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The Global Blueprints for Change contain guidance for working together to improve the capability to identify indicators of physical, social, enterprise, and environmental vulnerabilities throughout the world and to select and implement realistic solutions to reduce them towards acceptable levels.

Theme A: LIVING WITH NATURAL AND TECHNOLOGICAL HAZARDS
Topic A.2: Reducing Vulnerabilities in Existing Building and Lifelines

**“Seismic Hazard and Earthquake Engineering
in the Republic of Kazakhstan”**

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SEISMIC HAZARD AND EARTHQUAKE ENGINEERING IN THE REPUBLIC OF KAZAKHSTAN

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Abstract: Our experience in the Republic of Kazakhstan indicates that compliance with seismic design regulations will contribute significantly to earthquake disaster mitigation, regardless of the intensity of the seismic loads and specific features of the earthquakes. The regulations of each country depend on local experience in seismic design, however they have some common factors. The following factors have been found to be critically important in the design and construction of seismically resistant buildings in the Republic of Kazakhstan:

- To select sites for construction that are the most favorable in terms of the frequency of occurrence and the likely severity of ground shaking and ground failure;
- To apply structural-spatial solutions that provide symmetry and regularity in the distribution of mass and stiffness in plan and in elevation;
- To implement the design of building elements and joints between them in accordance with analysis that take into account the structural requirements;
- To provide high quality of construction to ensure good performance during future earthquakes.

Introduction

The territory of southern and southwestern parts of Republic of Kazakhstan is one of the most seismically active zones in the Central Asian region. Several strong earthquakes have occurred during the last 100 years. Four of them: Vernyi – 1887, Chilik – 1889, Kebinsk – 1911, Zaysan – 1990, had magnitudes ranging from 7 to 8.

The seismic regions of Kazakhstan occupy about 300 thousand sq. km, which make up approximately 11 % of the total area of the republic. The population of the area is approximately equal to 4800 thousand, or 30 % of the total population of Kazakhstan.

The information on allocation of seismic hazardous areas and distribution of residents in seismic regions as shown in Table 1.

Table 1

Maximum expected intensity of the territory of Republic of Kazakhstan (by MSK-64 scale)	Area, sq. km	Number of inhabitants
7	170 000	2 000 000
8	100 000	1 100 000
9	31 000	1 700 000

The favorable climate conditions and availability of energy resources in seismic regions caused the concentration of industrial and agricultural potential of the republic.

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About 30 % of the total housing resources and approximately 25 % of the industrial and agricultural sector of Kazakhstan are located in earthquake-prone regions. The largest cultural and most industrial centers of Republic of Kazakhstan such as Almaty, Taraz and Shymkent are situated in the regions with a high level of seismic activity.

Principal concern in this work is devoted to economical and social consequences after possible earthquake in the largest city of Republic of Kazakhstan – Almaty. The development of this city is typical for other cities as well.

Almaty City is located in the zone of possible seismic center (seismicity of some sites – more than 9) and distinguished by its high density of population. There are about 1 200 000 habitants in Almaty city (3.7 thousands per sq. km). The density of buildings aggregates 80 thousands sq. m per sq. km, including residential buildings – 60 thousands sq. m per sq. km. The building development of the city was constructed in quite difficult conditions. The territory of Almaty city contains unfavorable sites for construction, in terms of: a) soil conditions, b) fault zones, which can rupture the ground surface, c) slopes of more than 15 %, and d) saturated soft soil, located in zones of possible occurrence of mudflows.

According to the information given by seismologists, the greatest hazard for Almaty City is presented in three seismic zones:

- Kungeisk ($M_{\max} = 8.3$, $h = 25$ km)
- Zailiysk ($M_{\max} = 8.0$, $h = 25$ km)
- Almaty ($M_{\max} = 7.5$, $h = 15$ km)

The territory of Almaty City is at risk from future earthquakes likely to occur at the above mentioned magnitudes and depths, and the intensity is likely to be more than 10 on the MSK-64 scale.

Since 1928, the construction in Republic of Kazakhstan was carried out in accordance with the requirements of normative documents, which regulate Rules on construction in seismic regions. The first normative document was, “The Temporary Technical Conditions of the Design and Construction of Civil Structures in Seismic Regions of Kazakhstan». It is necessary to mention, that these norms, issued in 1928 by the government, were widely used in the Soviet Union at that time. They were based on Italian norms and differed only a little from them.

By 1935, in addition to “The Temporary Technical Conditions of the Design and construction of Civil Structures in Seismic Regions of Kazakhstan,” amendments were prepared. They were devoted to extend the limitation of construction of the buildings with brick load-bearing walls. Those rules were rather severe. For instance, the height of the masonry buildings was limited to three stories, and the width of the external walls in the ground floor could not be thinner than 77 cm (3 bricks), first floor – 64 cm (2.5 bricks), second and third – 51 cm (2 bricks). The slab of the ground floor in such buildings should have been implemented from cast-in-situ reinforced concrete, and on the other floors – wooden beams, which made up rigid frame. Some of the buildings, which were designed according to those Rules still exist.

From 1951 to 1957 the design of structures were implemented in accordance with “The Regulations on Construction in Seismic Regions” (PSP 101-51).

Up to 1957 the estimation of seismic loads for designed buildings was based on static theory of seismic design. In 1957 “The Regulations on Construction in Seismic Regions” (SN 8-57) were worked out in the USSR. They were based on dynamic theory of seismic design. During the ensuing years SNIP II-A.12-62, SNIP II-A.12-69, SNIP II-7-81 were applied in earthquake engineering.

At present, the new Regulations, SNIP RK V.1.2-4-98, “Construction in Seismic Regions” are used in the territory of Republic of Kazakhstan. They were developed by KazNISSA and have been enforced since 1998.

The analysis of normative documents, which were valid and still remain in force, indicates that the qualifying standards, required to the buildings, constructed in seismic regions, always raises. This tendency is also observed in all other countries. At the same time, the most drastic modifications in Seismic Codes are introduced after destructive earthquakes, when the modern structures in metropolis are exposed to the seismic forces.

As new results of investigations and the facts regarding the buildings’ behavior of various structural types at real seismic loads become available, the opinions of engineers on effectiveness of the Regulations are revised. The most obvious evidence is the fact, that during last 70 years the Regulations on Design of the buildings in seismic regions of former Soviet Union were revised 8 times.

In connection with the observed toughening of the seismic code requirements, researchers and designers are faced with the challenge, concerned with seismic assessment and estimation of seismic safety of existing buildings.

It is necessary to notice that in the Regulations acting currently on the territory of Republic of Kazakhstan, the following types of buildings designed before 1998 are considered to be earthquake-resistant:

- Buildings that satisfy to the requirements of the current Seismic Code;
- Buildings with the strength of elements, corresponding to the design seismic loads, which are defined in accordance with SNIP RK V.1.2-4-98, taking into account reduction factor 0.5-0.75.

Approximately 80 % of the multi-story residential construction of Almaty consists of brick, frame and large-panels buildings constructed in accordance with standard designs.

Building with Load-bearing Brick Walls (Masonry Buildings)

The residential buildings with load-bearing brick walls of two or more stories were constructed in Almaty for a long time, however the intensive construction took place from 1930 to 1960.

Masonry buildings were designed according to the standards that were valid during the various periods of construction. Considering this circumstance, all masonry buildings can be divided into two main groups.

The buildings with load-bearing brick walls with a height of 2-3 m and with wooden beam ceilings belong to the first group. Most of the buildings of this group were designed in accordance with static theory of seismic resistance and were constructed between 1930 and 1957.

For the first group of buildings, the following attributes are very common:

- Low strength of the brickwork.
- Insufficient stiffness of floor slabs.
- Considerable depreciation of the elements.

The buildings of this type are not earthquake resistant and many are scheduled to be demolished.

The second group of buildings is represented by residential buildings with heights up to 4 stories with floor slabs made from cast-in-situ or prefabricated reinforced concrete.

Most of the masonry buildings with RC floor slabs were designed using dynamic theory of earthquake engineering. The resistance of brickwork against seismic loads in the buildings of this group typically is higher than in the buildings of the first group, and the constructive measures are more close to the measures that are provided in current Regulations.

The buildings of the second group are inspected to assess their seismic resistance. As needed, these buildings are strengthened, using methodologies for strengthening developed in KazNISSA.

It is important to note that at the present time the construction of residential buildings with load-bearing brick walls with height of two or more stories has been suspended in Almaty City. The main reason is the extremely low seismic resistance of buildings of this structural type. The vulnerability of these building types was proven by the analysis of consequences of strong earthquake ground shaking that occurred in past earthquakes centered in the territory of the Republic of Kazakhstan as well as in other countries of Central Asia.

Large Panel Buildings

Mass construction of large-panel buildings in Almaty City was started in 1959 and continued until 1992.

The peak of construction of large-panel buildings occurred in 1985-1988. In that period the amount of annually constructed large-panel buildings was about 400 thousand sq. m, which was roughly 70 % of total volume of the residential construction in Almaty. Currently the total area of large-panel buildings constructed in Almaty and adjacent territory is about 9.7 million sq. m. There are about 600 thousand inhabitants living in the large-panel buildings.

In terms of structural layouts the large-panel buildings represent the systems combined from longitudinal and transverse load bearing walls with connections by butt-joints and floor slab panels.

From the beginning only four-story buildings were constructed in the city, and connections between panels were performed on welding of embedded fitting. Later, the height of large-panel buildings was extended up to 9 stories and joints between panels were performed on welding of reinforcement with follow-up filling by concrete.

The first major experiment on the seismic resistance of large-panel buildings in Almaty City was carried out in 1967 while a mud-flow prevention dam was under construction in Medeo Canyon. The construction of the dam was carried out by setting off explosions, which caused

ground shaking with intensity of 7-8 (MSK-64) on the area within 2 km of the source of the explosions. The experiment was conducted on site located 800 m away from the place of explosions. During the explosions (total weight of the explosive was about 3900 ton) peak ground accelerations of 0.4-0.6 g were recorded at the foundation level of the building under test and acceleration at the roof level of masonry and large-panel buildings was recorded at 0.9 g and 0.6 g respectively. The building observation indicated, that after the exposure of seismic blasting loads the brick building was severely damaged (through-wall cracks in the corners), and large-panel buildings were slightly damaged (hair-line crack in the walls and in the joints between panels).

The results of blasting experiments in Medeo Canyon have clearly demonstrated the high resistance of the large-panel buildings to the intensive dynamic loads and provided a basis for comparing the seismic resistance of large-panel and masonry buildings.

At present, it is possible to consider the large-panel buildings as experimentally investigated structural systems. For the last 30 years only in KazNISSA were conducted dynamic experiments of about 25 real large-panel buildings. Many of the experimental models sustained dynamic loads 2-3 times exceeded design seismic loads, some of them were put to the ultimate conditions.

The analysis of the state of large-panel buildings, subjected to the intensive dynamic loads, proves that such buildings possess remarkable margins of strength with respect to the design loads and ability to dissipate energy. At the same time, the quality of prefabricated elements of large-panel buildings and high level of static indeterminacy of the structure play important role in damage prevention.

Seismic reliability of large-panel buildings was repeatedly proved by consequences after strong earthquakes. There are many data, proved that large-panel buildings rather good withstand seismic forces even in case when the intensity of real seismic loads exceeds the design intensity on 2-3. The most illustrative example of this statement is the fact that in Spitak city two five-storied buildings designed on the sites with expected seismicity of 7 were subjected to the seismic loads with the intensity of 10. These buildings were slightly damaged in comparison with the damage of surroundings structures.

At the same time, by the conducted investigations was determined that in large-panel buildings which were constructed 30-40 years ago and with butt-joints performed by welding of embedded fittings between panels, the significant corrosion of the connected details can be observed. Residual thickness of some steel elements is about 60 % of the initial thickness.

Significant corrosion of some joints between panels poses hazard for large-panel buildings. In order to provide safety in such buildings the detailed investigations are going to be conducted and some programs for strengthening of the joints will be designed.

Frame residential buildings

Before 1995, the construction by using prefabricated reinforced concrete frames and combination of prefabricated and cast-in-place reinforced concrete frames predominated in residential development of Almaty. The great part of frame type dwellings was constructed by standard design. The height of most of them was within 4 to 9 stories.

Almost all frame buildings were constructed with using prefabricated hollow floor slabs with framing by cast-in-place reinforced concrete. Brick was used as a frame filling. All connections were performed by welding of reinforcement in the joints with follow-up filling by concrete.

The seismic resistance of these buildings is mainly determined by the quality of butt-joints between prefabricated frame elements (columns and beams). Conducted investigations indicated that the welding quality in real conditions not always satisfies the design requirements and some buildings of this type (poor quality) cannot be considered as seismic resistant.

Besides, the type of brick exerts a significant influence on seismic resistant of frame buildings. The results of experimental investigations and analysis of consequences indicated that in case of use solid brick for frame infilling the damage is less than in case of use for this purpose hollow brick. The most obvious example was elicited from the investigations of consequences of Turkey earthquake (1999).

In addition to the above-mentioned structural types of construction in Almaty there are also some frame buildings with stiffening core and with “first flexible story”. The level of seismic resistance of these buildings seems to us as insufficient. These findings are based on analysis of consequences after strong earthquakes occurred during last years particular after Spitak earthquake, Armenia. The Spitak earthquake was the first severe examination of some new structural types the construction of which was started applying in seismic region of the former Soviet Union. Frame buildings with one or two stiffening core of moderate dimensions are related to these types.

Two multi-storied buildings with cast-in place stiffening cores were built in Leninakan. One of them (ten-storied) collapsed during earthquake, and another one (sixteen-storied) was severely damaged and inclined. As a result of the investigation of design documentation and observation analysis of damaged buildings with stiffening core it is possible to recognize three main reasons of their low seismic resistance:

- The design of the buildings was performed based on expected seismicity of the site – 7 (MSK-64); actual intensity of seismic loads was much higher;
- Structural elements of the buildings designed for seismic loads were presented as static determinate vertical cantilever (stiffening core) with insignificant ability to redistribution of loads and with deformability and ability to dissipate the vibration energy.
- Some parts of stiffening cores were carried out with poor quality.

In our opinion, in this case, the most significant factors are the second and third reasons. The low seismic resistance of buildings having a flexible first story is well known and it is not necessary to explain it in more detail here. At the same time, it is necessary to note that the damage of structural elements of the first story in these buildings is accompanied with terrible consequence: – collapse of the entire building. Besides, in most cases, after strong earthquakes the buildings with first flexible stories are not repairable.

Summarizing the brief descriptions of constructive solutions of buildings which were constructed by standard designs let us mention that the performed by experts of KazNISSA the seismic assessment indicates that approximately 27 % of population of Almaty occupy seismic vulnerable buildings, up to 31 % - buildings which require investigation and seismic assessment in order to specify the level of seismic resistance, and only 42 % - in seismic reliable buildings.

According to the information given by experts, participants of the conference on estimation of seismic risk, which was held in Almaty, October 22-25, 1996, at an earthquake of 9 in Almaty region (depending on season and time) the number of human loss can reach 75 thousand and number of injured people up to 300 thousand.

By 2000, the portion of seismic vulnerable buildings in total development of Almaty had not been reduced, old structures gradually decay, and in near future at predicted devastating earthquake the human loss is inevitable. At last decade the portion of individual dwelling construction on the territory of Almaty has raised. As a rule, such kind of construction is carried out without thorough investigated design, without due quality inspection and materials, and cannot be considered as seismic reliable.

The experts' data regarding the direct loss for Almaty City at earthquakes of various intensities are given in Table 2.

Table 2

Seismic intensity	Direct loss at the given earthquake (In percents of total damage amount /million US \$)
7 (Ms=5.5-6.1)	10 / 400
8 (Ms=6.2-6.6)	24 / 900
9 (Ms=6.7-7.0)	48 / 2 000
10 (Ms>7.0)	80 / 3 200

For entire territory of Kazakhstan similar numbers would be still more significant (Table 3).

The estimation of the state of existed development in Almaty which was performed in 1990 indicated that 16.6 million sq. m (19 %) of the residential buildings were required the strengthening; 10 million sq. m (12 %) – were scheduled to be demolished. The portion of seismic vulnerable buildings in social sphere (schools, kindergarten, hospitals) is even greater.

By now the portion of seismic vulnerable buildings in housing stock has not been reduced, since the building volume has been reduced since that time however the seismic vulnerable buildings were not demolished or strengthened.

Table 3

Seismic intensity	Direct loss at the given earthquake (In million US \$)
7	500
8	1 200
9	3 500

As appears from the given data of Table 3 the potential direct loss from one possible earthquake with intensity of 9 (regardless engineering infrastructure and equipment that located in these buildings and the consequential loss) exceeds the budget of Republic of Kazakhstan in terms of expenditure on 2001.

The given experts' estimation is evidenced by facts. Even only direct loss after recent earthquakes that have occurred for the last 10-12 years add up to approximately 1 billion US \$, at that 70-80 % of the amount was the damage for the residential buildings and structures of social sphere.

Summarizing the paper we would like to notice that the problems of seismic strengthening of the buildings that were constructed without sufficient seismic measures are extremely actual and urgent not only for the engineers of the Republic of Kazakhstan. International cooperation in this field, particular the researches for looking-for the most effective technical solutions will reveal the way to avoid huge human loss and to prevent economical loss. We have to always remember the possibility of severe consequences from earthquakes on vulnerable structures located in earthquake-prone regions.

In order to reduce seismic risk and socio-economical consequences of destructive earthquakes it is necessary to perform complex of preventive measures, science and industrial mobilization, and also to intensify role of the governmental regulations in construction field in seismic regions.

Conclusions

1. The tasks of providing absolute seismic safety for the residents inhabiting the most earthquake-prone regions are far from being solved. However, new regulations on construction that contribute to earthquake disaster mitigation have been introduced and implemented in accordance with world practice. These regulations are based on experience of past earthquakes and results of special researches, summarized in adequate documents of many states.

The regulations of each country depend on local experience in seismic design, however they have some common guidance. In the regulations adopted for implementation in Kazakhstan, the following factors have been found to be critically important in the design and construction of seismic resistant buildings:

- To select sites for construction that are the most favorable in terms of the frequency of occurrence and the likely severity of ground shaking and ground failure;
- To apply structural-spatial solutions that provide symmetry and regularity in the distribution of mass and stiffness in plan and in elevation;
- To implement the design of building elements and joints between them in accordance with analysis that take into account the structural requirements;
- To provide high quality of construction to ensure good performance during future earthquakes.

Our experience indicates that compliance with the above-mentioned requirements will contribute significantly to disaster mitigation, regardless of the intensity of the seismic loads and specific features of the earthquakes.

The tragic consequences of earthquakes during recent years were taken into consideration by the Regulations of Republic of Kazakhstan during the development of SNIP V. 1.2-4-98, "The Construction in Seismic Regions." In particular, the design seismic loads have been significantly increased for frame buildings and for buildings with a flexible first story in comparison with provisions that were valid in 1982 to 1998 (SNIP II-7-81). In addition, the design requirements for engineering solution of the buildings have been toughened.

The modifications in construction and design that have been introduced increase seismic reliability of the buildings and seismic safety for human life.

At the same time, current regulations cannot be considered as final. As new data become available they have to be defined more precisely and new provisions have to be added to meet the needs.

During the past 10 years, the economical system in Republic of Kazakhstan has been drastically changed. As a result, a number of new problems not directly related to earthquake engineering appeared in seismic design. In this regard, the analysis of main reasons of the tragic earthquake consequences during last years, which took place in Armenia, Turkey, Taiwan, Central Asian countries and in other countries, takes on special significance. The conducted analysis illustrated that the main reasons of tragic earthquake consequences are to be considered as follows:

- The violations of code requirement on design and construction of structures, and in some countries – low normative basis of earthquake engineering, in part of legislative force;
- Selection for construction sites of multi-storied buildings – the sites with unfavorable in terms of seismic design soil conditions;
- The Application of simplified procedure for co-ordination and licensing on launching of construction;
- Lack of due quality control of performance construction.

In order to improve seismic safety of residents and to prevent huge property damage caused of earthquake it is necessary:

- To strengthen role of design and construction control by State body;
- To design and construct on seismic unfavorable sites only by authority of appropriate experts' commission;
- To implement widely the test practice and quality control of building material and elements, used in construction; The buildings of new construction types must be put into operation only after conducting model and real tests;
- To develop guidance on design for buildings of some types (e.g. frame and frame buildings with stiffening core) and to specify series of current seismic code provisions;
- To allow implementation of construction activity only for companies with appropriate license and documents proved the right on conducting certain kinds of works;
- To conduct full-scale investigation of built-up area developments which are located in seismic active regions, and then in accordance with systematization and analysis of investigation results to carry out the measures in order to mitigate consequences of disaster.