한국전산구조공학회
1998년도 봄학술발표회 논문집

STRUCTURAL RETROFIT AND COMPUTATIONAL ENGINEERING FOR SEISMIC ENGINEERING IN JAPAN

by
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ABSTRACT

It is needless to say that the computer and/or computational engineering has contributed much to the development of the earthquake engineering such as seismic design of structures in providing good tools to researchers and engineers. However, it has been also pointed out that the proper selection of numerical analysis and/or computer program is very important for engineers in utilizing it in the design of structures, because a numerical analysis method is based upon its own coverage. A rigorous analysis does not always gives a correct solution in a sence of engineering or of structural safety, but, some times, it gives mathematically rigorous but unrealistic solution. Therefore, numerical analysis should be performed with engineering judgement or experiments specially in the field of earthquake engineering because this field has large uncertainties on predicting the effect of earthquake on structures.

This paper is based on the presented paper at the Bertero Symposium held in January 31and February 1 at Berkeley, California, USA which was entitled "Needs to Evaluate Real Seismic Performance of Buildings-Lessons from 1995 Hyogoken-Nambu Earthquake-". The lessons for buildings from the damage due to the Hyogoken-Nambu Earthquake are necessity to develop more rational seismic design codes based upon a performance-based design concept, and to evaluate seismic performance of existing buildings.

In my keynote lecture at the Korean Association for Computational Structural Engineering, the history of seismic design and use of structural analysis in Japan, the lessons for buildings from the Hyogoken-Nambu Earthquake, the building damage due to the earthquake, the reasons why the seismic retrofit has not been implemented much, the responses to the lessons from the earthquake , the Network Committee for promotion of seismic retrofit of buildings, the Law for promotion of seismic retrofit of buildings and the implementation of seismic retrofit in Japan are presented.

INTRODUCTION

The lessons from the Great Hanshin-Awaji Earthquake Disaster caused by the 1995 Hyogoken-Nambu Earthquake on building structures could be summarized as follows;

1)Most new buildings designed and constructed according to the present seismic codes showed fairly good performance for preventing severe structural damage and/or collapse, even to such severe earthquake ground motions. However, the problem was that the seismic performance of buildings was widely ranged from the level of collapse preventing to function keeping, which could not have been identified by the present seismic codes. Therefore, it is strongly needed to develop more rational seismic design codes based upon the performance-based-seismic design concept, where the performance of buildings including structural and functional safety during and after earthquake is explicitly explained.

2)Most buildings which took serious damage were those designed and constructed before the present seismic codes adopted in 1981. About 3,000 buildings, of which stories were more than two. collapsed or severely damaged and almost same number of buildings took medium structural damage. The collapsed or seriously damaged ratio was 6.4% in average and about 15% in most affected area. Besides them, about 46,000 wooden houses, which was 9.4% in average, were collapsed or severely damaged [1].

Therefore, urgent needs of seismic evaluation of their seismic performance to identify seismically vulnerable buildings, which have not experienced severe earthquake ground motion yet, and of seismic retrofit to upgrade their seismic performance have been strongly recognized.

A lot of projects to develop performance-based-seismic design and to carry out seismic upgrading of existing vulnerable buildings have launched since the Hyogoken-Nambu Earthquake. In this paper, the emphasis is laid upon the seismic retrofit of existing reinforced concrete buildings which has been considered as one of the most urgent earthquake preparedness since the Hyogoken-Nambu earthquake.

BUILDING DAMAGE DUE TO HYOGO-KEN NAMBU EARTHQUAKE

As mentioned above, the damage to buildings and houses was serious for those constructed before 1981, especially before 1971, because Japanese seismic design codes in 1950, which was basically same as the first Japanese seismic design codes for buildings in 1924, was revised in 1971 and 1981[Table 1]. In 1971, specifications such as detailing of re-bar arrangement of reinforced concrete members were revised to increase ductility and the consideration of ductility was required in estimating ultimate lateral strength in 1981. In order to promote seismic retrofit of pre-code revision buildings, the standards for evaluation of seismic capacity and guidelines for retrofit of existing reinforced concrete buildings were developed and published from the Japan Building Disaster Prevention Association in 1977[2]. However, they have been applied only to a limited number and limited types of buildings in a limited areas excluding the Hanshin-Awaji area.

Table.2 is a statistic showing the relationship between the damage grades due to the Hyogoken-Nambu Earthquake and the construction years of reinforced concrete buildings in a part of Kobe city. The ratio of severely damaged buildings constructed before 1971 is mich higher than new buildings[1]. Fig.1 is another example showing the similar tendency for reinforced concrete school buildings, where the vertical axis is showing the damage grade index of each building and the horizontal the construction year. No school buildings constructed after 1982 suffered from serious damage[3].

WHY THE SEISMIC RETROFIT HAS NOT BEEN IMPLEMENTED MUCH?

Even though the necessity of seismic retrofit had been pointed out before the Hanshin-Awaji Earthquake Disaster, why the seismic retrofit has not been implemented much? the reasons could be summarized as follows;

1) The seismic retrofit is less attractive for owners, architects, engineers, researchers, constructors, administrators and politicians than new building construction.
2) Since a return period of a big earthquake is usually long, owners are apt to hesitate to spend money in seismic retrofit of existing buildings.
3) Since a seismic retrofit is more complicated than construction of new buildings, it is usually troublesome for architects and engineers, and less paid.
4) Since the Japanese Building Code is not retroactive, a seismic retrofit is not enforced by law.

RESPONSES TO THE LESSONS FROM THE GREAT HANSHIN-AWAJI DISASTER

Since the Great Hanshin-Awaji Earthquake Disaster was a great shock to Japanese people, various responses have been quickly taken to upgrade the seismic capacities of pre-code revision buildings all over Japan. In order to promote the seismic retrofit, it is necessary 1) to develop methodologies to evaluate seismic capacities, 2) to develop techniques to strengthen existing buildings, 3) to train engineers, and 4) to prepare subsidies, low-interest loan, tax exemption and so on, to increase public incentive for retrofit.

Some of the major responses are; 1) The notices to recommend seismic capacity evaluation and retrofit of pre-code revision buildings and houses were issued by the Ministry of Construction in March 1995, 2) Network Committee for promotion of seismic retrofit of buildings was established in April 1995, 3) Architectural Institute of Japan published the recommendations reflecting the damage due to Hyogoken-Nambu Earthquake including the importance of seismic retrofit in July 1995, 4) Japan Basic Plan for Disaster Mitigation was revised emphasizing the importance of seismic retrofit by

Land Agency in July 1995, and 5) Law for Promotion of Seismic Retrofit of Buildings was enforced in December 1995.

In the followings, the activities of the Network Committee, the Law for Promotion of Seismic Retrofit of buildings, and the Method for evaluation of seismic performance of existing reinforced concrete buildings are briefly described;

NETWORK COMMITTEE FOR PROMOTION OF SEISMIC RETROFIT OF BUILDINGS

The network committee chaired by the author consisting of 76 organizations related to the design and construction of buildings and houses including associations for academic people, for architects, for engineers, for consultant offices and for building owners. Major activities of the Committee are; 1) to exchange information on seismic retrofit, 2) to organize seminars to train engineers, 3) to support local governments and groups of engineers to establish local centers for promoting seismic retrofit, and so on.

More than 12,000 engineers attended the seminars in last two years, while they were only about 2,500 for 15 years before the Hyogoken-Nambu Earthquake, and more than 60 local centers have been established. One of the major activities of such local centers is to organize committees to review the results of evaluation and retrofit design by engineers, which may also contribute to improve the level of engineers

LAW FOR PROMOTION OF SEISMIC RETROFIT OF BUILDINGS

The objective of the Law is to enforce the seismic retrofit on the owners of the specified occupancy and/or large occupants buildings and to prepare the incentives to implement seismic retrofit of other buildings and houses. For this purpose, the law identifies the important buildings such as schools, hospitals, department stores, theaters, office buildings and so on, which occupy a large number of inhabitants and visitors, and enforces the owners to make seismic retrofit, If the building officials approve the retrofit plans of such buildings, the owners are eligible to apply lower interest loan, tax exemption, and exemption from regulations for land use and fire protection codes. The owners of other types of buildings and houses may have similar eligibility.

IMPLEMENTATION OF SEISMIC RETROFIT

It is assumed that there are about 18 million wooden houses and more than 2 million buildings which were designed and constructed by the previous seismic codes. Considering the damage due to past earthquakes including the Hyogoken-Nanbu Earthquake, about 20 percent of wooden houses and 10 percent of buildings are assumed to be vulnerable. Therefore, a lot of retrofit works have been going on since the Great Hanshin-Awaji Earthquake Disaster.

In order to evaluate the seismic capacity and retrofit of existing reinforced concrete buildings, the Evaluation Standard and Retrofit Guideline for Existing Reinforced Concrete Buildings [1] have been widely used since 1977.

The procedure to judge the seismic performance of existing building by the Evaluation Standards is as follows;

First, the seismic index of Is is estimated to evaluate the seismic capacity of the building, then it is compared with the judging index of Iso. If the Is index is larger than the Iso index, the building is judged to habe good seismic performance.
This standard was applied to the reinforced concrete buildings which suffered from the 1968 Tokachi-oki Earthquake, 1978 Izuoshima-Kinkai Earthquake, and 1978 Miyagiken-oki Earthquake, and it was clarified that most buildings of which Is indices were less than 0.3 took severe or moderate damage and the damage was slight for building of which Is indices were greater than 0.6. Therefore, Is of 0.6 has been recommended for judging criterion [1, 4 and 5]. Similar study was carried out for reinforced concrete school buildings suffered from the 1995 Hyogoken-Nambu Earthquake and it was found that the Is index of 0.6 is almost border between severe damage and moderate damage [3]. Considering these studies, the judging index of 0.6 is adopted in the Law for Promotion of Seismic Retrofit of Buildings as a standard criterion to prevent collapse or severe damage. The law says 1) if the Is index is greater than 0.6, the building may have a low possibility of collapse or severe damage, and 2) if the Is index is less than 0.3, the building may have a very high possibility of collapse or severe damage.

It is a hard task and takes a long time to complete the retrofit of vulnerable buildings and houses, however, it should be implemented to mitigate disaster due to future earthquakes.

REFERENCES

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APPENDIX

The Evaluation Standard basically judges the building safety based upon the following structural index(Is):

$$Is = E_0 \times S_D \times T$$

where, E_0 : basic structural index, estimated by strength Index(C), Ductility index(F), and Story Index(Φ) at each story and each direction when the story or building reaches at the ultimate limit state due to lateral force.

C : index of story lateral strength, estimated by ultimate story shear in terms of story shear coefficient.

F : index of story ductility, estimated by ultimate deformation capacity normalized by the story drift of 1/250 when a standard size column is assumed to fail in shear. For most ductile column, F is assumed as 3.2 and for short and extremely brittle column, F becomes smallest of 0.8.

ϕ : index of story shear distribution during earthquake, estimated by the inverse of design story shear coefficient distribution normalized by base shear coefficient.

S_D : modification factor, estimated by stiffness discontinuity along stories, eccentric distribution of stiffness in planes, irregularity of framing and so of, ranging from about 0.5 to 1.2

T : reduction factor, estimated by the grade of deterioration, ranging from about 0.5 to 1.0

TABLE 1
HISTORY OF JAPANESE SEISMIC DESIGN CODES FOR BUILDINGS

1924 K=0.1 Allowable Stress Design	Steel : 1/2 of Yield Strength Coordinate : 1/3 of Compressive Strength
1950 K=0.2 Allowable Stress Design	Steel : Yield Strength Coordinate : 2/3 of Compressive Strength
1971 K=0.2 Allowable Stress Design Ductility Requirement	Steel : Yield Strength Coordinate : 2/3 of Compressive Strength Ultimate Shear Strength > Bending Strength Specifications : Revision of Tie Spacing
1977 (Standards for Evaluation of Seismic Capacity)	Seismic Capacity = Strength x Ductility
1981 C_0=0.2 Allowable Stress Design C_0=1.0 Ultimate Strength Design	Steel : Yield Strength Coordinate : 2/3 of Compressive Strength Design Strength = C_0 / Ductility (C_0=1.0)

TABLE 2
DAMAGE GRADE VS.CONSTRUCTION YEARS OF REINFORCED

	Pre-1971	1971-1981	Post-1981
Collapse or Severe Damage	22 (24%)	5 (5%)	3 (6%)
Medium Damage	8 (9%)	4 (4%)	2 (4%)
Minor Damage	12 (13%)	12 (13%)	6 (13%)
No Damage	51 (55%)	73 (77%)	34 (76%)
Total	93 (100%)	94 (100%)	45 (100%)

CONCRETE BUILDINGS IN A PART OF KOBE CITY [REFERENCE 1]

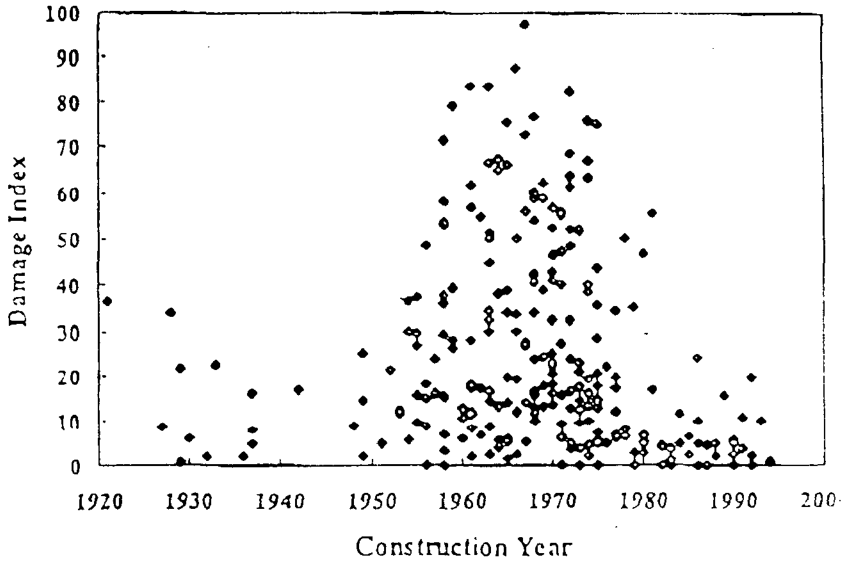

FIG.1 DAMAGE GRADE INDEX VS. CONSTRUCTION YEAR OF REINFORCED CONCRETE SCHOOL BUILDINGS DAMAGED DUE TO HYOGOKEN NAMBU EARTHQUAKE [REFERENCE 3]

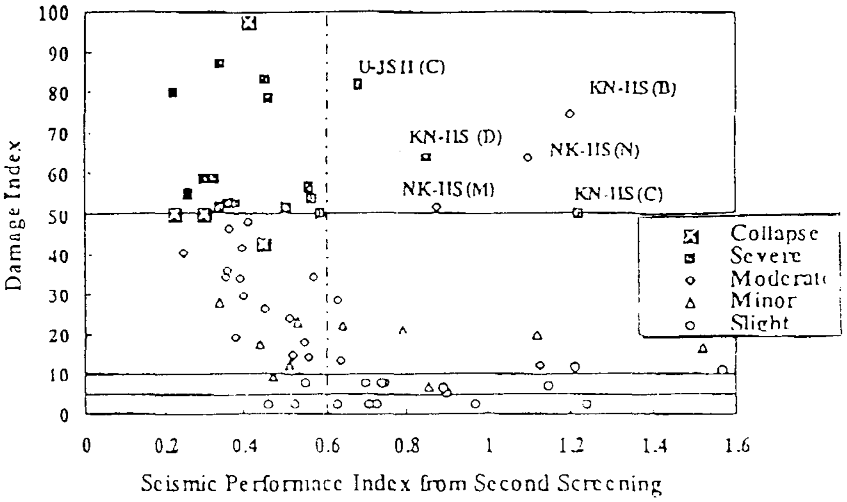

FIG.2 DAMAGE GRADE INDEX VS. SEISMIC INDEX IS OF REINFORCED CONCRETE SCHOOL BUILDINGS SUFFERED FROM 1995 HYOGOKEN NAMBU EARTHQUAKE [REFERENCE 3]