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A PROPOSED METHOD FOR EVALUATING THE TOTAL SEISMIC PERFORMANCE OF EXISTING PUBLIC BUILDINGS AND ITS VERIFICATION

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SUMMARY

Ever since the Great Earthquake in the Southern Hyogo District in 1995, the seismic performance of existing public buildings has been reviewed throughout Japan. It has been established that a substantial number of buildings require seismic strengthening. It is necessary to establish a workable plan of seismic strengthening systematically and efficiently. With that purpose in mind, the seismic measures for the respective buildings must be ranked in accordance with the actual conditions. This paper proposes a method for judging the total seismic performance of existing RC buildings and the results of the verification study, towards meeting the purpose stated above.

The method reflects not only structural seismic performance but also the condition of each ground and characteristics of each building as known from the items listed below.

1) Seismic performance is represented by “ Is = E0 SD T”(.E0 : Factor in consideration of the ductility and toughness of building. SD : Seismic sub-index of structural profile. T : Seismic sub-index of time-dependent deterioration.) 2) Judgement index of seismic safety is represented by “yIso = Es G1 G2 G3” .(G1 : Factor in consideration of the scale of earthquake in a particular area. G2 : Factor in consideration of the resonance between building and ground. G3 : Factor in consideration of the topography in a particular area.) 3) I do the final judgment of the seismic performance by comparison of the “yIso” above and the “Is” which took strength of concrete, amount of wall, scale of building, and the other factor which is not considered, into consideration afresh.

This study verified the method with 326 public buildings located in an area. In a current seismic diagnosis, it was judged to 11 %, 56 %, 33 % with Safe, Reinforcement is needed, Reconstruction is needed. In a After considering ground conditions, it was judged to 50 %, 41 %, 9 % with Safe, Reinforcement is needed, Reconstruction is needed. In a this method, it was judged to 48 %, 47 %, 5 % with Safe, Reinforcement is needed, Reconstruction is needed.

This method is able to easily establish both a ranking of seismic performance and incorporation of the factors which influence seismic performance. This method, as an effective seismic measure, will surely satisfy the needs of organizations or bodies which possess a number of buildings.

INTRODUCTION

Buildings completed before the new seismic design method was put into operation in 1981 were severely damaged during the Hyogo-ken Nanbu earthquake on January 17, 1995. Many public buildings, included in the damaged buildings, lost their functions although they should have played a central role in the subsequent disaster rehabilitation activities. As a result, particular seismic resistance performance have required for the public buildings and the seismic diagnosis of many existing public buildings has been completed in some areas resulting in the pinpoint of the following problems.

1) Need for a total seismic performance evaluation based on the seismic diagnosis.

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2) Need for a total project management associated with a large number of public buildings requiring the seismic retrofit.
3) Need for a retrofit method that fits the characteristics of the targeted buildings.
4) Not all the targeted buildings are cost-effective at seismic retrofitting.
5) Topographic and ground conditions are not reflected in the current seismic design standards.

In this paper, we have proposed a total decision making system for the seismic performance of buildings in an area. It includes the decision of the need for the seismic retrofit, the decision of repair or replacement for the buildings to be retrofitted and the decision of setting the priority for the seismic retrofit methods. The decision workflow is shown in Fig.1.

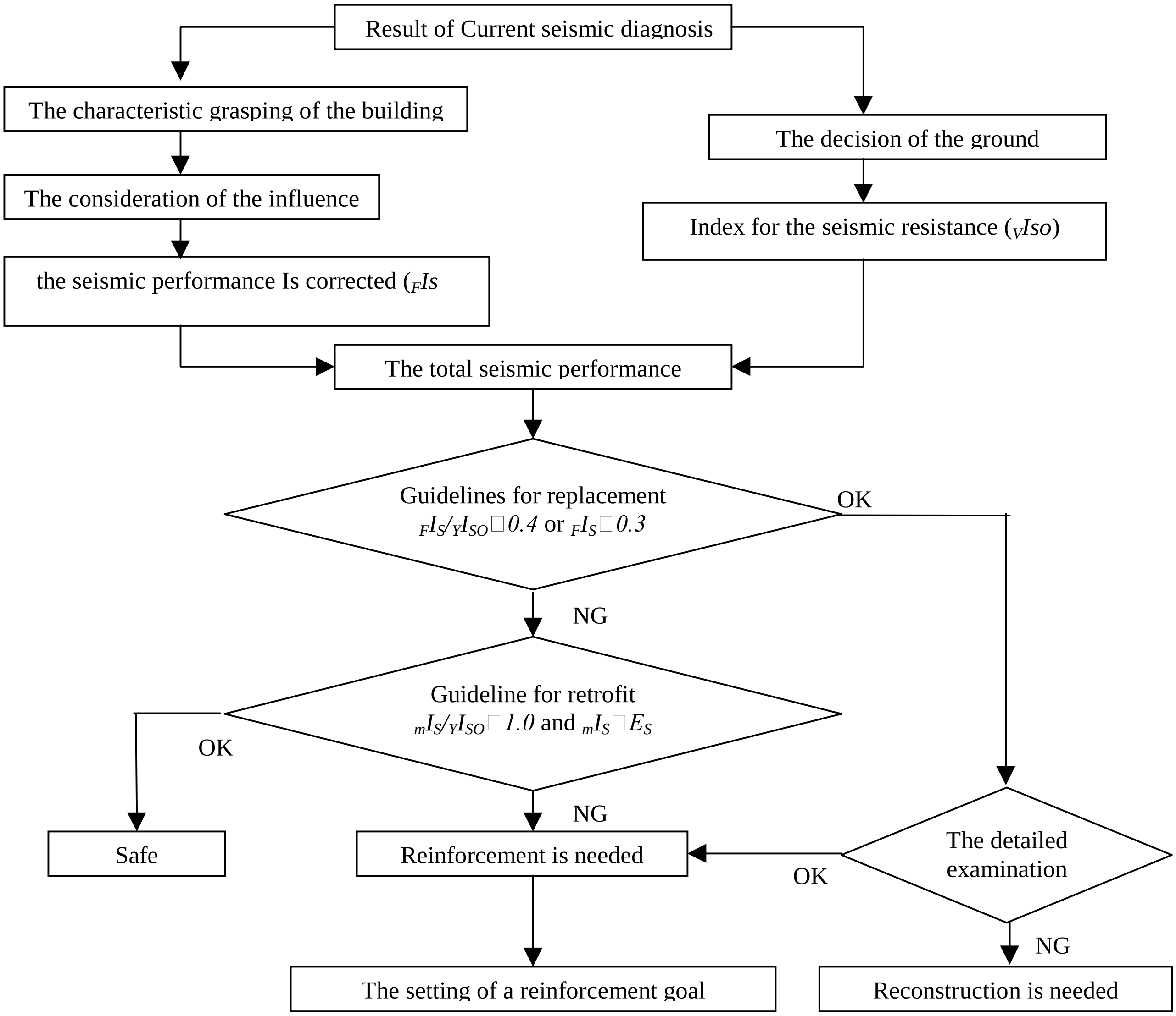

Fig.1 The flow chart of the work

SETTING OF THE DECISION INDEX

1) Range of seismic vibrations

Supposed earthquake is a Sagami-wan focus, magnitude 7.9 class model earthquake (the Minami-Kanto Earthquake) resulting surface earthquake motion level of 300 gals

2) Degree of seismic damage in the past

The decision criteria can be determined with reference to the seismic damage in the past and the result of seismic diagnosis. Relationship between the seismic damage in the past and result of seismic diagnosis was studied by collecting and analyzing information of buildings damaged in the Hyogo-ken Nanbu earthquake, the

Kushiro-oki and the Tokachi-Oki earthquakes. Usage of the buildings were school, domestic and office. The result of seismic diagnosis and the damage are shown in Fig. 2 and 3. In the first diagnosis results, buildings collapsed or largely damaged when *Is* was less than 0.7, while *Is* was less than 0.4, nearly all buildings collapsed, largely or intermediately damaged. In the second diagnosis, buildings collapsed or largely damaged when *Is* was less than 0.6 to 0.7, while *Is* was less than 0.4, nearly all buildings collapsed or largely-intermediately damaged.

The current basic seismic resistance index Es, 0.8 in the first diagnosis and 0.6 in the second and third diagnosis, is therefore reasonable with a slight variation depending on the magnitude of earthquakes and ground conditions.

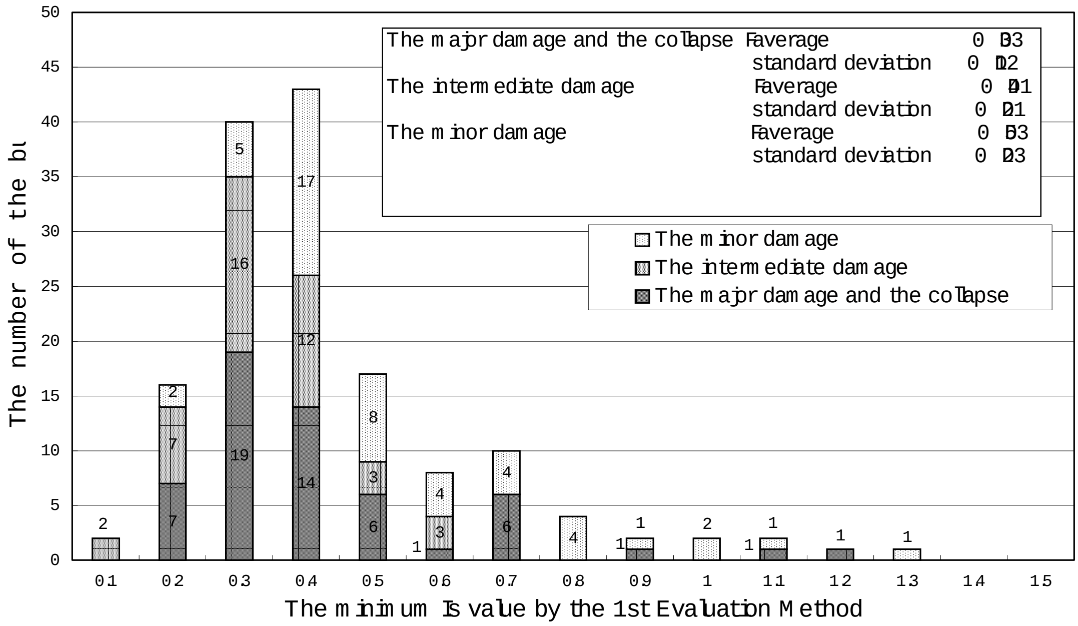

Fig. 2 Relationship between the first diagnosis result and the number of damaged buildings

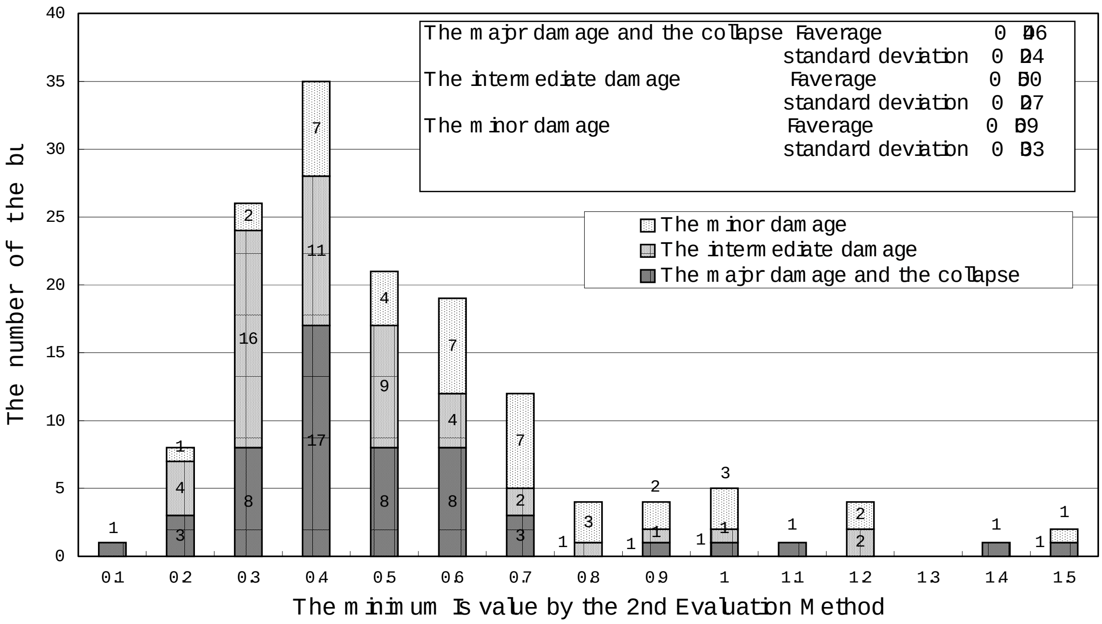

Fig. 3 Relationship between the second diagnosis result and the number of damaged buildings

3) Occupancy importance factor *I*

Importance factor I aims to minimize the seismic damage to important buildings. We classified the usage of building into three groups based on their roles in the disaster and proposed their respective importance factors in Table 1 which will be used in the retrofit design.

Table 1 Importance factor

The important-ness	The usage of building	Occupancy importance factor
1	The building which is important in case of the disaster	1.5
2	The building which a lot of persons use	1.25
3	The other building	1

4) Regional factor *G1*

The surface acceleration level (G_{ACC}) differs according to the ground conditions of each buildings. We consider the magnitude of earthquake specific to a ground with buildings as the regional factor (*G1*) which can be determined as a possible earthquake intensity ranging from V-weak to VII, a five grades supposing the Minami-Kanto Earthquake. The regional factor 1.0 corresponds to the earthquake intensity of VI-weak at an earthquake of approximately 300 gals. The relationship between the regional factor and the possible earthquake intensity grade is shown in Table 2. The possible earthquake intensity grade is defined as a five intensity levels related to the surface acceleration level calculated with the ground response analysis using 7300 boring data.

Table 2 Relationship between the regional factor and the possible earthquake intensity grade

Earthquake intensity	The surface acceleration level（gal）	Regional factor
Ⅶ	$400 < G_{ACC}$	1.2
VI-more	$320 \leqq G_{ACC} < 400$	1.1
VI-weak	$250 \leqq G_{ACC} < 320$	1
Ⅴ-more	$140 \leqq G_{ACC} < 250$	0.8
V-weak	$80 \leqq G_{ACC} < 140$	0.8

5) Topographical factor *G2*

On a scarp area, the order of magnitude of an earthquake may increase as the ground approaches to the top. The topographical factor *G2* takes into account of the shape of scarp and can be determined as functions of the height, distance of the top and the slope of the scarp as shown in Table 3 and Fig. 4.

Table 3 Topographical factor G2

The slope of the scarp θ	X/H	Topographical factor
30　45 degrees	From 0 to 1 above 1	1.1 1.0
above 45 degrees	From 0 to 1 From 1 to above 4	1.2 1.1 1.0

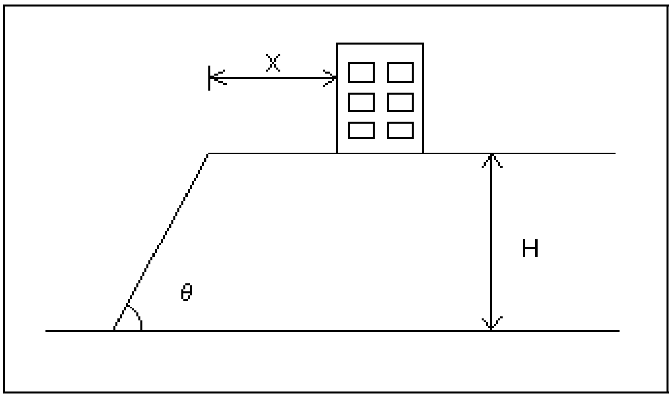

Fig. 4. Shape of scarp

6) Building-ground interaction factor *G3*

The building-ground response may increase due to the resonance, or decrease due to the damping effect of the soft ground. We introduce the building-ground interaction factor *G3* taking into account of the period characteristics (*Tg*) of ground and the number of stories in a building. The period characteristics of ground can be determined form the possible predominant period map of a ground at a 500 m resolution. The Building-ground interaction factor is shown in Table 4 on the basis of a mid rise, say 5-story (natural period of approximately 0.3 seconds), building.

Table 4 Building-ground interaction factor G3

Tg / story	Tg < 0.2sec	0.2sec ≦ Tg <0.6sec	0.6sec ≦ Tg <1.0sec	1.0sec ≦ Tg <1.4sec	1.4sec≦ Tg
F≦5	1.1	1.2	1.1	1.0	0.9
5<F	0.9	1.0	1.1	1.2	1.2

7) Liquefaction of the ground

Possibility of the ground liquefaction can be estimated using the possible ground liquefaction map at a resolution of 500 m and expressed in a thee grades, highly possible, less possible and not possible. Because the ground liquefaction is highly depending on the building conditions, we do not consider this factor for the seismic resistance estimation.

8) Essential seismic resistance index *Es*

Essential seismic resistance index *Es* can be set as 0.8 for the first diagnosis and 0.6 for the second and third diagnosis according to the revised version of the Guidelines and Commentaries on the Seismic Diagnosis for the Existing Reinforced Concrete Buildings published by the Association of Building Disasters in Japan [1].

9) Index for the seismic resistance of buildings $_{Y}Iso$

We propose an index capable of estimating the seismic resistance of building integrating the above defined factors. The index $_{Y}Iso$ can be used to rank the overall seismic resistance of buildings

$$_{Y}Iso = Es \times G1 \times G2 \times G3 \quad \cdots\cdots (1)$$

where Es is the essential seismic resistance index , G1 is the regional factor, G2 is the topographical factor and G3 is the building-ground interaction factor.

GUIDELINES FOR THE TOTAL EVALUATION OF SEISMIC RESISTANCE

1) Factors unconsidered in the current seismic diagnosis

Because the ease of retrofitting is not taken into account in the current seismic diagnosis, we numerically examine various factors affecting the ease of retrofitting to improve the seismic diagnosis. The factors are shown in Table 5.

a) Concrete strength (correction of the diagnosis results)

Because the designed concrete strength (σB) is considered as the highest possible value in seismic diagnosis, the underestimation may often occur when the actual strength is larger than the designed strength, while otherwise, the overestimation may result because the concrete low strength is not considered in the current shear force calculation method.

b) Date of construction (correction of the diagnosis results)

The seismic resistance of RC buildings differs by the date of construction (y) because the standard seismic design methods have revised time to time. Furthermore the seismic resistance of SRC buildings reflects the revision of computer software

c) Wall quantity (correction of the diagnosis results)

Wall quantity (aw) is defined as the wall area per unit floor area. Though it has been reported that the building with large wall quantity showed the least damage in the past earthquakes, the seismic resistance of buildings with brittle columns, but with large wall quantity, have often be evaluated solely by the brittle columns.

d) Standard floor area (estimation of retrofit quantity)

When the floor area of each story is small, the retrofit quantity becomes small. Taking the floor area that can be retrofitted by a steel brace as the reference floor area, we introduce the standard floor area (A).

e) Story (estimation of retrofit quantity)

When the number of story (*N*) is large, retrofit construction cost per unit floor area becomes higher. Retrofit construction becomes relatively difficult at a floor higher than 6-story but easier less than 4-story.

f) Aging index (estimation of retrofit quantity)

The aging index (*T*) may differ largely according to the knowledge of individual inspector, but the presence of some structural problems may be believed certain when T is less than 0.9. Retrofit cost of this case becomes higher associated with the degradation recovery cost.

g) Shape index (estimation of retrofit quantity)

When the seismic resistance of a building is poor with a shape index (*SD*) more than 1.0, the basic performance of the building can also be poor, but when *SD* is larger than 1.0, the seismic resistance is easily recovered by an appropriate arrangement of reinforcing components.

h) Average of *E0* (estimation of retrofit quantity)

(The ductility index E0 represents the ductility and toughness of a building.)

Whether the seismic resistance of a building is poor in some floors or in totality, the seismic retrofit cost differs. Then the average of E0 (E_{AV}) is helpful for the seismic resistance evaluation.

i) Effects of connections (correction of diagnosis results)

When beams are eccentrically connected to columns, the seismic resistance may be reduced due to the torsional moment occurring in columns while effects of the beam-column eccentric connections are not considered in the current seismic design guidelines. As a connection index, we introduce the eccentricity rate (e) which can be defined as the quotient of the beam-column eccentric distance divided by the shorter side of the column.

Table 5 Factors unconsidered in the current seismic diagnosis

The item factor	Concrete strength kN *Fc*	Date of construction *Fy*	Wall quantity cm^2/m^2 *Fw*
0.8	σB 10	----	*aw* 20
0.9	10 σB 15	----	20 *aw* 33
1	15 σB 18	*Y* ’71	33 *aw* 40
1.1	18 σB 25	’72 *Y*	40 *aw* 50
1.2	25 σB	----	50 *aw* 66
1.5	----	----	66 *aw* 100
2	----	----	100 *aw*
The item factor	**Standard floor area m^2 *FA***	**Story *FN***	**Aging index *FT***
0.8	----	6 *N*	----
0.9	800 *A*	*N*=5	*T* 0.9
1	200 *A* 800	*N* 4	0.9 *T*
1.1	*A* 200	----	----
1.2	----	----	----
1.5	----	----	----
2	----	----	----
The item factor	**Shape index *FSD***	**Average of E0 *FAV***	**Effects of connections *Fe***
0.8	----	E_{AV} 0.3	0.25 e
0.9	1.0 *SD*	0.3 E_{AV} 0.35	0.25 e 0.15
1	0.9 *SD* 1.0	0.35 E_{AV} 0.55	e 0.15
1.1	0.8 *SD* 0.9	0.55 E_{AV} 0.6	----
1.2	*SD* 0.8	0.6 E_{AV}	----
1.5	----	----	----
2	----	----	----

2) Basic guidelines for replacement/retrofit

The guidelines are set with reference to the past seismic disaster. Evaluation of replacement/retrofit is made in combination with $_{Y}Iso$, given by the equation (1), and $_{F}Is$, given by the equation (2). Replacement may be made when $_{F}Is$ / $_{Y}Iso$ is less than 0.4 or $_{F}$Is is less than 0.3. The final decision is made after a careful examination of the other factors that cannot be numerically included. The rank is the sequence of $mIs/\ _{Y}Iso$.

FIs = mIs□Fc□Fy□Fw□FA□FN□FT□FSD□FAV□Fe ……………………………………………… (2)

where $_{F}Is$ is the minimum seismic performance *ls* corrected by the above factors and *mls* is the minimum *ls* in a building.

3) A guideline of the decision of retrofit

Decision of the necessity of retrofit can be made with conditions both *mIs/* $_{Y}Iso$*□1.0* and *mIs□Es* paying cares of concrete strength, shape index and aging index. The occupancy importance factor I may be used when further building functions have to be retrofitted.

CONCLUSIONS

We examined the seismic resistance of 326 public buildings in an area. The results are shown in Fig.5.

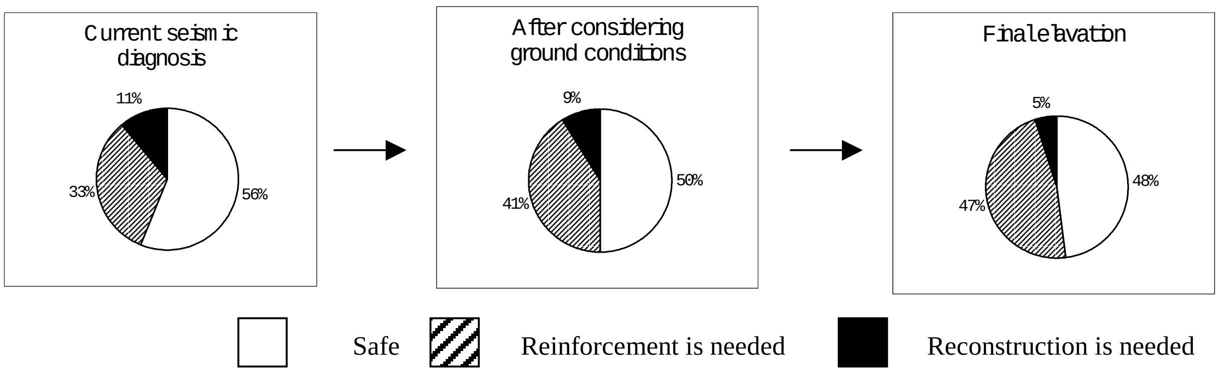

Fig. 5 Seismic resistance evaluation by the proposed method

It was proven that the proposed method was able to rank the seismic resistance of buildings and easily take into account of factors affecting the evaluation of the seismic resistance of buildings. The proposed method can be an effective decision-making measure for the bodies with a large number of facility buildings.

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