AIJ Technical Guide for Temporary Restoration of RC School Buildings Damaged by 921 Chichi Earthquake

by

Yoshiaki Nakano[1]

ABSTRACT

An earthquake of a magnitude of 7.7 (USGS) occurred at 1:47 local time on September 21, 1999, with an epicenter near Chichi in the central part of the Republic of China (921 Taiwan Chichi Earthquake). This earthquake caused extensive damage to buildings and civil infrastructures, and more than 2,000 people were killed mainly due to devastating damage to reinforced concrete buildings.

Immediately after the earthquake, the Architectural Institute of Japan (AIJ) organized a reconnaissance team including the author based on the Agreement of Cooperation between Architectural Institute of the Republic of China (AIROC) and AIJ. They surveyed hardest-hit areas during October 13 through 21 under the cooperation of AIROC and recognized the urgency of cooperation on reconstruction of damaged communities. AIROC also requested technical cooperation for prompt recovery of damaged buildings, especially of low to medium-rise RC school buildings.

Following the request from AIROC, a second team to contribute to the prompt recovery from aftermath in the affected areas was again dispatched by AIJ during November 18 through 28, and proposed a technical guide applicable to RC school buildings in Taiwan through field surveys, several discussions and exchange of mutual knowledge and experiences.

In this paper, the outline of the AIJ technical guide for temporary restoration of RC school buildings damaged by 921 Chichi Earthquake is briefly presented.

INTRODUCTION

The 921 Taiwan Chichi Earthquake, which centered on the middle part of Taiwan, destroyed numerous buildings and facilities including low- to high-rise apartment houses, individual residences, school buildings, hospitals, public offices etc. Immediately after the event, the Architectural Institute of Japan (AIJ) dispatched the first reconnaissance team led by Prof. Akenori Shibata, Tohoku Bunka Gakuen University, to survey damaged areas.

After the earthquake, Architectural Institute of the Republic of China (AIROC) was in charge of reconstruction planning of school buildings. Although prompt recovery from the aftermath was most needed, rational guides on quantitative damage assessment, simplified seismic capacity evaluation procedures, decision criteria for repair, strengthening or demolition, and technical manuals for restoration were not available, and AIROC requested

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AIJ to cooperate on the restoration of damaged RC school buildings.

Following the request from AIROC, AIJ decided to dispatch an expert team on damage restoration. The team consisting of 6 members led by the author visited the damaged areas and discussed with researchers and structural engineers in Taiwan, and compiled a technical guide for temporary restoration which could be applied to damaged RC school buildings in Taiwan and held a technical seminar based on the guide.

OBJECTIVES AND SCOPE OF TEMPORARY RESTORATION

To restore a damaged community as quickly as possible, well-prepared reconstruction strategy and available technical guides, both of which need deep and wide discussions among engineers and governmental personnel prior to earthquake, are most essential. ***Figure 1*** shows an example of reconstruction strategy for earthquake damaged buildings, which is under discussion in Japan. As is shown in the figure, there may be several stages chronologically after the event in general. Although the detailed and practical flow should be determined after further discussions considering wide array of issues related to earthquake disaster planning and social system in each country, local authority and community, temporary restoration of damaged buildings can be the second action to be taken following quick inspections after a major earthquake.

Since the 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 second quasi-stable stage following the emergency stage, damage assessment should be more precisely and quantitatively performed, and then technically and economically sound solutions should be applied to damaged buildings, if restoration is needed. For this end, a technical and quantitative procedure, which is the main objective of the technical guide presented herein, should be well prepared.

The technical guide presented herein mainly focuses on the temporary restoration of RC school buildings for short- to mid-term use, where the seismic capacity of damaged buildings is upgraded to the original capacity before earthquake damage.

OUTLINE OF TECHNICAL GUIDE FOR TEMPORARY RESTORATION

(1) General Flow of Temporary Restoration Strategy

The Technical Guide (AIJ, 1999) for temporary restoration of damaged school buildings proposed by the second AIJ team consists of the following chapters:

1. Scope and Objectives of the Temporary Restoration of Damaged Buildings
2. Damage Assessment
3. Simplified Procedure for Seismic Capacity Evaluation of Original and Damaged Buildings
4. Temporary Restoration Instructions
5. Application Example

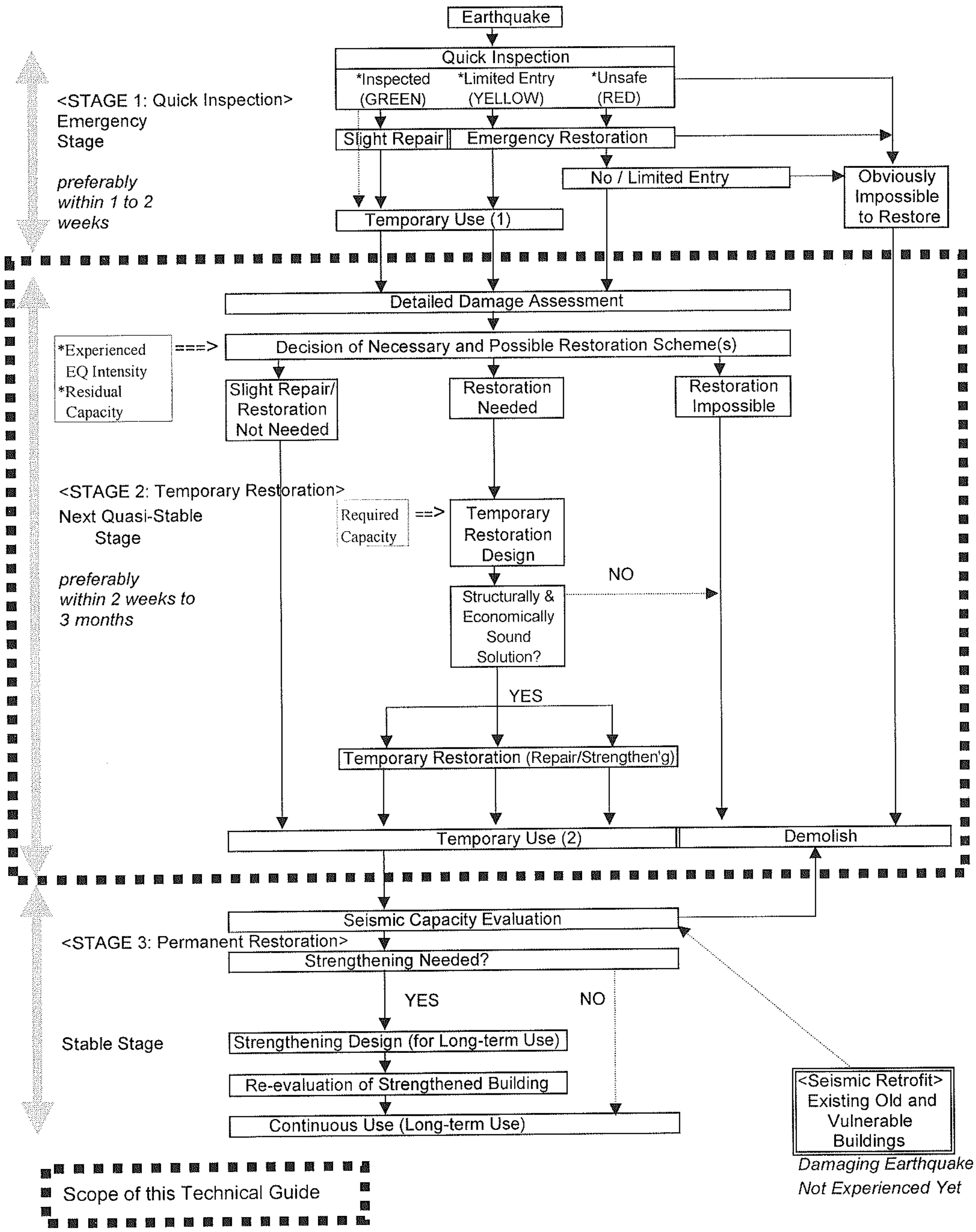
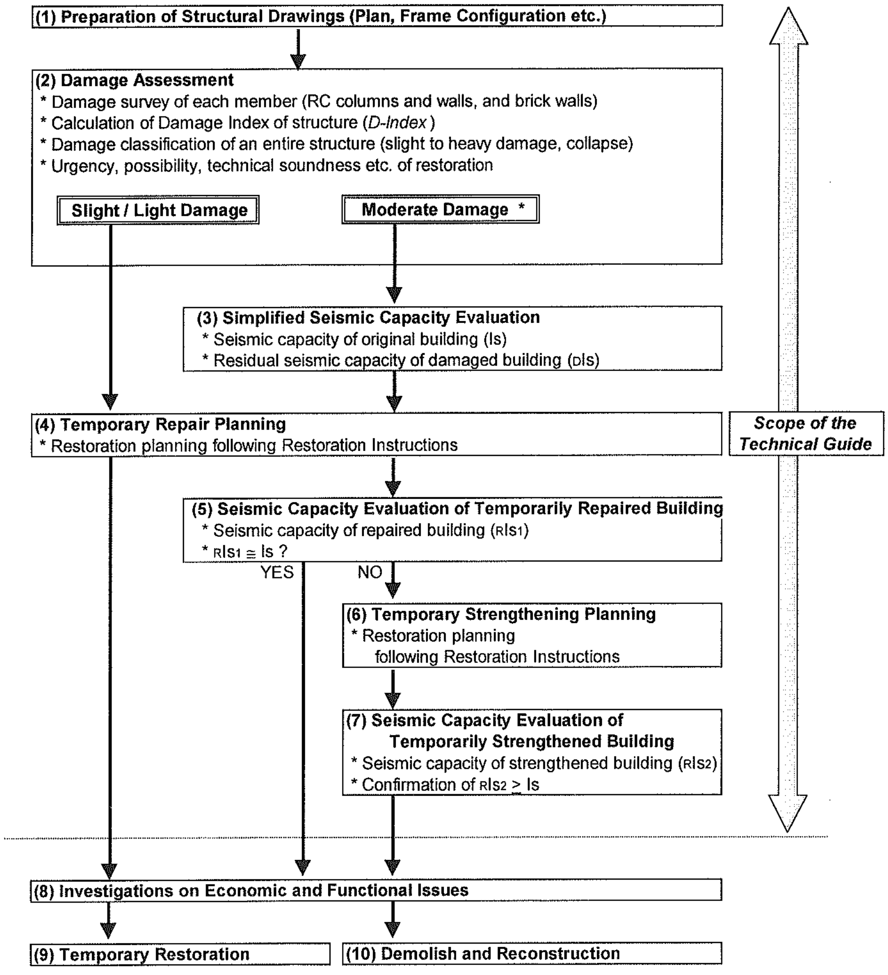


Figure 1: General Flow of Reconstruction Strategy

While discussing on the structural restoration of damaged buildings, damage to both foundation structures and superstructures must be carefully examined and available restoration techniques should be applied to each structure. However, restoration of foundation structures is in general rather costly and the variety of available techniques and solutions can be much wider than superstructures. Note that the Guide is therefore focusing on the temporary restoration techniques of superstructures.

Figure 2 shows a general flow of the temporary restoration of damaged buildings described in the Technical Guide. In the Guide, key words which are essential to understand the concept of the temporary restoration are also defined. Definitions of several essential key words are described below. In ***Figure 3*** are illustrated the basic concepts of the key words.



** The Technical Guide recommends not to use heavily damaged buildings even when they are temporarily upgraded to the original seismic capacity.*

Figure 2: General Flow of Temporary Restoration of Damaged Buildings

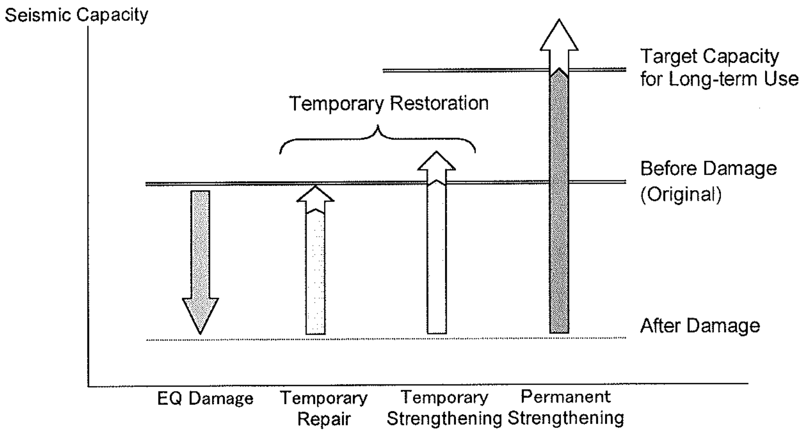


Figure 3: Basic Concept on Temporary Repair, Temporary Strengthening and Permanent Strengthening

Temporary restoration defines actions to damaged buildings and their surrounding environment to ensure and upgrade structural safety and function for short- to mid-term use, which are temporarily carried out for several months to around one year until their demolition or permanent restoration. It is further subdivided into *temporary repair* and *temporary strengthening* depending on the level of restoration. In this Technical Guide, it is fundamentally aiming to recover the original seismic capacity of members and/or an entire structure.

Permanent restoration defines actions to damaged buildings and their surrounding environment to ensure and upgrade structural safety and function for long-term use. For this purpose, the damaged buildings should be retrofitted against a future major earthquake in addition to aftershocks.

Temporary repair defines actions to damaged members and/or subassemblage to upgrade their structural capacity. It includes repair of cracked members using epoxy resin etc., which is focusing on the recovery of their original capacity. It should be noted that their seismic capacity may not be fully recovered only by temporary repair when they are heavily damaged, and strengthening may be needed in some cases.

Temporary strengthening defines actions to damaged members and/or subassemblage to upgrade their structural capacity to the level of or higher than the original. It includes steel or RC jacketing techniques of temporarily repaired columns, installation of additional structural members such as RC walls, steel braces etc. Seismic capacity of temporarily strengthened members and/or subassemblage need to be confirmed through technical evaluation based on related technical guides, if their capacity higher than the original is taken into account in evaluating their improved capacity.

In the following sections, basic concept and procedures described in chapters 1 through 4 will be briefly presented. An application example will be discussed elsewhere.

(2) Damage Assessment

To seek possible restoration teahniques, quantitative damage assessment of the target building is first needed. In the Guide, a check sheet for damage assessment is proposed as shown in ***Table 1***, which is essentially based on the Japanese Standard for Damage Level Classification (JBDPA, 1991). ***Table 1*** containes following items:

1. General discription of building

1.1 building name, 1.2 address, 1.6 structural type, 1.9 number of stories, 1.14 construction year etc.

2. Damage to building

2.1 Settlement of building (S m) [Damage Level Classification (1)]

❒None (S=0) ❒Light (0<S≤0.2m) ❒Moderate (0.2m<S≤1m) ❒Heavy (1m<S)

2.2 Tilting of building (θ rad.) [Damage Level Classification (2)]

❒None (θ=0) ❒Light (0<θ≤0.01) ❒Moderate (0.01<θ≤0.03) ❒Heavy (0.03<θ≤0.06) ❒Collapse (0.06<θ)

2.3 Damage to RC columns, RC walls and brick walls [Damage Level Classification (3)]

$D = 10\,B_1/A + 26\,B_2/A + 60\,B_3/A + 100\,B_4/A + 1000\,B_5/7A$

Bi : number of RC columns categorized in damage class i (i = I to V) shown in ***Figure 4*** and ***Table 2***

A : number of inspected members in each story

❒None (D=0) ❒Slight (0<D≤5) ❒Light (5<D≤10) ❒Moderate (10<D≤50) ❒Heavy (50<D) ❒Collapse (D_5=50)

3. Other damage observed

Falling/overturning hazards such as penthouse, exterior stairways, etc.

4. Damage class of entire building

Judgement from maximum damage observed in questions 2.1 through 2.3 above.

❒None ❒Slight ❒Light ❒Moderate ❒Heavy ❒Collapse

5. Sketches and comments

* *Items listed above correspond to those shown in* ***Table 1.***

As was often observed in RC buildings damaged during 921 Taiwan Chichi Earthquake, brick walls which are widely used but generally considered non-structural members in structural design calculations often had severe damage, and their restoration was therefore identified a major concern in the temporary restoration. Since the original Japanese Standard for Damage Classification does not include damage assessment of brick walls, their damage survey is added in the check sheet. Damage definitions of RC members and brick walls, and their sample photos are shown in ***Figure 4*** and ***Table 2***, respectively. It should be also noted that discussion results with researchers and engineers in Taiwan are incorporated in defining brick wall's damage shown in ***Figure 4*** and ***Table 2***.

Damage to brick walls should be considered to categorize the damage level of an entire structure. However, since the original formulations for damage index D (JBDPA, 1991) to define the damage level of an entire structure is based only on RC column damage to simplify calculations, damage to brick and RC walls are provisionally neglected in the damage level classification as shown in 2.3(6) of ***Table 1*** and the definition of *D-Index* described in the above box, while their contribution to the seismic capacity of an entire structure, as will be discussed later, is taken into account. It should be therefore noted that a more rational formulation to represent damage level needs to be developed in the future considering contribution of wall damage to entire damage category through further discussions and calibrations.

Table 1 : Check Sheet for Damage Assessment

表2.1 鉄筋コンクリート造学校建築物の被災度区分判定調査表（案）

整理番号：_____番　調査日時：______年_____月_____日 午前／午後_____時～_____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 □学校 □その他（ ）
1.6 構造種別 □RC造 □その他（ ）
1.7 壁の構造 □RC造 □煉瓦造 □その他（ ）
1.8 基礎構造 □直接基礎□杭基礎（種別 ） □不明
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
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 □不明

2．建築物全体の沈下・傾斜による判定

杭の被害の有無：□有 □無 □不明　液状化の有無：□有 □無 □不明

2.1 建築物全体の沈下による判定 ① 最大沈下量 S=______m

□無被害（S=0m） □小破（0m<S≦0.2m） □中破（0.2m<S≦1.0m） □大破（1.0m<S）

2.2 建築物全体の傾斜による判定

① x方向傾斜角 θx=_________radian
② y方向傾斜角 θy=_________radian
③ 最大傾斜度 $\theta = \sqrt{\theta x^2 + \theta y^2}$ =_________radian

□無被害（θ=0） □小破（0<θ≦0.01） □中破（0.01<θ≦0.03）
□大破（0.03<θ≦0.06） □倒壊（0.06<θ）

2.3 構造体の損傷割合による判定

①被害の最も激しい階		_____階			
				煉瓦造壁	RC造壁
②柱の総本数A_0		=_____本	壁の総枚数	=_____枚	=_____枚
③調査した柱本数A		=_____本	調査した壁枚数	=_____枚	=_____枚
④調査柱率A/A_0		=_____%	調査壁率	=_____%	=_____%
⑤各損傷度の柱本数Bi					
損傷度Ⅴ	B_5	=_____本	損傷度Ⅴ	=_____枚	=_____枚
損傷度Ⅳ	B_4	=_____本	損傷度Ⅳ	=_____枚	=_____枚
損傷度Ⅲ	B_3	=_____本	損傷度Ⅲ	=_____枚	=_____枚
損傷度Ⅱ	B_2	=_____本	損傷度Ⅱ	=_____枚	=_____枚
損傷度Ⅰ	B_1	=_____本	損傷度Ⅰ	=_____枚	=_____枚
損傷度0	B_0	=_____本	損傷度0	=_____枚	=_____枚

⑥柱の損傷度に対応するDiの計算

損傷度Ⅴ $D_5 = \min(1000B_5/7A =$_______, 50) = _______
損傷度Ⅳ $D_4 = \min(100B_4/A =$_______, 50) = _______
損傷度Ⅲ $D_3 = \min(60B_3/A =$_______, 30) = _______
損傷度Ⅱ $D_2 = \min(26B_2/A =$_______, 13) = _______
損傷度Ⅰ $D_1 = \min(10B_1/A =$_______, 5) = _______
$D = \Sigma(D_1 \sim D_5) =$ _______

□無被害（D=0） □軽微（D≦5） □小破（5<D≦10）
□中破（10<D≦50） □大破（50<D） □倒壊（D_5=50）

3．その他

付属構造物の被害（被害有の場合，危険箇所の指定，処置の要否などを記入する）

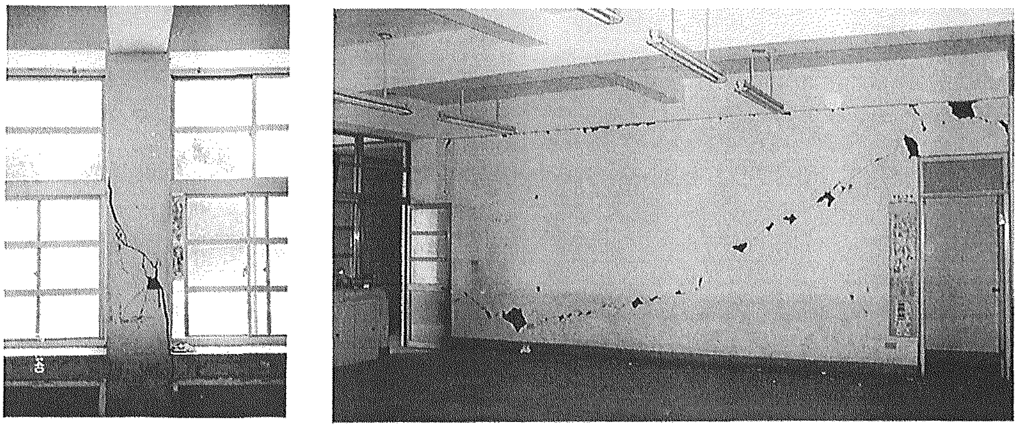
□ペントハウス：□無被害 □被害有（ ）
□屋外階段 ：□無被害 □被害有（ ）
□屋上煙突 ：□無被害 □被害有（ ）
□渡り廊下 ：□無被害 □被害有（ ）
□Exp.Joint ：□無被害 □被害有（ ）
□その他（ ）：□無被害 □被害有（ ）

4．被災度区分判定結果

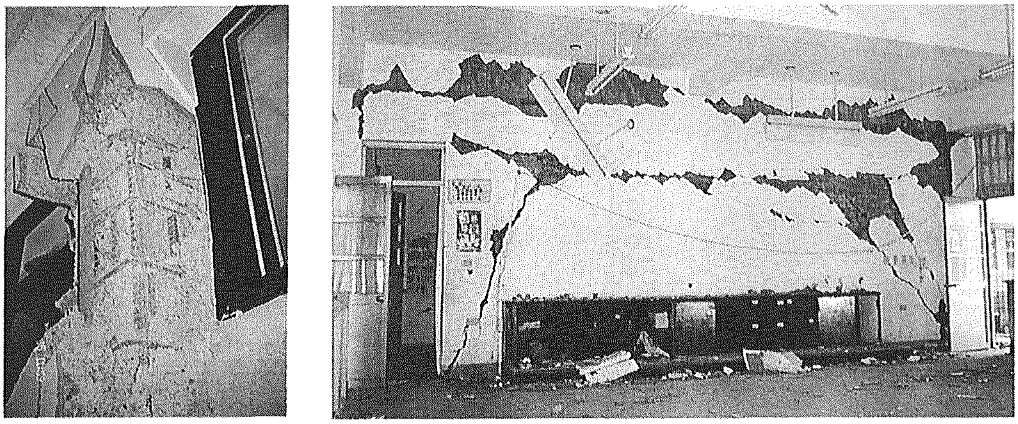
「2.1」,「2.2」,「2.3」の被災度区分のうち最も大きい被災度

□無被害 □軽微 □小破
□中破 □大破 □倒壊

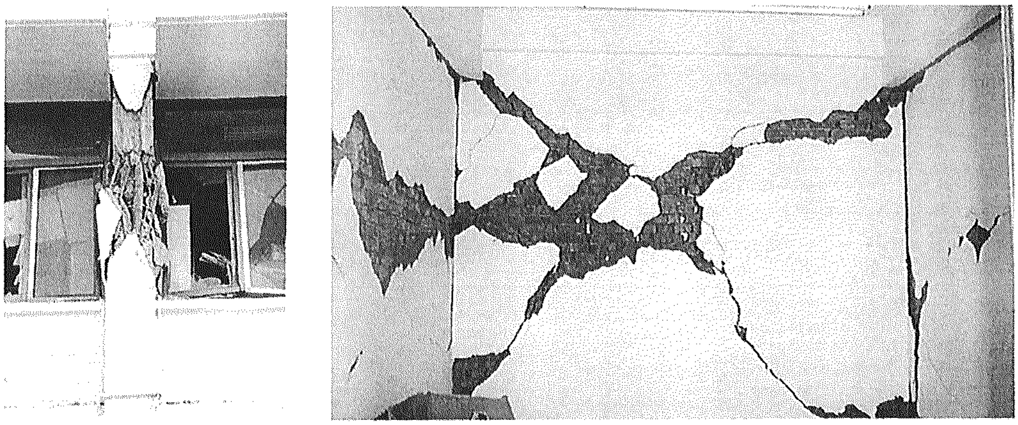
5．被災部分のスケッチ，所見等のメモなど



Damage Class III



Damage Class IV



Damage Class V

Figure 4: Damage Example Photos (left: RC columns / right: brick walls)

Table 2: Definition of Damage Class

(a) 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 deformation in columns and/or walls - Visible settlement and/or inclination of the building

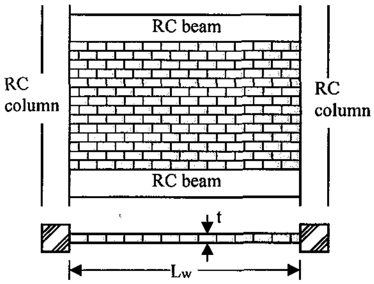
(b) Brick walls

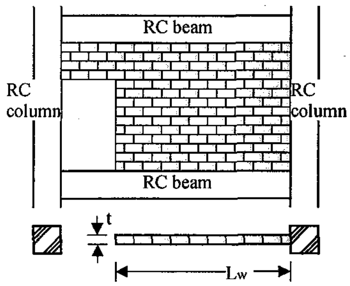
Damage Class	Description of Damage
I	- Visible narrow cracks at interfaces between brick walls and boundary RC members (i.e., columns or beams)
II	- Visible clear cracks at interfaces between brick walls and boundary RC members (i.e., columns or beams), but slight shear cracks and/or spalling of finishing at corner(s) on brick wall
III	- Clear shear cracks and/or slippage of brick wall, and spalling of finishing
IV	- Extensive shear cracks, slippage and/or spalling of finishing - Spalling of some bricks
V	- Massive spalling of bricks - Out-of-plane deformation of brick wall

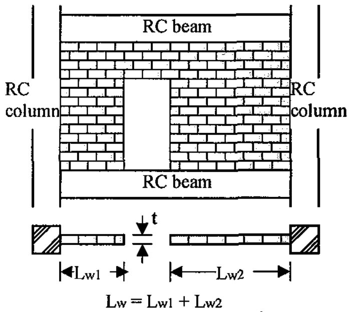
(3) Seismic Capacity Evaluation

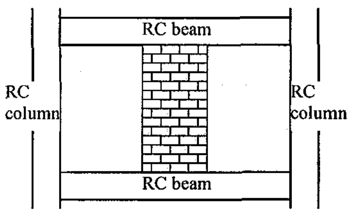
Seismic capacity index *Is* is defined by ***Eq. (1)***. Although the basic concept is essentially based on the Japanese Standard for Seismic Capacity Evaluation (JBDPA, 1990), a calculation procedure is simplified and modified from the observed evidence of damaged buildings, i.e., (a) most of the damaged buildings failed in a brittle manner and (b) brick walls highly contributed to the overall structural performance. Member ductility is therefore neglected in the Guide while sectional properties such as re-bar arrangement, sectional size, material strength etc. are taken into account in calculating shear and flexural strengths of columns. Furthermore, the contribution of wall strength to overall lateral resistance of a building is considered through its sectional area A_w and the ultimate shear stress τ_w. ***Figure 5*** illustrates definitions of typical brick wall types and their ultimate shear stress τ_{bw}, where the values of τ_{bw} are determined considering the past experimental results carried out in Taiwan.

<table>
<tr><th>Definition and Ultimate Shear Stress Proposed</th><th>Sketch</th></tr>
<tr><td>Brick walls which have no openings and their four sides are confined by RC boundary members.

$$\tau_{bw} = 6\left(kg/cm^2\right)$$
$$A_w = t \cdot Lw$$</td><td>
</td></tr>
<tr><td>Brick walls which have opening(s) but their three sides are confined by either RC beams or RC columns.

$$\tau_{bw} = 2\left(kg/cm^2\right)$$
$$A_w = t \cdot Lw$$</td><td>


</td></tr>
<tr><td>Others defined above.

$$\tau_{bw} = 0\left(kg/cm^2\right)$$</td><td>
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</table>

Figure 5: Definitions of Brick Wall Types and Their Ultimate Shear Stress

$$Is = Eo \times S_D \times T \qquad (1)$$

where, Eo : Basic structural index, estimated by Strength Index (C), Ductility index (F), and Story Index $(n+1)/(n+i)$ at each story and each direction when the story or building reaches at the ultimate limit state due to lateral force. In the Guide, Eo is defined as the larger value of the following ***Eqs. (2)*** and ***(3)***.

$$E_0 = \frac{n+1}{n+i}\{(C_{sc} + C_{bw}) + 0.7(C_c + C_w)\} \times F_1 \qquad (2)$$

$$E_0 = \frac{n+1}{n+i}(C_c + C_w) \times F_2 \qquad (3)$$

n : Number of stories.

i : Story level concerned.

Csc : Shear coefficient of short columns.

Cc : Shear coefficient of columns other than short columns.

Cw : Shear coefficient of RC walls.

Cbw : Shear coefficient of brick walls.

Cj (j=sc, c, w or bw) is calculated from the following equation.

Cj =Σ[lateral resistance of member j in i-th story]/ [weight of building above]

F_1 : Ductility index of short columns and brick walls. (=0.8)

F_2 : Ductility index of columns and RC walls. (=1.0)

S_D : Modification factor, estimated by stiffness discontinuity along stories, eccentric distribution of stiffness in planes, irregularity of framing, etc. In the Guide, S_D index of a building is simply defined as $S_D = S_{D1} * S_{D2}$, where S_{D1} = 0.9 when it has plan irregularity and S_{D2} = 0.9 when it has elevation irregularity.

T : Reduction factor, estimated by the grade of deterioration. Considering that the Guide aims to upgrade the damaged building to the original capacity, T is simply assumed 1.0.

To discuss necessary actions to damaged buildings, the relationship between their original and residual capacity can be most informative. To estimate the residual seismic capacity of damaged buildings, capacity reduction factors η corresponding to each damage class of members are proposed in the Guide as shown in ***Table 3***. The seismic capacity index of damaged building $_DIs$ can be therefore calculated from the original capacity and reduction factors η of each member.

In the Guide, decision criteria for necessary actions are proposed as follows:

(1) When the seismic capacities of original (Is) and damaged buildings ($_DIs$) are almost same ($_DIs$ / $Is \geq 0.95$ is proposed in the Guide), temporary repair is not necessarily required.

(2) When $_DIs$ is lower than Is ($_DIs$ / $Is < 0.95$ is proposed in the Guide), temporary repair is required based on the Instructions for Temporary Restoration which will appear subsequently. The seismic capacity of repaired building ($_RIs_1$) is then calculated considering the recovery factors ψ shown in ***Table 4***.

(3) If $_RIs_1$ is still lower than Is ($_RIs_1$ / $Is < 0.95$), then temporary strengthening is required.

Each technique available for temporary repair and strengthening can be found in the following section.

Table 3: Capacity Reduction Factors η due to Damage

Damage Class	RC Columns/Walls	Brick Walls
I	0.95	0.95
II	0.7	0.7
III	0.3	0.3
IV	0	0
V	0	0

Table 4: Capacity Recovery Factors ψ after Temporary Repair

Damage Class	RC Columns/Walls	Brick Walls
I	0.95$^{(1)}$ - 1.0	0.95$^{(1)}$ - 1.0
II	0.95 - 1.0$^{(2)}$	0.90 - 1.0$^{(2)}$
III	0.9 - 1.0$^{(2)}$	1.0$^{(3)}$
IV	0.8 - 1.0$^{(2)}$	1.0$^{(3)}$
V	0.7 - 0.9$^{(2)}$	1.0$^{(3)}$

In case of (1) no repair, (2) careful design and good workmanship, and (3) reconstruction of brick wall, respectively.

(4) Instructions for Temporary Restoration

In the Technical Guide, approximately 30 restoration techniques are instructed. They include emergency restoration technique and temporary restoration techniques. ***Figure 6*** shows an example of temporary restoration techniques for RC columns compiled in the Guide.

CONCLUDING REMARKS

The AIJ Technical Guide for temporary restoration of RC school buildings damaged due to 921 Taiwan Chichi Earthquake is briefly described. Although the Guide still contains issues which need further investigations and discussions, the author strongly desire that the Guide can lead to a more rational and practical guide for RC buildings through further researches in Taiwan.

REFERENCES

AIJ/Architectural Institute of Japan, "Technical Guide for RC School Buildings damaged by 1999.9.21 Taiwan Chichi Earthquake", November 1999, 120 pp., (in Japanese)

JBDPA/Japan Building Disaster Prevention Association, "Standard for Evaluation of Seismic Capacity of Existing Reinforced Concrete Buildings," 1977, revised in 1990. (in Japanese)

JBDPA/Japan Building Disaster Prevention Association, "Standard for Damage Level Classification and Guideline for Rehabilitation of Damaged Buildings," 1991. (in Japanese)

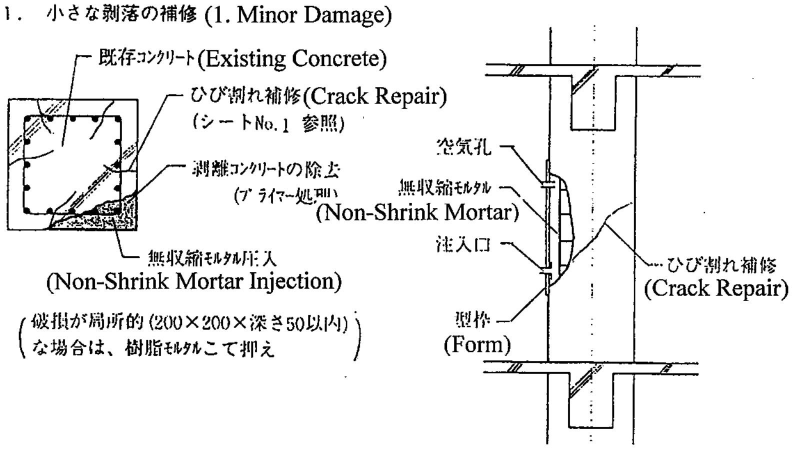
Temporary Restoration of RC Columns	Instruction Sheet No. 2
応急復旧技術（柱・壁・梁・その他）	応急復旧技術シート No. 2

No. 2 Mortar Injection and/or Concrete Casting — Applicable Damage Class

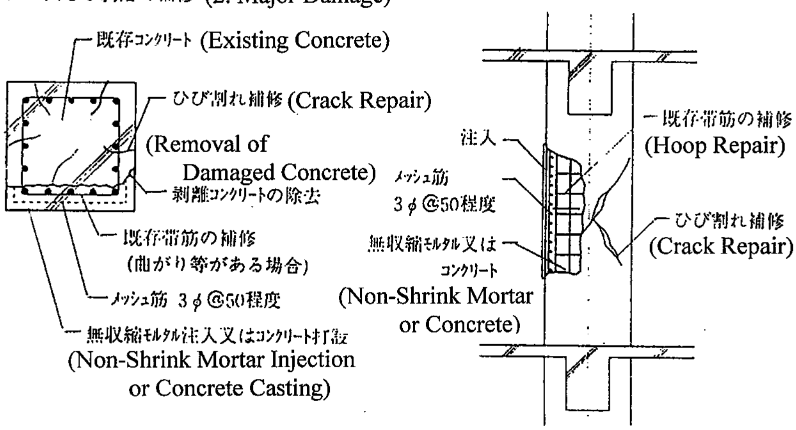
No. 2	柱へのモルタルの注入・コンクリート打設	復旧レベル
区分	応急補修 ・ 応急補強 ・ 恒久補修 ・ 恒久補強	II・III・IV・V
目的	被りコンクリートが剥落した柱に，モルタルまたはコンクリートを打設し，構造性能の回復を図る． **Objective**: Recovery of seismic capacity of RC columns with spalling of covering concrete through mortar injection and/or concrete casting.	

参考図

1．小さな剥落の補修 (1. Minor Damage)



2．大きな剥落の補修 (2. Major Damage)



Repair Procedure

1. Removal of Damaged Concrete
2. Repair of Cracked Concrete
3. Repair of Hoops
4. Form Setting
5. Non-shrink Mortar Injection and/or Concrete Casting

(Some English keywords are added to the original sheet in Japanese.)

Figure 6: Temporary Repair Techniques for RC Columns with Concrete Spalling