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SEISMIC REHABILITATION OF EXISTING CONCRETE BUILDINGS IN JAPAN

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SUMMARY

After the 1995 Hyogoken-Nanbu Earthquake (Kobe Earthquake), new approaches to utilize seismic isolation, supplemental damping and continuous fiber jacketing have been applied for seismic rehabilitation of concrete buildings in addition to conventional strengthening techniques to infill, to brace and to jacket existing framing systems. An overview of the state-of-the-art in techniques for seismic rehabilitation of existing reinforced concrete (RC) and steel reinforced concrete (SRC) buildings in Japan is presented in this paper with emphasis on research and practice after the 1995 Kobe Earthquake. The response to lessons from the Kobe Earthquake is firstly summarized. Seismic rehabilitation strategy and techniques, research on the behavior of rehabilitated structures and implementation of seismic rehabilitation utilizing various techniques are introduced.

INTRODUCTION

Many seismic rehabilitation techniques to infill, to brace existing frames and to jacket existing framing members to increase lateral resistance and ductility of a building have been investigated over twenty five or more years so as to apply to both pre-earthquake and post-earthquake rehabilitation. In addition to these conventional “seismic resistant techniques”, other approaches “seismic isolation” and “supplemental damping” to reduce seismic response of a building have been recently adopted for seismic rehabilitation. Thus, the seismic rehabilitation technique is now in wide variety. A large number and many types of vulnerable buildings have been seismically rehabilitated since 1995 Kobe Earthquake. Recent demands for seismic rehabilitation are “no disturbance to building function” and “no evacuation of building occupants” as well as “structural safety”.

In this paper, the emphasis is put on seismic rehabilitation of existing reinforced concrete (RC) and steel reinforced concrete (SRC) buildings which has been considered as one of the most urgent earthquake preparedness in Japan since the 1995 Kobe Earthquake. The lessons learned from the Kobe Earthquake are summarized firstly to present the importance of seismic rehabilitation. Recent seismic rehabilitation techniques utilizing seismic isolation, supplemental damping and continuous fiber as well as new frame strengthening techniques, which have been applied mainly after the 1995 Kobe Earthquake to meet the demands above, are introduced. Examples of implementation utilizing these approaches and techniques are also introduced.

2. LESSONS FROM THE 1995 HYOGOKEN-NANBU EARTEQUAKE AND THEIR IMPACT

2.1 Lessons Learned from the 1995 Hyogoken-Nanbu Earthquake

The lessons on concrete buildings learned from the 1995 Kobe Earthquake are summarized as follows. 1) Most new buildings to meet the present seismic codes showed fairly good performance from the view of preventing severe structural damage and/or collapse for life safety as a minimum requirement (Figure 1). 2) Most collapsed or severely damaged buildings were those designed and constructed in accordance with the codes before 1971 revision (concrete standards) or 1981 revision (building standard law). 3) Seismic performance of buildings

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widely ranged from the level of collapse preventing to function keeping, which has not been identified by the present seismic codes. Therefore, urgent needs of seismic evaluation to identify vulnerable buildings which have not experienced severe earthquake ground motion yet, and of seismic rehabilitation to upgrade their seismic performance have been strongly recognized. Also it has been recognized that we need to develop performance-based seismic design concept where the performance of buildings including structural and functional safety during and after earthquake is explicitly explained.

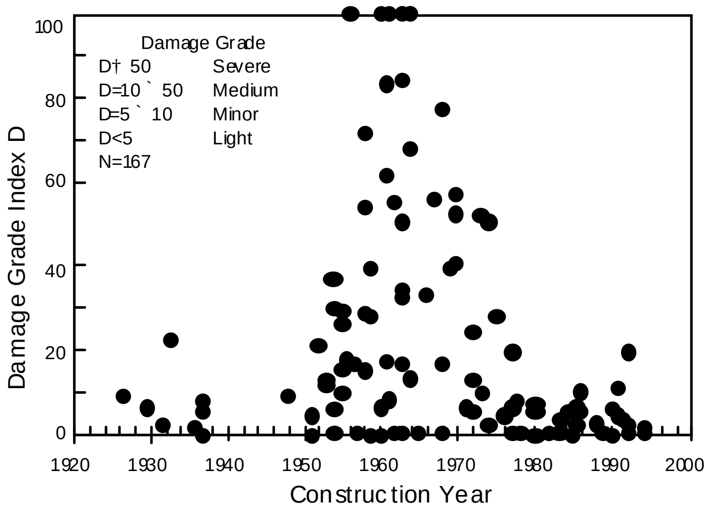


Figure 1: Damage Grade Index and Construction Year of R/C School Buildings Damaged by 1995 Hyogoken-Nanbu Earthquake (Architectural Institute of Japan 1997)

2.2 Response to the Lessons Learned from the 1995 Hyogoken-Nanbu Earthquake

After the 1995 Kobe Earthquake, various responses have been quickly taken to upgrade the seismic performance of vulnerable buildings all over Japan. It is assumed that there are about 18 million wooden houses and 2 millions or more buildings which were designed by the previous seismic codes. Considering the damage ratio in the past earthquakes including the Kobe Earthquake, 10 percent of these buildings are assumed to be vulnerable. Therefore, many seismic evaluation and rehabilitation works have been going on.

The Network Committee for Promotion of Seismic Rehabilitation of Buildings was established in April 1995. It consists of many organizations and associations for academic people, architects, engineers, consultant offices and building owners. Major activities are; 1) to exchange information, 2) to organize seminars to train engineers, and 3) to support local governments organizing review committees for seismic evaluation and rehabilitation design for public buildings.

The Law for Promotion of Seismic Rehabilitation of Buildings was enforced in December 1995. Its objectives are 1) to enforce the seismic rehabilitation to owners of specified occupancy and/or large occupants buildings and 2) to prepare the incentives to implement seismic rehabilitation of other buildings. It identifies the important buildings, which accommodate a large number of inhabitants and visitors, and enforces the owners to implement the rehabilitation. If the building officials approve the rehabilitation plans the owners are eligible to apply for lower interest loan, tax exemption, and exemption from regulations for land use and fire protection codes.

3. SEISMIC REHABILITATION STRATEGY AND TECHNIQUES

3.1 Seismic Rehabilitation Strategy

The aims of seismic rehabilitation are 1) to recover original seismic performance, 2) to upgrade original seismic performance, and 3) to reduce seismic response, so as to reduce earthquake vulnerability. To recover original performance, damaged portions of a building may be repaired with adequate material or replaced with new element. General approach to upgrade original performance is to strengthen existing structures. Irregularity or discontinuity of stiffness or strength distribution, which may result in failure or large distortion of a building, must be eliminated by changing structural configuration. It is effective to supplement energy dissipating devices to enhance damping effect of a building and to reduce seismic response. Another concept to reduce seismic response is to isolate existing structure from the ground excitation by extending fundamental period of building (seismic isolation) as well as to reduce building masses. Schematic concept of seismic strengthening, seismic isolation and supplemental damping is shown in Figure 2.

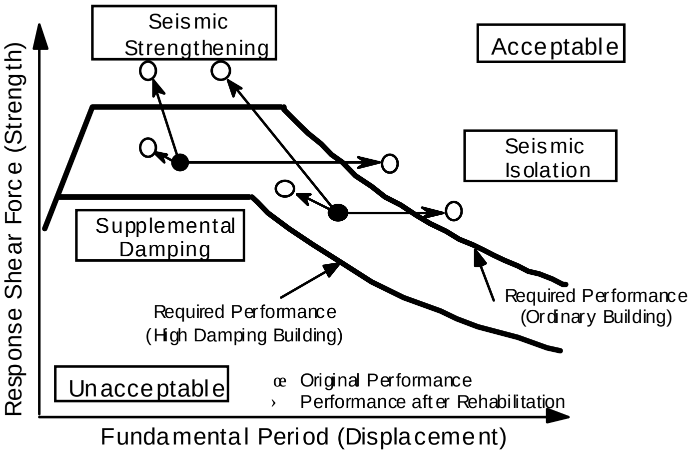


Figure 2: Concept of Seismic Rehabilitation

3.2 Social Demands for Seismic Rehabilitation after the 1995 Hyogoken-Nanbu Earthquake

Since the seismic rehabilitation has been applied to many buildings in large variety after the 1995 Kobe Earthquake, the demands for seismic rehabilitation have been changing. Recent strong demands are 1) to avoid loss of building function and evacuation of building occupants, 2) to avoid change of building design and facade and 3) to shorten construction period. The items to be considered for selecting rehabilitation techniques are 1) effect on building function (lighting, traffic line, usability), 2) hindrance associated with construction (noise, vibration, dust, chemical smell), 3) effect on foundation system, and 4) construction cost and period. Many existing construction techniques have been improved and new techniques and approaches have been developed to meet these demands as well as to provide structural safety.

3.3 Recent Seismic Rehabilitation Techniques

Continuous fiber jacketing techniques

The continuous fiber jacketing (Figure 3) to use carbon, aramid or glass fibers is a relatively new technique developed firstly in Japan. This method is characterized by its excellent constructional workability in addition to the characteristics as material which exhibit high levels of anti-corrosion, high strength and lightweight. With these features, it is considered one of the most effective rehabilitation methods today. Until the 1995 Kobe Earthquake, this method had been studied only by a handful organizations and employed by a few construction projects. After the 1995 Kobe Earthquake, however, various agencies have initiated research on this method and the guidelines for design and construction have been established. The number of projects adopting this technique has also drastically increased. Continuous fiber jacketing is applied mainly to brittle columns or to columns subjected to high axial force so that their ductility may be improved. Continuous fibers are used in a form of sheet, strand or panel (Figure 3). They are used generally in a form of continuous fiber sheet to save workmanship in the site. Carbon fiber strands are also used. Carbon fiber panels which are formed in channel-shape in a factory are recently used to simplify the work in the site and to shorten construction period.

Frame strengthening techniques

Figure 4 shows examples of recent frame strengthening techniques to meet the previously described demands. Precast concrete constructions in Figure 4 (a) and (b) contribute to shorten construction period. Steel braces in Figure 4 (c) are confined with reinforced concrete section, concrete filled steel tube or steel tube to prevent buckling and, as a result, to provide large energy dissipation and ductile behavior. Steel brace system in Figure 4 (d) is connected to existing frame with epoxy resin instead of with conventional post-install anchors, stud bolts and mortar grout. This simple connection avoids noise, dust and mortar curing associated with the construction. Exterior walls (buttresses), frames, braces and mega-frames in Figure 4 (e) have recently been investigated to apply to buildings where construction can not be achieved in their inside.

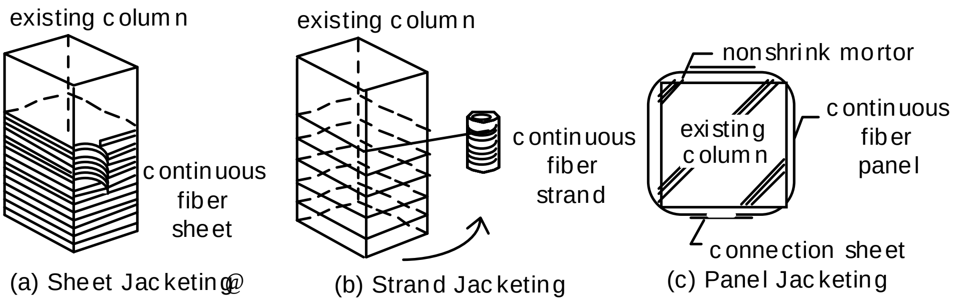


Figure 3: Column Jacketing with Continuous Fiber

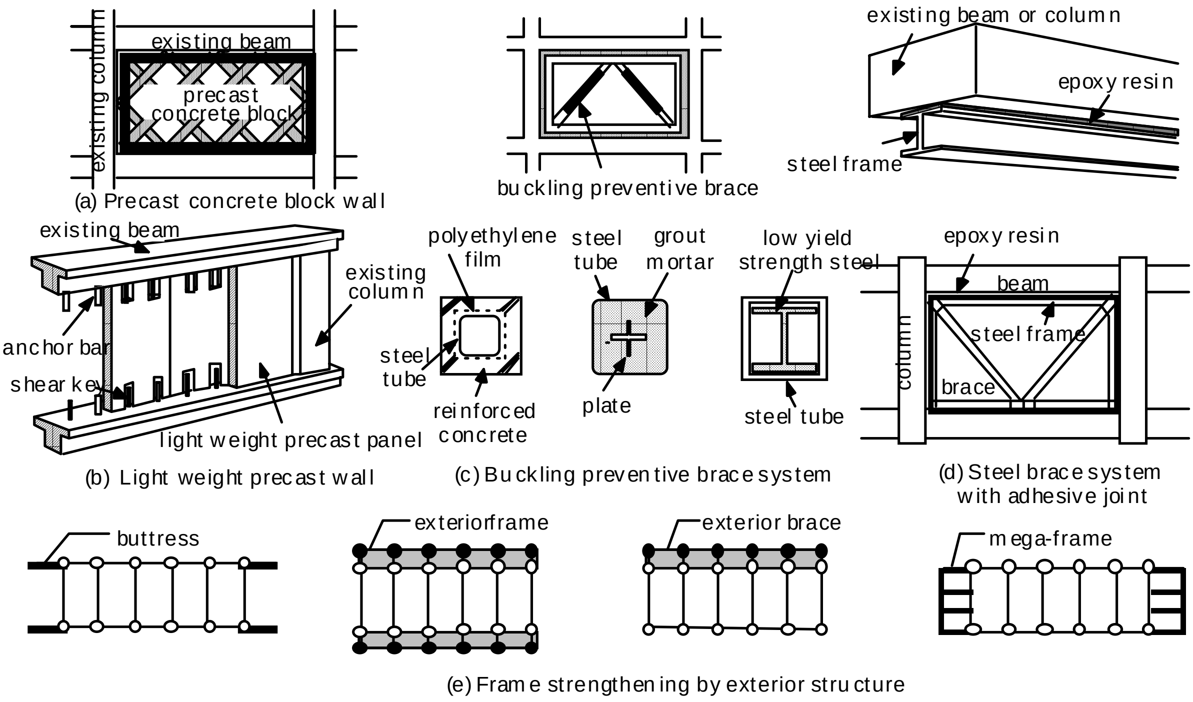


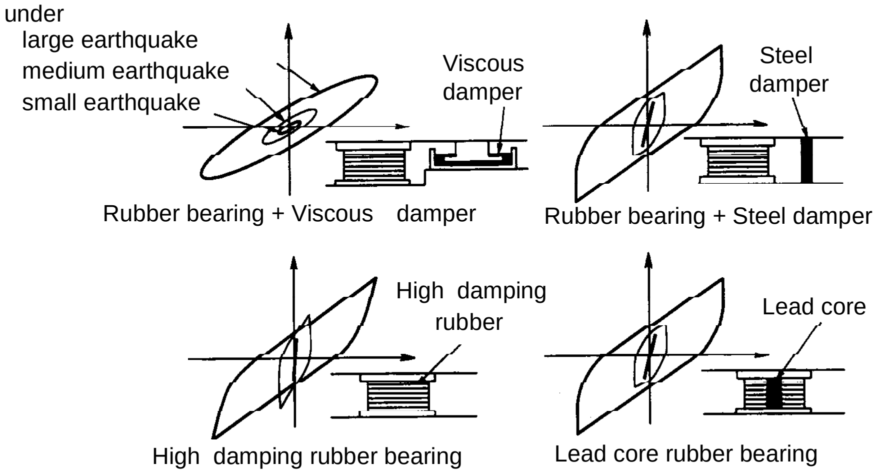
Figure 4: New Frame Strengthening Techniques

Seismic isolation

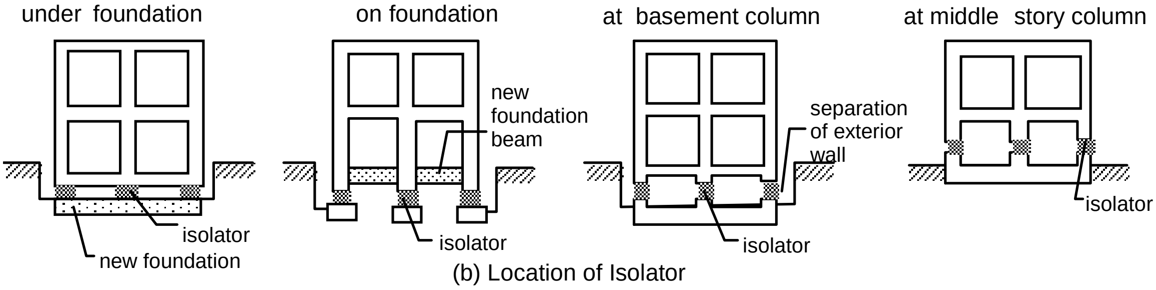
The seismic isolation has been adopted for the rehabilitation of critical or essential facilities, buildings with expensive and valuable contents, and structures where superior seismic performance is required. For isolation bearings, elastomeric systems (high-damping rubber and lead core rubber) are available (Figure 5 (a)). In other cases, rubber bearings accompany damping element such as viscous damper. Isolators are located under or on the existing foundation or at the basement or middle story column level (Figure 5 (b)). The merits of the seismic isolation system are, 1) construction area in a building is less than that of other rehabilitation methods, 2) disturbance to the users is decreased because building function can be maintained during the construction, and 3) building facade can be preserved. However, because of lack of appropriate design guidelines, the application of this system for seismic rehabilitation is not so much though that for new building is increased drastically. The seismic isolation rehabilitation means to develop a new structural system, therefore, careful considerations of design criteria, structural planning and verification of performance are required.

Supplemental damping system

Supplemental damping systems have recently been also adopted for existing buildings to reduce inelastic deformation demand by increasing damping effect of structures. Many ideas of dampers are proposed for new buildings, however, steel yielding damper, friction damper, rheological fluid damper and viscoelastic damper are available for seismic rehabilitation (Figure 6 (a)). These devices may be installed into braces, wall panels or between braces and beams (Figure 6 (b)). The merits of the supplemental damping system are 1) large effect on reducing seismic response and 2) easy installation, which can reduce disturbance to users and functional limitation of buildings during rehabilitation.

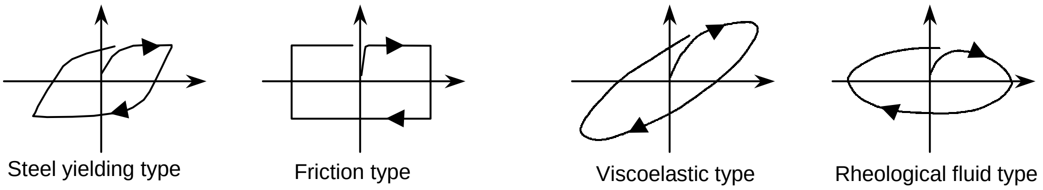


(a) Isolation Bearings and Lateral Force-Displacement Relationships

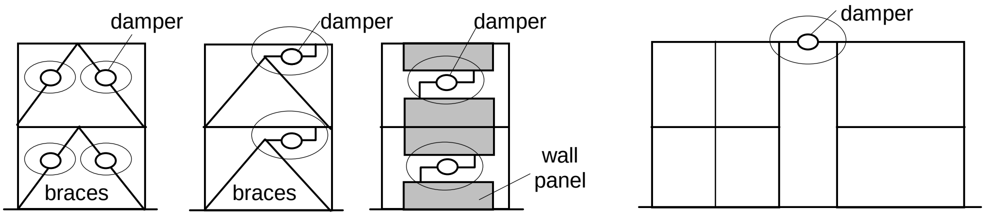


(b) Location of Isolator

Figure 5: Seismic Isolation Used for Seismic Rehabilitation



(a) Type of Dampers and Idealized Load-Displacement Relationships



(b) Location of Supplemental Dampers

Figure 6: Supplemental Damping System Used for Seismic Rehabilitation

4. RESEARCH ON SEISMIC REHABILITATION

Since 1968 Tokachioki Earthquake a number of experimental studies have been conducted to investigate the behavior of rehabilitated buildings. Many of them are reflected to design guidelines (Japan Building Disaster Prevention Association 1997, 1990, 1997). Typical behavior of rehabilitated frames and columns utilizing various techniques were reviewed by the author (Sugano 1996).

After the 1995 Kobe Earthquake, a large number of experimental studies have been conducted to improve existing techniques and to develop new techniques to meet the previously described demands for seismic rehabilitation. They are 1) RC and SRC column jacketing with steel plate or continuous fiber, 2) shear walls to use precast elements, 3) frame strengthening utilizing exterior walls, frames or braces, 4) frame strengthening utilizing supplemental dampers. All the recent techniques shown in Figure 4 have been experimentally or analytically investigated. The number of experimental studies, particularly those of column jacketing, has been significantly increased recently. An example of their results as of 1997 is shown in Figure 7.

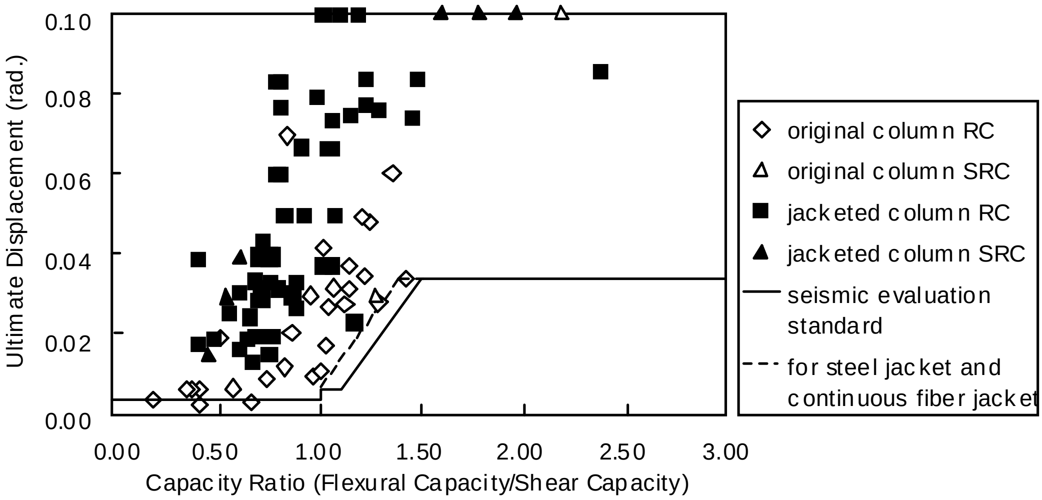


Figure 7: Ultimate Displacement vs. Capacity Ratio of Jacketed Columns (Japan Building Disaster Prevention Association 1997)

5. IMPLEMENTATION OF SEISMIC REHABILITATION OF EXISTING BUILDINGS

5.1 Implementation of Seismic Rehabilitation

Since the disaster caused by the Kobe Earthquake was a great shock to Japanese people and the Law for Promotion of Seismic Rehabilitation of Buildings was enforced in 1995, almost every local government has been promoting the seismic evaluation and rehabilitation of a large number of public buildings. The Network Committee for Promotion of Seismic Rehabilitation of Buildings reported that seismic evaluation of 12,500 RC public buildings were implemented until July 1999. Roughly 70% of them are school buildings. An investigation of private buildings reported that roughly 5,500 buildings were evaluated until August 1998 and the seismic rehabilitation was planned and implemented for 36% and 18% of them, respectively.

5.2 Objective Performance

The seismic performance of rehabilitated buildings is generally evaluated in terms of the seismic structural index (I_s) following the Seismic Evaluation Standards (Japan Building Disaster Prevention Association 1977, 1990, 1997). The I_s index is the product of strength index times ductility index and the index I_s =0.6 is used for the objective performance as the boundary between severe damage or less (Figure 8). Importance factors may be considered. The design for seismic isolation and supplemental damping must be subjected to the review of appraisal committee. The performance of the buildings utilizing these system is evaluated generally with time history response analysis. The objective performance for these buildings are summarized in Table 1

5.3 Rehabilitated Buildings Utilizing Seismic Isolation and Supplemental Damping

Tables 2 and 3 show the buildings rehabilitated with seismic isolation and supplemental damping systems, respectively (Nikkei Architecture 1999, Japan Concrete Institute 1998). These new approaches are applied at present to only limited number of buildings. Seismic isolation is used for many types in usage and structure of low to medium-rise buildings. The used isolators are high damping rubber bearing, lead core rubber bearing or a combination of rubber bearing and dampers. These isolators are installed under the existing foundation or at the top or middle of existing mid-story columns. Seismic isolation is selected to avoid heavy strengthening and loss of function of the building associated with conventional rehabilitation methods.

Supplemental damping system is used for tall buildings, mainly offices. The used energy dissipating devices are steel elasto-plastic damper which are installed on the top of braces or wall panels, and low yield strength steel used as a brace element. Rheological fluid damper and friction damper are also used. These devices are used to reduce response displacement and, as a result, to reduce the number of portions to be rehabilitated in a building compared with those of conventional methods.

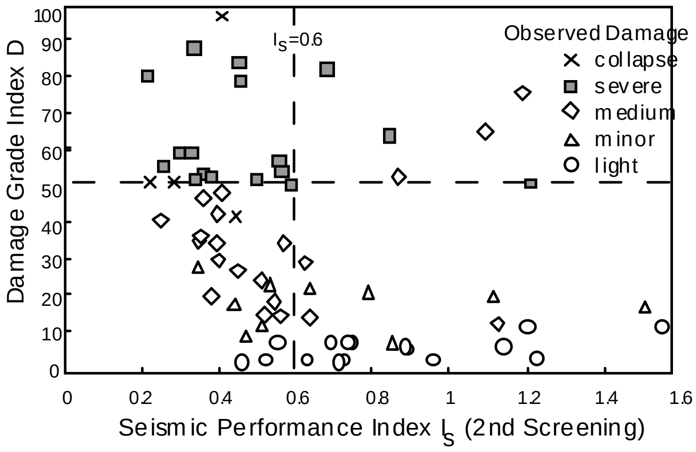


Figure 8: Seismic Performance Index Is and Damage Grade Index D of RC School Buildings Suffered from 1995 Hyogoken-Nanbu Earthquake (Architectural Institute of Japan 1997)

Table 1: Objective Performance for Seismic Rehabilitation Utilizing Seismic Isolation and Supplemental Damping System

		Level of Ground Motion	
		for Max. Probable in Building Life	for Safety Margin Check
	Max. Velocity of Ground Motion	Recorded and/or Artificial Motions 50 cm/sec or more	Recorded and/or Artificial Motions larger than 65 cm/sec
Seismic Isolation	Super Structures	Interstory Drift <1/400 No yielding	Interstory Drift <1/200 Sufficient Margin to Failure
	Isolator (Rubber Bearing)	Lateral displacement of isolator < 200%	Lateral displacement of isolator < 300% or more
Supplemental Damping	*Super Structures*	Interstory drift <1/200 Sufficient safety margin to member failure	Interstory drift <1/100 Safety margin to member failure
	Damping System	Sufficient safety margin of energy dissipation capacity	Safety margin of energy dissipation capacity

Table 2: Rehabilitated Buildings Utilizing Seismic Isolation

Building	Structure, Size	Isolator	Location of Isolator
Museum	RC, B1 F3	High Damping Rubber Bearing	*under foundation*
Training Institute	RC, SRC, F16	Rubber Bearing + viscous slider	middle story column
Training Institute	RC, F7	Rubber Bearing + viscous slider	under foundation
City Office	RC, B1 F4	Rubber Bearing + viscous slider	under foundation
Condominium	RC, F5	Lead Core Rubber Bearing	1st story column
School	RC, B1 F4	Rubber Bearing + sliding isolator	under foundation
Research Institute	RC, B1 F5	Lead Core Rubber Bearing	1st story column
City Office	RC, F5	High Damping Rubber Bearing	1st story column
Post Office	RC, SRC, F10	Rubber Bearing + rheological damper	basement column
Office	SRC, B1 F9	Rubber Bearing + rheological damper + oil damper	basement column
School	RC, B1 F4	Rubber Bearing	basement column
School	RC, B1 F4	Lead Core Rubber Bearing	basement column

Table 3: Rehabilitated Buildings Utilizing Supplemental Damping System

Building	Structure, Size	Damping Device
Office	SRC, B1 F10	steel elasto-plastic damper
Hotel	S, SRC, B2 F12	steel elasto-plastic damper
Office	S, SRC, F10	rheological fluid damper
Office	SRC, B1 F16	low yield strength steel damper
Department Store	S, F9	steel elasto-plastic damper
Office	SRC, B2 F9	low yield strength steel damper
Office	RC, SRC, B3 F12	oil damper
Hospital	RC, F4	friction damper
Office	SRC, B2 F9	low yield strength steel damper
Office	SRC, B3 F9	low yield strength steel damper
City Office	RC, F4	low yield strength steel damper

6. CONCLUDING REMARKS

The present state of seismic rehabilitation of existing concrete buildings were overviewed based on the survey of existing data of research and practice. The results of the review are summarized as follows.

1) The effective rehabilitation techniques must be established to meet the strong social demand that building can be operated even under the construction for seismic rehabilitation.
2) In addition to conventional seismic resistant type rehabilitation techniques, other approaches to isolate an existing structure from the ground shaking and to supplement energy dissipation devices have been recently adopted to reduce seismic response. Seismic isolation can be applied to critical or essential buildings with expensive and valuable contents and to structures where superior seismic performance is desired. Supplemental damping system can be used for tall buildings where large inter-story drift is expected. Their applications are only in small number now, however, they will be widely used in future.
3) Seismic rehabilitation techniques should be selected in accordance with required performance level. Generally, the seismic rehabilitation is achieved to upgrade the original performance up to current code level. However, codes do not clearly figure out the post-earthquake condition of designed building. Design approaches corresponding to more detailed required performance level will be necessary.
4) A performance based engineering system should be applied for seismic evaluation and seismic rehabilitation to control building damage in accordance with the type of buildings and their occupancy.

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