World Housing Encyclopedia

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

an initiative of
Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Large concrete block walls with reinforced concrete floors and roof (typical series: 1-306c, 1-307c, 114c)

Report #	54
Report Date	05-06-2002
Country	RUSSIAN FEDERATION
Housing Type	Others
Housing Sub-Type	Others: Hybrid System
Author(s)	Mark Klyachko, Yuriy Gordeev, Freda Kolosova
Reviewer(s)	Svetlana Uranova

Summary

This is a typical residential construction found both in urban and rural areas. It represents a

construction practice followed in the former Soviet Union. Buildings of this type constitute 15 to 30% of the housing stock in earthquake-prone areas of Russia (Far East, Siberia, Baikal Lake Region, North Caucasus) and CIS states (Central Asia, Armenia, Georgia, etc.). The main load bearing system for lateral and gravity loads consists of concrete block masonry walls and concrete floor slabs. Seismic resistance is relatively good, provided that the welded block wall connections are present and are well constructed.

1. General Information

Buildings of this construction type can be found in the seismic zones of Russia (Far East, Siberia, Baikal Lake Region, North Caucasus) and CIS (Central Asia, Armenia, Georgia, etc.) where it represents 15-30% of the housing stock. This type of housing construction is commonly found in both rural and urban areas. This construction type has been in practice for less than 50 years.

Currently, this type of construction is being built. This is the Soviet Union construction practice that was followed in the last 50 years.

Figure 1: Typical Building

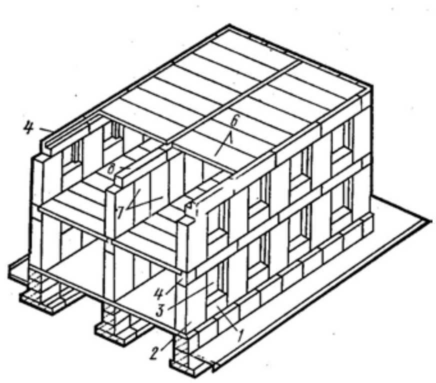

Figure 2A: Key Load-Bearing Elements

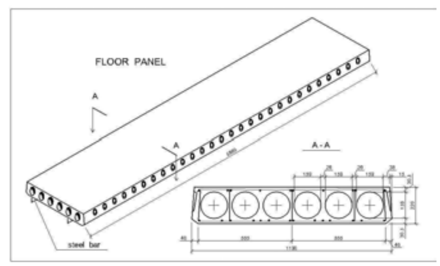

Figure 2B: Precast Hollow-Core Reinforced Concrete Floor Slab (Credit: U. Begaliev and S. Uranova)

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. It can be more than 5 meters also. In hilly areas from 1.5% to ~15%; on the flat terrain ~85% When separated from adjacent buildings, the typical distance from a neighboring building is 5 meters.

2.2 Building Configuration

In general, all buildings of this type are of a rectangular plan. Windows: 10-15%; Doors: 5-8%.

2.3 Functional Planning

The main function of this building typology is multi-family housing. Some buildings of this type (approximately 5% of the total number) are of mixed use. In case of mixed use buildings, commercial ground floor causes a soft-storey effect and reduces seismic resistance of a building. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Usually there is one exit stair with one main entry in one section of a building. An average section includes 12 housing units in total (i.e. 3 per floor).

2.4 Modification to Building

Typical patterns of modification indude demolishing of interior walls and the perforation of walls with door openings.

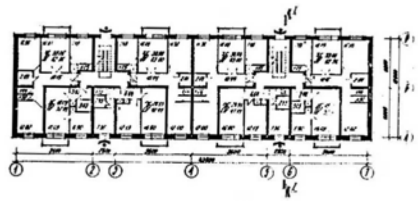

Figure 3: Plan of a Typical Building

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	☐
	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads 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	☐
			Moment frame with in-situ	

Structural concrete	Structural wall	22	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)	☑

Large concrete block walls with concrete floors and roofs.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is others (described below). Same as lateral load-resisting system. The main elements of the load-bearing structure for this construction type are illustrated in Figure 2A: 1- breast block; 2-interfenestral block; 4- lintel member, 6-floor panel, 7-regular block, 8-web block.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). Lateral load-resisting system consists of concrete block walls and precast concrete floors. Blocks are joined together by means of welding. In most cases, the floor structure consists of precast concrete hollow-core slabs, combined in horizontal disk by special reinforced monolithic concrete bond beams (web blocks) located at the building perimeter.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 44 and 44 meters, and widths between 12 and 12 meters. The building is 4 storey high. The typical span of the roofing/flooring system is 6 meters. The typical storey height in such buildings is 2.8 meters. The typical structural wall density is more than 20 %. 20-25%.

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)	☐	☐
Timber	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	☐	☐
	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	☑	☑

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	☐
	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin	☐

Deep foundation	friction piles	
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

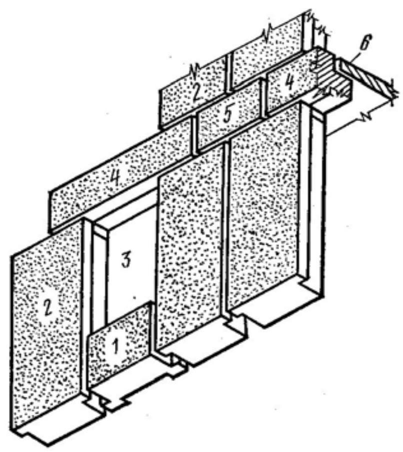

Figure 4: Critical Structural Details

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 21-50 housing unit(s). 48 units in each building. Usually there are 12 - 64 units in each building. 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 others (as described below). > 200.

4.2 Patterns of Occupancy

One family per unit (apartment).

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)	☐

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)	☐

In each housing unit, there are 1 bathroom(s) without toilet(s), no toilet(s) only and 1 bathroom(s) including toilet(s).

Usually one bathroom per family (unit). .

4.4 Ownership

The type of ownership or occupancy is outright ownership and long-term lease.

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)	☐

Own outright (for unit), Long-term lease (most common).

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	☑	☐	☐
Wall openings	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; 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	Others: Welding connections for the block walls are adequate is poor.			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	-Low cohesion of masonry (<120 kPa) (cohesion equals to tension strength when shear stress=0). -Welded block wall connections are inadequate or absent; -Poor strength of the block walls.		
Frame (columns,			

beams)			
Roof and floors	Floor slabs cannot be considered as rigid due to poor quality of joints and connections		

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance), the lower bound (i.e., the worst possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), and the upper bound (i.e., the best possible) is D: MEDIUM-LOW VULNERABILITY (i.e., good 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
1959	Kamchatka, Russia	7.8	8 (MSK)
1971	Kamchatka, Russia	7.2	7 (MSK)
1995	Neftegorsk, Sakhalin Island, Russia		9 (MSK)

Typical earthquake damage patterns for this construction type are illustrated in Figures 5A to 5G. Figures 5H and 5I illustrate the seismic performance of this construction type in the 1995 Neftegorsk earthquake. At the time of the earthquake, there were 17 five-story large-block residential buildings constructed in the period 1967-1971. These buildings were constructed without any seismic provisions. All 17 buildings collapsed in the earthquake, as illustrated in Figure 5H. Several two-story large-block buildings were also exposed to the Neftegorsk earthquake (see Figure 5I), however these buildings had suffered some damages, e.g. vertical and horizontal cracks between blocks, diagonal cracks in partitions, vertical cracks in the wall connections, partial damage to chimneys, and displacement of entrance canopies. For more information on the Neftegorsk earthquake, refer to Klyachko (1999) and Melentyev (1999).

Figure 5A: Typical Earthquake Damage to the exterior longitudinal walls

Figure 5B: Typical Earthquake Damage - A View of the Damaged Building

Figure 5C: Typcial Earthquake Damage- Shearing of Blocks at the Joint Locations

Figure 5D: Typcial Earthquake Damage- Shearing of Blocks at the Ground Floor Level

Figure 5E: Typical Earthquake damage - Interior View of Damages

Figure 5F: Typical Earthquake Damage at the Wall Corner

Figure 5G: Typical Earthquake Damage- Shearing Failure of Blocks at the Joint Locations

Figure 5H: Collapse of Five-Story Large-Block Masonry Buildings (1995 Neftegorsk earthquake)- Source: Klyachko (1999)

Figure 5I: Two-Story Large-Block Masonry Buildings Did Not Suffer Major Damage in the 1995 Neftegorsk Earthquake (Source: Klyachko, 1999)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Steel concrete (large-block)	Yield strength = 295 MPa cube compressive strength (15-20 MPa)		
Foundation	Concrete	15-20 MPa (cube compressive strength)		
Frames (beams & columns)	Reinforced concrete	20-30 MPa (cube compressive strength)		
Roof and floor(s)	Slabs - Reinforced Concrete	30 MPa (cube compressive strength) 295 MPa (Steel yield strength)		

6.2 Builder

Buildings of this type were built by government-owned construction companies.

6.3 Construction Process, Problems and Phasing

All precast structure members and concrete blocks are manufactured in special construction plants. Masonry mortar is produced either in the factory or at the construction site. Lifting crane is used for the erection of the building. 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

Expertise for design of buildings of this type was available, including the construction quality procedure developed by the author of this contribution. Design performed by Professional Engineers and Architects.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Building Catalog of Typical Housing Projects, seria 1-306c, 1-307c, 1957y. The year the first code/standard addressing this type of construction issued was 1951. Construction in the Seismic Regions. SNiP II-7-81*. The most recent code/standard addressing this construction type issued was 1981 (followed by several amendments). Title of the code or standard: Building Catalog of Typical Housing Projects, seria 1-306c, 1-307c, 1957y. Year the first code/standard addressing this type of construction issued: 1951 National building code, material codes and seismic codes/standards: Construction in the Seismic Regions. SNiP II-7-81* When was the most recent code/standard addressing this construction type issued? 1981 (followed by several amendments).

The process consists of issuing permits for the design and construction, including the architectural permits and urban planning/municipal permits. Designers need to have license to practice and are responsible to follow the building codes. Building inspection is performed and the permit is issued.

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 Owner(s). The maintenance is performed either by the owner (city) or (periodically) by a contractor - a maintenance firm.

6.8 Construction Economics

250-350 $US/m² (official rate). It takes about 34 man-months to build a 4-story building of this type with plan dimensions 12 m X 42 m.

7. Insurance

Earthquake insurance for this construction type is typically available. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. The insurance is available as a part of the usual property insurance. Insurance covers about 3-5 % of the total estimated property value.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Inadequate seismic resistance of masonry walls	The method of exterior frame

Inadequate seismic resistance of masonry walls	Vertical post-tensioning (see Figure 6A, 6B and 6C)
Inadequate seismic resistance of masonry walls	The method of upper damping storey

The recommended seismic strengthening techniques are: THE METHOD OF EXTERIOR FRAME (MEF) - Goal: To increase lateral seismic stability of the building with load-bearing masonry or large-block concrete walls. - Concept: The system of precast or "cast-in-situ" concrete buttresses (counterforts) (1) tied to the longitudinal exterior wall. - Application: This method has been used successfully for seismic strengthening of the buildings with longitudinal bearing walls and deficient seismic resistance both as self-contained strengthening system and as a combination with PTS (for stringer walls) or with SIS (for extended masonry buildings with widely spaced lateral inner walls). - Description: The MEF is performed by constructing special concrete buttresses (counterforts) tied to the longitudinal load-bearing walls at the building ends and other locations as required. In order to ensure a uniform seismic performance of the existing structure strengthened with the buttresses, the buttresses are tied to the existing walls by means of the dowels and anchors. This solution does not require to tie the pairs of buttresses (counterforts) together at each floor level. Instead, it is adequate to install a prestressed tie to connect the buttresses (counterforts) at the roof level. STRENGTHENING OF BUILDINGS USING THE POST-TENSIONING SYSTEM (PTS) - Goal: To increase seismic resistance of load bearing masonry buildings. - Concept: Reduction in the principal tensile stresses induced by seismic loads to allowable levels. - Description and sequence of operations: Drilling of the vertical holes is carried out by means of special equipment; the amount of opening (10) is not less than one for each partition. The wire cables (2) are pulled through each opening (10). Cables are anchored at the basement level and then post-tensioned up to 1600 KN. A special cement-based grout (1) is injected into the holes and the cables are subsequently anchored at the roof level. Post-tensioning of walls prevents the formation of cracks in an earthquake and results in the increased seismic resistance of the individual walls and the building as a whole. - Equipment: For drilling: "GEARMEC" (Sweden); for post-tensioning: IMS system (Yugoslavia). THE METHOD OF UPPER DAMPING STOREY (UDS) - Goal: To develop a big mass damper for the self-damping of buildings under seismic impact. - Idea: To achieve a flexible structure with stiffness and mass capable of reducing the seismic demand to a permissible level. - Application: Masonry or block buildings with deficient seismic resistance D=2.0 (MSK scale). A highly effective and fast application for 4- to 5-story residential masonry and large-block houses with D=1.0-1.5. The superstructure can be constructed as a "cold" garret or as additional floor (duplex apartment).

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?

Yes. Some buildings of this type have been strengthened using the above described methodology.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
Some work was done as a mitigation effort (strengthening of undamaged existing buildings), and in some cases earthquake-damaged buildings were strengthened.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?

Yes, the construction instruction in same manner as the new construction.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
Strengthening is done in a similar way as new construction. The construction is done by the contractor. Engineers manage each stage of construction.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?

Information not available.

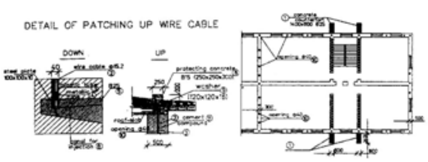

Figure 6A: Illustration of Seismic Strengthening Techniques


Figure 6B: Seismic Strengthening: Application of Post-Tensioning System


Figure 6C: A building Strengthened using Post-Tensioning System

Reference(s)

1. Manual on Certification of Buildings and Structures in the Seismic-Prone Areas (Second Edition)
   CENDR, Russia 1990

2. Recommendations for Preventive Aseismic Strengthening of Buildings
   CENDR, Russia 1993

3. Earthquakes and Us
   Klyachko,M.A.
   Intergraf, Saint Peterburg, Russia (in Russian) 1999

4. Lessons of the 1995 Sakhalin and 1994 Kuril Islands Earthquakes
   Melentyev,A.
   Seismic Hazard and Building Vulnerability in Post-Soviet Central Asian Republics, Eds. King,S.A., Khalturin,V.I., and Tucker,B.E., NATO ASI Series 2. Environment - Vol.52, Klywer Academic Publishers, The 1999

Author(s)

1. Mark Klyachko
   Director, Centre on EQE and NDR (CENDR)
   9 Pobeda Avenue, Petropavlovsk Kamchatka 683006, RUSSIA
   Email:cendr@svyaz.kamchatka.su cendr@peterlink.ru FAX: +7(415)22-8774 +7(812)222-0676

2. Yuriy Gordeev
   Head of Dept., Centre on EQE and NDR (CENDR)
   9 Pobeda Avenue, Petropavlovsk Kamchatka 683006, RUSSIA
   Email:cendr@svyaz.kamchatka.su cendr@peterlink.ru FAX: +7(415)22-8774 +7(812)222-0676

3. Freda Kolosova
   Professor, Centre on EQE and NDR (CENDR)
   9 Pobeda Avenue, Petropavlovsk Kamchatka 683006, RUSSIA
   Email:cendr@svyaz.kamchatka.su; cendr@peterlink.ru FAX: +7(415)22-8774 +7(812)222-0676

Reviewer(s)

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