SEISMIC EVALUATION AND RETROFIT PLAN OF EXISTING REINFORCED CONCRETE BUILDINGS OF ALGIERS IN ALGERIA

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ABSTRACT :

SEIMIC EVALUATION AND RETROFIT PLAN BY THE JAPANESE STANDARD FOR THREE EXISTING REINFORCED CONCRETE BUILDINGS (AN APARTMENT HOUSE, A SCHOOL AND A HOSPITAL) OF ALGIES, THE CAPITAL OF ALGERIA, WERE INTRODUCED. THESE BUILDINGS HAD BEEN DESIGNED BASED ON OLDER DESIGN STANDARD. SEISMIC RETROFIT IS A USEFUL MEASURE TO MITIGATE EARTHQUKA DAMAGES. SEISMIC JUDGMENT WAS DONE BY THE COMPARISON OF SEISMIC INDEX OF STRUCTURE, *Is*, AND SEISMIC DEMAND INDEX OF STRUCTURE, *Iso*, WHICH WAS ADJUSTED BASED ON EXPECTED SEISMIC INTENSITY OF ALGIERS. THE VULNERABILITY OF THREE BUILDINGS WAS CLARIFIED THROUGH THE ESTIMATION OF STRENGTH INDEX, *C*, AND DUCTILITY INDEX, *F*, WITH RESPECT TO STRUCTURAL PLAN AND DESIGN. THE IMPROVEMENT OF SEISMIC PERFORMANCE AFTER THE RETROFIT PLAN WAS INTRODUCED. THEN SEISMIC INDEX OF STRUCTURE, *Is*, WAS EVALUATED FOR COLLAPSED APARTMENT HOUSES BY THE 2003 BOUMERDES EARTHQUAKE TO COMPARE WITH THE SEISMIC INTENSITY. THE RESULTS WILL BE USEFUL IN OTHER SEIMIC COUNTRIES TO DEVELOP SEISMIC RETROFIT PLAN AND DESIGN OF EXISTING OLDER REINFORCED CONCRETE BUILDINGS FOR THE EARTHQUAKE RISK REDUCTION.

KEYWORDS: SEIMIC EVALUATION, RETROFIT, REINFORCED CONCRETE, ALGIERS, DUCTILITY INDEX, SEISMIC INDEX OF STRUCTURE

1. GENERAL

Seismic evaluation and retrofit plan by the Japanese Standard for three existing reinforced concrete buildings (an apartment house, a school and a hospital) of Algiers, the capital of Algeria, were introduced. Algeria is a seismic country, and the Boumerdes earthquake in 2003 caused more than 2,200 deaths and 19,000 building collapse. Seismic evaluation and retrofit of existing buildings are useful measures to mitigate earthquake damages. Approximately 65% of existing buildings are reinforced concrete buildings in Algiers, which has the population of 1.5 million. Many of those are reinforced concrete moment frame structures designed by older seismic design standard (reference 1).
Seismic judgment is done by the comparison of Seismic Index of Structure, *Is*, and Seismic Demand Index of Structure, *Iso*, which is adjusted based on expected seismic intensity of Algiers. Seismic performance of three buildings was not satisfactory as a result. The vulnerability of three buildings was clarified with respect to structural plan and design through the evaluation of Ductility Index, *F*, Strength Index, *C*, and Seismic Index of Structure, *Is*. The improvement of seismic performance expressed by above Indices, after proposed retrofit, was introduced quantitatively.
In addition, the Seismic Index of Structure, *Is*, of collapsed buildings by the 2003 Boumerdes earthquake was also introduced based on the concrete strength by the core sampling.

2 SEIMIC EVALUAION AND RETROFIT PLAN OF EXISTING BUILDINGS

2.1 Methodology

There are three levels of seismic screening procedures in the Japanese Standard of reference 2. The first level seismic screening is simple and the result is on the safe side. The second level screening is performed based on column collapse mode. The third level screening is performed including beam collapse mode, but calculation volume increases. Column collapse mode will be dominant for buildings in Algiers as shown in Appendix 3. As a result, the second level seismic screening procedure was applied for the evaluation.

2.1.1 Seismic Evaluation
Related equations for the seismic evaluation are shown in Appendix 1 for information, and key equations are as follows.
Seismic Index of Structure, *Is*,

$$Is = EoS_DT \tag{1}$$

whrere; Eo : Basic Seismic Index of Structure, S_D : Irregularity Index, *T* : Time Index,
Eo is expressed by the product of Strength Index, *C*, and Ductility Index, *F.*

Seismic Demand Index of Structure, *Iso,*

$$Iso=EsZGU \tag{38}$$

where; Es : Basic Seismic Demand Index of Structure, *Z* : Zone Index, *G*: Ground Index, *U*: Usage Index, The *EsZ* with the range of 0.5 to 0.6 will be suggested to apply instead of 0.6, which is used in Japan, based on the estimated seismic intensity of Algiers as shown in Appendix 2. The value of 0.5 was used for the judge of three buildings.

2.2. A Five Storey Apartment House

2.2.1. General
This building is a typical apartment house of reinforced concrete moment frame with cast-in- place concrete, and was designed based on "The Algerian Paraseismic Regulations RPA 88". Typical column sizes are 35cmx35cm, and 30cmx30cm at the 1st storey. Concrete strength by the core sampling was 27.5 N/mm^2. Hoops are ϕ 8mm@100mm. All walls are hollow brick works. The Seismic Index of Structure, *Is*, was 0.40, and C_TS_D was 0.18 and were not satisfactory. It is noted that columns were evaluated as flexural columns but the ductility index of columns was low because of the high axial force ratio at the 1st storey.

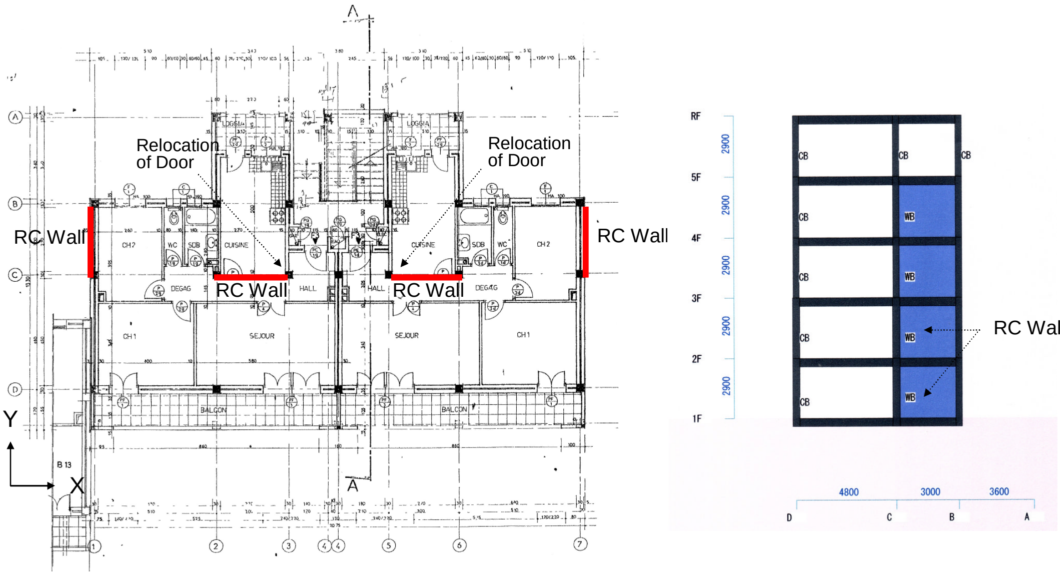


Figure 1 Framing Plan (Left) and Framing Elevation of Grid 1 & 7 (Right) for Retrofit

Table 1 Seismic Index of Structure, *Is*, and $C_T S_D$ before and after Retrofit

Storey	After Retrofit				Before Retrofit	
	X direction		Y direction		X, Y direction	
	Is	$C_T S_D$	Is	$C_T S_D$	Is	$C_T S_D$
5	0.82	0.26	0.82	0.26	1.02	0.32
4	0.78	0.40	0.71	0.36	0.60	0.19
3	0.58	0.34	0.59	0.30	0.47	0.16
2	0.59	0.30	0.54	0.27	0.53	0.18
1	0.51	0.26	0.52	0.26	0.40	0.18

S_D; 0.76 (5th storey), 0.95 (1st to 4th storey after retrofit), 0.95 (all stories before retrofit)
T; 0.975 was used

2.2.2.A Plan and Basic Design for Retrofit

The method that providing RC walls for the 1st storey to the 4th storey was planned to increase strength, as shown in Figure 1. These were evaluated as flexural walls with the ductility index of 2.0. The value of *Is* of the 1st, 2nd, 3rd and 4th storey were increased to more than 0.50 as shown in Table 1. The relationship of the ductility index and the strength index at the 1st storey is shown in Figure 2. Typical detail for retrofit of reinforced concrete wall is shown in Figure 3.

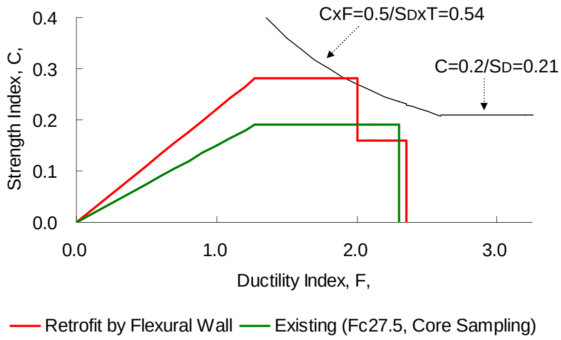


Figure 2 Ductility Index and Strength Index Relation

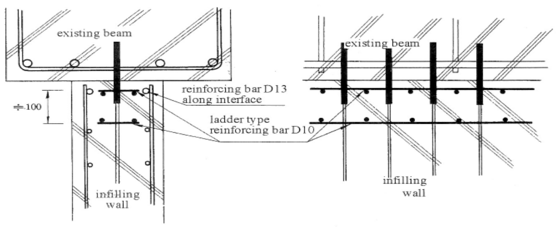


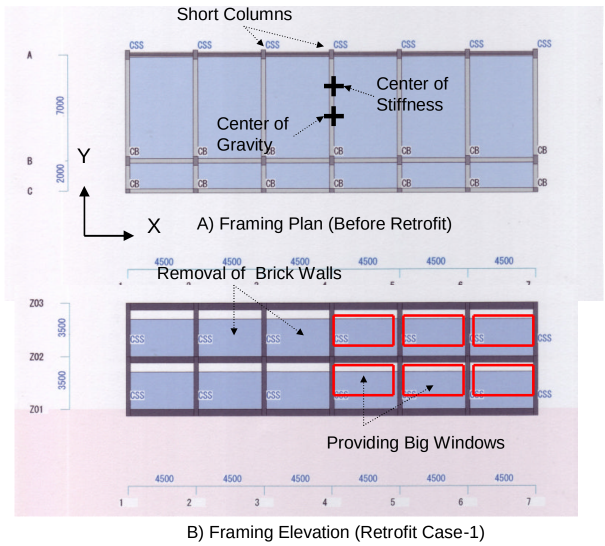
Figure 3 Typical Detail of Reinforced Concrete Wall
(Figure3.1.4 of Reference 2)

2.3. A Two Storey School

2.3.1 General

This building is a typical school of reinforced concrete moment frame, and was designed based on RPA88. It was supposed that columns were short columns due to solid brick walls at the Grid A in the X direction. The value of *Is* in the X direction was low before retrofit, because of the extremely brittle columns and the eccentricity caused by the brick walls as shown A) of Figure 4. Refer to Figure A2 of Appendix 3 for shear failure of short columns for reference. Typical column sizes are 60cmx30cm and 30cmx30cm. Hoops are ϕ 8mm@100mm at top and bottom. The value of *Is* before retrofit in the X direction of the 1st storey is as follows.

$Is=EoS_DT=0.34x0.80x0.95=0.26 < 0.5$



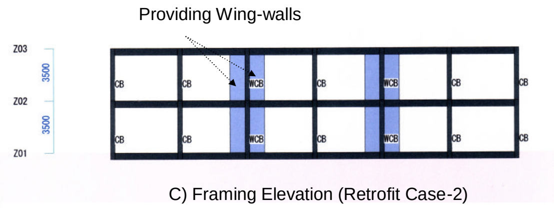


Figure 4 Framing Plan (A) and Elevation (B, C)

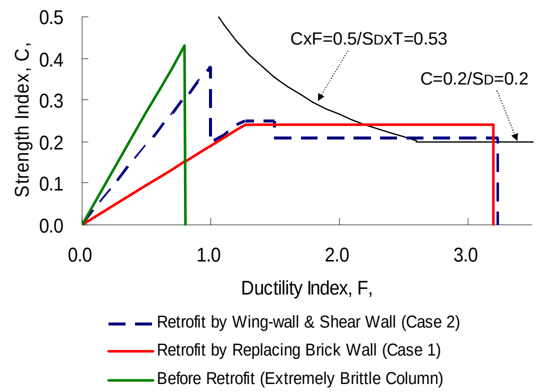


Figure 5 Ductility Index and Strength Index Relation

2.3.2. A Plan and Basic Design for Retrofit

Two cases for the retrofit were considered as shown below.

Case 1; Retrofit by replacing brick walls and windows at grid A

Columns at grid A are modified from extremely brittle columns to flexural columns by replacing the walls and windows as shown B) of Figure 4. Another method is to provide slits at walls, but the reinforcement of the walls against out of plane overturning will be required. The value of *Is* after retrofit at X direction of 1st storey is as follows.

$Is=EoS_DT=0.67x1.0x0.95=0.64 > 0.5$

Case 2; Retrofit by providing shear walls and wing-walls, and without extremely brittle columns

Columns with wing-walls as shown in C) of Figure 4, were estimated as flexural columns with the ductility index of 1.5. The ductility index and the strength index relation for both cases in the X-direction of the 1st storey before and after retrofit is shown in Figure 5.

2.4 A Three Storey Hospital

2.4.1.General

This hospital is a reinforced concrete moment frame structure, and was designed based on RPA83. This hospital has been nominated as an essential building, and Usage Index of 1.5 was applied. Following Seismic Demand Index *Iso* will be suggested.

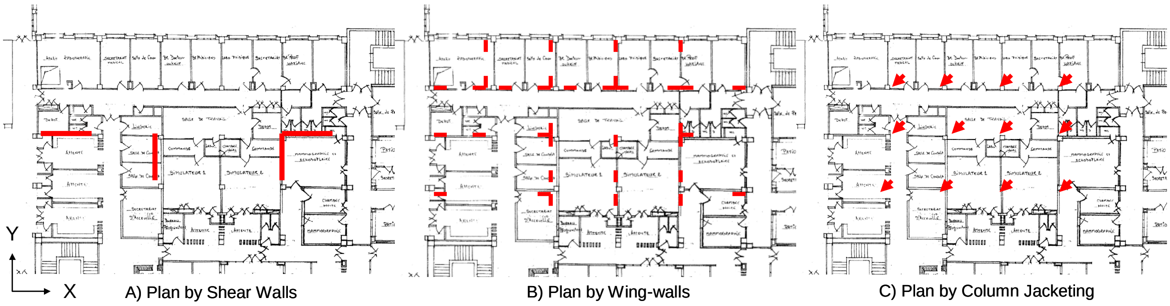
$Iso = 0.50x1.5=0.75$, C_TS_D: 0.20 x 1.5 = 0.30

Column sizes were 50cmx50cm. Design concrete strength was 27N/mm^2. Hoops were ϕ 10mm@100mm. Horizontal strength at the 1st storey only was requested to increase for both directions as shown in Table 2.

Table 2 Seismic Index of Structure, *Is*, and $C_T S_D$ before Retrofit

Storey	Y direction								X direction	
	C	F	n+1/n+i	Eo	S_D	T	Is	$C_T S_D$	Is	$C_T S_D$
3	0.76	3.2	0.67	1.61	1.11	0.95	1.72	0.84	1.74	0.85
2	0.42	3.2	0.80	1.07	1.11	0.95	1.13	0.46	1.15	0.47
1	0.24	3.2	1.00	0.76	1.00	0.95	0.72	0.24	0.72	0.24

S_D 1.11 (3rd and 2nd storey), 1.0 (1st storey), T: Time Index (0.95 is used)
S_D: Irregularity Index (Expansion Joint, x 0.95, Storey Height Uniformity, x 0.975,
Underground Storey, x 1.20, Stiffness/mass Ratio, x 1.0 (3rd &2nd Storey), 0.9 (1st Storey)),



A) Plan by Shear Walls B) Plan by Wing-walls C) Plan by Column Jacketing

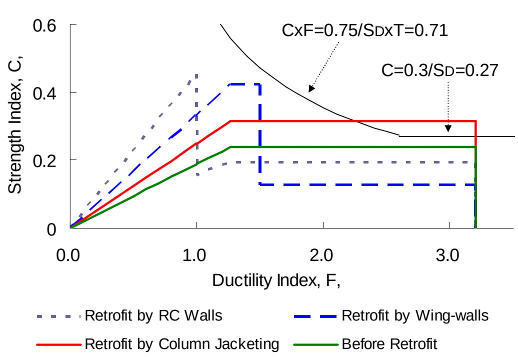
Figure 6 Retrofit Plans for 3 Cases of A, B and C

2.4.2. A Plan and Basic Design for the Retrofit

A plan and basic design of following 3 cases for the retrofit at the 1st storey was considered.

Case 1; Retrofit by providing shear walls
Case 2; Retrofit by providing wing-walls
Case 3; Retrofit by providing jackets for the internal columns only.

The value of *Is* for Case 1 was decreased because of the shear walls with the ductility index of 1.0. The value of *Is* for Case 2 was decreased because of the columns with wing-walls with the ductility index of 1.5. The value of *Is* for Case 3 was increased to 1.06 with maintaining the original ductility index. $C_T S_D$ was increased to 0.35. The value of S_D has increased from 1.0 to 1.1 due to the stiffness increase for Case 3. The relationship of the strength index and the ductility index in the X direction of the 1st storey before and after the retrofit is shown for 3 Cases in Figure 7. The standard detail for the column jacketing is shown in Figure 8.



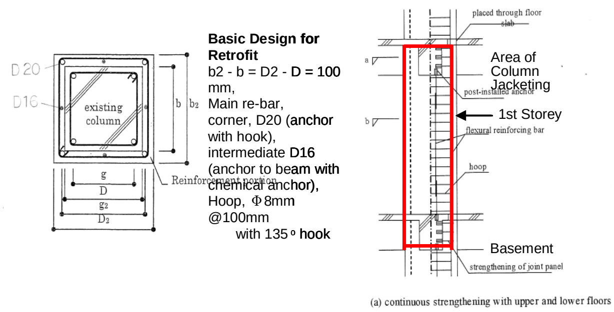


Figure 7 Ductility Index and Strength Index Relation

Figure 8 Standard Detail of Column Jacketing (Figure3.3.4-2 and 3.1-4 of Reference 2)

3. APARTMENT HOUSES HEAVILY DAMAGED BY 2003 BOUMERDES EARTHQUAKE

3.1. General

Seismic evaluation was done to assess the vulnerability of a five storey apartment house, which was typical of those that suffered heavy damage or collapsed in the 2003 Boumerdes earthquake. The effect of low strength concrete on the seismic index of structure was assessed. Concrete strength of 25N/mm2 was the required construction standard, and concrete strengths in the range of 14 N/mm^2 to 17 N/mm^2 were reported by CGS as a result of core sampling of collapsed apartment houses.

A reinforced concrete frame structure with 4 span x 2 span x 5 storey building was evaluated. Member sizes and reinforcements were estimated based on the report of CGS and information by a project manager engaged in rebuilding apartment houses in Boumerdes. A framing plan is shown in Figure 9.

3.2. Unit weight and Column Section

Supposed unit weight of buildings is as follows,

Roof; 10 kN/m^2, Typical Floor, 13 kN/m^2, Balcony, 6.5 kN/m^2

Column section at 1st storey; 30cmx30cm. Main bar; 8-D16. Hoop; 8mm@150mm.

3.3. Results of the Seismic Evaluation

The seismic index of structure, *Is*, at the 1st storey with different concrete strength is shown in Figure 10.

a) The value of *Is* with standard strength concrete was 0.25 or more.

b) The value of *Is* with low strength concrete was in the range of 0.13 to 0.15. This was caused by the combination of the low strength index, and the low ductility index subject to the high axial force ratio of the columns.

c) It can be said that apartment houses with the value of *Is* not more than 0.15 were collapsed by the 2003 Boumerdes earthquake, and the seismic intensity by EMS-98 was 8 and more at the areas of these collapsed buildings in Algiers and Boumerdes.

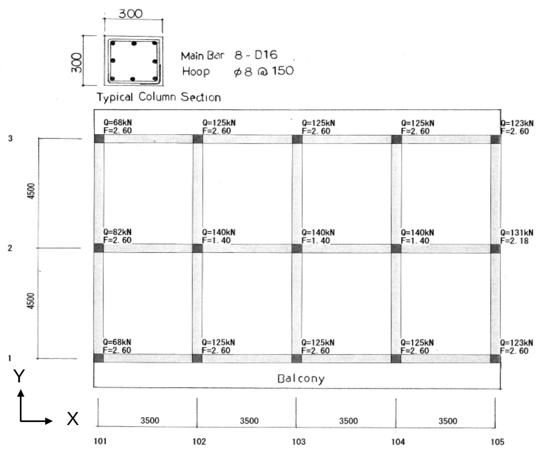


Figure 9 Framing Plan

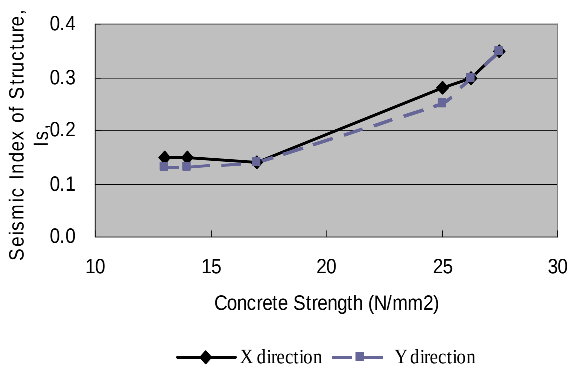


Figure 10 Concrete Strength and Seismic Index of Structure

4. CONCLUSIONS

(A) Seismic evaluation and retrofit plan was introduced for three existing RC buildings of Algiers. Providing RC walls, wing-walls, and column jacketing were proposed for the retrofit. It is important to evaluate quantitatively the strength and the ductility of a building for the seismic evaluation. It is necessary to consider the retrofit by means of strength upgrading or ductility upgrading based on characteristics of a building. Cost estimate that is not shown in this paper will also be required to judge retrofit, or demolish and new construction.

(B) Basic Seismic Demand Index x Zone Index in the range of 0.5 to 0.6 was suggested based on the expected seismic intensity in Algiers and to coordinate with the present seismic design code RPA99 ver.2003. The value of 0.5 was used for the judge of seismic safety for the three buildings. These values will be adjusted based on further investigation.
(C) It can be said that reinforced concrete buildings with the value of *Is* not more than 0.15 will be collapsed by an earthquake with the seismic intensity of 8 and more of EMS-98 through the seismic evaluation of collapsed apartment houses by the 2003 Boumerdes earthquake.
(D) Other option not introduced in this paper for the retrofit such as proving steel members is also worth studying.

ACKNOWLEDGEMENT

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APPENDIX

Appendix 1: Equations of the Seismic Evaluation by the Japanese Standard (Reference 2)

Seismic Index of Structure,

$$Is = EoS_DT \quad (1)$$

whrere; Eo : Basic Seismic Index of Structure, S_D : Irregularity Index, *T* : Time Index
Eo as the larger one from eqs (4) and (5).
Eo of ductility-dominant Structure,

$$Eo = (n+1)/(n+i) \mathrm{x} \sqrt{(C_1F_1)^2+(C_2F_2)^2+(C_3F_3)^2} \quad (4)$$

Eo of strength-dominant Structure,

$$Eo = (n+1)/(n+i) \mathrm{x} (C_1+\Sigma\alpha_j C_j)F_1 \quad (5)$$

wrere; C: Strength Index, *F*: Ductility Index, $(n+1)/(n+i)$: Storey-shear modification factor, α : Effective strength factor

$$C = Qu / \Sigma W \quad (12)$$

where; Qu :Ultimate lateral load-carrying capacity of the vertical members in the storey concerned, ΣW :Total weight supported by the storey concerned
Seismic Judgment

$$Is \geqq Iso \quad (37)$$

Iso : Seismic Demand Index of Structure

$$Iso=EsZGU \quad (38)$$

where; Es : Basic Seismic Demand Index of Structure, *Z* : Zone Index, *G*: Ground Index, *U*: Usage Index
Regarding the, *EsZ*, values in the range of 0.5 to 0.6 will be suggested to apply instead of 0.6, which is typically used in Japan, based on the estimated seismic intensity of Algiers as shown in Appendix 2, and acceptance criteria of the damage of buildings.
Another equation of the judgment is as follows;

$$C_{TU}S_D \geqq 0.3ZGU \quad (39)$$

where: C_{TU} : Cumulative strength index at the ultimate deformation of the structure
Above value of 0.3 *Z* will be suggested to replace by the value in the range of 0.2 to 0.3 in Algiers.

Appendix 2: Seismic Intensity among EMS-98, MSK-64 and JMA

A relation of seismic intensity among EMS-98, MSK-64 and JMA is shown in Figure A1 for information. Expected seismic intensity in Algiers by Scenario Earthquakes is in the range of 8 to 9 of EMS-98 as shown in Figure A1(reference 1). This is equivalent to 5 plus to 6 minus of JMA generally and is lower than that of Hyougoken Nanbu (Kobe) Earthquake in 1995.

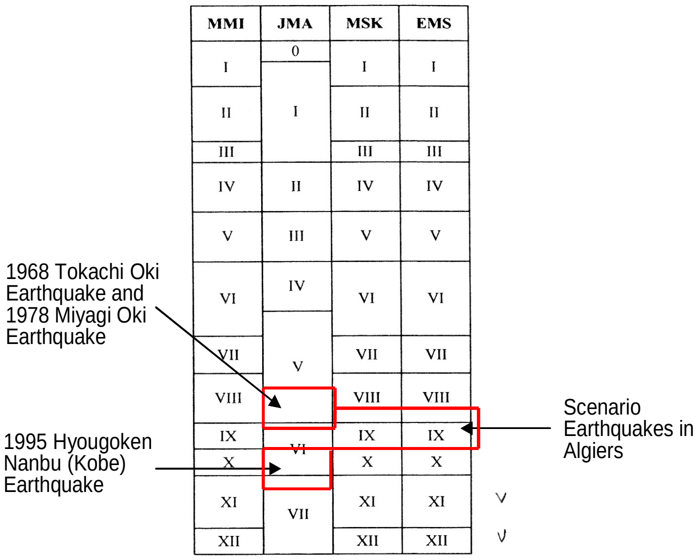

Figure A1 Seismic Intensity among EMS-98, MSK-64 and JMA (Added on the Figure 2-1 of 'The Vulnerability Assessment and the Damage Scenario in Seismic Risk Analysis' by Dr. S. Giovinazzi)

a) Destruction by Column Collapse

b) Shear Failure of Short Column

Figure A2 Apartment Houses Damaged by 2003 Boumerdes Earthquake (above) and A School Damaged by 1994 Mascara Earthquake (below, source CGS)

Appendix 3: Earthquake Damage

Typical destruction of apartment houses by column collapse by 2003 Boumerdes Earthquake, and shear failure of short column of a school by 1994 Mascara Earthquake in Algeria are shown in Figure A2.

REFERENCES

1) Japan International Cooperation Agency, "*A Study of Seismic Microzoning of the Wilaya of Algiers in the People's Democratic Republic of Algeria*", 2006, Tokyo, Japan.
2) The Japan Building Disaster Prevention Association, "*Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings*", 2001 (English Version), Tokyo, Japan.