Guideline for Post-Earthquake Damage Evaluation And Rehabilitation of
RC Buildings in Japan

*Yoshiaki NAKANO

Institute of Industrial Science, The University of Tokyo, Tokyo, Japan

Masaki MAEDA

Department of Architecture and Building Science, Tohoku University, Sendai, Japan

Hiroshi KURAMOTO

International Cooperation Center of Engineering Education Development,
Toyohashi University of Technology, Toyohashi, Japan

Masaya MURAKAMI

Waseda University, Tokyo, Japan

ABSTRACT

Presented in this paper is the basic concept of the Guideline for Post-earthquake Damage Evaluation and Rehabilitation of RC buildings in Japan. This paper discusses the damage rating procedure based on the residual seismic capacity index that is consistent with the Japanese Standard for Seismic Evaluation of Existing RC Buildings, their validity through calibration with observed damage due to the 1995 Hyogoken-Nambu (Kobe) earthquake, the decision policy and criteria to determine necessary actions through comparison between experienced earthquake intensity and damage rate.

Key words: Post-earthquake damage evaluation, Residual seismic capacity, Reinforced concrete building, Rehabilitation

1 - 3 Associate Professor
4 Professor
INTRODUCTION

To restore an earthquake damaged community as quickly as possible, well-prepared reconstruction strategy is most essential. When an earthquake strikes a community and destructive damage to buildings occurs, immediate damage inspections are needed to identify which buildings are safe and which are not to aftershocks following the main event. However, since such quick inspections are performed within a restricted short period of time, the results may be inevitably coarse. Furthermore, it is not generally easy to identify the residual seismic capacities quantitatively from quick inspections. In the next stage following the quick inspections, damage assessment should be more precisely and quantitatively performed, and then technically and economically sound solutions should be applied to damaged buildings, if rehabilitation is needed. To this end, a technical guide that may help engineers find appropriate actions required in a damaged building is needed, and the Guideline for Post-earthquake Damage Evaluation and Rehabilitation[1] originally developed in 1991 was recently revised considering damaging earthquake experiences in Japan. The main objective of the Guideline is to serve as a technical basis and to provide rational criteria when an engineer identify and rate building damage quantitatively and to determine necessary actions required in the building, and to provide technically sound solutions to restore the damaged building.

The Guideline describes damage evaluation basis and rehabilitation techniques for three typical structural system, i.e., reinforced concrete, steel, and wooden buildings. Presented in this paper are the outline and the basic concept of the Guideline for reinforced concrete buildings. This paper discusses the damage rating procedure based on the residual seismic capacity index that is consistent with the Japanese Standard for Seismic Evaluation of Existing RC Buildings[2], their validity through calibration with observed damage due to the 1995 Hyogoken-Nambu (Kobe) earthquake, the decision policy and criteria to determine necessary actions through comparison between experienced earthquake intensity and damage rate.

OBJECTIVE AND SCOPE

The major target of the Guideline for RC buildings is cast-in-place reinforced concrete buildings with less than around 10 stories designed and constructed before 1981, since they are most vulnerable as was found in the past major damaging earthquakes in Japan and the residual seismic capacity index employed in the Guideline is designed to be consistent with the Japanese Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings, which basically applies to medium- to low-rise reinforced concrete buildings.

Higher buildings may be exposed to earthquake induced high axial forces, which give significant influence on the strength and ductility of columns. Furthermore, their failure may cause catastrophic consequences to the building and community. It should be noted, therefore, that the higher buildings need to be more carefully surveyed and judged in addition to the results based on this Guideline.

The Guideline consists of 4 major sections:
(1) Damage rating of foundation and building superstructure
The damage of each structural member is inspected and classified into one of damage classes I through V. Then the residual seismic capacity ratio index $R$ is calculated and the overall damage rating of the building is performed based on $R$-index.

(2) Determination of restoration action needed

Based on the intensity of shaking experienced and damage rate made in (1) above, necessary restoration actions such as repair and strengthening are determined.

(3) Visual instructions for repair and strengthening

In the Guideline, approximately 50 restoration techniques are illustrated with recommended section and reinforcement detail as well as construction procedure.

(4) Application examples

Finally two example buildings, which were damaged during 1994 Sanriku-haruka-oki earthquake and 1995 Hyogoken-nambu earthquake, are presented to help engineers understand the concept and application procedure.

In the subsequent sections, damage rating and decision criteria for restoration level are mainly described.

DAMAGE EVALUATION AND REHABILITATION

General flow

Damage evaluation of a building is performed on foundation system and superstructure system, respectively, and the damage rating of each building is made in a combination form for each system such as “no damage in foundation and moderate damage in superstructure”. Figure 1 shows the general flow of damage evaluation and subsequent rehabilitation.

Foundation

In general, foundation damage concurrently causes two major evidences, i.e., building settlement ($S$) and foundation leaning ($\theta$), and the Guideline defines the foundation damage in the matrix form of these two evidences. Foundation leaning may be identified from the leaning of an entire building unless the superstructure has apparent damage and/or localized residual story drift along the building height.

(1) Damage rating of foundation

Table 1 shows damage classification for pile foundation and shallow foundation, respectively. Leaning of foundation ($\theta$) may be determined from the tilting angle in each principal axis ($\theta_x$ and $\theta_y$) of a building superstructure defined in Eq.(1), unless apparent residual story drift due to localized structural damage can be found in superstructure building.

$$\theta = \sqrt{\theta_x^2 + \theta_y^2}$$  \hspace{0.5cm} (1)

where, $\theta_x$ and $\theta_y$ signifies tilting angel in the principal axis X and Y of a building superstructure.
Earthquake

Quick Inspection

*Inspected *LTD Entry *Unsafe
(GREEN) (YELLOW) (RED)

Temporary Abatement

*1

LTD Entry or No Use

Damage Evaluation and Rehabilitation

Damage Survey of Building

(1) Foundation

Damage Classification

- Apparently No Damage
- Light - Heavy Damage

Redesign

- Reparable?*2
- Rehabilitation

Long-term Use

(2) Superstructure

- R-index vs. EQ Intensity
  - Minor Repair
  - Structural Repair
  - Shoring / Bracing

Temporary Use

- No Entry

Residual Capacity vs. Required Capacity

- Non-structural Repair
- Structural Repair

Strengthening

- Reparable?*2
- Rehabilitation

Long-term Use

Not Reparable

Demolish

*1 Damage evaluation fundamentally includes buildings after quick inspection since the inspection results do not necessarily provide sufficient information related to the residual seismic capacity which is most essential for continuing long-term use of buildings.

*2 Economic as well as technical issues should be considered.

Figure 1: General Flow of Damage Evaluation and Rehabilitation in the Guideline
Table 1: Damage Classification Criteria for Foundation

<table>
<thead>
<tr>
<th>Leaning</th>
<th>Settlement S (m)</th>
<th>(a) Pile Foundation</th>
<th>(b) Shallow Foundation</th>
</tr>
</thead>
<tbody>
<tr>
<td>θ (rad)</td>
<td>0</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>1/300</td>
<td>None</td>
<td>Light</td>
<td>Moderate</td>
</tr>
<tr>
<td>1/150</td>
<td>Light</td>
<td>Moderate</td>
<td>Heavy</td>
</tr>
<tr>
<td>1/75</td>
<td>Moderate</td>
<td>Heavy</td>
<td>Heavy</td>
</tr>
</tbody>
</table>

Leaning criteria between damage and no damage is determined considering damage experiences in the 1995 Kobe earthquake. Excavation surveys after the event show that (1) all buildings with more than 1/100 leaning and 2/3 of those with 1/100 to 1/300 leaning had damage in pile foundation, and (2) no buildings having shallow foundation with less than 1/150 leaning were rehabilitated. Another criteria is determined from the evidence that (1) pile foundations experienced extensive damage when they had more than 0.3 m settlement and some damage when more than 0.1 m settlement, and (2) shallow foundations were repaired when they had more than 0.05 m settlement. Note that large settlement is unlikely to occur together with slight leaning and the Guideline therefore does not intend to cover such damage combination as indicated by “*” in Table 1.

(2) Rehabilitation criteria

The Guideline fundamentally intends to restore the damaged foundation to the state of original performance prior to shaking primarily because the foundation rehabilitation may cause damage to building superstructures unless they are upgraded, and generally costly rehabilitation is required to upgrade both foundations as well as building superstructures. However the Guideline recommends that heavily damaged foundation should be properly upgraded for long-term use especially when the damage is attributed to minor to moderate shaking intensity.

Building superstructure

An inspection engineer first surveys structural damage and performs damage classification of structural members in the most seriously damaged story. The residual seismic capacity ratio index \( R \) is then calculated and the damage rating of the building superstructures, i.e., [slight], [light], [moderate], [heavy], and [collapse] is made. Necessary actions are finally determined comparing the ground shaking experienced at the building site, entire building damage rating, and required seismic capacity against a future earthquake.

(1) Damage classification of structural members

Damage classification of columns and shear walls is performed based on the damage definition shown in Table 2 and Photo 1. As was revealed in the past damaging earthquakes in Japan, typical damage is generally found in vertical members resulting in life-threatening damage, and the Guideline is essentially designed to identify and classify damage in columns and walls rather than in beams. When damage is found in beams, damage classification needs to be performed considering their effects on vertical load carrying capacity as well as lateral resisting of columns connecting to them. As defined in Table 2, columns and walls are classified in one of five categories I through V. Figure 2 schematically illustrates the load carrying capacity, load-deflection curve, and member damage class.
Table 2: Definition of Damage Class for RC columns and walls

<table>
<thead>
<tr>
<th>Damage Class</th>
<th>Description of Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Visible narrow cracks on concrete surface (Crack width is less than 0.2 mm)</td>
</tr>
<tr>
<td>II</td>
<td>Visible clear cracks on concrete surface (Crack width is about 0.2 - 1.0 mm)</td>
</tr>
<tr>
<td>III</td>
<td>Local crush of covering concrete</td>
</tr>
<tr>
<td></td>
<td>Remarkable wide cracks (Crack width is about 1.0 - 2.0 mm)</td>
</tr>
<tr>
<td>IV</td>
<td>Remarkable crush of concrete with exposed reinforcing bars</td>
</tr>
<tr>
<td></td>
<td>Spalling off of covering concrete (Crack width is more than 2.0 mm)</td>
</tr>
<tr>
<td>V</td>
<td>Buckling of reinforcing bars</td>
</tr>
<tr>
<td></td>
<td>Cracks in core concrete</td>
</tr>
<tr>
<td></td>
<td>Visible vertical and/or lateral deformation in columns and/or walls</td>
</tr>
<tr>
<td></td>
<td>Visible settlement and/or inclination of the building</td>
</tr>
</tbody>
</table>

Figure 2: Damage Class vs. Load Carrying Capacity

(a) Ductile Member  
(b) Brittle Member

(2) Residual Seismic Capacity Ratio Index $R$

A residual seismic capacity ratio index $R$, which corresponds to building damage, is defined by the ratio of seismic capacity after damage to that before an event (i.e., the ratio of the residual capacity to the original).

$$R = \frac{DIs}{Is} \times 100 \, (\%)$$

where,  
$Is$ : seismic capacity index of structure before earthquake damage  
$DIs$ : seismic capacity index of structure considering deteriorated member strength
Damage class III:
(Left) Crack width about 2mm on structural concrete
(Right) Spalling of covering concrete and rebar slightly exposed

Damage class IV:
Rebars exposed but their buckling/fracture not observed

Damage class V

Photo 1: Damage Class Examples
$I_s$-index can be calculated based on the concept found in the Standard for Seismic Evaluation\textsuperscript{[2]}, which is most widely applied to evaluate seismic capacity of existing structures in Japan. The basic concept of the Standard to calculate $I_s$-index can be found in Appendix. The Guideline recommends to calculate $dI_s$-index for a damage building in the analogous way for pre-event buildings, considering seismic capacity reduction factor $\eta$ which is defined as the ratio of the absorbable hysteretic energy after earthquake to the original absorbable energy of structural member as illustrated in Figure 3. Table 3 shows the reduction factor $\eta$ defined in the Guideline, where several experimental results shown in Figure 4 \textsuperscript{[3]} are taken into account for the values. It should be noted that the residual member strength is simply calculated from the product of reduction factor $\eta$ and original strength assuming initial member ductility is preserved even after damaging event, since no data are available to precisely determine ductility reduction factors. Furthermore, experimental results related to residual capacity are still few especially for wall members and brittle columns, and more efforts should be directed toward clarifying and verifying residual performance of damaged members.

![Figure 3: Basic Concept of Seismic Capacity Reduction Factor $\eta$](image)

<table>
<thead>
<tr>
<th>Damage Class</th>
<th>Column (Brittle)</th>
<th>Column (Ductile)</th>
<th>Wall w/o boundary columns</th>
<th>Column w/ wing wall(s)</th>
<th>Wall w/ boundary columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>II</td>
<td>0.60</td>
<td>0.75</td>
<td>0.60</td>
<td>0.60</td>
<td>0.60</td>
</tr>
<tr>
<td>III</td>
<td>0.30</td>
<td>0.50</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>IV</td>
<td>0</td>
<td>0.10</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>V</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
After Kobe earthquake, seismic capacity evaluation has been made in numerous buildings, and when the evaluation results are available, they would greatly help engineers calculate the $R$ index. Most buildings that have been seismically evaluated, however, are public use building such as school, central/local government buildings, and their available data are still limited.

The Guideline, therefore, proposes an alternative procedure to calculate $R$ index in a simplified way. This procedure would efficiently help engineers identify necessary actions for a building, especially when the damage is extensive and a large number of buildings need to be rated. In the simplified procedure, a normalized strength index $C$ for each typical member section which often appears in existing RC buildings in Japan are proposed considering ultimate shear stress and effective sectional area of each section type as shown in Table 4. Considering strength index $C$ and reduction factor $\eta$ listed in Table 3 for damaged member, the residual seismic capacity index $R$ can be simply expressed as shown in Eq. (3).

$$R = \frac{\sum A_j}{A_{org}} \times 100 \quad (\%)$$  

$$A_0 = S_0 + M_0 + W_0 + 2CW_0 + 6CWC_0$$
$$A_1 = 0.95S_1 + 0.95M_1 + 0.95W_1 + 1.9CW_1 + 5.7CWC_1$$
$$A_2 = 0.6S_2 + 0.75M_2 + 0.6W_2 + 1.2CW_2 + 3.6CWC_2$$
$$A_3 = 0.3S_3 + 0.5M_3 + 0.3W_3 + 0.6CW_3 + 1.8CWC_3$$
$$A_4 = 0.1M_4$$
$$A_5 = 0$$

Note: Experimental results for 4 beam specimens subjected to cyclic loadings are shown here, where the relationship between reduction factor $\eta$ calculated by the concept shown in Figure 3 and maximum residual crack width are plotted. Curves shown together in the figure are obtained assuming Takeda hysteretic model.

**Figure 4: Seismic Capacity Reduction Factor $\eta$ Obtained from Experimental Investigations** [3]
\[ A_{\text{org}} = S_{\text{sum}} + M_{\text{sum}} + W_{\text{sum}} + 2CW_{\text{sum}} + 6CW_{\text{sum}} \]

\( S_0, S_1, S_2, S_3, S_4, S_5, S_{\text{sum}} \) : Number of brittle columns having damage class 0 through V and their total number, respectively

\( M_0, M_1, M_2, M_3, M_4, M_5, M_{\text{sum}} \) : Number of ductile columns having damage class 0 through V and their total number, respectively

\( W_0, W_1, W_2, W_3, W_4, W_5, W_{\text{sum}} \) : Number of walls without boundary columns having damage class 0 through V and their total numbers, respectively

\( CW_0, CW_1, CW_2, CW_3, CW_4, CW_5, CW_{\text{sum}} \) : Number of columns with wing wall(s) having damage class 0 through V and their total number, respectively

\( CW_{\text{C}0}, CW_{\text{C}1}, CW_{\text{C}2}, CW_{\text{C}3}, CW_{\text{C}4}, CW_{\text{C}5}, CW_{\text{C}sum} \) : Number of walls with boundary columns having damage class 0 through V and their total number, respectively

| Table 4: Normalized Strength Index \( \bar{C} \) for Simplified Procedure |
|---------------------------------|-----------------|-----------------|-----------------|
|                                 | Ductile/Brittle Column | Wall w/o Boundary Column | Wing Wall and Column | Wall w/ Boundary Columns |
| Section | 60cm 60cm | 15cm 240cm | 15cm 240cm | 15cm 480cm |
| \( \tau_0 (N/mm^2) \) | 1 | 1 | 2 | 3 |
| \( \bar{C} \) | 1 | 1 | 2 | 6 |

(3) Damage rating of building superstructure

The residual seismic capacity ratio index \( R \) defined in (2) can be considered to represent damage sustained by a building. For example, it may represent no damage when \( R = 100 \% \) (100 % capacity is preserved), more serious damage with decrease in \( R \), and total collapse when \( R = 0 \% \) (no residual capacity). To identify the criteria for damage rating, \( R \) values of 145 school buildings that experienced 1995 Kobe Earthquake are compared with observed damage and judgement by experts as shown in Figure 5. The Guideline then defines the damage rating criteria shown below.

- [Slight] 95 (%) \( \leq R \)
- [Light] 80 (%) \( \leq R < 95 \% \)
- [Moderate] 60 (%) \( \leq R < 80 \% \)
- [Heavy] \( R < 60 \% \)
- [Collapse] Building which is deemed to have \( R \lessgtr 0 \) due to overall/partial collapse

It should be noted, however, that the boarder line between two adjacent damage rating such as [heavy damage] and [moderate damage] is not necessarily explicit, and overlappings or gray zones may be found in the figure. Those close to the damage criteria should be categorized after careful damage examination rather than a simple numerical judgement.
(4) Rehabilitation criteria

When a damaged building needs to be reused for a certain long period of time, the most fundamental strategy to restore the building is to provide seismic capacity required for new constructions at the site. The Guideline specifies the criteria for $I_s$ and $CT \times SD$ to conform with $Iso$ and $0.3 \times Z \times G \times U$, respectively, which are required in the Japanese Standard for Seismic Evaluation as shown in APPENDIX. In most cases structural strengthening as well as repair is needed to meet such criteria, which is in general costly and time consuming.

It should be noted, however, that such a complete rehabilitation can not be made for all buildings immediately following a major event, and therefore a temporary action scenario and its criteria should be prepared. This is especially so when the damage is extensive and widespread, and a huge number of buildings are damaged. To this end, the Guideline describes criteria for continuing use after temporary restoration. The basic concept for the criteria is shown in Figure 6, where the criteria is expressed in the matrix form of ground shaking and sustained damage. When a building sustains heavy damage under minor earthquake shaking, it is deemed to have poor seismic capacity and therefore careful assessment and judgement is needed. When a building sustain minor damage under major earthquake shaking, it is deemed to have better seismic capacity and therefore just minor repair on structural/non-structural element can be accepted. Table 5 shows the criteria for temporary restoration.

Damage evaluation form

To facilitate the field survey, a damage evaluation form is provided in the Guideline, which includes survey items listed in Table 6. The form contains general description of the building concerned, damage classification of foundation and superstructure building and damage rating of entire building, other damage observed including nonstructural members, recommended restoration level. Table 7 shows the damage evaluation form.
**Figure 6: Basic Concept to Estimate Seismic Capacity**

**Table 5: Criteria for Temporary Restoration**

<table>
<thead>
<tr>
<th>Damage Intensity</th>
<th>[Slight]</th>
<th>[Light]</th>
<th>[Moderate]</th>
<th>[Heavy]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \leq V^- ) (lower)</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
<tr>
<td>( V^+ ) (upper)</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
<tr>
<td>( V^- ) (lower)</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
<tr>
<td>( \geq V^+ ) (upper)</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
</tbody>
</table>

Note

- [ ]: Continuing use after minor structural/non-structural repair
- [ ]: Continuing use after structural repair to restore initial seismic capacity
- [ ]: Detailed examination required
- Symbols in parentheses represent criteria for pre-1971 buildings that have less strict requirement for shear reinforcement

**Table 6: Survey Items Included in the Damage Evaluation Form**

1. **General description of building**
   1.1 Building name / 1.2 Address / 1.3 Building owner / 1.4 Contact person / 1.5 Building use (office, residential building etc.) / 1.6 Structural type (RC, PCA, etc.) / 1.7 Construction type (frame, wall-frame etc.) / 1.8 Foundation type / 1.9 Building size / 1.10 Geological condition / 1.11 Near-site topography / 1.12 Exterior Finishing Material / 1.13 Presence/absence of construction records (calculation, structural drawings and construction records) / 1.14 Construction year

2. **Damage rating**
   2.1 Damage rating of entire building from obvious damage
   2.2 Damage rating of foundation
   (1) foundation settlement / (2) foundation leaning
   2.3 Damage rating of superstructure building
   (1) most seriously damaged story and its direction / (2) presence/absence of localized damage / (3) damage identification of structural members / (4) residual seismic capacity ratio index R

3. **Other damage**

4. **Decision of necessary action**

5. **Sketches and comments**
表7: Damage Evaluation Form

| 整理番号 | 年 | 月 | 日 | 午前/午後 | 調査担当者
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>記述</td>
<td>記述</td>
<td>記述</td>
<td>記述</td>
<td>記述</td>
</tr>
</tbody>
</table>

1. 建築物概要

① 建築物名称

② 建築物所在地

③ 所有者

④ 連結先

⑤ 建物用途

⑥ 建物構造: 基礎構造 (地表面) または 基礎構造 (地下)

⑦ 建築物規模

⑧ 数地の形状 (台地・地表面)

⑨ 周辺の地形: 川や海

⑩ 外装仕上げ: モルタル・コンクリート

⑪ 設計図書: 創作設計図書・施工設計図書

⑫ 建設年代

2. 被災の区分

① 建築物の崩壊・落壊等による判定

② 建築物の崩壊・落壊等による判定

③ 基礎構造の値

④ 基礎構造の値

⑤ 基礎構造の値

⑥ 基礎構造の値

⑦ 基礎構造の値

⑧ 基礎構造の値

3. その他

① 他

② 他

4. 破壊の要因の判定

気象条件: 風力の強さ以上: 0.1kN以上 0.1kN以下 風力の要因を判定

5. 基礎構造の要因

6. 基礎構造の要因

7. 基礎構造の要因

8. 基礎構造の要因

9. 基礎構造の要因

10. 基礎構造の要因

11. 基礎構造の要因

12. 基礎構造の要因

13. 基礎構造の要因

14. 基礎構造の要因

15. 基礎構造の要因

16. 基礎構造の要因

17. 基礎構造の要因

18. 基礎構造の要因

19. 基礎構造の要因

20. 基礎構造の要因

21. 基礎構造の要因

22. 基礎構造の要因

23. 基礎構造の要因

24. 基礎構造の要因

25. 基礎構造の要因

26. 基礎構造の要因

27. 基礎構造の要因

28. 基礎構造の要因

29. 基礎構造の要因

30. 基礎構造の要因
REHABILITATION TECHNIQUES

To facilitate rehabilitation design and construction, visual instructions consisting of 19 foundation examples and 28 superstructure examples are provided together with photo examples. Figures 7 and 8 show typical examples for foundation and building superstructure, respectively.

CONCLUDING REMARKS

Seismic evaluation and rehabilitation before damaging earthquake is definitely most essential to mitigate damage. It is also true, however, that such efforts need a certain period of time, manpower and budget to complete nationwide structures. Well prepared post-earthquake strategy, although no damage desired, including damage evaluation and reconstruction scheme as well as pre-event preparedness is therefore an urgent task to be developed in the researchers and engineers community, and should be ready for the immediate application after the event.

In this paper, the basic concept and procedure for post-earthquake damage evaluation of RC buildings in Japan are presented, together with background and several supporting data. As discussed herein, available data related to residual seismic capacity and their evaluation method are still few, and researchers in both countries are encouraged to direct their efforts for further understanding and clarifying performances after earthquakes.

APPENDIX BASIC CONCEPT OF JAPANESE GUIDELINES FOR SEISMIC EVALUATION AND RETROFIT OF EXISTING RC BUILDINGS

The Guideline for Seismic Evaluation[2] defines the following structural seismic capacity index $I_s$ at each story level in each principal direction of a building.

$$I_s = E_o \times S_d \times T$$

(4)

where, $E_o$ : basic structural seismic capacity index, calculated by the products of Strength Index ($C$), Ductility Index ($F$), and Story Index ($\phi$) at each story and each direction when a story or building reaches at the ultimate limit state due to lateral force. ($E_o = \phi \times C \times F$)

$C$ : index of story lateral strength, calculated from the ultimate story shear in terms of story shear coefficient.

$F$ : index of story ductility, calculated from the ultimate deformation capacity normalized by the story drift of 1/250 when a standard size column is assumed to fail in shear. $F$ is dependent on the failure mode of structural members and their sectional properties such as bar arrangement, member’s geometric size etc. $F$ is assumed to be in the range of 1.27 to 3.2 for ductile columns, 1.0 for brittle columns and 0.8 for extremely brittle short columns.

$\phi$ : index of story shear distribution during earthquake, estimated by the inverse of design story shear coefficient distribution normalized by base shear coefficient. $\phi = (n+1)/(n+i)$ is basically employed for the $i$-th story of an $n$-storied building.
$SD$ : factor to modify $Eo$ index due to stiffness discontinuity along stories, eccentric distribution of stiffness in plan, irregularity and/or complexity of structural configuration, basically ranging from 0.4 to 1.0.

$T$ : reduction factor to allow for the grade of deterioration, ranging from 0.5 to 1.0.

Required seismic capacity index $Iso$, which evaluates structural safety against an earthquake, is defined as follows.

$$Iso = Es \times Z \times G \times U$$ (5)

where, $Es$ : basic structural seismic capacity index required for the building concerned. Considering past structural damage due to severe earthquakes in Japan, standard value of $Es$ is set 0.6.

$Z$ : factor allowing for the seismicity.

$G$ : factor allowing for the soil condition.

$U$ : usage factor or importance factor of a building.

Typical $Iso$ index is 0.60 considering $Es = 0.6$ and other factors of 1.0. It should be noted that $CT \times SD$ defined in Eq. (6) is required to be larger than or equal to $0.3 \times Z \times G \times U$ in the Standard for Seismic Evaluation [2] to avoid fatal damage and/or unfavorable residual deformation due to large response of structures during major earthquakes.

$$CT \times SD = \phi \times C \times SD$$ (6)

Seismic retrofit of buildings is basically carried out in the following procedure.

1. Seismic evaluation of the structure concerned. : $Is$ and $CT \times SD$ are calculated.
2. Determination of required seismic capacity: $Iso$ is determined.
3. Comparison of $Is$ with $Iso$.
   
   (if $Is < Iso$ or $CT \times SD < 0.3 \times Z \times G \times U$ and retrofit is required, then following (4) through (6) are needed.)
4. Selection of retrofitting scheme(s).
5. Design of connection details.
6. Reevaluation of the retrofitted structure. : $Is$ and $CT \times SD$ are checked.

REFERENCES


Figure 7: Rehabilitation Technique Example for Foundation

[Image of diagrams and text explaining the rehabilitation technique for a foundation, with steps and illustrations.]
Figure 8: Rehabilitation Technique Example for Columns and Walls

![Figure 8: Rehabilitation Technique Example for Columns and Walls](image_url)

### 柱のせん断補強

#### 区分
- 応急復旧 - 恒久補修 - 恒久補修
- 損傷度 II - III - IV - V

#### 目的
大きなせん断ひび割れが発生した柱をせん断補強する。

1. 溶接金網による補強
   - 溶接金網
   - ひび割れ補修
   - 継手長さ: 100 程度以上
   - 無反射ヒアルロン酸または豆粉をコンクリート打設
   - 補強コンクリートの製法

2. 炭素繊維シートによる補強
   - R面取り (R>30)
   - ひび割れ補修
   - 炭素繊維シートをかけ
   - 灰泥部補修

#### 参考図

### 壁のひび割れの補修

#### 区分
- 応急復旧 - 恒久補修 - 恒久補修
- 損傷度 II - III - IV - V

#### 目的
ひび割れやコンクリートの部分的な剥落が生じた壁に、耐力修復および劣化防止のための補修を行う。

![Figure 8: Rehabilitation Technique Example for Columns and Walls](image_url)

#### ひび割れ部注人材

<table>
<thead>
<tr>
<th>使用材</th>
<th>ひび割れ幅（mm）</th>
</tr>
</thead>
<tbody>
<tr>
<td>エポキシ樹脂基材</td>
<td>低粘度 0.1 〜 0.5</td>
</tr>
<tr>
<td></td>
<td>中粘度 0.3 〜 1.5</td>
</tr>
<tr>
<td></td>
<td>高粘度 0.5 〜 2.0</td>
</tr>
<tr>
<td>セメントベースト</td>
<td>濃 0.1 〜 2.0</td>
</tr>
</tbody>
</table>

* 1995年米軍新会社技術では5mm程度のひび割れに適用された事例もあるが、このような耐候性ひび割れ補修の大きさ箇所に適用する場合は、施工性や補修効果を十分検討する必要がある。

#### 要点
- 耐震壁の場合で恒久補修に用いる柱補材には、エポキシ樹脂を用いる。

### 施工手順
1. 補強コンクリートの打設
2. 注入用シートの施工
3. ひび割れ部の注入
4. 下地処理（使用材料に適した処置とする）
5. 灰泥部の補修