DESIGN PROVISIONS OF THE NEW SEISMIC CODES OF THE REPUBLIC OF KAZAKHSTAN AND KYRGYZ REPUBLIC

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Abstract

The paper discusses specific features of the recently updated seismic design codes RK 2.03–30–2017 and SN KR 20-02:2018 for the Republic of Kazakhstan (RK) and the Kyrgyz Republic (KR) respectively. The key provisions are related to the determination of design seismic actions and loads on buildings and structures, as well as checking irregularities of building configuration in plan and elevation. Seismic hazard for the territories of both countries is characterized by means of complex seismic hazard maps, which have a probabilistic basis for the RK and deterministic basis for the KR. The maps contain information about earthquake intensity for various locations, and the corresponding peak ground accelerations depending on the rock geological formations. Seismic actions at a construction site are characterized by an acceleration response spectrum. The design seismic loads for building structures are determined taking into account their importance, regularity of their configuration in plan and elevation, as well as torsional resistance. According to these codes, buildings are classified into classes depending on their importance, occupancy, and the number of storeys. Based on the combination of building importance classes and number of storeys, an importance coefficient is assigned which is taken into account in determining the design seismic loads. Structural configurations are classified by regularity in plan and elevation into regular, moderately regular and excessively irregular. In terms of the torsional resistance a structural configuration either possesses adequate torsional stiffness or it is torsionally sensitive (irregular). The adopted classification system is based on the combination of features, which characterize structural systems both qualitatively and quantitatively: by specific features of configuration in plan and/or elevation; by balancing the distribution of mass and stiffness in plan; by specific distribution of masses and stiffness in elevation; by the capacity of floor and roof slabs to act as rigid horizontal diaphragms. The classification of structural systems according to regularity in terms of plan and elevation and torsional resistance are important for the structural and seismic design and are discussed in the paper. Structural and seismic analysis of buildings take into account interaction with the subgrade and/or basement soil. The parameters of equivalent elastic soil stiffness are to be determined as one of the two alternative cases. The paper also discusses two other new building codes from the KR, that is, SN KR 22-01:2018 “Seismic resistance assessment of existing buildings” and SN KR 31-02:2018 “Design and construction in territory of the Bishkek city and villages, adjacent to the Ysyk-Ata fault”. Bishkek is the KR’s capital, and the Ysyk-Ata fault located at the south border of the town. SN KR 31-02:2018 prescribes rules for construction close to the fault, and divides the area into 5 zones, depending on the location and distance from the main line of the active Ysyk-Ata fault.

Keywords: seismic codes, seismic response, seismic hazard map, earthquake intensity, peak ground accelerations

1. Introduction

In almost all CIS-countries national codes were initially based on the standards that were developed and applied during the USSR period. However, since the breakdown of the USSR each CIS country began to develop its own standards and methodology. Therefore, current codes and standards are slightly different between the countries, but the basic requirements remain similar [7].
For example, new probabilistic seismic hazard maps for Russian Federation and other countries have been developed for 10%, 5% and 1% probability of exceedance in 50 years. The probability levels correspond to the average return period for design earthquake of 500 years (map A), 1000 years (map B), and 5000 years (map C).
Republic of Kazakhstan (RK) and Kyrgyz Republic (KR) are located in Central Asia in the region with high seismic hazard. Central Asia's earthquake activity has long been recognized as one of the highest in the world. A significant portion of the KR's terrirory is expected to be exposed to earthquakes of magnitude 7.5 or higher per Richter scale (corresponding to the shaking intensity 9 per MSK-64 scale). The territory of the KR was subjected to several damaging earthquakes, including the 1992 Sysamyr earthquake (magnitude 7.3). In the period from June 1, 2009 to September 30, 2010, the country experienced 2,398 earthquakes of magnitude 6 or higher.
The seismic codes for these countries were recently updated, both in terms of seismic design provisions and seismic hazard maps, which have a probabilistic basis for RK and deterministic basis for KR. This paper discusses relevant provisions of the Building Code RK 2.03–30–2017 (Kazakh Code) and Building Code KR 20-02:2018 (Kyrgyz Code) related to the determination of design seismic actions and loads on building structures, as well as checking their regularity in plan and height.

2. Code provisions related to the seismic hazard area and construction site

Seismic hazard for the territory of the RK is characterized by the Building Code RK 2.03–30–2017 through of a set of maps of general seismic-risk zoning (GSZ RK), which have a probabilistic basis. The development of a complex of GSZ RK maps was performed by the LLP "Institute of Seismology" according to the terms of reference and accompanied by JSC "KazNIISA". JSC "KazNIISA" has developed the rules for use of GSZ RK maps in structural and seismic design of buildings and structures [3].

Set of GZS RK maps contains:

1) GSZ-1_{475} (Fig. 1) and GSZ-2_{475} maps, representing seismic intensity values with 10% probability of exceedance in 50 years (the corresponding average earthquake return period is 475 years);

2) GSZ-1_{2475} and GSZ-2_{2475} maps, representing seismic intensity values with 2% probability of exceedance in 50 years (the corresponding average earthquake return period is 2475 years);

Note that GSZ-1_{475} and GSZ-1_{2475} maps show the seismic hazard of the territory, which is characterized by isolines with reference values of the horizontal peak ground accelerations $a_{gR\,(475)}$ and $a_{gR\,(2475)}$ (in fractions of g), corresponding to the rock geological formations. GSZ-2_{475} and GSZ-2_{2475} maps show zones within which the seismic hazard is conditionally assumed to be constant and is characterized by integer grades assigned to "average" soil conditions (based on seismic properties).

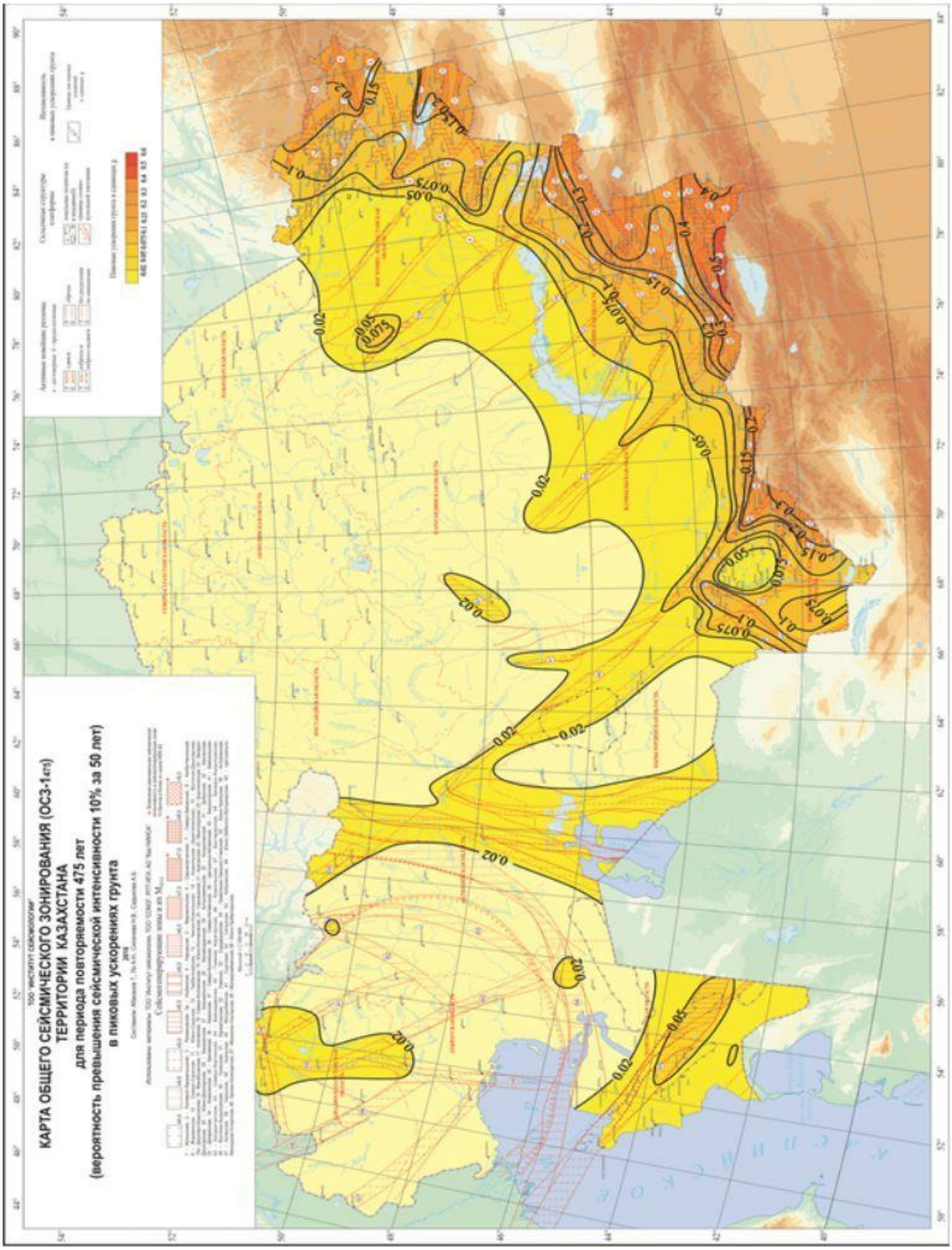

Fig. 1 – GSZ-1$_{475}$ RK map, representing seismic intensity values with 10% probability of exceedance in 50 years (the corresponding average earthquake return period is 475 years)

In case of absence of micro-seismic zoning maps, GSZ-1 and GSZ-2 maps can be used to determine the seismic hazard for construction sites. In this case, seismic hazard for a construction site in terms of the accelerations $a_{g(475)}$ and $a_{g(2475)}$ is determined using the following expressions:

$$a_{g(475)} = a_{gR(475)} \times S\,(a_{gR(475)}) \times S_T \quad (1)$$

$$a_{g(2475)} = a_{gR(2475)} \times S(a_{gR(4275)}) \times S_T \quad (2)$$

where:

$S(a_{gR(475)})$ and $S(a_{gR(2475)})$ are the coefficients which characterize the influence and effect of the actual soil conditions of the construction site on the intensity of seismic actions (see Table 1), and

S_T is coefficient that takes into account the topographic effects of increasing horizontal seismic actions at the construction site.

The design peak ground acceleration a_g (expressed as a fraction of g) at the construction site is determined using the expression:

$$a_g = \max\{a_{gR\,(475)},\ (2/3) * a_{gR\,(2475)}\} \quad (3)$$

Seismic hazard for the territory of the KR is characterized by the Building Code 20-02:2018 through seismic hazard maps which were developed and approved by the Institute of Seismology of the National Academy of Sciences of the KR, by Abdrahmatov K.E., Doctor of Geological Mineralogical Sciences, Professor, Omuraliev M.O. and Omuralieva A.M., Candidates of Geological Mineralogical Sciences, Zahozhaya I.G [1]. The following maps are included in the Code:

1) map of maximum local magnitude (MLH) distribution of active seismic faults and their segments, which generate earthquakes in the KR;
2) map of peak ground accelerations in rock soils (Fig. 2) for the horizontal component of seismic vibrations within the KR's territory (seismic-risk zoning map), and
3) map showing intensities of earthquake vibrations for probable maximum earthquakes in the KR.

The above-mentioned maps are supplemented by a list of settlements within the KR and the corresponding seismic hazard parameters, both in terms of the intensity and peak ground accelerations.
The design value of the horizontal peak ground acceleration for a construction site a_g takes into account its actual soil (ground) and topographical conditions, and it is defined from the following expression:

$$a_g = a_{gR} \times S(a_{gR}) \times S_T \quad (4)$$

where:

a_{gR} – reference value of horizontal peak ground acceleration (as a fraction of g) for the considered construction site under soils type IA (rock soil), determined based on map of peak ground accelerations and/or based on list of settlements;

$S(a_{gR})$ – a coefficient which takes into account the effect of the actual soil conditions of the construction site on the intensity of seismic impacts (actions) defined in accordance with Table 1;

S_T – a coefficient that takes into account the topographical effects of increasing horizontal seismic actions at the construction site.

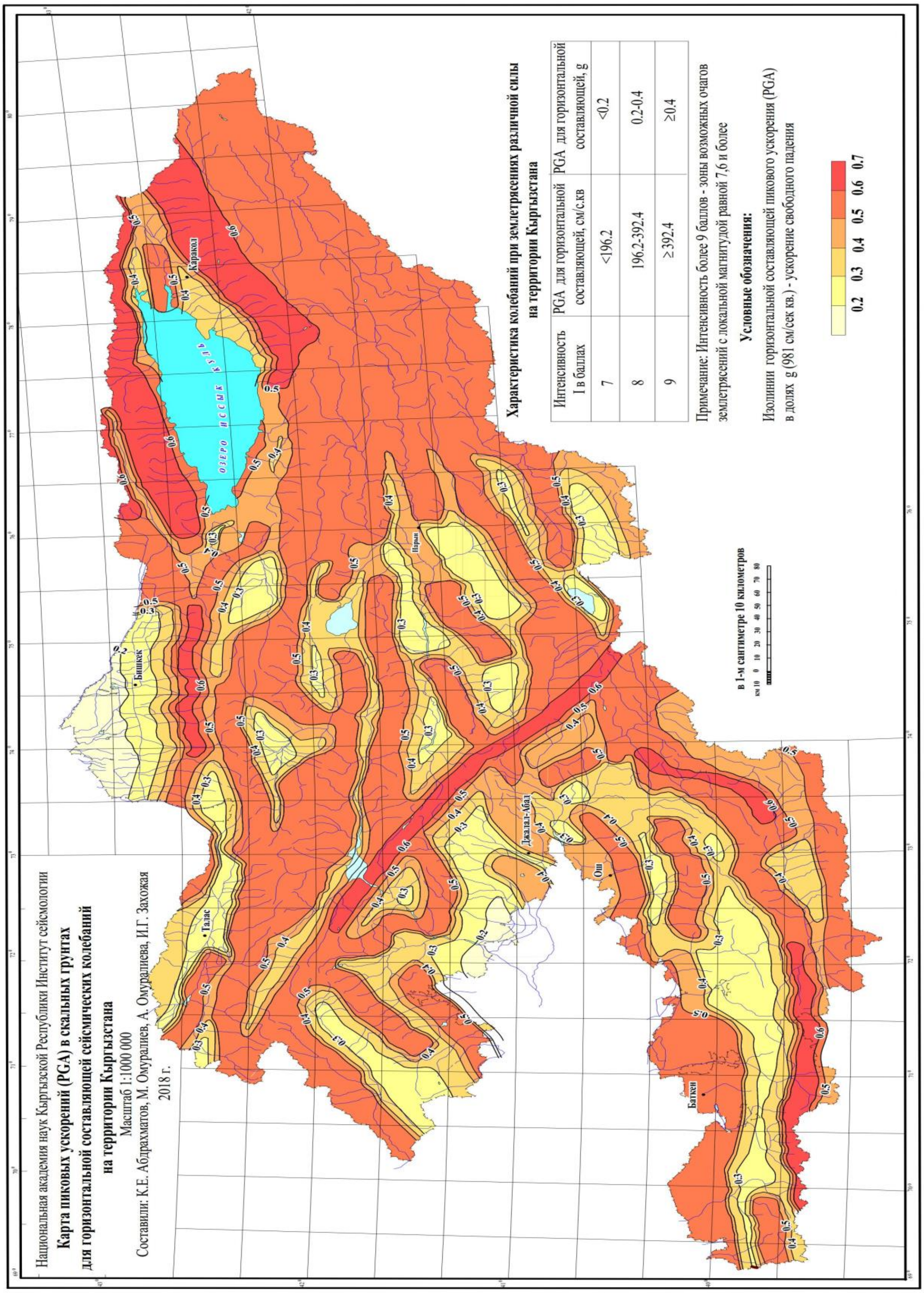

Fig. 2 – Map of peak ground accelerations in rock soils for the horizontal component of seismic vibrations within the KR’s territory (seismic-risk zoning map)

Table 1 – Values of the $S(a_{gR(475)})$, $S(a_{gR(2475)})$ and $S(a_{gR})$ coefficients in Kazakh Code and Kyrgyz code

Types of soil conditions by seismic properties (shear wave velocity in surface soil columns)	**RK Code: Values of $S(a_{gR(475)})$ and $S(a_{gR(2475)})$ coefficients depending on $a_{g(475)}$ and $a_{g(2475)}$ values**	**KR Code: Value of $S(a_{gR})$ coefficient depending on a_{gR} value**
IA – Rock soils ($V_{s,30} \geq 800$ m/sec.)	1,0	1,0
IB – Coarse clastic soils - mainly from igneous rocks content more than 70% ($V_{s,10} \geq 350$ m/sec, $550 \leq V_{s,30} < 800$ m/sec)	$1,0 \leq (1,4 - a_{gR}/g) \leq 1,2$	$1,0 \leq (1,4 - a_{gR}/g) \leq 1,2$
II – Coarse clastic soils of all types - with aggregate content more than 30% ($230 \leq V_{s,10} < 350$ m/sec, $270 \leq V_{s,30} < 550$ m/sec)	$1,1 \leq (2,0 - 2,5 * a_{gR}/g) \leq 1,6$	$1,1 \leq (2,0 - 2,5 * a_{gR}/g) \leq 1,6$
III – Friable sands, coarse and mean size water saturated ($V_{s,10} < 230$ m/sec, $V_{s,30} < 270$ m/sec)	$1,3 \leq (2,5 – 3,0 * a_{gR}/g) \leq 2,4$	$1,3 \leq (2,5 – 3,0 * a_{gR}/g) \leq 2,4$

The design seismic actions at a construction site are characterized by response spectra and peak ground accelerations. The shape of the response spectra for the codes in KR and RK are the same.

For the horizontal components of seismic action, the design response spectrum $S_d(T)$ should be determined from expressions (5) and (6):

$$0 \leq T \leq T_C: \qquad S_d(T) = a_g \cdot \frac{2,5}{q} \tag{5}$$

$$T \geq T_C: \qquad S_d(T) = a_g \cdot \frac{2,5}{q} \cdot \left[\frac{T_C}{T}\right], \text{ but no less than } \beta \cdot a_g, \tag{6}$$

where:

T_C is the maximum value of period on the constant section of the spectral accelerations graph $S_d(T)$, taken in accordance with the data in Table 2;

T is the period of linear oscillations in horizontal direction;

q is a behavior coefficient; note that q is an inverse value of the reduction coefficient k_2, adopted in the previous seismic codes: $q=1/k_2$;

β is an indicator of lower limit of the spectrum taken as 0,2.

For the vertical components of seismic action, the design response spectrum $S_{dv}(T)$ should be determined using the expressions (7) and (8):

$0 \le T_v \le T_{Cv}$: $$S_{dv}(T) = a_{gv} \cdot \frac{2{,}25}{q} \quad (7)$$

$T_{Cv} \le T_v \le 2{,}0$: $$S_{dv}(T) = a_{gv} \cdot \frac{2{,}25}{q} \cdot \left[\frac{T_{Cv}}{T_v}\right]^k, \quad (8)$$

where T_{Cv} is the maximum period on a constant segment of spectral acceleration graph $S_{dv}(T)$, taken equal to 0.2 seconds;

T_v is a period of linear oscillations in vertical direction;

k is an exponent depending on the type of soil, taken in accordance with Table 3;

a_{gv} is a design vertical acceleration at the construction site (see Table 4);

q_v is a behavior coefficient, whose value should always be taken as 1.5 (see Table 5).

Table 2 - Values of T_c periods

Type of soil	T_c (sec)
IA and IB	0,48
II	0,72
III	0,96

Table 3 - Values of k

Type of soil	k
IA and IB	0,60
II	0,45
III	0,35

Table 4 – Characteristic a_{gv} value depending on a_g

Type of soil			
	$a_g \le 0{,}12g$	$0{,}12g \le a_g \le 0{,}4g$	$a_g \ge 0{,}4g$
IA, IB, II and III	0,7	0,8	0,9

Table 5 – Values of a behaviour coefficient ***q*** for buildings regular in height

Type of structural system for buildings	*q*
1 Buildings for which structural damages or inelastic deformations are not allowed.	1.0
2 Buildings with loadbearing walls of cast reinforced concrete, large panel, volumetric-block: a) cross-wall structural systems with external and internal bearing walls located at spacing not exceeding 6 m, and slabs resting on four sides of the walls;	5.0

b) cross-wall structural systems with one loadbearing wall in each main direction; c) other wall structural systems.	3.3 4.0
3 Frame buildings (except as specified in 7 and 8): a) with spatial channel frames having all rigid joints of columns and crossbars; with frame-bonded skeletons having all rigid joints of columns and crossbars; with bonded frames, frame-wall structural systems; one-story frames of all structural systems, except for those specified in b); b) other structural systems, except as indicated in a).	4.0 3.3
4 Buildings with monolithic masonry walls	3.5
5 Buildings with loadbearing walls of brick (masonry) work of composite structure.	3.3
6 Buildings with loadbearing walls of reinforced brick masonry with seismic safety measures	3.0
7 Torsionally-pliable structural systems	2.0
8 Structural systems of "inverted pendulum" type	1.5
9 Wooden buildings in the form of: a) statically indeterminate portal frames with connections on pins or bolts; b) wall panels joined with nails and bolts;	 3.0 4.0
10 Buildings with loadbearing walls of local construction materials (adobe and similar). Buildings with loadbearing walls of unreinforced brick masonry without seismic safety measures.	To be determined based on the results of a special survey
Type of Engineered Structures	
1. Structures including free-standing towers, chimneys and masts: a) with loadbearing reinforced concrete or steel structures behaving as unbraced consoles for more than half of their total height; b) with reinforced concrete or steel structures behaving as a cantilever console for less than half of their full height or fixed by guy lines in the level of the center of the structural weight or above this level c) brick masonry structure.	 2.5 3.5 2.5

2. Structures in the form of single pillars and towers serving as supports for reservoirs and tanks located at their top levels.	1.5
3. Structures of silage towers and elevators.	3.5
4. Structures in the form of frame skeleton towers without infill	3.0
5. Torsionally pliable structures.	2.0
6. Other structures (not specified in 1-5).	3.0

3. Code provisions related to the design seismic loads and actions on buildings

The design seismic loads for buildings are determined taking into account the importance of these facilities, the regularity of their structural layouts in terms of plan and height, as well as torsional resistance in plan. In the RK 2.03–30–2017 [3] and SN KR 20-02:2018 [4], buildings are divided by importance: a) depending on the functional purpose (into 4 classes), and b) depending on the number of storeys (into 5 classes). Each combination of building importance classes and number of storeys in the RK 2.03–30–2017 and SN KR 20-02:2018 are assigned corresponding values of importance coefficients which are taken into account in determining the design seismic loads.

Structural schemes are classified in the RK 2.03.30-2017 by regularity in plan and elevation into three types as regular, moderately regular, and excessively irregular, while in terms of torsional resistance structural schemes are classified into schemes that possess adequate torsional stiffness, and torsionally-pliable schemes. The adopted classification system is based on the combination of features, which characterize structural systems both qualitatively and quantitatively:

- by peculiarities of configurations in plan and/or elevation;
- by balancing the distribution of mass and stiffness in plan;
- by peculiarities of the distribution of mass and stiffness in elevation;
- by the capacity of the slabs to perform the functions of horizontal stiffening diaphragms.

The classification of structural systems according to regularity in terms of plan and elevation, and torsional resistance is important for the structural and seismic design aspects associated with the selection of the following seismic design parameters:

- coefficient f_{vk} which increases the effects of design seismic actions in the structure at storeys which due to a sharp increase in mass or decrease in stiffness, violate the uniformity of the structural scheme in elevation;
- random eccentricity e_{ak}, which must be taken into account when determining the building torsion effects in plan, caused by spatial variations of the seismic movement, uncertainties in the location of the masses and the consequences of various nonlinear effects;
- behavior coefficient q for torsionally-pliable structural systems in plan, which are defined as systems in which the first mode shape is torsional, and also for excessively irregular structural systems.

In the process of performing calculations, structural and seismic analysis of buildings and structures, taking into account their interaction with the subgrade and/or basement soil, the parameters of equivalent elastic soil stiffness are allowed to be determined using:

1) experimental data on the velocity of distribution of elastic waves in the soil layers below the base of the foundations;

2) correlation of empirical relationships for the physical and mechanical soil properties under static loads with the velocity distribution of elastic waves through soil layers. When taking into account interaction of a building or structure with the basement soil, the following recommendations are provided:

a) as the base parameter of the equivalent elastic soil stiffness, increase the value of its modulus of deformation determined by the results of static tests 10 times;

b) consider two numerical design models for the same structure: a model in which the base equivalent stiffness of the foundation soil should be increased 1,5 times, and in the other in which it is reduced 1,5 times.

c) adopt the highest values of seismic effects obtained from the numerical design models discussed under b). It should be noted that the seismic hazard assessment for construction sites in slopes are not taken into account when determining the design seismic actions, but are taken into account when prescribing structural measures to be applied regardless of the analysis results for the designed structures.

4. Code provisions for design and construction close to the Issyk-Ata fault, KR

The zone of influence of the Issyk-Ata seismic fault in the KR refers to the territory of the Bishkek city (Fig. 3), which is 3000 m wide and adjacent to the magistral line of the Issyk-Ata seismic fault from both sides (1500 meters each on the north and south sides). The area adjacent to the seismic fault has been divided into 5 zones depending on the degree of suitability for construction. In accordance with the provisions of the Building Code KR 31-02:2018 "Design and construction in territory of the Bishkek city and villages, adjacent to the Ysyk-Ata fault" [6], the seismic hazard of construction sites should be determined using the map of the magistral line location of the Ysyk-Ata seismic fault developed and approved by the Institute Seismology of the National Academy of Sciences of the Kyrgyz Republic from 29th December 2018 [1].
The map of the magistral line location of the Ysyk-Ata seismic fault (see Figure 5) presents the potential seismic hazard adjacent to the seismic fault and characterized by isolines with horizontal peak ground accelerations values of 290, 350, 392.4 and 490,5 cm/sec^2. Seismic intensity indicators and/or parameters a_{gR}, shown in the map refer to the rock sites (soil condition type IA according to SN KR 20-02: 2018).
On the map of the location of the trunk of the Issyk-Ata fault, the potential seismic hazard of the territory adjacent to the fault is characterized by isolines with horizontal peak acceleration values of 290, 350, 392.4 and 490.5 cm /sec^2. Indicators of seismic intensity a_{gR}, shown on the map, refer to the rock (type of soil conditions IA according to SN KR 20-02: 2018).
The value of the coefficient $S(a_{gR})$, depending on the type of soil conditions of the construction site for seismic properties and the peak acceleration a_{gR}, respectively, are determined according to SN KR 20-02: 2018.

The value of the coefficient $S(a_{gR})$ for the construction sites located in zone 4 should be multiplied by the coefficient k_{gF}, taking into account the distance from the construction site to the main line of the Ysyk-Ata fault. The values of the coefficient k_{gF} are determined using the equation (9):

$$1{,}0 \leq k\text{gF} = 1{,}25 - 0{,}0002 \cdot R \leq 1{,}2 \quad (9)$$

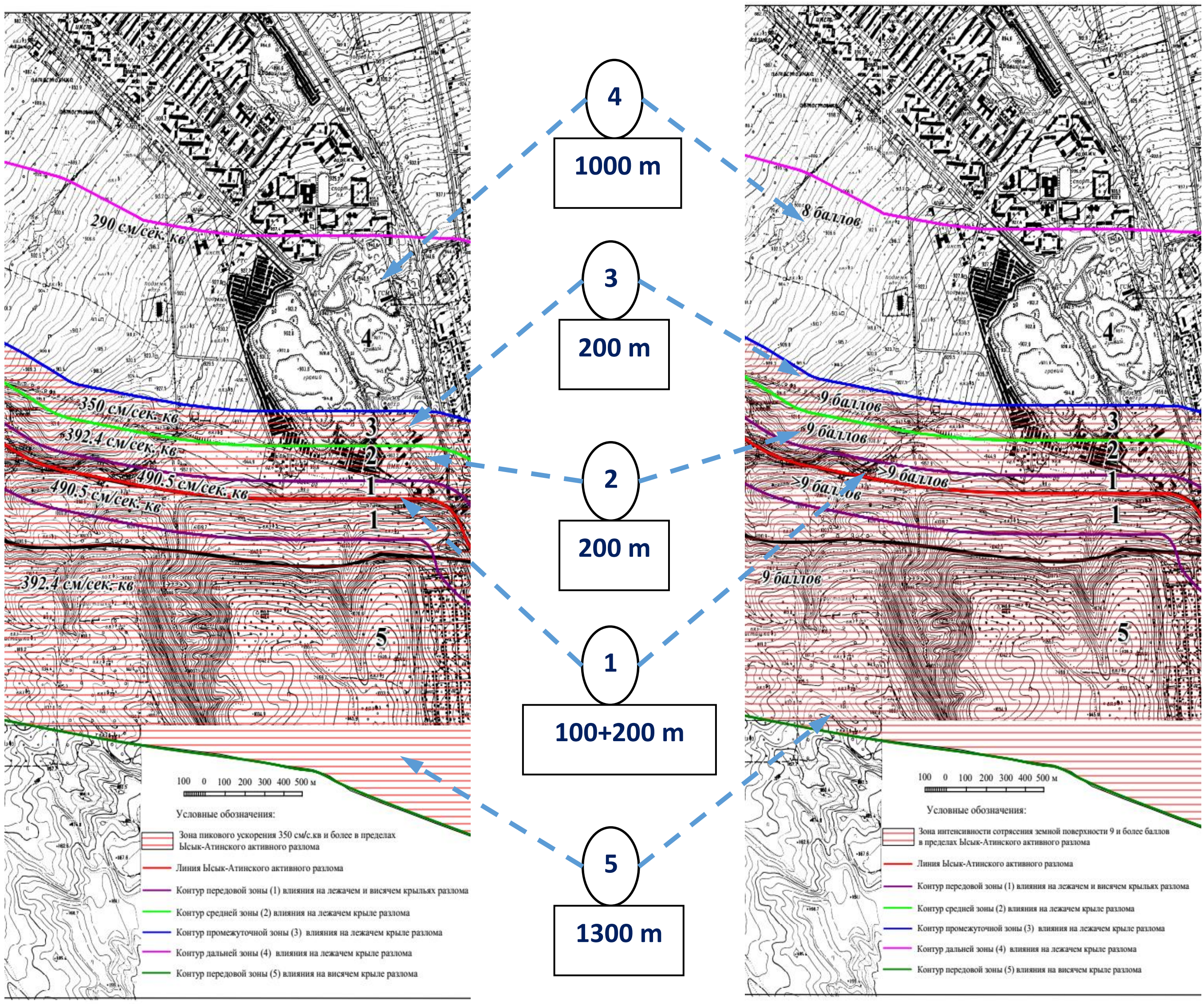

Fig. 3 – Zones of influence of the Issyk-Ata fault

5. Code for seismic resistance assessment of the existing buildings

In accordance with the provisions of the recently updated KR's code SN KR 22-01:2018 [5], seismic resistance assessment of the existing buildings should be performed by taking into account the actual condition of their loadbearing structures, determined based on the review of project design and technical documentation and the detailed building inspection. These provisions are similar to the provisions contained in the codes applicable in the RK.

The compliance of an existing building with the design requirements of the seismic design and/or building codes for seismic resistance assessment is established using the coefficient r_s which is determined as follows:

$$r_s = C/D \quad (10)$$

where:

C is the calculated and/or designed loadbearing capacity of the considered structural system or its structural elements;

D is the required calculated and/or designed loadbearing capacity of the considered structural system or its structural elements based on the applicable existing design standards and norms.

For seismic assessment purposes *C* and *D* values can be determined for storey-wise seismic loads, base shear force or shear force at any storey level, or obtained forces from seismic loads in building structure cross-sections.

An existing building should be considered as safe for seismic design effects if its structural design scheme complies with the mandatory structural requirements of applicable building and seismic codes. The coefficient r_s has a value exceeding those specified in KR 22-01:2018. For example, r_s has been prescribed the minimum value of 0,8 for education facilities, 0,5 for residential and public buildings. The inspected buildings are considered to be safe when the r_s value exceeds the minimum prescribed by SN KR 22-01:2018.

6. Conclusion

In recent years the requirements of the seismic and/or building codes, governing and regulating the structural and seismic design in seismic areas and the seismic resistance assessment of existing buildings in the RK and KR have undergone significant changes.

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