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SEISMIC INSPECTION AND STRENGTHENING OF PUBLIC REINFORCED CONCRETE BUILDINGS, MAINLY IN CASE OF SCHOOL BUILDINGS

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SUMMARY

In 1970, the Japanese government revised an ordinance on seismic design method of reinforced concrete buildings for the purpose of improving the ductility of building structures. For a period of three years from 1982, we researched to examine the seismic safety of public buildings that had been constructed in the area A before the revision, mainly those of four-story school buildings. As a result, it was found that their seismic performance were almost satisfactory in the transverse direction, but were poor in the longitudinal direction for 30 to 40% of those buildings. Thus, we discussed a guide-line for seismic strengthening and appropriate reinforcing methods. Based on the results of the discussion, strengthening design for the elementary school H was carried out.

OUTLINE OF SEISMIC INSPECTION

The Tokachioki Earthquake that occurred in 1968 brought a great deal of damage to reinforced concrete buildings. Particulary in school buildings, so-called short column which is not high in proportion to its width, located on the passage side, was caused to collapse in a great number. In 1970, with regard to this type of damages, the government ordinance was revised so that ductility of reinforced concrete columns might be improved by increase of web reinforcements. Public buildings, mainly school buildings, that were constructed in the area A by seismic design method before this revision, have been inspected for seismic safety since 1982, with cooperation of scholars and authorities on this matter. Table 1 shows the number of schools in the area A which are classified by the number of stories and the construction year. Among them, Table 2 shows the number of buildings which were inspected in the three years from 1982 to 1984. As shown in the tables, except a few office buildings (12%), most of them were four-story school buildings (88%). For seismic evaluation, the second screening method, the third screening method and the seismic response analysis method were applied to 30%, 60% and 10% of those schools, respectively. As shown in Table 1, the total number of school buildings in the area A was about 870. Most of those public buildings which were inspected in the three years as mentioned above were four-story school buildings that had been constructed before 1970. The number of such four-story school buildings were about 130. Among them, the number of those which were inspected in the above-mentioned three years was 28(about 22%).

The first purpose of this inspection was to examine the seismic safety of such buildings. Also, it was intended to develop a simplified evaluation method that can be applied to other buildings of different specific conditions, and to

Table 1 Number of School Buildings Constructed in the Area A

Construction Year / Number of Stories	Before 1970	From 1971 to 1980	After the New Seismic Code in 1981	Total
4	130	270	45	445
3	110	110	45	265
2	15	45	40	100
1	5	40	15	60
Total	260	465	145	870

Table 2 Number of Investigated Buildings and Kind of Applied Evaluation Methods

Year	1982		1983		1984		Total	
Kind of Buildings / Evaluation Methods	School	Office	School	Office	School	Office	School	Office
2nd Method	9	1	10	-	-	-	19	1
3rd Method	-	-	7(3)	2	8(3)	2	15(6)	4
Response Analysis	-	-	-	-	4	1	4	1
Total	10		19(3)		15(3)		44(6)	

( ) : Only 3rd evaluation method was applied

find adequate strengthening methods for buildings with poor seismic performance.

RESULTS OF SEISMIC INSPECTION

The seismic performance of buildings were examined by the "Seismic Evaluation Standard for Existing Reinforced Concrete Buildings". The seismic performance of buildings is evaluated by the standard from the following continuous index, as structure index, Is.

$$Is = Eo \times S_D \times T \quad (1)$$

where Eo, S_D and T are the mean seismic sub-index of basic structural, seismic sub-index of structural profile and seismic sub-index of time-dependent deterioration, respectively. There are three evaluation methods of the first to the third, mainly for calculating Eo-index in the Is-index. In the first evaluation method, Eo-index is calculated by the ultimate strength that is approximately calculated using the ratio of wall and column sectional area to sum of floor area and ultimate average shearing stress by sectional type. In the second evaluation method, based on the assumption that the strength of beams is sufficiently large, Eo-index is calculated by the ultimate strength of walls and columns, failure mode, ductility and so on. Further, Eo-index in the third evaluation method is calculated by the ultimate strength and ductility of the whole structure that are calculated basing on the failure mechanism by strength of beams and columns, and others.

First in the examination, the first evaluation method was applied. Then, for buildings which were found not to be excellent in seismic performance,the second screening (for 14 buildings) and/or the third screening (for 25 buildings) methods were further applied. Results were obtained as a distribution of the seismic structure index(Is), as shown in Figs. 1 and 2. Fig. 3 shows the proposed values for Is (Iso) recommended as a boundary where the seismic performance is judged excellent. These values were proposed considering the case of the Tokachioki-Earthquake in 1968. It is intended by these values to evaluate seismic performance being based on the safety against an earthquake a little greater than the Tokachioki-Earthquake whose maximum ground acceleration was about 300 gal. These Is values of the buildings evaluated were compared with Iso values. As a result, it was found that the school buildings were almost satisfactorily seismic in the transverse direction but were doubtfull in the longitudinal direction, principally

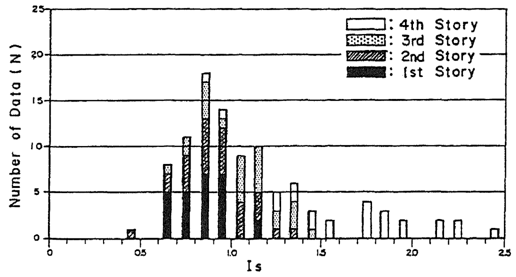


Fig. 1 Frequency Distribution of Is Values by the 2nd Evaluation Method (Transverse Direction)

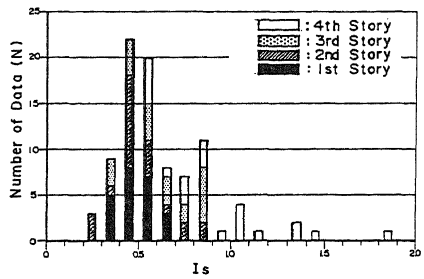


Fig. 2 Frequency Distribution of Is Values by the 3rd Evaluation Method (Longitudinal Direction)

in the first and second stories at the rate of 10 per 34 buildings (about 30%). Then, among those which underwent up to the third screening evaluation, five buildings were chosen to make an elasto-plastic seismic response analysis in the longitudinal direction. As a resurt, it was found that all of the five buildings were poorly resistant to a great ground acceleration of 450 gal, moreover that each one of the school and office buildings was unsatisfactorily seismic against the medium earthquake level of about 225-gal ground acceleration.

In the three-year seismic evaluation, it was found that 30 to 40% of the public buildings in the area A were incomplete in seismic performance, principally in the longitudinal direction.

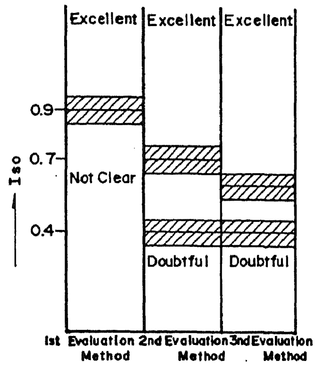


Fig. 3 Proposed Judgment Index of Seismic Safety (Iso) for Each Evaluation Method

GENERAL UNDERSTANDING OF SEISMIC CHARACTERISTICS OF SCHOOL BUILDINGS

Outline of Simplified Evaluation Method The four-story school buildings constructed in the area A before 1970 were inspected to evaluate roughly their seismic performance in the longitudinal direction. This rough calculation method was compiled by simplifing partially the second screening evaluation method under the " Seismic Evaluation Standard for Existing Reinforced Concrete Buildings" (hereafter called simplified evaluation method). This simplified evaluation method is simplified concerning the following points over the conventional second screening evaluation method of the above standard. That is, by simplifing the calculation method of load carrying capacity of walls with columns at both ends and at one end and by simply evaluating the time dependent index and the structure profile index. It becomes advantageous to evaluate seismic performance in a short time using construction drawings of the building. In the simplified evaluation method, bearing capacity of columns is calculated according to the second screening evaluation method, but bearing capacity of walls is calculated using their sectional area and ultimate average shearing stress being specified by sectional type of wall. Table 3 shows values of ductility index (F) related to ultimate average shear stress (τ). These values are specified by a statistic analysis on the basis of the third screening evaluation results. The structure profile index S_D in the simplified evaluation method is to be calculated with only considering the side/length ratio and the effect of exp. joint, because of characteristics of buildings studied. The time dependent index (T) is to be decided with only considering whether each structure was finished or not.

Applicability of the Simplified Evaluation Method The four-story school buildings that had already been examined by the third screening method were subjected to the simplified evaluation method, in the longitudinal direction, in order to

Table 3 Average Shear Stress (τ) and Ductility Index (F) of Various Wall Type

Wall Type	τ (kg/cm^2)	F
Wall with Columns at Both Ends	10.0	2.5
Wall without Surrounding Columns	6.5	2.0
Wall with a Column at One End	(N-8)/50L+(59-7N) ($11-N \leq \tau \leq 25$)	(N+7)/τ+(0.75-0.05N) ($0.99 \leq F \leq 2.12$)

N: Number of Stories, L: Wall Length (cm)

discuss adaptability of the simplified evaluation method instead of the third screening evaluation method. The results is as shown in Fig. 4. According to Fig. 4, part of the results of the simplified evaluation indicated a more dangerous level than those of the third screening method. The detailed examination of this fact found that it had occurred with buildings with special plan, with very slender beams or with extreamly great unit weight. Except those abnormal ones, however, it was found that ordinary four-story buildings brought similar results either by the simplified method or by the third screening method.

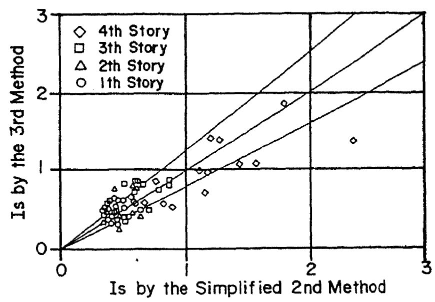


Fig. 4 Relationship between Is-Values by the Simplified 2nd Evaluation Method and by the 3rd Evaluation Method

Results of Applying the Simplified Evaluation Method As the simplified evaluation method can be almost reasonable as mentioned above, about 120 school buildings of four stories that had been constructed in the area A before the year of 1970 were subjected to the simplified evaluation method in the longitudinal direction.

As a result, the frequency distributions of Is values of each story were obtained as shown in Fig. 5. Assuming that Is values of the simplified evaluation method are almost equivalent to those of the third screening evaluation method, if the critical value of Is (Iso) is 0.6 as shown in Fig. 3, the percentage of exceeding this value is 93% for the fourth story, 50% for the third story, 17% for the second story and 15% for the first story. This fact means that many of the four-story school buildings constructed before the year of 1970 were poorly seismic, mainly in the first and second stories.

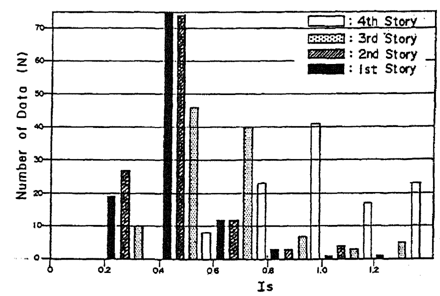


Fig. 5 Frequency Distribution of Is Values by the Simplified 2nd Evaluation Method

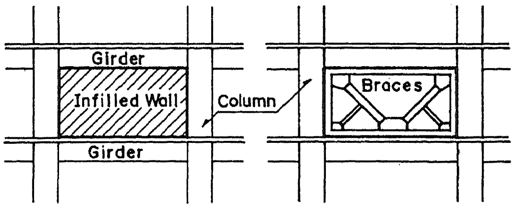
SEISMIC STRENGTHENING

Concept of Seismic Strengthening Most of the objective buildings were constructed after 1955. That is, only less than 30 years had passed when they inspected. Therefore, we have planned to execute seismic strengthening for those buildings which were judged to be poor in the safety against earthquake. To plan an seismic strengthening, it is necessary to consider systematically the functions of building after reinforcing work, a time period of reinforcing work, cost, and others so that a proper reinforcing method can be chosen. Economy needs a seismic work to be limited to as narrow an area as possible. In the past examples, particularly for school buildings, such reinforcement was often limited to the north structural plane on the passage side. In such cases, strengthening has been executed to the reinforced concrete infilled walls or the steel braces since they can be reinforced with high efficiency in a small reinforcing area, rather than to columns for which many members must be equally reinforced. Fig. 6 shows these strengthening method, whose features are described below.

Extension of reinforced concrete wall This method is the one extend new infilled walls in the open frame of the existing building to use earthquake-resistants walls.

To join these walls with the existing frame, post-executed anchors are used so that the stress can be transmited without fail. The major purpose of this extension is to enhance the rigidity and increase the seismic strength.

The extension of seismic walls can provide high seismic strength, while it may involve drawbacks by finely partitioning the inner space or interfering with lighting. Besides, since it causes a considerable additional weight and may greatly fluctuate the axial force when an earthquake occurs, the extention of seismic walls should be executed to buildings on the foundation with sufficient bearing capacity.



a) Strengthening by Infilled Walls b) Strengthening by Steel Braces

Fig.6 Illustration of Various Construction Techniques for Strengthening

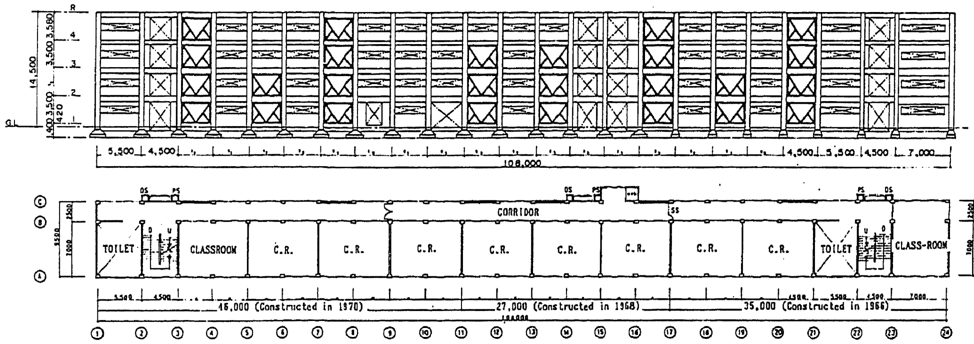


Fig. 7 Arrangement of members for Retrofitting at the 3rd Floor plan and in the North Structural Plane (Upper:a) Structural Plane, Lower:b) floor plan)

Extension of steel brace This method is the one to extend steel braces in the open frame of the existing building. For this method, framed braces should be used, and the steel frames should be joined with the existing structure by post-executed anchors so that the stress can be transmitted without fail. Similar to the above method, this method is chiefly intended to improve the strength. However, special care must be taken for this method, because it impossible to increase the toughness if the buckling of the braceing members precede, or because, when the spaces among

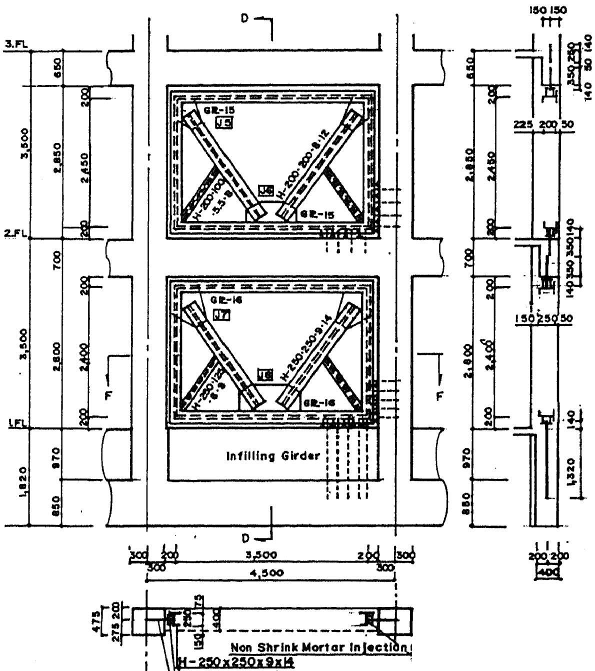


Fig. 8 Details of Strengthening by K-Type Steel Braces

columns into which braces are inserted are too narrow, the brace angle is so acute as to make reinforcing effects unsatisfactory. Compared with the extension of reinforced concrete infilled wall, this method is advantageous in that an increase in weight is not so great and that an opening can be provided for lighting by using K-shaped braced. On the other hand, it needs additional treatments against fire and rust.

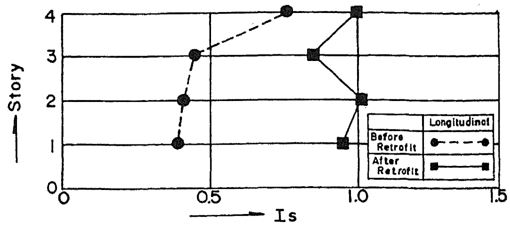


Fig. 9 Distribution of Seismic Structure Index (Is) Before and After Retrofitting

Seismic Strengthening of Elementary School H Selecting two buildings of which seismic properties were judged not to be suficient, we tried to strengthen them. With the concept as mentioned above, here was discussed a seismic strengthening plan in the longitudinal direction for one of the two buildings, the elementary school H. This school building was considerably poor in the seismic strength and besides insufficient in the long-term bearing capacity of piles. Thus, whole strengthening were made by installing steel-framed K-type braces. Fig. 7 a) and b) show arrangements of reinforcing members in the north plane and 3rd floor plan. Fig. 8 illustrates the details of reinforcing members. The footing beams where such reinforcing members are installed are additionally placed up to the first-floor line becouse of the consideration of rust-preventive treatment for steel braces and bracing angle. The execution of this method increased the seismic structure index (Is) about 1.3 to 2.4 times (Fig. 9). It is because the installation of braces greatly increased the seismic strength and also because the deformation properties were satisfactorily improved by setting the failure mode of the braced plane to the overturning type.

CONCLUSION

Forty public buildings, mainly including four-story school buildings, which had been constructed before 1970 were inspected and evaluated on their seismic characteristics. As a result, it was obtained that thirty to forty percent of those buildings were poorly seismic principally in the longitudinal direction. As for about 120 four-story school buildings which had been constructed before 1970, their seismic characteristics in the longitudinal direction were examined by a newly developed simplified evaluation method. This found that many of them were poorly seismic in the first and second stories. Then, the discussion of the policy and method for seismic strengthening found that, for school buildings, it was effective to add reinforced infilled walls or steel braces structure to the north structural plane on the passage side. On the basis of these findings, we designed a strengthening method that steel-framed K-type braces were added in the longitudinal direction for the elementary school H. On the north structural plane of total 23 spans, 4-layer, 3-layer and 2-layer bracing structures were installed in four, two and two spans, respectively. As a result, the seismic strength increased greatly compared with that before this reinforcement (was 1.3 to 2.4 times as high in the Is value).

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