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

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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*

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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

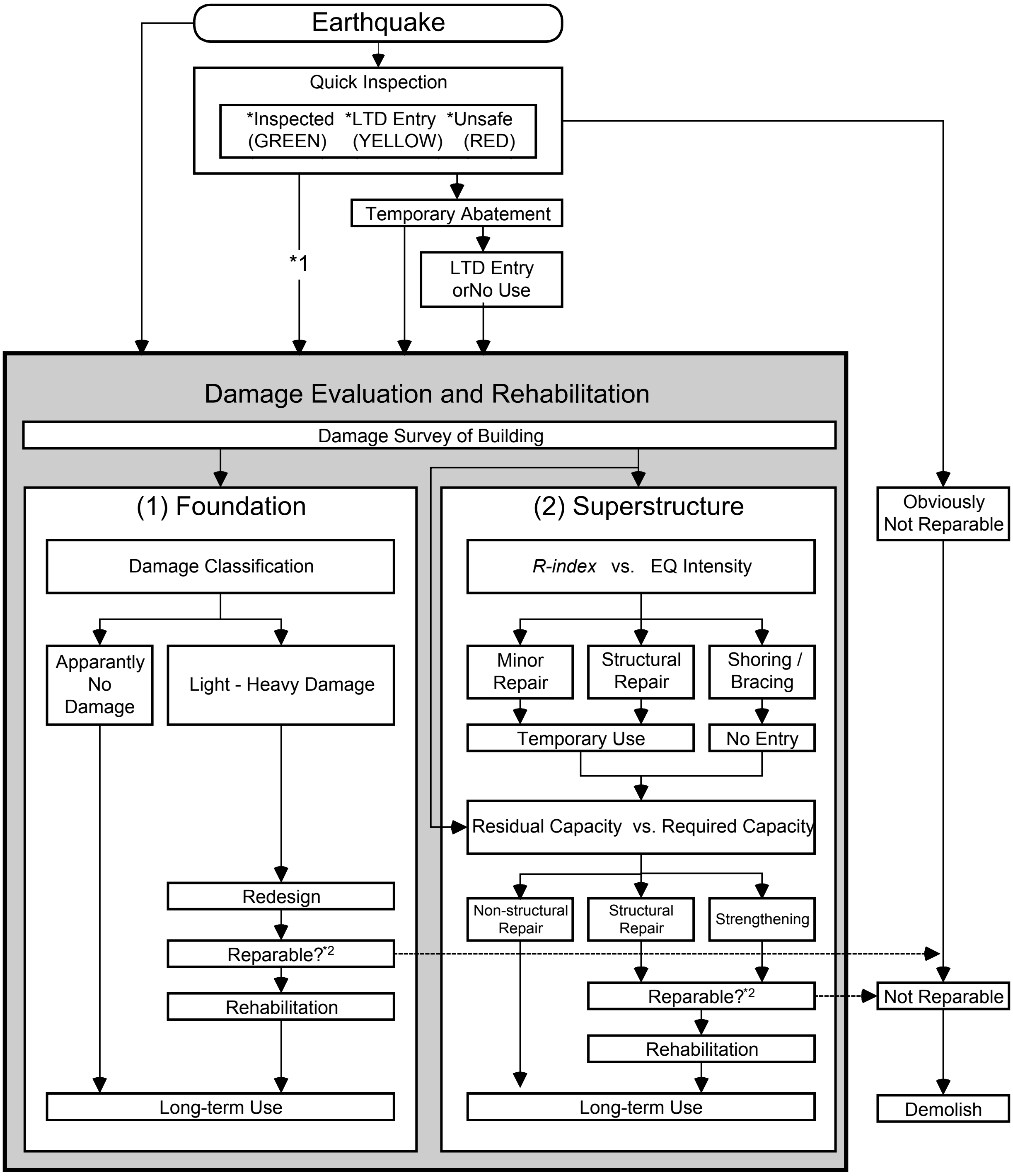
In general, foundation damage concurrently causes two major evidences, i.e., building settlement (*S*) and foundation leaning (θ), and the Guideline defines the foundation damage in the matrix form of these two evidences. Foundation leaning may be identified from the leaning of an entire building unless 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 (θ) may be determined from the tilting angle in each principal axis (θ_x and θ_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.

$$\theta = \sqrt{\theta_x{}^2 + \theta_y{}^2} \tag{1}$$

where, θ_x and θ_y signifies tilting angel in the principal axis X and Y of a building superstructure.



*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

(a) Pile Foundation

	θ (rad)	Settlement S (m)			
		0	0.1	0.3	
Leaning	1/300	None	Light	Moderate	*
	1/150	Light	Moderate	Moderate	Heavy
	1/75	Moderate	Moderate	Heavy	Heavy
		Heavy	Heavy	Heavy	Heavy

(b) Shallow Foundation

	θ (rad)	Settlement S (m)			
		0.05	0.1	0.3	
Leaning	1/150	None	Light	*	*
	1/75	Light	Moderate	Moderate	*
	1/30	Moderate	Moderate	Heavy	Heavy
		Heavy	Heavy	Heavy	Heavy

* Not covered in the Guideline and more careful examinations needed

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

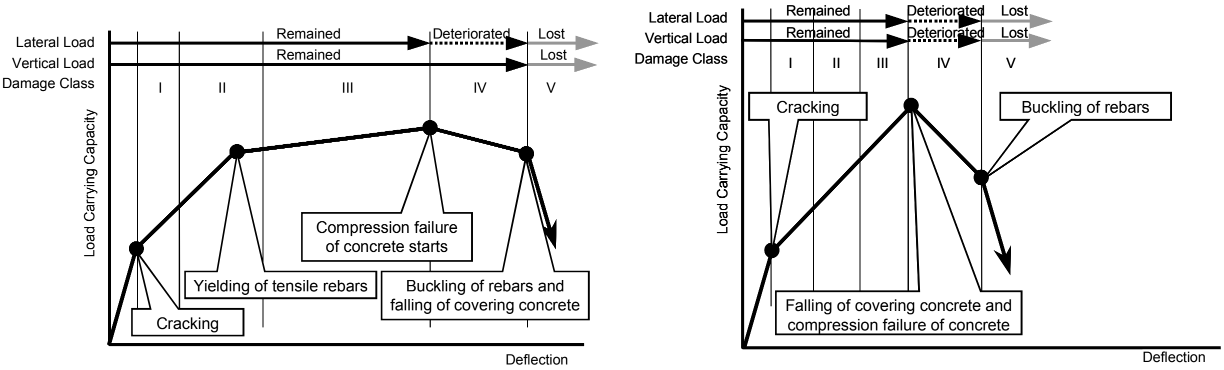
An inspection engineer first surveys structural damage and performs damage classification of structural members in the most seriously damaged story. The residual seismic capacity ratio index R is then calculated and the damage rating of the building superstructures, i.e., [slight], [light], [moderate], [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

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



(a) Ductile Member (b) Brittle Member

Figure 2: Damage Class vs. Load Carrying Capacity

(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).

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

where, Is : seismic capacity index of structure before earthquake damage (2)

${}_D Is$: 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

Is-index can be calculated based on the concept found in the Standard for Seismic Evaluation[2], which is most widely applied to evaluate seismic capacity of existing structures in Japan. The basic concept of the Standard to calculate *Is*-index can be found in Appendix. The Guideline recommends to calculate *DIs*-index for a damage building in the analogous way for pre-event buildings, considering seismic capacity reduction factor η 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 η defined in the Guideline, where several experimental results shown in **Figure 4** [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 η 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.

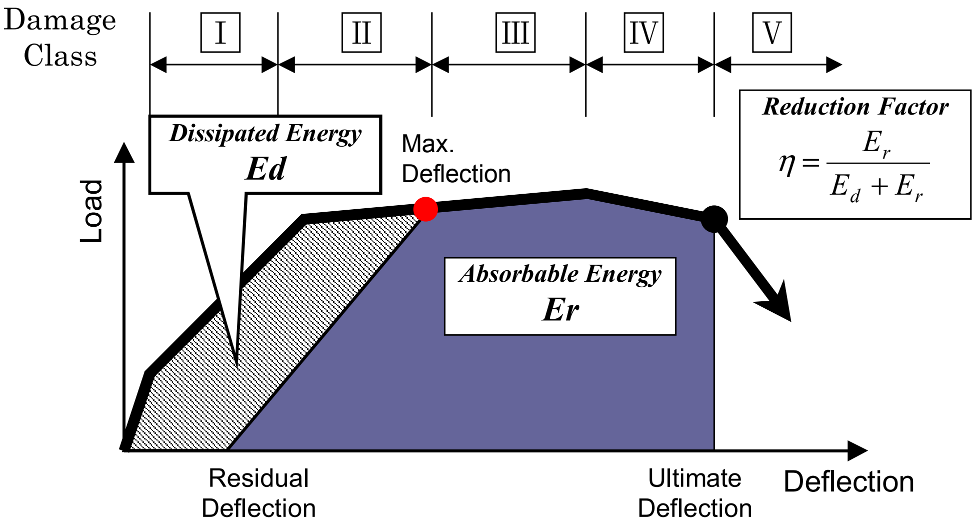
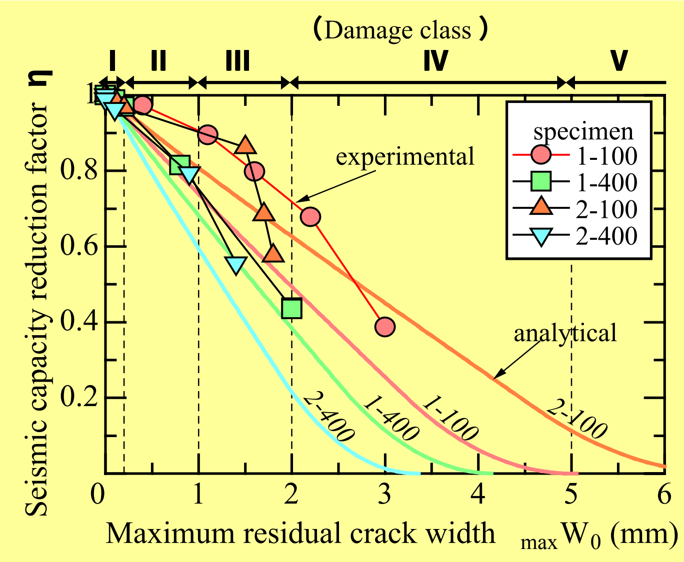


Figure 3: Basic Concept of Seismic Capacity Reduction Factor η

Table 3: Seismic Capacity Reduction Factor η[1]

Damage Class	Column (Brittle)	Column (Ductile)	Wall w/o boundary columns	Column w/ wing wall(s)	Wall w/ boundary columns
I	0.95	0.95	0.95	0.95	0.95
II	0.60	0.75	0.60	0.60	0.60
III	0.30	0.50	0.30	0.30	0.30
IV	0	0.10	0	0	0
V	0	0	0	0	0



Note: Experimental results for 4 beam specimens subjected to cyclic loadings are shown here, where the relationship between reduction factor η 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 η Obtained from Experimental Investigations [3]

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 $\overline{C}$ 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 $\overline{C}$ and reduction factor η listed in **Table 3** for damaged member, the residual seismic capacity index *R* can be simply expressed as shown in **Eq. (3)**.

$$R = \frac{\sum_{j=0}^{5} A_j}{A_{org}} \times 100 \quad (\%) \tag{3}$$

$$A_0 = S_0 + M_0 + W_0 + 2CW_0 + 6CWC_0$$

$$A_1 = 0.95S_1 + 0.95M_1 + 0.95W_1 + 1.9CW_1 + 5.7CWC_1$$

$$A_2 = 0.6S_2 + 0.75M_2 + 0.6W_2 + 1.2CW_2 + 3.6CWC_2$$

$$A_3 = 0.3S_3 + 0.5M_3 + 0.3W_3 + 0.6CW_3 + 1.8CWC_3$$

$$A_4 = 0.1M_4$$

$$A_5 = 0$$

$$A_{org} = S_{sum} + M_{sum} + W_{sum} + 2CW_{sum} + 6CWC_{sum}$$

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

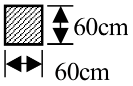
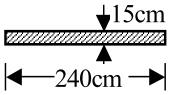
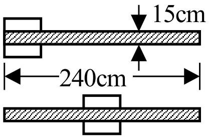
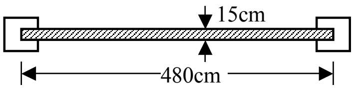
M_0, M_1, M_2, M_3, M_4, M_5, M_{sum} : Number of ductile columns having damage class 0 through V and their total number, respectively

W_0, W_1, W_2, W_3, W_4, W_5, W_{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_{sum} : Number of columns with wing wall(s) having damage class 0 through V and their total number, respectively

CWC_0, CWC_1, CWC_2, CWC_3, CWC_4, CWC_5, CWC_{sum} : Number of walls with boundary columns having damage class 0 through V and their total number, respectively

Table 4: Normalized Strength Index $\overline{C}$ for Simplified Procedure

	Ductile/Brittle Column	Wall w/o Boundary Column	Wing Wall and Column	Wall w/ Boundary Columns
Section				
$\tau_u (N/mm^2)$	1	1	2	3
$\overline{C}$	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 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.

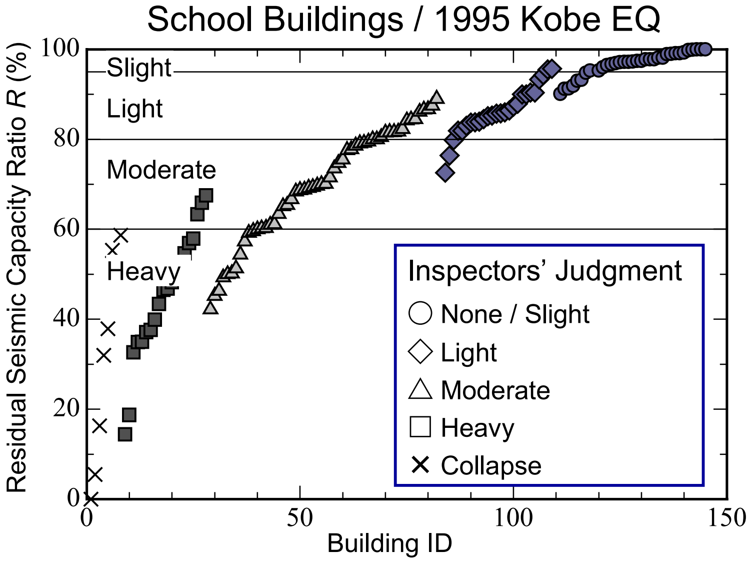


Figure 5: Residual Seismic Capacity Ratio *R* vs. Observed Damage

(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 $C_T \times S_D$ to conform with I_{SO} and 0.3 $Z \times G \times U$, 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.

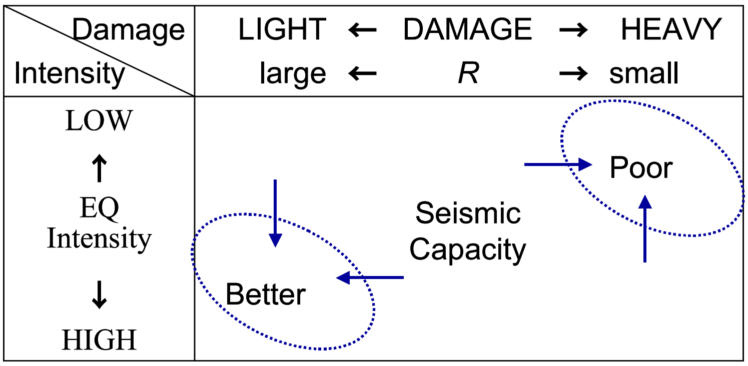


Figure 6: Basic Concept to Estimate Seismic Capacity

Table 5: Criteria for Temporary Restoration

Damage Intensity	[Slight] $95 \leqq R < 100$	[Light] $80 \leqq R < 95$	[Moderate] $60 \leqq R < 80$	[$\geq$ Heavy] $R < 60$
$\leq$ V$^-$ (lower)	×	×	×	×
V$^+$ (upper)	◎	△	△	△
VI$^-$ (lower)	◎	○ (△)	△	△
$\geq$ VI$^+$ (upper)	◎	◎ (○)	○ (△)	△

Note ◎: Continuing use after minor structural/non-structural repair
○: Continuing use after structural repair to restore initial seismic capacity
△: Continuing use not accepted until complete structural rehabilitation
×: 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

Table 7: Damage Evaluation Form

付表１　鉄筋および鉄骨鉄筋コンクリート造建築物の被災度区分判定調査表

整理番号：＿＿＿＿番　　調査日時：＿＿年＿＿月＿＿日　午前／午後＿＿時
調査回数：＿＿＿＿回目　　調査者：＿＿＿＿＿＿＿＿＿＿
所　属：＿＿＿＿＿＿＿＿＿＿

１．建築物概要

1.1　建築物名称　＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿
1.2　建築物所在地　＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿
1.3　所有者　＿＿＿＿＿＿＿＿　連絡先　＿＿＿＿＿＿＿＿
1.4　連絡者　＿＿＿＿＿＿＿＿　連絡先　＿＿＿＿＿＿＿＿
1.5　建物用途　□事務所　□住宅　□共同住宅　□店舗　□工場　□倉庫　□学校
（複数選択可）　□保育所　□庁舎　□公民館　□体育館　□病院　□その他（　　　）
1.6　構造種別　□鉄筋コンクリート造　□プレキャストコンクリート造　□ブロック造
□鉄骨鉄筋コンクリート造　□併用構造（　　　　造と　　　　造）
1.7　構造形式　□ラーメン構造　□壁式構造　□その他（　　　　　　）
1.8　基礎構造　□直接基礎　□杭基礎（種別　　　　　　）
1.9　建築物規模　地上＿＿階　地下＿＿階　塔屋＿＿階　1 階寸法：約＿＿m×約＿＿m
1.10　敷地の地形　□平坦地　□傾斜地　□台地　□凹地　□その他（　　　　　）
1.11　周辺の地形　崖から＿＿m　川・海・湖・沼から＿＿m（注：50m 以上の場合には記入不要）
1.12　外装仕上げ　□打放し　□モルタル　□タイル　□石貼り　□カーテンウォール
（複数選択可）　□PC 板　□ALC 板　□ブロック　□その他（　　　　　）
1.13　設計図書　構造計算書　□有　□無　設計図　□有　□無　施工記録　□有　□無
1.14　建設年代　＿＿＿＿年（□1971 年以前　□1972 年以降　□不明）

２．被災度の区分

2.1　建築物の崩壊・落階等による判定

崩壊、落階等の有無：□有（**2.3** へ：計算は省略し上部構造の被災度は［倒壊］とする）　□無（**2.2** へ）

2.2　基礎構造の沈下・傾斜による判定

基礎構造の被害
杭の被害の有無：□有　□無　□不明　液状化の有無：□有　□無　□不明

①　基礎の沈下量　S ＝＿＿＿＿m

②　基礎の傾斜角　θ_x ＝＿＿＿＿rad.　θ_y ＝＿＿＿rad.　$\theta = \sqrt{{\theta_x}^2 + {\theta_y}^2}$ ＝＿＿＿rad.

（0.01rad.＝0.573 度、1 度＝0.01745rad.）

表１　杭基礎建物の被災度区分

		基礎の沈下量 (m) 0　0.1　0.3			
基礎の傾斜		［無被害］	［小破］	［中破］	※
	1/300	［小破］	［中破］	［中破］	［大破］
	1/150	［中破］	［中破］	［大破］	［大破］
	1/75	［大破］	［大破］	［大破］	［大破］

表２　直接基礎建物の被災度区分

		基礎の沈下量 (m) 0.05　0.1　0.3			
基礎の傾斜		［無被害］	［小破］	※	※
	1/150	［小破］	［中破］	［中破］	※
	1/75	［中破］	［中破］	［大破］	［大破］
	1/30	［大破］	［大破］	［大破］	［大破］

※：想定外、要詳細調査

基礎構造の沈下・傾斜による被災度区分
□無被害　□小破　□中破　□大破

2.3　上部構造の耐震性能残存率 R による判定

①　被害の最も激しい階と方向　＿＿階　方向：□短辺方向　□長辺方向
②　ゾーニングの要否：□不要（建物全体で判定する）
□　必要（ゾーニングした区画を平面図などで明示し、区画ごとに判定する）
③　構造部材の損傷度調査結果　※（　　）内にそれぞれの柱本数や壁枚数を記入し合計を計算する。
「両側柱付壁」は、1 スパン分を 1 枚と数える。

	せん断柱	曲げ柱	柱なし壁	柱型付壁	両側柱付壁	合計	
総部材数	(　　) +	(　　) +	(　　) +	(　　) +	(　　) =	(　　)	
調査部材数	(　　)① +	(　　)② +	(　　)③ +	(　　)④ +	(　　)⑤ =	(　　)	
	①×1 +	②×1 +	③×1 +	④×2 +	⑤×6 =	(　　)	$= A_{org}$
損傷度 0	(　) +	(　) +	(　) +	(　)×2 +	(　)×6 =	(　　)	$= A_0$
損傷度 I	(　)×0.95 +	(　)×0.95 +	(　)×0.95 +	(　)×1.9 +	(　)×5.7 =	(　　)	$= A_1$
損傷度 II	(　)×0.6 +	(　)×0.75 +	(　)×0.6 +	(　)×1.2 +	(　)×3.6 =	(　　)	$= A_2$
損傷度 III	(　)×0.3 +	(　)×0.5 +	(　)×0.3 +	(　)×0.6 +	(　)×1.8 =	(　　)	$= A_3$
損傷度 IV	(　)×0 +	(　)×0.1 +	(　)×0 +	(　)×0 +	(　)×0 =	(　　)	$= A_4$
損傷度 V	(　)×0 +	(　)×0 +	(　)×0 +	(　)×0 +	(　)×0 =	0	$= A_5$

$$\sum A_j = A_0 + A_1 + A_2 + A_3 + A_4 + A_5 = (\qquad)$$

④　耐震性能残存率 R

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

上部構造の耐震性能残存率 R による被災度区分
□無被害（R＝100）　□軽微（95≦R＜100）　□小破（80≦R＜95）
□中破（60≦R＜80）　□大破（R＜60）　□倒壊（崩壊・落階等によりほぼ R　0 とみなせる）

３．その他の被害

付属構造物の被害（被害有の場合、被害状況、危険箇所、処置の要否などを記入する）
□床スラブ　：□無被害　□被害有（＿＿＿＿＿＿＿＿）
□ペントハウス　：□無被害　□被害有（＿＿＿＿＿＿＿＿）
□屋外階段　：□無被害　□被害有（＿＿＿＿＿＿＿＿）
□屋上煙突　：□無被害　□被害有（＿＿＿＿＿＿＿＿）
□渡り廊下　：□無被害　□被害有（＿＿＿＿＿＿＿＿）
□エキスパンションジョイント：□無被害　□被害有（＿＿＿＿＿＿＿＿）
□その他（＿＿＿＿＿＿）：□無被害　□被害有（＿＿＿＿＿＿＿＿）

４．復旧の要否の判定

気象庁震度階：□VI強以上　□VI弱　□V 強　□V 弱以下（要詳細調査）

表３　基礎構造の復旧の要否

被災度 / 震度階	小破	中破	大破
V 弱以下	×	×	×
V 強	△	×	×
VI弱	○	△	×
VI強以上	○	○	△

表４　上部構造の応急復旧の要否

被災度 / 震度階	軽微 95≦R＜100	小破 80≦R＜95	中破 60≦R＜80	大破・倒壊 R＜60
V 弱以下	×	×	×	×
V 強	◎	△	△	△
VI弱	◎	○（△）	△	△
VI強以上	◎	◎（○）	○（△）	△

※（　）は 1971 年以前の建物の場合

- **基礎構造の被災度：**□無被害　□小破　□中破　□大破
- **基礎構造の復旧の要否：**
  □不要（無被害）　□補修（○）　□補修（詳細調査が望ましい）（△）　□詳細調査（×）

- **上部構造の被災度：**□無被害　□軽微　□小破　□中破　□大破　□倒壊
- **上部構造の応急復旧の要否：**
  □不要（無被害）　□軽微な補修（◎）　□応急復旧（構造補修）（○）
  □応急措置または応急復旧（△）　□詳細調査（×）　□明らかに応急復旧不可能（倒壊）

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.

APPENIDX 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 *Is* at each story level in each principal direction of a building.

$$Is = Eo \times S_D \times T \quad (4)$$

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

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.

ϕ : 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.

S_D : 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.

$$Iso = Es \times Z \times G \times U \tag{5}$$

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 $C_T \times S_D$ defined in **Eq. (6)** is required to be larger than or equal to 0.3 $Z \times G \times U$ 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.

$$C_T \times S_D = \phi \times C \times S_D \tag{6}$$

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

(1) Seismic evaluation of the structure concerned. : Is and $C_T \times S_D$ are calculated.

(2) Determination of required seismic capacity: Iso is determined.

(3) Comparison of Is with Iso.

(if $Is < Iso$ or $C_T \times S_D < 0.3\ Z \times G \times U$ 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 $C_T \times S_D$ are checked.

REFERENCES

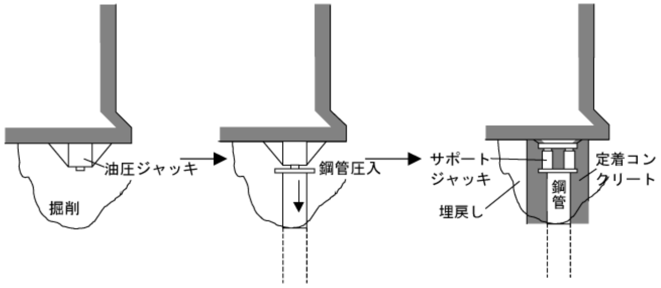
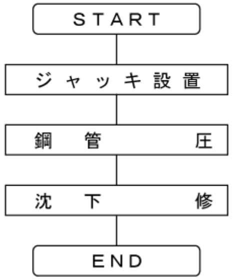
[1] The Japan Building Disaster Prevention Association, "Guideline for Post-earthquake Damage Evaluation and Rehabilitation", 1991 (revised in 2001). (in Japanese)

[2] The Japan Building Disaster Prevention Association, "Standard for Seismic Capacity Evaluation of Existing Reinforced Concrete Buildings", 1977(revised in 2001). (in Japanese)

[3] Masaki Maeda and Masahiro Bunno, "Post-earthquake damage evaluation for RC buildings based on residual seismic capacity in structural members", US-Japan Workshop on Performance Based Seismic Design of Reinforced Concrete Building Structures, Seattle, August 19-20, 2001

Figure 7: Rehabilitation Technique Example for Foundation

基礎補修技術シート　No. 1

補修方法	鋼管圧入による仮受け
補修目的	[✓ 1.沈下修正] 2.支持力確保　3.性能回復（曲げ・せん断・軸力）　4.耐久性回復　5.美観回復
参考図	
施工法・施工手順	 建物の自重を利用してジャッキで鋼管を圧入し、建物全体を仮受けした状態で沈下修正を行う。この方法は、支持層があまり深くなく、沈下を緊急に止める必要のある場合に有効な工法で,鋼管の圧入と同じに沈下を止めることができる。なお、定着コンクリートによって基礎フーチングの増設を行う場合には、基礎補修技術シート No.9 を参照されたい。

基礎補修技術シート　No. 2

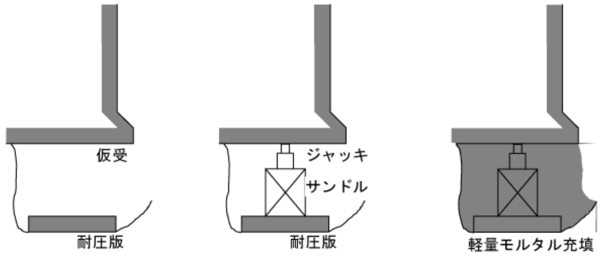
補修方法	耐圧版による仮受け
補修目的	[✓ 1.沈下修正] 2.支持力確保　3.性能回復（曲げ・せん断・軸力）　4.耐久性回復　5.美観回復
参考図	
施工法・施工手順	 沈下修正は、サンドル上に油圧ジャッキを設置し、ジャッキアップにより行う。定着コンクリートについては、支持地盤への荷重軽減と沈下修正による基礎下の空隙の充填を考慮して軽量盛土材（発泡モルタル）を使用する。なお、定着コンクリートによって基礎フーリングの増設を行う場合には基礎補修技術シート No.9 を参照されたい。

Figure 8: Rehabilitation Technique Example for Columns and Walls

復 旧 技 術 （[✓ 柱]・壁・梁・その他）

応急措置・復旧技術シート No. 12

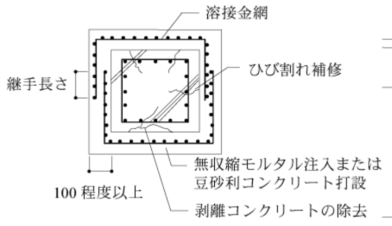
柱のせん断補強

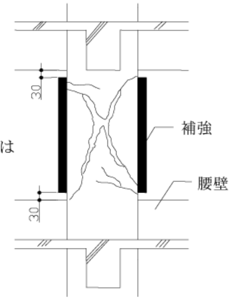
区分 [✓ 応急復旧]・[✓ 恒久補修]・[✓ 恒久補強]　**損傷度** Ⅱ・[✓ Ⅲ]・[✓ Ⅳ]・[✓ Ⅴ]

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.

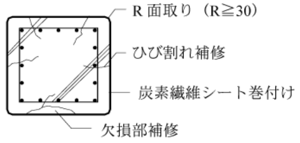
参考図

1．溶接金網による補強





2．炭素繊維シートによる補強



要点

- せん断補強を目的とする場合は，直交部材に対して 30mm 程度のスリットを設ける.
- 溶接金網の継手長さは最外端の縦筋寸法で測定し，溶接金網間隔に 10cm を加えた長さ以上とする.
- 炭素繊維シートの重ね代はメーカーの指定による.
- 炭素繊維シートの表面は不燃材で覆う.

施工手順

① 仕上げ材，剥離コンクリートの除去

② 溶接金網巻き	② 表面の調整
③ 型枠建て込み	③ ポリマー塗布
④ モルタル注入	④ 炭素繊維シート巻付け

復 旧 技 術 （柱・[✓ 壁]・梁・その他）

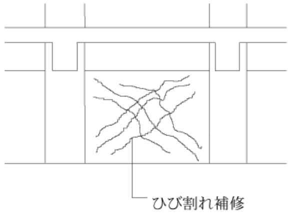
応急措置・復旧技術シート No. 17

壁のひび割れの補修

区分 [✓ 応急復旧]・[✓ 恒久補修]・恒久補強　**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.

参考図



ひび割れ部注入材

使 用 材 料		ひび割れ幅 (mm)
エポキシ樹　脂	低 粘 度	0.1 ～ 0.5
	中 粘 度	0.3 ～ 1.5
	高 粘 度	0.5 ～ 2.0*
セメントペースト	超微粒子	0.1 ～ 2.0
	一　　般	1.0 ～ 30.0

* 1995 年兵庫県南部地震では 5mm 程度のひび割れに適用された事例もあるが，このような比較的ひび割れ幅の大きい箇所に適用する場合は，施工性や補修効果を十分慎重に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注入材には，エポキシ樹脂を用いる.

施工手順

① 剥落コンクリートの除去
② 注入用シールの施工
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 欠損部の補修