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Functional Damage and Rehabilitation
of Lifelines in Earthquakes

by

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FUNCTIONAL DAMAGE AND REHABILITATION OF LIFELINES IN EARTHQUAKES

by

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SUMMARY

The Miyagiken-oki (i.e. Off Miyagi Prefecture) Earthquake of June 12, 1978 with 7.4 of Magnitude brought many disasters to Sendai City of about six hundred thousand at population and its adjacent area. It killed 28 people and the property loss amounted 276 bil. yen (1.1 bil. dollars). The disaster was supposed as one of the biggest earthquake disasters since the Kanto Earthquake of 1923. After then such earthquake disasters in modernized prefectural metropolises had been experienced in the Fukui Earthquake of 1948 and the Niigata Earthquake of 1964. However Sendai City was urbanized than Fukui and Niigata at those days.

This paper discusses the functional damage and rehabilitation of life-line systems.

FUNCTIONAL DAMAGE TO LIFELINE FACILITIES

General Description

After the earthquake, Sendai City and its adjacent area experienced suspension of electric power, water and gas supply, sewerage, railway operation, traffic signals and telecommunications. They brought an inconvenience in urban activities.

Lifeline facilities perform their function when they are operated as a network. The experiences through the past earthquakes show us the possibility of the functional paralysis of whole lifeline systems caused by the partial damage. In this earthquake, the "bottleneck" was the electric power facilities. Traffic signals and some of the water pumps for water supply operated by electricity did not work due to the electricity outages. The electricity-relied urban life was obliged to stop for a few days.

Transportation Facilities

Roads

After the earthquake at 5:14 p.m. of June 12, the automatic control system for traffic signals at Sendai Central Police Station did not work due to electricity outages. Two hundred sixty traffic signals in Sendai could not be operated. That was just at rush hours in the evening so that the traffic became confused. Owing to the recovery of electricity at 8 p.m., policeman's hand signal for traffic control and the temporary electric-power supply to traffic signals by portable generators, traffic congestion was gradually dissolved.

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The traffic on major roads was restricted by structural damage to national and prefectural highways and Tohoku Expressway.

Railways

After the earthquake, all the railways under the control of Sendai Railway Control Bureau JNR were suspended. Many commuters and travelers were deprived of means of transportation. As a result of inspection and temporary restoration, Tohoku Main Line south of Sendai and Joban Line (both connecting Tokyo and Sendai) reopened on June 14, and north part of Tohoku Main Line on June 15. Local lines in and around Sendai reopened on July 8.

Harbors

Ishinomaki Industrial Harbor, Sendai Harbor and other harbors in Miyagi Prefecture suffered such damage as cracks in aprons, breakdown of loading machines, etc. But by emergency measures, the function of the harbors was mostly secured.

Airport

Sendai Airport suffered slight damage of cracks on runways. Taking-off and landing of planes were suspended for a while. But normal operation was soon resumed.

Water Supply Facilities

Water supply facilities were damaged at 54 cities, towns and villages. In Sendai water supply was suspended at about 7,000 houses after the earthquake. The number of houses suspended decreased to 2,000 on June 14 and to 700 on June 15. Water supply was suspended at all 16,000 houses in Shiogama City, 15 km east of Sendai, and at 10,500 houses in Izumi City, 10 km north of Sendai. Due to the damage to industrial water supply facilities, more than 20 factories were obliged to be supplied no water for 24-79 hours.

Sewerage Facilities

After the earthquake, sewerage treatment and pump yards in Sendai and some other cities could not work because of electricity outages and structural damage. Under such situations, sewage was obliged to be discharged into a river without full treatment. After the temporary restoration, the function of these damaged facilities was recovered within a few days except for Koriyama Pump Yard (recovered at 4:25 p.m. of June 23) in Sendai.

Medical Facilities

Medical activities after the earthquake were more or less impeded because of electricity outages and the damage to equipments and fittings at hospitals and clinics. However accidents of patients were prevented by emergency measures. Serious confusion of medical activities did not come about by means of the cooperation among the hospitals with slight or no damage.

Energy Supply Facilities

Electric Power Facilities

Total demand of electric power in Tohoku District (northern part of Japan) was 4,900 MW just before the earthquake. After the earthquake the demand for electric power reduced by 1,500 MW, and the supply reduced by 1,000 MW owing to the damage of both facilities of customers and the electric power company.

The number of electricity-failed houses reached 681,600 (419,100 in Miyagi Pref., 103,000 in Fukushima Pref., 95,800 in Yamagata Pref., 59,000 in Iwate Pref.). Owing to the temporary restoration it decreased to 280,000 at the end of June 12, and to 12,000 on June 13. The function of electric power facilities was completely recovered on the early morning of June 14.

Gas Supply Facilities

The earthquake caused the damage to gas supply facilities in four cities of Sendai (including Izumi and Tagajo), Shiogama, Furukawa and Ishinomaki. There was slight damage in the latter three cities. The function of gas supply facilities was completely recovered on June 13 in Ishinomaki, on June 16 in Shiogama and on June 18 in Furukawa.

However, in Sendai gas production facilities at Minato and Haramachi Plants were damaged. A cylindrical gas holder in Haramachi Plant with the capacity of 17,000M³ caught fire and what was worse, gas pipes were damaged at 533 places. The gas supply in Sendai was wholly suspended by such serious damage. With the temporary restoration gas supply was resumed in some part of Sendai on June 16. After the accomplishment of inspection and restoration of all gas pipes, from main pipelines to twig pipes inside every house, gas supply resumed block by block. It was on July 9 that gas supply was resumed to every house.

Areal propane-gas supply through pipes was also suspended at 7,861 among 16,266 customers in Miyagi Pref.. The supply to 4,444 houses was resumed on June 14.

Telecommunication Facilities

3,845 telephones of 1,738,000 subscription telephones in four affected prefectures were damaged by snapping of wires, the damage to telephone sets, etc. They were entirely restored on June 20. As for long-distance transmission lines, 4,000 circuits into, out of and through Sendai were down by the damage to coaxial cables, inclination of microwave antennas, etc. All the circuits were restored on June 14. Short-distance transmission lines were slightly damaged, but all the circuits were soon recovered on June 13. As many telephone calls poured into Sendai immediately after the earthquake, extraordinary congestion of calls took place until June 14.

Public telephones were unusable for several hours by electricity outages. Telegraph was not able to be serviced at Sendai Central Telegraph Office by the damage to transmission lines. Their functions were soon recovered. In three days after the earthquake sixtyfour thousand telegrams reached Sendai, that is 20 times more than usual.

Wireless facilities for emergencies connecting the prefectural government office and local communities were slightly damaged in Miyagi Prefecture. There was only one town that could not communicate by wireless.

As for broadcasting, TV and radio stations could not broadcast for a while after the earthquake by the electricity outages and the damage to micro-wave circuits. Their functions were recovered within less than an hour.

CHARACTERISTICS OF THE DAMAGE AND ITS REHABILITATION

Relationships among Damage, Topography and Geology

The sites where structures suffered damage approximately correspond to the areas of topographically or geologically poor conditions. For instance the razed houses are concentrated to alluvium, eastern suburb of Sendai, and to the hilltop, northern and south-western suburb of the city. The latter area also suffered slope failures. The distribution of the damage roughly coincides with that of the water supply facility and of the gas supply facility.

Through the experiences of past earthquakes, we have learned that structures on the alluvium are likely to suffer greater damage than those on the diluvial layer. The earthquake proved that the experience was fairly true.

The hills in the western part of Sendai and the western part of Natori are covered with 5M thick loam layer at the top and with 10-20M thick gravel layer underneath. The Tertiary of sandstone spreads beneath them. N-value of the loam layer at 2.5M beneath the surface and of the gravel layer are on the average 5 and 20-30 respectively. Midorigaoka District, Sendai where residential lots had been developed in late '50s through early '60s and many slope failures took place, has the same geological conditions. The residential lots had been developed by cutting the hilltops and filling the valleys. There were the fills more than 10M thick and whose N-value was less than 10. Slope failure and settlements occurred mostly at these fills due to the earthquake, which caused the damage to residential houses, water supply and gas supply pipes.

In the residential lots of northern part of Sendai and Izumi there are no loam and gravel layers. Hard rock and soft rock lies alternately. The residential lots had been developed by using bulldozers attached by the ripper. Fig. 3 shows the damage distribution of water supply and gas supply pipes at Nanko-dai Housing Complex, Izumi. The damaged sites concentrate to the areas where they have used to be swamps and had been artificially filled.

Damage and Function of Lifelines

Table 1 shows the individual loss ratios of lifeline facilities in Miyagi Prefecture. The individual loss ratio is defined as the ratio of the loss caused by the earthquake and the existing assets in the affected area both valued in money. The existing assets can be estimated from the population density.

$$\text{Individual Loss Ratio} = \frac{L}{W} \frac{P}{P_D}$$

where

L : loss valued in money,

W : national wealth,

P : national population and

P_D: population of the quake-affected area.

The data of the national wealth of 1978 was not available, so that the data of 1970 were used.

Table 1 Comparison of Individual Loss Ratios of Lifeline Facilities

	Loss (L) in million yen	National Wealth ^{*1} in billion yen	$\frac{L_K P}{W_K P_D}$
Highway	^{*2} 10,721	8,121.5	0.076
Harbor	3,746	2,076.5	0.103
Water Supply	1,733	4,502.2	0.022
Gas Supply	947	867.4	0.063
Electric Power	2,960	8,133.7	0.021
Telecommunication	850	4,857.2	0.010

*1 Referred from the National Wealth Survey of 1970.

*2 Excluding National Expressways.

P : 111,933 thousand

P_D: 1,955 thousand

The individual loss ratio of harbor facility shown in the table is the highest and those of highway and gas supply facilities are also high. Water supply and electric power facilities have relatively low ratios and telecommunication facility has the lowest. The sequence of the individual loss ratios suggests that the ratio represents the extent of damage. It can be used as the index quantifying damage of various kinds of facilities.

The sequence also roughly coincides to that of the functional damage. In Ishinomaki Port, the mostly heavily damaged harbor, the function was maintained after the earthquake by the emergency repair and by utilizing the little damaged warves. As for the facilities themselves, the damage was not minor but the reserved facilities had been well prepared.

Many highways had been blocked due to the earthquake damage since the occurrence of the earthquake. It took more than four months to resume the traffic in one highway section and three highway bridges due to reconstruction works. Many bridges suffered considerable damage which made discontinuity of highway network in Miyagi Prefecture. The gas supply facility suffered great functional damage, as the individual loss ratio was relatively high. It took about one month to completely resume the supply. The area where gas supply stopped after the earthquake encompassed Sendai and adjacent cities. The water supply facility sustained less functional damage than the gas supply, as the individual loss ratio of the water supply was also less. The suspension of water supply in Sendai was over on June 20, eight days after the earthquake. During the suspended period, water wagons supplied water to the residents. Functional damage of the electric power was not severe. The domestic power supply was resumed on June 14. On the other hand the suspension influenced other lifeline facilities. For example traffic signals did not function because they did not have the reserved electric power. It brought traffic congestion in the central Sendai. The Traffic Control Center of Sendai Central Police station, which had controlled areal traffic signals in Sendai, disordered. Tohoku Electric Power Co. Ltd. asked

industries to reduce the consumption of electric power, until the power plants and transformer stations recovered. It would have influenced the industrial productivity to some extent. The telecommunication facility suffered little functional damage. However the demand for the telephone call increased after the earthquake, which caused difficulties of telephone calls.

As stated above, functional damage and individual loss ratio fairly correlate in each other.

LESSONS FROM THE EARTHQUAKE DISASTER

- (1) The loss ratio valued in money represents successfully the extent of damage of lifeline facilities and the functional disturbance.
- (2) Gas supply was stopped for about one month after the earthquake. One reason for this was that the gas pipe networks were continuous within the supplying area. The supply could not be resumed until whole damages of pipes were repaired.

Functional damage of the electric power facilities was not big. However it caused the disorder of traffic signals and water pumps of water supply. Functional damage of the electric power facilities had much consequence on other lifelines.

- (3) This earthquake revealed the vulnerability of the artificial land, which was developed by cutting and filling a large volume in a swamp or steep slope. Most of the damages were caused not only by ground shaking itself but also by ground failures.

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Fukushima Prefectural Government
Iwate Prefectural Government, and
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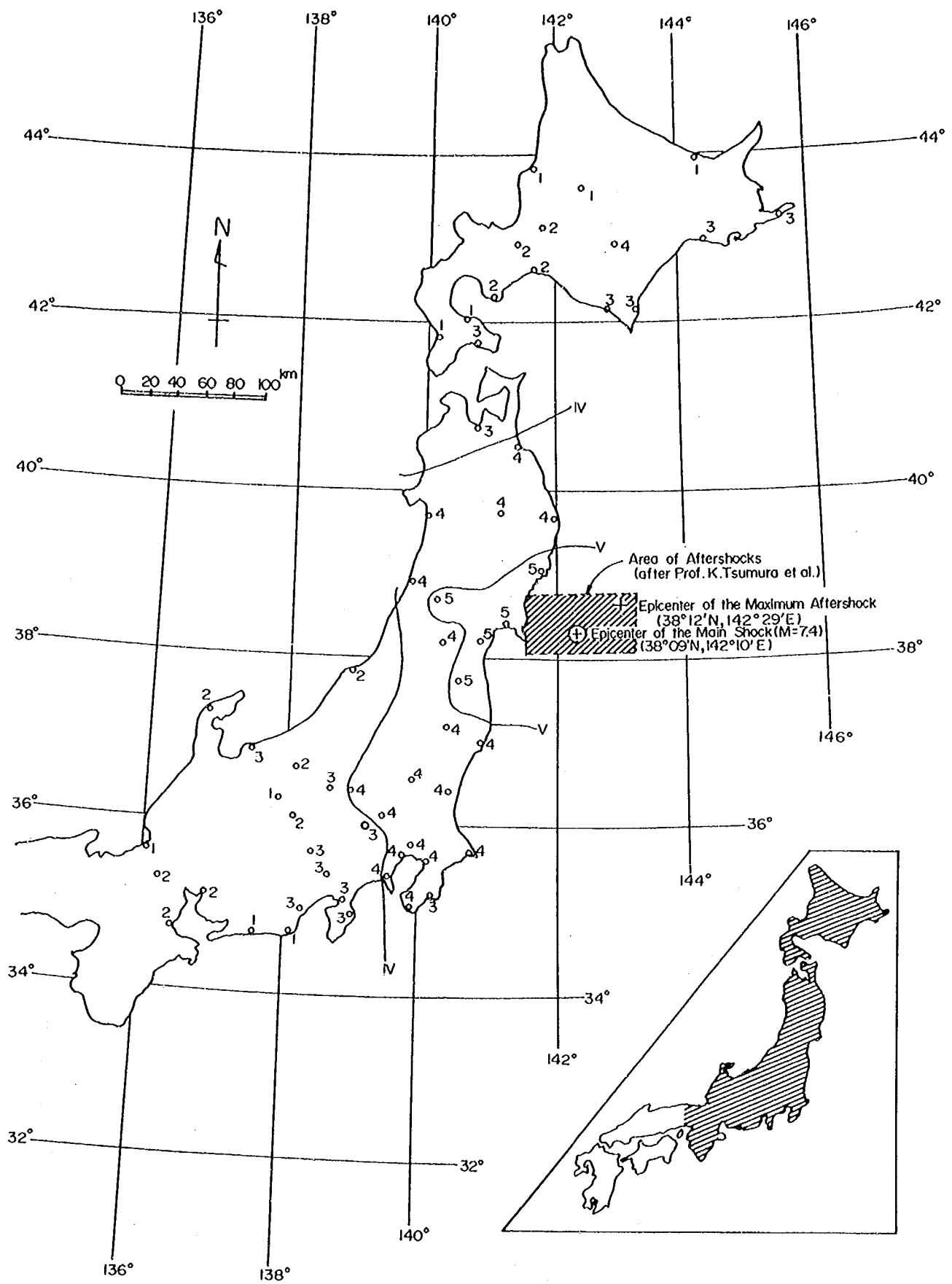


Fig. 1 Isoseismals (in JMA's 7th intensity scale)

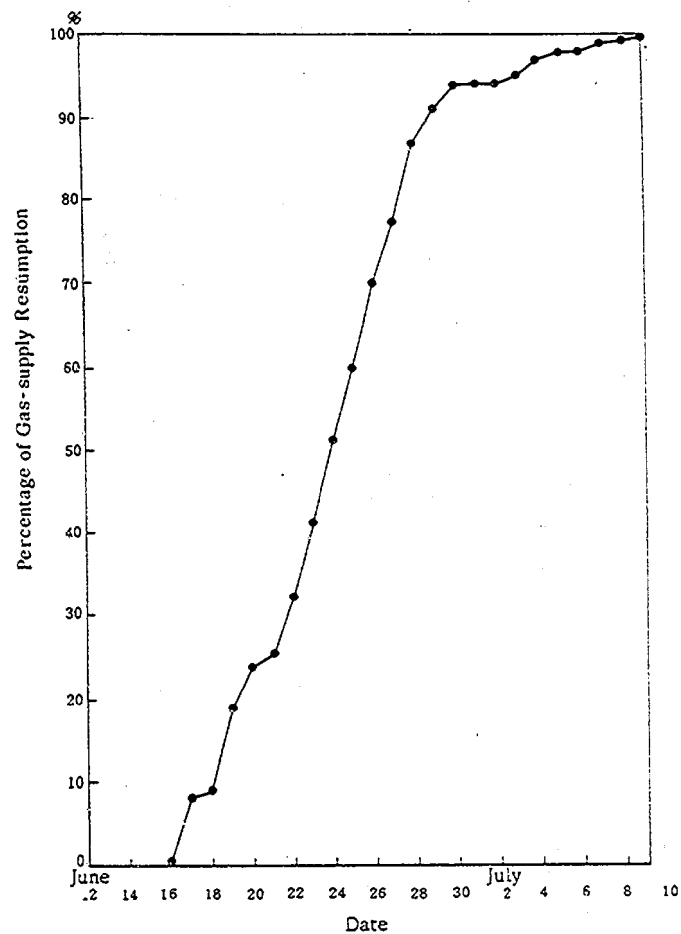


Fig. 2 Transition of Gas-supply Resumption
(Gas Bureau of Sendai Municipal Government)

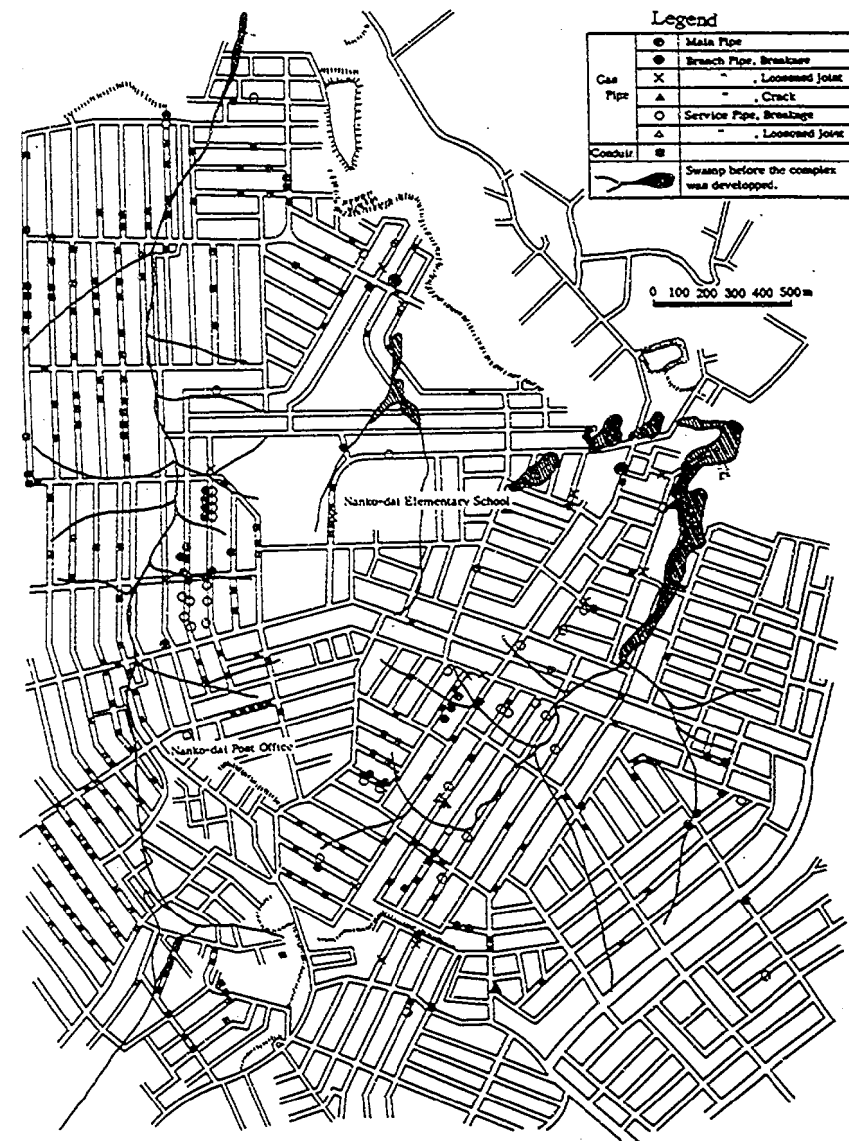


Fig. 3 Damaged Sites Distribution of Conduits and Gas Pipes at Nanko-dai, Izumi City

Inspection and Retrofitting of
Earthquake Resistance Vulnerability
of Highway Bridges in Japan

by

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INSPECTION AND RETROFITTING FOR EARTHQUAKE RESISTANCE VULNERABILITY OF HIGHWAY BRIDGES IN JAPAN

by
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SUMMARY

All highway bridges in Japan are supervised technologically through the authorized specifications by the Ministry of Construction. The ministry has conducted the inspection of highway bridges three times (i.e. 1971, 1976 and 1979). The first one in 1971 was to point out the deteriorated bridges liable to be damaged in earthquakes. The second in 1976 was to check the items being closely related with the possibility of damage. The third inspection in 1979 was to classify bridges according to their earthquake resistances. This paper introduces the procedure of the latest inspection and its retrofitting in 1979.

INTRODUCTION

It is necessary in earthquake disaster mitigation planning to extract structures liable to be damaged in earthquakes. Two methods exist for the extraction. The one is to point out the structures liable to be damaged when they have the vulnerable structural factors according to the experiences of past earthquakes. The other is to analyse structures and to judge their safety.

The inspection of highway bridges conducted by the Ministry of Construction, Japan, in 1979 sequentially applied both of the methods. Possibly vulnerable bridges were extracted by the former method. The vulnerable factors considered were;

- (1) the design based on the old specifications,
- (2) deteriorated materials, and
- (3) vulnerable types of structures according to the damage in past earthquakes.

The extracted bridges were inspected by the latter method.

The priority of retrofitting was determined by the importance of bridges.

PROCEDURE OF THE INSPECTION

The inspection of highway bridges conducted in 1979 consists of four steps. The first step is to select the routes to be inspected, which are indispensable in emergency.

The second step is to extract the possibly vulnerable bridges. Referring the reports of past earthquakes, damage of bridges is more affected by the vulnerable subgrounds and substructures than superstructures, so that the formers are emphatically inspected.

The bridges extracted by the second step are to proceed to the third step. It is to inspect the stability of subgrounds and foundations, and

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the section moduli of piers.

The fourth step is to analyse structures dynamically if required.

The retrofitting method for each type of vulnerability identified is lastly proposed. The priority of retrofitting is to be determined by the availability of substitutive routes and the easiness of traffic resumption in emergency.

The procedure of the inspection is shown in Fig. - 1. This paper mainly describes the second and third steps.

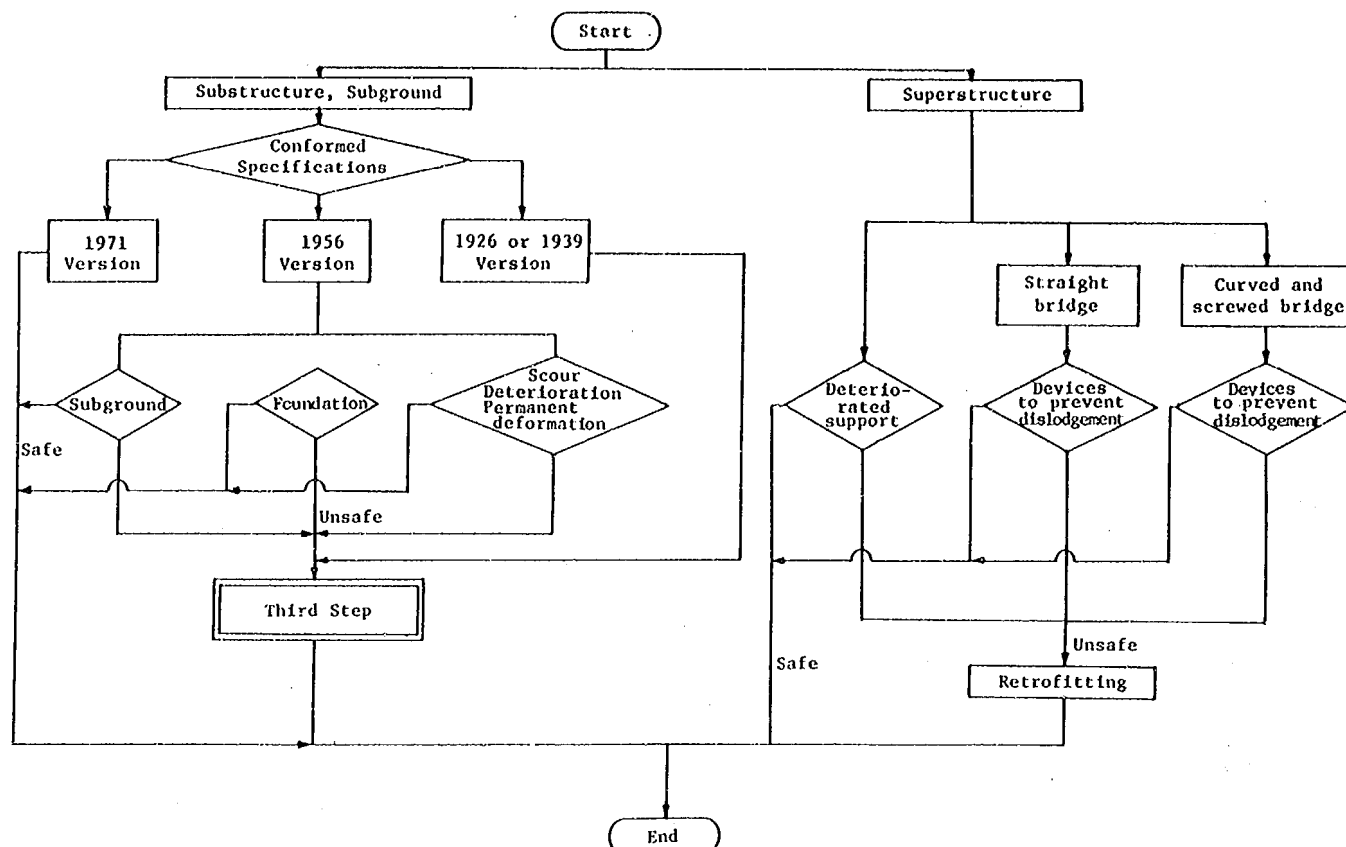


Fig. 1 Flow Chart of Inspection in the Second Step

Possibly Vulnerable Bridges (Second Step)

The second step is to extract the possibly vulnerable bridges which should proceed to the more detailed inspection in the third step. The vulnerable factors considered are as follows:

(1) Specifications Conformed

Owing to the progress of earthquake engineering, specifications have been revised several times.

At least the structures conformed with the latest specifications of 1971 were considered to have enough safety. The structures before the 1956 specifications were considered to be possibly unsafe. Those between 1956 and 1971 were judged depending on the subground, foundation and deterioration of the substructure.

For instance of the improvement of the specifications no attention had been paid to liquefaction before the specifications of 1971 were issued.

(2) Subground

a. Loose and Saturated Sand

Loose and saturated sand is liable to liquefy in earthquakes. Sandy layers which were less than 10 m deep and whose N-values were less than or equal 10, or the sites where historical liquefaction was reported were extracted.

b. Poor Subsoil

Peat layers or the sites where adjacent dikes and embankments settled were extracted.

(3) Substructure

a. Lack of Enough Rigidity

The substructure as shown in Fig. 2 suffered damage in Miyagiken-oki earthquake of 1978. The damage would have been attributable to the independent two caissons and insufficient rigidity of the tying members.

The pile bent substructure as shown in Fig. 3 experienced damage in Niigata earthquake of 1964.

Both types of the foregoing substructures have insufficient rigidity. Therefore the substructures without enough rigidity were extracted.

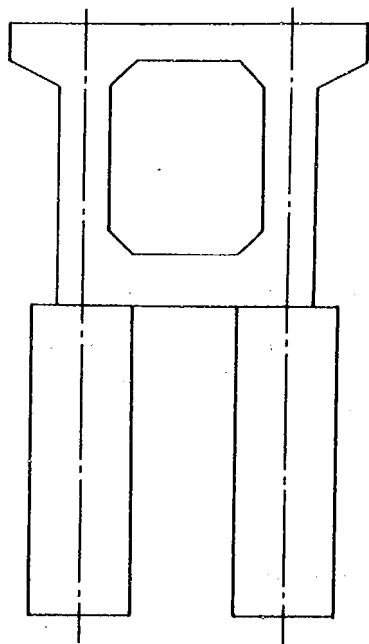


Fig. 2 Independent Caisson Foundation

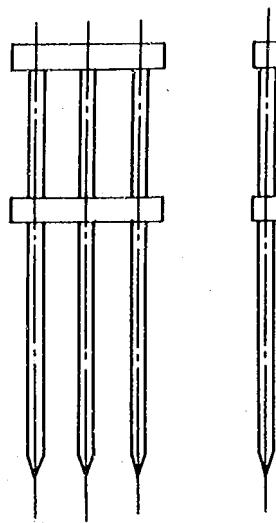


Fig. 3 Pile-bent Foundation

b. Brittle Materials

Substructures made of plain concrete, brick and masonry were extracted.

c. Settlement and Inclination

The substructures which settled or inclined were extracted.

(4) Superstructure

a. Curved Bridge

A curved bridge acts rather different in an earthquake from what is expected in conventional design. In conventional design a bridge was designed in longitudinal and transverse directions.

However a curved bridge bears not only the forgoing loadings but also torsional loading. The curved bridges without considerations of torsional loading and whose radius were less than 100 m were extracted.

b. Skew Bridge

By the similar reason as curved bridges, skew bridges of less than 60° of angles were extracted.

c. Deteriorated Supports

The supports of deteriorated anchor bolts, deteriorated bearings and over-dislodged supports were extracted.

d. Lack of Devices to Prevent Dislodgement

The supports without devices to prevent dislodgements which were specified by the specifications of 1971 were extracted.

Classifying Bridges by their Resistance (Third Step)

The bridges extracted by the second step were to be inspected in the third step. Here only subgrounds and substructures were inspected, because superstructures do not affect the damage according to the experiences of past earthquakes as far as they passed the second step inspection.

(1) Subground

a. Liquefaction Resistance Factor

Liquefaction resistance factor, F_L is defined as the ratio of the resistance index of soil elements to dynamic loads R , and the shearing stress loads index to soil elements induced by earthquake motions L . The procedures to calculate R and L are shown in Reference [2]. Subground having the total thickness of the layers of greater than 10 m whose F_L were less than 0.6 was judged to be liquefied in earthquakes.

b. Bearing Capacities

In the relationship between the overturning moment and the bearing capacity of foundation three zones were defined as safe (A), slightly unsafe (B) and unsafe (C) in Fig. 4.

(2) Substructure

a. Section Modulus of Pier

Aged piers possibly have the insufficient section moduli compared to the current specifications. The section moduli of inspected piers were compared with those of the Standard Design issued by the Ministry of Construction and other institutions, which were designed based on the current specifications. The checking charts are shown in Figs. 5 - 7. Fig. 5, Fig. 6 and Fig. 7 correspond to wall pier, column pier and rigid frame pier

respectively. The line dividing zones A and B was drawn by enveloping the dimensions designed by the Standard Design. The line dividing B and C was drawn by multiplying by 1.1 (reserve strength of reinforcement) of the line between A and B. Zone C was determined to be preferentially retrofitted.

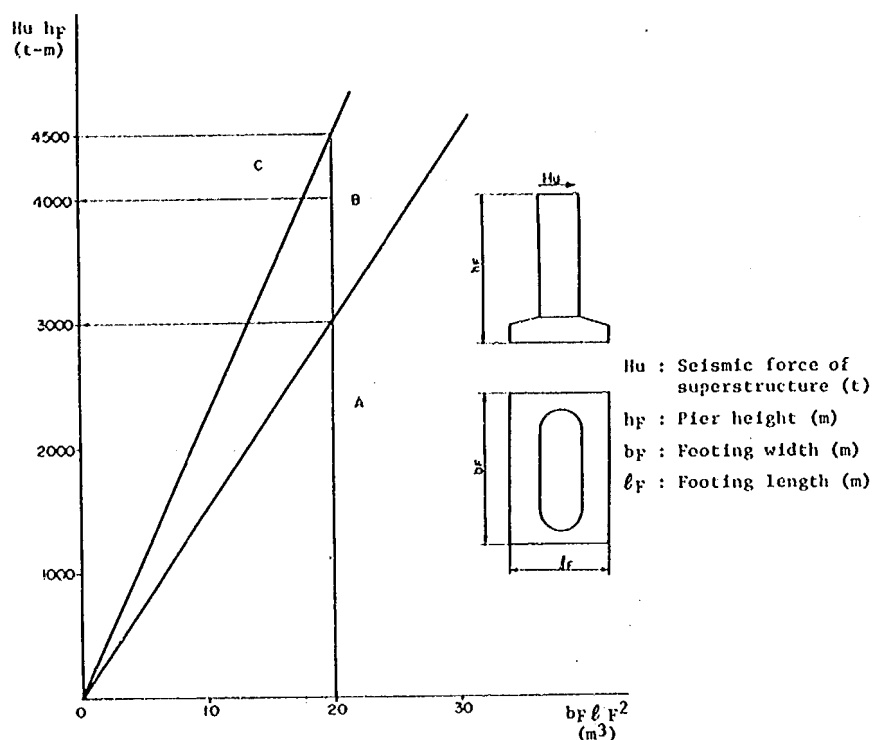


Fig. 4 Checking Chart for Bearing Capacity

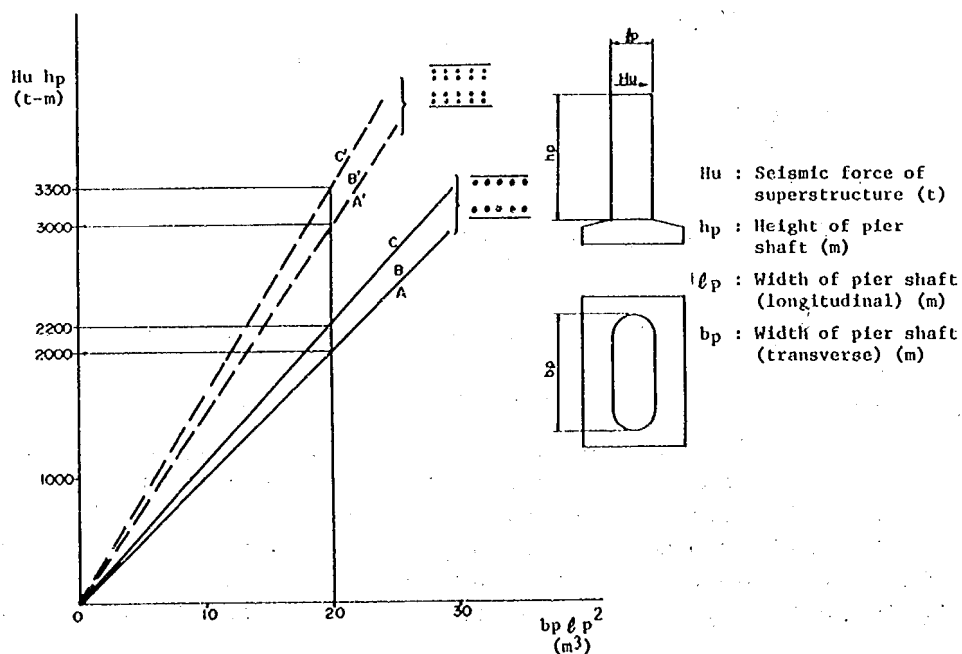


Fig. 5 Checking Chart for Wall Pier

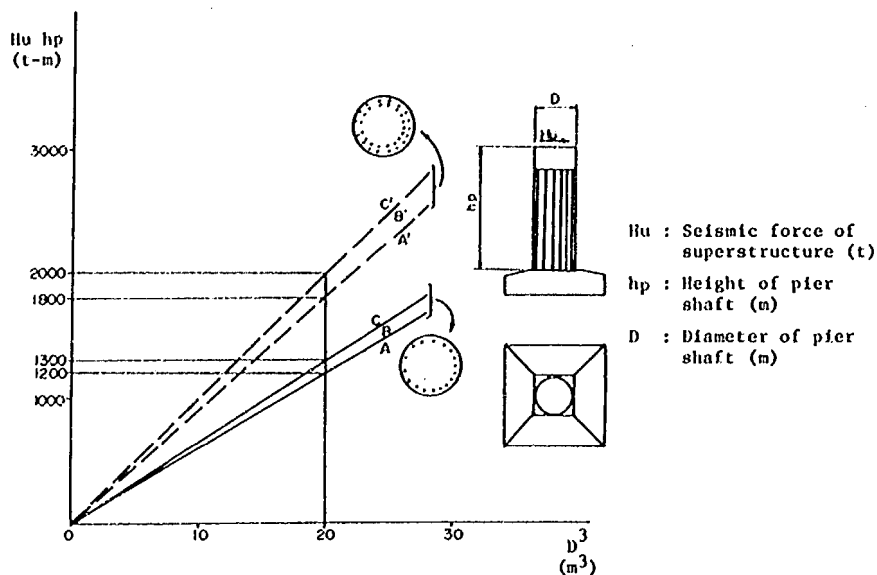


Fig. 6 Checking Chart for Column Pier

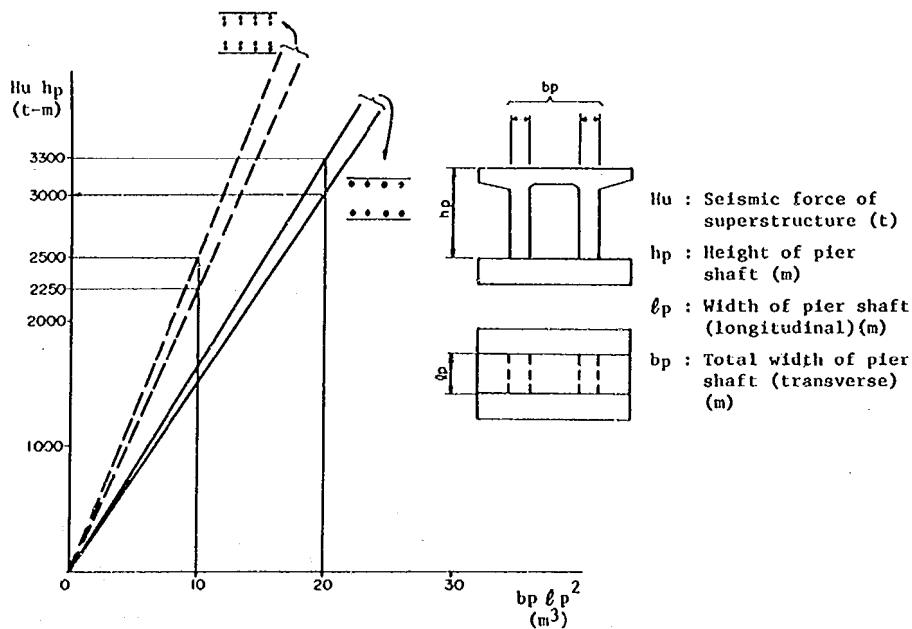


Fig. 7 Checking Chart for Rigid Frame Pier

b. Safety Factor of Pile Foundation

Aged pile foundations are liable to be damaged than other types of foundations according to the experiences of past earthquakes. The reason for this would be that there did not exist capable pile drivers in old days. Additionally most piles before 1950 were made of timber. Therefore pile foundation was exceptionally inspected by calculating the safety factor SF as follows.

$$SF = \frac{R_u}{V_1}$$

R_u : Ultimate bearing capacity of a pile (t)

V_1 : Vertical reaction of pile 1 (t) = $\frac{V}{n} + \frac{Ve}{X_1^2} X_1$
 V : Vertical load (t)
 n : Number of piles
 e : Eccentricity (m)
 X_1 : X coodinate of i-th pile (m)

Dynamic Analysis

The bridges extracted by the above step were inspected by applying the the dynamic analysis, if required.

Determining the Method of Retrofitting

The retrofitting method for each type of vulnerability identified is shown in Table 1.

Table 1. Proposed Method of Retrofitting

Classification	Vulunerable Factor	Method of Retrofitting
Subground		Surrounding by sheet piles Pile driving behind abutments Driving additional piles Sand compaction piles
Substructure	Scour Lack of enough rigidity Section modulus of pier Section modulus of footing Safety factor of pile foundation	Consolidation of foundation Additional rigidity Additional section Expansion of footing Additional piles
Superstructure	Curved bridge Screw bridge Deteriorated support Lack of devices to prevent dislodgement	Devices to prevent dislodgement Enlargement of bridge seat Connecting devices of adjoining girders Exchange of support Installing devices

DISCUSSIONS

About 37000 bridges were inspected in which 42% were judged to be retrofitted.

It is necessary to get a reasonable level of restrofitting from an economic point of view. Because of the low recurrence of damaging earthquakes, the retrofitting investment is obliged to be at a lower level, when the direct effects of retrofitting are only considered. However the retrofitting also has the indirect effects, such as the traffic and transportation, regional economy and opportunity loss for repair and reconstruction. When such indirect effects are considered, more retrofittings are reasonalized.

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Earthquake Disasters and
Disaster-Resistivities

by

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EARTHQUAKE DISASTERS AND DISASTER-RESISTIVITIES

by
Eiichi KURIBAYASHI^I and Osamu UEDA^{II}

ABSTRACT

The countermeasures to earthquakes are aiming at mitigation of losses of human lives and properties caused by earthquakes with a high probability of the occurrence which are naturally immanent in Japanese islands.

Nowadays, earthquake disaster mitigation measures are roughly divided into "Prediction of Earthquakes" and "Countermeasures for Disaster Prevention".

In the following, introduced are present problems concerned to countermeasures, some considerable factors in measuring the earthquake disaster resistivity of cities and a consideration about the improvement of the disaster-resistivity of lifelines.

COUNTERMEASURES TO EARTHQUAKE DISASTERS

Among all of natural disasters, especially earthquakes cause the greatest loss of human lives and properties. (refer Table 1.)

Table 1 Historical Record of the Death
by Natural Disasters in the World

Disasters	Year of Christian Era	Country	Number of Death
Earthquake	1556	China	830,000
Flood and Tidal wave	1642	China (Break on coastal embankment)	300,000
Storm	1876	India	200,000
Volcanic eruption	1693	Italy	60,000
Fire	1871	U.S.A. (Wood fire)	1,152

In central Japanese land along Pacific coast with relatively high density of population, if there occurs such earthquake of around eight of Magnitude, as the Kanto Earthquake of 1923, it is said that several hundred thousand lives will be lost carrying with a possible loss of some tens trillion yens (\$ two hundred billion) exceeding the budget of Japanese Government.

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The countermeasures to earthquakes are aiming at the reduction of human damage and economical losses so as to minimize disturbances in activities of both of citizens and enterprises concerning production, circulation and consumption, in activities of administrative agencies and in socio-cultural activities such as educations, cultures, recreation and entertainments.

When central and local governments cope with earthquakes adequately, and citizens and individuals behave as a member of the community properly, it is possible to mitigate almost all of the disasters.

One of targets in the adequate measures of administrative agencies is to get an equilibrium between safety and economy. Entrusted public investments as well as private investments should be efficiently applied under a careful guideline.

However, the phenomena caused by earthquakes are of immense variety even in physical phases. These phenomena should be proved with scientific facts and rearranged as utilizing them for the countermeasures technically and administratively.

On the other hand, there is a question that they should be applied to the countermeasure only after resolving them scientifically, though many phenomena concerned with economy, sociology and psychology related to earthquakes are not clear to comprehend.

Here lies a very difficult problem in the promotion of earthquake countermeasures. It would be necessary to place hypotheses for reexamination on facts, to pile up the vague facts one upon another many times for examining facts and falsehood, and to finally refine the hypotheses from more believable images. At the same time, the result of the repetition of such trials should be thoughtfully reflected upon the countermeasures.

Heretofore, in the words "earthquake countermeasures" there has mainly implied at first earthquake proof of structures. But now, the word has been changed to advanced idea consisting of earthquake predictions and improvements of resistivities of districts to earthquakes. The resistivity is going to be recognized as consisting of not only those of earthquake-proof, fire-proof and inundation-proof but also matters concerned with after-earthquake functions of facilities, indicators of local and groval land use planning.

DISASTER RESISTIVITIES OF URBAN DISTRICTS

As mentioned above, the earthquake countermeasures hitherto were promoted with emphasis upon the earthquake-proof of structures. However, the disasters of houses in the Kanto Earthquake of 1923 (M7.9) were as follows, (1).

Burnt	447,128 houses
Razed	128,266 houses
Half Razed	126,231 houses
Lost by Floods	868 houses

As seen from above, the damage by fire is much greater than that by shaking, and very many lives were lost in addition to substantial damage.

On the contrary, in the Tottori Earthquake of 1943 and the Fukui Earthquake of 1948, the disasters by shaking widely surpassed those by fire as shown below, (1).

Tottori Earthquake (M=7.4) Fukui Earthquake (M=7.3)

Burnt	254 houses	3,960 houses
Razed	7,485 houses	35,420 houses
Half Razed	6,158 houses	11,449 houses
Lost by Floods	none	none

These historical facts indicate that the damage by fire is prevailing in larger cities, and those by shaking in local cities. Furthermore, in case of our country, there are disasters caused by water, namely, by tsunamis in coastal regions and by inundations in lowlands along sea coasts and rivers. As one of the other factors which further increase these physical disasters and the loss of human lives, the panic may be considered.

In addition to these direct losses, we may consider the indirect losses which occur after earthquakes such as economical confusion, collapse of local societies or communities, and changes of international relations.

If a disastrous earthquake occurs as covering with whole areas such the Metropolitan area where all sorts of functions are densely packed, the influences of the earthquake are immeasurably large. Accordingly, causative factors as to be triggers for damage by shaking, fires, floods and panics, must be investigated, and in order to cut off the disaster in its primary stage, the factors of disaster expansion should be removed.

Durableness of a city to disasters, or rare occurrence of disasters of a city, is called "disaster resistivity of cities". Namely, this is a concept which is defined by assuming those of earthquake disasters, floods and great fires resulting only from natural effects such as earthquakes, typhoons and strong winds except such avoidable disasters as epidemics and wars.

Well, let us temporarily name the disaster-resistivity of a city to earthquakes as the earthquake disaster-resistivity.

As for the scale to measure the earthquake disaster-resistivity, there has not yet been any such scales so clear as design seismic coefficients in earthquake-resistant design. However, the several elements shown below may be considered in defining such scales.

• Geographical and topographical elements:

Density of population and its distribution ----- (Depopulation and concentration)

Sorts of industries and their distribution ----- (Density of industrial distribution)

Vacant lands and aquatic area ----- (Open spaces)

Topography and altitudes ----- (Landslide, inundation)

Meteorological and hydrological phenomena ----- (Wind, flood)

• Physical and artificial elements:

Frequencies of earthquakes and intensities of ground motions ----- (Intensities of earthquakes)

Geology and soil properties ----- (Ground conditions)

Aseismic resistances and fire-resistant properties ----- (Properties of structures)

Water supply and energy supply ----- (Water, gas, electricity, and petroleum)

• Dynamic and planning elements:

Population in day and night ----- (Short-term movement of population)

Dangerous facilities and disaster-prevention facilities -----
(Potentials of disaster occurrence in facilities)

Flow of goods and traffic volume ----- (Activities of districts)

Regional planning and urban planning ----- (Redevelopments of cities)

• Social and cultural elements:

Origination and transmission of information ----- (Networks of information)

Control functions and local functions ----- (Administrations)

Cultural inheritances and convenience facilities ----- (Historical changes)

Divisions of elements and their contents in all of the aboves are not necessarily adequate, and the other items may be added. From this, it is insufficient to clearly measure the earthquake disaster-resistivity in our knowledge.

In contrast to the earthquake disaster-resistivity, an idea of earthquake disaster risk potentials exists. Tokyo Metropolitan Government made trials for this idea, and the results obtained in 1974 fiscal year have found, for each of the items shown below, the relative risk potentials among twenty three of the wards. (2)

- i. Accumulated risk potentials for wooden buildings
(earthquake-resistances of grounds and buildings)
- ii. Risk potentials due to local characteristics
(population, open spaces and traffic volume)
- iii. Accumulated fire risk potentials (outbreaks of fires)
- iv. Risk potentials due to burnt houses (by spreading fires)
for the two cases of fire fighting powers included or not
- v. Risk potentials from refuge distances (refuge distances)

These relative risk potentials classified by items as aboves are totally piled up, and the totalized risk potentials are finally obtained. The order of 5 wards having higher potentials is as follows,

	(Fire fighting powers included)	(Fire fighting powers not included)
1st	Sumida	Sumida
2nd	Arakawa	Arakawa
3rd	Taitō	Taitō
4th	Toshima	Toshima
5th	Kōto	Shinagawa

In the above-mentioned earthquake disaster risk potentials of Tokyo, the public works or facilities other than roads, parks and green zones were not included in the evaluation. However, all of urban public works are so-called lifeline systems in earthquake engineering and they are indispensable to evaluate earthquake disaster risk potentials, but all of them were

not included in the evaluation of Tokyo. And disasters by water during and after earthquakes were not included in the evaluation either.

It is easy to find out some items lacking in the evaluation done, but there are many difficulties to obtain a totalized evaluation satisfying all of the important elements.

"A guide-line for drafting programs on mitigation of earthquake disasters in three major metropolitan areas, Tokyo, Nagoya and Ōsaka (draft)" issued by Ministry of Construction in August 1975 gives such a direction for the existing urban area and their suburban areas, as the scale and density on installation of facilities serving for safety.

This guide-line is, so to speak, a tentative guide-line which, by making a new step of advance from being a merely qualitative indicator showing the potentiality of earthquake risks, aims improvements of urban disaster-resistivities and protections of human lives. (3) The guide-line is composed as follows,

- i. Object areas.
- ii. Extensive refuge places.
- iii. Allocations of extensive refuge places and refuge roads.
- iv. Refuge roads.
- v. Buffer zones.
- vi. Water-gates, channels and pumping stations to inundations.
- vii. Strategy for arrangement and promotion.
- viii. Others.

This composition suggests that urban disaster-resistivities at present will be greatly improved by aiming primarily at the safety of human lives and next at the prevention of enlargements of disasters.

IMPORTANCE FACTORS AND DISASTER-RESISTIVITIES OF LIFELINE SYSTEMS IN EARTHQUAKES

Lifeline systems

In 1971, the San Fernando Earthquake which occurred in the suburbs of Los Angeles brought great damage in roads and other public facilities, and after then the word "lifeline" has been used in wider sense. In Japan facilities related to lifelines are selected as follows,

Facilities	Elements
Transportation	Road, street, railway, airport and harbour
Communication	Telegram, telephone, mail, broadcasting and newspaper
Sanitary	Watersupply, sewerage and solid waste disposal
Energy	Electricity, gas and liquid fuel
Vacant area	River, seashore, lake, park, green zone and open space

All of them are indeed the indispensable facilities in and after earthquakes occurred in large cities. Gases and liquid fuels are needed as heat sources, but on the other hand, they have the possibility of increasing expansion of fires. In addition, the facility of vacant areas is one of the lifelines, which should be seriously considered in Japan with densely populated characteristics in many cities located in one of the strongest earthquake regions in the worlds.

The importance factors of lifelines

It seems that some resemblance exists between the protection against natural hazards such as earthquakes and tactics on battlefields. Facilities which are generally named "lifelines" have respectively their individual characteristics, and probably should be ranked according to their importance in emergency.

In this consideration the strong-armored facilities with large functional capacities should be installed in important strategic points and fronts.

Accordingly, such as various adequate responses in case of battles, e.g. alternations of soldiers, guarantee of commissary, communications, first aid, withdrawal in the worst case, etc., those are similar ideas of the improvement and arrangement of lifelines for an emergency. Almost all of public facilities are included in the important facilities which should be retrofitted, and in fact, at present the retrofitting is advanced more than others.

However energy must be supplied from its sources into cities, as well as bullets must be carried into battle fields. After it catches once fire in such gas and liquid fuel as the energy sources they would make fire so much expanded that the functions of the important facilities as mentioned above could be lost.

According to an extracted census mainly conducted to an object of technological specialists, the majority of the opinions indicates that the importance factors of the important facilities should be taken larger than others for strengthening and refining them to effects of earthquakes in earthquake resistant design. But as for the influence of dangerous substances to the important facilities the opinions are divided into two, namely, one which stated that the facilities containing dangerous substances should protect the dangerous influence to other facilities by themselves and another one which stated that all of the important facilities should be more strongly armored. (4)

Now, concerning the problem of the lifelines with high importance, there is regretfully no clear standard to treat concretely. But if we must say forcibly, the following four items may be indicated.

- i. The facilities must have surplus functional-capacities.
- ii. The facilities must have a alternative to substitute the function.
- iii. The facilities must have a measure to promptly recover the functions immediately after the disaster.
- iv. The facilities must have an uniformity in the functional and structural capacities.

The residual life and disaster-resistivity of lifeline systems

Though it is an ideal situation that the simple and clear measures as stated above could be taken for improvement of the disaster-resistivity in earthquakes, corresponding to actually ordinary and daily demands the problem is usually arranged by considering growth of utilization for future demands and effects of investments etc.

Here, a consideration will be presented about the improvement of the disaster-resistivity of lifelines by employing their residual lives. The residual life is the length of time obtained by the subtraction of ready-served times from durable life-times of structures. Now, in the following there is shown an example of bridges in case of Kanto district for consideration of their earthquake-resistance.

Assumptions are as follows,

- i. Probability of earthquake damage (U^*), namely, the probability of earthquake damage (complete losses of the functions) of bridges which have existed since the Kanto Earthquake of 1923, is assumed to be 2.1×10^{-3} . (The probability of human earthquake damage (death) is supposed to be $10^{-3} \sim 10^{-4}$ for reference.)
- ii. Capacities of earthquake resistances of bridges (R) is exponential-functionally degrading depending time passing.
- iii. Durable life-time of bridges are assumed as 50 years.

Examples of the analyses are shown in Figure 1 and 2.

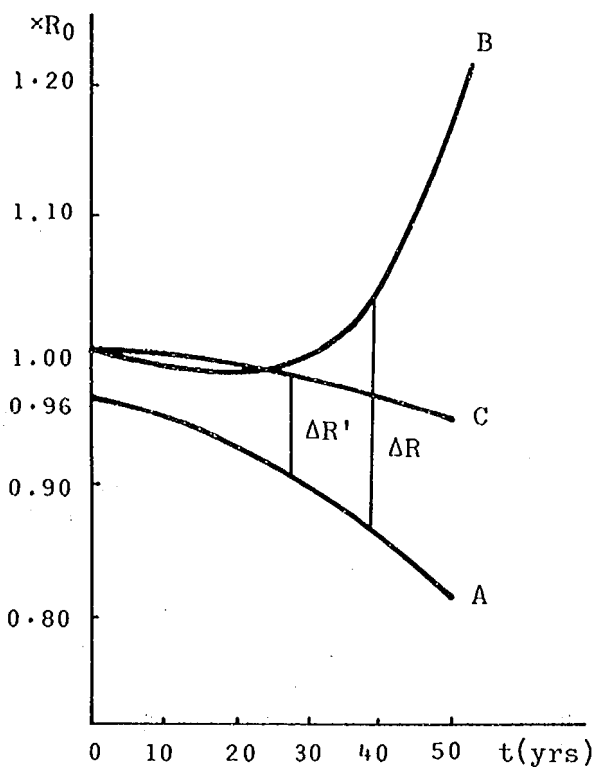


Fig. 1 Retrofitting required, case 1

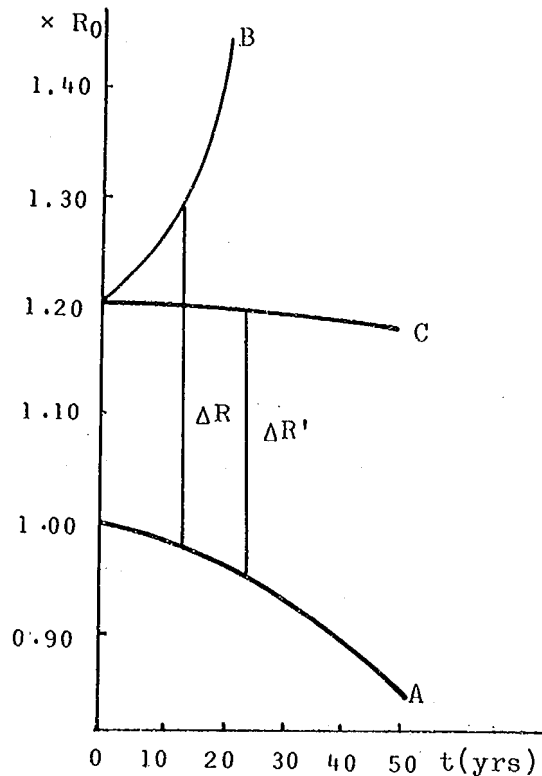


Fig. 2 Retrofitting required, case 2

- R_0 : Required capacities of earthquake resistance of bridges
 ΔR : Retrofitting ratios between capacities retrofitted and required.
- Curve A : Changes of the existing capacity without any retrofitting
 Curve B : Changes of the retrofitted capacity to maintain the level of required capacities corresponding to the durable life of 50 years at any moment.
 Curve C : Changes of the retrofitted capacity to maintain the level to the residual life at any moment, but with reductions of probabilities of risks being proportional to ratios of the residual life-time and durable life-time.

In Fig. 1 retrofitting ratios (ΔR : A-B and $\Delta R'$: C-A) are shown in case of satisfying initially 96 percents of the required capacity. In Fig.

2 retrofitting ratios (ΔR and $\Delta R'$) are shown in case of satisfying the full required capacity, but with reductions of probabilities of risks (1.05×10^{-3}) to half of the assumed probability before. (5)

CONCLUSIONS

During earthquakes, other than abrupt violence of the nature, distortions and confusions occur in the societies and organizations in cities, which have been built without any consideration such situations.

It is not easy to find the principle for improvements and arrangements to earthquakes occurred in cities and lifeline systems in them, with a naive logic. Capacities of the lifeline systems in strengths and functions are limited, and they could not avoid from disastrous damage with a certain probability during periods in even their life-time, and the probability is told by the history. From such situation we must find out the facts of disasters and apply them into.

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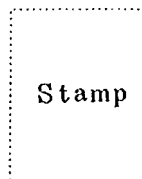
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