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SEISMIC RETROFIT OF RC SCHOOL BUILDINGS USING POST-INSTALLED WALLS WITH OPENINGS

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SUMMARY

In Ota City, which is located in the south of urban center of Tokyo, seismic evaluation and retrofit of public buildings had started before the 1995 Kobe Earthquake, and currently efforts are centered on school buildings since the Japanese Mombusho (Ministry of Education) launched a five-year project in 1996 to financially support their seismic retrofit throughout Japan. However, difficulties to retrofit school buildings with conventional strategies are often found especially when they have relatively long spans and post-installed members such as new RC walls and steel framed elements are placed in their interior frames between classrooms and corridors. This is mainly because the retrofit members need openings for doorways, which may cause significant loss of resistance and/or ductility of overall structures as well as of retrofitted frames unless carefully designed and detailed in a technically sound method. To solve such problems, both communities of researchers and practitioners in Japan are currently trying to develop new but reliable and cost-effective retrofit techniques. In this paper, two RC school buildings retrofitted using post-installed walls with openings employing inventive techniques to overcome such difficulties are presented, and their seismic capacities are discussed.

INTRODUCTION

Following the 1995 Hyogoken-nambu Earthquake (Kobe Earthquake) which caused devastating damage to older buildings, seismic evaluation and retrofit of existing buildings designed in accordance with dated seismic codes has been a key issue in Japan to mitigate extensive damage to structures and human lives. To implement the lessons learned from the disaster, the Ministry of Construction promulgated a new law to promote seismic evaluation and retrofit of existing vulnerable buildings in the end of 1995. The Japanese Mombusho (Ministry of Education) then launched a five-year project for earthquake preparedness program of school buildings to financially support their seismic evaluation and retrofit in 1996. These actions, however, caused increase in number of buildings to retrofit and wider variety of their structural and/or architectural types, and hence structural designers often find it more difficult to retrofit a building using conventional schemes. To solve such problems, both communities of researchers and practitioners in Japan are currently trying to develop new but reliable and cost-effective techniques, and some of them have been applied to existing buildings.

In Ota City, which is located in the south of urban center of Tokyo, seismic evaluation and retrofit of public buildings had started before the Kobe Earthquake, and currently efforts are centered on school buildings since the Mombusho project started. As described above, however, difficulties to retrofit school buildings with conventional strategies are often found especially when they have relatively long spans and post-installed members such as new RC walls and steel framed elements are placed in their interior frames between classrooms and corridors. This is mainly because the retrofit members need openings for doorways, which may cause

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significant loss of resistance and/or ductility of overall structures as well as of retrofitted frames unless carefully designed and detailed in a technically sound method.

In this paper are exemplified two school buildings retrofitted using post-installed walls with openings employing inventive techniques to overcome difficulties described above, and their seismic capacities are discussed.

RETROFIT EXAMPLES OF RC SCHOOL BUILDINGS

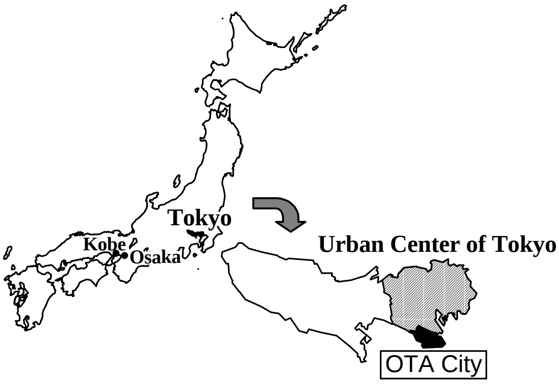


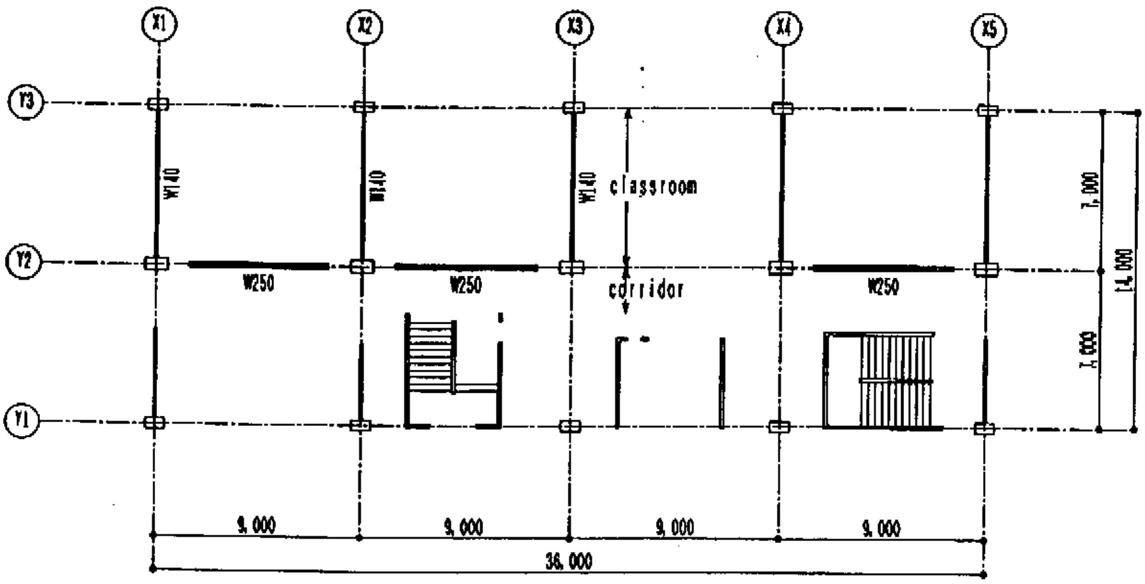
Figure 1: Location of Ota City, Tokyo

Both school buildings presented in this paper are located in Ota City that is in the south of urban center of Tokyo as shown in **Figure 1**. The Seismic Evaluation Guideline [JBDPA, 1990a], which is most widely applied to existing RC buildings in Japan, is applied to both buildings to calculate their seismic capacity index *Is*, and the index *Is* is compared with the required seismic capacity index *Iso* to identify their vulnerability. The basic concept of *Is* and *Iso* appears in **APPENDIX**.

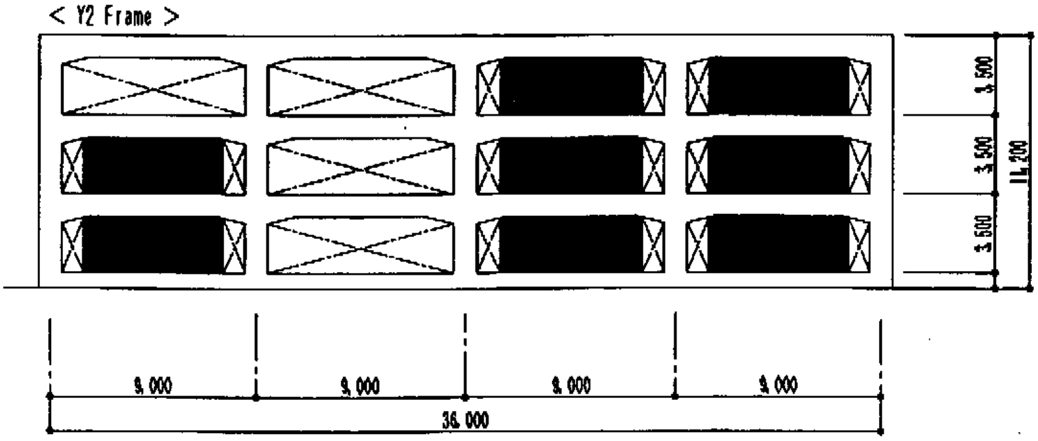
In the new law to promote seismic retrofit enforced in 1995, the minimal decision criteria index to screen sound buildings is set 0.6 for standard buildings. As observed after the Kobe Earthquake, however, school buildings generally need to be functional as temporary refugee centers as well as structurally survivable. In Ota City, the required seismic capacity index *Iso* is, therefore, set 0.75 considering the importance factor of 1.25 for school buildings. Based on the criteria described above, both buildings are identified seismically vulnerable in their longitudinal direction, as is usual case with typical old RC school buildings in Japan, and their interior frames in the longitudinal direction are retrofitted with either RC walls or steel framed panels. Since the new retrofit members are placed in the interior frames between classrooms and corridor, they need openings for doorways. Minimal loss of structural performance due to openings are therefore identified a key issue to be solved through a technically sound solution in their seismic retrofit design.

Retrofit with Post-cast RC Walls with Openings:

Figure 2(a) shows the typical plan of a 3 storied RC school building designed and constructed in 1958. Each classroom consists of a 1 bay x 1 bay frame whose span is 9 m long in the longitudinal direction and 7 m long in the transverse direction, respectively. The exterior frame has narrow and deep beams (wall girder) of 270 mm x 1,300 mm in cross-section, which is a typical structural plan of RC school buildings designed in the late 1950s to 1960s in Japan. It should be also noted that the 9 m span in the longitudinal direction is relatively longer than typical Japanese modern school buildings having a 4.5 m span. As can be found in **Figure 3**, the seismic capacity index *Is* of original building varies from 0.49 to 0.89 in its longitudinal direction and lower than the required capacity *Iso* in the first and second stories while higher in the transverse direction having enough RC walls.

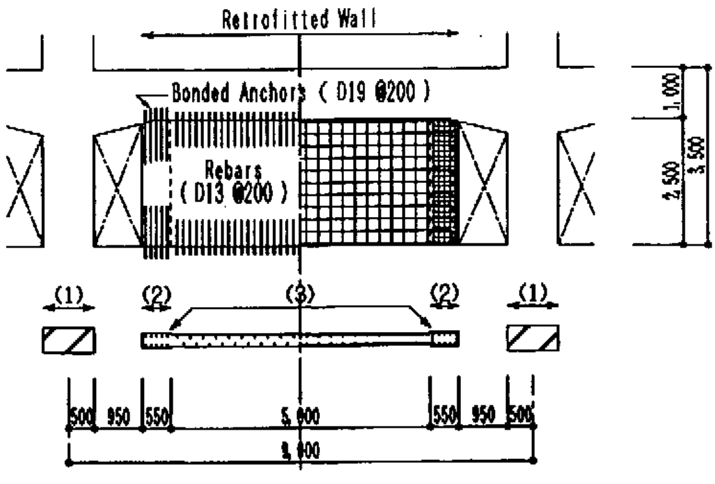


(a) plan view



(b) sectional view

Note: (1) existing column (2) new boundary column (3) inner wall panel



(c) details of inner wall panel

Figure 2: Three storied RC school building retrofitted with RC walls (unit: mm)

Since the structure has insufficient lateral resistance in the longitudinal direction, a retrofit technique to increase strength is employed as a basic strategy. The retrofit scheme and member arrangement are then determined in the following manner.

(1) RC walls can be the best solution since the building has a foundation with enough vertical load carrying capacity, and the increase in building weight may not be a major concern in the retrofit design.
(2) As stated earlier, however, the building has relatively long and narrow beams in its exterior frames. It is often found in such beams that they are not straightly formed and their reinforcing bars are too congested to properly install post-installed anchors to fasten new members with existing frames.
(3) RC walls should be, therefore, placed in the interior frames.

Since each classroom consists of a 1 bay x 1 bay frame, the newly cast RC wall panels need two openings for doorways adjacent to the existing RC columns as shown in **Figure 2(a) and (b)**. Although experimental researches on the structural performance of retrofitted RC frames with new RC wall have been made extensively in Japan, most of them assumes around 4.5 m to 6 m long spans in full scale, and furthermore few researches on post-cast walls with two openings can be found.

From engineering point of view, confining the new inner wall panel between two openings is a key issue for the sound seismic performance of the retrofitted frame during major earthquakes. As shown in **Figure 2(c)**, new boundary RC columns are therefore provided on the right and left sides of the new wall panel, and reinforcement in the new boundary columns and inner wall panel is carefully detailed so that they may not result in premature failure.

As stated earlier, few researches on retrofitted frame with walls having two openings within a long span can be found, and no theoretical nor experimental results to estimate their capacity are currently available. The shear capacity Vw of the new retrofit scheme proposed herein is therefore estimated from the smallest of Vw_1, Vw_2 or Vw_3 as shown below, which is often applied to estimate the capacity of conventional retrofit walls [JBDPA, 1990b].

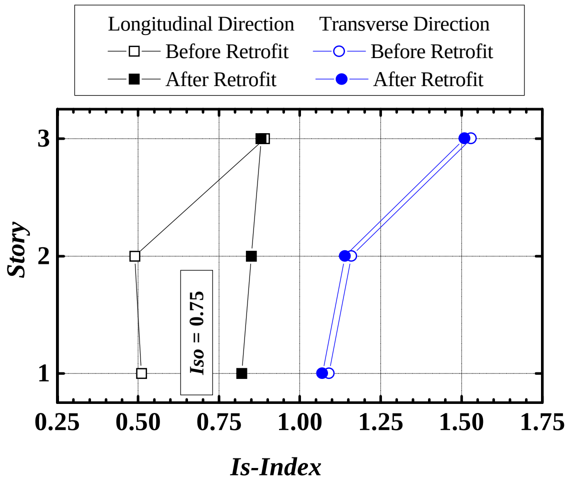


Figure 3: Comparison of seismic capacity index *Is* before and after retrofit

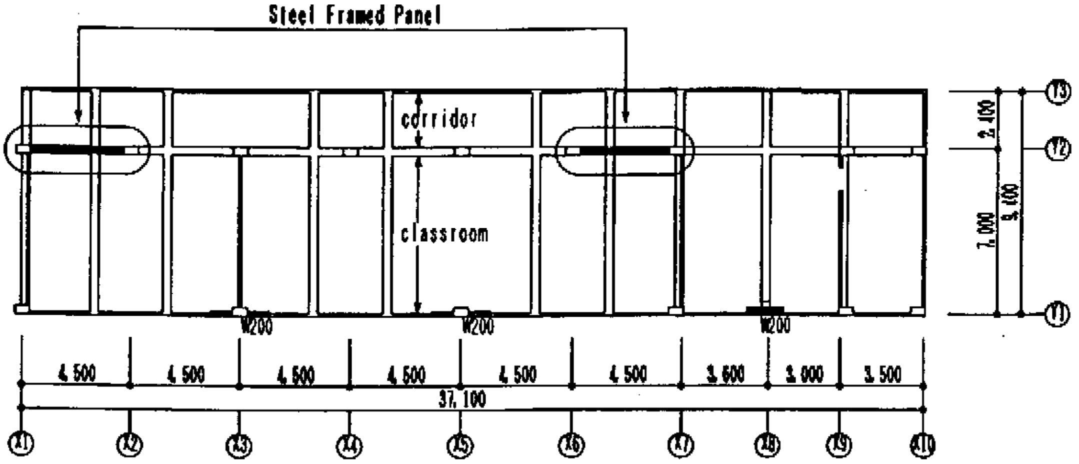
$$Vw = \min (Vw_1, Vw_2, Vw_3) \tag{1}$$

where, Vw_1 : shear capacity of a wall calculated assuming monolithically cast member
Vw_2 : $= Vwo + 2\,V_C$
Vw_3 : $= Vj + 2\,V_C$
Vwo : shear capacity of an inner wall panel
V_C : shear capacity of a new boundary column
Vj : shear capacity of anchors installed at the wall-beam interface

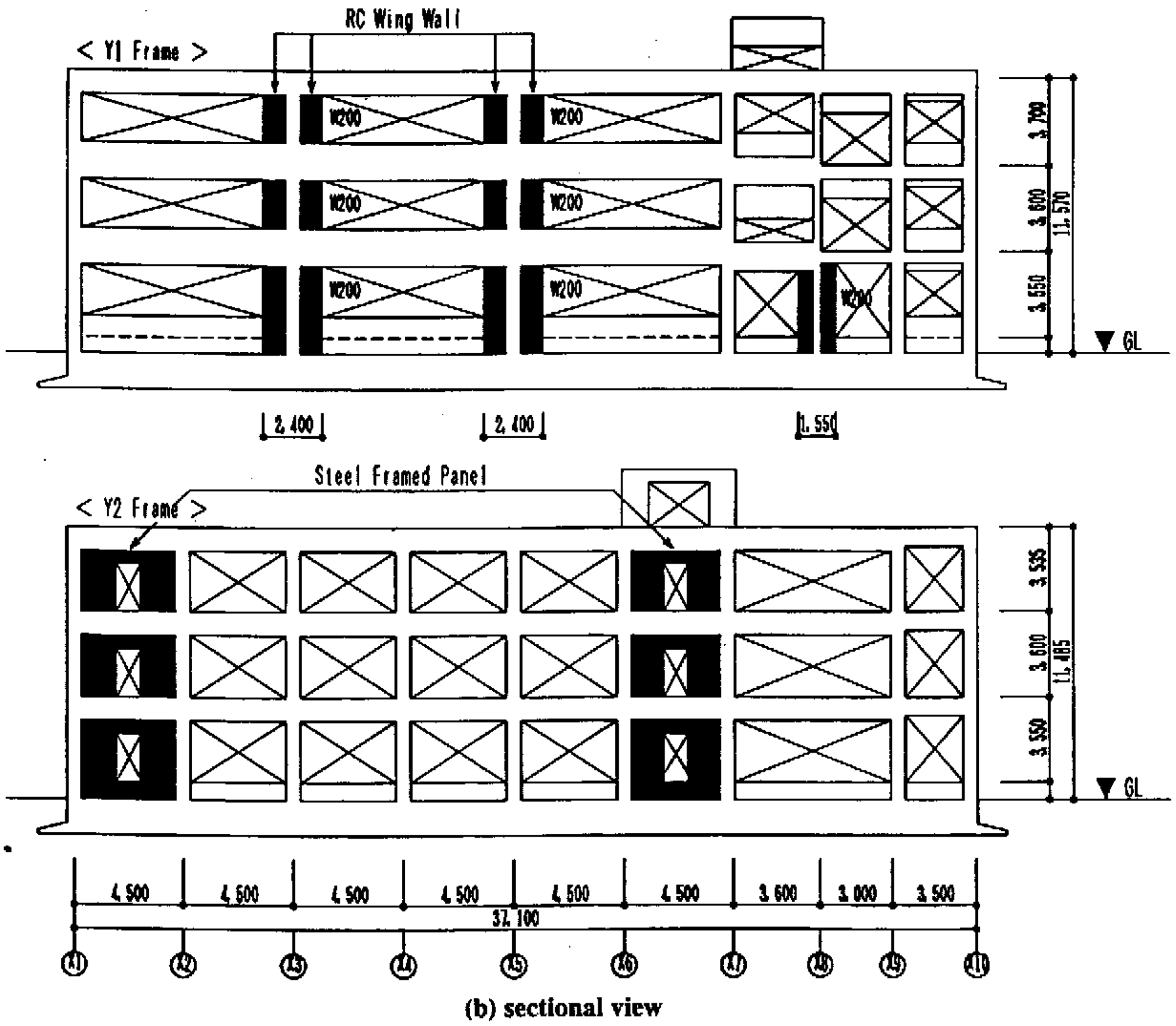
Shear capacity Vw of a typical post-cast wall in the first story is approximately 2,200 kN calculated from Vw_2. Considering the safety factor of 0.9 allowing for uncertainties due to few researches, the design capacity is then reduced to 2,000 kN. Based on the design capacity, the number of new walls needed to ensure the required seismic capacity is determined and the retrofitted structure is then reevaluated. As can be bound in **Figure 3**, Is index after retrofit upgrades to more than 0.80.

Retrofit with Steel Framed Panel:

Figure 4 shows the typical plan and section of a 3 storied RC school building designed and constructed in 1960. The exterior Y1 frame is 9 m long with narrow and deep beams (wall girder) of 200 mm x 1,550 mm in cross-section, while the interior Y2 frame is 4.5 m long with beams of 350 mm x 1,000 mm. As can be found in **Figure 5**, the seismic capacity index Is of original building varies from 0.47 to 0.55 in its longitudinal direction and lower than the required capacity Iso in all stories while higher in the transverse direction. Since the structure has insufficient lateral resistance in the longitudinal direction, as is same case with the building previously described in section 2.1, a retrofit technique to increase strength is employed as a basic strategy. However, the vertical load carrying capacity of foundation structure is poor and minimal increase in building weight is highly required to avoid costly redesign of foundation. Steel framed panels, which are relatively light but can provide lateral resistance as much as RC walls, are therefore employed in this building, while the previous building is retrofitted with RC walls. The steel panels are then determined to place in the interior frame because the exterior frame has long and narrow beams, and difficulties to install anchors are expected, as discussed in section 2.1. As shown in **Figure 4(a)** and **(b)**, RC wing walls are also provided in the exterior frame Y1 to improve lateral resistance of the structure.

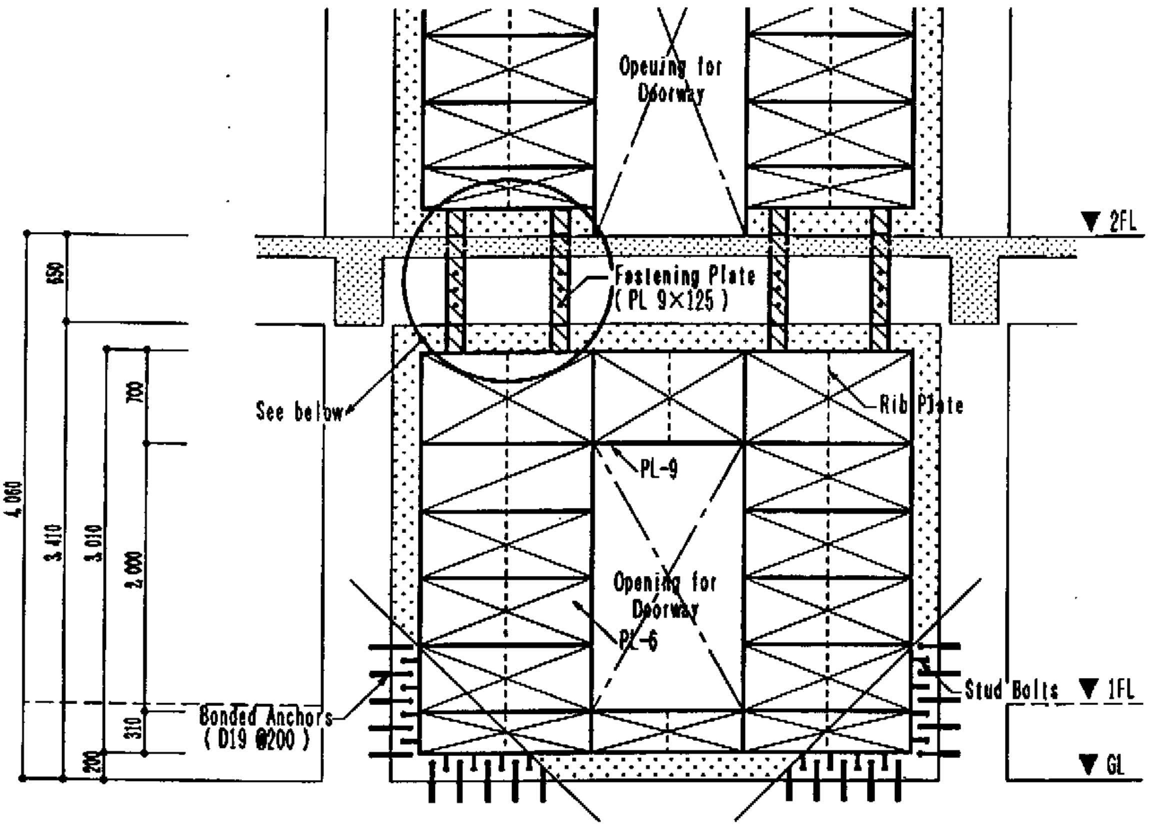


(a) plan view



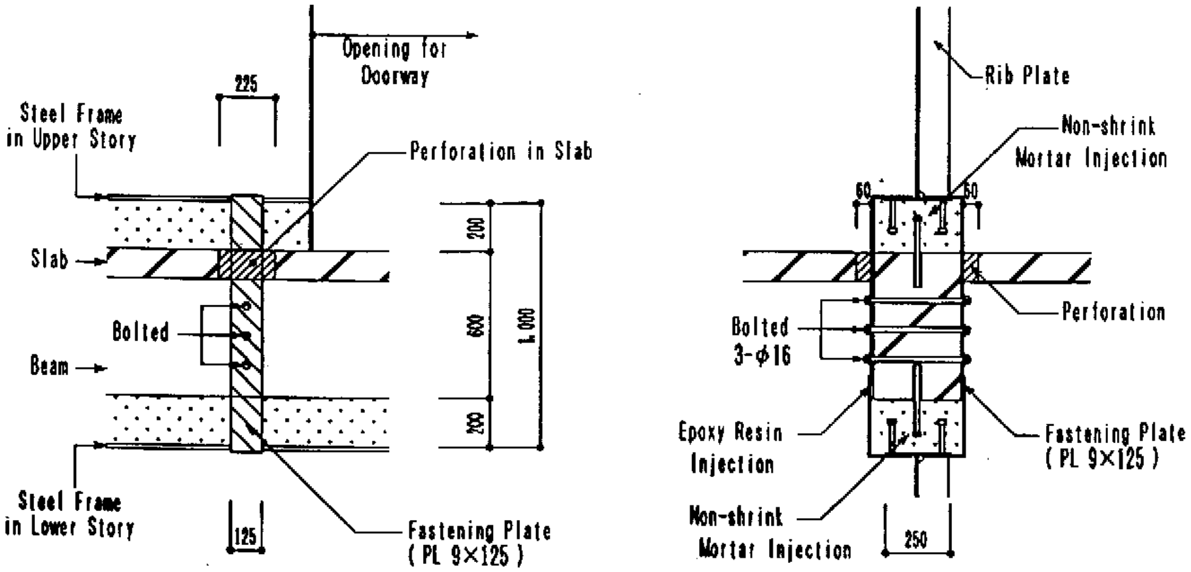
(b) sectional view

Figure 4: Three storied RC school building retrofitted with steel panel having discontinuous frame



Note: Bottom steel frame is *continuous* in the first story while *discontinuous* in the second story. Fastening plates are detailed below.

(c) steel frames



(d) fastening details around the discontinuous steel frame

Figure 4: Three storied RC school building retrofitted with steel panel having discontinuous frame

Steel framed panels conventionally used for seismic retrofit in Japan have steel frames on all four sides, and their top and bottom sides are fully connected with existing RC beams using post-installed anchors, and right and left sides with RC columns, as shown in the lower figure of **Figure 4(c)**. However, since steel panels are planned to be placed between classrooms and corridor in this building, they need a doorframe which is flush with the slab in the bottom and stepless for easy passage through openings. As shown in **Figure 4(b)** and **(c)**, the steel frames on the bottom side in the second and third stories are therefore partially cut off in the mid-span, which causes discontinuity of the steel frames, while they are embedded in concrete slab in the first story. It should be noted that experimental investigations on similar retrofit schemes [Tange and Yamamoto et al., 1998] with cut-off steel frame resulted in less ductility due to slippage of the discontinuous steel frame for the opening. To fasten the discontinuous steel frame rigidly with existing RC beams, steel plates are placed through perforations in slab on both sides of the discontinuous steel frame. The fastening plates are also welded at the steel frames above and below the existing RC beams, and they are bolted together with the beams to ensure stable seismic performance as shown in **Figure 4(d)**. The fastening plates and bolts are designed so that they can resist the shear and tensile forces acting on the connection. **Figure 5** shows the comparison of seismic capacity index before and after retrofit. As can be seen from the figure, the reevaluated *Is* after retrofit in each story satisfies *Iso*.

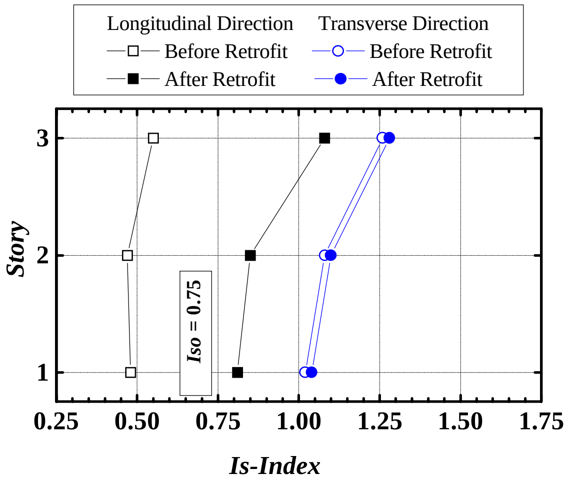


Figure 5: Comparison of seismic capacity index *Is* before and after retrofit

CONCLUDING REMARKS

In the seismic retrofit practice, it is most essential to apply techniques that can meet both structural and functional requirements. In this paper, two school buildings in Ota City, Tokyo, Japan, were presented to show seismic retrofit schemes and technical solutions to harmonize both requirements together with their details. By using the techniques proposed in this paper, both buildings could be upgraded to meet the required seismic capacity. Although they were carefully designed and detailed considering suitable construction practice as well as deficiencies expected during earthquakes, their structural capacities were conservatively evaluated since their performances have not been experimentally clarified yet and no formulas to precisely estimate their capacity and ductility were currently available. More efforts should be therefore directed to experimental researches to new and inventive retrofit techniques aiming at wider design and field applications.

REFERENCES

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Tange, S. Yamamoto, Y. Hattori, M., Hirosawa, M. and Tagawa, Y.(1998) "Experimental Study on Various Retrofit Methods Using Steel Elements with an Opening for Doorway", *Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan*, Vol. C-2, pp. 109-116. (in Japanese)

APPENDIX

BASIC CONCEPT OF JAPANESE GUIDELINES FOR SEISMIC EVALUATION AND RETROFIT OF EXISTING RC BUILDINGS

The Guideline for seismic evaluation [JBDPA, 1990a] defines the following structural seismic capacity index I_S at each story level in each principal direction of a building.

$$I_S = E_O \times S_D \times T \tag{2}$$

where, E_O : basic structural seismic capacity index, calculated by the products of Strength Index (C), Ductility Index (F), and Story Index (ϕ) at each story and each direction when a story or building reaches at the ultimate limit state due to lateral force. ($E_O = \phi \times C \times F$)

C : index of story lateral strength, calculated from the ultimate story shear in terms of story shear coefficient.

F : index of story ductility, calculated from the ultimate deformation capacity normalized by the story drift of 1/250 when a standard size column is assumed to fail in shear. F is dependent on the failure mode of structural members and their sectional properties such as bar arrangement, member geometric size etc. F is assumed to vary from 1.27 to 3.2 for ductile columns, 1.0 for brittle columns and 0.8 for extremely brittle short columns.

ϕ : index of story shear distribution during earthquake, estimated by the inverse of design story shear coefficient distribution normalized by base shear coefficient. $\phi = (n+1)/(n+\mathrm{i})$ is basically employed for the i-th story of an n-storied building.

S_D : factor to modify *Eo-Index* due to stiffness discontinuity along stories, eccentric distribution of stiffness in plan, irregularity and/or complexity of structural configuration, basically ranging from 0.4 to 1.0.

T : reduction factor to allow for the grade of deterioration, ranging from 0.5 to 1.0.

Required seismic capacity index I_{SO}, which evaluates structural safety against an earthquake, is defined as follows.

$$I_{SO} = E_S \times Z \times G \times U \tag{3}$$

where, E_S : basic structural seismic capacity index required for the building concerned. Considering past structural damage due to severe earthquakes in Japan, standard value of E_S is set 0.6.

Z : factor allowing for the seismicity.

G : factor allowing for the soil condition.

U : usage factor or importance factor of a building.

I_{SO} index for school buildings in Ota City is 0.75 considering $E_S = 0.6$, $U = 1.25$ and other factors of 1.0. It should be noted that $C_T \times S_D$ defined in **Eq. (4)** is required to be larger than or equal to 0.3 in the Guideline for seismic evaluation [JBDPA, 1990a] to avoid fatal damage and/or unfavorable residual deformation due to large response of structures during major earthquakes.

$$C_T \times S_D = \phi \times C \times S_D \tag{4}$$

Seismic retrofit of buildings is basically carried out in the following procedure. [JBDPA, 1990b]

(1) Seismic evaluation of the structure concerned. : I_S and $C_T \times S_D$ are calculated.
(2) Determination of required seismic capacity : I_{SO} is determined.
(3) Comparison of I_S with I_{SO}.
  (if $I_S < I_{SO}$ or $C_T \times S_D < 0.3$ and retrofit is required, then (4) through (6) are needed.)
(4) Selection of retrofitting scheme(s).
(5) Design of connection details.
(6) Reevaluation of the retrofitted structure. : I_S and $C_T \times S_D$ are checked.