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SEISMIC REHABILITATION OF SCHOOL BUILDINGS IN JAPAN

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ABSTRACT: Following the 1995 Hyogoken-nambu (Kobe) earthquake, various integrated efforts have been directed toward upgrading seismic performance of vulnerable school buildings. In this paper, damage statistics of school buildings due to the Kobe earthquake, criteria to identify their vulnerability, the subsidy program for seismic rehabilitation, and their implementation examples, are briefly described, together with recent challenging efforts for further promotion of seismic rehabilitation on a nationwide basis.

Key Words: Hyogoken-nambu (Kobe) earthquake, Seismic evaluation, Seismic rehabilitation, School building

INTRODUCTION

The 1995 Hyogoken-nambu (Kobe) earthquake caused devastating damage to urban centers and triggered a new direction in seismic evaluation and rehabilitation of existing vulnerable buildings in Japan. The widespread damage to older buildings designed to meet the code criteria of the time of their construction revealed the urgency of implementing rehabilitation of seismically vulnerable buildings. The damage to school buildings was no exception to this.

Since the catastrophic event in Hanshin-Awaji district, various integrated efforts have been directed by the Japanese Government and engineering professionals toward upgrading seismic performance of vulnerable buildings and implementing learned and re-learned lessons for earthquake loss mitigation. Several new laws promulgated soon after the event such as *Special Measures Law on Earthquake Disaster Prevention* and *Law to Promote Seismic Rehabilitation* have undoubtedly served as fundamentals for nationwide seismic rehabilitation of vulnerable buildings. Along with these actions, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) has contributed to earthquake disaster mitigation of school buildings through enhancing a subsidy program for seismic rehabilitation to financially support local districts and publishing technical guides to help engineers determine technically and economically sound solutions of rehabilitation (MEXT 1998a, b).

In this paper, damage statistics of school buildings due to the Kobe earthquake and criteria to identify their vulnerability, are briefly overviewed, and the subsidy program for seismic rehabilitation of school buildings, its implementation examples, and other responses made to mitigate damage to school buildings after the Kobe earthquake are described together with recent challenging efforts for further promotion of seismic rehabilitation on a nationwide basis.

DAMAGE DUE TO 1995 HYOGOKEN-NAMBU (KOBE) EARTHQUAKE

The 1995 Hyogoken-nambu (Kobe) earthquake, which centered the urban area of Hanshin-Awaji district, caused extensive structural and/or non-structural damage to approximately 4,500 educational facilities. No fatalities fortunately resulted from damaged schools since the quake struck the area early in the morning. Some school buildings, however, sustained serious damage as shown in **Photo 1**, and 54 buildings were demolished and reconstructed following the event. The Japanese Government appropriated 94 billion yen for fiscal years 1994 and 1995 to restore damaged educational facilities and subsidized 1,126 buildings (MEXT 1998a, b).

Immediately after the event, the Architectural Institute of Japan (AIJ) set up a task committee consisting of approximately 40 members to investigate damage to educational facilities. The committee members surveyed approximately 800 school buildings and other educational facilities in the affected area, identified their damage levels, calculated seismic capacities of some 100 buildings, and investigated the correlation between damage level and seismic capacity.

Figure 1 shows the damage statistics of RC school buildings due to the Kobe earthquake (after AIJ 1997). In the last 3 decades, the Japanese seismic design code was revised in 1971 and 1981.


Photo 1: Seriously damaged schools (1995 Hyogoken-nambu earthquake, AIJ 1997)

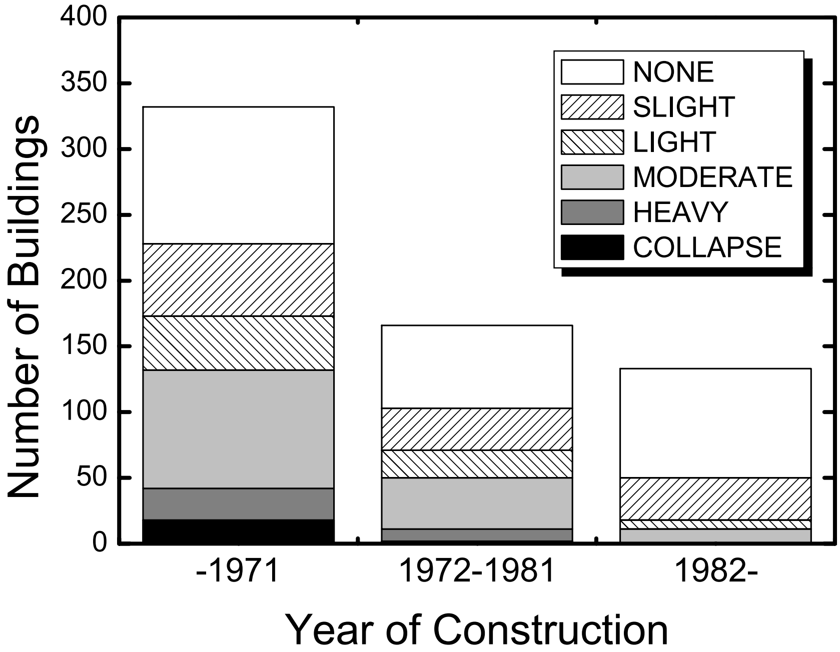


Figure 1: Damage statistics of RC schools due to the 1995 Kobe earthquake (after AIJ 1997)

As can be found in the figure, the damage rate is highly dependent on the code generation, and those designed in accordance with the pre-1981 code had more serious damage.

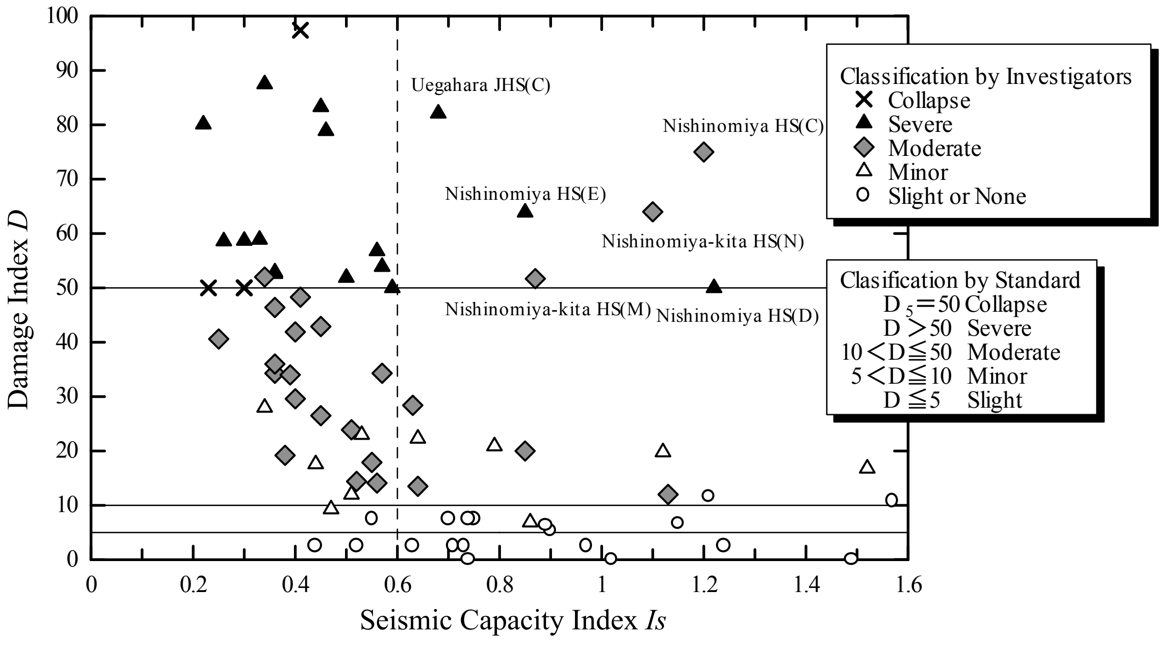
In **Figure 2** is shown the relationship between damage rate index *D* and seismic capacity index *Is* of surveyed RC buildings, where *D* and *Is* are computed according to the Guidelines for Post-earthquake Damage Evaluation (JBDPA 1991) and the Standard for Seismic Evaluation of Existing RC Buildings (JBDPA 1990a), respectively (Okada et al. 2000). The basic concept and procedure to compute *Is* is briefly described in **APPENDIX**. The figure reveals that the damage rate is inversely correlated with the computed *Is* values, and that buildings with *Is* value equal to or exceeding 0.6, which is a required seismic capacity index defined in the Standard for non-essential (standard occupancy) buildings, sustain generally minor damage. It should be pointed out, however, that 6 buildings in **Figure 2** designated (C), (D), (E), (M), and (N) are considered to have serious damage, although their *Is* values are higher than 0.6. Further investigations conclude that the observed serious damage may be attributed to the directivity of predominant ground shaking that agrees with the longitudinal direction (generally weaker than the transverse direction due to fewer shear walls in school buildings) of these 6 buildings, and their larger residual displacements due to relatively ductile failure mode but low lateral strength.

Similar results are also found in steel school buildings. Pre-1981 gymnasiums sustained more serious damage and their *Is* values fell in the range of 0.3 to 0.6 (Kabeyasawa et al. 2000).

SEISMIC REHABILITATION PROGRAM OF SCHOOLS AND ITS IMPLEMENTATION

Seismic Rehabilitation Program

The 1995 Kobe earthquake caused serious damage to older buildings, especially to those constructed before 1981. Recognizing the serious vulnerability of older buildings, the Japanese Government



Note: *Di* index is calculated based on the number of columns *Bi* categorized in Damage Class *i* defined in the Guideline, and the total number of columns *A* (JBDPA 1991). The overall rating of a building *D* (= Σ *Di*, *i* = 1 to 5) is then determined depending on the criteria as shown in the legend above. Although a new index *R* denoting a residual seismic capacity is employed in the Guideline revised in 2001 (JBDPA 2001) considering experiences of recent damaging earthquakes, calibrations made in the revised Guideline show that these two indices roughly correspond in the form of *R* = 100 - *D*.

Figure 2: Seismic capacity index *Is* vs. damage level (Okada et al. 2000)

promulgated the *Special Measures Law on Earthquake Disaster Prevention*, and launched a five-year program starting in 1996 to upgrade vulnerable buildings, facilities, infrastructures etc. throughout the country. The program was then extended for another five years in 2001 to 2005, because the earthquake disaster mitigation through eliminating vulnerable potentials is still an urgent task in Japan.

The Ministry of Education (MEXT) also has directed significant efforts toward upgrading seismic performance of vulnerable school buildings, since more than 60 % of the current school building stock are, as shown in **Figure 3**, designed in accordance with pre-1981 code. To promote the seismic rehabilitation program, the MEXT financially supports the local governments to upgrade school buildings as shown in **Table 1** (Kabeyasawa 2000).

Figure 4 shows the subsidy budget of the MEXT for public elementary and middle schools. The total budget for school facilities covers new construction, structural extension, rehabilitation, and reconstruction. Although the total budget appropriated for school facilities has been decreasing over the last decade, primarily due to social and economic trends such as declining birthrate and consequent reduction in number of students, and the nationwide recession, the budget ratio for seismic rehabilitation and reconstruction of vulnerable buildings has been increasing.

The basic concept and procedure of seismic evaluation and rehabilitation design of existing buildings are in general based on the Seismic Evaluation Standard and Retrofit Guidelines for RC buildings (JBDPA 1990a,b, 2001a,b) and the Guidelines for Seismic Evaluation and Rehabilitation for Steel buildings (JBDPA 1996). In addition to these Standards and Guidelines, the Design Guides for Seismic Rehabilitation of School Facilities, which are primarily designed for RC school buildings and steel gymnasiums (MEXT 1998a, b), have been widely applied to school facilities. When a building

Table 1: Subsidy rate for public school buildings by MEXT (Kabeyasawa 2000)

Category		Subsidy Rate
Pre-event	Reconstruction	1/3
	Seismic Rehabilitation	1/2
	Extensive Remodeling due to Rehabilitation	1/3
Post-event	Restoration	2/3

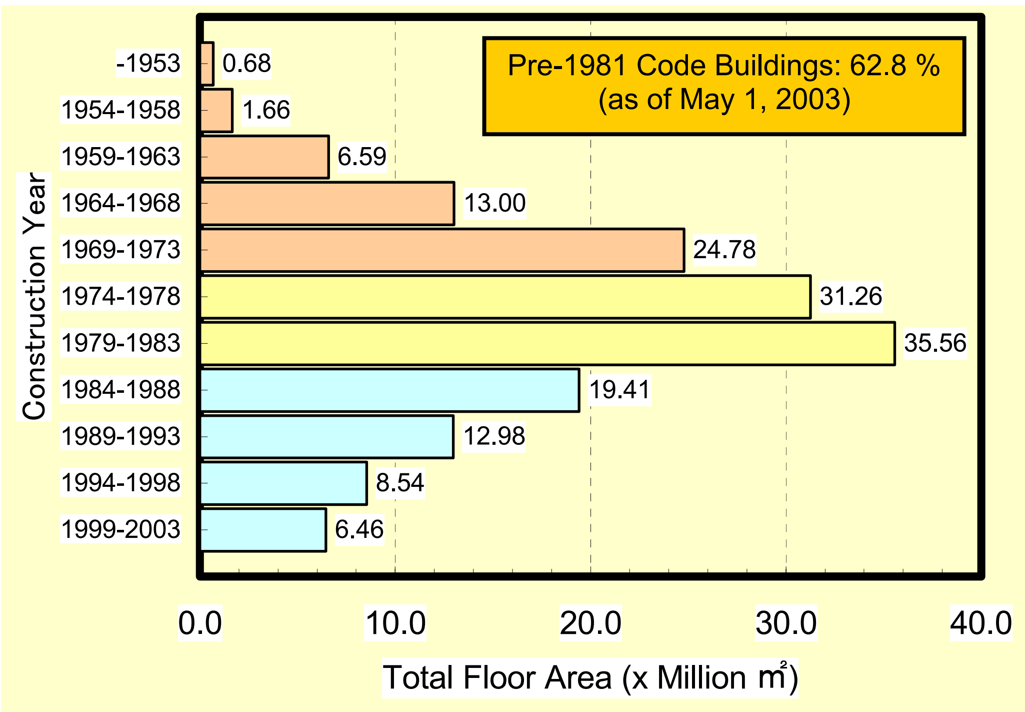


Figure 3: Total floor area of existing school facilities (after MEXT HP)

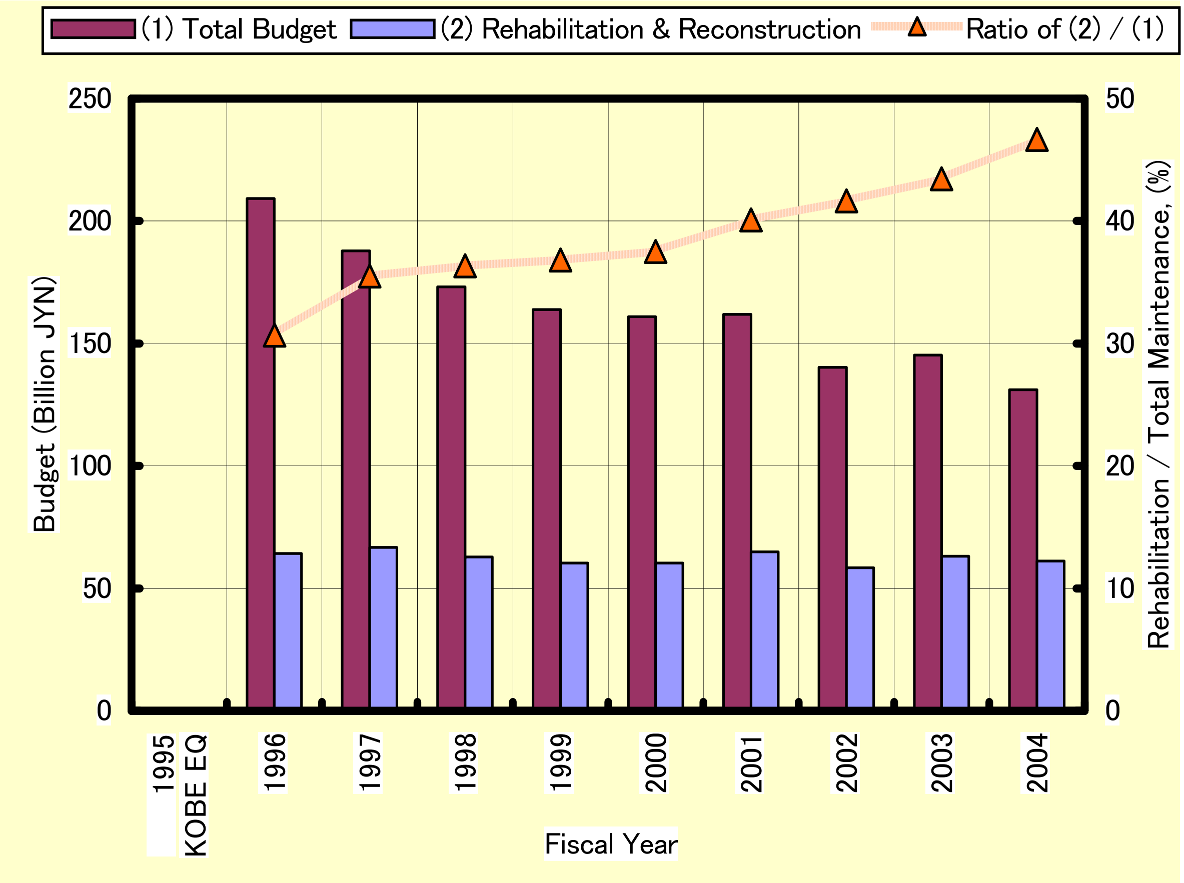


Figure 4: Subsidy budget for public elementary and middle schools

has *Is* index less than a criteria value of 0.7, which is determined considering the relationship between observed damage to schools and their *Is* values shown in **Figure 2** and the essential role as refugee centers as well as educational facilities, the building is to be seismically rehabilitated with financial support by MEXT so that *Is* value should not be less than the criteria 0.7.

For a successful rehabilitation, it is most essential to predict seismic performance that is most likely to be achieved under strong ground shaking and to find a rational solution to minimize expected damage. To this end, a review committee consisting of professionals on building engineering such as university professors, practitioners etc. is generally set up in each local district. In the committee, structural modeling, calculations results, and rehabilitation proposals are reviewed from the effectiveness and economical engineering practice point of view based on sound engineering and scientific principles and knowledge.

Implementation Example of Program (Ohba et al. 2000)

Outline of the Program

As previously stated, a five-year program to upgrade school buildings started in 1996. Since then, extensive efforts have been directed toward seismic evaluation and rehabilitation of school buildings throughout the country.

Ota City, which is located in the south of the urban center of Tokyo as shown in **Figure 5**, may be the most successful district in implementing the program, because all the school buildings in the City designed according to the dated codes were evaluated and all buildings identified vulnerable had been already rehabilitated (Ohba et al. 2000). The City consists of residential areas in the north and industrial areas in the south, having a population of 650,000 and a population density of 10,800 per km^2. The City has 91 elementary and middle schools, and they consist of 340 school buildings including both old and new constructions.

Figure 6 shows the rehabilitation schedule of the City (as of April 1999). Seismic evaluation of all schools constructed before 1981 and all rehabilitation design and works are completed to date. In the subsequent section, the fundamental statistics of 219 RC buildings of 82 schools are presented. They are all constructed before 1981 (mostly 3 story buildings) and correspond to about 65 % of the total 340 school buildings in the City. The remaining 35 % are RC school buildings constructed after 1981, steel gymnasium facilities etc.

Seismic Capacity of Existing Buildings and Rehabilitated Buildings

The shaded area in **Figure 7(a)** shows the distribution of seismic capacity index *Is* in the first story of entire 219 school buildings, where *Is* indices in both principal directions of each building evaluated in accordance with the Standard are plotted. As can be found in the figure, the distribution has two peaks, and a distribution containing a peak at smaller *Is* index corresponds to the longitudinal direction while the other to the transverse direction. This is generally because a school building has fewer shear walls in the longitudinal direction than in the transverse direction where shear walls are in general placed between each classroom.

Figure 7(b) shows the distribution of *Is* indices in the first story before and after rehabilitation of 143 buildings which are identified rehabilitation candidates. In the City, the decision criteria *Iso* to

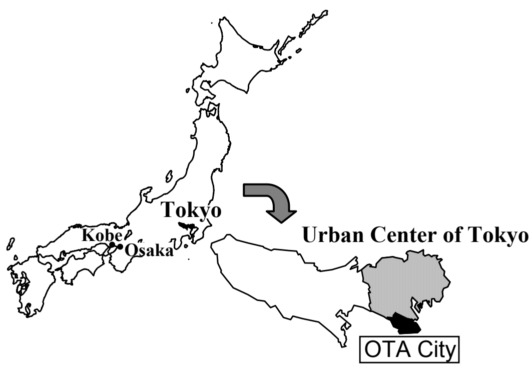


Figure 5: Location of Ota City, Tokyo

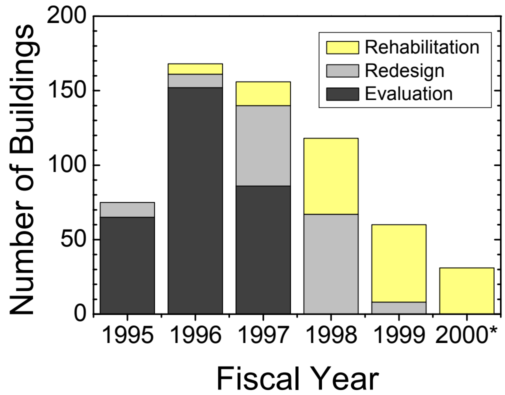


Figure 6: Budget plan in Ota City

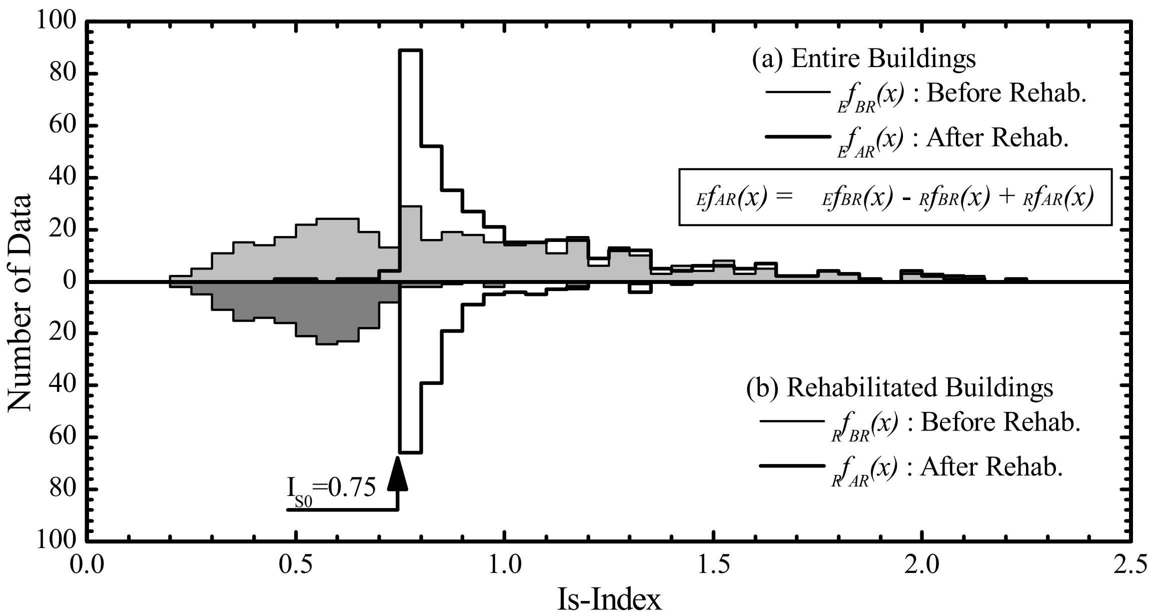
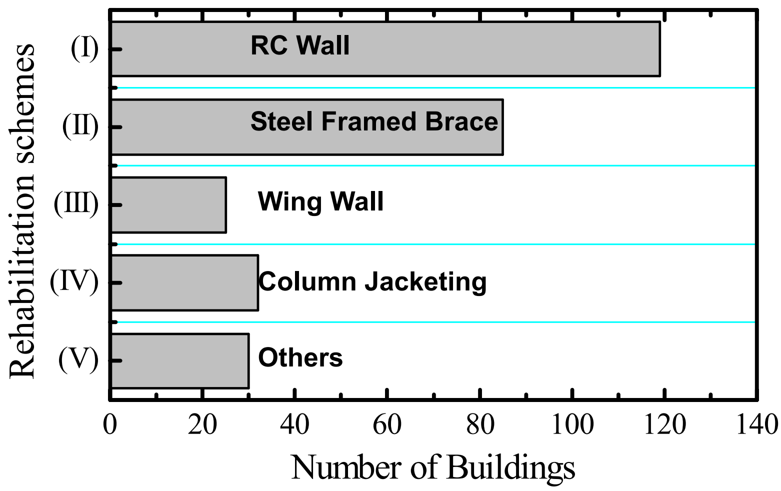


Figure 7: Distribution of *Is* index in the first story



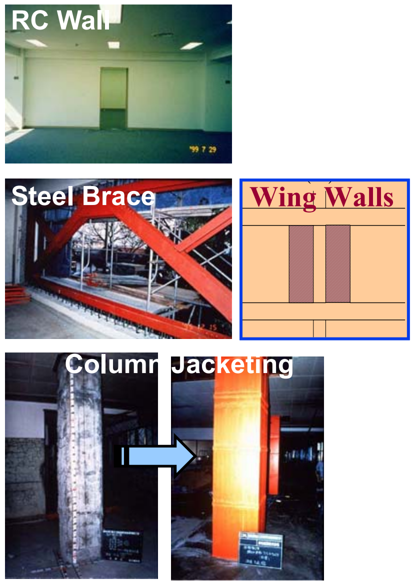


Figure 8: Employed rehabilitation schemes

screen sound buildings is set 0.75 considering the basically required seismic capacity index of 0.6 and the importance factor of 1.25 for school buildings. As can be seen in the figure, seismic capacities of rehabilitated buildings have a significant peak just beyond Is = 0.75, and then sharply decrease.

Knowing the frequencies of existing and rehabilitated buildings described above, the Is index distribution (i.e., frequency) of entire buildings including rehabilitated buildings can be obtained as shown by a thick line in **Figure 7(a)**. The figure shows that the rehabilitation significantly improves seismic capacities of RC school buildings in the City.

Trends in Seismic Rehabilitation Schemes

Figure 8 shows rehabilitation schemes employed in 143 rehabilitation candidates. It should be noted that some buildings employ not a single but several schemes together, and the total number in the figure is much larger than 143. In rehabilitating an existing RC building, a scheme to infill new RC walls into existing bare frames had been most conventionally applied in Japan because of numerous practical experiences as well as experimental and analytical researches extensively made on this technique. Although it is one of the most reliable strategies to upgrade a seismically vulnerable RC building, *infilling* often causes less flexibility in architectural and environmental redesign and/or the increase in building weight sometimes leads to costly redesign of foundation. On the other hand, steel framed braces have been more widely applied in recent years, particularly following the 1995 Kobe earthquake, to overcome such shortcomings resulting from the conventional RC walls mentioned above. As can be found in **Figure 8**, RC walls are most widely used but steel framed braces are applied to approximately 60 % of rehabilitation candidates in Ota City, which is same as the recent trends of seismic rehabilitation schemes employed in other cities in Japan.

SEISMIC PERFORMANCE OF REHABILITATED SCHOOL BUILDINGS

Structural behaviors of upgraded buildings under actual ground shaking is an evidence of great importance to understand their seismic performances, and the damage observed after a major event may serve as fundamental data to verify effectiveness of seismic rehabilitation although a few have been reported to date in Japan.

An earthquake of magnitude 6.2 struck the northern Miyagiken on July 23, 2003, and caused considerable damage to buildings and infrastructures. Field surveys were made by AIJ following the event and the damage report shows structural behaviors of two school buildings having a similar original structural design, one of which was seismically rehabilitated before the event (Tanaka 2004).

Investigated are two RC middle school buildings (referred to as Building No. 1 and No. 2, hereafter). They are located 6 km apart in Yamoto-cho, which is approximately 50 km north from Sendai city, Miyagi prefecture. The maximum seismic intensity of 6-Upper on JMA scale is recorded in Yamoto-cho. They are both 3 story, pre-1971 RC school buildings having a typical span length of 9m in the longitudinal direction and column size of 700mm x 500mm.

Building No. 1, which had not been rehabilitated at the time of the quake, sustained damage to columns in frame (A) and exterior walls in frame (C). **Figure 9** shows the plan view and observed damage pattern in frame (C).

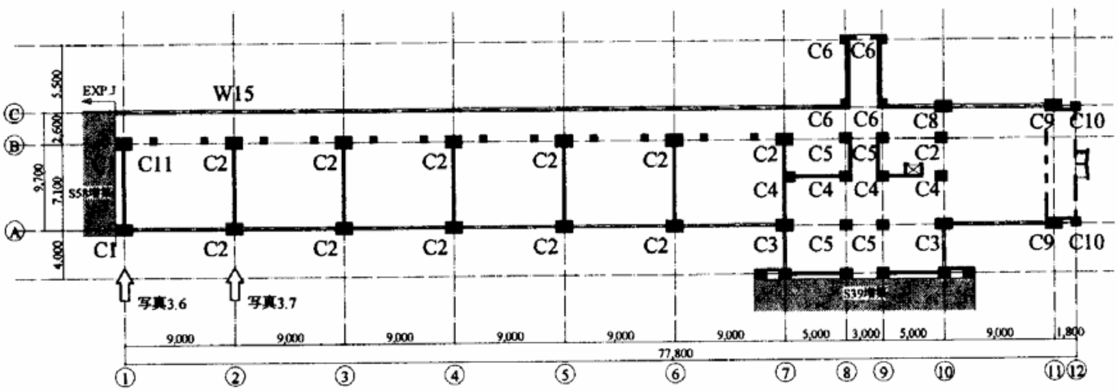
Although Building No. 2 has a structural design similar to the other one, it sustained no structural damage since it had been, prior to the 2003 event, seismically rehabilitated after the Kobe earthquake. **Figure 10** shows the original and re-designed building. As can be found in the figure, Building No. 2 is rehabilitated in frame (B) with infilled RC shear walls having new boundary columns on both sides, which is one solution recommended in the Technical Guide (MEXT 1998a).

These evidences demonstrate the importance and effectiveness of seismic rehabilitation with technically sound solutions.

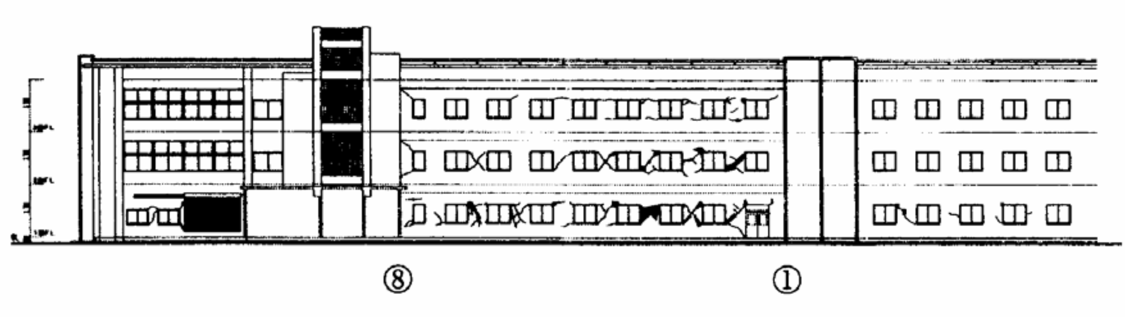
FURTHER PROMOTION OF SEISMIC REHABILITATION

Although the rehabilitation program has been successfully implemented in some local districts, a recent Government's survey on earthquake preparedness (as of March 2001), which reviews various facilities and equipment essential for earthquake disaster mitigation, reveals that the implementation is not necessarily activated on a nationwide basis (Cabinet Office 2003). **Figure 11** shows the survey results on school buildings, which reveals that approximately 2/3 of pre-1981 buildings are not seismically evaluated, and that less than half of the overall school building stock are deemed to have high seismic capacity.

The slow progress of implementation is a serious concern for earthquake disaster mitigation since



(a) Plan view



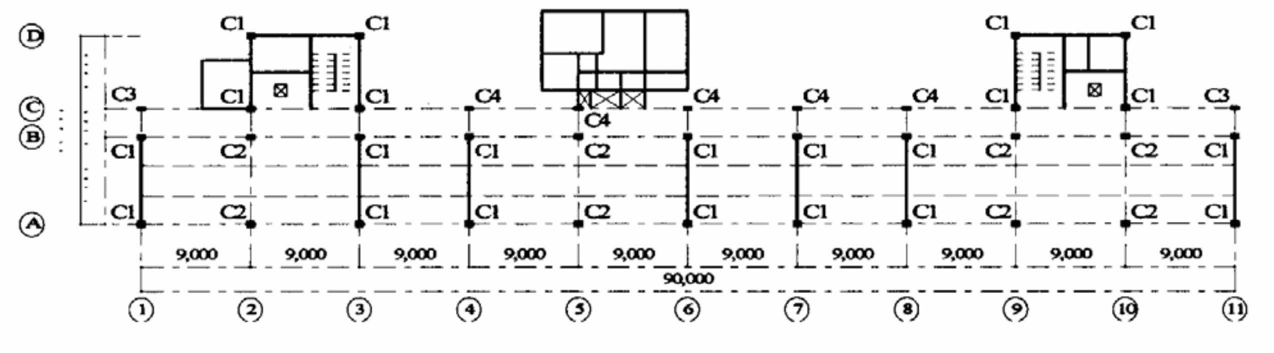
(b) Damage in frame (C)

Figure 9: Plan view and damage of Building No. 1 (Tanaka 2004)

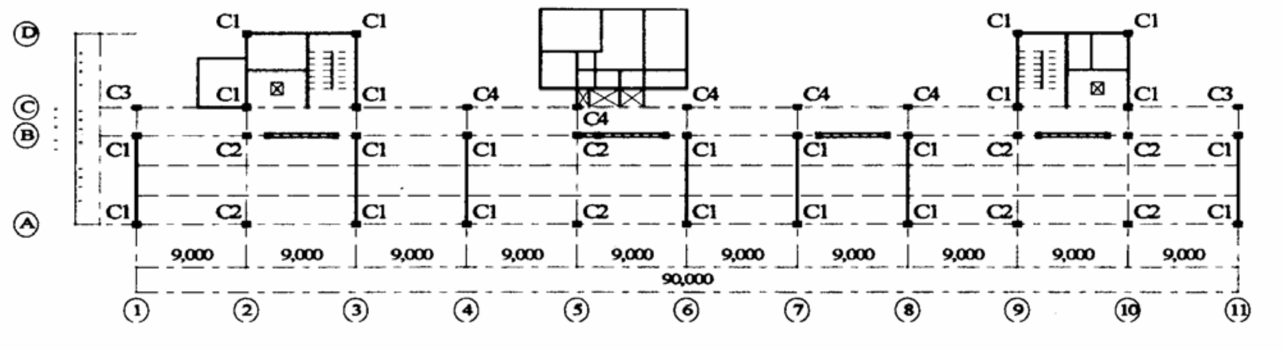
large-scale earthquakes are expected to occur along the coastal region in the near future, and they may result in a great loss of life and widespread property damage in Japan. The report by the Special Board of Inquiry on Tokai Earthquake Response (CDMC 2003) points out the great urgency of upgrading seismic performance of essential facilities including schools, hospitals, highways, railroads etc., and proposes to disclose facilities' information regarding their seismic capacity to promote seismic rehabilitation through public awareness of vulnerable buildings.

The cause of slow progress can be attributed primarily to the facts that (a) local governments hold many facilities and all buildings can not be upgraded at the same time, and (b) a practical and rational procedure to prioritize buildings of great urgency has not yet been established. In 2002, the MEXT therefore set up a special committee to discuss and seek a strategy for promoting seismic rehabilitation of school buildings. The committee summarized a report proposing a two-step procedure to identify a building to be upgraded immediately (MEXT 2003). The procedure consists of (1) preliminary priority setting of buildings to be seismically evaluated and (2) identification of vulnerable buildings to be upgraded. The first priority setting to identify buildings *to be evaluated* can be made for RC school buildings and steel gymnasiums, respectively, considering conditions described below.

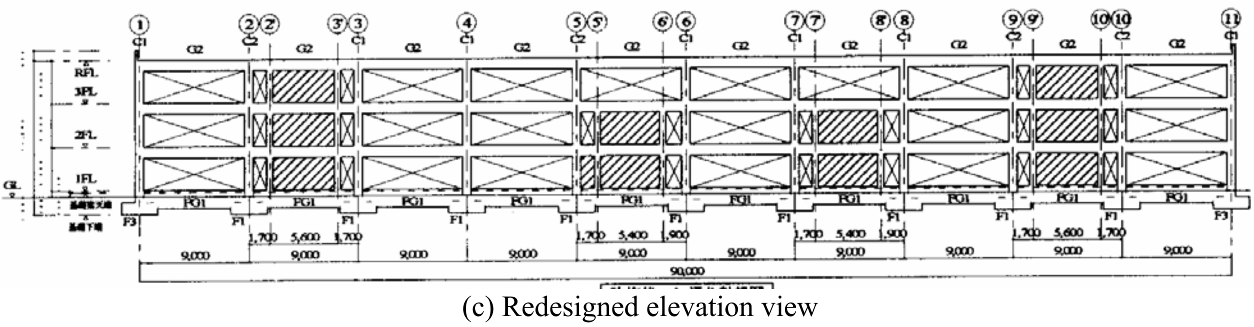
- RC buildings: the number of stories and the year of construction, material strength, structural



(a) Original plan view



(b) Redesigned plan view



(c) Redesigned elevation view

Note: The hatched areas above indicate new shear walls installed before 2003 event.

Figure 10: Plan and elevation view of Building No. 2 (Tanaka 2004)

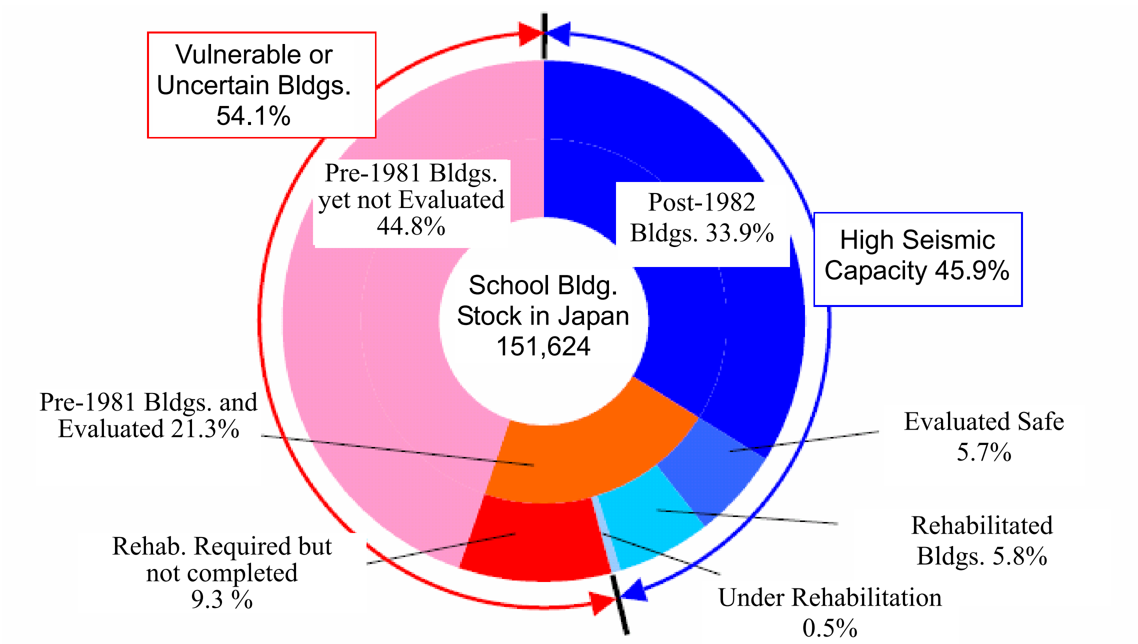


Figure 11: Review results on earthquake preparedness of school buildings (as of March 2001)

deterioration, structural plan, and expected ground shaking

- Steel gymnasiums: brace capacity, member deterioration, presence of local buckling, welding condition, falling hazard, expected ground shaking

Buildings are then selected considering the priority made in the first procedure above, and their *seismic evaluation* is performed. Finally their urgency of *seismic rehabilitation* can be quantitatively determined depending on the computed seismic capacities. The procedure described above is applied to existing school buildings in some local districts to categorize the urgency of seismic rehabilitation, and the time and budget schedules are under preparation considering their priorities.

Another aspect to hamper efforts of seismic rehabilitation may result from conventional solutions with less flexibility in architectural design. Conventional rehabilitation schemes have been primarily (and often solely) focused on improvement of structural performance rather than of education and learning environment. A recent wider variety of education and learning style, however, often requires a new and flexible concept in designing new schools, and such efforts are also often desired in seismic rehabilitation. In 2002, AIJ therefore launched a research project sponsored by the MEXT, and the research committee jointly consisting of architects and engineers proposed challenging solutions in the report such as extensive remodeling in plan and change in use through structural alteration that can meet the functional requirements as well as structural performance criteria (AIJ 2003).

CONCLUDING REMARKS

The seismic rehabilitation program of school buildings and its implementation after the 1995 Kobe earthquake is presented. The Japanese Government and the Ministry of Education has been implementing the program throughout the country under the cooperation with building engineering professionals, and they have been successfully upgraded in some local districts. There still remain a large number of vulnerable schools, however, and their rehabilitation is an issue of great urgency. A new practical procedure that may help promote program implementation and challenging solutions to meet both functional and structural requirements are recently proposed as described herein, and they are greatly expected to contribute to further implementation of the program.

APPENIDX: BASIC CONCEPT OF JAPANESE STANDARD FOR SEISMIC EVALUATION OF EXISTING RC BUILDINGS

The Standard for Seismic Evaluation (JBDPA 1990a, 2001a), designed primarily for pre-damaged existing RC buildings in Japan, defines the following structural seismic capacity index *Is* at each story level in each principal direction of a building.

$$I_S = E_O \times S_D \times T \tag{1}$$

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

C : index of story lateral strength expressed 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 typical-sized column is assumed to fail in shear. F is dependent on the failure mode of a structural member and its sectional properties such as bar arrangement, member's geometric size etc. F is assumed to be in the range of 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 the base shear coefficient. $\phi = (n+1)/(n+\mathrm{i})$ is basically employed for the i-th story of an n story building

S_D : reduction factor to modify E_O 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 time-dependent deterioration grade, ranging from 0.5 to 1.0

A required seismic capacity index *Iso*, which is compared with *Is*-index to identify structural safety against an earthquake, is defined as follows.

$$I_{SO} = E_S \times Z \times G \times U \tag{2}$$

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

Typical *Iso* index is 0.6 considering $E_S = 0.6$ and other factors of 1.0. It should be noted that $C_T \times S_D$ defined in **Eq.(3)** is required to equal or exceed $0.3\ Z \times G \times U$ in the Standard to avoid fatal damage and/or unfavorable residual deformation due to a large response of structures during major earthquakes.

$$C_T \times S_D = \phi \times C \times S_D \tag{3}$$

Seismic rehabilitation of existing buildings is basically carried out in the following procedure.

(1) Seismic evaluation of the structure concerned (I_S and $C_T \times S_D$)

(2) Determination of required seismic capacity (I_{SO})

(3) Comparison of I_S with I_{SO} and of $C_T \times S_D$ with $0.3\ Z \times G \times U$

* If $I_S < I_{SO}$ or $C_T \times S_D < 0.3\ Z \times G \times U$ and therefore rehabilitation is required, the following actions (4) through (6) are needed.

(4) Selection of rehabilitation scheme(s)
(5) Design of connection details
(6) Reevaluation of the rehabilitated building to ensure the capacity of redesigned building equals or exceeds the required criteria

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