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INVESTIGATION AND ELASTO-PLASTIC ANALYSIS OF AN RC BUILDING IN WHICH MAJOR SLIPPAGE OCCURRED ON THE 1ST FLOOR-SLAB DURING THE 1995 HYOGO-KEN NANBU EARTH-QUAKE

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SUMMARY

A concrete building with five stories and a basement collapsed due to the Hyogo-ken Nanbu Earthquake on January 1995 in Japan. The collapse was caused by displacement between the structure of the first story and the basement, accompanied by torsion due to the eccentricity of the walls. On the basis of these facts, an elasto-plastic analysis was performed on a model of the frame which took account of slippage of the first floor. It was found that the shear resistance was reduced remarkably by the slippage

INTRODUCTION

Many buildings founded on alluvium ground suffered great damage and collapse due to the Hyogo-ken Nanbu Earthquake in January 1995 in Japan. In the neighborhood of the building investigated for collapse, many concrete buildings of apartments collapsed at soft first stories used as parking lots. The building suffered shear failure in the columns and walls in the first story and was left for two years in such state that the reason of collapse was not clarified. Therefore, we investigated with the purpose of studying the mechanism of collapse. Consequently, it was found from field investigations that the great slippage was caused in the columns and walls between the first and underground stories, accompanying torsion due to the eccentricity of walls.

A further factor was that the concrete interface between these elements was unstructured by not rough but smooth finish. To confirm the failure mechanism, an elasto-plastic analysis was performed on a model of the frame which took account of the slippage in the first floor. It was clarified that the shear resistance in the frame decreased remarkably by the slippage.

OUTLINE AND INVESTIGATIONS OF A COLLAPSED RC BUILDING

States of failure of RC buildings nearby:

On January 17, 1995, at 5:46 in the morning, the Hyogo-ken Nanbu Earthquake occurred with an epicenter located underground 14 (km) of the northern edge of Awaji Island. The great earthquake was caused by movement of several active faults along Awaji Island and had a scale of magnitude 7.2. It caused an earthquake directly below the site and brought unprecedented damage for many buildings and many more wooden houses. In particular great damage was brought for many buildings in the strip area formed by alluvium ground covering an area 1km wide and 20 (km) long. Here the earthquake intensity was upgraded to intensity 7 according to the Japan Meteorological Agency (JMA) intensity scale (Maximum = 7).

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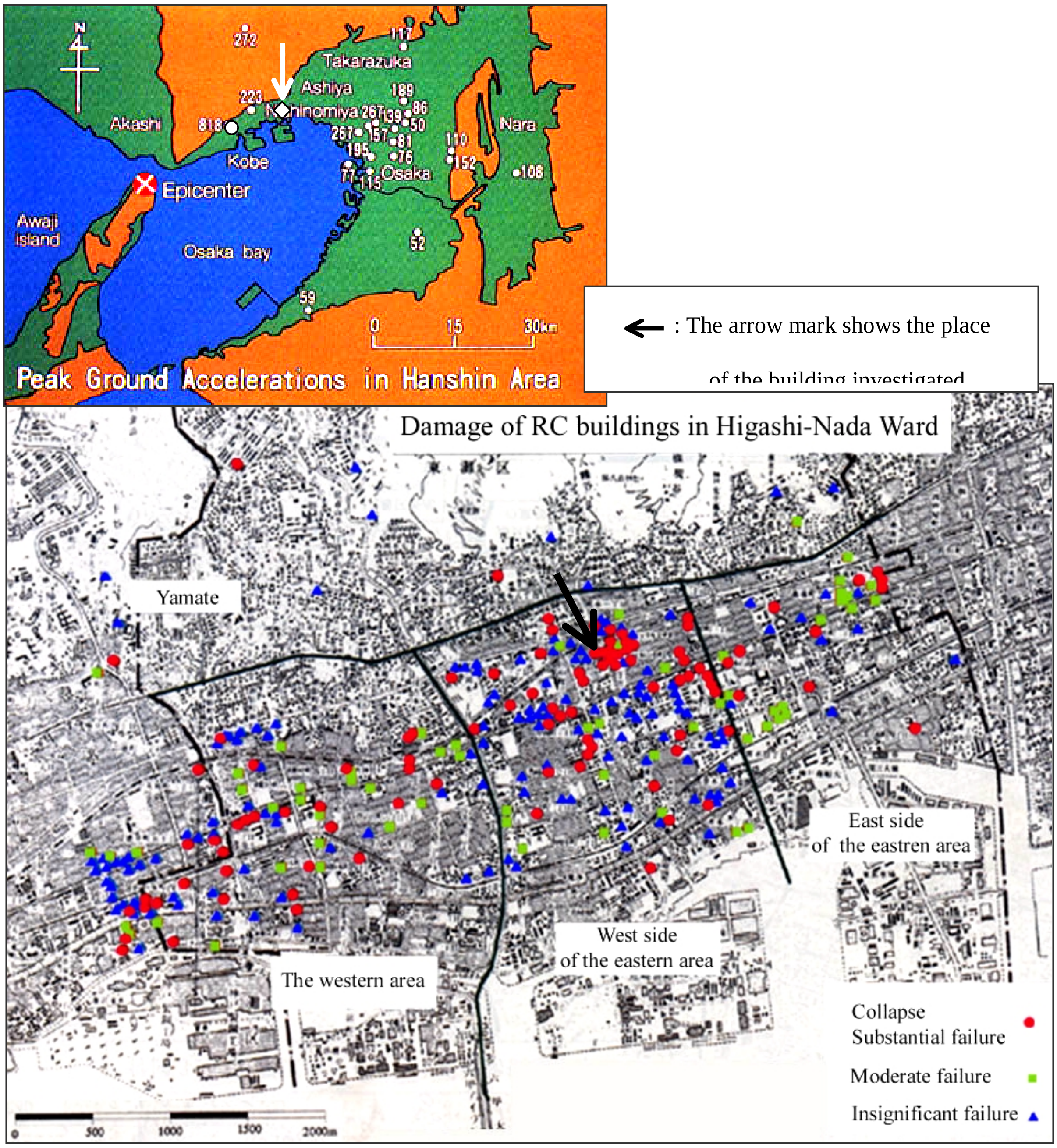
The building investigated to clarify the reason for failure was constructed in this area. The maximum acceleration amplitude of ground motions was measured as 818 (cm/sec2) for NS direction, 617 (cm/sec2) for EW direction and 332 (cm/sec2) for vertical direction at the Kobe meteorological observatory about 10 (km) from this building. The buildings suffering greatest damage and collapse were concentrated in this area. The collapse of thirty RC buildings was caused nearby and also the great damage was brought to thirty-four other RC buildings. Many of those buildings were formed with an open space or fewer walls in the first story and typically collapsed at the first level. The distribution map of collapsed and greatly damaged RC buildings are plotted by circle and rectangular marks respectively in Fig.1. [1], [4]



← : The arrow mark shows the place of the building investigated

Fig.1 Distribution of collapsed buildings nearby

Outline of the collapsed building:

The building was constructed by reinforced concrete on the area with seismic intensity 7 in Higashi Nada-Ku of Kobe on 1998 as a commercial building with a basement and five floors above ground as well as a penthouse. The overall scene of the building is shown in Photo.1.

The structure consists of frames and walls, where the external walls in X direction is separated by an open window between columns so as not to act as a shear wall. Also, the external wall in Y direction consists of continuous shear type with openings which was subjected to great damage as shown in Photo.2, and secondary walls arranged on external side of column. The plan is constituted by two spans in X and Y directions and an L-shape for outer stair case. The first floor rises about two meters from the ground, so that, it constitutes a half basement.

Method of investigation:

The state of cracking and failure in columns, beams and walls were recorded by sketch drawing and photography. The inclination of the building was measured by method of plumb bob which used a weight. The slip displacement was measured by a caliper and a right angle measure. Also, the laser type of displacement meter was applied to the measurement of the roughness on the interface between the first floor and the column or wall, by which the slippage between them was caused. The compressive strength of concrete was measured by Schmidt hammer apparatus.

RESULTS OF INVESTIGATION

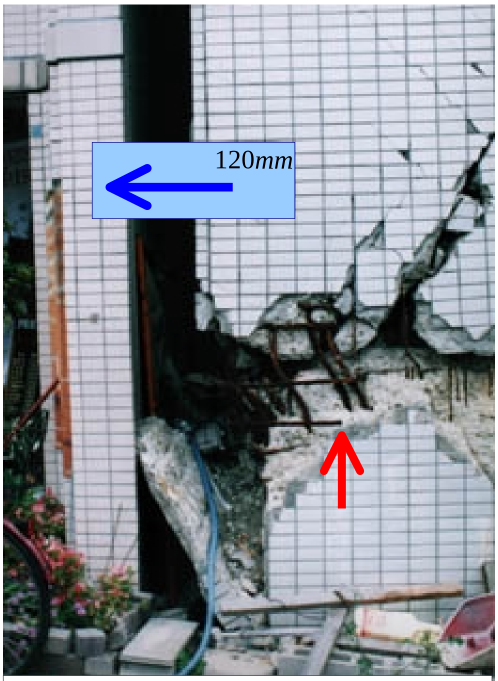
Damage level:

The damage level was evaluated on the basis of “Standards for judgement of damage indices in building subjected to earthquake disaster” [2], in which the damage level classification was defined by the factors such as inclination of building, settlement and damage rate of RC column structure, and the damage of building is classified into five levels such as collapse, substantial failure, moderate failure, insignificant failure and minor failure. According to the standards, the building was judged as “collapse” from the viewpoint of level of structural damage.

State of failure:

The collapse of the building originates in the great slippage of columns and walls which was caused on the first floor because the concrete interface of structures between the first story and basement story was constructed by smooth finish. Such a phenomenon has not been seen in the disasters of past great earthquakes in Japan. The shear failure occurred on the frame and the shear wall with openings in the external first story, where a corner column moved greatly outward after the shear failure at its base, as shown in Photo.3. It was observed in many buildings that the hoop reinforcement of column was broken at the corner and the intermediate straight portion. The same rupture was seen at the hoop reinforcement of the connection of the corner column and the first floor beam, as shown in Photo.3. Otherwise, shear failure was recognized in the connection of first story column and second floor beam. The same phenomenon was also found in many buildings in which great damage was caused, as shown in Photo.4.

The cracks in frame and wall are concentrated from first story to third story, as shown in Photo.2. In particular great damage was caused in the columns and walls of the first story, consistent with features of first-story collapse.



: The arrow mark shows rupture of Hoop reinforcement

Photo.3 Shear failure by slippage in bottom of corner column of first story

Photo.4 Shear failure in column-beam connection in second floor

Photo.5 Failure of wall by slippage in elevator-shaft

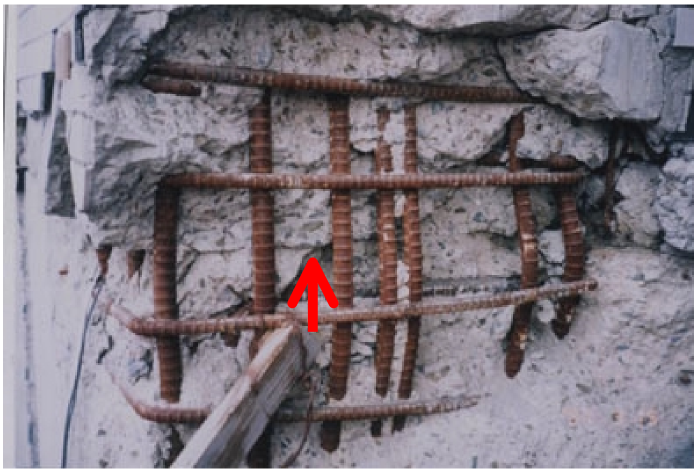


Photo.6 Slippage in the bottom connection of corner column on the first floor

State of slippage:

The outward movements of corner columns and walls on the surface of the first floor in X and Y directions are depicted by dotted lines in Fig.2. The movement indicates the residual displacement by slippage and the maximum values are measured as 120 (mm) and 50 (mm) at the corner columns in X direction as shown in Photo.3 and Photo.6 respectively and 140 (mm) at the elevator shaft wall in Y direction respectively, as shown in Photo.5. Therefore, it is recognized that those movements are affected by the torsion caused from the eccentricity of external walls in X direction. They occurred because the interface of concrete connection was constructed by not rough finish but smooth one, where the mean height of concave and convex is measured as 1.86 (mm) using a laser type of displacement meter as shown in Fig.3, although it should be more than 4 to 5 (mm).

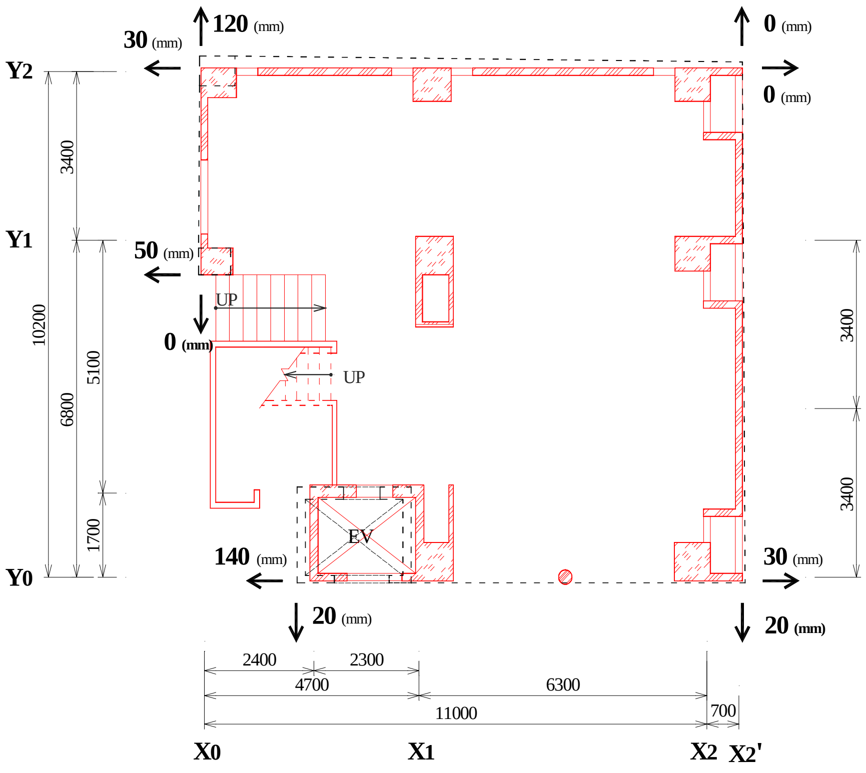


Fig.2 Slip displacement of corner columns and wall in first floor

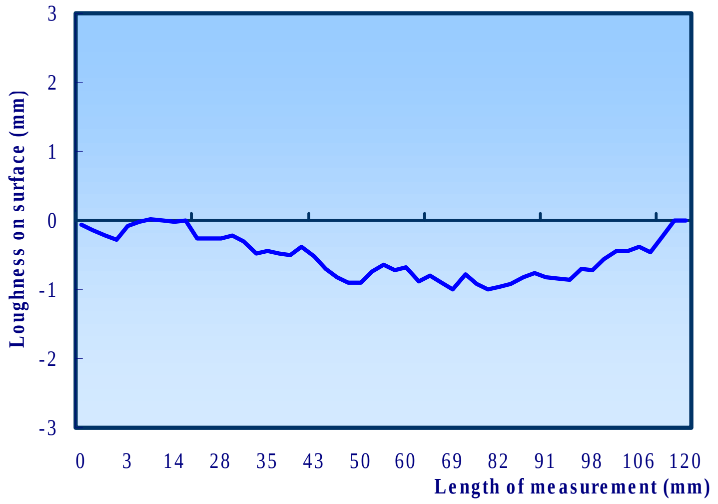


Fig.3 Result of measurement for roughness on the surface of first floor

ELASTO-PLASTIC ANALYSIS

Analytical Model

The elasto-plastic analysis method was used for studying behavior until the upper structure from first to fifth story reached a state of failure, taking account into great slippage on the first floor. It was calculated by the load increment method for X direction that the greater damage was caused.

By inserting a dummy story, which corresponds to a maximum slippage of 125 (mm) between bottom of column and top of beam of first floor, the displacement by slippage is replaced by the lateral displacement of the dummy story. The shear resistance for the dummy story was evaluated by the accumulative ultimate strength of dowel and shear frictional effects as follows. [3]

$$Q = 13.06 \times a_s \sqrt{\sigma_B \times \sigma_y} + \alpha \cdot N \quad (N) \qquad \cdots\cdots\cdots (1)$$

where as is area of cross section of longitudinal reinforcement in column (mm2), σB is compressive strength of concrete (N/mm2), σy is yield-point strength (N/mm2), N is axial force of column (N), and α (=tan ϕ) is coefficient for shear friction, in which α is internal frictional angle and α=0 for maximum slippage as well as α=0.4 for smooth surface.

Also, the effect of torsion is neglected because such an analytical model is very complicated.

Analytical Results

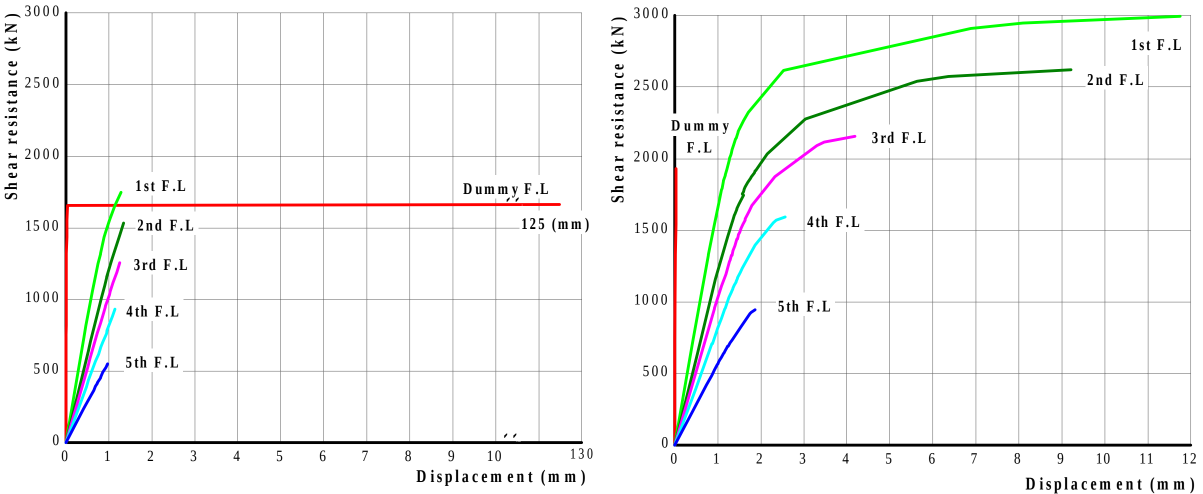
When the flexural failure mechanism of frames is formed, the lateral displacements in each floor for X0-frame are demonstrated for α=0 and α=0.4 in Fig.4. It is recognized from this figure that the lateral displacement corresponding to slippage in bottom of first story column attains a maximum value of 125 (mm) when the coefficient α is equal to zero although it attains 0.7 (mm) when the coefficient α is equal to 0.4.

The relationships between shear resistance and lateral displacement in each floor are plotted for α=0 and α=0.4 in Fig.5, where the lateral displacement concentrates in the first floor. In the upper floors it is very small in the case of α=0.

The shear resistances in each story are plotted for the case of α=0 and α=0.4 as well as the normal case which does not evaluate the slippage in Fig.6.

The shear resistance in frame is observed to reduce remarkably as the value of α decreases. It is found that the slippage of column in the first floor gives a great influence to the shear resistance in the frame.

The failure modes in frame X0, X1 and X2 are plotted for the case of α=0 in Fig.7, where the numbers represents the increment step, and when the flexural failure is shown by a circular mark and the shear failure is shown as a triangle. It is found that the frame mechanism for failure is almost formed in the story less than the third one. This is justified from such a result where the failures of column, beam and wall occurred almost on the story less than the third one.



ƒ¿=0 ƒ¿=0.4

Fig.5 Relationships shear resistance and lateral displacement for α=0 and α=0.4

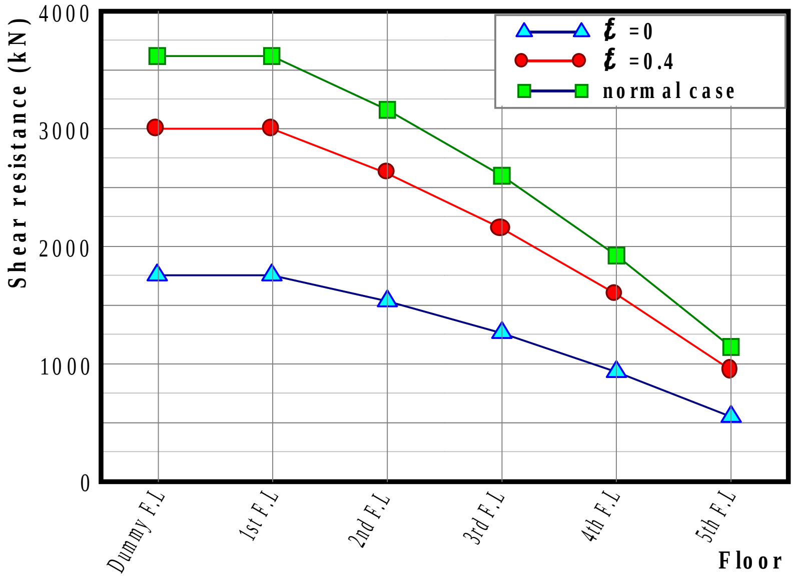


Fig.6 Shear resistance for each floor

CONCLUSIONS

On the basis of investigation of a building suffering the first story collapse by the slippage in first story, the following suggestions are indicated. :

The building is judged as first story “collapse” according to standards of damage level classification for RC structure.

The collapse of the building is considered to be due to construction of smooth finish on concrete connection between structures of first and underground stories, where large slip displacement was caused on the first floor.

The shear resistance of the frame deteriorated remarkably when the slip displacement occurred on the concrete connection of RC elements.

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