Proposed Damage Function for Existing RC Residential Buildings in Almaty, Republic of Kazakhstan

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SUMMARY:
Damage function for existing RC residential buildings in Almaty city, former capital of Republic of Kazakhstan, has been proposed. Since useful structural data was limited, method incorporating seismic evaluation was developed. Seismic index of structure “Is” of a typical structure is estimated and its distribution is supposed. Accumulation of the distribution provides damage function, which shows the relation between the seismic intensity and heavy damage/collapse ratio, which is directly linked to human casualty. Existing RC frame buildings (series VP/VT) and RC buildings with flexible ground floor (soft story) are introduced. Both types of buildings were evaluated as vulnerable against scenario earthquakes. Retrofitting plan to meet present SNiP (building code) has been introduced. It means the change of damage function. The result of a building sampling survey is also introduced. This was done as a part of the Study (ref.1, 2) funded by Japan International Cooperation Agency (JICA).

Keywords: Damage Function, RC Residential Buildings, Seismic Retrofitting, Almaty City

1. GENERAL

Damage function (or vulnerability function) of buildings is utilised to estimate building damages caused by scenario earthquakes in the process of earthquake disaster mitigation plan in urban areas. The ratio of heavy damage/collapse of buildings is estimated related to the ground intensity or the acceleration, and is directly linked to human casualty. But it is often the case, existing structural data is limited to develop reliable damage function for specific structural types in a region or in a country. In this paper, damage function of existing RC residential buildings incorporating seismic evaluation is proposed. At first seismic index of structure “Is” is evaluated from strength index, ductility index and others. Then the relation between the seismic intensity and the “Is” is studied regarding the ratio of heavy damage/collapse, and the accumulation of the supposed distribution of “Is” provides the damage function. This approach is applied for RC multi-story residential buildings in Almaty city (Figure 1)
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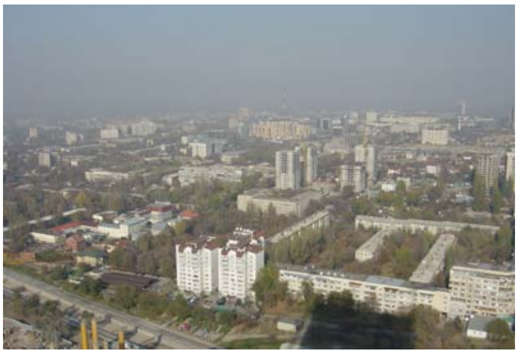


Figure 1. A whole view of Almaty city

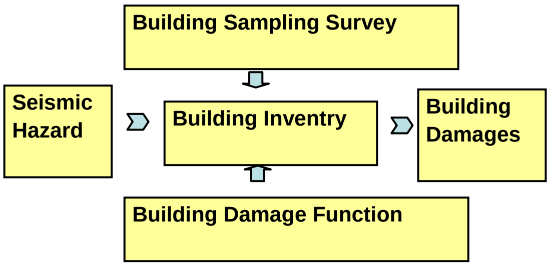


Figure 2. General flow of seismic risk assessment

2. GENERAL FLOW OF SESIMIC DAMAGE ASSESSMENT FOR BUILDINGS

A general flow of seismic damage evaluation for buildings is shown in Figure 2, to show the relation with damage function. Since there was no proper data of each structural type in Almaty city, a building sampling survey was conducted for the classification and the seismic evaluation.

3. BUILDING INVENTORY

3.1 Building sampling survey

A building sampling survey for 320 no. of randomly selected multi-story residential buildings was conducted to get characteristics of building structure. Building structure information sheet called 'Passport' was prepared for this survey. This survey was done by KazNIISSA (Kazakh Scientific Research and Experimental Design Institute of Aseismic Engineering and Architecture) under JICA.
As far as building damage data by earthquakes, there is Lugovskoy earthquake in Kazakhstan in 2003, which caused damages for adobe houses. There is no construction in Almaty for series 111 of RC frames, which suffered heavy damage/collapse in Spitak earthquake in Armenia in 1988. Earthquakes which caused damages in Almaty were Verny in 1887, Chilik in 1889 and Kemin in 1911, caused heavy damages for one and two story brick masonry buildings at that time (ref. 3, 4, 5, 6, 7).

3.2 Building inventory

Following five kinds of data were utilized and were compiled for building inventory data.

1) Building sampling survey for the Study
2) Registered data of the Real Estate Center (constructed year, number of story, wall type)
3) Exiting GIS data of the Rescue Center
4) Building data of GIS database newly developed for the Study
5) Statistical paper of year 2007

There are approximately 8,800 multi-story residential buildings (with 360,000 dwelling units) and 1.2 million people are living there, which is 80% of the whole population of the city.

3.3 Structural type

Outline of structure for each category of multi-story residential buildings based on the result of the sampling survey is shown in Table 1. Popular local name is indicated for the type of structure. Information of individual houses is also included as category 1, 2 and 7 for reference only.

Table 1. Building category for damage estimation

Category	Application		Type of Structure	Typical Number of Story	Constructed Year/(Building Code)
	Multi-story residential	Individual house			
1		○	Adobe	1	all
2		○	Brick/ Block	1~2	all
3	○		Brick with Wooden Floor	2~3	1958 and Before
4	○		Building with Flexible Gground Floor	4~9	all
5	○		Brick with Concrete Floor (308)	3~4	1959 and After
6	○		RC Frame (VP/VT) 1988 and Before	5~9	1998 and Before (Old SNiP)
7	○	○	Wooden	1~2	all
8	○		RC Frame/Monolithic 1999 and After	all	1999 and After (New SNiP)
9	○		Large Panel (464-AS, DS, 158)	4~9	all

Note:
1) 'Large panel' means wall type pre-cast RC structure.
2) 'RC frame (VP/VT)' means moment resisting frame with pre-cast beams and cast-in-situ columns, series VP/VT.
3) 'RC Monolithic' means RC cast-in-situ structure, which has been constructed after the Spitak earthquake 1988.
4) 'SNiP' means Building Code.

3.4 External view of each structural type

Typical external view of each structural type for multi-story residential buildings based on the sampling survey is shown in Figure 3. The ratio of each structural type is shown in Figure 4.




〔3〕 Brick masonry with wooden floor 〔5〕 Brick masonry with con. Floor, series 308

〔4〕Flexible ground floor、frame type & large panel type




〔6〕 RC frame, series VT 〔6〕 RC (Individual design) 〔7〕 Wooden 〔8〕 RC frame/ monolithic


〔9〕 Large panel, 464-DS 〔9〕 Large panel, 158

Figure 3. External view of multi-story residential buildings

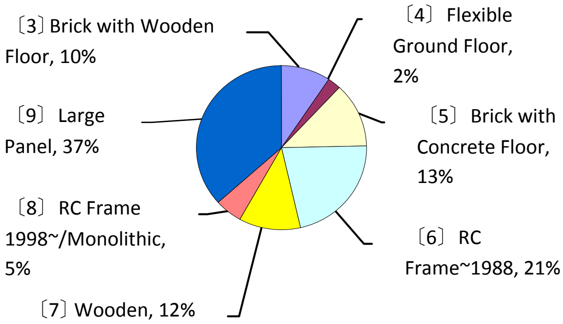


Figure 4. Ratio of each structural type for multi-story residential buildings

3.5 Structural type of buildings and constructed year

Structural type and constructed year based on the result of the building sampling survey and number of constructed buildings per year based on the statistical data by the Real Estate Center is shown in Figure 5. Most of multi-storey residential buildings were constructed after the Second World War till the collapse of former Soviet Union.

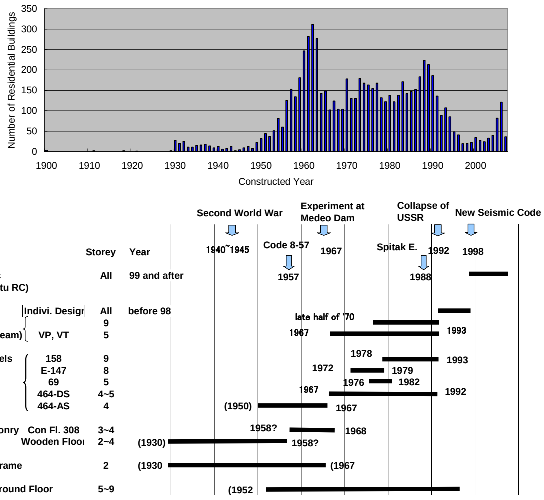


Figure 5. Building type and constructed year

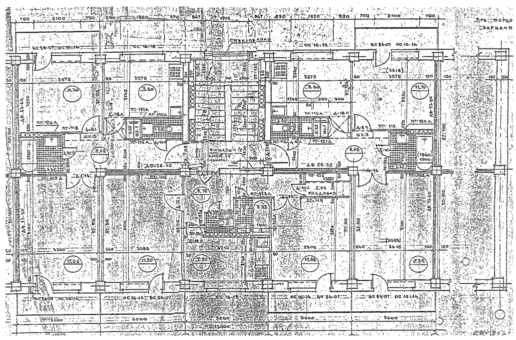


Figure 6. Typical floor plan of series VT

4. SEISMIC EVALUATION OF TYPICAL BUILDINGS

To develop damage function of each structural type, seismic evaluation was applied for typical buildings based on the Japanese Standard (ref. 8), and results are shown as follows.

4.1 RC resisting frame structure (series VT) designed by old SNiP (Building Code)

Typical floor plan of series VT is shown in Figure 6. Construction work including joint of pre-cast beams and cast-in-situ columns is shown in Figure 7. Floor slabs are pre-cast void slabs and are not connected with beams, and evaluation considering beam collapse mode was applied, as shown in Figure 8.

a) Overview b) Beam and column joint

Figure 7. Construction work of series VT (courtesy of KazNIISSA)

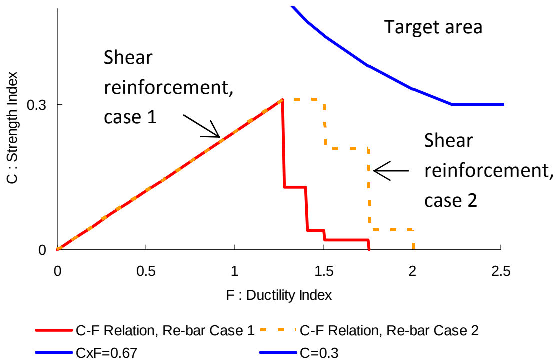


Figure 8. Strength index C and Ductility index F

4.2 Large Panel

1) Series 464-DS

Typical floor plan of a five story, series 464-DS, is shown in Figure 9. Concrete is B25 (275kg/cm^2, cube). Wall thickness is 10cm and wall ratio (numerical value of total length of wall (mm) divided by floor area (m^2)) is 160mm/m^2. Shear reinforcement ratio is 0.13% (weld mesh 5mm@150).
Strength index C is estimated as 0.55~0.61, excluding the contribution of orthogonal walls. Ductility Index F is assumed as 1.0. S_D (Irregularity index) is 1.0. T (Time index) is 0.9. Then, "Is" is estimated as 0.50~0.55.

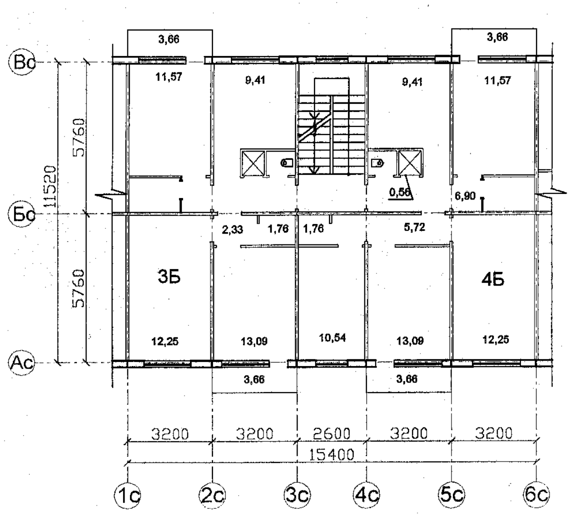


Figure 9. Typical floor plan of series 464-DS

b) Joint of wall panels

a)Wall panels

Figure 10. Series 158 under construction (Ref. 9)

2) Series 158

Large panel series 158 is used for 9 story residential buildings. Wall ratio is almost same to that of series 464-DS and was estimated that series 158 has similar seismic capacity to that of 464-DS. Building of series 158 under construction is shown in Figure 10. Large panel 464 and 158 suffered slight damage only at the Spitak earthquake in 1988 (ref. 2, 3).

4.3 Buildings with flexible ground floor

Residential building with flexible ground floor of large panel type was evaluated. Framing elevation consisting of RC frame at ground floor, and large panel at 1st floor and above is shown in Figure 11. Seismic index of structure, "Is" at ground floor was estimated as shown in Figure 12.

$$Eo = C \times F = 0.37 \times 1.5\ (\text{hoop}\varphi 6@100) = 0.56$$
$$0.37 \times 2.25(\text{hoop}\varphi 8@100) = 0.83$$
$$Is = Eo \times S_D \times T = 0.56\ (\sim 83) \times 0.48 \times 0.9 = 0.24 \sim 0.36$$

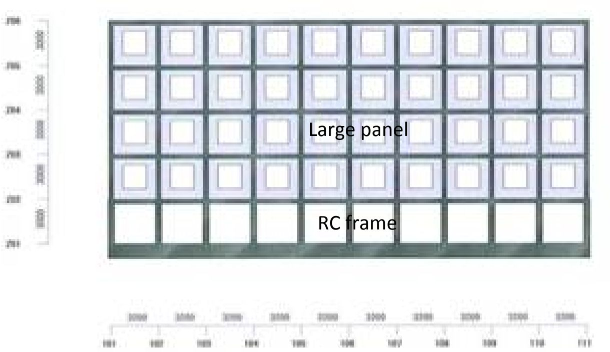


Figure 11. Framing elevation of 'flexible ground floor'

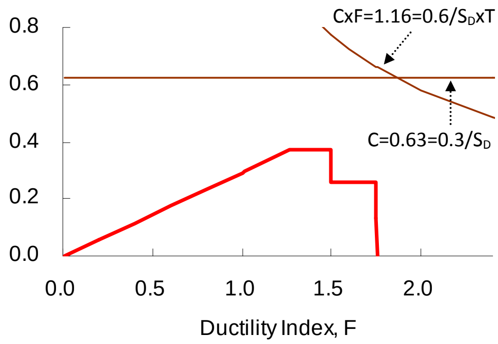


Figure 12. Strength index and Ductility index at ground floor

4.4 Brick masonry, series 308

Typical floor plan of a four story of series 308 is shown in Figure 13. Perimeter wall thickness is 51cm, and internal wall is 25cm. Design strength of mortar is 50kg/cm^2.

Seismic evaluation assuming shear strength of brick walls was done. The ductility index of 1.0 is supposed, and equivalent seismic index of structure, "Is" was estimated as 0.31 (longitudinal direction) and 0.34 (transverse direction) respectively.

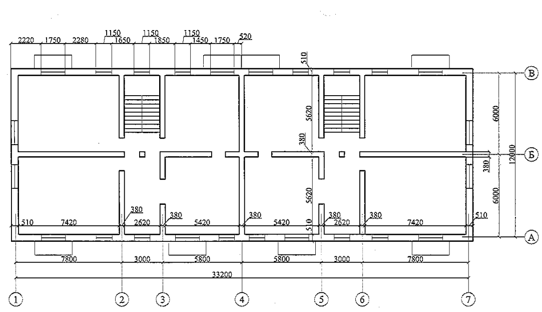


Figure 13. Plan of brick masonry series 308

a)Exciting machine located at roof

b) External view c) Internal view

Figure 14. Vibration test of brick masonry series 308 (tested by KazNIISSA)

A vibration test for a three story of series 308 was executed by KazNIISSA on 12 March 2008 as shown in Figure 14. An exciting machine installed for longitudinal direction on the roof level and co-vibration was caused. Test results such as natural period, acceleration record have not been opened but equivalent load of seismic intensity MSK-64(K) 8 was provided.

Heavily damages such as a fall of lintel, internal stairs, internal partition, and shear failure of walls, were observed, but a fall of external walls and floors were not observed.

5. DAMAGE FUNCTION

5.1 Development of damage Function

Following method was proposed for the damage function. The distribution of seismic index of structure "Is" for multi-storey residential buildings was supposed as shown in Figure 15. The distribution of typical buildings was supposed as a normal distribution by an engineering judgment. As far as low quality at site works, there is no concrete data, but relatively big standard deviation was provided for series VP/VT (category 6) and others.

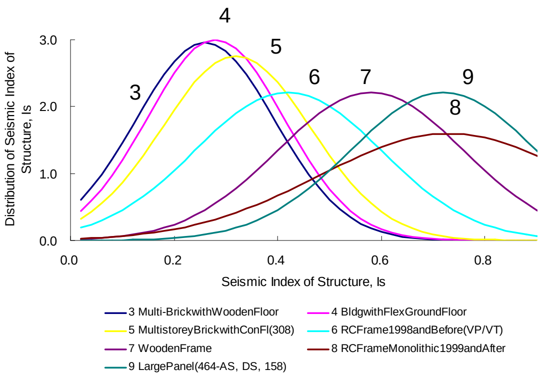


Figure 15. Assumed distribution of Seismic Index of Structure, "Is"

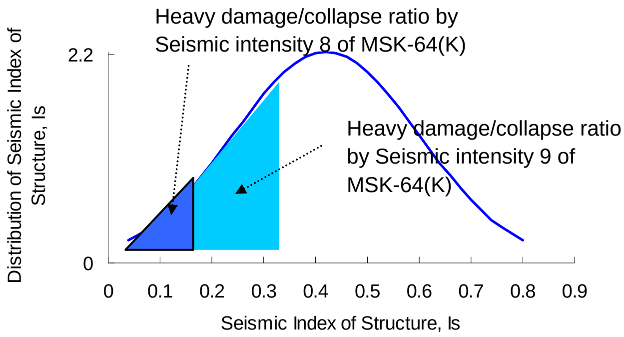


Figure 16. Seismic index of structure and assumed damaged ratio

It was assumed that the range of seismic index of structure which suffers heavily damage/collapse is proportional to the size of seismic intensity, and was decided by an empirical study for the relation between Seismic index of structure "Is" and damaged ratio as shown in Figure 16.
Heavily damaged ratio of buildings is expressed by the ratio of grade 4 (very heavy damage) and grade 5 (destruction) of EMS-98 as shown in Figure 17. Similar expression is shown in SNiP (Building Code) as MSK-64(K).

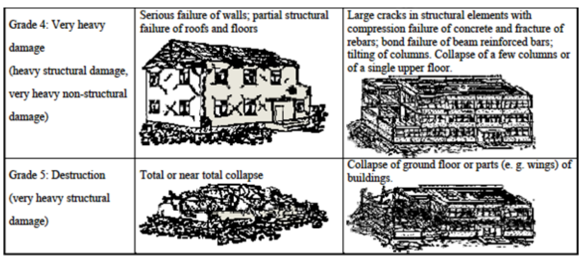


Figure 17. Building damage category by EMS-98 (MSK-64(K))

Table 2. Relationship between seismic intensity and acceleration specified in SNiP 2.03-28-2004

MSK-64(K) Seismic Intensity	Acceleration (gal, cm/sec^2)		
	Lower Boundary	Average	Upper Boundary
5	16	25	35
6	35	55	80
7	80	120	180
8	180	270	400
9	400	600	900
10	900	--	--

Relationship between seismic intensity and acceleration is specified in SNiP as shown in Table 2. Accumulation function of a normal distribution function is used as damage function. As a result, building damage function (vulnerability function) is shown in Figure 18. No.3 to No.9 are functions for multi-story residential buildings. No.1 and 2 are functions for individual houses for information.

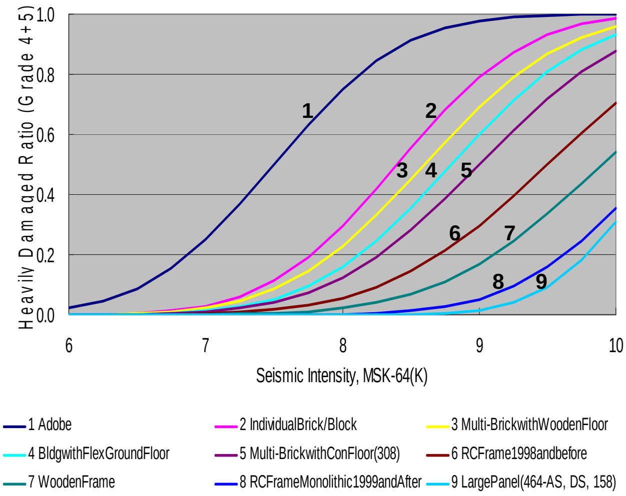
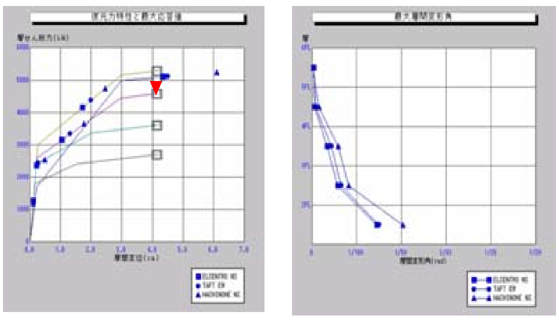


Figure 18. Proposed building damage function

5.2 Supplemental study by time history analysis

As far as "flexible ground floor of frame type", which is frame with non-structural brick walls at 1st story and above, time history analysis was executed to verify, since the evaluation incorporating non-structural walls is not covered by an conventional method. Tri-linear model was applied through the push over analysis. Stiffness and strength at 1st floor and above was assumed 2 times and 1.2 times of those of RC frames only respectively incorporating the influence of brick walls. Possible ductility was estimated by the seismic evaluation of frames for two types of hoops of columns. Three earthquake waves (El Centro NS, Taft EW, Hachinohe NS) were applied. The result is indicated in Figure 19. Estimation of damage ratio against different seismic intensity is shown in Figure 20.



a)Story shear force and story deflection

b)Story deflection angle

Figure 19. Result of time history analysis for "flexible ground floor of frame type"

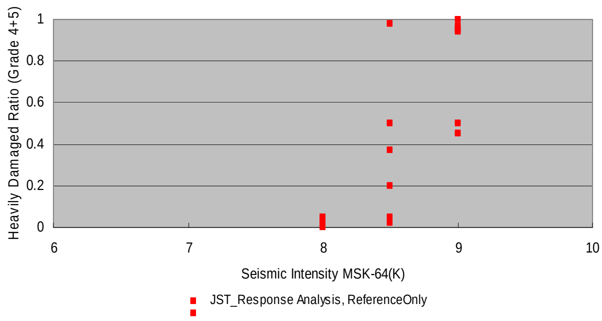


Figure 20. Estimated damage ratio and seismic intensity by time history analysis

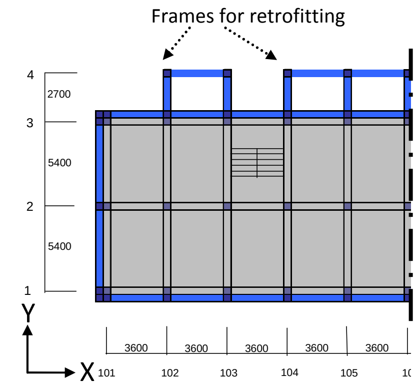
7. RETROFITTING PLAN

7.1 Series VP/VT

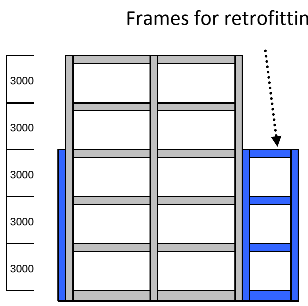
A plan of retrofitting is shown in Figure 21 for buildings of series VT (Series VP is slightly bigger than series VT in sizes of plan), which are one of vulnerable structural types, by providing external RC frames for both longitudinal and transverse direction.

This is a typical structure of RC frame buildings constructed before 1998. There are approximately 1,880 buildings and 91,400 dwelling units. Target of retrofitting is to satisfy present seismic design load equivalent to seismic intensity 9 of MSK-64(K).

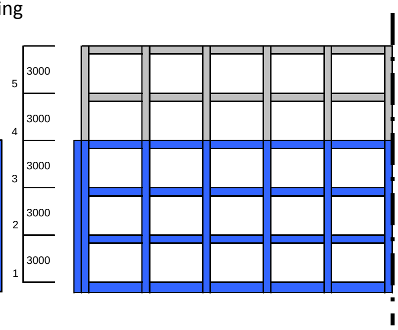
This retrofitting plan is prepared based on the structural design information by hearing, and it will be required to execute detail site survey for construction quality including cast-in-situ portion.



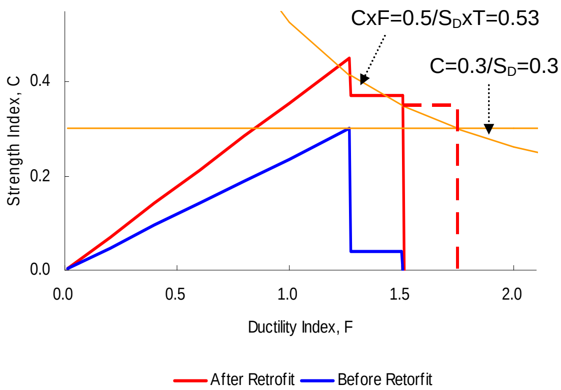
a)Floor Framing Plan



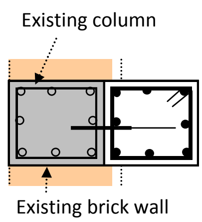
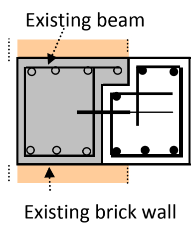
b) Grid 102~110 Elevation



c) Grid 1 Elevation



d) C-F Relation at ground floor

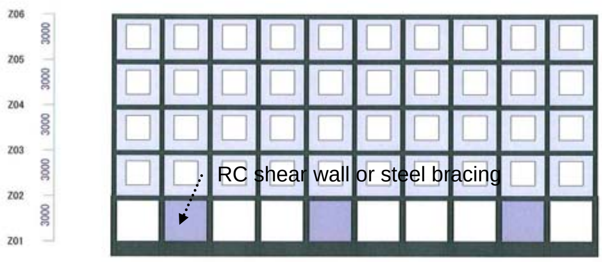
	Typical Column	Typical Beam
Section		
Sizes	BxD=40cmx40cm	BxD=35cmx50cm
Re-bars	Main : 8-D25	Main : 3-D29+3-D29
	Hoop: D10 @100mm	Stirrup: D10 @200mm
Anchor	D16 @200mm	D16 @200mm
Location	Typical at Perimeter and Grid 4	Typical Beams at Perimeter

e) Member list

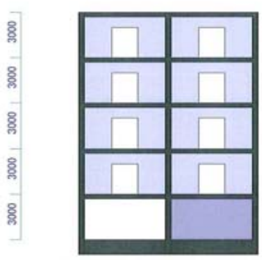
Figure 21. Retrofitting plan for series VT

7.2 Buildings with flexible ground floor

There are approximately 210 buildings and 8,000 dwelling units for buildings with flexible ground floor (soft story). It is requested to provide RC shear walls (case 1) or steel bracings (case 2) for both directions as shown in Figure 22.

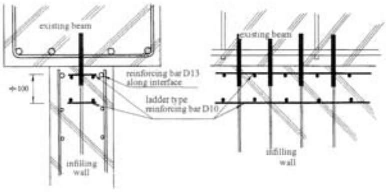


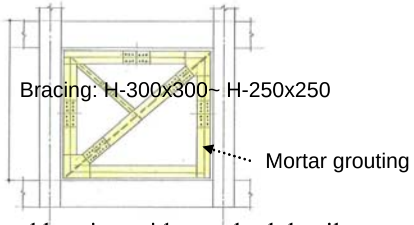
a)Framing elevation (1)



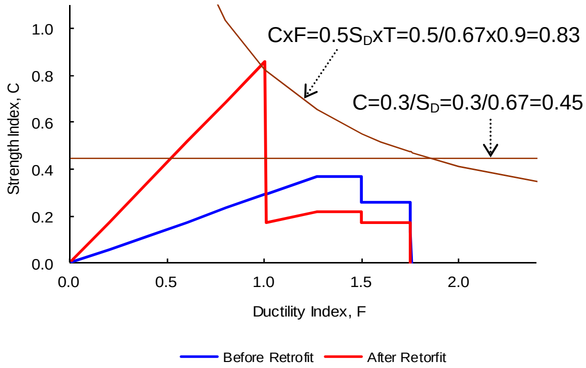
b) Framing elevation (2)

c) External view


Case 1) Reinforced concrete wall, typical detail by Japanese Standard



Case 2) Steel bracing with standard detail
d) Detail of retrofitting



e) C-F relation at ground floor

Figure 22. Retrofitting plan of "Flexible ground floor"

8. CONCLUSION

1) Damage function of existing RC buildings in Almaty, incorporating seismic evaluation was introduced. This proposed method will be useful in case that existing RC buildings do not have any seismic performance data at ultimate state or past earthquake damage data.
2) Seismic retrofitting plan for vulnerable structural types, such as series VP/VT and "flexible ground floor" is introduced. There are approximately 2,090 buildings and 99,400 dwelling units for these types. Category 6 and 4 for these types of damage function will be changed to category 8 by the proposed retrofitting.
3) It will be required to investigate further and to get data in order to develop suitable distribution of Seismic index of structure "Is", and to develop damage function incorporating the degree of construction quality, natural period of buildings and type of grounds.

ACKNOWLEDGEMENT
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REFERENCES

1) Japan International Cooperation Agency (JICA), (2009), "*The Study on Earthquake Disaster Risk Management for Almaty City in the Republic of Kazakhstan*", Japan.
2) Inoue A. Segawa S. (2011), "*Seismic Vulnerability of Multi-story Residential Buildings and Risk map of Almaty City, Republic of Kazakhstan*", Proceeding of Disaster Simulation and Safety 2011, Japan.
3) EERI, (1989), "*Armenia Earthquake Reconnaissance Report EERI"*, Earthquake Spectra, USA.
4) Building Center of Japan (1990), "*Learnings from Damages caused by Armenian Spitak Earthquake* (in Japanese)" , Japan.
5) Stephanie A. King, Vitaly I. Khalturin and Brian E. Tucker, (1996), "*Seismic Hazard and Building Vulnerability in Post-Soviet Central Asian Republics*", NATO.
6) UNDP, (2005), "*Local Risk-Management in Earthquake Zone of Kazakhstan*", Kazakhstan.
7) Ministry of Education and Science of Republic of Kazakhstan, UNDP, (2004) "*Lessons from Lugovskoy Earthquake in 23 May 2003 in Kazakhstan*", Kazakhstan.
8) The Japan Building Disaster Prevention Association, (2001), "*Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings (English Version 2001)*", Japan.
9) Ashimbaev M. "*Prefabricated Large Panel Concrete Buildings with Two Interior Longitudinal Walls*", Housing Report No.32, World Housing Encyclopedia.