METHODOLOGY OF ASSESSMENT AND MITIGATION OF URBAN SEISMIC RISK, TAKING INTO ACCOUNT VARIABILITY OF SEISMIC HAZARD PARAMETERS

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SUMMARY

In this report we would like to present main postulates and results of our methodology of assessment and mitigation of urban seismic risk for buildings and facilities, which has been developed and realised during implementation of Radius project for Tashkent Case Study City. The methodology developed allows use GIS technology and is, in certain degree, universal, so may be used for seismic risk assessment of all Central Asia cities.

INTRODUCTION

Provision of seismic safety for any given urban territory is connected with understanding and assessment of seismic risk and also with risk management, oriented to mitigate it up to level of acceptable risk. The last objective may be reached using long-term preventive measures with purpose to decrease unacceptable risk and to mitigate probable consequences of earthquakes.

Recent large earthquakes [Gazli earthquakes,1989] clearly showed that disaster size is depend on increasing vulnerability of existing buildings, when amount of real seismic resistant buildings is essentially less, than vulnerable ones.

An attempt is made in this study to demonstrate a procedure adopted for harmonising the risk levels in different stages of the seismic risk analysis. Seismic risk estimation requires calculation of probable social and economical losses for given urban territory for certain time interval. In this regard it is necessary to analyse existing buildings and infrastructure or concrete social economical environment, exposed to most probable and maximal earthquake hazard. Reliability of earthquake loss estimation essentially depend on the methodology chosen, which afterwards essentially shall influence to the choice of action plan measures for earthquake risk reduction

MAIN POSTULATES OF METHODOLOGY OF ASSESSMENT AND MITIGATION OF SEISMIC RISK

Methodology of assessment and mitigation of seismic risk, adopted in the framework of RADIUS project for Tashkent city, is based on results of seismic hazard assessment, selection of most probable earthquake scenario, classification of constructive systems and building types that exist on the city territory, technical inspection of buildings with purpose to obtain an index of its seismic resistance and physical state, estimation of damageability level and losses during scenario event, development of recommendations for strengthening the most vulnerable building types and the evaluation of consequences of a probable earthquake. The safety of buildings may be estimated using deterministic and probabilistic approaches.

Proposed methodology of earthquake risk assessment is foresee:
- account of historical and up-to-date seismological conditions of the territory and uncertainty of seismological information; - impact of natural-climatic and engineering-geological conditions of territory; - identification of variety of buildings constructive types by the vulnerability grade and composition of classification system by the damageability grade; - composition of damage probability matrices of different constructive type buildings in relation with local earthquake parameters, level of relative seismic resistance of buildings; - account of real

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physical degradation of buildings and facilities, initial level of earthquake protection measure; - estimation of seismic safety of existing buildings for given design period taking into account accumulation of damages during frequent earthquakes of medium intensity.

Recommended methodology of earthquake risk management is foresee:

- definition of level of (criteria) of unacceptable and acceptable risk (damage level) for the given urban territory; - development of plan of concrete measures for reaching acceptable risk level. The measures should be graded by importance and significance for different level - all country, sub-region, city, investors, house owners, individuals; - development of concrete action plan for the earthquake risk reduction taking into account possibility and social-economical state of local government for implementation; - development of monitoring of current state of seismic risk of urbanised area taking into account realisation of action plan, physical degradation of existing buildings and newly constructed sites.

Also our methodology includes an active part - optimisation measures of buildings safety upgrade and mitigation of damage for most vulnerable types of construction.

ALGORITHM OF EARTHQUAKE RISK ASSESSMENT AND OPTIMIZATION OF BUILDINGS ANTISEISMIC STRENGTHENING

For estimation of seismic risk and selection of optimal strengthening methods of existing buildings taking into account seismic risk the following model has been used:

$$R^0 = \sum_{i=1}^{N_i} \sum_{k=1}^{K_{ik}} R_{ik}^0 = \sum_{i=1}^{Ni} \sum_{k=1}^{N_{ik}} (R_{ik}^a + R_{ik}^b (A_{kc}, T, L)),$$

Where: R^0 - total investments (all building types), related with seismic resistance; R^0_{ik} – total investments for I-constructive type of k-storey building; R^a_{ik}– investments for strengthening of existing building (may be equal 0); R^b_{ik} – investments for rehabilitation after probable earthquakes for designed period of seismic risk assessment; i - number of constructive type of building; k- number of building floors; N_i- number of different constructive types of buildings; N_{ik} – maximal number of floors in i-type of buildings; A_{ks}- parameter of external impact (duration of motion t, frequency content, maximum amplitude of acceleration); T- designed period of seismic risk assessment; L- recurrence period of earthquakes.

Method of minimisation of R^0, presented by following algorithm: R^a_{ik} selected; R^b_{ik} calculated or chosen from graphs and tables; for n values R^a_{ik} constructed graph $R^0=f(R^a_{ik})$; selected a number of R^a_{ik}, which gave min for R^0.

SEISMIC HAZARD AND SCENARIO EVENT

Seismic hazard assessment for the territory of Tashkent city has been carried out based on selection of earthquake generating zones within the limits of surrounding region, estimation of the maximal probable magnitude event in limits of every selected zone and the selection of earthquake sources, which may be the most dangerous for the city [Khakimov,Nurtaev,1999].

On the basis of complex analysis of geological, tectonical, geophysical and seismological data, potential dangerous earthquake sources for Tashkent city territory have been selected: a) an earthquake with magnitude M=6.7, the depth of hypocenter estimated as h = 15 km, length of rupture 12 km and possible slip 90 sm. Macroseismic intensity in epicentral zone I = 9 ball (units of MSK-64 scale). This event referred to Karjantau-Pskem source zone and are situated at 75 km distance from Tashkent. The last event with M = 5.8 occurred here in 1959. b) an earthquake with magnitude M = 6.5, probable depth 20 km, length of rupture 7 km and slip - 50sm. Macroseismic intensity in epicentral zone I = 9 ball. This event referred to Teshiktash source zone and is situated at distance 18 km from Tashkent. The last historical event with magnitude M = 6.5 occurred in 1868 c) an earthquake with magnitude M = 6.1, probable source depth 10 km, length of rupture 6 km and slip 45 sm. Macroseimic intensity is I = 8 ball. This event referred to Tashkent ruptural-flexural zone and is situated just underneath the city centre of. The last historical earthquake with M = 5.3 occurred here in 1966, produced 8 ball intensity effect and many buildings were heavily damaged. Using observation of the detailed macroseismic fields of 10 relatively strong recent earthquakes of the region with $4.6<M<5.8$, we estimated the attenuation of seismic energy with distance in the conditions of region structure. Map of theoretical isoseists for three selected scenario events has been compiled. We took into account real local conditions: the probable position of earthquake source in limits of seismogenerating zones, the orientation of isoseistal axis, magnitude and depth of expected earthquake, average focal mechanism of strong earthquakes of the region.According to this calculation during event a) with M = 6.7 at a distance 75 km can produce an intensity of shaking, on the territory of Tashkent, equal to 7 ball at average soil conditions; event b) with magnitude M = 6.5 at a distance 18 km can

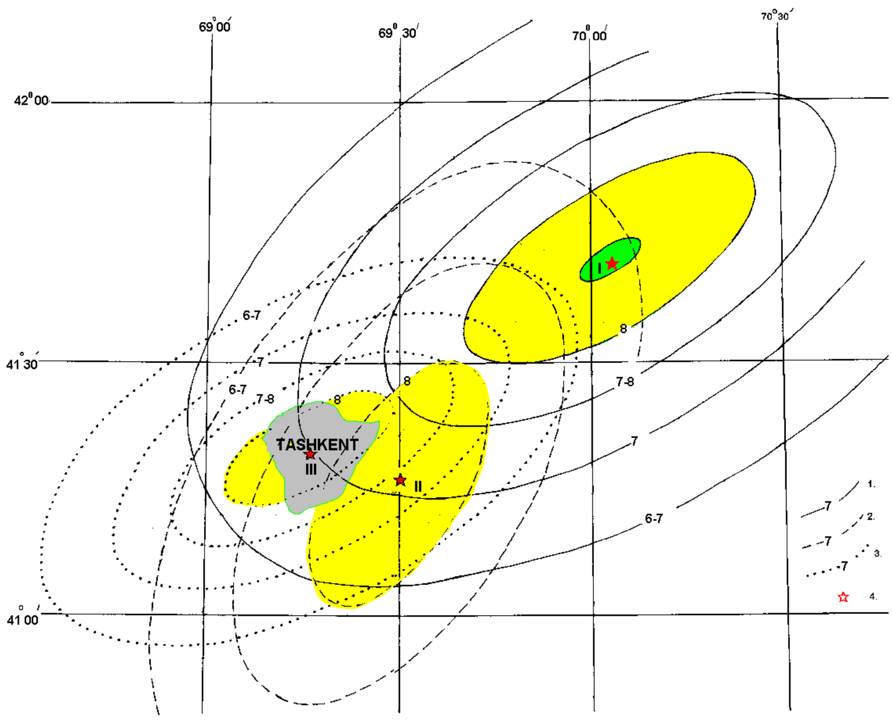


Fig.1 Map of theoretical isoseists of selected for Tashkent scenario earthquakes.

1-isoseists of earthquake from Karjantau-Pskem zone,2-isoseists of earthquake from Teshiktash zone,3-isoseists of earthquake in Tashkent source zone

produce an estimated intensity equal to 7 ball also within the borders of the city; during event c) M=6.1 with foci just underneath the city intensity on average soils estimated as 8 ball. Recurrence period of shaking with intensity 6,7,8 ball for Tashkent city has been estimated as: 6 ball - 20 years, 7 ball - 50 years, 8 ball - 100 years. Probability of at least one event with intensity 6,7,8 ball for the period 50 years is equal to 0.92; 0.58; 0.39. For the Radius case study scenario for Tashkent city we recommended to adopt probable earthquake with the magnitude M = 6.1 within Tashkent focal zone and an intensity of 8 ball on average soils. Then, taking into account local soil conditions the evaluation of the probable distribution of seismic effects on Tashkent, based on the results of the earthquake scenario, has been carried out. Influence of ground conditions was determined by consideration of such factors as: soil type; thickness of layer; seismic response of upper layer; level of ground water; possibility of manifestation of seismogeological effects.

According to this estimation, zones with expected intensity 7, 8 and 9 (MSK) were identified. Within the zone of intensity 9, some parts with probable manifestation of collateral seismo-geological effects should be found. Distribution of seismic effects within the boundaries of the city is as follows: approximately 20 % - intensity 7, 40 % - 8, 40 % - 9. More populated area is covered by the zone of intensity 8 to 9. Within the zone of intensity 9 about 10 % - the territory with probable seismo-geological effects (including 8% - ground failure in the nature of liquefaction and 2 % - slope phenomena).

CLASSIFICATION OF CONSTRUCTIVE SYSTEMS, BUILDINGS TYPE AND DAMAGE GRADE

The dwelling stock of Tashkent City is presented mainly by 6 constructive systems: residual buildings from local weak materials and brick buildings, constructed without any antiseismic measures; brick buildings (reinforced and complex walls); mixed (combined) constructive systems; frame buildings (RC and metal); unframed buildings with planar reinforced concrete bearing elements; wooden residual buildings. By combining these construction systems, it is possible to construct 30 building types, differing in material, bearing elements, number of floors, technology of construction and so on. Additionally, the level of seismic resistance provision can differ in dependence with year of construction of building of the same type, that is safety during earthquake of design intensity[KMK,1996]. Thus, the seismic risk for the existing dwellings is the sum of seismic risks for different building types.

Indexes of dwelling stock by main constructive systems, number of floors and number of residents are analysed [Khakimov,Nurtaev,1999]. It is defined that in dwelling stock structure, large panel and brick buildings and houses from local weak materials are dominant. As for the number of floors, 1-5-storey buildings are the majority.

Classification of building types has been carried out by the vulnerability grading (Table 1). Vulnerability assessment is based on results of analysis of earthquake consequences, expert judgement, experimental and theoretical works. Set of analysed situations includes broad range of building types, characteristic earthquakes, and engineering-geological conditions. Damageability is characterised by average value of damage grade diy of design seismic intensity " i " ball during earthquake with intensity "I" measured in the same units. During the estimation, 6 building damage grades were adopted, according to scale MSK-98; 0-absence of visible damage, 1 –light damage, 2 – moderate damage, 3- severe damage, 4 - collapse of some parts, 5 – collapse of building.

Table 1. Classification of buildings in Tashkent by vulnerability index.

N	Building type and bearing elements	Average value of damageability index
1	Residential buildings from weak local materials	3.95
2	1 storey frameless adobe ("gualyak" and "pahsa" type	3.68
3	3-5 storey frameless brick buildings with wooden ceilings	3.84
4	Assembly RC frame from linear elements with welded joints in the zone of maximal loads or with stiffness walls in one direction(111 seria, IIS-04)	2.96
5	1-2 storey frameless brick buildings with wooden ceilings	3.15
6	Frames without girder or lift slab construction (frame without rigidity core)	2.75
7	Building with flexible first and stiff upper floors	2.7
8	Brick walls from concrete or natural stones. Assembled RC slab	2.62
9	Large panel without antiseismic measures	2.61
10	Building with external bearing wall, inner wall – RC elements of frame	2.58
11	Assembled frame from planar cross-shaped RC, H-shape elements with monolith nodes	2.56
12	Frames from monolith RC	2.55
13	Walls from large blocks (concrete, vibrated and reinforced brick panels)	2.5
14	RC frame with brick filling	2.41
15	1-2 storey wooden frame with adobe filling	2.37
16	Walls of complex construction (with RC inclusions).Assembled RC slabs	2.33
17	Assembled RC frame braced with monolith nodes with stiffness walls in two directions or with stiffness core	2.22
18	Frame from blocks (volume cross) with monolith nodes	2.17
19	Large panel buildings with external brick walls	2.0
20	Monolith walls	1.86
21	Large panel walls	1.73
22	Room shaped volume blocks	1.67
23	1-2 storey wooden houses	1.16
24	Metallic frame	1.16

Note: 1- In the table is presented average value of damage index of buildings, design intensity of which correspond to intensity of site. 2. Disposition of table is from most vulnerable to less vulnerable

The vulnerability grade of building types may be corrected, if we take into account frequency content of earthquakes and soil conditions of site. When we take into account frequency content of earthquakes, the most vulnerable are:

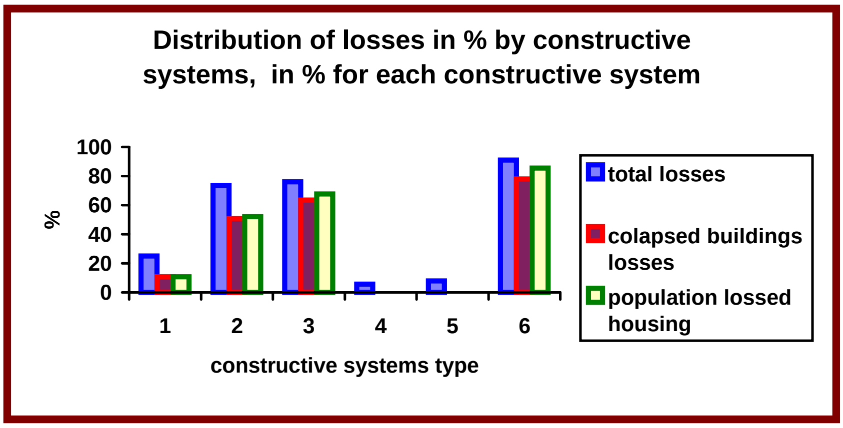
During high frequency impact T=0.1-0.3s: 1-2 storey buildings from local materials; 2-4 storey brick buildings with wooden ceilings; buildings of mixed constructive systems (external walls from bricks, inner – reinforced concrete frame); large panel buildings constructed without antiseismic measures.

During low frequency impact T=0.5 - 1.0 s: buildings erected using method of ceilings uplifting; frame systems without stiffening ribs; buildings with flexible first floor; buildings of mixed systems; prefabricated reinforced concrete frame from linear elements of series IIS-04 with welding joints in the zone of maximal loads.

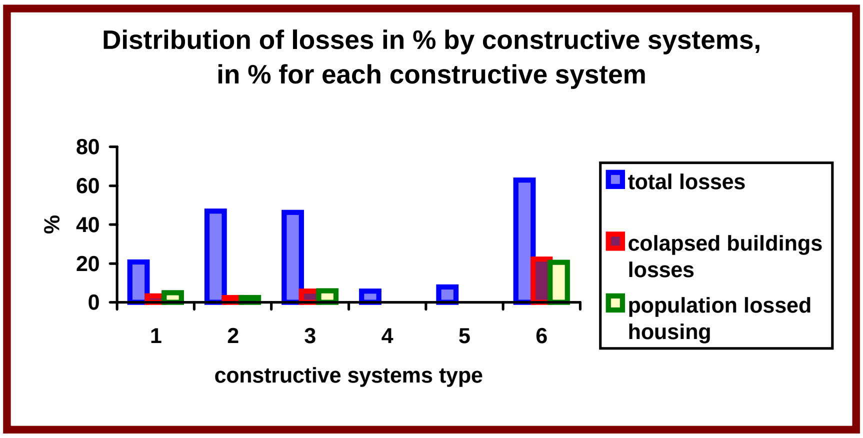
DAMAGE ASSESSMENT DURING SCENARIO EVENT

Taking into account the volume of buildings of different constructive types, having damageability graph for every type, graphs of relationship of losses in seismic impact and seismic resistance level with economical and material losses during scenario earthquake were estimated. The results of calculation are presented in fig.2 and 3.

Analysis of the results shows that the buildings from adobe and adobe bricks would completely collapse, and buildings without antiseismic measures would be seriously damaged. All these systems are situated, mainly, on territory with intensity 9 ball. A high percentage of assembled RC frame buildings (serial 111,IIS-04) would be damaged too. Large panel RC buildings, monolithic buildings, volume blocks and wooden houses would be less damaged. 1-2-storey buildings with wooden frames with adobe filling (synch) would be preserved in repairable state in 8-ball zone. Less damage would be found in brick buildings of complex construction, but they would be damaged due to the low quality of brickwork. More than 12% of damaged buildings are situated in the zone with collateral seismogeological hazards.

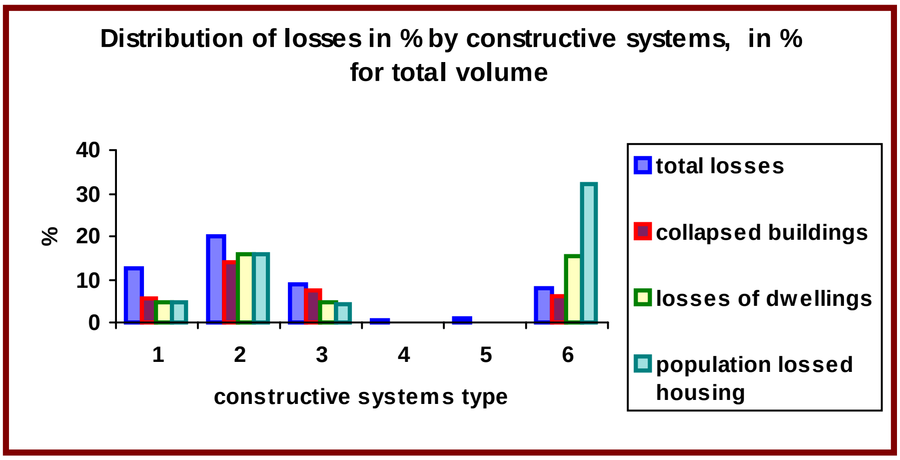


a)before implementation of action plan

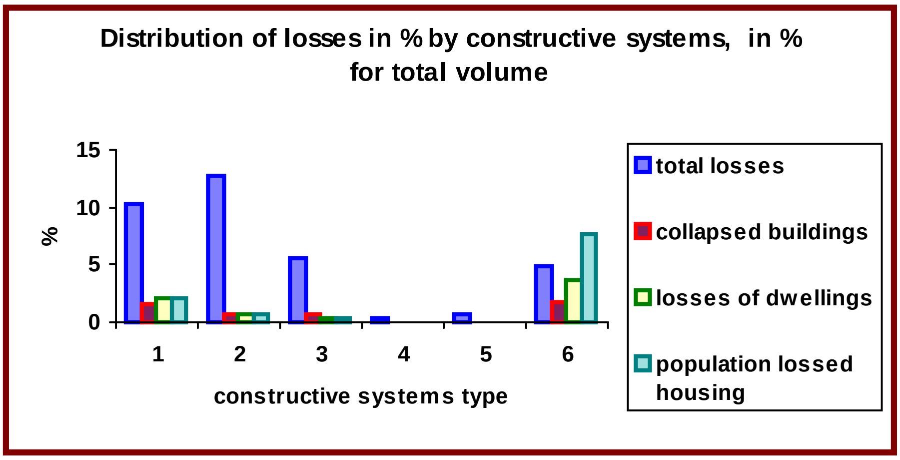


b) after implementation of action plan
Fig.2 Distribution of losses in %

Constructive systems type: 1-large panel, 2-brick, 3-frame panel, 4-monolith, 5-volume block, 6 – other(adobe materials)



a) before implementation of Action plan



b) after implementation of Action plan
Fig.3 Distribution of losses in %

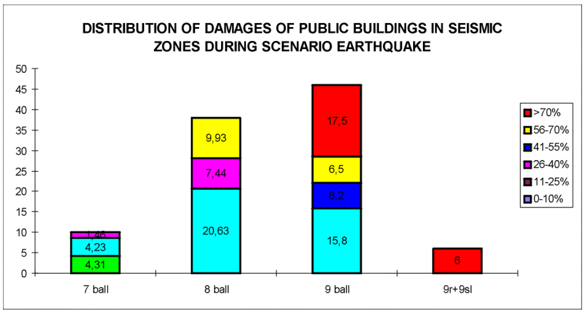
Constructive systems type: 1-large panel,2-brick,3-frame panel,4-monolith,5-volume block, 6 – other(adobe materials)

The total economic losses of residential buildings make up nearly 49% of the value of total dwelling stock cost, including 30% of economic losses from completely collapsed buildings. Nearly 40% of total dwelling stock would be irretrievably lost.

The structure of total economic losses was analysed in terms of housing losses and population left homeless due to building construction type. The analysis showed that majority of the economic losses were constituted by: buildings with brick bearing walls, buildings from local weak materials, brick buildings with wooden ceilings without antiseismic measures, buildings with assembled RC frame from IIS-04 serial and large panel buildings in the zone with soil liquefaction potential. These data may be corrected if to take into account frequency content and repetition period of earthquakes.

Public buildings are divided by functionality and costructive types. By functionality we have distinquished 6 main groups: 1-schools, 2-hospitals, 3-commercial, 4-cultural, 5-high education, polyclinics, administrative buildings, 6 - hotels. By constructive types public buildings are presented mainly by brick, brick with RC (combined) and frame panel buildings. As for the number of floors, 2-5 storey buildings are the majority.

For the losses estimation of public buildings stock we used damageability matrices of different type buildings and graphs of economical losses for different functional type buildings. The analysis showed that economical losses for public buildings constituted more than 40% of public buildings cost, including 24% of completely collapsed buildings[Fig.4].



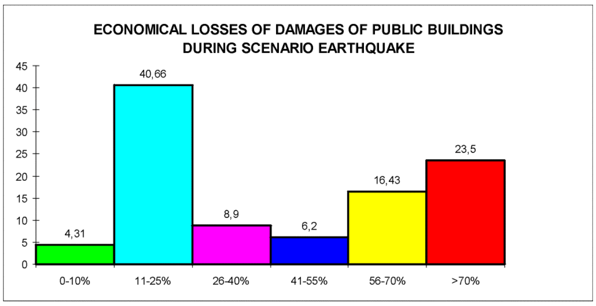


Fig.4 Distribution of damages and economical losses of public buildings during scenario earthquake

ACTION PLANE AND RECOMMENDED MEASURES FOR MITIGATION OF LOSSES FROM SCENARIO EARTHQUAKE

Proposed measures are connected with the preventive actions which should be undertaken for the mitigation of losses during earthquakes of design intensity. A group of minimal measures should provide the required seismic resistance, under which is undertaken the capability of constructive system do not become critical and dangerous for human life. Human life would be safe, if the damage grade do not exceed third grade. This damage grade may be adopted as a criterion of design limit state actually for every constructive type of building. It is not expedient to rehabilitate buildings which are damaged more than 3.5 grade or which have lost 70% of their bearing capacity, because the cost of rehabilitation of such building would exceed the cost of new construction. Taking into account the results of seismic risk assessment, methods of seismic strengthening have been developed for existing buildings from weak local materials, multi-storey brick and frame buildings. Some of the old houses from weak materials should be demolished. For 1 -2 storey buildings from weak local materials simple methods of strengthening have been proposed[Khakimov et al,1988], such as using wooden or metal beams on the level of ceilings, mounting of window and door arches, arrangement of non yielding retaining walls and foundation strengthening. It is recommended that special attention be paid to the strengthening of bedrooms.

The level of seismic strengthening should be adopted in line with the probability parameters of earthquakes and frequency content. Strengthening methods were developed for buildings from local weak materials, buildings of rigid types and frame buildings. For multi-storey brick buildings, constructed before 1958, the recommended strengthening method employs techniques of spatial (3D) compression of external walls by pre-stressed metal elements. Such an approach would provide stability of building and safety for residents, although the building would get serious damage. It is difficult to strengthen frame systems, where necessary to provide safety of non-bearing elements. One of the proposed approaches is the inclusion of rigidity elements, such as bar-mat reinforcement of existing non-bearing walls or new stiffeners. An efficient approach for frame building strengthening may be reinforcement of beam-column joint using volume metal elements. For buildings with flexible first floors, it is necessary to include additional stiffeners. Especially dangerous are buildings, situated in the zone of possible seismogeological effects during an earthquake. For such buildings it is necessary to carry out complex of measures of foundation strengthening or the alternative is demolition of these buildings and evacuation of residents.

For new construction, less vulnerable construction systems are recommended such as frame systems, where welded joints are excluded in the zone of maximal loads or planar wall RC systems (large panel, volume block, monolithic). It is also recommended that multi-storey brick construction with on site brick works should be discontinued. For construction by owners, special regulations should be developed including the recommended simple methods of strengthening of 1-2-storey buildings from weak local materials.

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