Special feature: Are its lessons being adequately applied? Follow-up on the ten-year anniversary of the Hanshin-Awaji Earthquake

- What has JSCE done? -

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First, a thorough analysis of what caused the damage

Before the Hanshin-Awaji Earthquake, earthquake engineers and disaster prevention engineers working in the fields of civil engineering and construction felt that Japan was adequately prepared, having the world's most advanced technologies as well as earthquake-resistant design and disaster prevention measures. The 1995 earthquake truly shattered these notions. The extent of the damage caused by this catastrophe clearly revealed the inadequacy of modern technology.

Immediately after the earthquake, the Japan Society of Civil Engineers sent survey teams to conduct four investigations and launched full-scale cooperative efforts in investigation, research, cooperation, and the development of new standards. First, accurate records were gathered for the sake of surveying the actual state of damage in many civil engineering structures in as much detail as possible and analyzing the resulting data. A twelve-volume survey report on the Hanshin-Awaji Earthquake was then issued, based on analysis of the causes of damage.

First, Volumes 1-3 summarize the state of damage to civil engineering structures in six chapters (Chapter 1: Bridges, Chapter 2: Tunnels and Underground Structures, Chapter 3: Earth Structures, Chapter 4: Foundation Structures, Chapter 5: Harbors and Coastal Structures, and Chapter 6: Rivers and Erosion Control Facilities). Next, Volumes 4-6 present the results of detailed study to analyze the causes of damage in each type of civil engineering structure, based on changes over time in the earthquake resistance standards for the structures in question. Volumes 7 and 8 summarize restoration work and future measures for each type of civil engineering structure in terms of emergency restoration, repair, and reinforcement. Volume 9 discusses the damage and restoration of lifeline facilities. Volume 10 covers the damage and restoration of transportation facilities and agricultural facilities. Volume 11 presents an analysis of the social and economic effects. Last, Volume 12 summarizes the recovery plans.

JSCE proposals for revision of earthquake resistance standards

JSCE formed a council for the study of earthquake resistance standards and other basic problems, which discussed future directions for earthquake resistance and design methods of civil engineering structures. The results were issued in the form of two sets of recommendations (Proposals 1 and 2) in May 1995 and January 1996. Those proposals included the following content.

i) When examining the earthquake-resistant performance of a structure, it is necessary to assume two different levels of seismic motion: an earthquake of a strength level that has a probability of occurring once or twice during the usable lifetime of the structure (Level 1 seismic movement), and an earthquake of a very high strength level (Level 2 seismic movement) which has a low probability of occurrence but could occur in the vicinity of a fault.

ii) The earthquake-resistant performance which a structure should possess (that is, the state of damage which would result from an assumed earthquake strength level) should be determined with consideration for the importance of the structure as well as the frequency of occurrence of that earthquake strength level. The importance of a structure is determined through comprehensive consideration of various factors, including effects on human life and survival; emergency rescue activities immediately after an earthquake; prevention of secondary disasters such as fires; functions of community life and economic activities after the earthquake; and difficulty of restoration.

In other words, the two proposals issued by JSCE advocate a two-tiered approach to design, along with the establishment of performance standards. The consideration of seismic movements of two different strength levels is taken as the basic policy for the earthquake-resistant design of civil engineering structures.

Impact of the JSCE proposals

The government's Basic Disaster Management Plan, adopted in July 1995, includes exactly the same content as the JSCE recommendations. The first section of Chapter 1 (Earthquake-Proofing Japan and its Cities) contains this statement:

"In the earthquake-resistant design of structures, facilities, and the like, consideration shall be given not only to general seismic motion with a probability of occurring once or twice within the usable lifetime, but also to higher-level seismic motion caused by an inland earthquake or massive offshore earthquake that has only a low probability of occurrence."

In other words, the government of Japan has adopted its basic policy for earthquake-resistant design based on the principles that two levels of seismic motion are to be taken into consideration when examining the earthquake-resistant performance of a structure, and that earthquake-resistant performance with regard to both of these levels of seismic motion is to be prescribed according to the importance of the structure.

During the ten-year period since the Hyogoken-Nanbu Earthquake, changes have been made in earthquake-resistant design standards for various types of civil engineering structures, including the Design Standards and Explanations for Railroad Structures, Etc. In each case, these changes have also followed the proposals of JSCE and the basic policies indicated in the Basic Disaster Management Plan.

What information has the JSCE Journal provided?

The JSCE Journal has carried a very large number of articles related to the Hanshin-Awaji Earthquake. In the February 1995 issue, just after the earthquake, the journal carried photographs of the damage as a preliminary report. Next, in March, it summarized the emergency debriefing of the first and second survey teams.

Beginning in April 1995, the journal carried a series of feature articles on the Hanshin-Awaji Earthquake, emphasizing the three aspects of prompt reporting, information disclosure and recording, and critical exchange of views. This series continued for 15 issues, ending in June 1996.[1] In April 1995, it began issuing news flashes to promptly communicate the content of investigation and research by experts in various fields. In July 1995, the journal began carrying short restoration reports in which various agencies reported on the damage and restoration methods. In November 1995, the Earthquake Disaster Forum was launched as a venue for the frank exchange of views at the level of individual members. A lively discussion ensued on the pages of the journal, with a total of 123 persons sending in their views on twelve subjects, from No. 1 (seismic movement) and No. 2 (liquefaction) to No. 11 (future issues) and No. 12 (significance). The journal introduced Committee Review in April 1996, providing members with information on the content of discussions by JSCE committees as well as various government committees. Please consult the June 1996 issue[1] for a list of articles in the series on the Hanshin-Awaji Earthquake.

During the past several years, the journal has carried four special features focused primarily on earthquake disasters and prevention thereof, including the present special feature. These features have looked back at the Hanshin-Awaji Earthquake from time to time, or provided dialogue concerning preparedness and countermeasures for future major earthquakes. Their titles are as follows.

- January 2000 issue Feature, "Lessons from the Hanshin-Awaji Earthquake: What will be carried forward into the twenty-first century?"
- December 2002 issue Feature, "Preparedness for major earthquakes"
- September 2003 issue Feature, "Disaster prevention and infrastructure development: What can and should JSCE do to build infrastructure that provides safety and peace of mind?"
- January 2005 issue Feature, "Are the lessons of the Hanshin-Awaji Earthquake being adequately applied? Follow-up on its ten-year anniversary"

The state of investigation and research on earthquake disasters, and the level of practical application

In August 2004, JSCE conducted a questionnaire survey of its investigation and research committees to determine the current state of research and development related to earthquake disaster mitigation and related issues, as one of its activities marking the ten-year anniversary of the Hanshin-Awaji Earthquake. Please refer to Column 4 of this feature for a summary of the symposium[2] which was based on those survey results. In addition, Chapter 5 of this feature contains information on a wide range of activities by each of the research committees.

Here, I will attempt to summarize the current state of research and development on earthquake damage mitigation along with related issues by means of a technical map of investigation and research activities (Fig. 1), which is based on the results of that questionnaire survey. The vertical axis indicates the level of maturity of the technology related to those issues. The maturity level is divided into three stages: I. Practical matters, II. Investigation and research, and III. Identification of issues. The horizontal axis indicates the level of progress according to the nature of the issues. The progress level is also divided into three stages: A. Clarification of phenomena (mainly the study of earthquake damage incidents and seismic movements), B. Application (mainly analysis and design), and C. Generalization and systematization (mainly urban disaster prevention). The map evaluates two phases, the present time (2004) and the time just after the

Hanshin-Awaji Earthquake.

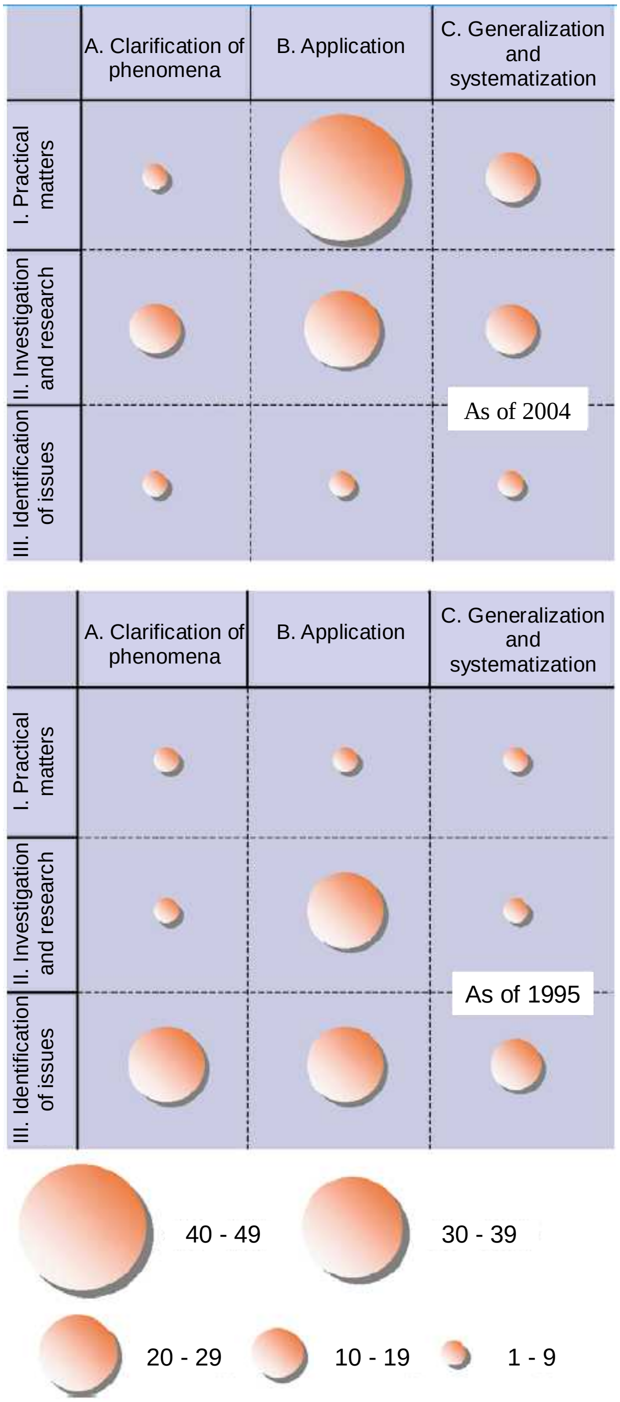

Fig. 1. Technical map of investigation and research activities (comparing 2004 and 1995)

In Fig. 1, the number of issues in each region of the map is represented by the size of a circle. Responses were received on a total of 121 issues. Since it is not possible to cover each of these issues here, the main issues on the technical map were selected for a comparison of the level of maturity of related technology in 1995 and 2004, as shown in Fig. 2.

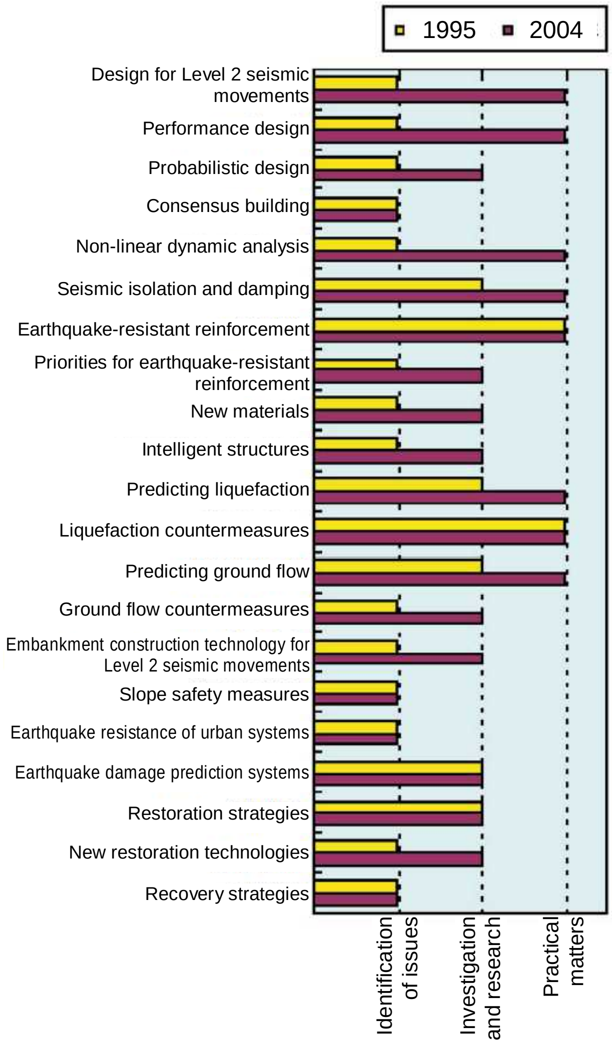

Fig. 2. Maturity in main areas of technological issues (comparing 2004 and 1995)

The technical map indicates obvious differences between the situations of 1995 and 2004. The technical map for 2004 is weighted toward practical matters of earthquake-resistant design and reinforcement. Meanwhile, the technical map for 1995 is more weighted toward the identification of issues, including a mixture of clarifying the phenomena raised by the Hanshin-Awaji Earthquake and issues of earthquake-resistant design along with issues which were already subject to investigation and research at that time.

Technologies at the stage of practical application

The technologies which have reached the stage of practical application as of 2004 include the following eight areas: design for Level 2 seismic movements, performance design, non-linear dynamic analysis, seismic isolation and damping (semi-active or passive), earthquake-resistant reinforcement, predicting liquefaction, liquefaction countermeasures, and predicting ground flow. These areas are directly related to the so-called "hard" aspects of earthquake-resistant design.

Technologies are judged to have reached the stage of practical application for various reasons, including their inclusion in earthquake-resistant standards such as the volume of Concrete Testing Methods and Specifications which deals with the determination of earthquake-resistant performance, their implementation in actual construction projects, the spread of dynamic analysis to the level of actual operations, and progress in the development of seismic isolation and damping devices.

The issues related to determination of Level 2 seismic motion and performance design are in agreement with the two basic policies of the JSCE proposals. Items that were at the stage of identifying the issues in 1995 had progressed to the stage of practical application by 2004. It is evident that related institutions including academic societies have been engaged in vigorous investigation and research activities to realize the proposals of JSCE. Several factors have contributed to advances in the development of technology for determination of Level 2 seismic motion, including the melding of physics with engineering, progress in earthquake investigation and research on the national level, and enhancement of the strong motion seismograph network, which includes K-NET and KiK-net. Meanwhile, technology related to performance design saw advances because of rapid progress in the move toward performance regulation in structural design, both in Japan and in Europe and North America; as well as the fact that nonlinear earthquake response analysis techniques were already available in 1995 and it was possible to use various types of test data to verify the analytical methods.

Issues at the investigation and research stage

The following nine areas are considered to have reached the stage of investigation and research: probabilistic design methods, priorities for earthquake-resistant reinforcement, new materials, intelligent structures (high-performance steel materials, damage control, and residual displacement reduction), ground flow countermeasures, embankment construction technology for Level 2 seismic movements, earthquake damage prediction systems, restoration strategies, and application of new technologies at the time of restoration work (robots, IT, GIS, etc.). These correspond to earthquake disaster prevention research and the like, especially relating to "hard" technologies and restoration, with "soft" elements and economic elements added to the existing "hard" technologies.

Next, I will examine some of the reasons for judging these areas to be in the stage of investigation and research. Regarding intelligent structures, there are limits on the extent of application to a wide variety of civil engineering structures. Regarding probabilistic design, it is not yet possible to quantify the degree of indeterminacy of materials and loads. Regarding priorities for earthquake-resistant reinforcement, there is still a lack of methodology and objective indices. Regarding embankment construction technology, there are some organizations which incorporate the prediction of deformation into design, but this is not yet generalized. Last, regarding earthquake damage prediction, there have been no advances beyond system construction and trial operation.

Issues at the stage of issue identification

Several issues are still only at the stage of issue identification as of 2004. Four representative issues of this type are as follows: consensus building in design based on determination of performance, slope safety measures, improving the earthquake resistance of urban systems, and recovery strategies. These are the current issues in the fields of earthquake engineering and earthquake disaster prevention. Collaboration is needed between earthquake engineering and other technological areas with regard to these issues, including the preparation of more detailed hazard maps, urban disaster prevention efforts and residents, and economic models. In the future, further study is anticipated toward the resolution of these issues, including the systematization of the decision-making process, quantification of redundancy in urban functions, and proposal of economic recovery models.

Niigata-ken Chuetsu Earthquake

Not quite ten years after the Hanshin-Awaji Earthquake, another magnitude-7 earthquake took place when the Niigata-ken Chuetsu Earthquake struck on October 23, 2004. Many problems were evident as slope failure occurred in mountainous areas, lifeline networks ceased functioning, private homes collapsed, transportation networks were cut off, and measures were taken for continuing aftershocks. Meanwhile, the fact remains that those structures, which had been designed for earthquake resistance, did not experience devastating damage. JSCE sent a survey team to determine whether the lessons of the Hanshin-Awaji Earthquake had been adequately applied.

References

1. Hayashi, Yoshitsugu, Director General of the JSCE Journal Editorial Board. Closing comments for the series on the Hanshin-Awaji Earthquake: Has JSCE provided an environment to nurture the critical exchange of views? JSCE Journal, June 1996 issue, Vol. 81, pp. 68-72.
2. JSCE, Symposium on advances in disaster prevention engineering and future issues, ten years after the Hanshin-Awaji Earthquake (joint endeavor by 7 committees), October 2004.