World Housing Encyclopedia

an Encyclopedia of Housing Construction in Seismically Active Areas of the World

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HOUSING REPORT
Buildings protected with "disengaging reserve elements" (vyklyuchayu-shchiesya svyazi)

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Housing Type	Seismic Protection Systems
Housing Sub-Type	Seismic Protection Systems: Buildings Protected with Seismic Dampers
Author(s)	Jacob Eisenberg, Svetlana Uranova, Ulugbek T. Begaliev
Reviewer(s)	Svetlana N. Brzev

Summary

This building type is characterized with a special system of seismic protection called "Disengaging Reserve Elements" (DRE). DRE are installed at the ground floor level of a building, which is typically a RC frame structure. The upper part of the building, usually 9

stories high, is a load-bearing wall structure, either of large-panel RC construction or brick masonry construction. DRE consist of a "rigid structure" (usually RC wall panel) connected to the adjacent RC frame members by means of disengaging restraints. Disengaging restraints are sacrificial reserve elements (fuses) that serve as restraints for the "rigid structures." Typical restraints are steel plates joined together by means of rivets or steel bolts, steel bars, concrete prisms or cubes, etc. Initially, at the lower ground motion level, DRE and RC frame work together; at that stage, disengaging elements transfer lateral loads to rigid structures. DRE is an adaptive seismic protection system whose unique feature, the variable (self-adjusting) rigidity and periods of vibration during an earthquake, prevent resonance. This system is widely used in seismic-prone areas of Russia and Kyrgyzstan. Buildings of this type have not yet been exposed to the effects of damaging earthquakes.

1. General Information

Buildings of this construction type can be found in seismic prone areas of Russia and other states of the former Soviet Union. In Russia, there are around 140 buildings protected with this system; out of them, 120 buildings were built in North Baykal-city (Neriungry, Severobaikalsk) in 1974-76 (Baykal-Amur Railway Road), and the remaining buildings were constructed in Siberia, Kamchatka in 1980s and 1990s. There are several dozens of buildings protected by means of this system in Kyrgyzstan, Kazakhstan, Tajikistan, and Georgia. The first building protected using this system was constructed in 1972 in Sevastopol, Ukraine (former Soviet Union). This type of housing construction is commonly found in urban areas. This construction type has been in practice for less than 25 years.

Currently, this type of construction is being built. .

Figure 1: Typical Building

Figure 1A: Typical Building - Load-Bearing Masonry Construction (Bishkek, Kyrgyzstan)

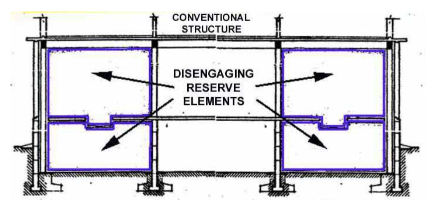

Figure 2: Key Load-Bearing Elements

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 10-50 meters.

2.2 Building Configuration

Typical shape of a building plan for this housing type is rectangular. Walls at the ground floor level (where "Disengaging Reserve Elements" are installed) are not load-bearing structures. The overall window area is on the order of 15 to 35% of the exterior wall area; overall door area is approximately 10% of the interior wall area. At the upper floor levels, the overall window and door areas account for approximately 20% of the overall wall area.

2.3 Functional Planning

The main function of this building typology is multi-family housing. Majority of the buildings are residential buildings. A few buildings (3-4) are used as a kindergarten and school. The first building protected this system (built in Sevastopol, Ukraine) is a bank. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. There is one stair in one building unit. Usually a building consists of 1-4 building units.

2.4 Modification to Building

The modifications at the lower floor levels usually include non-structural (exterior and interior) walls. Typical modifications at the upper floors include perforation of walls with door and windows openings, and/or partial removal of walls.

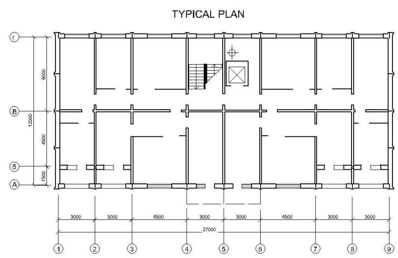

Figure 3A: Plan of a Typical Building

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
		17	Flat slab structure	☐
			Designed for gravity loads	

Structural concrete	Moment resisting frame	18	only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☑
	Hybrid systems	45	other (described below)	☐

There is a moment-resisting RC frame at the ground floor level and load-bearing wall system (precast large panel construction - type 22 or brick masonry wall construction-type 9) at the upper floor levels. Note that brick masonry construction was not completely unreinforced - reinforced concrete elements were added at certain locations in the walls.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is reinforced concrete moment resisting frame. Gravity load-bearing structure is RC frame at the ground floor level and large precast panels or brick masonry wall construction at the upper floor levels. In Russia, upper stories in majority of buildings protected with this system are of large panel RC construction of various series (e.g. 308), and in Kyrgyzstan upper stories are of reinforced brick masonry construction.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). Lateral load-resisting system consists of a concrete frame at the ground floor level and the load-bearing wall structure (either large precast panel construction or brick masonry wall construction) above the ground floor level. Ground floor structure is therefore substantially more flexible as compared to the structure above. Special devices called "Disengaging Reserve Elements" (DRE) are installed at the ground floor level. DRE consist of a "rigid structure" connected to the adjacent RC frame members by means of disengaging restraints. Lateral stiffness of a "rigid structure" is substantially larger as compared to the other elements e.g. concrete columns. Typically, "rigid structures" are RC wall panels (Type 2 Figure 4B). The "rigid structure" does not carry any gravity loads. Alternatively, "rigid structures" consist of spatial elements; see Type 1 Figure 4A). Disengaging restraints are sacrificial reserve elements (fuses) which serve as restraints for the "rigid structures". Typical restraints are steel plates joined together by means of rivets or steel bolts, steel bars, concrete prisms or cubes, etc. Initially (at the lower ground motion levels), DRE and RC frame system (at the ground floor level) work together as a rigid structure; at that stage, disengaging elements transfer lateral loads to rigid structures (RC panels). The initial fundamental period of vibration is typically on the order of 0.3 -0.45 sec, depending on the number of stories and a structural system. However, once the lateral load exceeds the prescribed level (depending on the site seismicity and other factors), disengaging elements get broken and disconnected from the "rigid structures". At that stage, due to the suddenly increased flexibility, a building changes vibration period to a higher value of about 0.8-1.0 sec. As a result, resonance effects are avoided and seismic load is reduced. After an earthquake, disengaging restraints need to be replaced by new elements,however the cost is not high and the replacement is not complex. It is considered that the seismic load in buildings protected with the DRE system is reduced to 1/2 of the level expected for a conventional building. Buildings with the DRE system are designed for lower level of seismic forces as compared to conventional buildings. Buildings with the DRE system were exposed to dynamic loads which simulate earthquake effects using the vibration equipment. Design recommendations for buildings protected with DRE system were developed based on numerous experimental and analytical investigations. The system was developed by Prof. J. Eisenberg. The development started in 1970 and the first building protected using the DRE system (vyklyuchayu-shchiesya svyazi) was constructed in 1972 in Sevastopol, Ukraine (former Soviet Union).

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 54 and 54 meters, and widths between 12 and 12 meters. The building is 9 storey high. The typical span of the roofing/flooring system is 3-6 meters. The typical storey height in such buildings is 3 meters. The typical structural wall density is up to 20 %. Total wall area/plan area is about 0.15. Wall density in two principal directions is not equal; in one of the directions wall density is less by 20 to 30% as compared to the other direction. Walls at the ground floor level are not load-bearing structures.

3.5 Floor and Roof System

Material	**Description of floor/roof system**	**Most appropriate floor**	**Most appropriate roof**
Masonry	Vaulted	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☑	☑
	Solid slabs (precast)	☑	☑
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐
	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
	Rammed earth with ballast and concrete or plaster finishing	☐	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☐	☐
	Thatched roof supported on wood purlins	☐	☐

Timber	Wood shingle roof	☐	☐
	Wood planks or beams that support clay tiles	☐	☐
	Wood planks or beams supporting natural stones slates	☐	☐
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles	☐	☐
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls	☐	☐
Other	Described below	☑	☑

Precast solid slabs (large panel construction), hollow core slabs (masonry construction).

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☐
	Reinforced-concrete isolated footing	☑
	Reinforced-concrete strip footing	☑
	Mat foundation	☐
	No foundation	☐
Deep foundation	Reinforced-concrete bearing piles	☑
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

It consists of reinforced concrete end-bearing piles. Type of foundation depends on soil conditions.

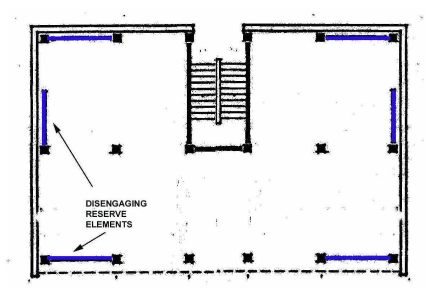

Figure 3B: Ground Floor Plan Showing the Locations of Disengaging Reserve Elements

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 51-100 housing unit(s). 60 units in each building. Number of units varies from 32-64 The number of inhabitants in a building during the day or business hours is more than 20. The number of inhabitants during the evening and night is more than 20.

4.2 Patterns of Occupancy

In general, in a building of this type there are 3-4 housing units per building unit ("Block-Section"). One family occupies one housing unit. Depending on the size of the building (number of stories), 32 to 64 families occupy one building.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	☐
b) low-income class (poor)	☑
c) middle-income class	☑
d) high-income class (rich)	☐

40% poor, and 60% middle class inhabitants occupy building of this type.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☐
4:1	☐
3:1	☐
1:1 or better	☑

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	☑
Personal savings	☑
Informal network: friends and relatives	☑
Small lending institutions / micro-finance institutions	☐
Commercial banks/mortgages	☐
Employers	☐
Investment pools	☐
Government-owned housing	☑
Combination (explain below)	☐
other (explain below)	☐

Until 1990 (the breakdown of the Soviet Union), the financing for buildings of this type had been provided by the Government. At the present time, all new and existing apartment buildings are privately owned. In each housing unit, there are 1 bathroom(s) without toilet(s), no toilet(s) only and 1 bathroom(s) including toilet(s).

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership and individual ownership.

Type of ownership or occupancy?	Most appropriate type
Renting	☑
outright ownership	☑
Ownership with debt (mortgage or other)	☐
Individual ownership	☑
Ownership by a group or pool of persons	☐
Long-term lease	☐
other (explain below)	☐

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		Yes	No	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☑	☐	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☑	☐	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☑	☐	☐
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☑	☐	☐
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☑	☐	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☑	☐	☐
	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls;			

Wall openings	For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☑	☐	☐
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☑	☐
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☐	☑	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☑	☐
Additional Comments				

5.2 Seismic Features

Structural Element	**Seismic Deficiency**	**Earthquake Resilient Features**	**Earthquake Damage Patterns**
Wall- upper floor levels	A conventional building of large panel concrete construction or brick masonry construction: poor quality of panel joints and inadequate masonry strength		Damage of load-bearing structure is possible; however it is expected to be less as compared to buildings without the disengaging elements.
Frame - ground floor level	Poor quality of concrete, lack of cover to the reinforcement in particular, the "as constructed"reinforcement locations do not match with the design; inadequate length of lap splices in steel rebars; inadequate confinement in the highly loaded areas.		Damage of sacrificial elements restraints) that are replaced after the earthquake.
Roof and floors			
Disengaging Reserve Elements	Quality and precision in the construction of the Disengaging Reserve Elements	Disengaging Reserve Elements are effective in reducing seismic demand in the building.	

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *E: LOW VULNERABILITY (i.e., very good seismic performance)*, the lower bound (i.e., the worst possible) is D: MEDIUM-LOW VULNERABILITY (i.e., good seismic performance), and the upper bound (i.e., the best possible) is *F: VERY LOW VULNERABILITY (i.e., excellent seismic performance)*.

Vulnerability	**high**	**medium-high**	**medium**	**medium-low**	**low**	**very low**
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☐	☐	☐	☑	☐	☑

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1984	Severobaikalsk	4	5 (MSK)

Buildings protected with the Disengaging Reserve Elements were not damaged in the 1984 earthquake. Buildings of this type were tested by the special vibration equipment and subjected to dynamic loads simulating seismic effects.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Reinforced concrete	30-35 MPa (cube compressive strength) 390 MPa (steel yield strength)		
Foundation	Reinforced concrete	10-15 MPa (cube compressive strength) 295 MPa (Steel yield strength)		
Frames (beams & columns)	Reinforced concrete	30-35 MPa (cube compressive strength) 390 MPa (steel yield strength)		
Roof and floor(s)	Reinforced concrete	30-35 MPa (cube compressive strength) 390 MPa (steel yield strength)		

6.2 Builder

Anyone can live in buildings of this construction type.

6.3 Construction Process, Problems and Phasing

Construction is performed by builders. Designs are developed in the design institutes. Specialized construction companies make precast concrete elements and perform casting of concrete in-situ. Precast elements are fabricated at the plants. The main construction equipment is the same as in the case of conventional concrete construction and it includes crane, welding equipment and concrete mixers. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

The expertise required for the design and construction of this type is available. Building designs were prepared by design institutes. The academic background of the designers is the same as for conventional construction. It is not required to have designers with high academic degrees e.g. M.Sc. and Ph.D. on the team. Construction of base isolated buildings and the approval of the designs were controlled by research institutes (State Experts) like any other new construction performed in accordance with the Building Code requirements. Design of buildings of this construction type was done completely by engineers and architects. Researchers also participated in the development of design documentation. Engineers played a leading role in each stage of construction.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. SNiP II-7-81. Building in Seismic Regions.Design Code. The year the first code/standard addressing this type of construction issued was 1981. SNiP II-7-81. Building in Seismic Regions - Design Code Recommendations for Design of Buildings with "Disengaging Reserve Elements" CNIISK, Moscow, 1987. The most recent code/standard addressing this construction type issued was 1981. Title of the code or standard: SNiP II-7-81. Building in Seismic Regions.Design Code Year the first code/standard addressing this type of construction issued: 1981 National building code, material codes and seismic codes/standards: SNiP II-7-81. Building in Seismic Regions - Design Code Recommendations for Design of

Buildings with #Disengaging Reserve Elements# CNIISK, Moscow, 1987. When was the most recent code/standard addressing this construction type issued? 1981.

Building permit will be given if the design documents have been approved by the State Experts. State Experts check the compliance of design documents with the pertinent Building Codes. According to the building bylaws, building cannot be used without the formal approval by a special committee. The committee gives the approval if design documents are complete and the construction has been carried out in compliance with the Building Codes.

6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and authorized as per development control rules. Building permits are required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Builder, Owner(s) and Tenant(s).

6.8 Construction Economics

For load-bearing structure only (including the disengaging elements) the cost is about 210 US$/m². For a similar prefabricated concrete panel building (seria 105) without disengaging elements the construction cost would be 50-200 US$/m². Therefore, the increase in unit cost due to the installation of seismic belt is in the range from 10 to 40 %. It would take from 12 to18 months for a team of 10 workers to construct a load-bearing structure.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Building damage - broken disengaging elements	Replacement of the damaged elements with the new ones

8.2 Seismic Strengthening Adopted

Has seismic strengthening described in the above table been performed in design and construction practice, and if so, to what extent?

No. Buildings of this type are already strengthened by means of disengaging reserve elements.

8.3 Construction and Performance of Seismic Strengthening

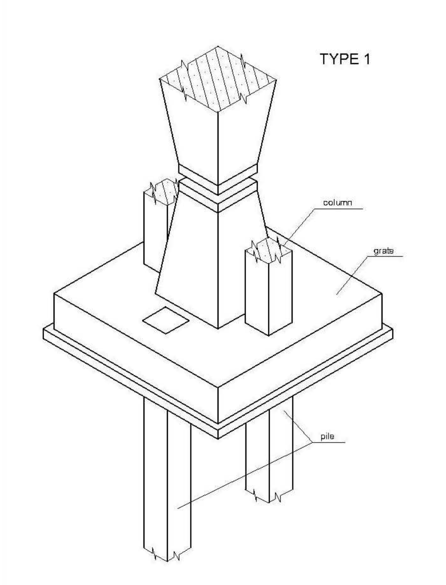

Figure 4A: Critical Structural Details - Disengaging Reserve Elements

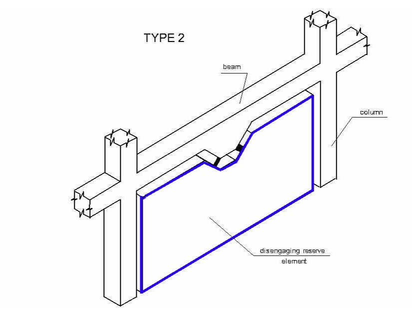

Figure 4B: Critical Structural Details - Disengaging Reserve Elements

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Author(s)

1. Jacob Eisenberg

President/Chairman, Russian National Committee for Earthquake Engineer
4 Berezhkovsky Embankment Art 110, Moscow 121059, RUSSIA
Email:seismo@online.ru FAX: 007-095-174-70-64

2. Svetlana Uranova
   Head of the Laboratory, KRSU
   Kievskai 44, Bishkek 720000, KYRGYZSTAN
   Email:uransv@yahoo.com FAX: 996-3312-282859

3. Ulugbek T. Begaliev
   Head of Department, KNIIPC
   Vost Prom Zone Cholponatisky 2, Bishkek 720571, KYRGYZSTAN
   Email:utbegaliev@yahoo.com

Reviewer(s)

1. Svetlana N. Brzev
   Instructor
   Civil and Structural Engineering Technology, British Columbia Institute of Technology
   Burnaby BC V5G 3H2, CANADA
   Email:sbrzev@bcit.ca FAX: (604) 432-8973