DEVELOPMENT OF SUPPORTING SYSTEM FOR QUICK INSPECTION AND RESTORATION OF EARTHQUAKE DAMAGED BUILDINGS

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ABSTRACT:

To restore an earthquake damaged community as early as possible, well-prepared reconstruction strategy is most essential. When an earthquake strikes a community and destructive damage to buildings occurs, immediate damage inspections are needed to identify which buildings are safe and which are not to aftershocks, in order to prevent disaster due to aftershocks. Presented in this paper is strategy of post-earthquake inspection and restoration of damaged buildings in Miyagi prefecture area in Japan.
A multi-layer Web-GIS system are developed by compiling various data about ground motion, damage distribution and so on, in order to fasten post-earthquake activities by local government and structural engineer. Major functions of the developed system are as follows:
1) Compile earthquake observation data from strong motion networks of various organizations in Miyagi prefecture areas through internet.
2) Evaluate distribution of seismic intensity and ground motion in the affected area.
3) Predict damage levels of public buildings and timber houses using database on characteristics of buildings
4) Present earthquake observation data, seismic intensity distribution and predicted damage distribution on Web-GIS.
5) Transmit information to support quick inspection and restoration to local government and structural engineers.
6) Integrate data of damage to buildings from field-survey by the structural engineers through internet and analyze damage statistics and tendency for improvement of scheme of damage inspection and restoration.
Details of damage prediction methodology and calibration of predicted building damage with those observed in recent major earthquakes in Japan, such as 2003 Miyagi-ken-hokubu, 2007 Notohanto, and 2007 Niigata-Chuetsu-oki Earthquakes, are also described.

KEYWORDS: Damage prediction, Quick inspection, Web-GIS, RC building, Timber houses,

1. INTRUDUCTION

To restore an earthquake damaged community as early as possible, well-prepared reconstruction strategy is most essential. When an earthquake strikes a community and destructive damage to buildings occurs, immediate damage inspections are needed to identify which buildings are safe and which are not to aftershocks, in order to prevent disaster due to aftershocks. Presented in this paper is strategy of post-earthquake inspection and restoration of damaged buildings in Miyagi prefecture area in Japan (Motosaka et al. 2006).
Figure 1 shows process of quick inspection for damaged timber houses damaged by the 2003 Miyagi-ken-hokubu Earthquake and activity of aftershocks (Higuchi 2004). From the figure, number of aftershock rapidly decreases day by day, on the other hand, it took a few days to start full-scale quick inspection from point of number of inspected houses. One of the reasons for the delay of quick inspection is un-prepared scheme of execution and transmission of various information among stake-holders.
The authors developed a supporting system for quick inspection and restoration of earthquake damaged buildings as shown in Figure 2. A multi-layer Web-GIS system are developed by compiling various data about ground motion, damage distribution and so on, in order to hasten post-earthquake activities by local government and structural engineer.

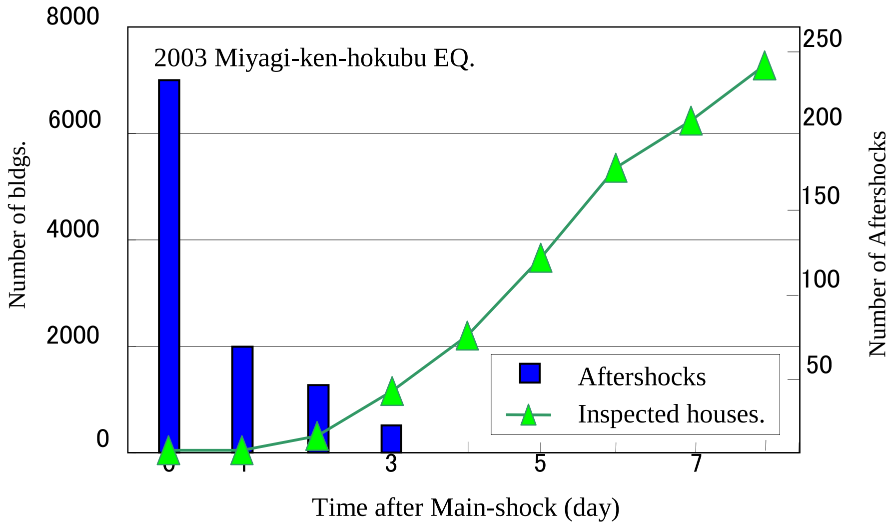


Figure 1 Process of quick inspection and activity of aftershocks

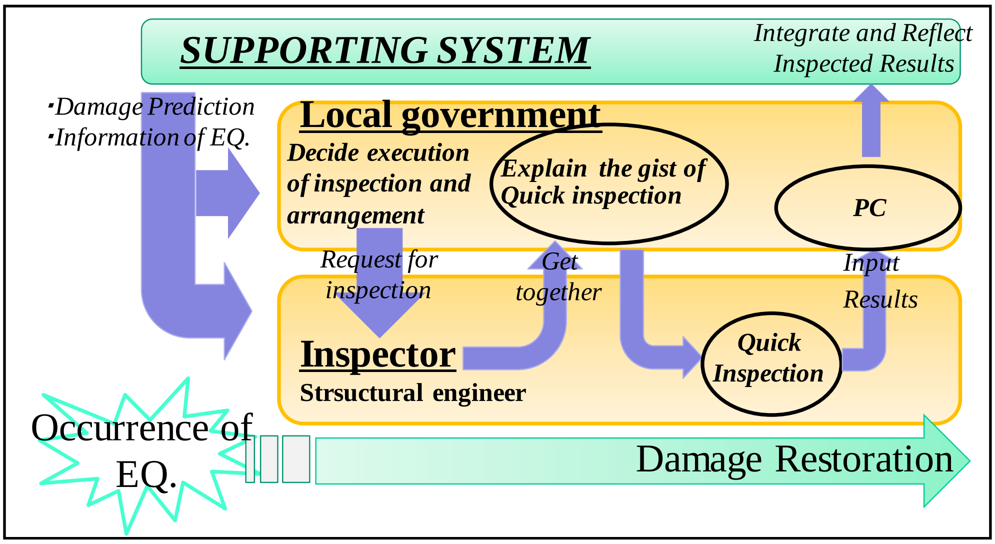


Figure 2 General concept of supporting system

2. BASIC FUNCTION OF QUICK INSPECTION SUPPORTING SYSTEM

Figure 3 shows a flow of operation of the system. Following functions are provided in the system;
(1) Database for information on buildings and inspectors
Database of buildings contains following items;

a) Information necessary to identify a building such as those name and address (latitude and longitude),
b) Structural characteristics necessary for damage prediction such as structural type, construction age, seismic capacity *Is*-index, etc,
c) Usage and importance of buildings.

Database of inspectors contains name of a inspector, his contact address, license and speciality.
Miyagi prefecture was divided into 500m square mesh and its soil type, number of timber houses in each mesh are recorded in area database.
(2) Integration and analysis of earthquake information
The system derives, just after the earthquake, information on location of epicentre, magnitude, seismic intensity at observatory station located in Miyagi pref. Acceleration records at JMA (Japan Meteorological Agency) and K-NET (Kyoshin Network, NIED/National Research Institute for Earth Science and Disaster Prevention)

stations are automatically downloaded from web-sites as early as possible. Seismic intensity and response spectrum at meshes without observatory station are estimated using integrated data.

(3) Prediction of building damage

Two procedures for damage prediction are provided in the system. Quick prediction is carried out just after the earthquake using estimated seismic intensity distribution in the affected area. After detailed information on ground shaking such as ground acceleration records, damage is predicted by seismic response analysis.

Damage to public buildings is estimated one by one using structural characteristics recorded in the database. Whereas, damage to timber houses is estimated as a damage ratio for each 500m mesh.

(4) Transmission of information on quick inspection to inspectors

Information on distribution of seismic intensity and damage is transmitted to local government and inspectors through e-mail and web site.

(5) Integration of inspected damage data and open to web site

Inspected and/or surveyed results are integrated through internet and displayed on Web-GIS system.

(6) Calibration and re-prediction of damage distribution

Integrated observed damage data are compared with predicted damage levels in order to calibrate and modify damage prediction method. Damage distribution is re-predicted based on modified method and updated information on ground motion.

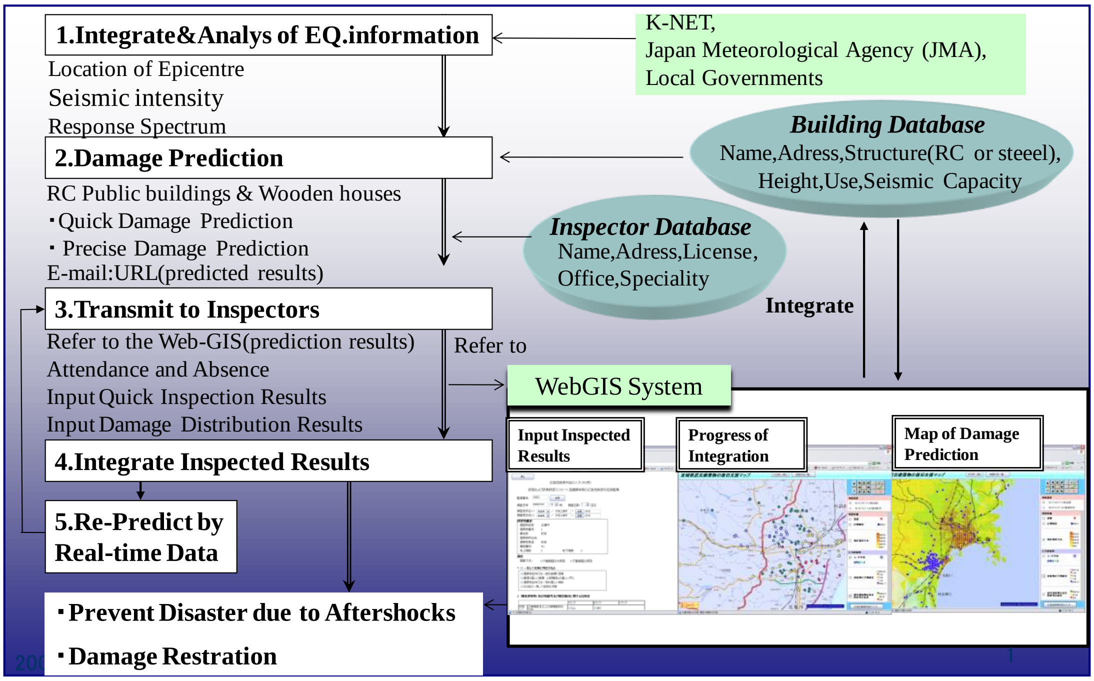


Figure 3 Flow of operation of the supporting system

3. PROCEDURE FOR DAMAGE PREDICTION

Damage prediction consists of two levels of procedures in this system depending on available information.

3.1 Quick damage prediction based on fragility function

Main purpose of “Quick damage prediction” is to grasp even rough but general damage distribution as early as possible. In this stage, priority is put on to grasp if there is damage to buildings or not and to identify more severely damaged area. This information is given to local government which manage quick inspection and will support them to judge execution of quick inspection and arrange staff and so on.

Seismic intensity distribution is employed in the quick damage prediction. Seismic intensity at a mesh without observation is linearly-interpolated from intensities at surrounding stations as shown in Figure 4.

(1) RC public buildings
Damage probability function shown in Figure 5 (Maeda and Shijima 2005) was employed for damage prediction for RC public buildings. Horizontal axis is representative ground acceleration A which can be converted to JMA seismic intensity I by Eq.(1).

$$I = 2\log A + 0.94 \qquad (1)$$

Where, A: acceleration value, of which exceeding time is equal to 0.3 sec during an earthquake. Note that acceleration used for this calculation is a vector of two horizontal and vertical components of filtered observed ground acceleration, during the record.

If Is value of a building and ground acceleration A at the site are given, damage probability can be obtained from Figure 5.

(2) Timber houses
Fragility curve, shown in Figure 6, is applied for damage estimation of timber houses. Houses are classified into 3 categories by construction age. Then damage ratio is evaluated for the 3 categories at each 500m mesh from estimated seismic intensity I. Total number of collapsed houses can be calculated from the damage ratio and number of timber houses in a mesh given by the database.

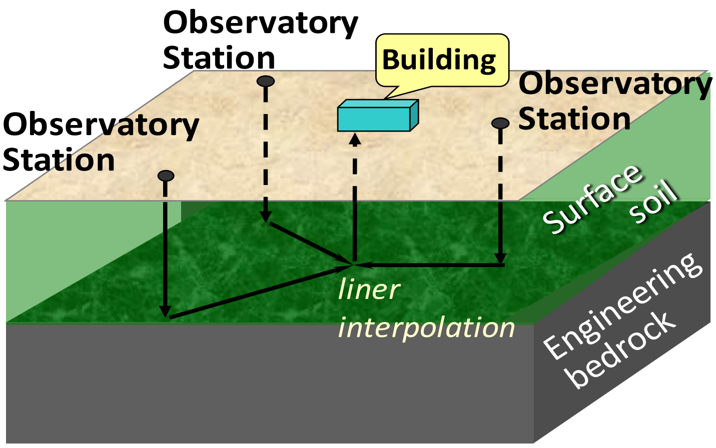


Figure 4 Concept of interpolation of seismic intensity

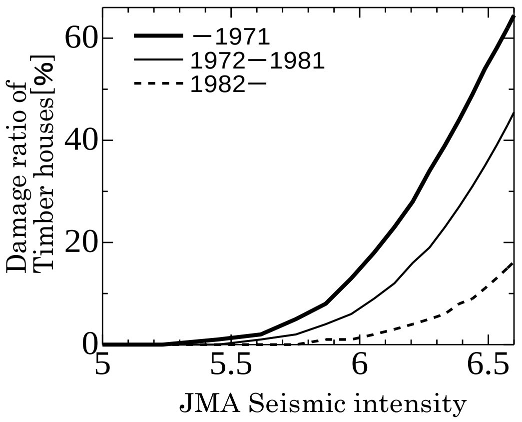


Figure 6

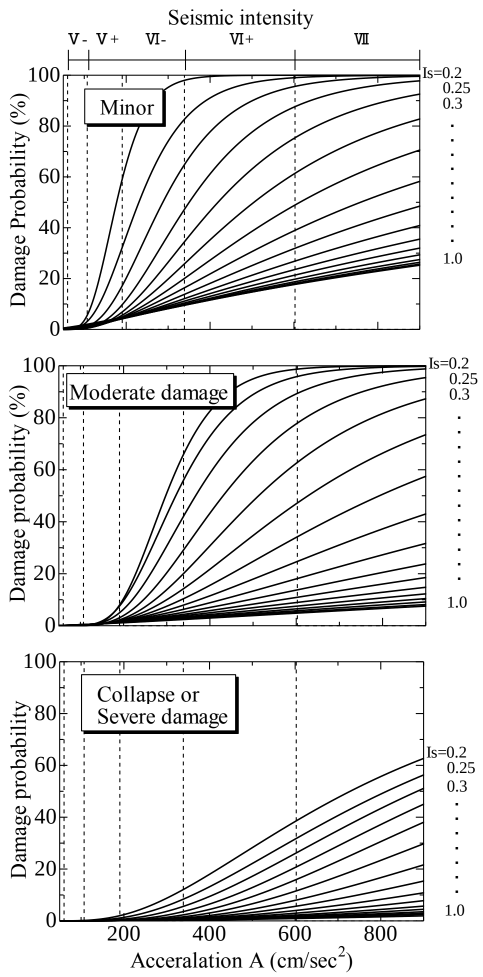


Figure 5 Fragility curve

3.2 Precise damage prediction based on equivalent linear seismic response analysis

Acceleration records might be integrated within several hours or one day after the occurrence of earthquake. The damage distribution is re-evaluated based on an equivalent linear seismic response analysis approach.

Seismic response spectrum is used in this approach. More precise damage prediction might be expected because differences in characteristics of vibration period in ground motion and structural system of a building are taken into calculation.
Damage prediction method for RC public buildings is as follows;
(1) Seismic response spectrum at a 500m mesh is estimated by linearly-interpolation of spectrum at surrounding observatory station in the same way with method used in seismic intensity (Sugawara et al. 2008).
(2) Buildings are classified into ductile structure and brittle structure depending on seismic capacity *Is*-value (JBPDA 2001a) and base shear coefficient $C_T S_D$-value. Base shear – lateral displacement relations are idealized as shown in Figure 7 for the two types of structures. Base shear at yielding was set $C_T S_D/0.8$ assuming mass of an equivalent single- degree-of-freedom system of a building is 80% of total mass. Drift angle at yielding was set 1/250 rad. and ultimate state was assumed 1/150 rad. for brittle structures and $\mu/250$ (μ: ductility factor) for ductile structures. Ductility factor μ is calculated from ductility Index $F = Is/ C_T S_D$.

$$F = \frac{\sqrt{2\mu - 1}}{0.75(1 + 0.05\mu)}$$

(3) Relationship of damage level of a building with drift angle was defined as shown in Figure 7 referring to Japanese “Standard for Damage Level Classification” (JBPDA 2000b). Drift angle was converted to lateral displacement by assuming the height of a building is 3.6m X number of stories.
(4) Maximum displacement response and damage level can be obtained by an equivalent linear response analysis using acceleration *Sa* - displacement *Sd* spectrum and base shear - lateral displacement relation obtained above.

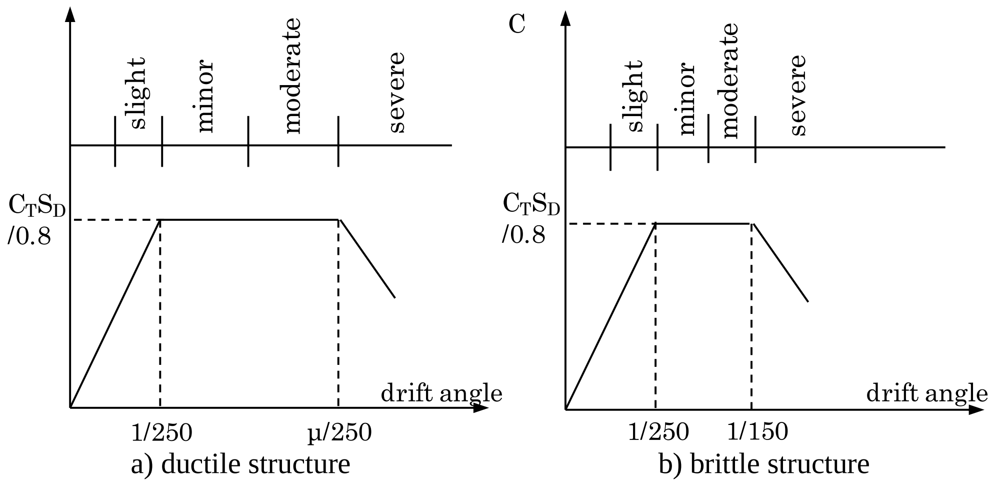


Figure 7 Base shear – lateral displacement relations and damage levels

4. COMPARISON OF PREDICTED AND OBSERVED DAMAGE DISRIBUTION

Damage prediction, by the developed system explained above, for buildings suffered recent severe earthquakes in Japan was presented in this chapter. Predicted damage distribution is compared with observed damage and accuracy of prediction is discussed.

4.1 Quick prediction

Distributions of seismic intensity for recent major earthquakes such as, the 2003 Miyagi-ken-hokubu, 2007 Notohantoh and 2007 Niigata-chuetsu-oki Earthquake were simulated based on the developed system as shown in Figure 8. Damage prediction for both RC public buildings and timber houses was carried out using distribution for the 2003 Miyagi-ken-hokubu Earthquake. On the other hand, only timber houses are predicted for the 2007 Notohantoh and the 2007 Niigata-chuetsu-oki Earthquakes because public building database is not provided for the area affected by the two earthquakes.
Table 1 shows predicted and observed damage levels (Sugawara 2008) of RC public buildings in Miyagi prefecture. Predicted results for RC buildings also generally agree with observed damage levels with some exceptions. For example, building of Kitamura Primary School was provided with relatively higher *Is*-value, but

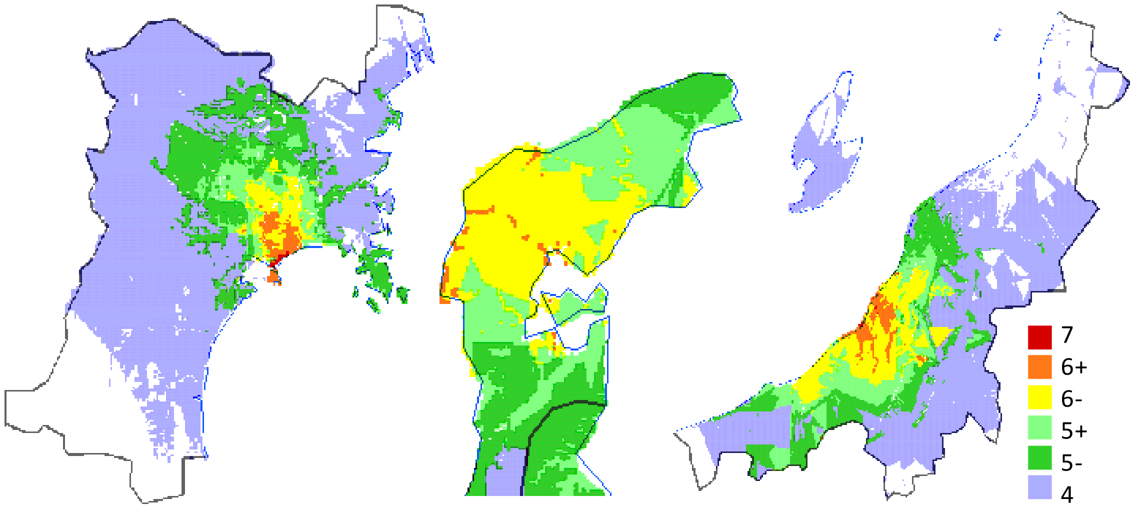
suffered severe damage.

Estimated distributions of seismic intensities are generally agree with tendency of obsereved damage distributions, although for the 2007 Niigata-chuetsu-oki Earthquake prediction tends to give higher seismic intensity even for no-damaged area. Figure 9 shows relationship between JMA seismic intensity and observed damage ratio of timber houses derived from authors' field survey (AIJ 2004, Igarashi 2007, Matsukawa 2007) with fragility curve employed in the damage prediction. Comparison of predicted damage ratio with surveyed damage ratio for the three earthquakes is shown in Figure 10.

From figures 9 and 10, predicted damage agreed well with surveyed damage ratio in the area affected by the 2003 Miyagi-ken-hokubu and the 2007 Notohantoh Earthquakes. On the other hand, damage prediction gives larger damage ratio than observed. One of the reasons for the disagreement might be that characteristics of vibration period of ground motion, in other words effect of shape of response spectrum, is not taken into consideration in the quick prediction. However, in practical point of view, quick prediction generally gives upper bound of damage ratio for the three earthquakes so that quick prediction is one of effective tools for decision making of the quick inspection activities.

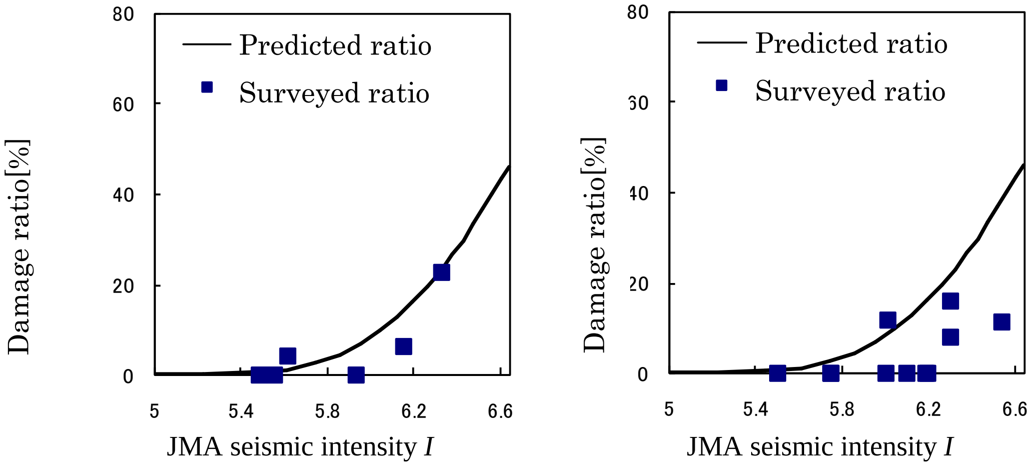
Table 1 predicted and observed damage level of RC public buildings

Name of buildings	Quick prediction	Precise prediction	Observed damage
Yamoto H. S.	moderate	severe	moderate
Ohmagari P. S.	minor	severe	Slight
Ono P. S.	minor	no damage	minor
Yamoto Dai-ichi Jr. H. S.	minor	Moderate	minor
Kashimadai P. S. East Bldg.	minor	minor	minor
Hamaichi P. S. No1 Bldg.	minor	no damage	slight
Miyato P. S.	minor	no damage	slight
Kitamura P. S.	slight	minor	severe
Hamaichi P. S. No2 Bldg	slight	no damage	slight
Ohshio P. S.	slight	slight	slight
Yamoto Hagashi P. S.	slight	slight	slight
Kasimadai P. S. West Bldg.	slight	minor	minor
Akai P. S.	slight	slight	slight
Akai Minami P. S.	slight	minor	slight
Yamoto Dai-ni Jr. H. S.	slight	no damage	no damage
Naruse Dai-ichi Jr. H. S.	slight	minor	no damage
Wakuya Jr. H. S.	slight	moderate	slight
others	No damage	No or slight damage	No damage



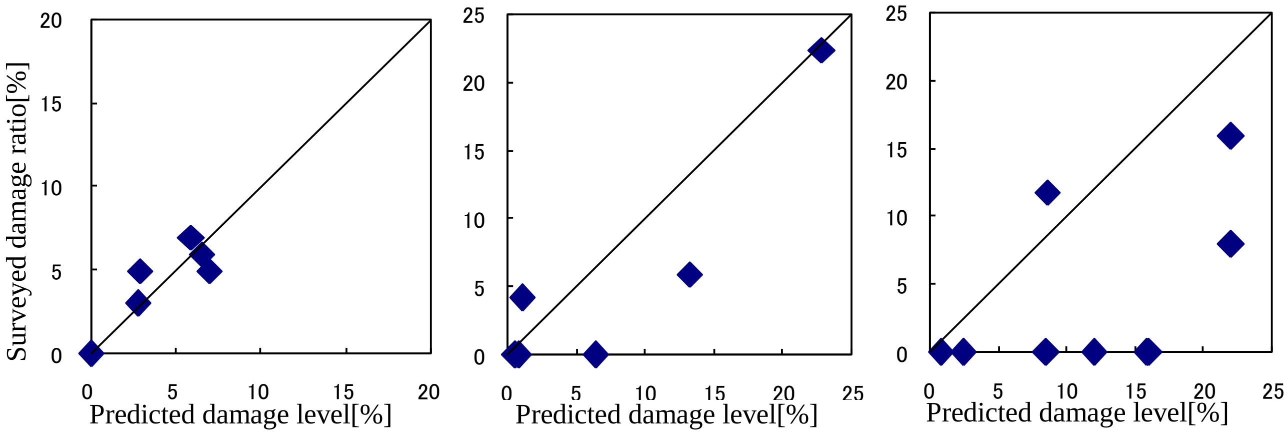
a) 2003 Miyagi-ken hokubu EQ. b) 2007 Notohantoh EQ. c) 2007 Niigata-chuetsu-oki EQ.

Figure 8 Seismic intensity distribution estimated by the system



a) 2007 Notohantoh EQ b) 2007 Niigata-chuetsu-oki EQ

Figure 9 JMA seismic intensity – damage ratio of timber houses



a) 2007 Miyagi-ken-hokubu EQ b) 2007 Notohantoh EQ c) 2007 Niigata-chuetsu-oki EQ

Figure 10 Comparison of observed damage ratio with predicted (quick prediction)

4.2 Precise prediction

Precise damage prediction was carried out for about 500 RC public buildings in Miyagi prefecture suffered from the 2003 Miyagi-ken-hokubu Earthquake. Comparison of predicted and surveyed damage levels is shown in Figure 11. Damage level *R* ,in the figure, represents residual seismic capacity ratio defined in Japanese “Standard for Damage Level Classification” (JBDPA 2001b). R=100 and R=0 correspond to “No damage” and “total collapse”, respectively.

Form the figure, quick prediction shows good agreement between predicted and surveyed damage level with one exception, whereas precise prediction tends to overestimate surveyed damage levels. Correlation coefficients of quick and precise prediction are 0.48 and 0.41, respectively. Reasons of worse agreement in precise prediction might be as follows:

The 2003 Miyagi-ken-hokubu Earthquake was inner plate type and epicenter was located in center of affected area. Most of damaged buildings concentrated in the 20-30km square area near the epicenter. On the other hand, available data on ground motion, especially acceleration records, in and around severely damaged area was quite limited, although density of seismic observatory network has been progressively increased after the 1995 Kobe Earthquake in Japan, observatory station. Therefore, response spectrum near the epicenter and in severely affected area is seemed to be underestimated.

Although damage prediction procedure has a problem, as mentioned here, in estimation of ground motion near epicenter for inner-land earthquakes, the proposed system is an effective and useful tool for ocean type earthquakes such as approaching Miyagi-ken-oki earthquake.

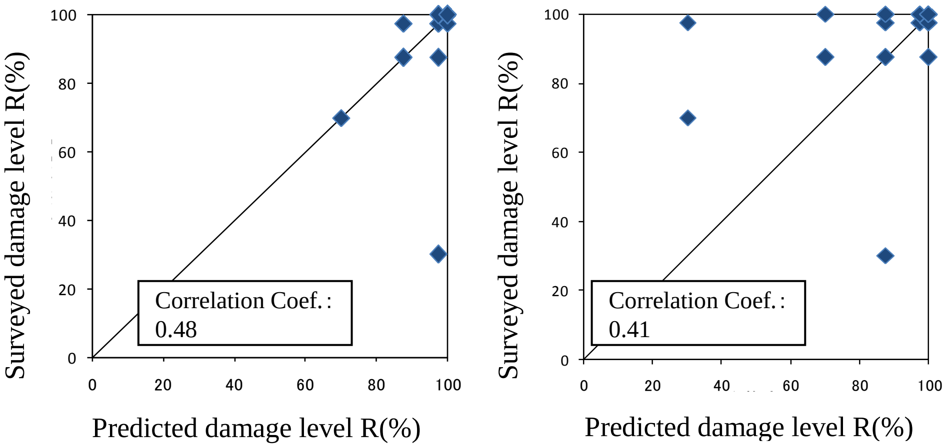


Figure 11 Comparison of observed damage ratio with predicted for RC buildings

5. CONCLUDING REMARKS

In this paper, a basic concept and general function of a developing supporting system for quick inspection and restoration of earthquake damaged buildings in Miyagi prefecture, Japan, was introduced. Details of damage prediction methodology and calibration of damage prediction for recent major earthquakes in Japan are described.

It is presented that damage prediction proposed herein gives generally good agreement with observed building damage distribution and, therefore, proposed system might be an effective and useful tool to improve various activities, such as quick inspection, after damaging earthquakes.

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