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Repair and Strengthening of Reinforced Concrete Buildings

Réparation et renforcement de bâtiments en béton armé

Reparatur und Verstärkung von Stahlbetongebäuden

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SUMMARY

In 1978, a severe earthquake shook the Peninsula Izu located 120 km southwest of Tokyo, Japan. Several R/C school buildings were damaged. This paper presents the damage, the method of repair and strengthening, and the seismic capacity of the pre- and post-strengthened buildings.

RESUME

En 1978, un tremblement de terre violent s'est produit dans la péninsule d'Izu située à 120 km au sud-ouest de Tokyo, Japon. Quelques bâtiments d'école ont subi des dommages. L'article présente ces dommages, la méthode de réparation et de renforcement et la capacité sismique avant et après le renforcement.

ZUSAMMENFASSUNG

Im Jahr 1978 hat ein mächtiges Erdbeben die Halbinsel Isu, die 120 km südwestlich von Tokio liegt, heimgesucht. Viele Schulgebäude aus Stahlbeton wurden beschädigt. Der Beitrag beschreibt die Schäden, die angewendeten Methoden der Reparatur und der Verstärkung sowie den seismischen Widerstand der Gebäude vor und nach der Verstärkung.

1. INTRODUCTION

On January 14, 1978, a severe earthquake shook the Peninsula Izu located about 120 km southwest from Tokyo, Japan(Fig.1). The earthquake had a Richter magnitude of 7.0 and its epicenter was located about 15km from a town, Higashi-Izu cho. The maximum intensity at the town was V or more in JMA scale (VIII in Modified Mercalli scale)(Fig.2). In the area of the intensity of more than V, there were five reinforced concrete school buildings.
Among them, a part of one junior high school building was severely damaged, another junior high school building had a moderate damage, and the rest were slightly damaged. The severely damaged wing of one junior high school building was demolished and reconstructed, and another junior high school building was repaired and strengthenend after the earthquake.
Seismograph was not installed near the site, however, the peak ground acceleration was estimated about 20 percent of the gravity by the observation of the damage to the structures, the overturning of tomb stones, etc.,([1],[2]).
The primary purpose of this paper is to present the studies on 1) Damage to the reinforced concrete school buildings, 2) Structural analysis on seismic capacity of the school buildings based on the Guideline for the Evaluation of Seismic Capacity of Existing Reinforced Concrete Buildings([3]), 3) Method of repair and strengthening of the damaged school buildings, and 4) Precise structural analysis on the seismic capacity of one of the school buildings before and after strengthening.

2. DAMAGE TO THE REINFORCED CONCRETE SCHOOL BUILDINGS

A short discription about earthquake damage is shown in Table 1. Among them, the damage of Inatori junior high school building was most severe, while the frames could maintain structural performance after the earthquake. As shown in Fig.3, a major fault line was found across the ground. A number of cracks were found in columns, beams, walls and slabs. The damage was most significant in the slabs at the center core. The crack pattern showed that the east wing and the west wing moved in the opposite direction(Fig.4).
Atagawa junior high school building was one of the damaged buildings. A number of cracks were seen in columns, beams and walls. Both ends of the building were sunk several centimeters. By the excavation of ground, it was found that the footing beams at the west end were failed in shear. Seismic performance of other school buildings were quite well, while hair cracks in the structures, and damage to the non-structural elements were found.

3. STRUCTURAL ANALYSIS ON SEISMIC CAPACITY AND METHOD OF REPAIR AND STRENGTHENING

Just after the earthquake, a temporary therapy was done to the damaged school buildings. Then, the permanent therapy was employed under the detailed consideration of seismic performance of the buildings.
In the case of Inatori junior high school buildings, the center core was demolished immediately and reconstructed. The expansion joints were newly provided between the center core and both wings. The cracks in the west and east wing were repaired by epoxy injection. Cracks in other buildings were also repaired by epoxy injection.
After the temporary therapy, a detailed diagnosis was done on the seismic performance to future earthquake effect. A criteria for structural performance was to avoid collapse to the ground motion having an acceleration of 30 percent of the gravity, since a severe earthquake (so called Tokai Earthquake) is predicted at the west sea of the Izu Peninsula by seismologists.
Seismic performence of the damaged and undamaged school buildings were examined by the Guideline to Evaluate Seismic Capacity of Existing Medium and Low-Rise Reinforced Concrete Buildings in Japan([3],[4],[5]).
The overall method of the guideline consists of three different level procedures;

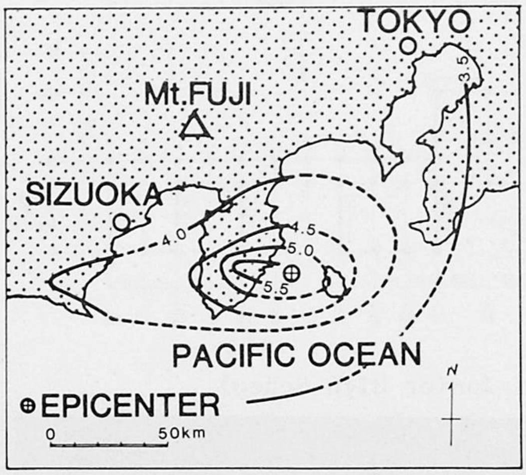


Fig. 1 Seismic intensity of 1978 Izu Oshima Kinkai Earthquake (Reference[1])

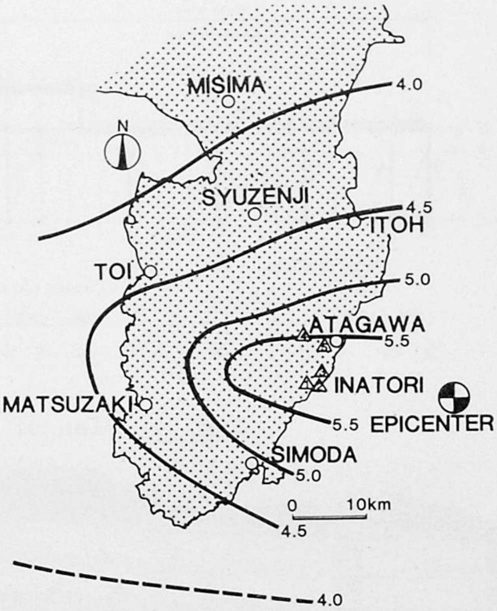


Fig. 2 Location of schools and seismic intensity([1])

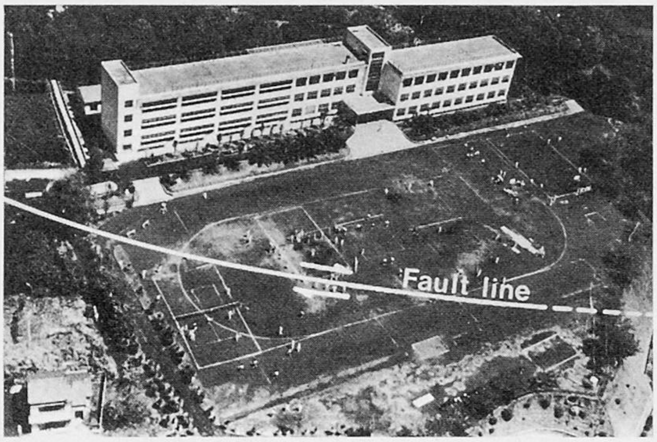
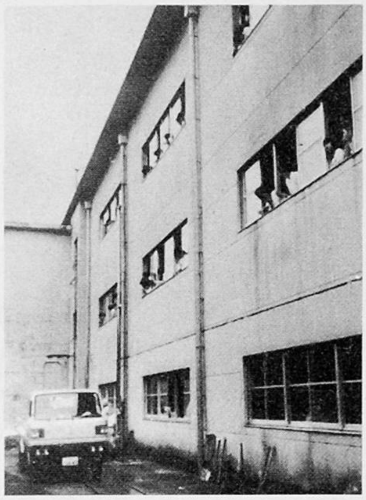


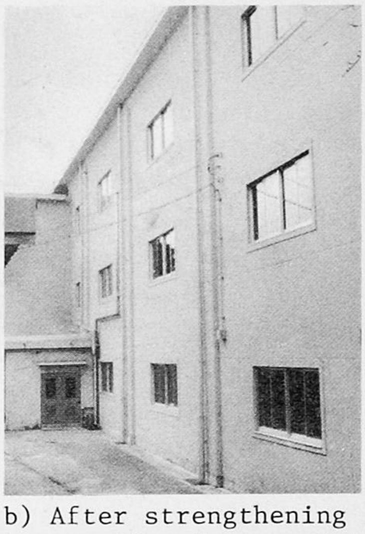
Fig. 3 Bird's eye view of Inatori Junior High School

ID Number in Fig. 2	Name of School	Location	Type of Structure Number of Stories	Year of Construction	Damage	Degree of Damage
1	Inatori Junior High	Higashi-Izu-cho Inatori	RC/3	1955	Broken in two parts at center core. Shear failure of some columns. Numerous cracks in columns,beams, walls and slabs. Surface breakes on ground.	midium damage (partially heavy damage)
2	Inatori Elementary	same as above	RC/4	1970	Hair cracks in walls and columns. Inclination of eaves of porch. Breakes of window glass. Fall of lighting implements.	slight damage
3	Inatori High	same as above	RC/4 (two buildings)	1965	Collision of expansion joint. Surface breaks on ground	slight damage
4	Atagawa Junior High	Higashi-Izu-cho Naramoto	RC/3 penthouse	1962	See Fig. 4. Breaks of under-ground pipes.	midium damage
5	Atagawa Elementary	same as above	RC/3 and RC/4 (two buildings)	1975	Shear cracks in walls and some slabs	slight damage

Table 1 Discription of damage



a) Before strengthening



b) After strengthening

Fig. 5 Shear walls of Inatori Junior High School

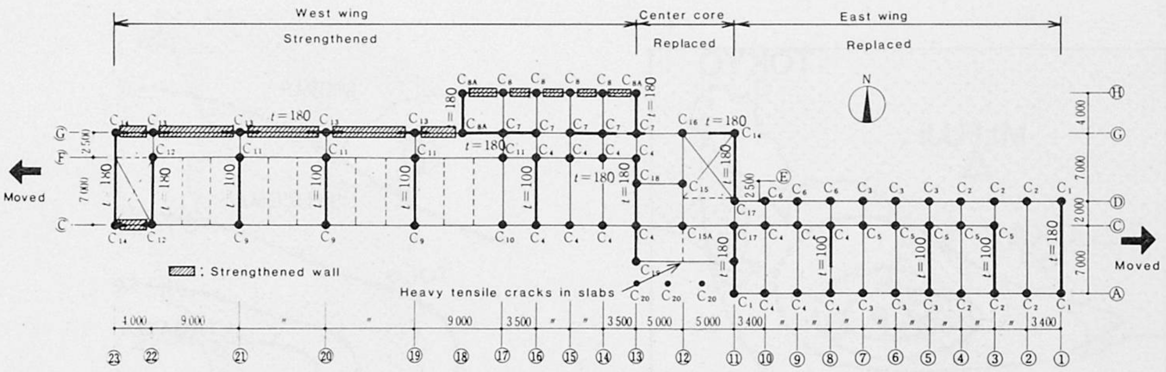
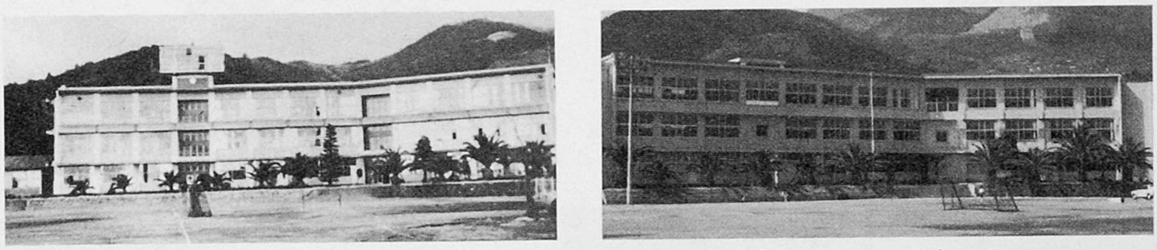


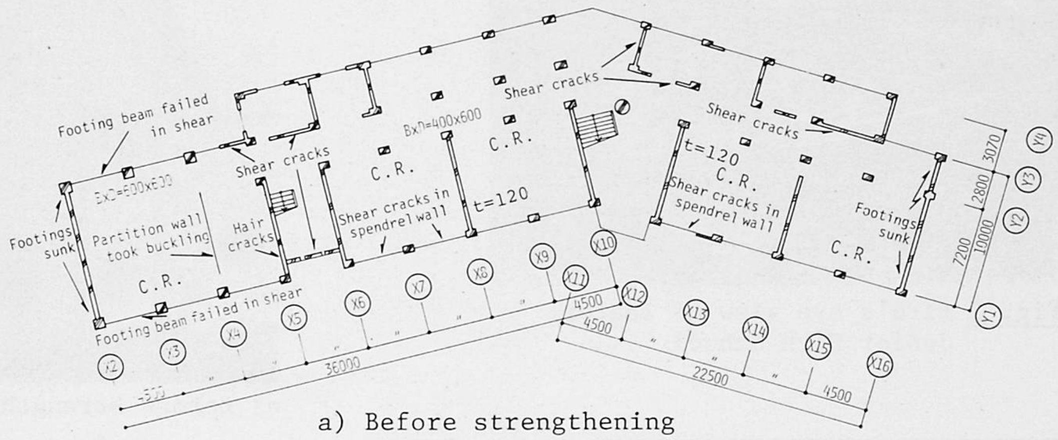
Fig. 4 Plan of Inatori Junior High School



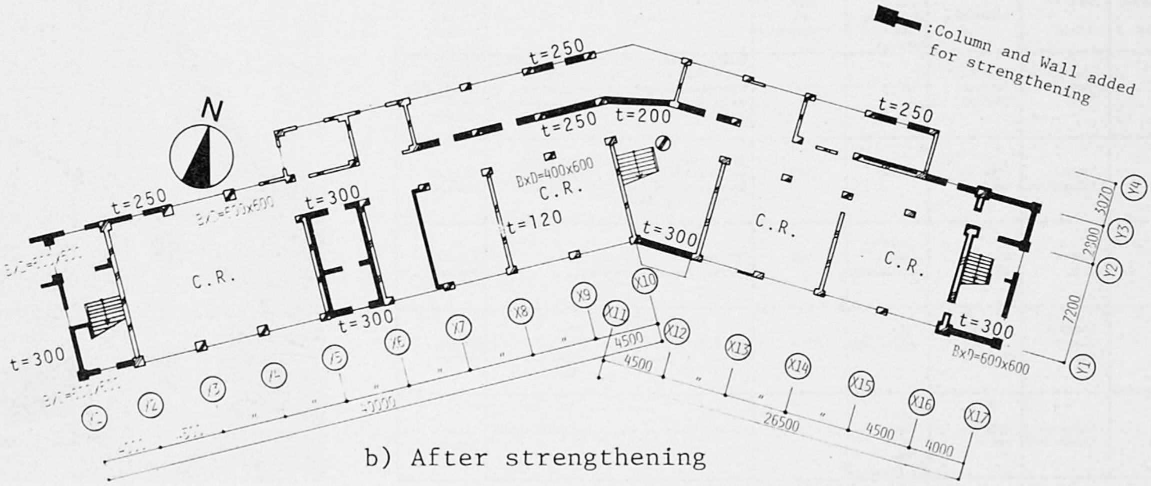
a) Before strengthening

b) After strengthening

Fig. 6 Overall views of Atagawa Junior High School



a) Before strengthening



b) After strengthening

Fig. 7 Plan of Atagawa Junior High School

first, second and third level procedures. The first level procedure is the simplest, but most conservative of the three, while the basic concept is common for all three.
In the guideline, the unified seismic performance index of structure (Is) up to six stories is evaluated by the following equation at each story and to each direction;

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

where, Eo = basic structural index calculated by ultimate horizontal strength, ductility, number of story 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 the distribution of stiffness
T = time index to modify the Eo-index due to the grade of the deterioration of strength and ductility

The Is-indices by second level procedure are shown in Table 2([2]). Since the seismic performance to the span direction is very high due to shear walls located between class rooms, the Is-indices to the logitudinal direction are shown in the table.
It is recognized that the grade of the Is-indices corresponds to the degree of damaged, except Inatori high school building. In the case of the high school, the building is considered to be shaken possibly to the span direction by the observation of the damage of other structures and the ground on and around the school complex.
By the results of earthquake response analysis to idealized structural models and the experience of earthquake damage, Is-index of about 0.6 is a border of damage and undamage to the ground motion having the acceleration of 25-30 percent of the gravity([3]-[6]).
Considering these analyses and the grade of damage, the following permanent therapy was adopted for two junior high school buildings : 1) Inatori Junior High School — The east wing was also demolished and replaced to new building in 1983. The west wing was strengthened by adding reinforced concrete shear walls in the existing frames(Fig.4,5). By this therapy, the Is-index of the west wing is estimated more than 1.0. 2) Atagawa Junior High School — This building was also strengthened in 1983 as shown in Fig.6,7,8. Reinforced concrete walls were added in the existing frames. Reinforced concrete cores were newly constructed at the both ends of the building and jointed to the existing part. The penthouse was taken off to reduce the building weight.
Detail of joints are shown in Fig.9, which are typical practices in Japan. By this therapy, the Is-index after strengthening is estimated more than 1.0.

4. PRECISE ANALYSIS OF ATAGAWA JUNIOR HIGH SCHOOL BUILDING

In order to verify the siesmic performance estimated by the Guideline, a precise analysis of Atagawa junior high school building on the ultimate strength and failure mechanism to lateral force was done based on the non-linear behavior of the structural members([7]).
As shown in Fig.10, each member was idealized into beam model having rigid zones at both ends. In order to represent the non-linearity of member, one-component model consisting of series combination of flexural spring and shear spring was used. A degrading tri-linear type of hysteretic rule was used for flexural spring and an origin-oriented type for shear spring. At the bottom of the wall, bi-linear elastic spring was attached representing the rotation of footing. A bent of the frame lines was not considered.
Lateral force distribution along stories was assumed as inverse triangular type in terms of lateral force coefficient. Based on the assumptions mentioned above, lateral force-displacement relationship of each frame was calculated.
Base shear coefficent-story drift relationship at the first story is shown in Fig.11. At the stage of the displacement of 2cm, where shear failure occurs

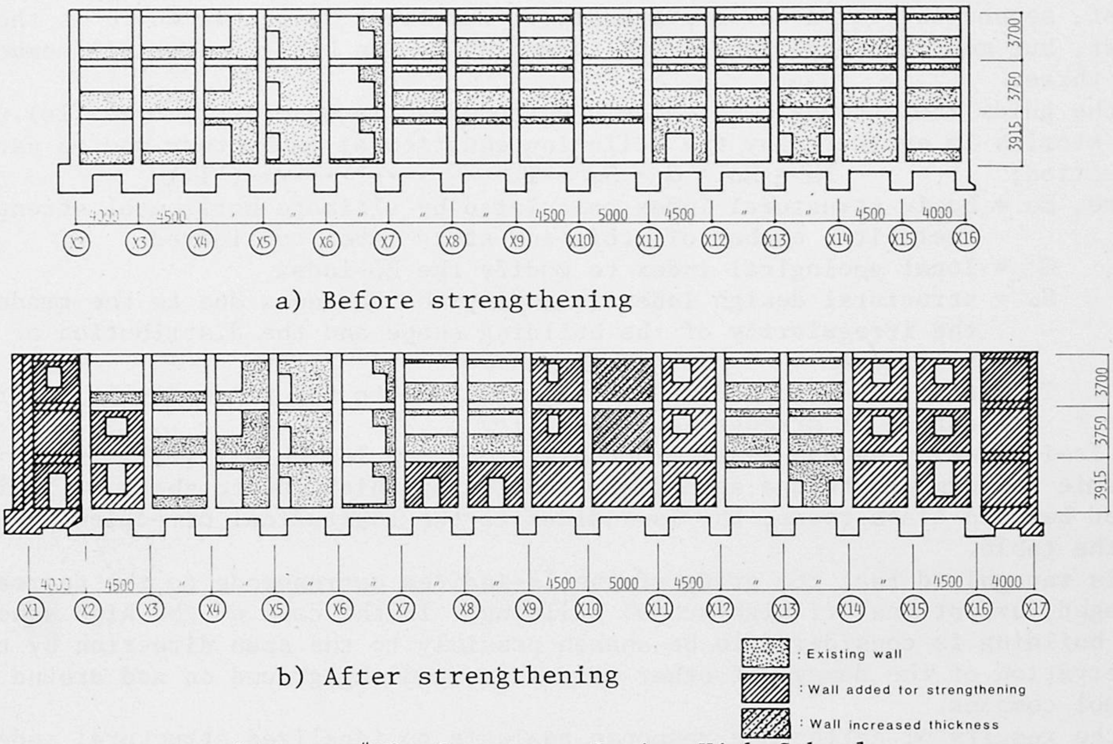


Fig. 8 Frame #Y3 of Atagawa Junior High School

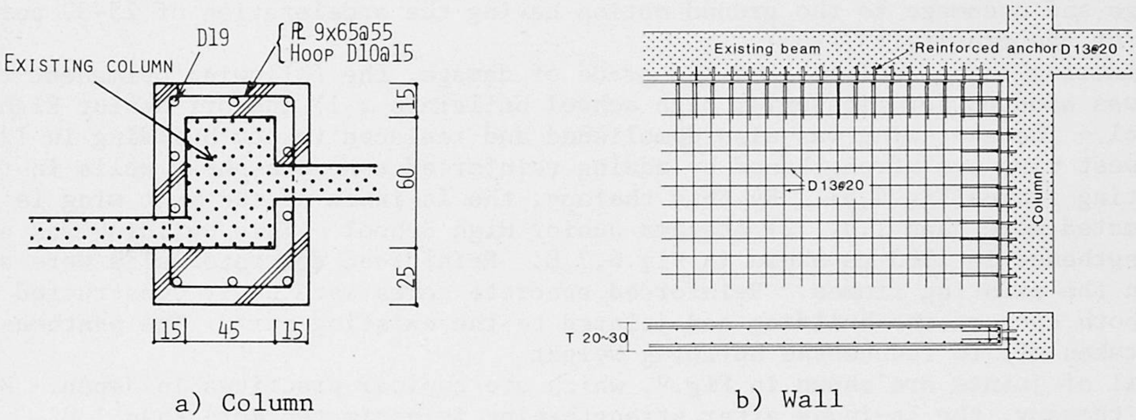
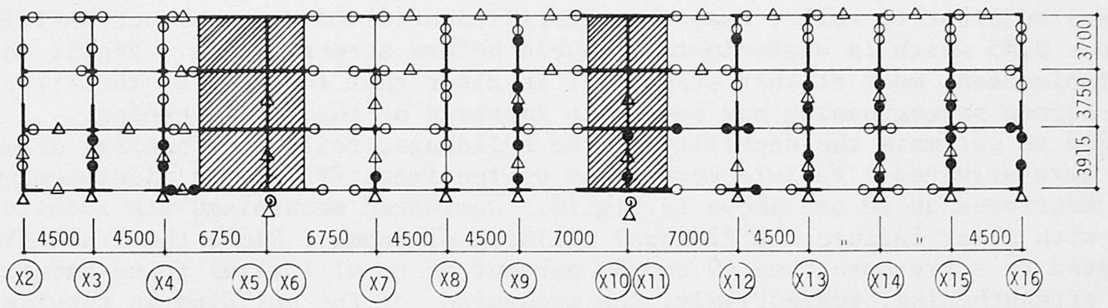


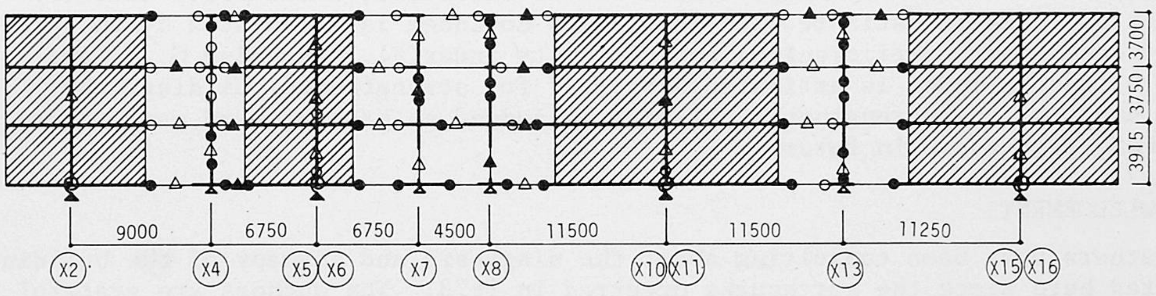
Fig. 9 Detail of joints

ID Number in Fig. 2	Name of School		I_S-indices at First Story
1	Inatori Junior High	East Wing	0.42
		West Wing	0.30
2	Inatori Elementary		0.67
3	Inatori High		0.35
4	Atagawa Junior High		0.43
5	Atagawa Elementary	North Building	0.61
		South Building	0.72

Table 2 I_S- indices by second procedure



a) Before strengthening



b) After strengthening

Fig. 10 Failure mechanism of Atagawa Junior High School (δ_1=2 cm, R_1=1/200)

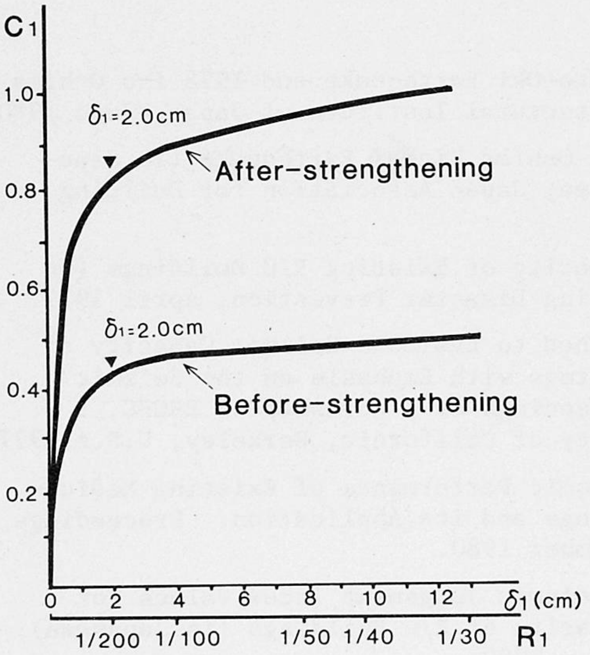


Fig. 11 Base shear coefficient - story drift relationship of Atagawa Junior High School (1st story)

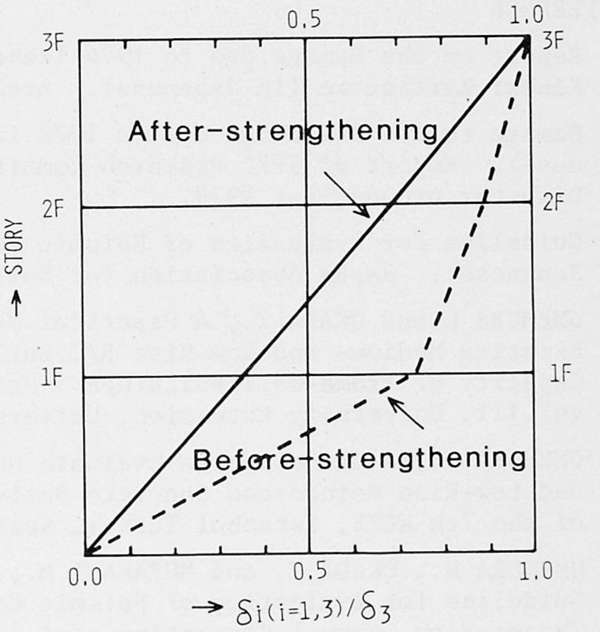


Fig. 12 Mode of displacement(δ_1=2 cm) of Atagawa Junior High School

in beams adjacent to walls, base shear coefficient(C) of strengthened building is about 0.85 which is approximately double before strengthening. Fig.12 shows the displacement mode at that stage. It is clear that the sway at the first story before strengthening has been also improved by the strengthening.
In order to estimate the ductility of the buildings, failure mechanisms of structures were examined. Failure mechanisms of the frame #Y3 at the displacement stage mentioned above are shown in Fig.10. Dominated mechanisms are rotation of walls with shear failure and flexural yielding of beams. Since the frame #Y3 is estimated to carry more than 40 and 60 percent of total lateral force before and after strengthening, respectively, the mechanism of the building is considered as same as the frame #Y3.
According to the third level procedure of the Guideline, a ductility index(F) of such building is estimated 1.0 to 1.5 and Eo-index is calculated by the product of base shear coefficient(C) and ductility index(F). Assuming G, S_D and T are 1.0, the Is-index is estimated 0.85-1.27 for strengthened building. By these studies, the strengthened building is judged to have a sound performance to severe earthquake in future.

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