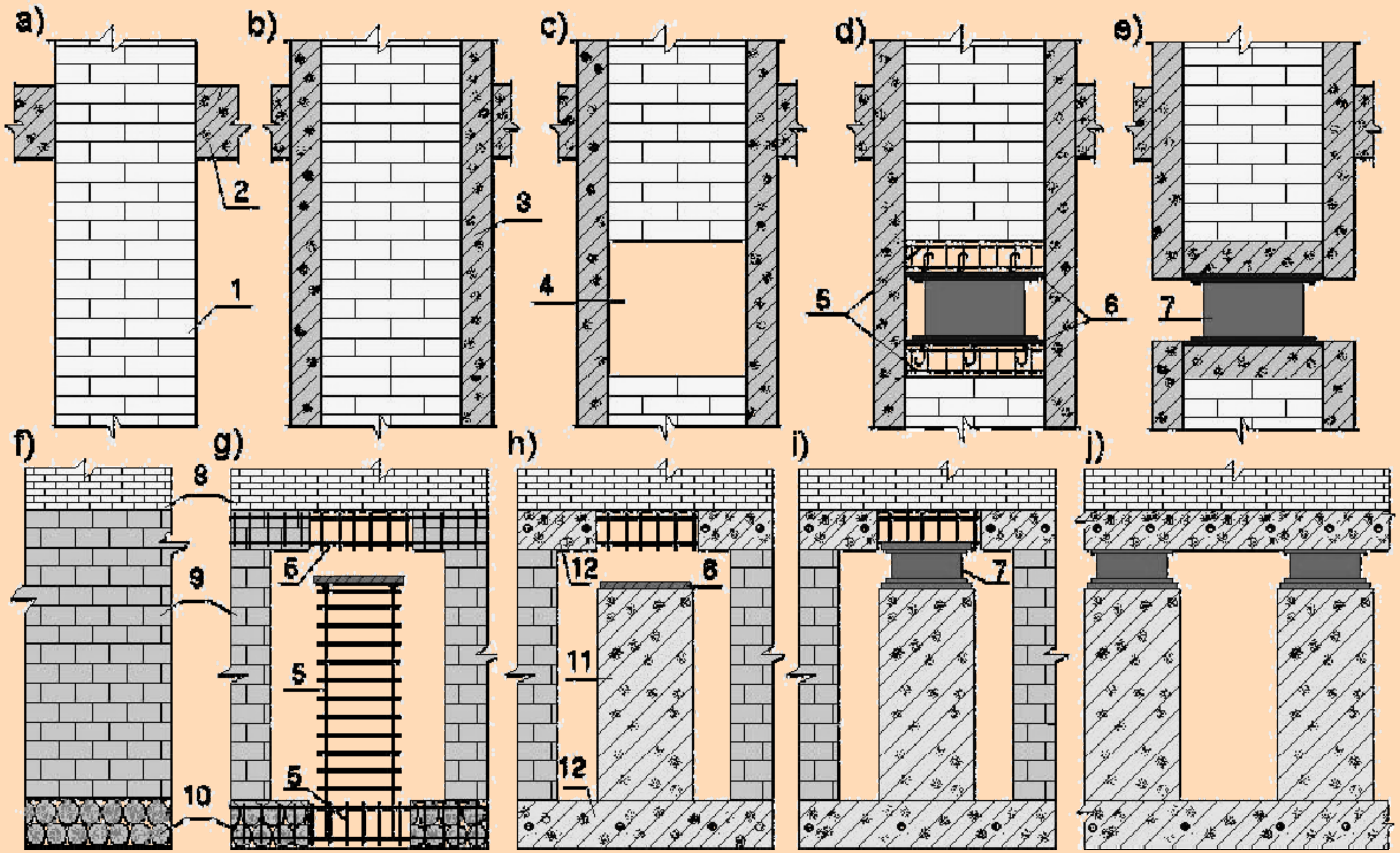




Application of Armenian Seismic Isolation Technologies in Russia and Romania

It is worth noting that the developed in Armenia technologies were successfully applied for retrofitting of an existing 100 years old Bank building in the city of Irkutsk, Russia,

and for design of retrofitting of an existing 177 years old Municipality building in the city of Iasi, Romania



Sequence of installation of the seismic isolators in the Bank building in Irkutsk

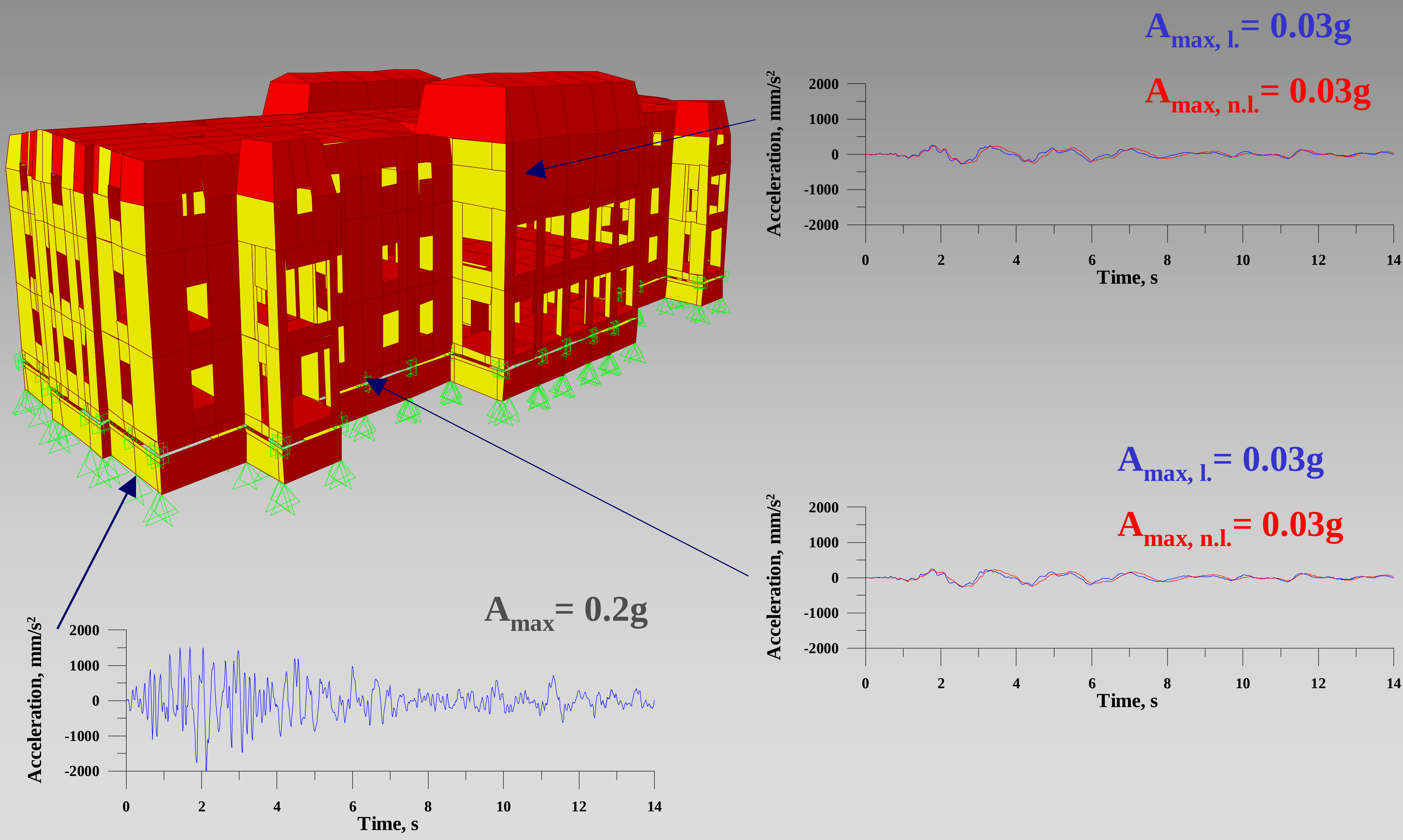
1 - brick masonry column; 2 - reinforced concrete beam; 3 - external reinforced concrete cage; 4 - cutting portion of column; 5 - steel bar; 6 - steel plate; 7 – seismic isolator; 8 - brick masonry wall of the first story; 9 - block masonry wall of the socle story; 10 - stone and concrete strip foundation; 11 - reinforced concrete pole; 12 - upper and lower portion of beams.

The view of the Iasi City Hall building

The average results of the linear and non-linear earthquake response analyses of the base isolated Iasi City Hall building using 26 acceleration time histories scaled to 0.2g

Level	Longitudinal (X) direction			Transverse (Y) direction		
	Displace-ment (mm)	Accelera-tion (g)	Shear forces (kN)	Displace-ment (mm)	Accelera-tion (g)	Shear forces (kN)
Linear analysis						
First floor slab	87.53	0.08		87.13	0.08	
Ground floor slab	86.66	0.08		86.46	0.08	
Top of isolators	86.02	0.08		86.13	0.08	
Bottom of isolators	0.09	0.2		0.08	0.2	
Foundation	0	0.2	11226	0	0.2	11242
Non-linear analysis						
First floor slab	111.65	0.06		111.77	0.07	
Ground floor slab	111.08	0.06		108.42	0.06	
Top of isolators	109.45	0.06		106.99	0.06	
Bottom of isolators	0.41	0.2		0.38	0.2	
Foundation	0	0.2	13700	0	0.2	13418

Comparison of the response accelerations on the levels of the top of isolators and of the slab of conference hall by the linear and non-linear analyses in longitudinal direction using 30.05.90 Vrancea Earthquake acceleration time history recorded in Iasi and scaled to 0.2g



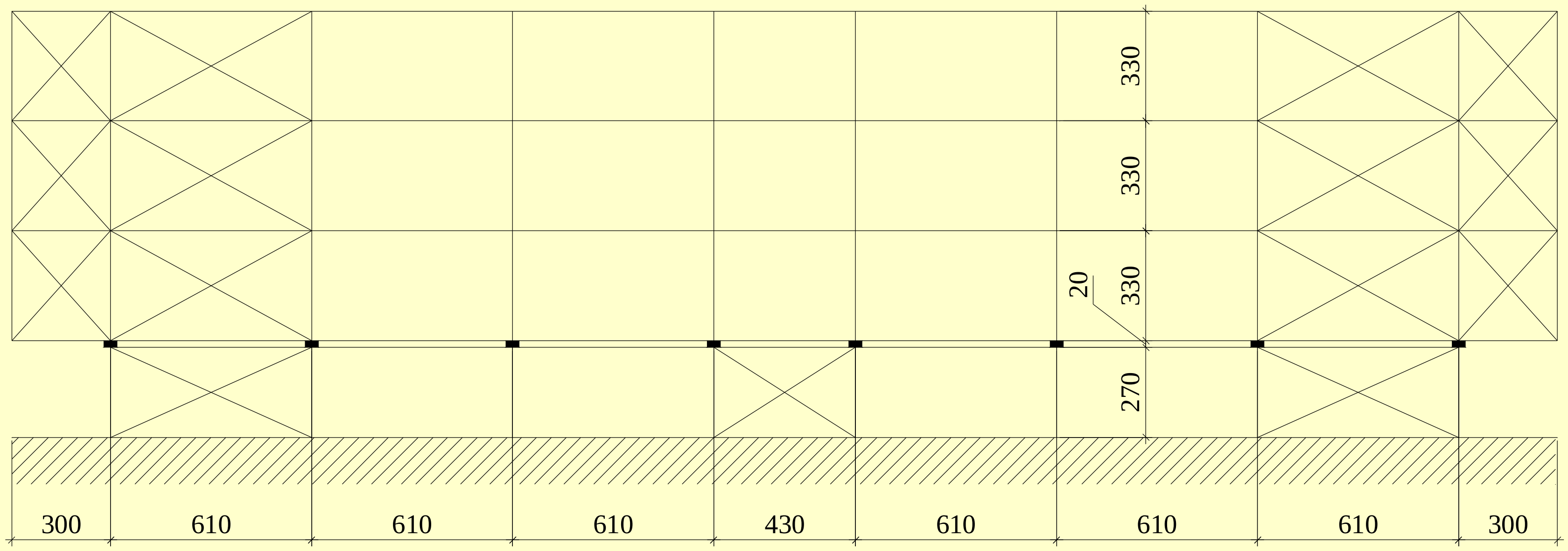
Seismic isolation techniques developed in Armenia are bringing to significant savings in construction and retrofitting costs. This fact has attracted the attention of the International institutions and private companies

Seismic isolation provides high reliability for buildings and structures and the possibility to accelerate the whole construction process

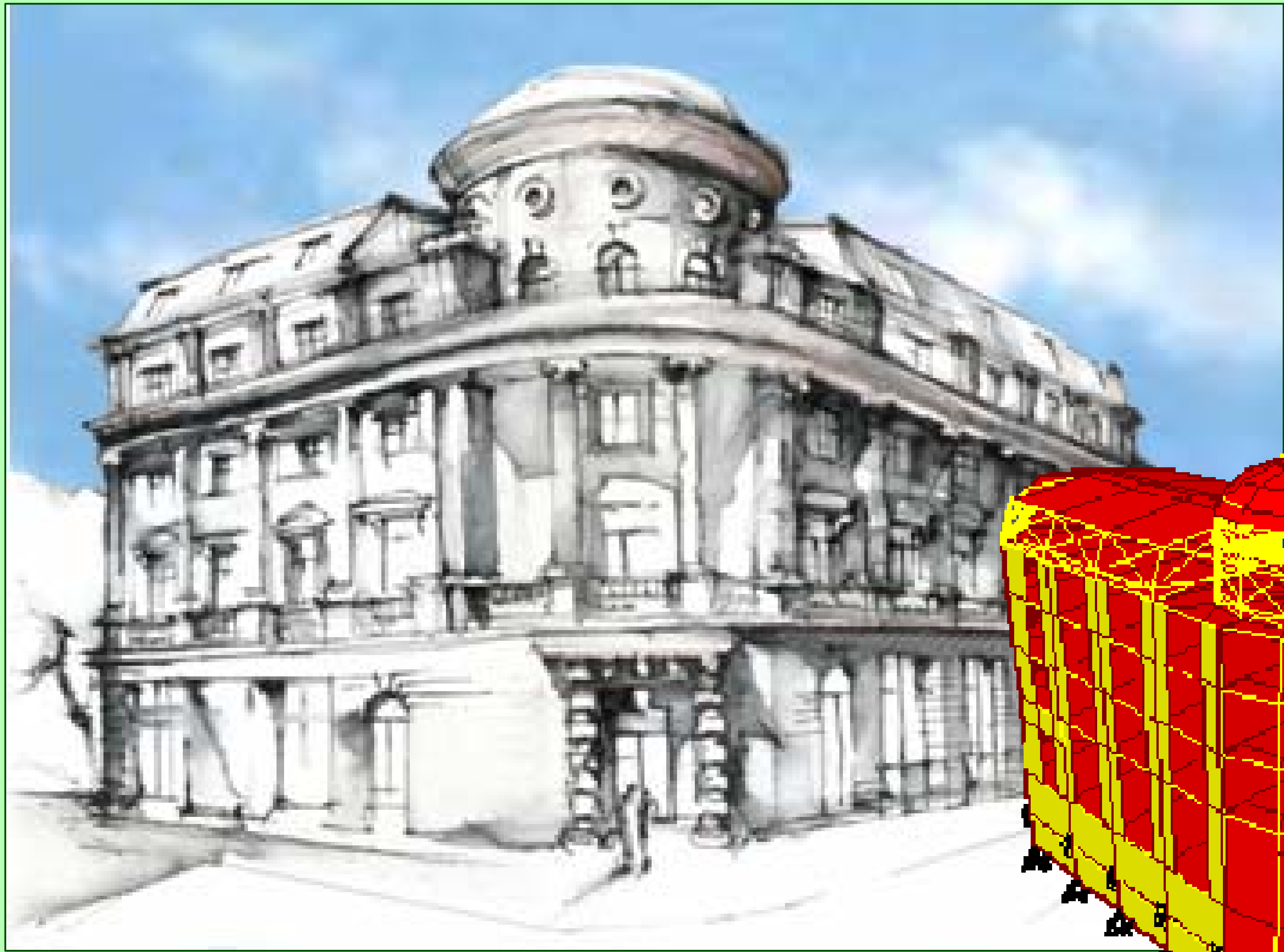
The possibility of retrofitting by seismic isolation without interruption of the use of the facilities gives a unique opportunity for the developing country to mitigate the seismic risk of destruction of existing buildings with minimal expenses

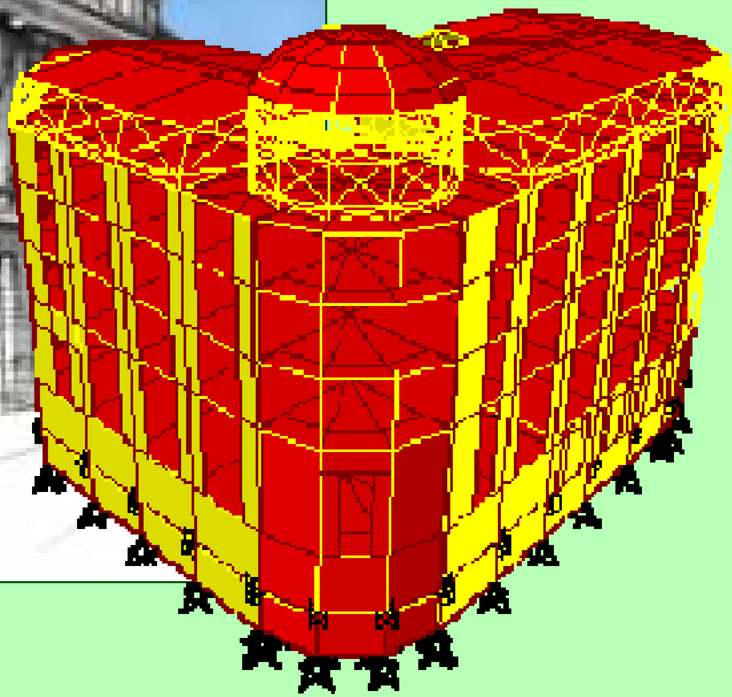
Newly constructed 4-story base isolated apartment buildings in Gyumri.

Newly constructed 3-story base isolated clinic building in Stepanakert.

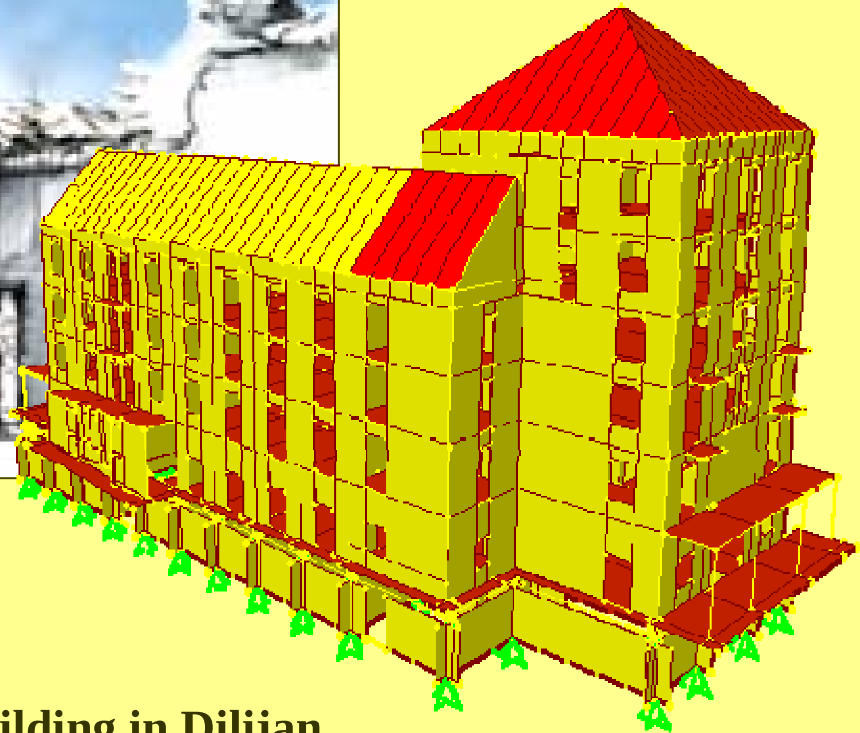


Schematic vertical elevation of the Clinic building

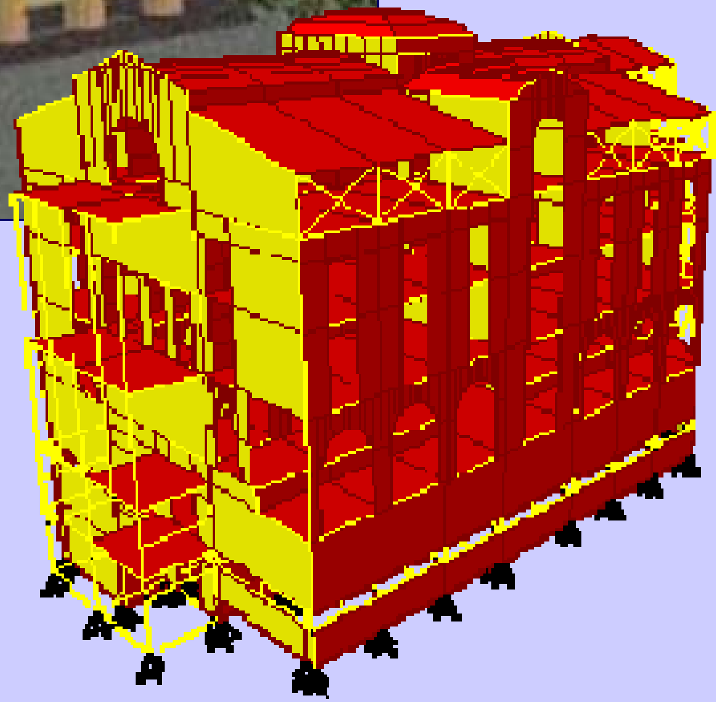




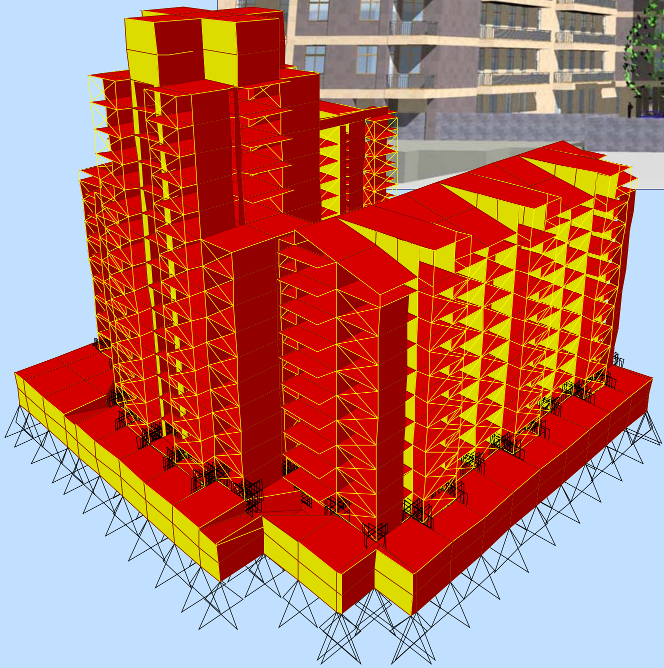
Newly constructed 7-story base isolated commercial center-hotel building in Yerevan



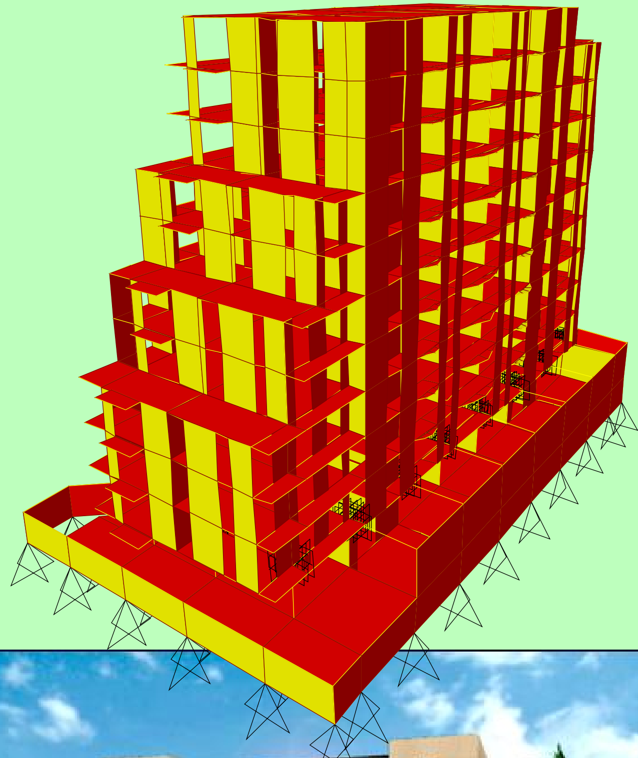
Newly constructed 6-story base isolated hotel building in Dilijan



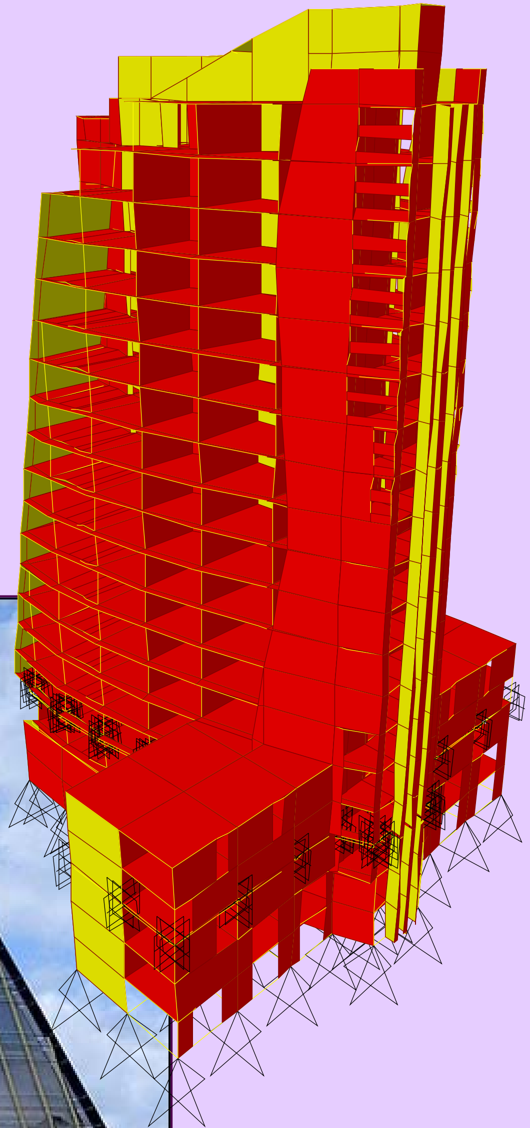
Newly constructed 5-story base isolated commercial center-hotel building in Stepanakert



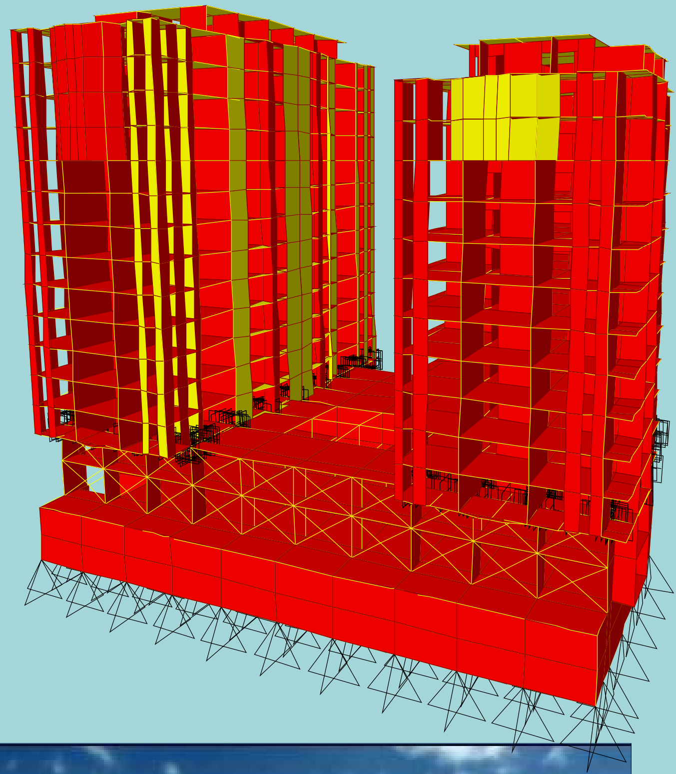
Newly constructed 16- and 10-story base isolated buildings of the multifunctional residential complex “Our Yard” in Yerevan



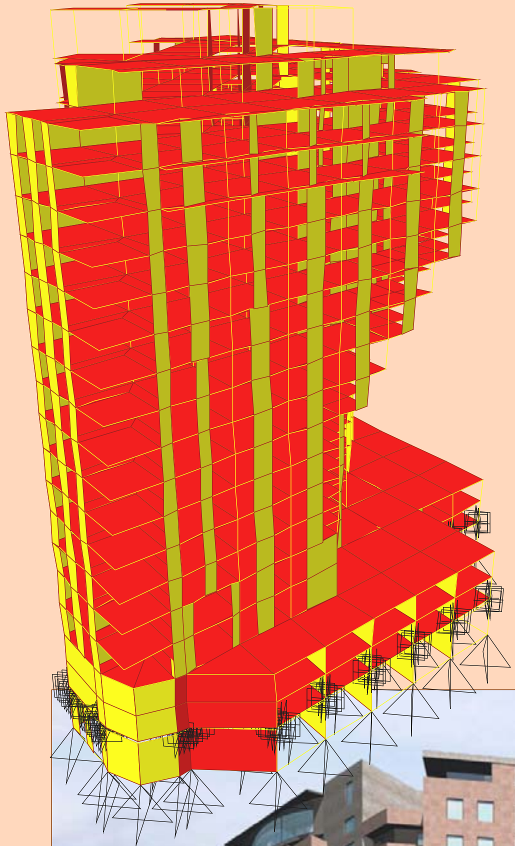
Newly constructed 11-story base isolated building of the multifunctional residential complex "Cascade"in Yerevan



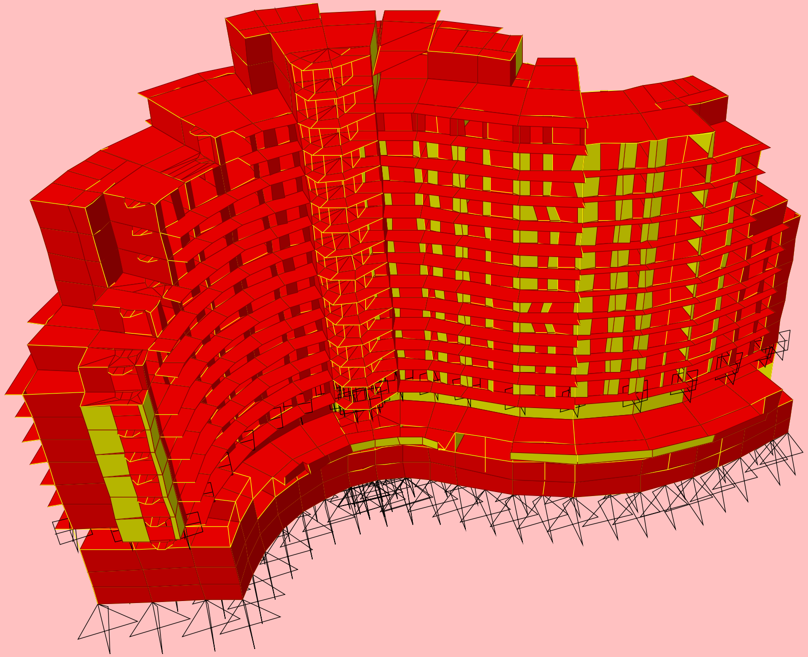
Newly constructed 20-story base isolated “Elite Plaza” business center building in Yerevan



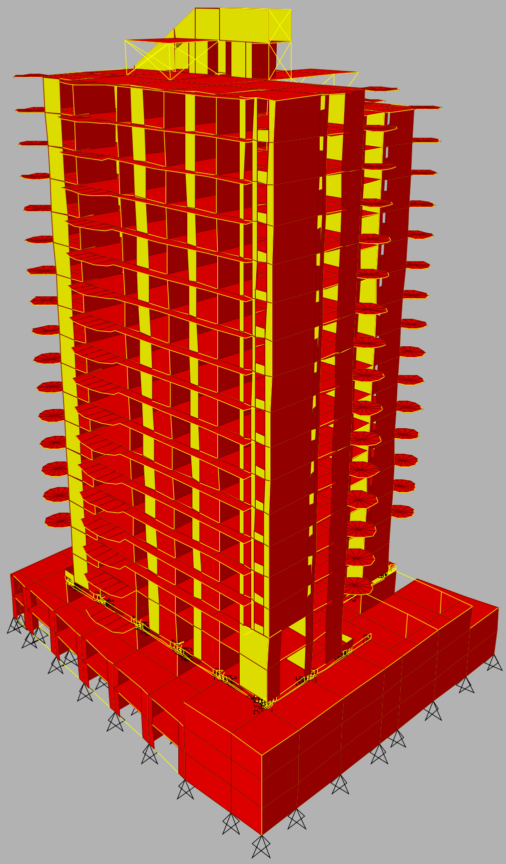
Newly constructed 13- and 11-story base isolated buildings of the multifunctional residential complex "Arami" in Yerevan



Newly constructed 15-story base isolated buildings of the multifunctional residential complex “Northern Ray”in Yerevan

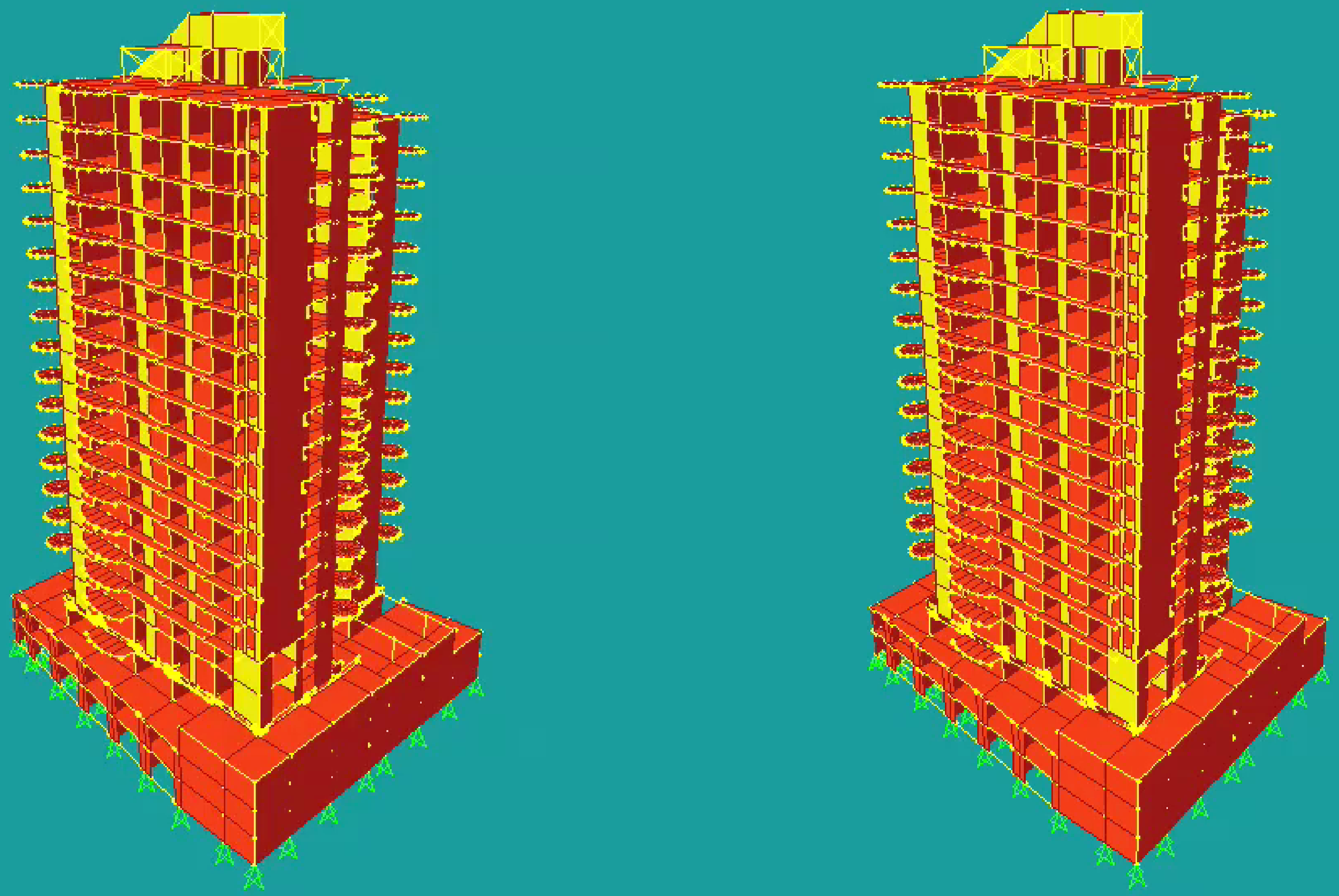


Newly constructed 15- and 13-story base isolated buildings of the multifunctional residential complex “Dzorap”in Yerevan



Newly constructed 17-story base isolated building of the multifunctional residential complex “Baghramian” in Yerevan

Direct comparison of vibrations of the 17-story base isolated and fixed base buildings in transverse direction



movie

Examples of installation of different quantities of rubber bearings under the columns of base isolated buildings

The advantages of the new approach:

- increased seismic stability of the building. This is confirmed by the carried out comparative response analyses. Moreover, it is obvious that in case of clusters of small rubber bearings the stresses and deformations from seismic impact will be distributed more evenly in the structural elements below and above the bearings without any significant concentration in one joint as it will be in case of one big bearing
- more uniform distribution of the vertical dead and life loads as well as additional vertical seismic loads on the rubber bearings
- small bearings can be installed by hand without using any mechanisms
- easy replacement of small bearings, if necessary, without using any expensive equipment
- easy casting of concrete under the steel plates with anchors and recess rings of small diameter for installation of bearings
- neutralization of rotation of buildings by manipulation of the number of bearings in the seismic isolation plane, etc.

Results of calculations of some base isolated buildings by the Armenian Seismic Code and by the time histories in transverse (X) and longitudinal (Y) directions

Name of building	Direction	Period T, sec	By the Armenian Seismic Code			By the time histories		
			Q, kN	D, mm	Δ, mm	Q, kN	D, mm	Δ, mm
10-story “Our Yard” building	X	2.04	20950	220	3.1	13037	133	2.1
	Y	2.08	19020	202	5.4	11370	119	3.7
16-story “Our Yard” building	X	2.06	19380	202	5.1	12018	124	3.3
	Y	2.17	18590	200	6.2	11224	117	4.0
11-story “Cascade” building	X	1.91	21386	188	3.6	12583	112	2.3
	Y	1.90	21839	199	3.2	12841	117	1.8
20-story business center “Elite Plaza	X	2.04	31439	192	7.8	16903	110	3.0
	Y	1.95	33259	204	2.8	17782	118	1.1
11-story “Arami” building	X	2.00	17860	218	4.3	11303	132	2.9
	Y	1.98	20990	185	4.3	13291	111	2.8
13-story “Arami” building	X	2.15	24835	202	4.7	15768	122	3.2
	Y	2.08	28990	169	4.3	18403	102	3.0
15-story “Northern Ray” building	X	2.41	98630	243	5.7	42069	110	2.2
	Y	2.24	91383	227	9.2	39009	102	3.6
17-story “Baghra-mian” building	X	2.46	51810	259	5.7	25943	138	3.0
	Y	2.41	51941	267	3.7	28780	145	1.9
6-story hotel building	X	1.88	18659	225	0.5	10035	120	0.3
	Y	1.89	18985	229	1.0	9927	120	0.5
5-story hotel building	X	1.98	17078	215	1.6	8390	94	0.7
	Y	1.99	17159	216	0.8	9245	96	0.4

Q – horizontal shear forces on the level of isolation system
D – maximum horizontal displacements of isolation system
Δ – maximum story drifts in superstructure

CONCLUSIONS

- For countries where the seismic risk is not only very high but it also increased due to areas of urbanization, the task that mostly lacks solutions is the absence of state policy with respect to reduction of seismic risk. The strategy for the twenty-first century to reduce seismic risk should be based upon prioritizing preparedness over the recovery

- The map of seismic risk of destruction of buildings and structures of the Yerevan City is given. Based on this map and the developed method for quantitative assessment of seismic resistance of existing buildings the example of creation of database on apartment buildings in one of the districts of Yerevan is considered. The conclusion is made that the seismic resistance of existing buildings is not provided and that seismic strengthening and upgrading of existing buildings is needed

- The present transition period of the economic development in Armenia brings to conclusion that non-conventional approaches, allowing the retrofitting of existing buildings without interruption of their functioning are more preferable

- Within a very short period of time since 1993, new unique and cost-effective non-conventional seismic protection methods based on the application of seismic isolation technologies were developed and introduced into the construction practice. The description of the structural concepts, which can provide the significant seismic safety for the existing vulnerable buildings, is given

CONCLUSIONS (continuation)

- Buildings and structures where seismic (base and roof) isolation technologies were applied for new construction and for retrofitting of existing ones are shown and the International institutions, as well as private companies, which funded different projects in Armenia are mentioned

- Local companies which are manufacturing different types of seismic isolators are listed and the numbers of isolators manufactured by each company are given

- The number of newly constructed or retrofitted buildings by years in Armenia is given. The number of seismic isolated buildings per capita in different countries is presented

- Cost effectiveness of seismic isolated buildings in Armenia in comparison with conventionally designed, constructed or retrofitted buildings is emphasized

- New structural concepts on installation of rubber bearings and on application of TMD or dynamic damper attached to the isolation floor are described. The advantages of a new approach on installation of the groups of small rubber bearings instead of one big bearing are listed

- Applications of the Armenian seismic isolation technologies in Russia and Romania for retrofitting of the old existing buildings are described