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A SEISMIC STRENGTHENING DESIGN AND PRACTICE OF AN EXISTING REINFORCED CONCRETE SCHOOL BUILDING IN SHIZUOKA CITY

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SUMMARY

This paper describes an example of seismic strengthening design and practice on an existing reinforced concrete (R/C) school building in Shizuoka City. The seismic capacity of the building was evaluated in accordance with "Standard for Evaluation of Seismic Capacity of Existing Reinforced Concrete Buildings" and compared with the required seismic index E_T. Effects of two different strengthening techniques, i.e., by cast-in-situ concrete walls and steel braced frames are also analytically examined.

INTRODUCTION

The objective of this paper is to report an example of the seismic strengthening design and practice on an existing R/C school building in Shizuoka City. Shizuoka City is located along the Suruga Bay, and 180 km south-west of Tokyo. Recently, a large-scale earthquake named "Tokai Earthquake" is predicted in the Suruga Bay area, where large earthquakes had occurred approximately every 100 years but have been quiet for the past 130 years.

Since 1979 the Shizuoka Prefectural Government has recognized the necessity of earthquake prepareness and promoted various projects to mitigate seismic hazards. The task committee in the Shizuoka Association for Architects and Structural Engineers has cooperated with the Prefectural Government and examined the seismic capacity of 3,500 existing R/C buildings and proposed the methods for strengthening of about 450 buildings including the school building described here. The emphasis is laid upon describing the design practice of strengthening of the school building in this paper.

OUTLINE OF THE BUILDING

The building is three storied R/C building with the total floor area of 2030 m^2 and consists of three school blocks constructed during the period of 1965 to 1971 as shown in Fig. 1. The specified compressive strength of concrete was 180 kg/cm^2 and the yielding strength of re-bars 3000 kg/cm^2(see also Table 1).

EVALUATION OF SEISMIC CAPACITY

The seismic capacity of the building was estimated according to "Standard for

Evaluation of Seismic Capacity of Existing Reinforced Concrete Buildings (Ref. 1)" accounting for the ultimate strength to lateral force and ductility of the building. The standard estimates the seismic capacity of the buildings by the seismic capacity index, Is-index, by the following equation at each story and in each direction;

$$Is = Eo \cdot G \cdot S_D \cdot T \quad \ldots\ldots \quad (1)$$

where, Eo = basic structural index calculated by ultimate horizontal strength, ductility, number of stories and story level considered.
G = local geological index to modify the Eo-index.
S_D = structural design index to modify the Eo-index due to the grade of the irregularity of the building shape and distribution of stiffness.
T = time index to modify the Eo-index due to the grade of the deterioration of strength and ductility.

The standard values of the G-, S_D- and T-indices are 1.0.

A criterion of the seismic capacity required to the building is determined by Eq.(2) considering ground soil conditions, intensity of ground motion at the site, number of stories, and failure type of the building etc..

$$E_T = Es \cdot C_G \cdot C_I \quad \ldots\ldots \quad (2)$$

where, E_T = Required seismic index
Es = Standard seismic index
C_G = Geological index (varies between 1.0 and 1.25)
C_I = Importance index (varies between 1.0 and 1.25)

Standard seismic index Es required for a building in the highest seismic zone in Shizuoka City where this building is located is shown in Table 2. Assuming the soil condition of type 2 and shear failure type, the E_T-index for this three storied building is determined 1.0. Geological index and importance index are assumed 1.0. The evaluated results are summarized in Table 3.

As shown in Table 3, the estimated capacity was smaller than required in the longitudinal direction for insufficient strength and ductility, while it has enough seismic capacity in the transverse direction for continuous shear wall. Therefore, it was decided to strengthen the building in the longitudinal direction.

METHOD FOR STRENGTHENING AND ANALYSIS

The purposes of the strengthening are basically 1)to increase lateral resistance and/or 2)to increase ductility. For a low-rise building reported herein, it is preferable to increase lateral resistance for the effective strengthening. In general, the following two methods are used to increase lateral resistance;

1)to provide cast-in-situ concrete walls
or 2)to provide steel braced frames.

It is necessary, first of all, to examine the effects by strengthening to the seismic capacity of the building. For this purpose, the effectiveness by the following two different methods, cast-in-situ concrete walls (case (1)) and steel braced frames (case (2)) was analytically examined.

In both cases, the additional walls or frames are provided from X4 through X10 in frame Y2. The specified material properties used for the analysis are listed in Table 1. Note that R/C walls are provided for both cases from X2 through X3 and X11 through X12 in both frames Y1 and Y2 to eliminate brittle shear failures in columns with short height and it was confirmed that the foundations at X2, X3, X11, and X12 could bear an increased load due to the additional walls. It is also noted that reduction in dead load by removing cinder concrete and parapets at the roof are also taken into account in evaluating the seismic capacity after strengthening.

Case (1) strengthening by cast-in-situ concrete walls Cast-in-situ concrete walls with opening were provided from X4 through X10 in frame Y2 at each story as shown in Fig. 2.

Case (2) strengthening by steel braced frames Steel braced frames are provided from X4 through X10 in frame Y2 except for the third story as shown in Fig. 2. Stiffness of steel braced frames are evaluated assuming the equivalent concrete walls. The overall seismic capacity was obtained considering lateral resistance and ductility of both existing R/C frames and steel braced frames which are calculated separately in accordance with Ref. 2.

In the second case, braced frames are provided only at the first and second stories because no defective behaviors such as eccentricity were predicted even if they are not provided at the third story. Calculated results are shown in Table 3. For both cases, the seismic capacity after strengthening increased more than three times to the original and was larger than required.

It is also essential to consider construction techniques, cost-to-performance ratio etc. in determining strengthening method. Generally, while it is more advantageous to strengthen by R/C walls than steel braced frames in the light of cost and/or construction convenience, it may take more construction term for strengthening foundations due to the increase of sustaining load by additional R/C walls. Furthermore, environmental conditions after strengthening by R/C walls with small opening may be unfavorable in both living and lighting conditions.

Finally, it was decided, therefore, to strengthen the building mainly by steel braced frames, allowing for the above mentioned conditions, although it may cost more than by R/C walls. Details in the connection of the additional frames to the existing frames are shown in Fig. 3.

CONCLUSIONS

A seismic design and practice of an existing R/C school building in Shizuoka City was reported. Analytical studies with two different types of construction techniques are conducted to investigate the effects by strengthening and it was found both two cases could provide sufficient seismic capacity in comparison with the required seismic index in Table 2. Finally, Steel braced frames are selected as a strengthening method in consideration of construction term, environmental conditions for living and lighting etc., in spite of higher cost-to-performance ratio.

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cooperation in conducting this study.

REFERENCES

1. Japan Building Disaster Prevention Association, "Standard for Evaluation of Seismic Capacity of Existing Reinforced Concrete Buildings", 1977. (in Japanese)
2. Shizuoka Prefectural Government, "Guideline for Strengthening Methods by Steel Members", 1983 (in Japanese)

Table 1 Specified Material Properties

material	existing frames	additional R/C walls or steel braced frames
concrete	180 kg/cm^2	210 kg/cm^2
mortar*	-	250 kg/cm^2**
steel		
SR24	2,400 kg/cm^2	2,400 kg/cm^2** (stud bolts)
SS41	-	2,400 kg/cm^2**
SD30	-	3,000 kg/cm^2***

*:non-shrinkage mortar **:for steel braced frames
***:for R/C walls

Table 2 Required Seismic Index in the Highest Seismic Zone in Shizuoka Prefecture

N	SOIL CONDITIONS TYPE 1 (HARD)	TYPE 2 (MEDIUM)	TYPE 3 (SOFT)
1	1.10 (1.10)	1.00 (1.00)	0.85 (0.85)
2	1.10 (0.95)	1.00 (0.95)	0.85 (0.85)
3	1.00 (0.90)	* 1.00 (0.90)	0.85 (0.85)
4	0.95 (0.85)	0.95 (0.85)	0.85 (0.85)
5	0.90 (0.85)	0.90 (0.85)	0.85 (0.85)
6	0.90 (0.80)	0.90 (0.80)	0.85 (0.80)

N : Number of Stories
( ): Values in parentheses are for ductile buildings
* : Required seismic capacity adopted for the building described herein

Table 3 Seismic Capacity Index (Is-Index)

story	before strengthening		after strengthening case (1)	case (2)
3	0.44 *	2.62 **	1.72	1.11
2	0.32 *	1.75 **	1.21	1.57
1	0.30 *	1.61 **	1.04	1.08

* : for longitudinal direction
** : for transverse direction

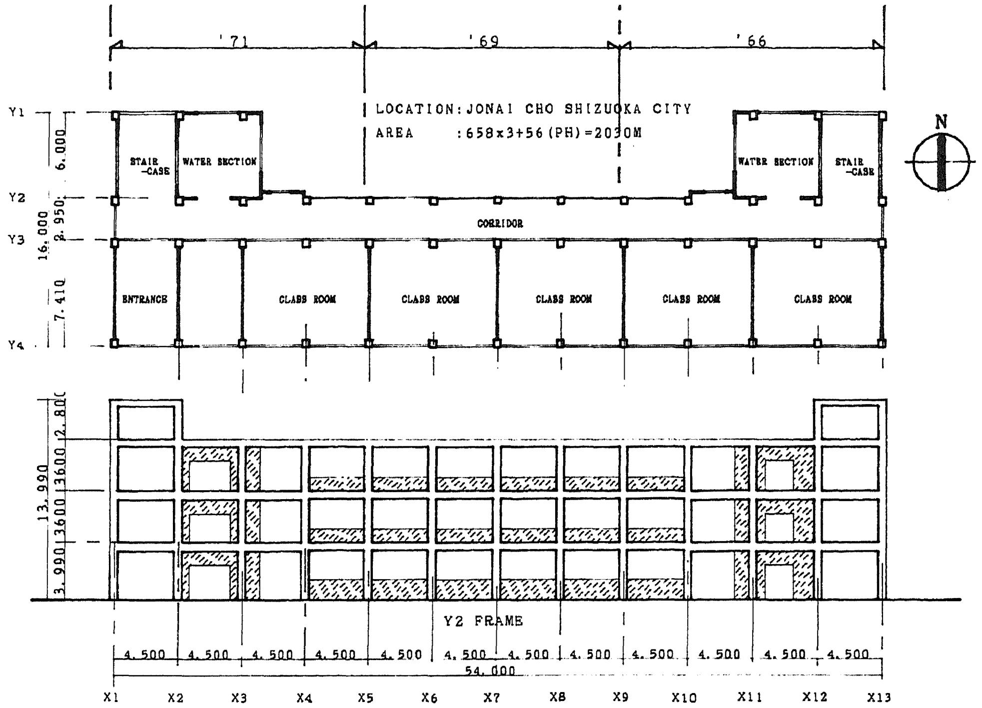
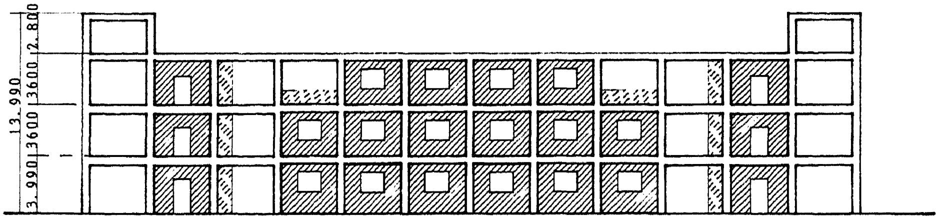
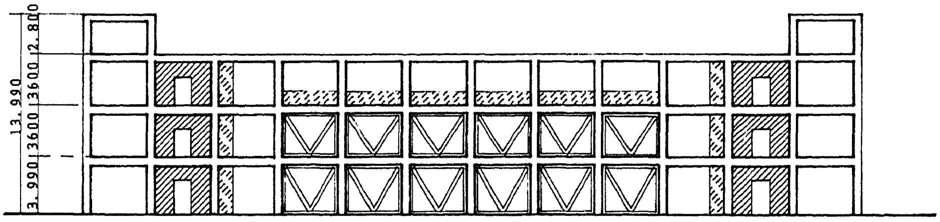


Fig. 1 Plan And Elevation of Existing School Building



CAST-IN-SITU CONCRETE WALLS



STEEL BRACED FRAMES

Fig. 2 Location of Additional Members

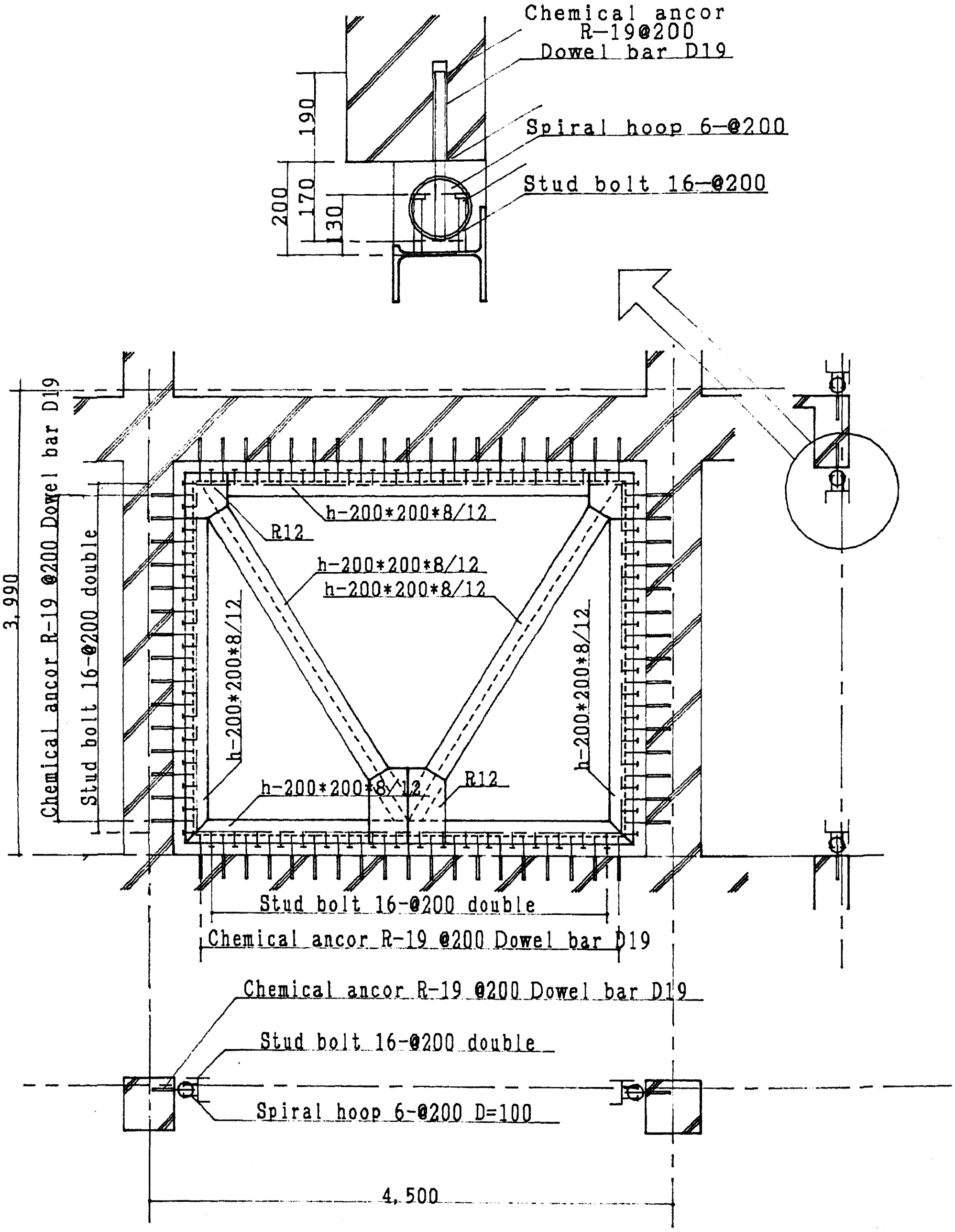


Fig. 3 Details in The Connection of The Additional Steel Braced Frames to The Existing Frames