A CASE STUDY OF SEISMIC STRENGTHENING OF EXISTING REINFORCED CONCRETE BUILDINGS IN SHIZUOKA PREFECTURE, JAPAN

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SUMMARY

The Shizuoka Prefectural Government established the Earthquake Counter Section in 1977, since a severe earthquake, so called Tokai Earthquake, is Predicted at the west sea, so called Suruga Bay (Fig. 1), of the Izu Peninsula by seismologists. The Counter Section has carried out the many counterplans of disaster prevention. The objective of this paper is to present the outline and an example of strengthening of existing reinforced concrete buildings as one of the earthquake countermeasures in Shizuoka Prefecture.

INTRODUCTION

As one of the earthquake countermeasures to Tokai Earthquake, the Shizuoka Prefectural Government chose 576 buildings out of 1400 reinforced concrete buildings of the Shizuoka prefectural Government as important buildings from the standpoint of disaster prevention (Ref. 1). Seismic performance of those 576 buildings were examined since 1977 under a four-year plan by the Guideline to Evaluate Seismic Capacity of Existing Medium and Low-Rise Reinforced Concrete Buildings in Japan (Ref.2). Seismic performance estimated of those 576 buildings were shown in Table 1. The permanent therapies, namely, reconstruction or strengthening, of the buildings which were judged as likely to lead to collapse by the above mentioned seismic guideline and designated as the main buildings of disasters prevention or refuge just after the earthquake have been done since 1980. At present, the reconstruction works of 22 buildings and strengthening works of 28 buildings were done, and in 1984 the reconstruction or strengthening works of 15 buildings are planed.

METHODS OF SEISMIC STRENGTHENING

The aims of strengthening in order to improve the seismic performance of existing reinforced concrete buildings are as follows;
(1) Increase of the story shear strength by adding new shear walls.
(2) Increase of story ductile capacity by improving the member ductility.
(3) Reduction of the floor weight by removing of live load on the floor,

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decreasing in dead load or elimination the upper stories.

At present the Shizuoka Prefectural Government adopted mainly the above (1) method after examing the term of works, the functional aspects and the economical ones.

After the strengthening, the following relation should be satisfied;

$$I_S \geqq E_T \qquad \text{.................} \quad (1)$$

where, I_S = the unified second level seismic performance index of structure in the guideline (Ref. 2).

E_T = the unified seismic judgement index of structure in Shizuoka Prefecture (Ref. 3).

In order to verify the above seismic performance estimated by the guideline, the third level seismic performance in the guideline and a precise earthquake response analysis based on the non-linear behavior of structural members were done. In calculation of I_S-indices after strengthening, the ultimate strength of members are calculated by the Guideline for Seismic improvement of Existing R/C buildings (Ref. 4).

For the ultimate infilled walls strength by adding new shear wall panels the minimum value of following four strength was used;

(1) 80% of the ultimate shear strength evaluated by the assumption that the infilled wall has as much strength as that of monolithic walls by providing the adequate connections.
(2) Total strength summed up the shear strength of wall panel and that of connection and the ultimate strength of column taking account of the deflection of frame.
(3) Flexural strength of infilled walls considering the surrounding frames.
(4) Rotation strength of infilled walls considering the surrounding frames.

In the actual construction works of adding the new shear walls, the connections which can confirm transfer of horizontal shear force should be made by uniting adding wall panels to existing surrounding members as far as possible.

The typical methods of connections are presented as follows;

(1) Dowell connection method (Fig. 2-(a));
Wedge anchors are drived into the existing frames and the shear force between existing frames and adding walls is transfered by the dowell actions of wedge anchors.
(2) Scraped out shear key connection method (Fig. 2-(b));
Shear keys are formed by scraping out the existing frames and shear force is transfered by the scraped out shear keys.
(3) Adhered precast concrete shear key connection method (Fig.2-(c));
Precast concrete shear keys are adhered to the surface of the existing frames by epoxy bonding agent and shear force is transfered by the adhered shear keys.

At present, the Shizuoka Prefectural Government used the above (1) dowell connection method. For the wedge anchor, both mechanical anchor (Fig. 3-(a)) and chemical anchor (Fig. 3-(b)) were used.

AN EXAMPLE OF SEISMIC STRENGTHENING

Outline of the Strengthening Building

This building is the reinforced concrete 4 stories technical high school building located in Kakegawa City between Shizuoka City and Hamamatsu City, and was constructed in 1964 (Ref. 5). It has 1 span in the transveres direction and 20 spans in the longitudinal direction. The plan and elevation before strengthening are shown in Fig. 5-(a) and 6-(a), respectively. Photo 1-(a) shows the north side view before strengthening.

Results of Seismic Performance

I_S-indices by the guideline are shown in Table 2. In the second procedure, I_S-indices of both transverse and longitudinal directions were less than the judgement indices (E_T) of Shizuoka Prefecture. Since this school building was located near the epicenter of predicted Tokai Earthquake as shown in Fig. 4. high judgement indicies (E_T=0.95) was required for the second procedure in seismic zone A. And furthermore, it was revealed that some column in the north side were extremely brittle columns. In third procedure, the result of very low seismic performance in the longitudinal direction was obtained. Namely, in the longitudinal direction, (1) the ductility of the building could not be expected because of the shear failure of beams, and (2) the ultimate strength low, while in the transverse direction, (1) the ductility could be expected becouse of the flexural failure of beams and the rotation of shear walls, and (2) the ultimate strength of each story was relatively high.

Methods of Strengthening

By the above results of seismic performance, the following principles of strengthening methods were adopted;

(1) Making I_S-indices of second procedure after strengthening more than 0.95 which is E_T-indices of this building.
(2) Increasing the story shear strength by adding the new shear walls.
(3) Making the opening ratio of new shear walls less than 0.4.
(4) Changing the failure mechnism of extremely brittle columns by making slits between columns and spandrel walls, or adding new shear walls.

The plan and elevation after strengthening are shown in Fig. 6-(b) and 7-(b), respectively, Photo 1(b) shows the north side view of after strengthening. In the north side of longitudinal direction, some new shear walls were added in the frames providing the smaller eccentricites between the center of mass and that of resistance caused by the irregular distribution of stiffness. In the transverse direction, new shear walls were constructed in 1 st, 13 th and 15 th frame. The penthouse, the water proofing covering concrete of roof and the balcony from 2nd story to 4th story were taken off to reduce the dead weight. In order to support the incremental dead load after strengthening, the new foundation were constructed under the existing footing girders.

By these thrapies, the I_S-indices of both directions of building estimated more than E_T (Table 2). Increasing building stiffness was alse verified by comparing the micro tremor test results between before- and after- strengthening.

Construction Techniques and Strengthening Works

The term of strengthening works was about five months from September 1982 to january 1983. Total cost of construction was ¥131,000,000 Japanese yens. Fig. 7 shows the used method of concrete casting (Ref. 4). Namely, twice concrete castings were done and after then the excessive part was scraped out. For the casted fresh concrete, the disperaing agent was used in order to improve of the workability. Fig.8 shows an example of the detail used in the strengthening works. As shown in this figure, for the connection between newly adding wall and existing frame, the dowell connection method was used, namely, the chemical anchor (Fig. 3-(b)) for the wedge anchor was used. And furthermore, in order to avoid the spliting of concrete near the wedge anchor reinforcement was used.

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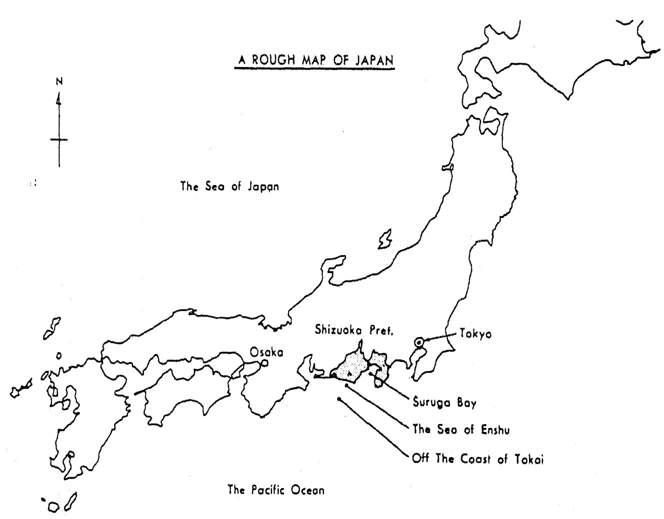
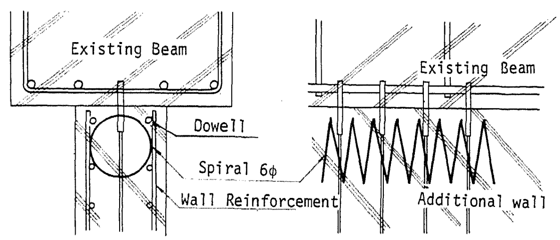


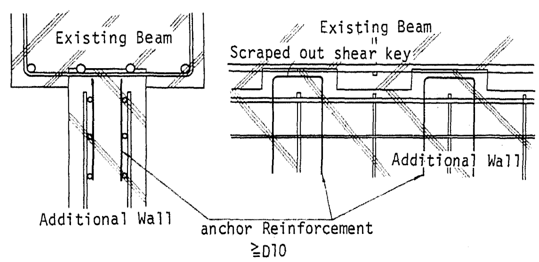
Fig. 1 Location of Shizuoka Prefecture

Table 1 Is - indicies estimated of the Shizuoka Prefectural buildings

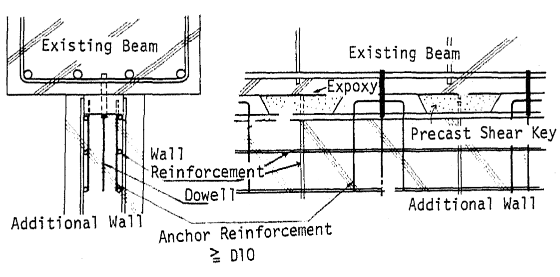
Levels	Evaluations	Factors ($E_T = E_s$)	the Number of buildings	Percentages
A	of the earthquake resistance	$I_s \geqq E_T$	79	14%
B	need a check-up in detail	$I_s \geqq 0.7E_T$	114	20%
C	need reinforcement	$0.3E_T < I_s < 0.7E_T$	227	40%
D	need urgent reinforcement	$0.3E_T < I_s < 0.7E_T$	127	21%
E	need rebuilding	$0.3E_T < I_s$	29	5%
Total	——	——	576	100%



(a) Dowell connection method

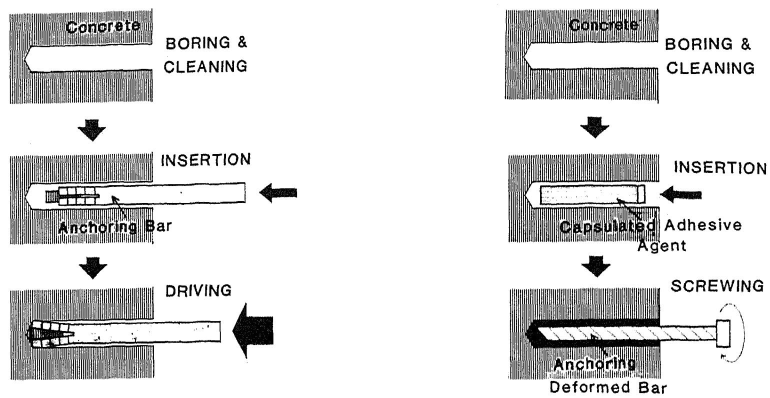


(b) Scraped out shear key connection method



(c) Adhered precast concrete shear key method

Fig. 2 Methods of connection



(a) Mechanical anchor (b) Chemical anchor

Fig. 3 Wedge anchor

Table 2 2nd procedure Is- and E_t-indicies of 1st story

Direction	I_S Before Strengthening	I_S After Strengthening	E_T
Transverse	0.49	1.00	0.95
Longitudinal	0.42 (0.26)	0.96	

( ):considering the extremely brittle colomns

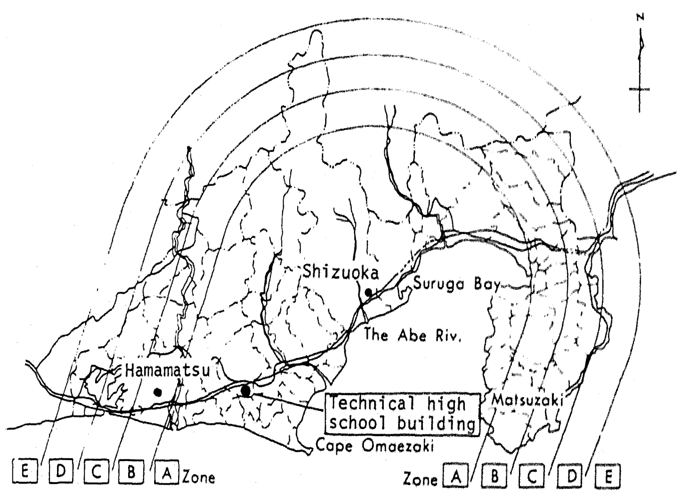
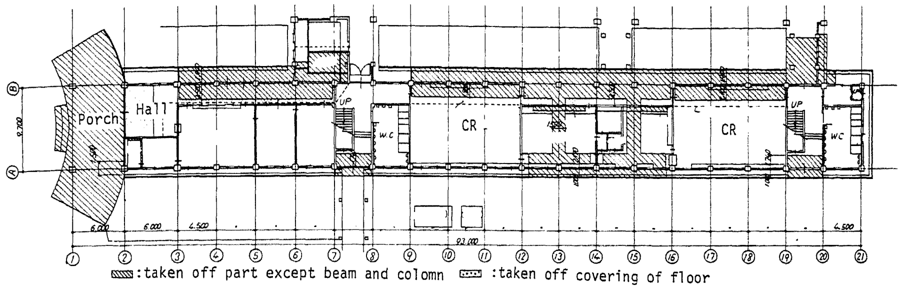
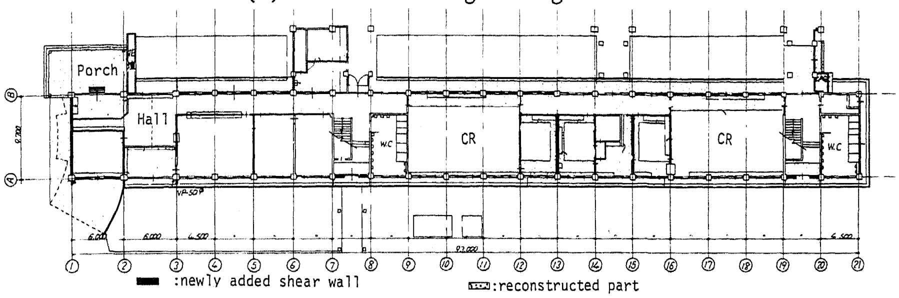


Fig. 4 Seismic zoning from the epicenter of predicted Tokai Earthquake

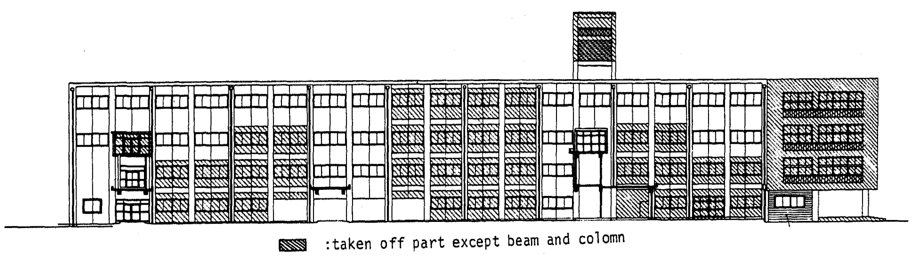


(a) Before strengthening

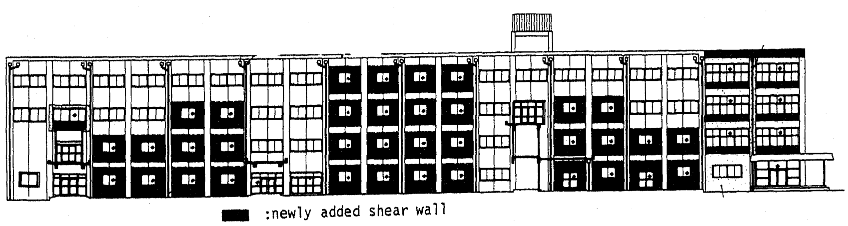


(b) After strengthening

Fig. 5 1st story plan of building



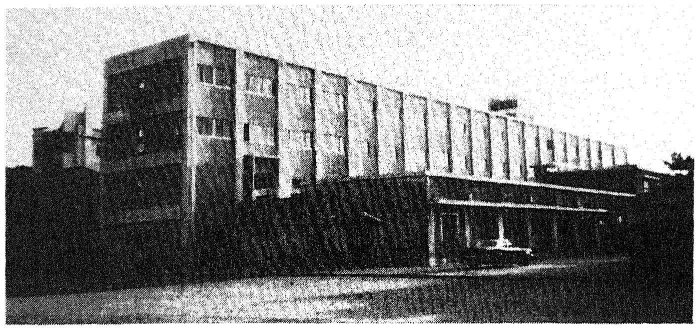
(a) Before strengthening



(b) After strengthening

Fig. 6 Elevation of building

(a) Before strengthening



(b) After strengthening

Photo 1 North side of view of building

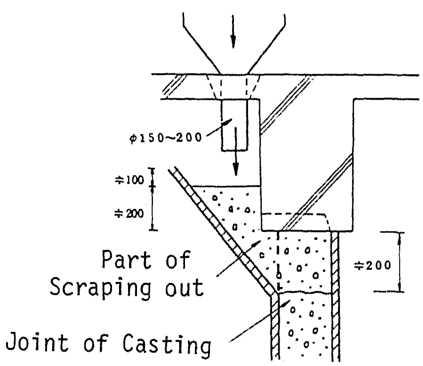


Fig. 7 Method of casting

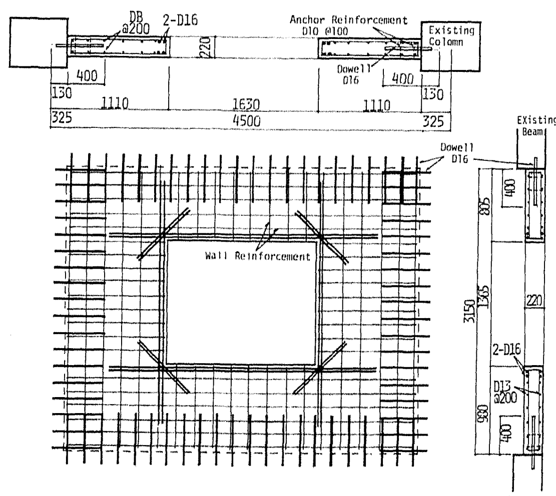


Fig. 8 Detail of strengthening