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DEVELOPMENT OF EARTHQUAKE ENGINEERING FOR CIVIL ENGINEERING CONSTRUCTIONS

By

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SYNOPSIS

Half a century has already passed since the anti-seismic code for steel bridges was enacted. During this period, about 30 big earthquakes whose magnitude was more than 7.0 have attached our country. Among damages due to these earthquakes, we can easily remember serious damages in the events of Niigata and Fukui earthquakes.

At first, the writer wants to try bird's-eye view of the history of development of earthquake engineering researches and practices, and secondly to mention about earthquake engineering problems related to public facilities including railways, highways, pipelines, communications and so on. In the latter part, the differences between earthquake problems of utilities and buildings are first mentioned. Characteristics of seismic damage to utility systems are discussed by using data from past earthquakes. The state-of-the-art of the earthquake resistant design methods for utilities are briefly reviewed. Finally, several problems are pointed out which deserve special attention in future research.

1. History of Development of Earthquake Engineering in Japan

Aseismic design criteria, in Japan, have been established since quite a long time ago by various organizations. These criteria have been revised taking account of the fruits of studies of the days by the respective organizations. It is considered that the present criteria are subject to alterations in the future corresponding with further analyses and examinations.

It is thought worthwhile to introduce the historical background of how the aseismic designs have been developed and what is being carried out in Japan, before going into details.

The development of aseismic design in Japan can be chronologically divided into the following four stages.

(A) Before Kanto Earthquakes (1923)

Noobi Earthquakes (1891) was the first strong earthquakes

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that has attacked the modern structures of Japan. This earthquakes had brought attention of the engineers and scientists to the necessity of aseismic design of structures to cope with the strong earthquake. However, recognition of the necessity was not immediately followed by the establishment of aseismic criteria, although a few structures were analyzed of their seismic resistivities with the so-called seismic coefficient method which is presently adopted.

(B) From Kanto Earthquakes (1923) to Fukui Earthquakes (1948)

The damages of various structures at the time of Kanto Earthquakes were investigated into details. As a result of the investigations, the criteria for aseismic design were established. However, the design seismic coefficient of these criteria was regarded to be of the same value for Japan as a whole.

In the field of studies and researches, prominent these were published by Dr. Mononobe. Furthermore, studies on dynamic behavior of soil and dynamic property of structure had made a great progress in this stage.

(C) From Fukui Earthquakes (1948) to 2nd World Conference on Earthquake Engineering (WCEE) (1960)

With the experience of Fukui Earthquakes, the aseismic design criteria were revised, and thenceforth, determination of seismic coefficient has been made taking into consideration the locality and ground property. The locality were brought under consideration since the activity and intensity of earthquake had come to be known to vary from one district to another. Consequently, the concept of "locality coefficient" was introduced and its value was determined on the basis of the "expectancy of earthquakes" designated by Dr. Kawasumi.

The coefficient is again modified corresponding with the nature of the ground since the earthquake damages vary according to the geological conditions in a district. With coefficient thus determined, structures are designed more rational and economical against earthquakes.

(D) II WCEE (1960) to Present

Since around the time of I WCEE (1956) and II WCEE (1960), dynamic analysis was extensively carried out in the analyses of deformation and stress of structure during earthquakes. Especially, the introduction of electronic computer has enabled the response analysis of such structures that will sustain complicated random external forces.

The progress in dynamic analysis has made it possible to calculate the dynamic behaviors of flexible structures that have not experienced strong earthquakes in Japan, e.g., suspension bridge and bridge with tall piers. Consequently, it has become possible to apply the aseismic design to the actual construction of these structures.

However, as a result of quantitative analyses made on the various earthquake damages, the dynamic computation has been judged not necessary for structures of high frequency, such as short piers. Today, the aseismic design criteria are provided in the following specifications and criteria.

Specifications for Steel Highway Bridges, Japan Road Association

Specifications for Steel Railway Bridges

Standard Specifications for Plain Concrete, J.S.C.E.

Standard Specifications for Reinforced Concrete, J.S.C.E.

Design Specifications for Plain Concrete and Reinforced Concrete Structures, the Japanese National Railways

Design Criteria for Large Dams, the Japanese National Committee on Large Dams

Japan Harbour Engineers' Manual, the Japan Port and Harbour Association

In general, the design seismic coefficient is determined based on the seismicity, dynamic characteristics of ground and dynamic property of the site and taking into consideration the past earthquake damages, significance, usable life and construction cost of the structure.

In order to ensure the aseismic resistivity of a structure, it is required to make aseismic design into details of the structure. Otherwise, aseismic consideration of the entire structure will not be effective, and past earthquake damages teach us that good workmanship is important more than anything else.

2. General Characteristic of Public Facilities

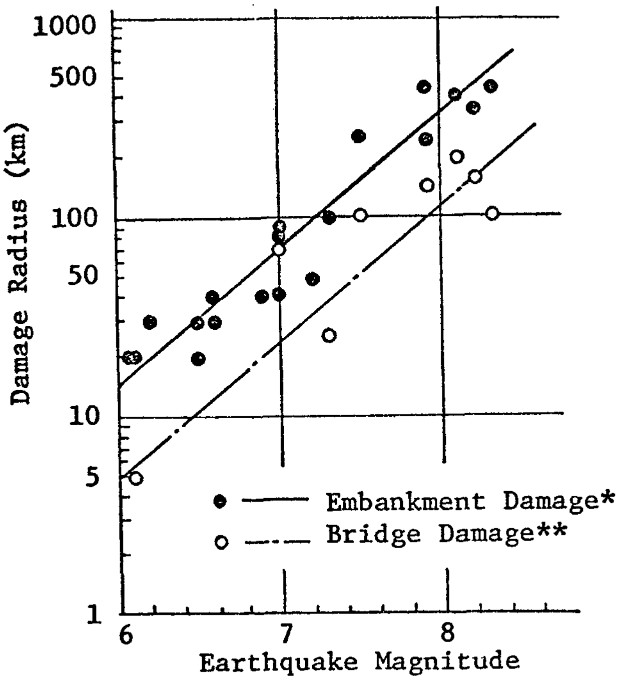
Though there are a number of earthquake records in which a great many people were killed by collapse of buildings or ensuing fires, numbers of deaths due to failures of utilities have been small in the past. For example, there has not been a case in which a number of deaths were caused by collapse of a highway bridge. One exception may be the case during the 1923 Kanto earthquake in which trains with a locomotive were swept down into sea by a large-scale landslide and the accompanying rock and mud flow taking 111 lives. Though the probability is smaller for railway trains to be encountered by bridge collapse or landslide than for motor vehicles on highways, the toll of casualties for one accident is inevitably greater for the former. Disruption of communication systems can rarely be a direct cause of the loss of human lives. Rupture of of above-ground or buried pipelines do not possibly cause human deaths unless explosions or fires are accompanied with it. Therefore, it may be stated that earthquake damage to utilities is different from that of other structures in that the former is less directly related to the loss of human lives. However, modern cities usually rely heavily on utility systems for their day-to-day activities. Destruction of transportation and energy transmission facilities, and disruption of communication and water supply will lead to extreme disorder in a city, which may in turn increases the potential for various secondary disasters. In this sense, earthquake problems of utilities are becoming increasingly more important in modern times, and the purpose of the study into these problems is not only to minimize direct financial loss but also to minimize the period of suspension of human activity due to earthquake effects.

Another significant and general difference between utilities and building structures is that each of the former is a network having sources, transmission lines, storage facilities and a distribution system within itself, whereas the latter are in principle independent and individual structures. Therefore, even if some of the weaker buildings should collapse during an earthquake, damage is restricted unless fires break out and spread. On the contrary, because of being network systems in which electricity, gas, liquid fuel, water, sewage, traffic or information flows incessantly, damage to certain locations in a utility network often affects significant portions of the system. Railways are forced to make shuttle services between the affected sections, and motor vehicles on a highway have to make a detour in order to avoid the damaged section. In any case, the efficiency of the network is greatly hindered.

3. Characteristic of Seismic Damage to Public Utilities

It seems possible to classify seismic damage to utility systems into two categories. They are seismic damage to natural ground and manmade soil structures and seismic damage to equipments and terminal structures. Typical examples of the former are highway and railway damage caused by landslide, rupture of buried pipelines by faulting and excessive relative ground displacement, and failure of highway and railway embankments. Examples of the latter include seismic damage to storage and treatment facilities in water supply and sewage systems, damage to equipments and structures in terminal stations of electrical power or communication systems. Seismic damage to bridges seems to come between these two categories because a number of bridges sustained earthquake damage due to failure of the supporting ground.

Seismic damage to railway and highway embankments is greatly affected by their heights, materials, and the intensity of ground shaking. Modes of seismic damage to bridges vary widely according to the type of super- and sub-structures and foundations, ground conditions of the site, and the intensity of ground motions. Fig. 1 shows the relationships between earthquake magnitude and damage radii for railway embankments and bridges. It is seen that a unit increase in magnitude corresponds to an approximately 4-fold increase in damage radius, and that damage to railway embankments has been observed at locations as far as 250 km or more from epicenters for major earthquakes with magnitudes greater than 7.5. Fig. 1 also shows that the damage radius for enbankments is twice larger than that for bridge structures. Experience indicates that one of the most common types of seismic damage to bridge systems is failure or subsidence of backfill soil behind abutments.



*Embankment failure and lateral shift of track more than 50mm.
**Lateral shift, damage to abutment and pier, and fall of girder.

Fig.1.Relation between Damage Radius and Magnitude for Railway Structructures.

Though seismic damage to oil pipelines or underground communication cables has been rare in the past earthquakes, there have been a number of instances in which buried water pipes were substantially damaged. One recent example can be found in the northern part of the city of Los Angeles during the 1971 San Fernando earthquake. Since this earthquake had a medium magnitude of 6.6 and its epicenter was located only about 10 km from the edge of the damaged region, the damage data is particularly suited for the analysis of the relation between water pipe damage and ground shaking intensity. Fig. 2 shows the result in which damage is expressed in terms of the failure ratio which was obtained by dividing the number of breaks in cast iron distribution mains by the length of piping. Also shown in Fig. 2 are the average failure ratios of cast iron water pipes in Tokyo during the 1923 Kanto earthquake, in Fukui during the 1948 Fukui earthquake, and in Managua during the 1972 Managua earthquake. It is doubtful that maximum ground acceleration is a suitable measure to describe the severity of ground shaking that is related to the failure of buried pipes. However, the results in Fig. 2 seem to be consistent each other. It is seen that damage becomes almost negligible when maximum acceleration is less than 200 - 250 gal. This was also found true even for vitrified clay pipes used for the sewage system in Los Angeles at the time of the San Fernando earthquake. Damage seems to increase sharply with maximum acceleration above this threshold level. It is well recognized that two important

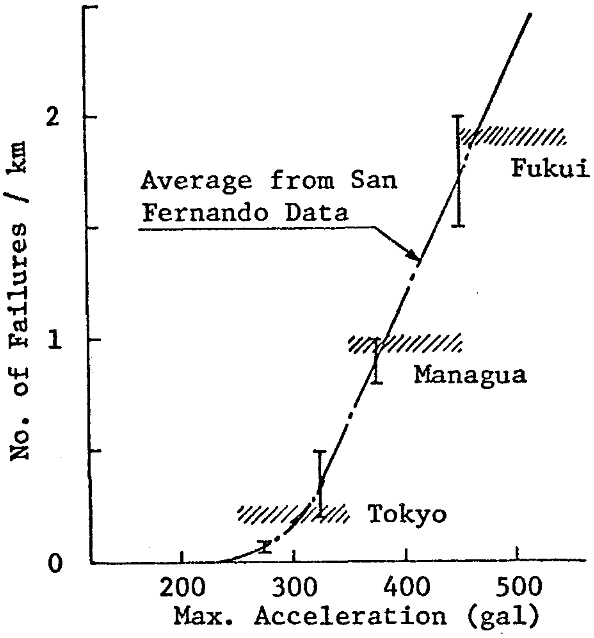


Fig.2.Failure Ratio of Water Pipe and Maximum Acceleration.

governing factors related to the seismic damage to buried pipes are the ductility of pipe material and the flexibility of joints. Generally speaking, welded steel pipes performed better than cast iron pipes with bell and spigot joints caulked with cement or lead.

The characteristics mentioned above are not always valid if buried pipes are located within fault zones or liquified areas. Pipes in fault zones are often virtually shattered to pieces and those in liquified areas completely lose their alignment. At this moment, it is doubtful that piping can be economically designed to resist such violent ground ruptures. Thinkable measures may be i) to plan crossings to avoid areas of such known seismic hazard, ii) to make fault crossings at right angles to the fault trace, iii) to make crossings at or near grade, or above-ground so that damage can be quickly and easily repaired, and iv) to give system redundancy in the pipeline network.

4. Present State of Earthquake Resistant Design Method

The state-of-the-art of earthquake resistant design methods of utilities can be best seen in "Earthquake Resistant Regulations - A World List - 1973" compiled by the International Association for Earthquake Engineering. This List contains earthquake resistant regulations of 28 countries, of which eight countries (Bulgaria, India, Japan, New Zealand, Turkey, USA, USSR and Yugoslavia) are found to possess earthquake resistant codes for general civil engineering structures other than buildings. However, most of these regulations are not so detailed as those for building structures. Since utilities cover a wide range of different types of structures and equipments, general regulations alone are usually not enough to perform practical anti-seismic design.

Regarding the seismic design of buried pipes, only the Japanese regulations give a basic philosophy, and there is no regulations which specifies practical calculation method. The Japanese Government established a standard for petroleum pipeline in 1972 which includes clauses related to earthquake resistant design. This standard specifies a design method of buried pipelines based on the deformation of surface layers of ground, but the assumptions of magnitude and shape of the ground deformation in the horizontal plane seem to require further examination and the design of bend in pipeline remains to be solved.

Earthquake resistant design of highway and railway bridges are usually made by the seismic coefficient method (or the equivalent static force method). The modified seismic coefficient method (or the simplified response spectrum method) which takes into account the dynamic properties of a bridge and the characteristics of real earthquake ground motions are being used in several countries such as Japan (Japan Road Association - 1971), New Zealand

(New Zealand Ministry of Works - 1972), and USA (California Department of Transportation - 1973). However, critical review seems to be necessary for the adequacy of design response spectra being used in various countries. Dynamic response analysis techniques are used (fairly widely in Japan) for special and important bridges in order to examine the design obtained by the seismic coefficient method. For this more sophisticated design method to be taken into practical design procedures, more work needs to be done on the method of structure idealization, the selection and the application of input earthquake motions, etc. If a bridge has to be built at a site where soft and deep surface layers exist, it should be noted that liquefaction and soil-foundation interaction problems often become critical in its seismic stability. Japanese specifications for earthquake resistant design of highway bridges (Japan Road Association - 1971) may be the only regulation that contains special criteria with regard to liquefaction. As mentioned in the previous section, failure or excessive subsidence of backfill materials behind abutments is one of the most common seismic damages to bridges. However, almost no research has been made so far with respect to this problem. Appropriate anti-seismic measures and strengthening method of this particular part in a bridge system certainly deserve more future attention. Special attention should be also paid to the importance of structural details in the earthquake resistant design of bridges. Keys, restrainers, devices for preventing superstructures from falling, and details of steel reinforcement in columns are some of the important features in this respect.

Seismic damage to utilities occurs to a variety of structures due to a number of different causes. Lanslides, embankment failures, cracking of tunnel lining, and failures of underground structures such as underground reservoirs due to earthquake soil pressure are only several examples. Anti-seismic design considerations presently adopted for these types of damages are mostly of empirical nature, and it may be said that studies have just made a beginning for most of these problems.

Earthquake resistant design of communication facilities and systems is no exception. There have been cases in which communications systems were totally disrupted by earthquake effects. Transmission of correct information is essential for the establishment of effective rescue and restoration programs. It should be borne in mind that earthquake resistance of communication equipments can be greatly improved by giving proper attention to equipment bracing and anchoring systems. However, it is more important to incorporate the concept that failures in a network should not affect the overall function of the system. System redundancy is recognized as desirable and effective in mitigating earthquake effects not only for communication utility but also for water supply and electrical power systems.

5. Research Problem in the future

As described in the previous sections, the present state of technology in the earthquake resistant design of utility systems is considerably underdeveloped in comparison with that of buildings. Especially, anti-seismic design of such structures like liquid-fuel pipelines and large storage tanks is quite a new problem in earthquake engineering. In order to provide reliable utility systems which will satisfactorily function during and after earthquakes, it is important for researchers and engineers of all the concerned countries to cooperate in raising the general level of technology in this field as fast as possible.

The followings may be some of the more important technical problems on which special emphasis should be placed in future research:

1) Quantitative analysis of earthquake damage to utility systems.

2) Reliable estimation of relative ground displacement in the horizontal plane, and establishment of earthquake resistant design method of structures, especially of buried pipelines, based on this concept.

3) Mechanism of landslide, slope and embankment failures during earthquakes.

4) Analysis of nonlinear dynamic behaviors of bridges, and establishment of earthquake resistant design method incorporating this knowledge.

5) Network or systems concept of water supply, electrical power, and communication utilities.

6) Possible measures for mitigating damage to pipelines or conduits due to faulting.

However, technical and engineering considerations alone are not sufficient to minimize the effect of seismic damage to utilities on human activity. It should be noted that such administrative measures are essential as i) providing standby and storage facilities and alternate routes, ii) insuring rapid restoration capability, iii) providing interconnections with other utilities, iv) reviewing older structures, and v) coordinating emergency planning with other utilities and agencies.