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POST-EARTHQUAKE INSPECTION AND EVALUATION OF EARTHQUAKE DAMAGE IN REINFORCED CONCRETE BUILDINGS

Hajime Umemura[1], Masaya Murakami[2], Tsuneo Okada[3], Masamichi Ohkubo[4]
Shunsuke Otani[5], Katsumi Takiguchi[6], Hisahiro Hiraishi[7]

[1]Department of Architect, University of Tokyo, Bunkyo-ku, Tokyo, Japan
[2]Department of Architectural Eng., Chiba University, Chiba-shi, Japan
[3]Institute of Industrial Science, University of Tokyo, Minato-ku, Tokyo, Japan
[4]Kyushu Institute of Design, Fukuoka-shi, Japan
[5]Department of Architecture University of Tokyo, Bunkyo-ku, Japan
[6]Tokyo Institute of Technology, Meguro-ku,Tokyo, Japan
[7]Building Research Institute, Tsukuba-shi, Japan

SUMMARY

As a part of Coordinated Technical Project on the Development of Methods for Repair and Retrofit of Earthquake Damaged Structures, three types of guidelines for reinforced concrete buildings have been developed in Japan for identification of earthquake damage and for counterplans after earthquake. After the September 19-20, 1985 Mexico Earthquakes, the guidelines were partially modified and were applied to twenty buildings in Mexico City. This paper describes the outline of each guideline and the results of application.

INTRODUCTION

After major earthquakes, quick inspection of damage grade of buildings is urgently requested to prevent the increase of loss of human lives and properties caused by aftershocks. Then, temporary strengthening works, evaluation of remaining seismic capacity, detail studies for repairing and strengthening for each building should be followed to restore the functioning of these buildings damaged by earthqakes. For the purpose, three types of guidelines for reinforced concrete buildings have been developed in Japan for identification of earthquake damage, as a part of the Coordinated Technical Project on the Development of Methods for Repair and Retrofit of Earthquake Damaged Structures (Refs. 1-4). They are called 1) Guideline for Quick Inspection of Safety (Quick Inspection), 2) Guideline for Damaged Evaluation - Level 1 (First Level Evaluation) and 3) Guideline for Damage Evaluation - Level 2 (Second Level Evaluation).

"Quick Inspection" has two fundamental objectives. The first objective is to inspect a risk of collapse of severely damaged buildings against following aftershocks, and to suggest the prohibition of entrance to the building if it is considered to be dangerous. The second objective is to inspect the safety of nondamaged and slightly damaged vital buildings, and to determine the suitability of use as a shelter for rescue, evacuation and rehabilitation.

The objectives of "First Level Evaluation" are to classify the damage level of buildings and to decide the necessary treatments to be applied after damage evaluation, such as re-use without any structural repairs, re-use after repairing and/or strengthening, or demolition without restoration. If necessary, the decision of risk level by "Quick Inspection" may be replaced by the decision by "First Level Evaluation". The damage evaluation in this stage is made primarily on the basis of remaining seismic capacity of the structure, but its estimation is rather approximate. Therefore, if the judgement for the treatment after

evaluation is difficult, "Second Level Evaluation" may be required.

"Second Level Evaluation" is used to judge the necessity of strengthening for damaged buildings, whose damage level is not clear only by "First Level Evaluation". "Second Level Evaluation" is also used to obtain the basic informations about the strengthening design.

After the September 19-20, 1985 Mexico Earthquakes, three types of guidelines were partially modified and were applied to twenty reinforced concrete buildings in Mexico City. The modifications were made , so that "Guidelines" could be applied to flat slab structures, so called "Losa Planna" and "Waffle Slab" structures.

GUIDELINE FOR QUICK INSPECTION OF SAFETY

Following items should be investigated: 1) overall inclination of a building, 2) overall settlement of a building, 3) damages of structural members, 4) possible overturning of the chimnies, exterior staircases, and others, 5) possible falling of the exterior finishings, exterior curtain walls, signboards fixed on the exterior walls, and others.

The investigation is made primarily from outside of building for the urgent screening of damaged buildings which may increase earthquake hazard by aftershocks. If necessary, however, the safety inside the building should be carefully investigated in addition to the above items for the decision on the suitability of use, especially as a shelter for rescue, evaluation and rehabilitation. The investigation is carried out using the prescribed mannual and completing the inspection sheets and may be completed in half an hour for a building.

Damage for the overall inclination and settlement of a building and for the structural members at the most severely damaged story should be classified from (a) to (c), as shown in Table-1, where damage ranking IV and V of structural members are determined according to Table-2. Damage degree (a) can be tolerable, whereas (c) is dangerous. However, damage degree of possible overturning and falling objects may be determined using the practical experience of an inspector.

On the basis of evaluated damage degree of structural members and possible overturning and falling objects, the risk level of the building against following aftershocks is determined as Class C, B, A, X, by the following criteria;
Class C: 1) If one or more c-degree, or two or more b-degree items exist in structural members, the entire building shall be determined as "Class C", 2) if a c-degree item exists in possible overturning and falling objects, the surrounding area of overturning and falling objects shall be also determined as "Class C". The building and the surrounding area determined as "Class C" shall be posted "Off-Limits", and the entrance shall be generally prohibited.
Class B: If one b-degree item exists in structural members, and possible overturning and falling objects, the building and the surrounding area shall be determined as "Class B" and be posted "Entry Limited".
Class A: This judgement is applied only to buildings investigated inside. If b or c-degree items do not exist in possible overturning and falling objects and if damage greater than damage ranking III shown in Table-2 does not exist in structural members, the building may be determined as "Class A" and shall be posted "Safe". Class X building should be examined more in detail in the following procedure, which includes buildings not investigated inside.

GUIDELINE FOR DAMAGE EVALUATION-LEVEL 1

The same investigation items as in "Quick Inspection" are provided, but

more detailed investigation than "Quick Inspection" is required. The investigation is made by building or civil engineers.

The evaluation criteria for overall inclination and settlement are shown in Table-3 and Table-4, respectively. The damages of structural members are evaluated in the most severely damaged story of the building, and the result is identified using Table-5. The story Damage Ratio $\Sigma d_i(\%)$, shown in Table-5, is caluculated as the sum of Damage Ratios at each damage ranking. The damage ranking of individual structural members and the damage ratio of each damage ranking are determined by Table-2.

Table-6 shows general relationships between the seismic intensity, the damage class of a building and the treatment after damage evaluation by First Level Evaluation. This implies that lower-seismic-capacity buildings would be damaged by a lower-seismic intensity.

GUIDELINE FOR DAMAGE EVALUATION-LEVEL 2

The necessity of repairing and/or strengthening for the soil, foundations and piles against future earthquake should be decided by a criterion based on the observed inclination angle, settlement level, soil condition and intensity of the earthquake. The criterion has been proposed based on the results of research on the 1964 Niigata Earthquake.

The necessity of repairing and/or strengthening for the building against future earthquake should be decided by a criterion based on the remaining seismic capacity and the observed intensity of the earthquake. The Damage Index ϕ is defined by the equation(1).

$$\phi = (1 - I_S'/I_S) \times 100 (\%) \qquad (1)$$

where, I_S is Seismic Index of Structure (Ref. 1) and I_S' is the reduced one after damage computed based on the reduced strength and stiffness of each structual member. The reduction factors have been proposed based on the results of experimental tests and so on, whitch depend on the damage ranking and the type of failure. The criterion has been proposed based on the results of research on the 1968 Tokachioki and 1978 Miyagioki Earthquakes and so on.

APPLICATION AND RESULTS

"Quick Inspection" and "First Level Evaluation" were applied to twenty reinforced concrete buildings in Mexico City. The results of their damage classes are shown in Table-7 together with the results judged by the engineers in Mexico, and both results agree with each other. "Second Level Evaluation" was applied to the No.1 building shown in Table-7, and the building was judged to be strengthened.

CONCLUDING STATEMENTS

The modified "Earthquake Damage Evaluation" were applied to twenty reinforced concrete buildings in Mexico City and the reasonable results were obtained. When considering the state of damaged buildings in Mexico City, however, in terms of economics is essentially required an earthquake damage evaluation for nonstructural elemens in ductilemoment-resisting-frame buildings. But this is the subject for future studies and is beyond a scope of this paper.

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REFERENCES

1. "Guideline for Evaluation of Seismic Capacity of Existing Reinforced Concrete Buildings", Japan Association for Building Disaster Prevention, 1977. (in Japanese)
2. Japan International Cooperation Agency Mission "Recommendations on Damage Evaluation, Repair and Strengthening for Buildings Damaged by the September 19-20, 1985 Mexico Earthquake", November 21, 1985.
3. M. Ohkubo and T. Okada, "The Outline of Post-Earthquake Damage Evaluation Guidelines of Reinforced Concrete Buildings", Paper for International Conference on Reconstruction, Restoration and Urban Planning of Towns and Regions in Seismic Prone Areas", Skopje, Yugoslavia, November 5-9, 1985.
4. S. Ohtani, "Emergency Standard for Classification of Risk Levels of Earthquake Damaged Reinforced Concrete Buildings", Paper for Third Meeting on the Evaluation of Structures for Seismic Hazard, Tokyo, May 17, 1985.

Table-1 Inspection Items and Damage Degree (for Quick Inspection)
(Inspected from outside of a building) Reference 2

Inspection Items	Damage Degree		
	Degree a	Degree b	Degree c
1. Overall inclination of a building	Less than 1°	1° - 2°	More than 2°
2. Largest settlement at a corner of a building	Less than 0.2m	0.2 - 1.0m	More than 1.0m
3. Damages of structural members			
(a) Frame type structure "Losa Plana" (Waffle Slab) *1			
* Ratio of exterior columns with Damage Ranking IV	Less than 10%	10 - 20%	More than 20%
* Ratio of exterior columns with Damage Ranking V *2	Less than 1%	1 - 10%	More than 10%
(b) Box type structure			
* Ratio of exterior wall length with Damage Ranking IV	Less than 10%	10 - 20%	More than 20%
* Ratio of exterior wall length with Damage Ranking V	Less than 1%	1 - 10%	More than 10%
(Following items inspected from inside shall be added to ensure the safety.)			
(c) Frame type structure "Losa Plana" (Waffle Slab) *1			
* Ratio of interior columns with Damage Ranking IV	Less than 10%	10 - 20%	More than 20%
* Ratio of interior columns with Damage Ranking V *2	Less than 1%	1 - 10%	More than 10%
(d) Box type structure			
* Ratio of interior wall length with Damage Ranking IV	Less than 10%	10 - 20%	More than 20%
* Ratio of interior wall length with Damage Ranking V	Less than 1%	1 - 10%	More than 10%

Note 1) Damage ranking of columns are replaced by more severe damage ranking of beams, and "losa plana" or waffle slab attached to them as shown in Commentary on Application.

2) Columns above the column with damage ranking V, except columns replaced as Note 1, are classified into damage ranking V.

Table-2 Damage Ranking of Structural Members and Structural Damage Ratio
Reference 2)

Ranking	Damage State of Structural Members	Existing Ratio of Damaged Members	Damage Ratio : d_i(%) *1
I	* Visible narrow crack on surface of concrete (Crack width is less than 0.2 mm.)	Less than 10%	0.5
		10 20	1
		20 30	2
		30 40	3
		40 50	4
		More than 50%	5
II	* Visible clear crack on surface of concrete (Crack width is about 0.2 ~ 1.0 mm.)	Less than 5%	0.5
		5 10	1
		10 15	2
		15 20	4
		20 25	5
		25 30	6
		30 35	8
		35 40	9
		40 45	10
		45 50	11
		More than 50%	13
III	* Local crush of covered concrete * Remarkably wide crack (Crack width is about 1 ~ 5 mm.)	Less than 3%	2
		3 5	3
		5 10	5
		10 15	8
		15 20	10
		20 25	13
		25 30	15
		30 35	18
		35 40	20
		40 45	23
		45 50	25
		More than 50%	30
IV	* Remarkable crush of concrete with explosure of reinforcing bar * Spalling of covered concrete	Less than 3%	3
		3 5	5
		5 10	9
		10 15	14
		15 20	18
		20 25	23
		25 30	27
		30 35	32
		35 40	36
		40 45	41
		45 50	45
		More than 50%	50
V	* Bending of reinforcing bar * Crush of core concrete * Visible vertical deformation of column (or wall) * Visible settlement and/or inclination of floor	Less than 3%	4
		3 5	7
		5 10	14
		10 15	21
		15 20	27
		20 25	34
		25 30	40
		30 35	48
		More than 35%	50

Note 1) Damage Ratio d_i(%): Assumed reduction ratio of seismic capacity for the story of a building

Table-3 Identification of Damage due to Overall Inclination
Reference 2)

Overall Inclination angle θ; (rad.)	$\theta < \frac{1}{100}$	$\frac{1}{100} \leq \theta < \frac{3}{100}$	$\frac{3}{100} \leq \theta < \frac{6}{100}$	$\frac{6}{100} \leq \theta$
Damage Class	Small or Slight (2)	Moderate (3)	Severe (4)	Collapse (5)

Table-4 Identification of Damage due to Settlement
Reference 2)

Maximum Settlement S; (m)	$S < 0.2$	$0.2 \leq S \leq 1.0$	$1.0 < S$
Damage Class	Slight (2)	Moderate (3)	Severe (4)

Table-5 Identification due to Damage of Structural Members
Reference 2)

Maximum Damage Ratio Σd_i (%)	$\Sigma d_i \leq 5$	$5 < \Sigma d_i \leq 10$	$10 < \Sigma d_i \leq 50$	$50 < \Sigma d_i$
Damage Class	Slight (1)	Small (2)	Moderate (3)	Severe (4)*1 Collapse (5)

Note 1) Building with the story where structural members of damage ranking V occupy more than 50% of all shall be judged as Collapse.

Table-6 Recommended Permanent Treatments for Damaged Buildings
Reference 2)

Seismic Intensity*1	Identification of Damage and Permanent Treatments				
	Slight	Small	Moderate	Severe	Collapse
Less than or equal to VIII			Repairing or Strengthening (Second Level Check)	Strengthening or Demolition	Strengthening or Demolition
Greater than or equal to IX	Re-use	Re-use	Repairing	Repairing or Strengthening (Second Level Check)	Strengthening or Demolition

Note 1) Modified Mercalli Scale

Table- 7 Results of Application

Building	Number of Story above the Ground/Basement	Use (Type)	Damage Class for Quick Inspection	Damage Class for First Level	Judgement by Mexican Technician
1	12/1	Office Building	Off Limit	Severe (Structure)	Reuse by Strengthening
2	4/0	School Building	Off Limit (Falling, Overturning)	Moderate (Structure)	-
3	4/0	School Building	Off Limit (Falling, Overturning)	Slight (Structure)	-
4	9/0	Apartment House (I)	Off Limit	Severe (Structure)	Structure (Severe)
5	9/0	Apartment House (I)	Entry Limited (Falling, Overturning)	Moderate (Inclination)	Nonstructure (Severe)
6	14/0	Apartment House (K)	Off Limit (Structure, Falling, Overturning)	Severe (Structure, Inclination)	Structure (Severe)
7	14/0	Apartment House (K)	Entry Limited (Structure, Falling)	Moderate (Structure, Inclination)	Nonstructure (Severe)
8	9/0	Apartment House (B)	Detail Investigation (Including Damage Rank III)	Slight	Nondamage
9	9/0	Apartment House (B)	Safe	Slight	Nonstructure (Severe)
10	24/2	Apartment House (M)	Entry Limited (Falling)	Slight	Structure (Moderate)
11	24/2	Apartment House (M)	Entry Limited (Inclination)	Moderate (Inclination)	Structure (Severe)
12	15/0	Apartment House (C)	Entry Limited (Overturning)	Small (Structure, Settlement)	Structure (Moderate)
13	15/0	Apartment House (C)	Entry Limited (Overturning)	Slight	Nonstructure (Severe)
14	14/0	Apartment House (L)	Off Limit (Falling)	Small (Structure)	Structure (Moderate)
15	14/0	Apartment House (L)	Off Limit (Falling)	Slight	Nonstructure (Severe)
16	6/0	Office Building	Off Limit (Structure, Falling)	Collapse (Structure)	-
17	9/1	Office Building	Off Limit (Structure)	Severe (Structure)	-
18	8/1	Apartment House	Off Limit (Structure, Falling)	Severe (Structure)	-
19	9/0	Department Store	Off Limit (Structure, Falling)	Collapse (Structure)	-
20	8/0	Building	Off Limit (Structure)	Severe (Structure)	-