EMERGENCY GUIDELINE FOR CLASSIFICATION OF RISK LEVELS OF EARTHQUAKE DAMAGED REINFORCED CONCRETE BUILDINGS

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ABSTRACT

As a part of Coordinated Technical Project on the Development of Repair and Strengthening Techniques for Buildings and Structures Damaged by Earthquakes, initiated in 1981 by Ministry of Constructiont Guidelines for Post-Earthquake Inspection and Evaluation of Earthquake Damage in Reinforced Concrete Buildings were developed. This paper describes the Guideline for Emergency Inspection and Evaluation for Hazard Risk of Damaged Buildings toward Aftershocks, which is intended for technical officers of a municipal government to evaluate a risk of damaged buildings immediately after earthquake hazards and to determine safe public buildings for use as places for evacuation and medical treatment. Damages of structural members, possible falling and overturning objects are to be investigated by external observation of a building.

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INTRODUCTION

A Coordinated Technical Project on the Development of Repair and Strengthening Techniques for Buildings and Structures Damaged by Earthquakes, was initiated in 1981 by Ministry of Construction, Japan, to prepare the measures to recover the area affected by a major earthquake. The project consists of two parts; i.e., (a) civil engineering constructions and (b) building constructions. As a part of the project, Guidelines for Post-Earthquake Inspection and Evaluation of Earthquake Damages were developed for reinforced concrete construction, steel construction, and timber construction. The Guidelines for Post- Earthquake Inspection and Evaluation of Earthquake Damages for Reinforced Concrete Buildings were developed by Sub-Committee on Reinforced Concrete Buildings (T. Okada, chairman). The guidelines consist of (1) Guideline for Emergency Inspection and Evaluation for Hazard Risk of Damaged Buildings toward Aftershocks, (2) Guidelines for the First-Level Inspection and Evaluation to Identify the Damage of Buildings for Continued Occupancy, and (3) Guideline for the Second-Level Inspection and Evaluation used to Judge the Necessity of Structural Strengthening. The Guideline for Emergency Inspection and Evaluation (drafted by S. Otani) is intended for non-structural technical officers of a municipal government to determine a risk of damaged buildings immediately after earthquake hazards. The Guideline for First-Level Inspection and Evaluation (drafted by K. Takiguchi) is used to estimate the damage approximately a week after the earthquake. The Guideline for Second-Level Inspection and Evaluation (drafted by M. Okubo) examines the repairing and retrofitting needs of a severely damaged building and assists the planning of a repair job.

This paper describes the emergency guideline, ,in which damages of structural members, possible falling of objects, and possible overturning of objects are taken into account.

OBJECT AND SCOPE

A main earthquake is normally followed by many after-shocks of comparable or smaller intensities, which might further develop the damage of a building. Therefore, immediately after a damaging earthquake, it is urgent to determine the risk of severely damaged buildings. If a building is shown to be dangerous, the public should be kept away from the building and the use of such a building must be prohibited. If there exists any concern about the safety of a building, the public should be warned against the use of the building. At the

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same time, it is important to identify safe buildings which can be used as a shelter for evacuation or a place for medical treatment. This decision must be made immediately by local governments of the affected area probably without the assistance of professional and knowlegeable structural engineers.

This guideline is used for reinforced concrete frame-type and boxed-type structures in the area suffered from a strong earthquake to investigate possible hazards towards human lives inside as well as outside a damaged building, taking into account the risk of collapsing of the building by possible after-shocks and falling and overturning of interior and exterior finishings and mechanical equipments. Based on the results of investigation, the building may be prohibited from entering or warned against regular use. The guideline examines all public buildings in the affected area for possible usage as shelters for evacuation and places for medical treatment.

METHOD OF INVESTIGATION

The investigation should be carried out within one or two days after an earthquake. A person in charge of the investigation may not be a structural engineer, but an ordinary building or civil engineer of the local government. The investigation may be completed in half an hour for a building, following a manual. No instrument may be required during this investigation.

It is not possible, in a limited time, to investigate all buildings in an affected area and evaluate a risk against human hazards by possible after-shocks. Hence, a private building is investigated only when its occupant reports a severe damage. On the other hands, all public buildings, eligible for use as a shelter and a place for medical treatment, should be investigated.

The outline of a building, including name, address, owner, contacting person, usage, number of stories above and under ground, type of structure (frame or box-type construction), types of exterior finishings, must be recorded. The investigation is made normally from outside of a building for
(1) state of structural damages,
(2) possible falling objects, and
(3) possible overturning objects.
A public building, however, must be investigated from inside and outside for
(1) state of structural damage,
(2) possible falling objects,
(3) possible overturning objects, and
(4) suitability as a place for shelter or medical treatment.

The degree of structural damage is determined by the observation of external appearances of the most severely damaged story. The investigation includes
(1) largest settlement at a corner of a building due to failure of sub-structure,
(2) overall inclination of a building due to failure of sub-structure,
(3) damages in columns of frame structures or walls of box-type structures; i.e., as the existence and degree of the cracking of concrete, the crushing and spalling of concrete, and the bending and fracture of reinforcing bars. The classification of damage levels of structural members is defined in Appendix "Classification of Damage Levels of Structural Members".

The falling of heavy or sharp-pointed objects might injure the passers-by along the building or persons coming into or going out from the building. Window glasses, exterior curtain walls, exterior finishings, penthouse roofs, balconies, parapets, chimneys, emergency staircases, machine equipments, cooling towers, pent houses, ceilings, lighting equipment, air conditioning equipment and others may fall and should be carefully examined especially for those located right above an entrance. The criteria for possible falling and accompanying risk may vary from an object to another depending on the geometry, weight, fixity, and damage of the object. The practical wisdom should be exercised in determining the degree of risk. The risk may be reduced if a balcony exists under the falling object.

Heavy overturning objects can jeopardize passers-by. Therefore, the emergency staircases, machine equipments, vending machines, fuel containers, masonry fences, book cases, lockers, tables, desks, display shelves, doors, and others should be examined for a possible overturning. Again, the criteria for possible overturning and accompanying risk may vary from an object to another depending on the geometry, weight, fixity, and damage of the object. The practical wisdom should be exercised in determining the risk.

RISK LEVELS

Risk levels of a building and structural members may be classified from A to C, where risk level A can be tolerable, whereas risk level C is dangerous. The risk levels are briefly described below;

a) Risk Level C:

1) A corner of a building settles more than 1.0 m due to the failure of sub-structure, such as piles, foundation, or soil.
2) A building tilts more than 2 degrees due to the failure of the sub-structure.
3) More than 20 per cent of external columns of a frame construction (or external walls of box-type construction) suffer damage greater than or equal to Damage Level 4 (see Appendix "Classification of Damage Levels of Structural Members").
4) More than 10 percent of external columns of a frame construction (or external walls of a box- type construction) suffer damage greater than or equal to Damage Level 5.

b) Risk Level B:

1) A corner of a building settles more than 0.2 m due to the failure of sub-structure.
2) A building tilts more than 1 degrees due to the failure of sub-structure.
3) More than 10 per cent of external columns of a frame construction (or external walls of box-type construction)

suffer damage greater than or equal to Damage Level 4.
4) More than 1 percent of external columns of a frame construction (or external walls of a box-type construction) suffer damage greater than or equal to Damage Level 5.

c) Risk Level A:
A damage state not included in either damage states C or B.

The failure of sub-structure such as foundation, piles, and soil may cause the settlement and tilting of an entire structure, sometimes without accompanying structural damage, as shown in Fig. 1. Such tilting or settlement of an entire building caused by failure of the sub-structure is called "overall tilting" or "overall settlement". The structure may also be tilted by the failure of structural members such as columns, walls, and beams, as shown in Fig. 2. The latter is called "partial inclination" and may be classified into two cases; i.e., the sloping of slabs due to the collapse of columns, and inclination of columns due to a large lateral deflection. In these cases, severe damage can be observed in either columns or walls. Therefore, the damage in the vertical structural members may be examined to define the damage rate instead of measuring an inclination angle of columns, walls, or slabs. Sometimes, a large lateral deflection may accompany severe damage in girders, but the.damage in girders is normally difficult to observe hidden by ceilings. At the same time, the angle of inclination is difficult to measure with the eye. Therefore, the damage in girders is not included herein. If a large side-sway deflection is observed clearly attributable to the damage in girders, the damage may be estimated as "overall tilting" of the building.

The measurement of inclination and settlement is made with the eye. When the angle of inclination becomes approximately 1 to 2 degrees, the lateral deflection becomes 1/60 to 1/30 of the story height. In other words, the lateral deflection becomes 6 to 12 cm for a normal story height of approximately 3.5m. When the overall angle of inclination exceeds 2 degrees (Fig. 3), or the settlement at a corner exceeds 1.0 m (Fig. 4), anyone can judge the building to be dangerous from external appearances.

The decision of risk should be based on the remaining resistance of a building. However, instead of structural analysis, a simple method is used; i.e., if structural members suffer damage less than damage level 3, then the structure is assumed to maintain the original resistance. It is beneficial for the public safety to overestimate the risk and keep the public away from a damaged building because the investigation has to be completed in a limited time and by an inexperienced officer. In case of a large earthquake, the criteria for a safe building may be loosened to increase the usable number of shelters for evacuation and places for medical treatment.

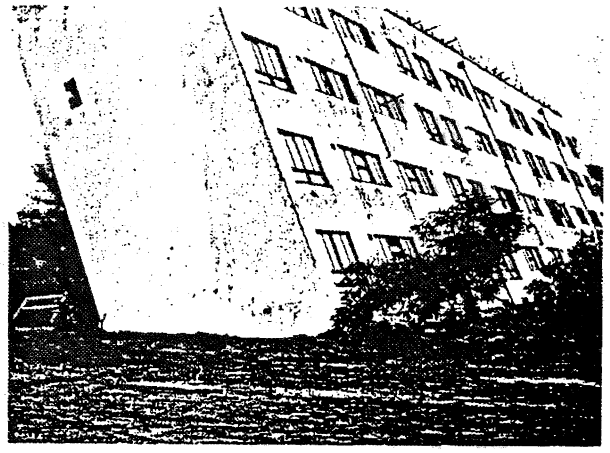


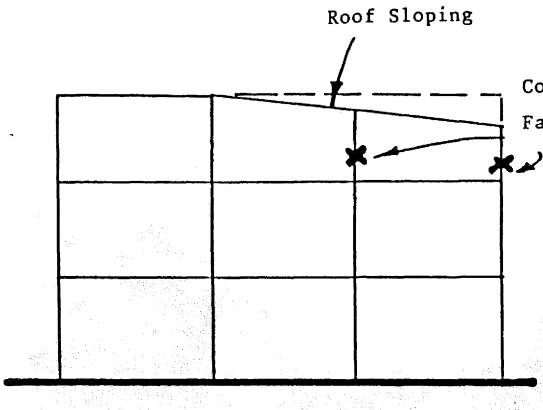
FIGURE 1 - EXAMPLE OF OVERALL SETTLEMENT AND INCLINATION (Ref. 1, 1964 Niigata Earthquake)

If more than 10 percent of columns in a frame building or walls in a box-type building suffer damages hard to imagine the original shape (damage level 5), and the floors above and the roof are observed to sink, the lateral resistance against after-shocks may be judged insufficient. Such columns and walls are doubtful to expect a resistance even against gravitational loads. In this case, the structure can be determined to be dangerous (Fig. 5). The occupant can normally judge the building to be dangerous using their own practical wisdom.

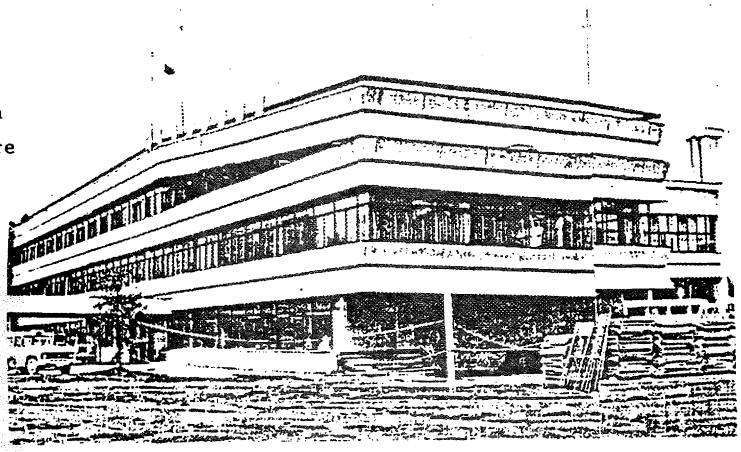
In order to examine the safety of a building, the survey of structural damage is not sufficient. Exterior and interior finishings, curtain walls and wthdow glasses may be broken and fall to the ground. Therefore, the area of possible falling objects is dangerous. The overturning objects should also be examined. The risk levels of possible falling and overturning objects are not defined herein, but rather the evaluation is relied on the practical wisdom of investigators because the criteria for possible overturning and accompanying risk may vary from an object to another depending on the geometry, weight, fixity, and damage of the object. Further study is necessary to establish the criteria.

DETERMINATION OF RISK

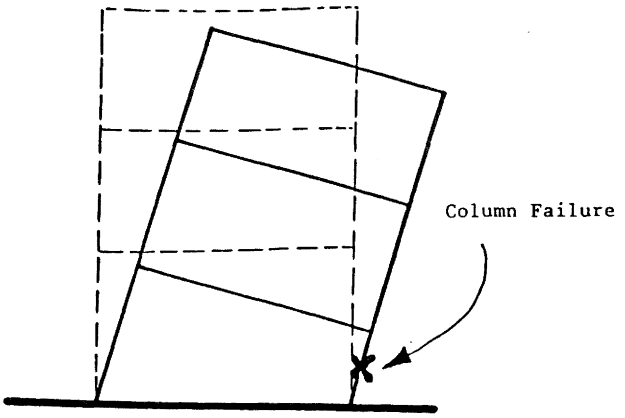
On the basis of observation about damages of structural members, possible falling objects, and possible overturning objects, the risk of a building is determined as (1) danger, (2) caution, and (3) safe. The classification of safe is applied only to public buildings because the public buildings need be assured for safety when they are used for evacuation and medical treatment. Those buildings classified neither as danger nor as caution are not necessarily safe, but non-public buildings



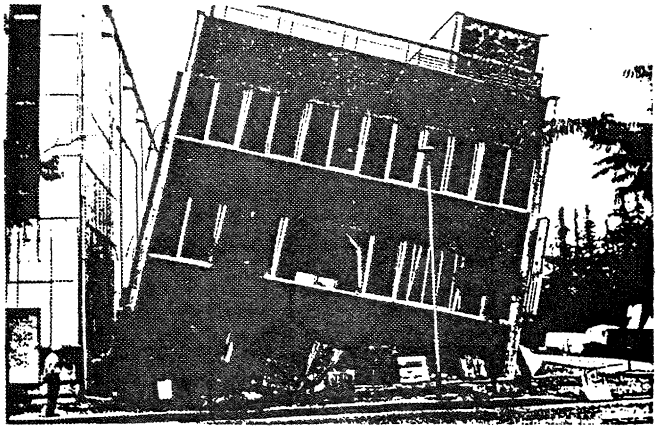
(a) CONCEPTUAL VIEW OF PARTIAL INCLINATION (Partial sloping of slab due to column failure)



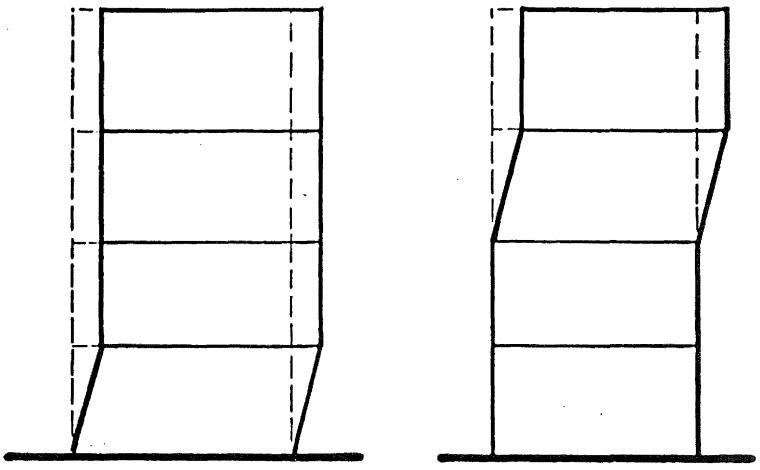
(b) EXAMPLE OF PARTIAL SLOPING IN THIRD STOREY (Ref. 2, 1968 Tokachi-Oki Earthquake)



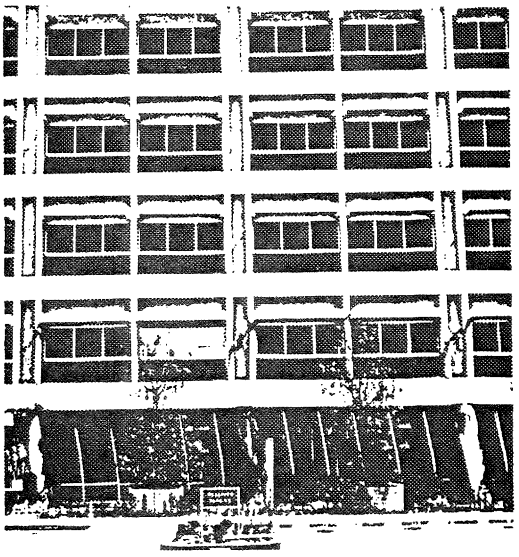
(c) CONCEPTUAL VIEW OF PARIAL SLOPING (Failure of first story column)



(d) EXAMPLE OF PARTIAL TILTING DUE TO COLUMN FAILURE (1978 Miyagiken-Oki Earthquake)



(e) CONCEPTUAL VIEW OF PARTIAL INCLINATION (Large column deflection)



(f) EXAMPLE OF PARTIAL INCLINATION DUE TO COLUMN DEFLECTION (1971 San Fernando Earthquake)

FIGURE 2 - EXAMPLES OF PARTIAL INCLINATION

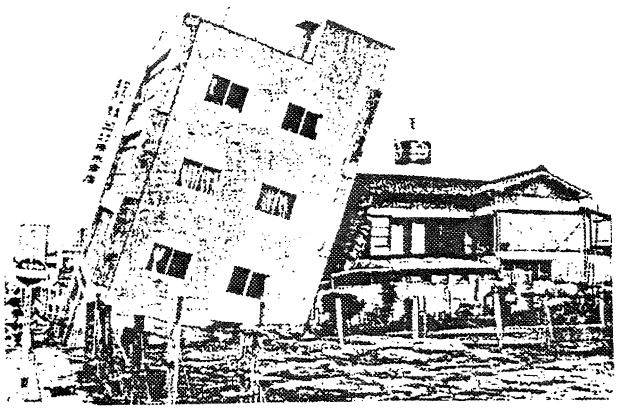


FIGURE 3 - EXAMPLE OF OVERALL INCLINATION OF MORE THAN TWO DEGREES (Ref. 1, 1964 Niigata Earthquake)

FIGURE 4 - EXAMPLE OF OVERALL SETTLEMENT OF MORE THAN 1.0M (Ref. 1, 1964 Niigata Earthquake)

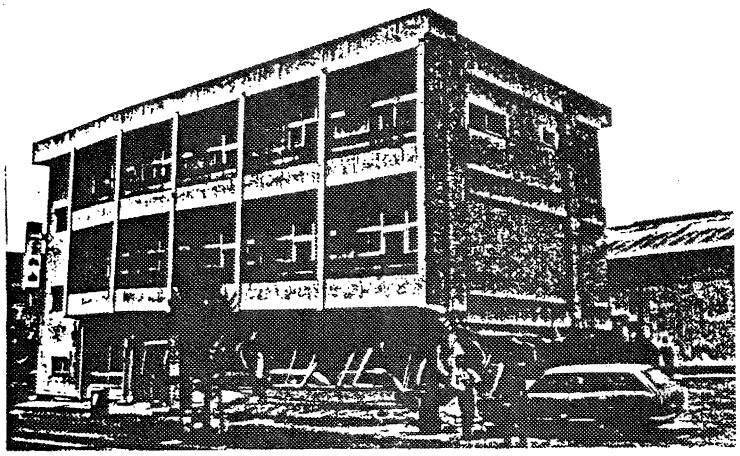


FIGURE 5 - EXAMPLE OF MORE THAN 10% OF FIRST STORY COLUMNS DAMAGED BEYOND A RECOGNISABLE STATE (1978 Miyagiken-Oki Earthquake)

are to be investigated only when they are heavily damaged and when some assistance is requested for the risk evaluation. A building should be identified as "completed" after investigation.

A building or a part of a building is classified to (a) danger, (b) caution, or (c) safe by the following criteria:

a) Danger:
(1) the entire structure if more than one C-rank or two B- rank risk level items exist in structural damages ,
(2) the area of heavily damaged columns (or walls) of damage level 4 or 5 to the nearest healthy (damage level 3 or less) columns (or walls) and that above the designated area if columns (or walls) suffer damage of level 5,
(3) all the stories above the floor where the staircases are heavily damaged,
(4) the area of possible falling objects if the risk is rated C,
(5) the area of possible overturning objects if the risk is rated C.

b) Caution:
A building where risk level B items exist in the survey of structural damages, possible falling and overturning objects.

c) Safe:
A public building with no structural damage greater than damage level 3 and free from any risk level B nor C items in possible falling and overturning objects. The damage to interior columns in a frame type construction (or interior walls in a box-type construction) should be evaluated in a manner identical to those of exterior structural members. The availability of city water, city gas, electricity, and sanitary facilities, usability of staircases, the safety of entrances, the storage of dangerous materials should be examined before the final decision is made.

ACTIONS

The purpose of the emergency guideline is to determine whether an area is safe or dangerous, and not to recommend to remove dangerous falling objects nor to suggest any reinforcement to the damage. Such actions should be taken after the emergency decisions have been made for entire buildings of the affected area. The following actions should be taken;

a) Danger:
(1) When an entire building has been classified to "danger", the building and area one-half of the height away from the building shall be posted "No entrance". However, a reinforced concrete building within the designated area may be exempted as long as its entrance does not fall into the prohibited area.
(2) The area of a part of a building classified to danger shall be posted "No entrance" only in that area.
(3) When falling objects are classified to "danger", the area within the radius equal to the height of the falling objects shall be posted "No entrance".
(4) When overturning objects are classified to "danger", the area within the radius

equal to the height of the overturning objects shall be posted "No entrance".

The area posted "No entrance" should be prohibited to enter except for those who investigate damages and those specially permitted by the local government.

b) Caution:
Those buildings classified to "caution" shall be posted "Warning against entrance".

The area posted "Warning against entrance" is not recommended to enter. In other words, those associated with the building may go into the building with caution only when it is necessary. The public is not allowed to go into the building. For example, in a commercial building, the employees may go into the building, but the facilities should not be used for business.

c) Safe:
Those public building classified to "safe" shall be posted "safe".

Public buildings not classified to "safe" shall not be used as a shelter for evacuation nor as a place for medical treatment.

REMOVAL OF BAN

If a structural engineer of the local government or that approved by the local government investigates the damage of a building in details, and judges the building to be safe, the decision of risk about the structure, possible falling or overturning objects may be removed. The emergency guideline is not perfect, but rather a guiding rule. Therefore, if a person with sufficient knowledge about the performance of the reinforced concrete gives a decision different from the guideline after a detailed investigation, the revised decision should be respected with the approval of the local government. If a dangerous item is removed or strengthened, the ban to enter the area may be removed with the approval of the local government.

ACKNOWLEDGEMENT

The work reported in this paper is a product of discussion in Sub-Committee on Reinforced Concrete Buildings chaired by Professor Tsuneo Okada. The members of the sub-committee are T. Goto, H. Hiraishi, M. Murakami, M. Ohkubo, S. Otani, K. Takiguchi, H. Tsukagoshi, M. Yoshimura. The suggestions and discussions by the sub-committee members are deeply acknowledged.

REFERENCES

1. Architectural Institute of Japan, "Report of Damage from Niigata Earthquake (in Japanese)", December 1964.

2. Architectural Institute of Japan, "Report of Damage from 1968 Tokachi-Oki Earthquake", December 1968.

3. Architectural Institute of Japan, "Report of Damage from 1978 Miyagiken-Oki Earthquake", February 1980.

APPENDIX: CLASSIFICATION OF DAMAGE LEVELS OF STRUCTURAL MEMBERS

In estimating the damage rate, the columns and walls in the most severely damaged storey should be investigated for the existance and extent of
(1) cracking of concrete,
(2) crishing and spalling of concrete, and
(3) bending and fracture of reinforcing bars. The wall in a box-type structure is a wall of more than 45cm width. The width of the walls is measured with the eye. The walls in a frame building are not investigated because it is difficult to distinguish, from external appearances, strucural walls from nonstructural walls. For each column and wall, damage levels (3 to 5) are estimated. Columns or walls located immediately above a column or wall having damage level 4 and above should be automatically rated as the same.

Damage levels are defined as follows. For a reference, typical crack patterns and crushing and spalling patterns of reinforced concrete members are shown in Fig. A1 and A2 (ref. A1).

(1) Damage Level 3 (Fig. A3): Crushing of concrete can be found at the top and bottom of a column, and reinforcing bars may be partially exposed. In the middle part of a column, inclined cracks open approximately 1 to 5mm. Normally these cracks can be easily recognised. Spalling of concrete at the top and bottom of a column occurs only outside of the reinforcing cage. The bending of vertical reinforcing bars is not found. The resistance of a column will not be reduced at this stage of damage.

(2) Damage Level 4 (Fig. A4): Crushing of concrete exists, and the reinforcing bars may be seen partially or wholly. The width of cracks may exceed 5mm. Vertical reinforcing bars may be bent, concrete over more than one half column width may spall out along inclined cracks in the middle of a column exposing vertical reinforcing bars. Exposed horizontal reinforcing bars may be pulled outward or fractured. A column or wall at this stage of damage has reached the maximum resistance and degradtion of resistance has started. In case of an additional deflection incurred by a large after-shock, the member may not be able to support the floors above.

(3) Damage Level 5 (Fig. A5): The reinforcing bars are bent and the concrete inside the reinforcing cage is crushed. The height of a member can be seen to be clearly shortened. Floor slab and roof supported by such a member can sink and slope. Vertical reinforcing bars are bent along the inclined cracks in the middle part of a column or wall. The column or wall cannot support the floors above and lateral resistance is significantly reduced.

REFERENCE

A1 Association for Promotion of Building Research, "Standard for Estimating Loss of Reinforced Concrete Buildings (Draft) (in Japanese)", March 1984.

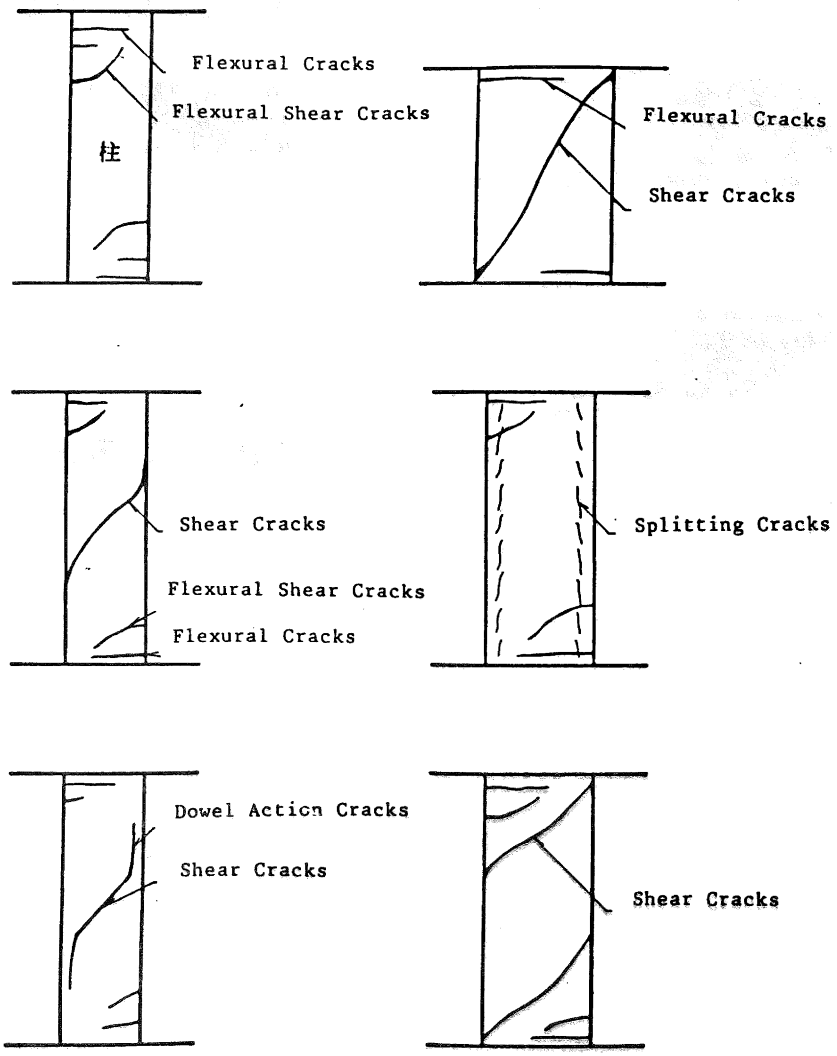


FIGURE A1 - TYPICAL CRACK PATTERNS (Ref. A1)

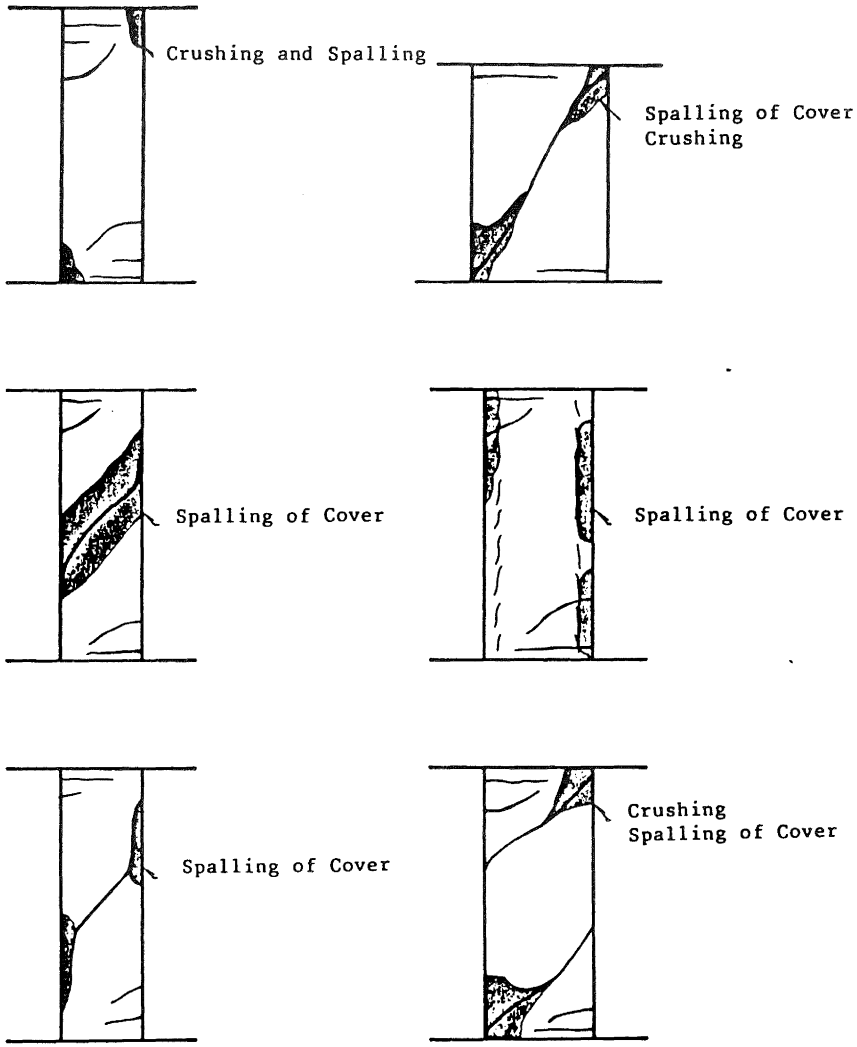


FIGURE A2 - CRUSHING AND SPALLING PATTERNS WITH CRACKING (Ref. A1)

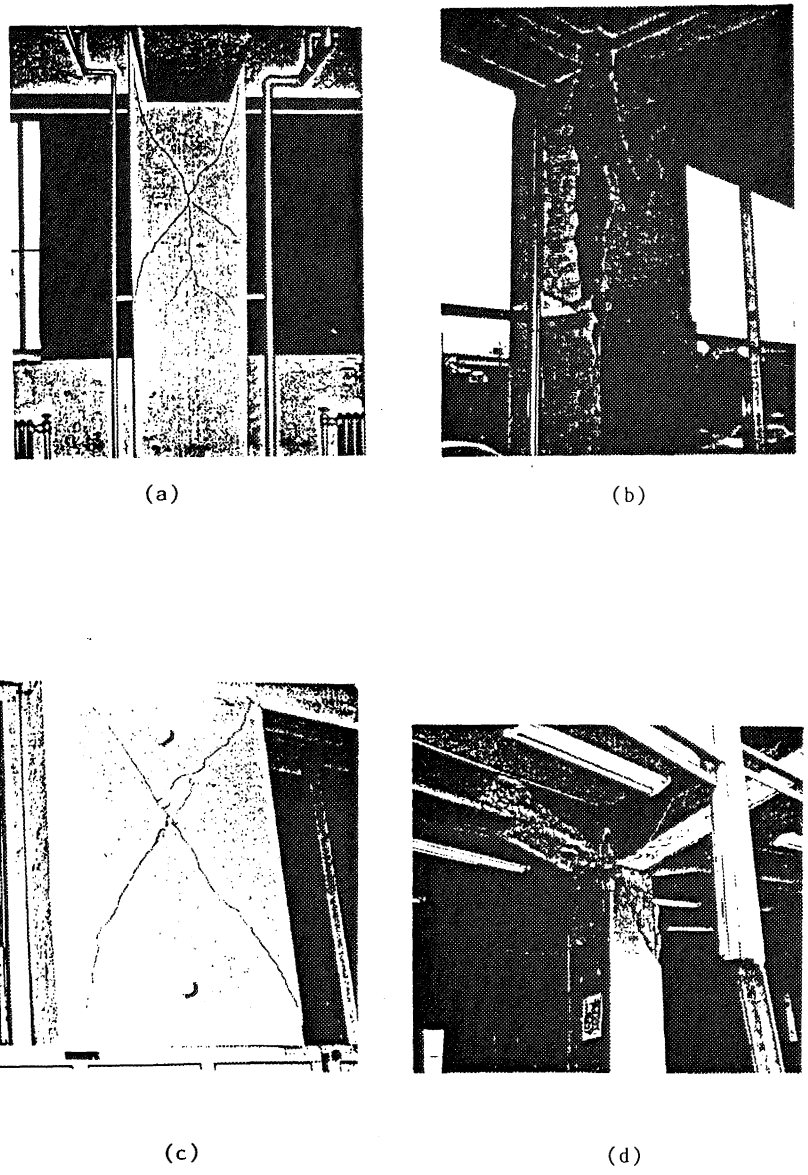
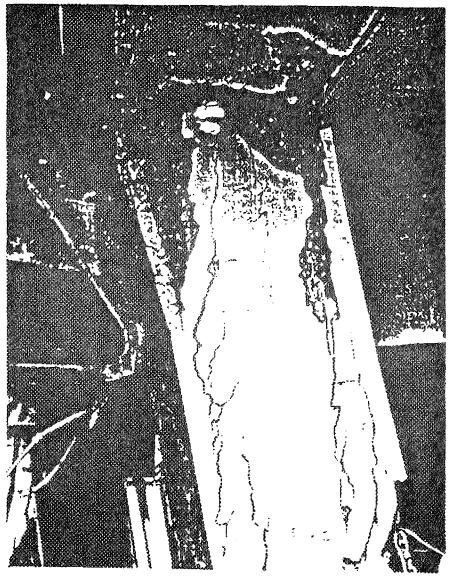


FIGURE A3 - EXAMPLES OF COLUMNS AND WALLS AT DAMAGE LEVEL 3

(a)



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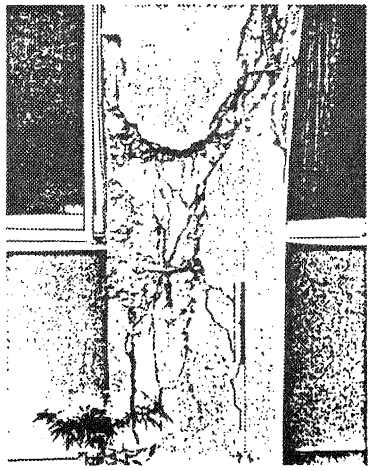

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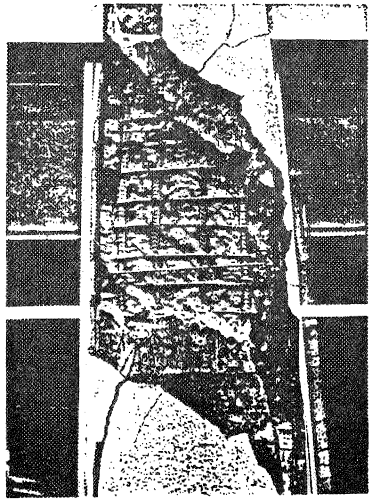
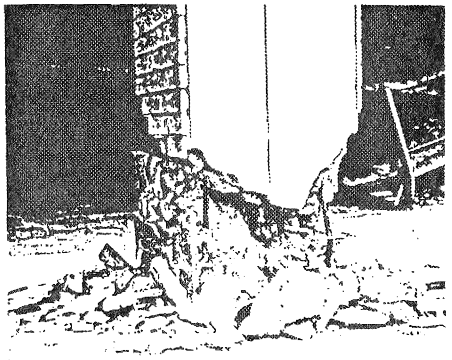
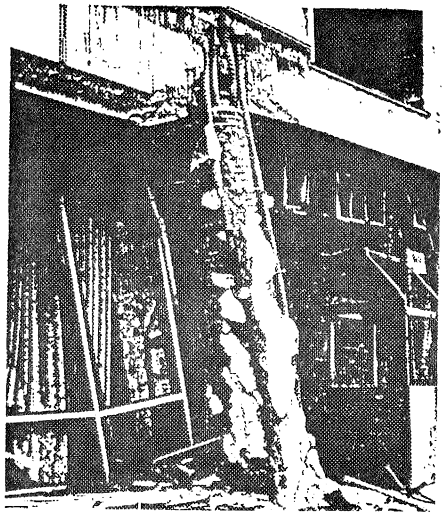


(d)

FIGURE A4 - EXAMPLES OF COLUMNS AND WALLS AT DAMAGE LEVEL 4

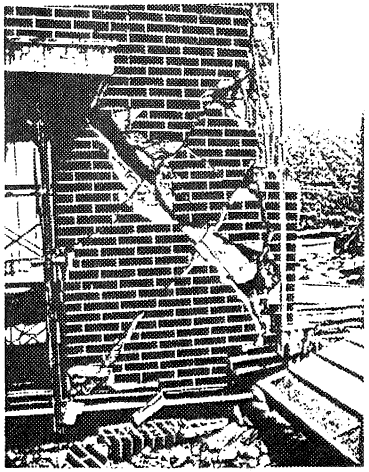


(a)



(b)

(c)



(d)

FIGURE A5 - EXAMPLES OF COLUMNS AND WALLS AT DAMAGE LEVEL 5