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DEVELOPMENT OF A WARNING INFORMATION SYSTEM OF EARTHQUAKE

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SUMMARY

Recognizing the importance of an information network at the time of an earthquake after the Kushiro Offshore Earthquake in 1993, the Hokkaido Development Bureau has developed an on-line digital information seismograph, and established the Warning Information System of Earthquake (WISE). The importance of earthquake damage information networks has also been recognized nationwide since the Great Hanshin Earthquake in January 1995. In establishing WISE, emphasis was placed on understanding damage and securing a data communication network, based on the lessons learned from three major earthquakes in Hokkaido. This system is for supporting the disaster-prevention system at the start of an earthquake. Existing and new strong motion seismographs installed on bridges, river dam bodies, in dam management offices and other places are connected on-line to obtain more accurate information more promptly. By doing this, damage to road structures and dam bodies can be estimated, allowing on-site instructions and countermeasures. Therefore, the status and problems of WISE, which is currently in test operation, and its damage estimation ability are now being studied.

By the end of 1996, 121 information seismographs and 101 terminals were installed. Although some earthquakes have occurred after installation, damage prediction has not yet been transmitted to the terminals throughout Hokkaido, as none of these earthquakes were of a seismic intensity of more than 3. Thus it is impossible to verify the adequacy of the damage prediction method for actual earthquakes. Ground conditions of areas where the information seismographs are installed and where significant damage is expected, and weather data for damage prediction have not been used on the system, as these data are still under examination. Although these are problems that need to be solved to improve the accuracy of the damage prediction data, data is still insufficient, and the progress of research will accelerate in the future with the data accumulated by actually operating the system.

The main purpose of this system is to help reduce damage at the time of earthquakes. It is necessary to improve the stability of system operation, immediacy and reliability of information, as well as the user-friendliness of the system. Although it is still in the stage of testing and research, improvements -- including the ones presented here -- will be made to allow WISE to contribute to post-earthquake recovery activities

INTRODUCTION

Since around 1955, strong-motion observations covering wide areas have been promoted in Japan at relevant agencies. However, because the former observation network was insufficient for civil engineering, people in this field have been constructing an observation network independently of others and collecting records

The objectives of strong-motion observations in civil engineering are: 1) designing structures incorporating seismic-safety features and 2) making their execution rational and economical. For these objectives the design

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seismic coefficient need to be determined by region, ground condition and kind of structure and by obtaining strong-motion response data of structures, such as bridges with high piers. However, beginning with the Kushiro-oki (Kushiro offshore) Earthquake of January 1993, earthquakes of magnitude-8 class occurred successively in Hokkaido. They included the Hokkaido Nansei-oki (Hokkaido southwestern offshore) Earthquake and the Hokkaido Toho-oki (Hokkaido eastern offshore) Earthquake. The Hokkaido Development Bureau, which manages and maintains national highways in Hokkaido, recognized the necessity of quickly collecting information to deal with post-earthquake situations.

Because strong-motion seismographs installed by 1993 recorded data on recording paper, about one month was needed per site to complete analysis of the data. Accordingly, these apparatuses could not be utilized for rapid information collection.

The Civil Engineering Research Institute of the Hokkaido Development Bureau, therefore, has replaced the strong-motion seismographs and has linked observation network with telecommunications to examine and develop a system that provides information to road administrators immediately after an earthquake. Strong-motion records are used not only for designing but also as an information source for post-earthquake inspections or for restoration following earthquake disasters.

This paper summarizes the development of this information communication system and its mechanism, as well as analysis of information provided to involved road administrators.2. System development

Table 2-1-1 Earthquakes of magnitude 7.0 or stronger recorded in Hokkaido

Date of occurrence	N.L.	E.L.	Focal depth	Magnitude	Epicenter location, or an earthquake name
22/Mar/1894	42.5	146.0		7.9	Off southwestern Nemuro
25/Dec/1900	43.0	146.0		7.1	Off Nemuro
18/Mar/1915	42.1	143.6		7.0	Off Hiroo
8/Sep/1918	45.5	152.0		8.0	Off Urup Island
8/Nov/1918	44.5	150.5		7.7	Off Urup Island
2/Aug/1940	44.3	139.5	10	7.5	Off nouthwestern Hokkaido
4/Mar/1952	41.8	144.1	0	8.2	Off Tokachi
7/Nov/1958	44.3	148.5	80	8.1	Off Etorofu island
12/Aug/1961	42.9	145.6	80	7.2	Off Kushiro
23/Apr/1962	42.2	143.9	60	7.0	Off Hiroo
13/Oct/1963	43.8	150.0	0	8.1	Off Etorofu island
26/Oct/1965	43.7	145.5	160	7.1	Southern coast of Kunashiri island
16/May/1968	40.7	143.6	0	7.9	Earthquake of Tokachi-oki
12/Aug/1969	43.4	147.8	41	7.8	Off Eastern Hokkaido
2/Aug/1971	41.2	143.7	60	7.0	Off southeast Nemuro Peninsula
17/Jun/1973	43.0	146.0	40	7.4	Off southeast Nemuro Peninsula
24/Jun/1973	43.3	146.4	26	7.1	Off southeast Nemuro Peninsula
21/May/1982	42.1	142.6	40	7.1	Off Urakawa
15/Jan/1993	42.9	144.4	107	7.8	Earthquake of Kushiro-oki
12/Jul/1993	42.8	139.2	34	7.8	Earthquake of Nansei-oki
4/Oct/1994	43.4	147.7	30	8.1	Earthquake of Hokkaido Touhou-oki

Earthquakes in or around Hokkaido

Since the dawn of history, many large-scale earthquakes have occurred in or around Hokkaido and have caused damage. Among those in the past 100 years, ones of Richter magnitude 7 or more are shown in Table 2-1-1. Considerable damage was caused to civil engineering structures of roads and rivers, houses, lifelines by three earthquakes of magnitude-8 class from 1993 to 1994, although this is thought to be very rare judging from previous earthquake records.

Most of Hokkaido's major, damage-causing earthquakes, such as that which occurred due to diastrophism accompanying the settling of the Pacific Plate in the area of eastern Hokkaido facing the Chishima Trench, have occurred in sea areas and have been accompanied by tsunami damage.

Damage

Here, damage to civil engineering structures caused by the Kushiro-oki, Hokkaido Nansei-oki and Hokkaido Toho-oki earthquakes (Table 2-1-1) is summarized in Table 2-2-1 for each earthquake.

The Kushiro-oki and Hokkaido Toho-oki earthquakes shared points in common partly because major seismic motions occurred in the same area in both earthquakes. In particular, characteristics of damage to road structures: embankment damage occurred in swampy areas of hills and along topographical bounder between hill and swamp; and many large and small bridges or culverts installed in such locations and many of their embankment damaged due to settlements or depressor.

The Kushiro-oki Earthquake caused severe damage to road facilities at 30 sites on 9 routes essential to the social and economic development of Hokkaido. Road sections totaling 3,733 km in length were closed to traffic or reduced to a one-way alternating flow. Because some of these took two months to be fully open for traffic after the earthquake, tremendous inconvenience was suffered by those engaged in the restoration work and those who used these road sections daily.

In taking emergency measures and carrying out restoration work the following problems were focused: 1) the shortage of personnel for emergency inspections, such as patrolling to confirm damage; 2) conflicting information; 3) items and methods of emergency inspections. The necessity of securing tools for rapid, accurate information collection, in order to strengthen the emergency system and preparatory measures and to make up for post-quake shortages of personnel.

Table 2-2-1 List of damage to civil engineering structures

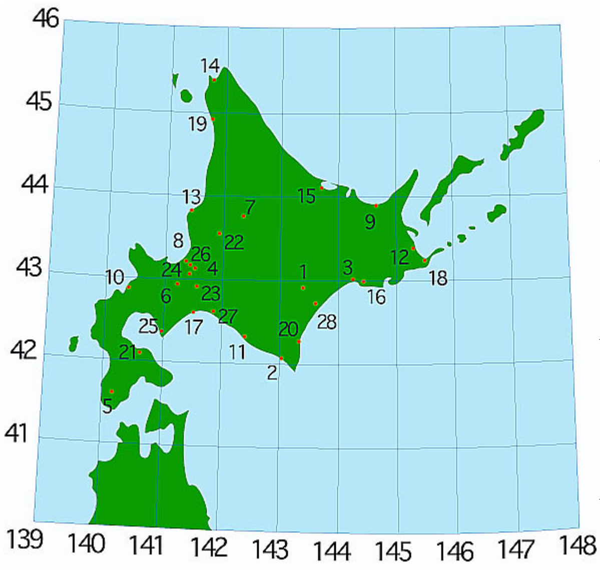
item		Kushiro-oki Earthquake of 1993	Hokkaido Nansei-oki Earthquake of 1993	Hokkaido Toho-oki Earthquake of 1994
Damage of civil engineering structures	River	184places	338 places	110 places
	Road	1591 places	621 places	1762 places
	Bridge	87 places	17 places	31 places
	Port and harbor	4 places	13 places	7 places
	Fishing port	102 places	67 places	28 places
	Others	25 places	122 places	83 places

DEVELOPMENT OF THE SYSTEM

Previous observations

After installing mechanical SMAC-B2s at the ground surface, abutment and pier of the Chiyoda Ohashi Bridge, constructed in Tokachi, Hokkaido in 1966, the Road Division of the Hokkaido Development Bureau installed strong-motion seismographs at the 28 sites by 1993 (Figure 3-1-1).

The measuring instruments installed at those sites were 1) SMAC-B2, -D, -E or -Q, a mechanical system united with a pendulum section and a recording section and 2) AJE, an electric measuring instrument. After an earthquake, we went to the sites of the measuring instruments to take recording paper or recording film. Then the recorded waveforms were scanned to make them digital data (e.g., circular correction). Calibrations such as circular correction were made and data obtained for an analysis. About one month per place was needed for this work. Only data relevant to structural design was collected, analyzed and stored.



Example
1.Chiyoda bridge
2.Horoman bridge
3.Otanoshike bridge
4.Shin-Ishikari bridge
5.Shichiho bridge
6.Muine bridge
7.Asahigawa bridge
8.Ishikari-kako bridge
9.Syari bridge
bridge
10.Isoya bridge
11.Shizunai bridge
12.Betsukai bridge
13.Toukei bridge
bridge
14.Koitoi bridge
15.Shibushi bridge
16.Senmou-kosen bridge
17.Nishikioka bridge
18.On-neto bridge
19.Teshio-kako bridge
20.Hiro bridge
21.Kamitori bridge
22.Sorachi bridge
23.Shimamatsuzawa
24.Sapporo IC bridge
25.Hakucho bridge
26.Sapporo bridge
27.Shin-Hamaatsuma
28.Tokachi-kako bridge

Figure 3-1-1 Arrangement of strong-motion seismographs installed by 1993

Development of sensors

Based on damage conditions described in Section 2, strong-motion records are efficient and effective, not only for securing seismic resistance of structures, such as bridges, but also for predicting damage to and appropriate design of earth works based on their strong-motion records. Regarding this, two issues remain to be resolved.

1) Unlike other structures, such as bridges, earth works are remarkably nonlinear.

2) Features of seismic waves, such as acceleration, velocity, displacement, duration and SI value related to the destruction differ by type of damaged subject.

Given these two issues, installing as many strong-motion seismographs as possible in order to examine phenomena is necessary. Furthermore, these strong-motion seismographs need to be able to collect large amounts of data for investigation of the mechanism of earth works damage.

Based on this conclusion, the Civil Engineering Research Institute proposed seismographs with the specifications described in Table 3-2-1. With the cooperation of an instrument manufacturing company, inexpensive strong-motion seismographs and sensors were developed. Their characteristics are as follows.

1) Acceleration, velocity, displacement, duration and maximum values of strong-motion records can be obtained immediately.

2) Recording conditions of seismographs can be changed at will.

3) Equipped with communication tools.

Table 3-2-1 Specification of sensors

	strong-motion seismograph for bridges	Seismograph of The WISE model
Type	Accelerometer of servo model	Velocity of servo model
Measuring frequency	DC□100Hz	0.018□100Hz
Measuring range	±2,000gal	±200kine, ±2,000gal
Sensitivity	5mA/gal	2V/1kine,10V/200kine,10V/2000gal
Resolution	About 0.01gal	About 300μkine

3-3. Examination of the network

When new seismographs are linked, they can provide emergency disaster information at the time of an earthquake, making it possible to provide appropriate information to road administrators, to expedite initial measures at the time of the earthquake, to prioritize emergency inspection sites, and to reduce secondary disasters.

Such a system could overcome the shortcoming of information in past cases of damage-causing earthquakes.

In developing a network system, determination of a communication tool capable of transferring information reliably and carbon copying transmissions was most important.

Development of this system started in 1996, but multiplex communication lines owned by the Hokkaido Development Bureau had not been digitized by that time. Issues of information reliability, transmission speed, and the state of data communication in Japan made us conclude that INS-P (digital lines) of NTT would be optimum for the improvement of the system's economy and reliability of information, and we constructed a network using the packet telecommunication. The network configuration is in Figure 3-3-1.

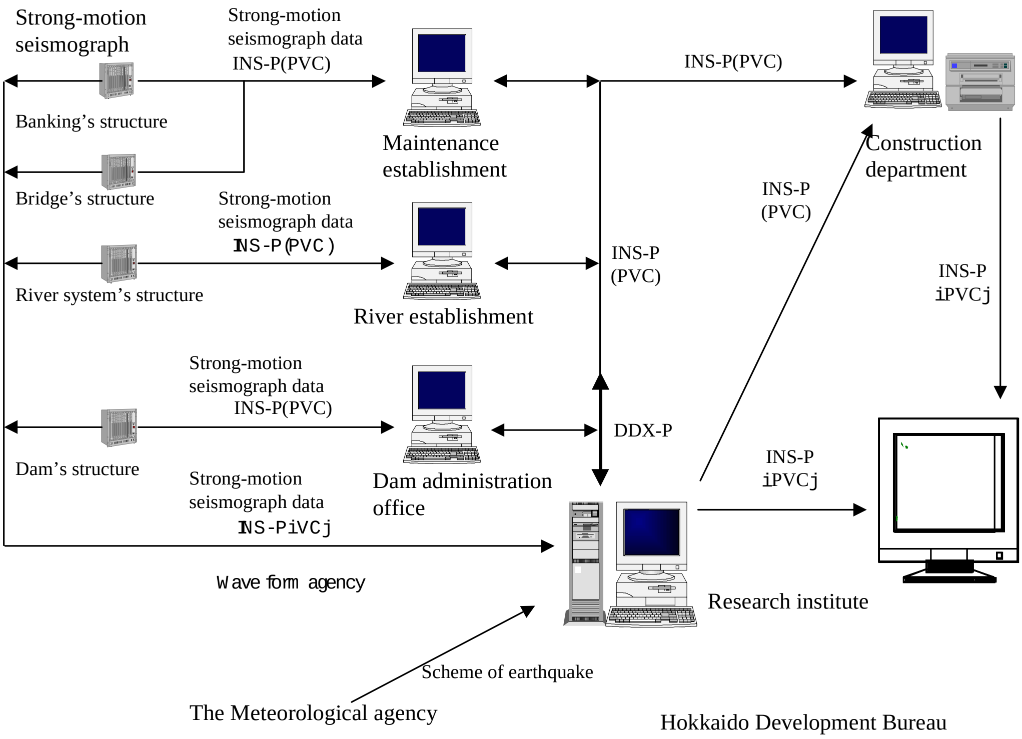


Figure 3-3-1 Configuration of the network

Outline of the system

In this system, strong-motion acceleration seismographs and velocity seismographs are installed at 146 sites in about 50-km mesh in Hokkaido. The seismograph's sensor transmits the maximum values of acceleration, velocity and displacement on each three coordinates when the values are recorded in the system server or a terminal installed at the road and river management office that controls the sensor. Then, information is updated every 30 seconds for about four minutes. After seismic motions abate, the measured seismic intensity and the SI value are transmitted again from the sensor for display on the terminal. Meanwhile, the server calculates the estimated epicenter and magnitude from the transmitted data and earthquake observed areas, and transmits data for display of the estimated damage range on the map on each terminal as the primary damage prediction within about two minutes after seismic motions are sensed. Also, the system takes in information of the hypocenter and magnitude calculated from observation results by the Meteorological Agency via a meteorological satellite called Himawari, re-calculates the estimated damage range, and transmits the information to each terminal as information on secondary damage prediction. Based on statistical analyses of past earthquake damage and seismic motions, this predicted damage range is calculated again from the results of a statistical analysis made using the data collected in the server. The prediction shows the probabilities of damage occurrence (high, medium or low), which are displayed onscreen as a contour map (Figure 3-4-1). This makes it possible to prioritize post-quake inspections and to estimate damage from seismic motions, and it is useful for information collection in an emergency.

Regarding waveform data necessary when compiling earthquake damage and the like, waveforms are automatically taken in after seismic motions abate, and they are entered in the database. At the same time, time history waveforms or a spectrum of these waveforms, as well as an acceleration response spectrum necessary to confirm damping characteristics, are automatically printed out for every operating seismograph. Because records are managed in the database, data from since 1967 can be obtained by search, and they also can be utilized to improve earthquake resistance of civil engineering structures.

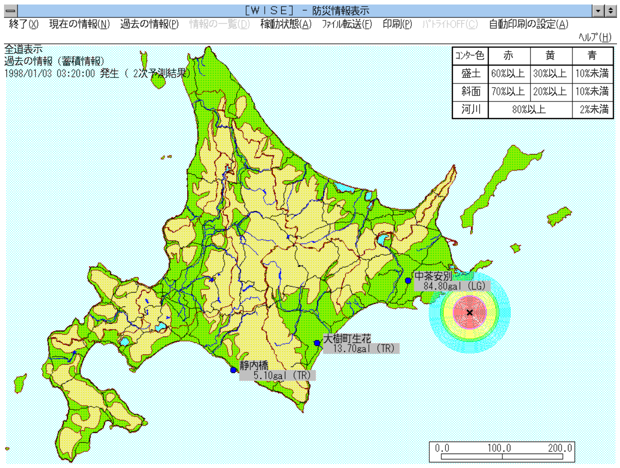


Figure 3-4-1 Display by which the system is operated

EARTHQUAKE DAMAGE AND SEISMIC MOTIONS

Recorded acceleration, velocity, displacement, measured seismic intensity and SI value are sent via terminals to users of the system. However, in some cases administrators are unable to make certain judgements from this information alone. If the relationship between past earthquake damage and seismic motions is clarified and its results are shown as an indicator, the system will be useful in an emergency. Accordingly, in analyzing the relationship between seismic motions and damage to structures, we derived damage function of distance damping of acceleration, velocity and displacement by multiple regression analysis in order to correlate seismic motions with damage. Acting on the assumption that seismic motions are greatly affected by the epicentral distance and that they decrease as the distance increases. Using data of earthquakes that occurred in 1993 or 1994 and for which strong-motion records are relatively plentiful, analysis was made with earthquake magnitude and epicentral distance as parameters.

Relatively high correlation coefficients were obtained from results of the analysis. Table 4-1-1 shows the obtained estimation formulae and correlation coefficients. However, the seismic intensity distribution of earthquakes in or around Hokkaido shown in Figure 4-1-1 indicates it is obvious that influence of seismic

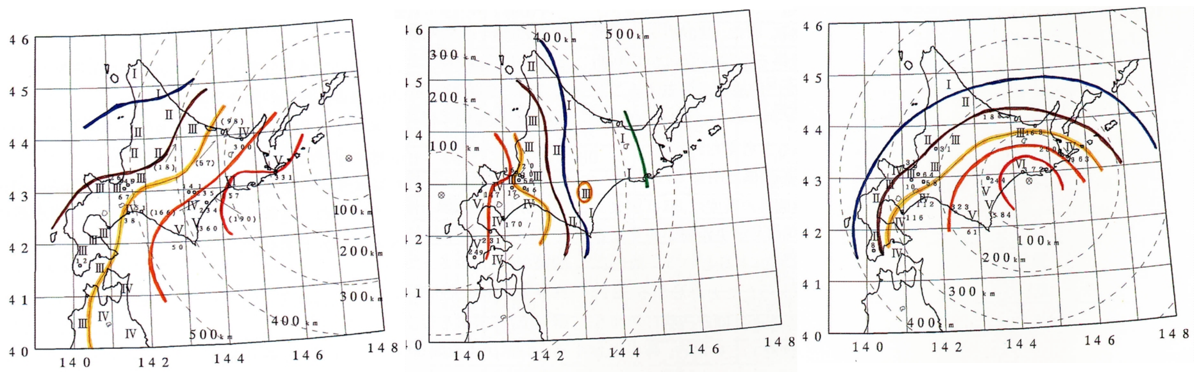


Figure 4-1-1 Seismic intensity distribution of earthquakes in or around Hokkaido

Contour lines of seismic intensity have been drawn by the author’s research section as a matter of convenience. Figures in parentheses are accelerations recorded by JR Hokkaido. The figure shows that seismic intensities of the Kushiro-oki Earthquake and Hokkaido Nansei-oki Earthquake tend to distribute in concentric circular form, with the epicenter as its center. In other words, it can be said that seismic intensities are strongly affected by epicentral distance. However, the Hokkaido Toho-oki Earthquake of 1994 was different, with seismic intensities broadly distributing in a shape going along a certain plane and without having its epicenter as their center. From records on the Sea of Okhotsk and the Sea of Japan sides, which are almost perpendicular to this plane, it is assumed that damping there is larger and seismic intensities are smaller than those distributing on the Pacific Ocean side. Although not shown here, past earthquakes near Toho-oki show similar tendencies and severe tremors were observed also at sites far from the epicenter. For estimation of formulae in the future, analysis should incorporate factors such as these that affect seismic motions. Because the relationship between seismic motion and damage in the present system had to be derived from simple indicators, the damage probability is calculated by this method.

Table 4-1-1 Estimation function of acceleration, velocity and displacement for distance damping

Item	Estimation function	Correlation coefficient
Acceleration	$\alpha=7.505\times10^{0.567M}\times(\Delta+30)^{-1.446}$	0.78
Velocity	$v=0.0191\times10^{0.776M}\times(\Delta+30)^{-1.412}$	0.73
distancement	$d=0.0029\times10^{0.749M}\times(\Delta+30)^{-1.180}$	0.78

earthquakes from 1993 to 1994 whose damage was recorded in detail. However, damage function was obtained by the least square method, and its contains a large error when compared with measured values. Therefore, on the assumption that error follows a normal distribution when compared with damage, we allowed some latitude in estimated values calculated from the epicentral distance. We obtained the following results.

1) Areas where the estimated acceleration was under 60 (gal), saw little damage.

2) Areas where the estimated acceleration exceeded 150 (gal) included most of the damaged sites.

3) Areas where the estimated acceleration was around 150 (gal) included about 60% of all sites of medium damage.

4) Areas where the estimated acceleration was around 300 (gal) included almost all the severely damaged sites.

These results are put into the system, and when an earthquake occurs, areas with a high probability of damage are output in three ranks from the conventional damage function. Then, distance damping formulae are obtained from actual records and damage is estimated again.

PRACTICAL USE oF THE SYSTEM, AND ITS FUTURE DEVELOPMENT

Information is stored from seismographs installed at 146 sites as of April 1999. However, because large-scale earthquakes that cause damage in Hokkaido fortunately have not occurred, damage function has not been verified. Accordingly, it is estimated that, for disaster prevention, the system still has many unrevealed issues. At present, we analyze the correlation between seismic motion and damage by general classification or by topography in order to derive this correlation in greater detail. Based on this information, we are examining how the damage occurrence probability should be incorporated to the system.

Regarding a hardware part, because the development of this system started in 1996 with terminals using Windows 3.1 as the operating system, the display ability is low and the expression of information is limited. We are investigating a future change of the system specification to build a LAN network that would use TCP/IP as a communication protocol on Windows NT and would analyze and express the damage occurrence probability. This would enable the following: shortening of the time needed to send and receive waveform records obtained at observation stations; adding of information displayed on terminals; and sharing of information with researchers via the Internet, as TCP/IP would be used.

CONCLUSION

This system was developed with these primary objectives: to support persons in charge of maintenance and management of structures so that they may quickly take initial action immediately after an earthquake, and to make materials for the restoration of damaged structures. It is necessary in the future to improve the system's stability of operation, the certainty and promptness of information, and the ease of operation.

As a result of our analysis of the relationship between seismic motions and damage, it has gradually become clear statistically that damage occurrence situations are affected by regional conditions after all. Based on these results, we must make more detailed investigation, analyze characteristics of seismic motions according to regional conditions. We need to continue research on the relationship between damage to structures and seismic motions as civil engineers, all with the expectation that the system will be helpful to some extent as a support system during disasters and for improvement of earthquake resistance.

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