REGIONAL DEVELOPMENT DIALOGUE

RDD

Vol. 28, No. 2, Autumn 2007

EARTHQUAKE SAFETY OF SCHOOLCHILDREN

UNITED NATIONS CENTRE FOR REGIONAL DEVELOPMENT

NAGOYA, JAPAN

SEISMIC REHABILITATION OF SEISMICALLY VULNERABLE SCHOOL BUILDINGS IN JAPAN

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INTRODUCTION

The 1995 Great Hanshin-Awaji Earthquake caused devastating damage to the city of Kobe and other urban centres 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 at the time of their construction revealed the urgency of implementing the rehabilitation of seismically vulnerable buildings. The damage to school buildings was no exception to this. Since the catastrophic event in the Hanshin-Awaji region, various integrated efforts have been directed by the Government of Japan and engineering professionals towards upgrading the 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 the *Special Measures Law on Earthquake Disaster Prevention* and the *Law to Promote Seismic Rehabilitation* have undoubtedly served as a basis for the 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 programme for seismic rehabilitation to financially support local districts and through publishing technical guides to help engineers determine technically- and economically-sound methods of rehabilitation.[1/]

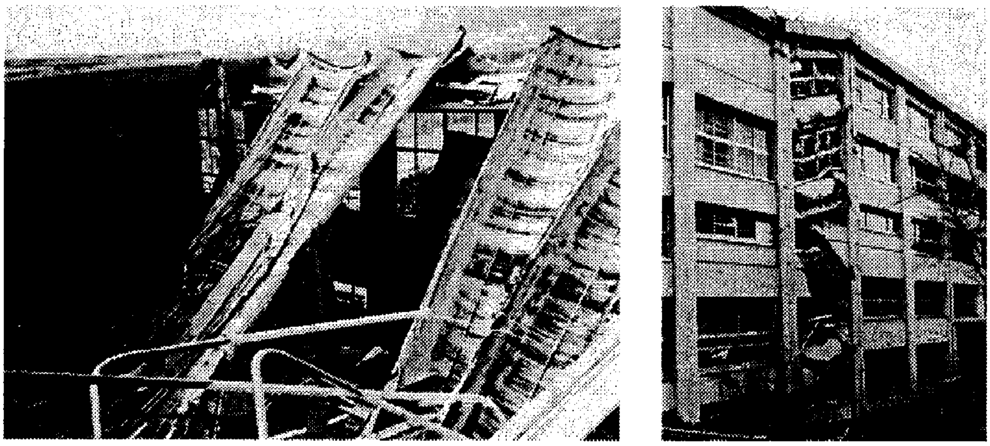
In this article, damage statistics of school buildings from the earthquake, and criteria to identify their vulnerability, are briefly overviewed, and the subsidy programme for seismic rehabilitation of school buildings, examples of its implementation, and other responses made to mitigate damage to school buildings after the Great Hanshin-Awajishima Earthquake are described together with recent challenging efforts for further promotion of seismic rehabilitation on a nationwide basis.

DAMAGE RESULTING FROM THE GREAT HANSHIN-AWAJI EARTHQUAKE

The Great Hanshin-Awaji Earthquake (hereinafter, the Kobe Earthquake), centred on the urban area of the Hanshin-Awaji region, caused extensive structural and/or nonstructural damage to approximately 4,500 educational facilities. Fortunately, no fatalities resulted from damaged schools since the quake struck the area early in the morning. Some school buildings, however, sustained serious damage as shown in figure 1, and fifty-four buildings were demolished and reconstructed following the event. The Government of Japan appropriated 94 billion yen for fiscal years 1994 (April 1994-March 1995) and 1995 (April 1995-March 1996) to restore damaged educational facilities and subsidized 1,126 buildings.[2]

Immediately after the event, the Architectural Institute of Japan (AIJ) set up a task force consisting of approximately forty 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 several hundred additional buildings, and investigated the correlation between damage level and seismic capacity.

Figure 1. Seriously Damaged Schools due to the 1995 Kobe Earthquake

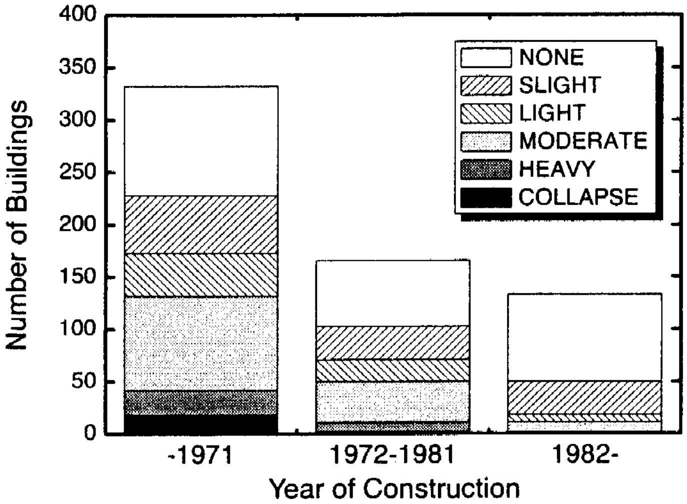


Source: Architectural Institute of Japan (AIJ), *Damage Investigation Report on Reinforced Concrete Buildings due to the 1995 Hyogoken-Nambu Earthquake -Part II School Buildings-* (Tokyo, 1997).

Figure 2 shows the damage statistics of reinforced concrete school buildings due to the Kobe Earthquake. The Japanese seismic design code was revised in 1971 and 1981 and as shown in the figure, the damage rate is highly dependent on the code in effect at the time of construction, and those designed in accordance with the pre-1981 code had more serious damage.

Figure 3 shows the relationship between damage rate index **D** and seismic capacity index **Is** of surveyed reinforced concrete buildings,[3] where **D** and **Is** are computed according to the Guidelines for Post-earthquake Damage Evaluation[4] and the Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings,[5] respectively. 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 six buildings in figure 3 designated (C), (D), (E), (M), and (N) have serious damage, although their **Is** values are higher than 0.6. Further investigations concluded that the observed serious damage could be attributed to the direction of predominant ground-shaking in the longitudinal direction

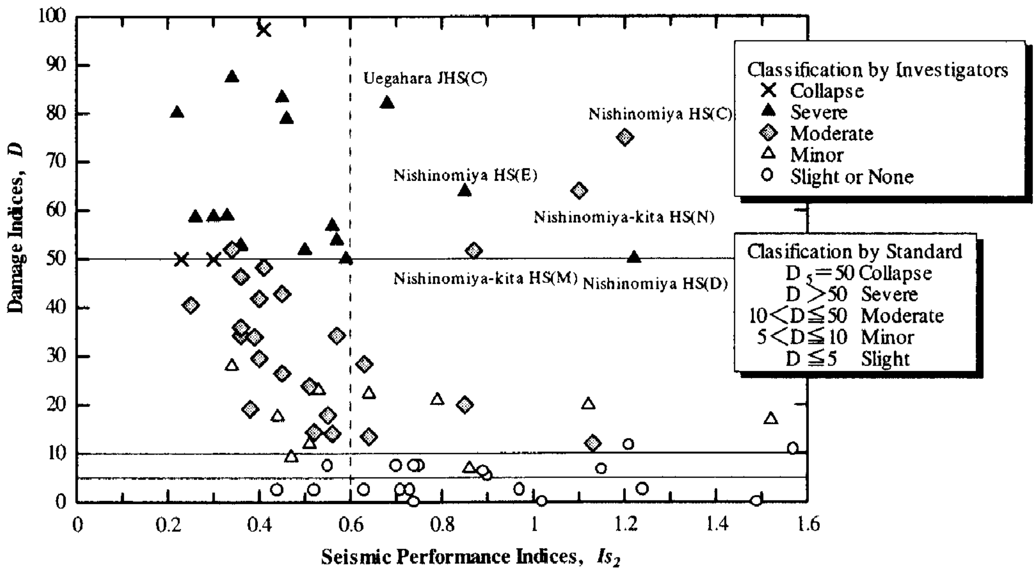
Figure 2. Damage Statistics of Reinforced Concrete Schools due to 1995 Kobe Earthquake



Source: Same as figure 1.

(generally weaker than the transverse direction due to fewer shear walls in typical Japanese school buildings) of these six buildings, and to their larger residual displacements due to the relatively ductile failure mode but low lateral strength.

Figure 3. Seismic Capacity Index Is vs. Damage Level



Source: T. Okada *et al.*, *Improvement of Seismic Performance of Reinforced Concrete School Buildings in Japan — Part 1 Damage Survey and performance evaluation after 1995 Hyogo-ken Nambu Earthquake* (Proceedings of 12th World Conference on Earthquake Engineering) (CD-ROM) (Wellington: New Zealand Society for Earthquake Engineering, 2000).

Note: A damage index **D** of a building classifies its damage rate (from slight to collapse) according to the index value. Damage to columns is first identified and the overall damage rating of the building is then determined. Detailed procedures for damage assessment can be found in the guidelines.

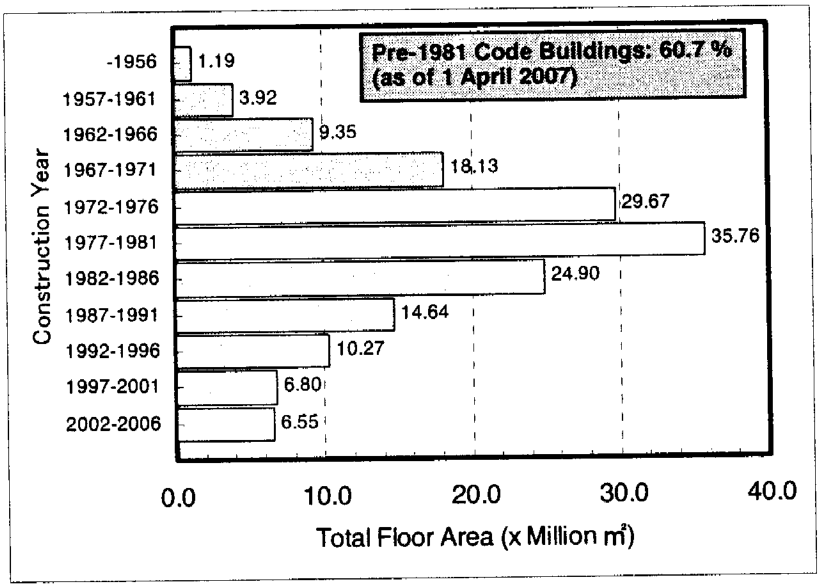
Similar results are also found in steel school buildings. Pre-1981 gymnasiums sustained more serious damage and their **Is** values fell in the range of 0.3 to 0.6.[6]

Seismic Rehabilitation Programme

The Kobe Earthquake caused serious damage to older buildings, especially to those constructed before 1981. Recognizing the serious vulnerability of older buildings, the Japanese Government promulgated the *Special Measures Law on Earthquake Disaster Prevention*, and launched a 5-year programme starting in 1996 to upgrade vulnerable buildings, facilities, and infrastructure throughout the country. The programme was then extended twice, covering 2001 to 2005 and 2006 to 2010, because earthquake disaster mitigation through eliminating potential vulnerabilities is still an urgent task in Japan.

MEXT has also directed significant efforts toward upgrading seismic performance of vulnerable school buildings, since more than 60 per cent of the current school building stock is, as shown in figure 4, designed in accordance with the pre-1981 code. To promote the seismic rehabilitation programme, MEXT financially supports local governments to upgrade school buildings as shown in table 1.[7] Note that the lower subsidy rate for the pre-event activities would generally not lead to an incentive to wait for an event rather than to undertake preventive measures in Japan because the total cost to restore damaged buildings is much higher than to rehabilitate buildings prior to damaging earthquakes and the catastrophic loss and damage would be particularly disruptive to the communities.

Figure 4. Total Floor Area of Existing Public Elementary and Middle Schools



Sources: Available from http://www.mext.go.jp/a_menu/shotou/zyosei/syokyuu.htm; and http://www.mext.go.jp/a_menu/shotou/zyosei/english/index.htm; both accessed 2007.

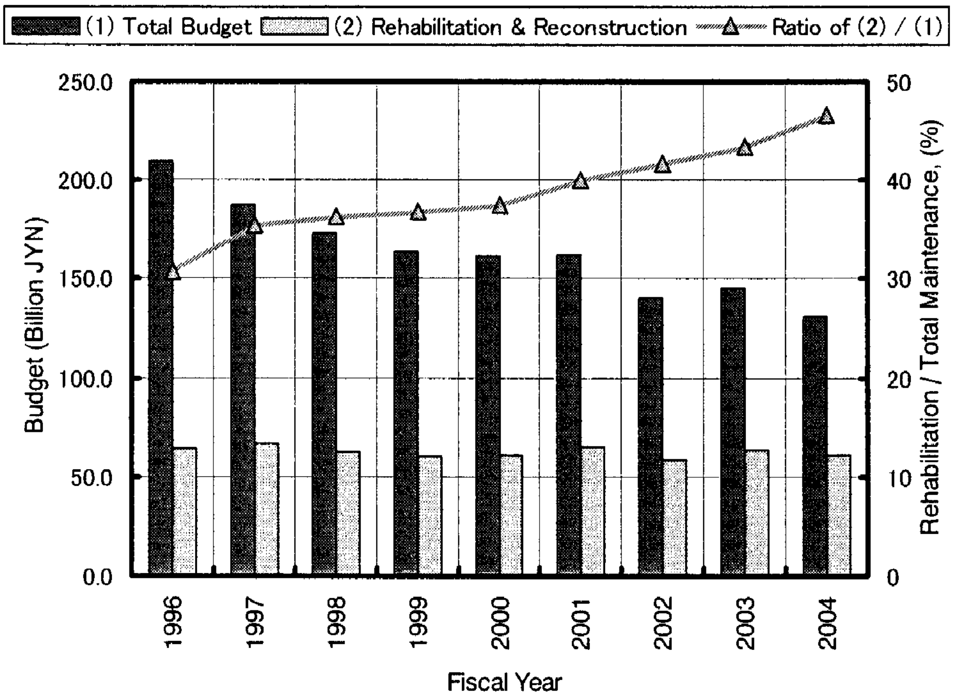
TABLE 1. SUBSIDY RATE FOR PUBLIC SCHOOL BUILDINGS BY MEXT[5]

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

Source: T. Kabeyasawa, K. Shinpo, and K. Kanemitsu, *Improvement of Seismic Performance of Reinforced Concrete School Buildings in Japan — Part 2 Systematic Project for Retrofit and Quick Response against Future Earthquakes* (Proceedings of 12th World Conference on Earthquake Engineering).

Figure 5 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 a declining birth rate and consequent reduction in the number of students, and the nationwide recession, the budget ratio for seismic rehabilitation and reconstruction of vulnerable buildings has been increasing.

Figure 5. Subsidy Budget for Public Elementary and Middle Schools



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 Reinforced Concrete Buildings[8] and the Guidelines for Seismic Evaluation and Rehabilitation for Steel buildings.[9] In addition to these standards and guidelines, the Technical Guides for Seismic Rehabilitation of School Buildings[10], which are primarily designed for reinforced concrete school buildings and steel gymnasiums, have been widely applied to school facilities. When a building has an **Is** index less than the criteria value of 0.7, which is higher than the standard value of 0.6 considering the essential role as centres for displaced people as well as educational facilities in addition to the relationship between observed damage to schools and their **Is** values shown in figure 3, the building is to be seismically rehabilitated with financial support by MEXT so that the **Is** value after seismic rehabilitation should not be less than the criteria 0.7.

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

Example of the Programme's Implementation[11]

Outline of the programme. As previously stated, the five-year programme to upgrade school buildings which started in 1996 has since been twice extended and now runs until 2010. Since then, extensive efforts have been directed towards seismic evaluation and rehabilitation of school buildings throughout the country.

Ota City, which is located in the south of the urban centre of Tokyo as shown in figure 6, may be the most successful district in implementing the programme, because all the school buildings in the city designed according to the older codes were evaluated and all buildings identified as vulnerable had already been rehabilitated.[12] 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 ninety-one elementary and middle schools spread across 340 buildings including both old and new constructions.

Figure 6. Location of Ota City, Tokyo

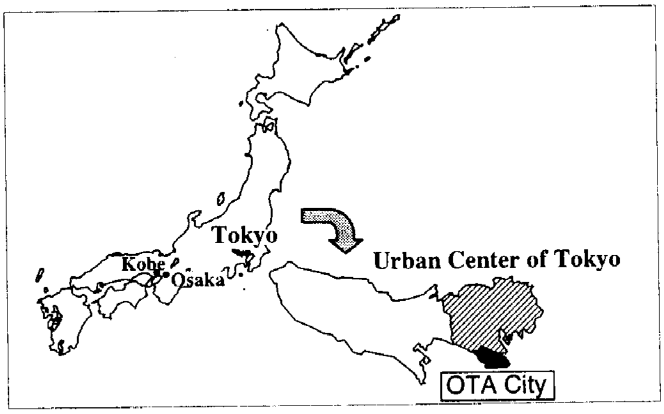
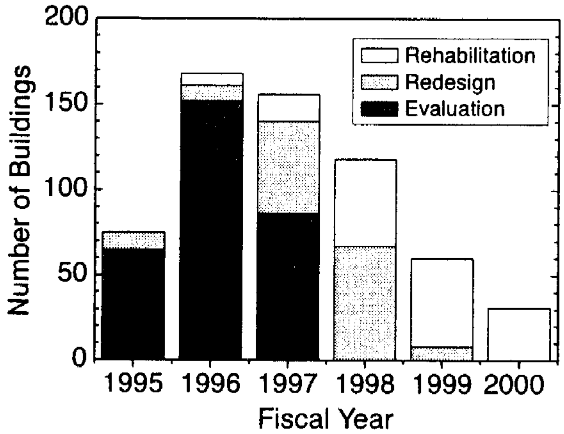


Figure 7 shows the rehabilitation schedule of the city. Seismic evaluation of all schools constructed before 1981 and all rehabilitation design and work are completed, to date. In the subsequent section, the fundamental statistics of the 219 reinforced concrete buildings of eighty-two schools are presented. They were all constructed before 1981

Figure 7. Budget Plan in Ota City

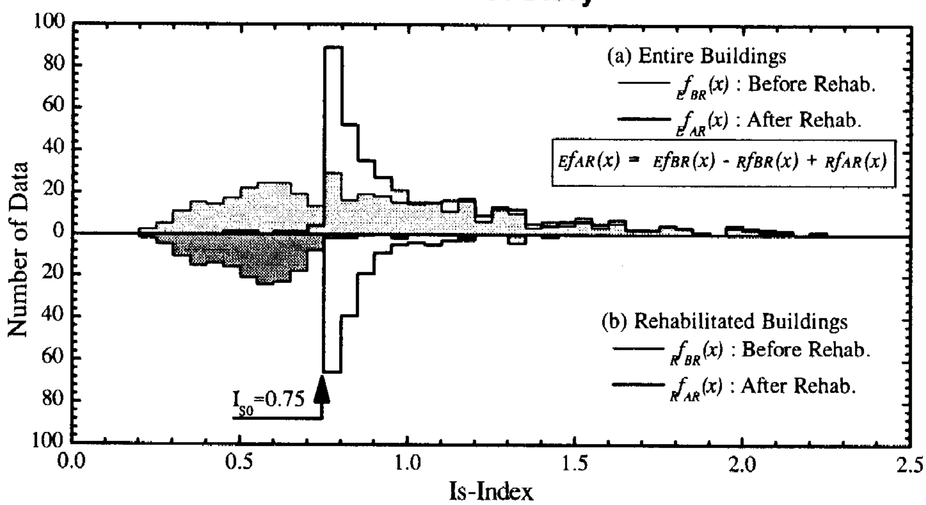


(mostly three-story buildings) and correspond to about 65 per cent of the 340 school buildings in the city. The remaining 35 per cent are mainly reinforced concrete school buildings constructed after 1981 and steel gymnasium facilities.

Seismic Capacity of Existing Buildings and Rehabilitated Buildings

The upper shaded area in figure 8 shows the distribution of seismic capacity index **Is** in the first story of all 219 school buildings, where **Is** indices in both principal directions of each building evaluated are plotted in accordance with the standard. As shown 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 primarily because typical school buildings in Japan have fewer shear walls in the longitudinal direction than in the transverse direction where shear walls are generally placed between each classroom. The lower shaded area in figure 8 shows the distribution of **Is** indices in the first story before and after rehabilitation of 143 buildings which are identified as rehabilitation candidates. In the city, the decision criteria **Iso** to screen sound buildings is set at 0.75 considering the basic 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

Figure 8. Distribution of Is Index in the First Story

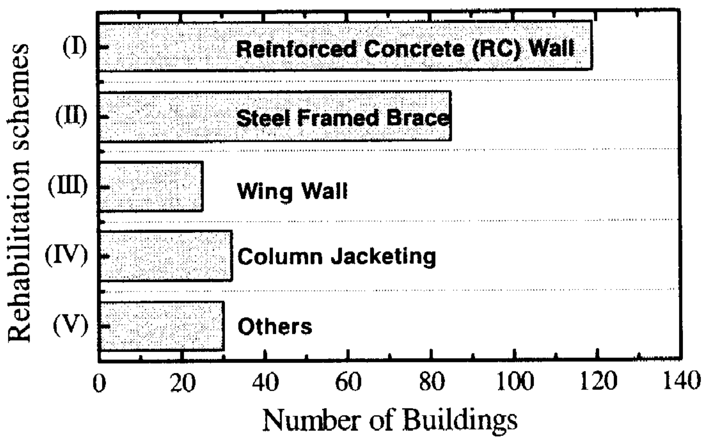


capacities of rehabilitated buildings have a significant peak just beyond **Is** = 0.75, and then sharply decrease. Knowing the frequencies of existing and rehabilitated buildings described above, the **Is** index distribution (i.e., frequency) of entire buildings including rehabilitated buildings can be obtained as shown by the thick line in figure 8. The figure clearly shows that the rehabilitation significantly improves seismic capacities of reinforced concrete school buildings in the city.

Trends in Seismic Rehabilitation Schemes

Figure 9 shows rehabilitation schemes employed in 143 potential rehabilitation subjects. It should be noted that some buildings employ not a single but several schemes, and the total number in the figure is much larger than 143. In rehabilitating existing reinforced concrete buildings, a scheme in which new reinforced concrete walls were installed in existing bare frames had been conventionally applied in Japan as a result of practical experience as well as experimental and analytical research studies conducted extensively on this technique. Although it is one of the most reliable strategies to upgrade a seismically-vulnerable reinforced concrete building, "infilling" often causes reduced flexibility in architectural and environmental redesign and/or an increase in building weight sometimes requiring costly redesign of the foundation. On the other hand, steel-framed braces have been more widely applied in recent years, particularly following the Kobe Earthquake, to overcome such shortcomings inherent in the conventional reinforced concrete walls mentioned above. As shown in figure 9, reinforced concrete walls are most widely used but steel-framed braces are applied to approximately 60 per cent of rehabilitation candidates in Ota City, which is the same as the recent trends of seismic rehabilitation schemes employed in other cities in Japan.

Figure 9. Employed Rehabilitation Schemes

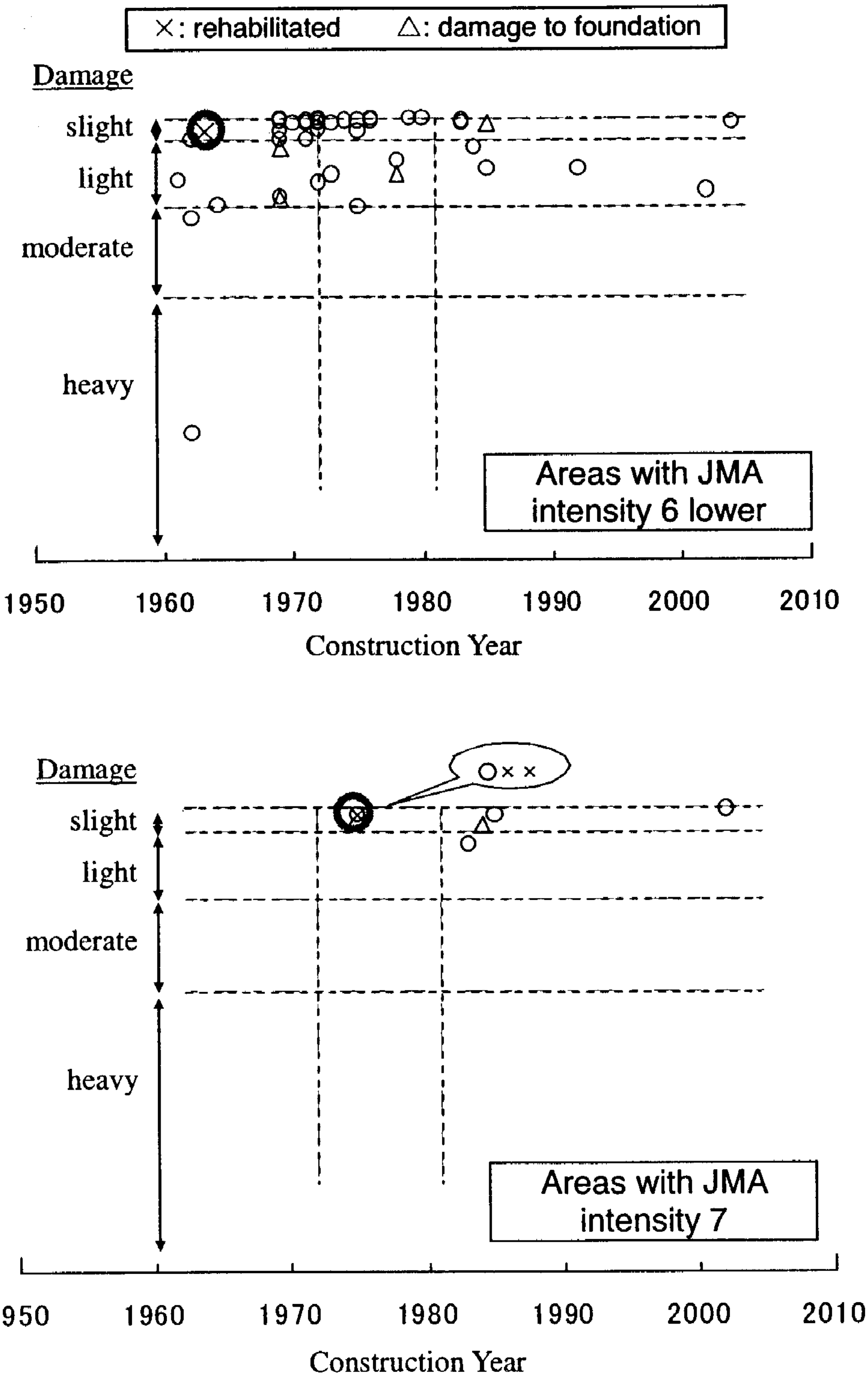


SEISMIC PERFORMANCE OF REHABILITATED SCHOOL BUILDINGS

The structural behaviour of upgraded buildings under real ground shaking conditions provides important evidence for understanding their seismic performance, and the damage observed after a major event may serve as basic data to verify the effectiveness of such seismic rehabilitation, although only a few such events have been reported to date in Japan.

Figure 10 shows an example from the Niigataken Chuetsu Earthquake which took place on 23 October 2004. This earthquake caused intensive ground-shaking of seismic intensity 7 on the Japan Meteorological Agency (JMA) scale[13] (roughly 11 on Modified

Figure 10. Comparison of Damage Level between Existing and Seismically Rehabilitated Schools



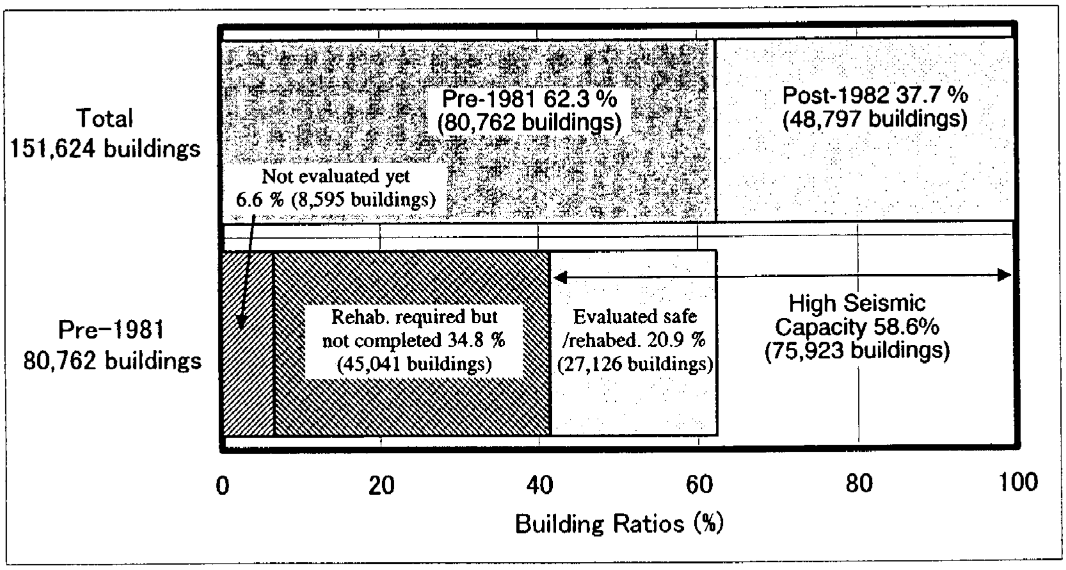
Source: Architectural Institute of Japan (AIJ), *Report on Seismic Performance of Educational Facilities* (2005). (Damage Investigation Report after the 2004 Niigataken Chuetsu Earthquake by a task force on seismic performance under the AIJ Educational Facilities Committee).

Mercalli Intensity (MMI) scale[14] in Kawaguchi town. Field surveys were made by AIJ task committee members immediately following the earthquake to identify the damage to school buildings including those seismically rehabilitated prior to the 2004 event. The relationship between damage and construction year was investigated based on the observed results. As shown in the figure, three buildings with "X", which were pre-1981 buildings but had been rehabilitated prior to the 2004 event, performed successfully even in the most seriously shaken areas although some old buildings sustained serious damage. The evidence found after the Chuetsu Earthquake demonstrated the importance and effectiveness of the seismic rehabilitation as a technically sound method of mitigating structural damage. Similarly, less damage to rehabilitated schools was found after other recent earthquakes such as the Miyagiken-Hokubu Earthquake which struck northern Japan in 2003 and the Noto-Hanto and Niigataken-Chuetsu-Oki earthquakes which both struck northwestern Japan in 2007.

FURTHER PROMOTION OF SEISMIC REHABILITATION

Although the rehabilitation programme has been successfully implemented in a few local districts, a recent government survey on earthquake preparedness of buildings, essential for post-earthquake operations, reveals that implementation has not been carried out nationwide. Figure 11 shows the survey results on school buildings (as of 1 April 2007), which reveal that the seismic capacities of approximately 7 per cent of the total building stock are still unknown, and that approximately 40 per cent of the total are potentially vulnerable to future earthquakes.

Figure 11. Statistics of 129,599 Public School Buildings in Japan (as of 1 April 2007)



Sources: MEXT website. Available from http://www.mext.go.jp/a_menu/shotou/zyosei/taishin/index.htm, and http://www.mext.go.jp/a_menu/shotou/zyosei/english/basic.htm; accessed 2007.

The slow progress of implementation is a serious concern for earthquake disaster mitigation since large-scale earthquakes are expected to occur along the coastal region in the near future in Japan, which may result in great loss of life and widespread property damage. The report by the Special Board of Inquiry on the Tokai Earthquake Response[15] points out the great urgency of upgrading seismic performance of essential facilities — including schools, hospitals, highways, and railroads — and proposes to disclose facilities' information regarding their seismic capacity to promote seismic rehabilitation through public awareness of vulnerable buildings.

The reason for slow progress can be attributed primarily to the facts that firstly, local governments hold numerous facilities and all buildings cannot be upgraded at the same time and secondly, a practical 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 buildings to be upgraded immediately.[16] The procedure consists of preliminary priority-setting of buildings to be seismically evaluated and identification of vulnerable buildings to be upgraded. The first priority-setting to identify buildings to be evaluated can be made for reinforced concrete school buildings and steel gymnasiums, respectively, considering the following conditions:

- Reinforced concrete buildings: the number of stories and the year of construction, material strength, structural 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 emerging from this procedure, 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 hampering efforts of seismic rehabilitation may result from conventional measures with have less flexibility in architectural design. Conventional rehabilitation schemes have been primarily (and often solely) focused on improving structural performance rather than education and the learning environment. The wide variety of education and learning styles, however, often require new and flexible concepts for designing new schools, and such efforts are necessary in seismic rehabilitation. In 2002, AIJ therefore launched a research project sponsored by MEXT. The research committee of architects and engineers jointly proposed solutions such as extensive remodeling in building plans and changes in use through structural alterations that can meet not only the functional requirements but also structural performance criteria.[17]

Recent trends in information disclosure are also contributing to the acceleration of seismic rehabilitation and to the public awareness of urgency. Local cities and towns, which are in charge of seismic evaluation and rehabilitation of public elementary and middle schools, are listed in detail on MEXT's website[18] to show their current state of upgrading implementation. Risk information disclosure has been taboo for a long time in Japan since it was deemed to result in confusion and/or panic in local administration and communities. Recent disaster experiences as well as those expected in the future are providing a wake-up call leading to increasing recognition of the importance of safety and risk information. The public awareness of vulnerable buildings is therefore expected to encourage the local cities and towns to promote and accelerate seismic rehabilitation programmes.

CONCLUDING REMARKS

The seismic rehabilitation programme of school buildings and its implementation following the Kobe Earthquake have been presented. MEXT has been implementing the programme throughout the country in cooperation with building professionals, and buildings have been successfully upgraded in many local districts. Recent damaging earthquakes in Japan demonstrate that seismic evaluation and rehabilitation prior to earthquakes are essential and undoubtedly effective in mitigating damage. Successful performance can be achieved through technically-sound redesign and rehabilitation work at the building site, and to this end, the review committees have been playing an important role in Japanese prevention.

The development of reliable but practical solutions through research, application, and verification through exposure to destructive earthquakes is fundamental to the programme. Yet it was almost 20 years from the first development of the seismic evaluation standard and rehabilitation guidelines in 1977 up to the nationwide seismic evaluation and rehabilitation programme started after the Kobe Earthquake in 1995. There still remains a large number of vulnerable school buildings and their rehabilitation is an issue of great urgency. Patient and continued efforts are therefore essential for upgrading their performance.

To implement the seismic upgrading programme, challenging and innovative ideas as well as conventional efforts are needed. Legislation to promote the programme, subsidies to assist implementation, public awareness through information disclosure and educational programmes, redesign of buildings to meet both functional and structural requirements through the collaboration of structural engineers with architects, and priority-setting to identify candidates for urgent seismic evaluation, as presented herein, are some recent efforts undertaken in Japan. As shown earlier, however, 35 per cent of the total school buildings are yet to be rehabilitated, although it is required. Budget problems may be the primary reason but the insufficient number of technicians often contributes to such a situation. In general, local municipalities have few staff members in charge of the technical management of school buildings. They are inevitably less experienced and the sharing of practical information and intellectual resources with other well-experienced districts is urgently needed. Transfer of knowledge and experience from other municipalities as well as technology transfer from practitioners therefore should be further encouraged to increase the number of schools that have been rehabilitated.

NOTES

1/ Government of Japan, Ministry of Education, Culture, Sports, Science and Technology (MEXT), *Technical Guide for Seismic Rehabilitation of Reinforced Concrete School Buildings* (Tokyo, 1998) (revised in 2003); and also its *Technical Guide for Seismic Rehabilitation of Steel Gymnasium Facilities* (Tokyo, 1998) (revised in 2003).

2/ *Ibid.*

3/ T. Okada *et al.*, *Improvement of Seismic Performance of Reinforced Concrete School Buildings in Japan — Part 1 Damage Survey and performance evaluation after 1995 Hyogo-ken Nambu Earthquake* (Proceedings of 12th World Conference on Earthquake Engineering) (CD-ROM) (Wellington: New Zealand Society for Earthquake Engineering, 2000).

4/ Japan Building Disaster Prevention Association (JBDPA), *Guidelines for Post-earthquake Damage Evaluation of Reinforced Concrete Buildings* (Tokyo, 1991) (revised in 2001).

5/ JBDPA, *Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings* (Tokyo, 1977) (revised in 1990 and 2001); and its *Guidelines for Seismic Retrofit of Existing Reinforced Concrete Buildings* (Tokyo, 1977) (revised in 1990 and 2001).

6/ T. Kabeyasawa, K. Shinpo, and K. Kanemitsu, *Improvement of Seismic Performance of Reinforced Concrete School Buildings in Japan — Part 2 Systematic Project for Retrofit and Quick Response against Future Earthquakes* (Proceedings of 12th World Conference on Earthquake Engineering).

7/ *Ibid.*

8/ JBDPA, *Guidelines for Post-earthquake Damage Evaluation.*

9/ JBDPA, *Guidelines for Seismic Evaluation and Rehabilitation of Existing Steel Buildings* (1996).

10/ Government of Japan, MEXT, *Technical Guide.*

11/ T. Ohba *et al.*, *Seismic Capacity of Existing Reinforced Concrete School Buildings in Ota City, Tokyo, Japan* (Proceedings of 12th World Conference on Earthquake Engineering).

12/ *Ibid.*

13/ Available from http://www.jma.go.jp/jma/kishou/know/shindo/shindokai.html; accessed 2007.

14/ Available from http://earthquake.usgs.gov/learning/topics/mercalli.php; accessed 2007.

15/ Central Disaster Management Council (CDMC), "Report on Review of Designation of Enhanced Earthquake Preparedness Region related to a Tokai Earthquake" (2003). (in Japanese)

16/ Government of Japan, MEXT, *Report on the Strategy to Promote Seismic Rehabilitation of School Facilities* (Tokyo 2003). (in Japanese)

17/ AIJ, *Research Report on Seismic Rehabilitation of School Facilities* (Tokyo, 2003). (in Japanese)

18/ The ministry's website is available from http:///www.mext.go.jp; accessed 2007.

19/ Okada *et al.*, *Improvement of Seismic Performance of Reinforced Concrete Buildings.*