IMMEDIATE EARTHQUAKE INFORMATION SYSTEM FOR ASSISTING EMERGENCY RESPONSES

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ABSTRACT

This paper deals with an earthquake information system which has been designed, in full-automatic basis, to assist optimal and immediate initiation of emergency responses by a local government against succeeding and expanding disasters.

Hardware of the system is simply composed of a set of three-component strong motion seismometer, a digital recorder and a PC type computer. The seismometer set is placed on the free ground, and the recorder and computer units are put in an office where emergency operations are to be managed. Software of the system is composed of three major parts of seismic input evaluation, damage estimation and emergency response support. Two kinds of data bases are stored in advance in the system as a major part of the software. One is a knowledge data base of seismic empirical equations, structural vulnerability functions, and disaster prevention strategies, etc. The other is a fact database as an ensemble of natural and social statistics in a given area, and in this reason the system can be materialized area-specifically.

When the seismic sensor detects a significant earthquake, the system starts stepwise processes for various assessments rapidly and automatically. The assessments are performed first for earthquake elements and the severity of seismic input motions in consideration of site soil effects, second for disaster features as damage to dwellings, break and spread of fires, casualties, interruption of lifelines and so forth, and finally for emergency responses as set-up of HQ, search and rescue, fire fighting, water and food provision, etc. The system can finish all of these processes in a few minutes after seismic shaking ends.

The designed system can be a pilot model of risk management facilities in an earthquake, and, with a slight modification in software as area-specific data bases, is applicable to any administrative district in earthquake countries.

1. INTRODUCTION

Earthquake disasters are characterized as time-dependent phenomena, as have been classified into primary, secondary and tertiary ones. In a developed country of which social setting is urbanized and complicated, earthquake disasters are in high danger to expand into succeeding and widely spreading disasters over the primary one of physical damages as sudden collapses of man-made structures and facilities, if no satisfactory countermeasures are initiated timely. Some of earthquake features in developing countries are also time-dependent. Most critical one is the occurrence of fatalities under collapsed houses due to seismic shaking. It is well-known that the number of

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fatalities increase sharply with increasing times after an earthquake and so the time most effective for search and rescue activities is limited as long as 24 hours.

In such situations any of emergency responses should be selected most appropriately and got into practice most timely. The key item that assists better selection of response activities is the area-specific "earthquake information." That is, the effectiveness of the activities following an earthquake depends mostly on if or not the responsible personnel in an areal government can get the information as early as and as precise as possible. This is, however, not an easy matter. The personnel engaged in disaster prevention management can never be experts in seismology and so it is far impossible for them to get any of idea so quickly about the severity of seismic inputs and regarded disasters in a concerned area. Earthquake perception by them is limited at the points where they happen to be, and it makes impossible, in a very moment of earthquake occurrence, to get any image of damaging in the full area concerned. This is clear if one simply assumes an occurrence of an earthquake in the nighttime. In spite of this, they are expected to engage in the response activities optimally and most appropriately. Such an expectation is undoubtedly an over-burden to them. Consequently, one wastes important time shortly after earthquakes, causing the response activities to be delayed and so the damage to become greater.

This demands an urgent and significant revision and development of the existing disaster prevention plans, laying special emphasis on how to acquire "earthquake information" in the scientific basis. The practical means, of making possible of a comprehensive understanding of damage features at or immediately after an earthquake and suggesting optimal selection of emergency responses, is definitely valuable in disaster prevention strategies.

To give a valuable means for the above-mentioned objectives, a system has been proposed and designed. This is an earthquake information system which detects an earthquake occurrence in real time and provides useful pieces of information for area-specific and immediate responses. System itself can be constructed either in a compact one for providing summary information or in an advanced one as powerful for providing minute information. The compact one is a system with a single seismic observation point in a given area and is called a stand-alone type. On the other hand, the advanced one is a system characterized with multiple seismic observation points in the area. In this paper a brief report is given in reference with a pilot model system in Kawasaki city, Kanagawa Prefecture, Japan.

2. FRAMEWORK OF SYSTEM

Fig. 1 shows a block diagram of the immediate earthquake information system. The system is made of hardware and software parts. The major equipment in hardware part is seismic strong motion observation and recorder units to detect a significant earthquake and a computer unit to perform immediate processes and calculations. The software part of the system is, as being considered more decisive and seen in this diagram, composed of three major subsystems. The first one is for the detection of an earthquake event, the evaluation of the severity of seismic input motions at the observation point and in a given area, and is called "seismic input evaluation" subsystem. The data bases concerned are a set of data on natural environments as topography and geology in a given area, and an essemble of seismic empirical equations. The processed data on the seismic severity is sent to the second subsystem. The second one called "damage estimation" subsystem is composed of software modules to estimate various kinds of damages due to the evaluated seismic input, incorporated with stored data bases on the social settings in a given area and on the empirical vulnerability equations. The role of the third subsystem called "response support" is to select better responses based on the estimated damages and in good reference with the existing resources and activity plans. By doing so, the system can take a basic and important role in the optimal initiation of post-event activities in an earthquake emergency. In this point of view, the system can functionally be said a value-added seismic strong motion observation system.

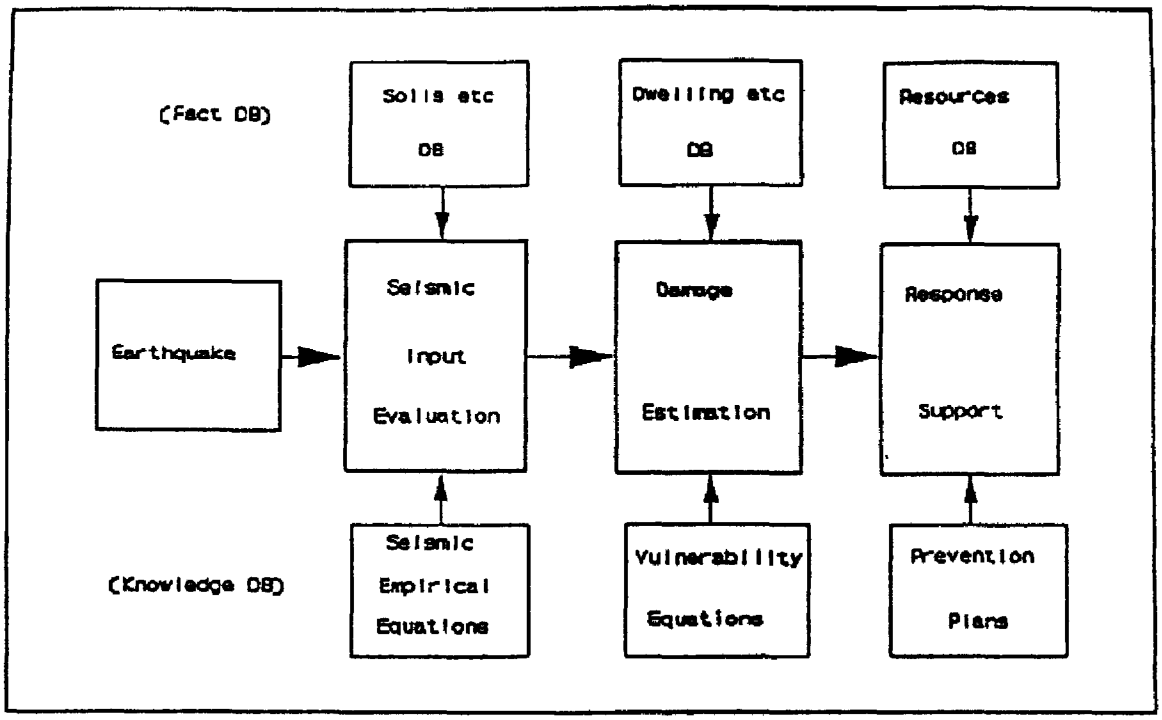

Fig. 1 Framework of system and general flow of processes.

The system can either be a stand-alone (single point) or multi-point (network) observation types, and the system with increasing number of observation points gives a better data set and provides better results. In this sense one can compose a variety of the systems appropriate for the objectives and the demands in the areal disaster prevention management and operation strategies.

3. STAND-ALONE TYPE SYSTEM

A pilot model has been designed in a scope of the above-mentioned framework, to examine the feasibility as a system to detect an earthquake event, to evaluate the severity of seismic input, to estimate probable damages, and to provide the necessary information at decision-making for post-event activities. This pilot model is, based on a single point observation, named a stand-alone type system that provides the information to grasp a wide view of things in an earthquake. The hardware part in a stand-alone system is made as simple as possible. Namely, the major equipment is composed of a three-component strong motion seismometer set of which available range is 0.1-1000 gals, a digital recorder with a 14 bit A/D converter and a PC type computer reinforced against shaking. A clock and an emergency electric power units are also equipped. A total look of the system equipment is shown in Fig. 2.

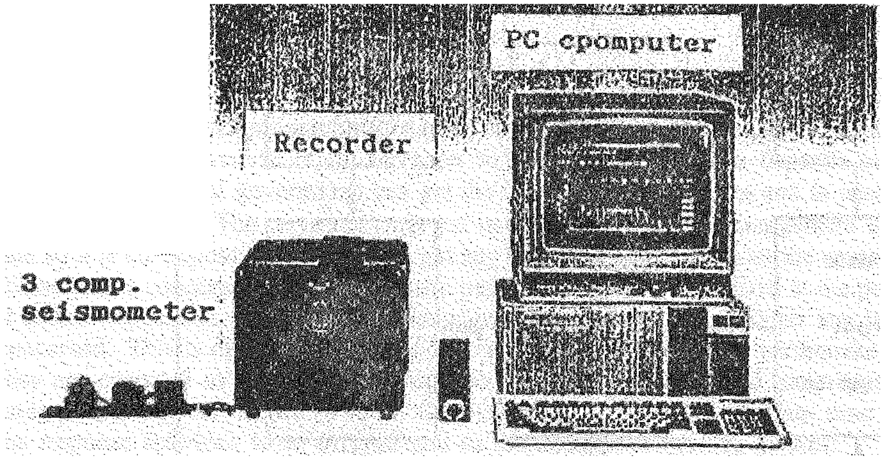

Fig. 2 General view of the stand-alone system.

As mentioned previously, the software system is composed of three major subsystems of seismic input evaluation, damage estimation and response support, with an auxiliary unit of software for displaying processed results. That is, the system has been designed i) to get real time data on seismic strong motions at a given point, ii) to determine the seismic intensity at a point of observation and to deduce spatial distribution of seismic intensities, iii) to estimate probable damages to principal social elements in an area, and iv) to select a better way of the initiation of immediate response activities, based on the estimated damages and on the regarded data. The system can provide such necessary information as quick as 2 minutes after seismic shaking ends, and can present all the outputs in a visual way as on a TV monitor display and in printing forms as well. Fig. 3 is a block diagram of flow of processes in regard with hardware and software parts in the pilot system.

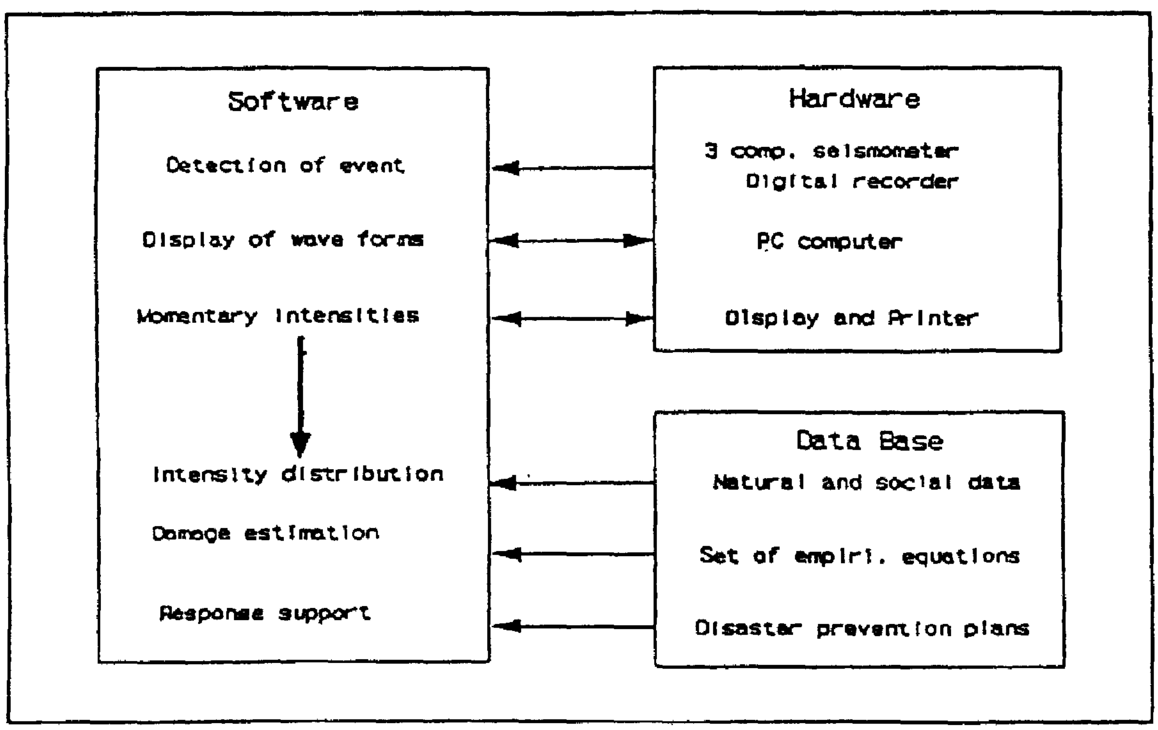

Fig. 3 Diagram of flow of processes in the stand-alone system.

4. ALGORITHM AND DATA PROCESSING

4.1. Seismic Input Evaluation

This subsystem is composed of several numbers of software modules, some of them being outlined in the following.

Detection of earthquake The digitized acceleration data by a 14 bit A/D converter is first converted to get velocity data and the onsets of P and S waves are detected to get an S-P time. The detection of P and S waves are made in a comparison of the averaged amplitude ratio between different time lengths of, say, 0.5 sec and 1.0 sec and at the time when the ratio exceeds a certain level. Epicentral distance, azimuth, depth and magnitude are principal items to evaluate automatically. Epicentral distance is determined by knowing an S-P time. The magnitude is, as usual, calculated as a function of maximum velocity amplitude and epicentral distance. Azimuth is an item derived from a simple calculation of two horizontal components of P first arrival. Focal depth is also calculated in a comparison of vertical and radial components of first-arrived P wave. In case when the transmission path is complicated as in layered soft soil medium, the focal depth is less determinable, and so categoric expressions as shallow, intermediate and deep is introduced instead of numerical one in km.

Determination of Seismic Intensity Evaluation of the seismic severity in terms of intensity in JMA (Japan Meteorological Agency) scale is made in different steps. At every moment when a new digitized data is sent from the sensor unit, the computer calculates an intensity momentarily in use of an empirical equation which is expressed as a function of horizontal velocity amplitude. The derived intensities are displayed time-sequentially in parallel with the original wave forms. On the other hand, an intensity which one may assign the representative one at the observation point is determined directly from the maximum amplitude in the whole record length. As is known well the intensities in an area are different from place to place in regard with soil and other conditions. In the system the soil data classified into three categories of reclaimed, alluvial and dilluvial grounds are stored in advance as a data base of natural environment in a given area, and areal distribution characteristic of intensity is evaluated in consideration of the effect of soils, in terms of derivation from the reference soil on which the observation point locates.

4.2. Damage Evaluation

Damage items to deal with in the system are decided based on the experiences in Japan, and those are damage to dwelling houses, fires, casualties, interruption of lifeline services and so forth. The following outlines processes for each of those items.

Damage to houses Typical structures of dwelling houses in Japan are first of wooden-framed and second of RC types. Vulnerability characteristics for these types of houses are well documented through frequent field surveys in past earthquakes, and, so, incorporated with areal seismic intensity distribution data and with stored area-specific data on building stock, numbers of damaged houses for each of structural types are estimated in different damage categories of collapse, heavy damage, partial damage and so forth.

Earthquake fires Fires accompanied by an earthquake are recognized most serious because of high percentage of wooden houses in Japan. The estimation is made for numbers of fire breaks and of burnt houses by spreading fires separately, based on each of empirical equations in which the numbers of collapsed houses, the average distance between houses, and temporal and seasonal conditions are taken into account as decisive factors. The occurrence date and time are automatically provided by calendar and clock units in the computer.

Human casualties The simplest equation to estimate the numbers of deaths and of serious and light injuries is described as a function of number of [collapsed + burnt] houses. The system adopts a rough estimation in use of such an empirical equation.

Damage to lifelines Covered damage items for lifelines as critical urban facilities are interruptions of electricity, water, gas, roads and telephones, etc. Damages of electricity, water and gas are evaluated by estimating the number of households to which supplies are interrupted. Damage to roads is made in terms of the number of collapsed portions per km by introducing categorized empirical damage functions due to soil types. For telephone lines, two different causes of physical damage and traffic overload are taken into account, in order to estimate short and long term interruptions separately.

4.3. Emergency Response Support

As for emergency responses, six major items of setup of headquarters station, mobilization of personnel, fire fighting, search and rescue, water and food provision are covered in the scope of the system. The immediate support is made in an optimal selection of response items, together with the suggested activity level from a categorized scale of [small, moderate, large, full] levels. The categorization itself is specified based on the existing disaster prevention plan in a given area. To identify the level of response activity, a typical index of damage to dwelling houses is simply employed. The scale can therefore be changed according to the severity of the earthquake and the estimated damages.

4.4. Displaying and Printing Outputs

The monitor TV unit in the system displays processed information time-sequentially in well designed graphics. In parallel with and followed to the data processing and regarded calculations, the system prints out the processed information. The total time required for providing all the outputs on the display and in printed forms is at most 2-3 minutes.

4.5. Education and Training in Ordinary Situation

In ordinary times when no earthquake attacks, the system is on a stand-by state and can take a role as an effective tool for education and training. To keep the system in good condition, the system itself performs a general self-check once a day at a certain pre-decided time as noon. In the unlike event of a system break-down, a warning alarm to let one know what has happened is fitted to the machine. After the self-check finishes, for a certain period of the next hour a small but important "memo" is displayed regarding earthquakes. This small memo changes day by day and a total of 365 has been prepared. By means of these, one can become familiar on a daily basis with earthquake protection problems. If a small part of software module in seismic evaluation subsystem can be somehow modified to feed any of hypothetical earthquakes as an input, the system can be a good simulator to train people engaged in earthquake disaster prevention programs.

5. EXAMPLES OF PROCESSED OUTPUTS

5.1. Model Area

Earthquake disasters are features dependent not only on the severity of seismic input motions but also on the natural and social characteristics of an area where an earthquake attacks. The stand-alone system has been designed to be applicable to any of given area by exchanging a stored set of data bases on natural and social environments, to the one good for an area under consideration. In the following, some examples of processed output information are briefly explained in a case study in Kawasaki city, Japan, as a model area.

Kawasaki city is one of the core cities in Japan having a population over 1 million, and locates next to Tokyo metropolitan city. The total area is about 200 km^2, and it extends 30 km in EW direction with 5-10 km in width. Low land zone of reclaimed and deep soils spreads widely in the eastern part as far as the coastal line and it gets altitude toward west as far as the hilly zone in the city end, changing surface geologies from alluvial, to dilluvial and to tertiary soils. Administratively the city is divided into 7 wards. Population densities range 3,000 to 10,000 persons/km^2 and higher in the eastern part than in the western part.

5.2. Simulated Results in Model Area

Processed and calculated results are in one hand displayed on a TV monitor unit and are printed out in another hand. Followed are some of results produced in printed forms for a simulation test by a stand-alone type system installed at the city hall on the alluvial ground. Seismic input motions were generated by an assumption of a hypothetical earthquake with M=8.0 in a distance of 100 km to down-town Kawasaki. Incidentally, this kind of assumption is based on our anxiety about a reoccurrence of the 1923 Great Kwanto earthquake.

Seismic input evaluation

i) Occurrence time: 11h 07m 13s
ii) Azimuth: N-S direction
iii) Tsunamis: Warning
vi) Intensity at the observation point: VI (JMA scale)
v) Average intensity: VI (JMA scale)

Damage estimation

i) Damage to wooden houses (Total number=170,000)

No damage	66,049 - 91,550 (*)
Partial damage	48,459 - 65,563
Heavy damage	26,642 - 36,046
Collapse	3,349 - 4,531

(*) Ranged numbers are due to probable errors at estimation.

ii) Damage to non-wooden (RC) houses (Total number=80,000)

No damage	44,371 - 56,373
Partial damage	18,416 - 24,916
Heavy damage	5,020 - 6,792
Collapse	191 - 260

iii) Earthquake fires (no. of houses)

Fire breaks	124 - 168	0.001 %
Burnt houses	6,128 - 8,291	0.04 %

iv) Casualties (No. of persons)

Deaths	401 - 545	0.0005 %
Heavy injuries	7,471 - 10,108	0.01 %
Light injuries	41,195 - 55,735	0.05 %

v) Interruption of lifeline supplies (No. of households)

Water	6,114 - 8,313	0.03 %
Electricity	10,492 - 14,196	0.05 %
Gas	3,416 - 4,622	0.02 %

vi) Damage to roads (Collapsed positions/km)

Total area	13
Dilluvial	1
Alluvial	3
Deep all. + reclaimed	9

vii) Interruption of telephone lines

Short term	90.0 %
Long term	27.5 %

Response activity support

Setup of HQ	none	small	moderate	large
Mobilization	none	level 1	level 2	level 3
SAR activity	none	small	moderate	large
Fire fight	none	level 1	level 2	level 3
Evacuation	none	local	areal	whole
Water etc	none	local	areal	whole

Underlined are examples of suggested outputs by the system for optimal response activities.

6. CONCLUDING REMARKS

6.1. Summary

An outline of the immediate earthquake information system is given in this paper in special reference to a stand-alone type. Really, this type of the system has been developed into practical use and, with a simple exchange of software modules regarding fact and knowledge databases, has gradually been popularized in local-to-regional governments in Japan. There is no significant difficulty of introducing the system into any of administrative areas in earthquake countries, if one can arrange a set of area-specific data bases, etc.

6.2. Future Developments

There are not a few ways for developing the proposed system in this paper. First, within the scope of the stand-alone type there is a possibility of extending the objectives, over a local area as in this case study, for which the system can supply the immediate information. Examples are schools, social care facilities as aged people's homes, critical and public facilities as hospitals and city halls, underground streets, railway stations, airports, factories and so forth.

For such enlargement of applications no serious changes are required in the hardware part in the system, although some modifications in the software part, that is, in both of knowledge and fact data bases, are inevitable to fit for a new objective.

Presenting ways of processed outputs are, as far as equipped in the system, in visual forms either as displayed on a TV monitor or printed in papers. There might be additional way, however. It is to introduce an audible method, and it can be more effective because listening is easier than watching in an unusual situation under seismic shaking. This way of version-up in the system is in progress.

Second, there is an essential way of development by which one can acquire more minute and accurate information than that by the stand-alone system. It is to design an advanced system based on multi-point (array) observation stations. A construction of a better system is also ongoing with seven seismic stations at each of ward offices in Kawasaki city. For this, however, both of hardware and software parts in the system should be modified significantly to introduce a center station with a super mini computer (EWS) by which rapid processes of mass data can be made on seismic signals transmitted from each of end stations and on subsequent seismic severity evaluation, damage estimation and response activity supports. The stand-alone type model takes an important role as each of end stations in the advanced system under construction.