Journal of Japan Association for Earthquake Engineering, Vol. 9, No. 3, 2009

FORWARD SPECTRAL FORECASTING OF GROUND MOTION WITH THE INFORMATION OF EARTHQUAKE EARLY WARNING SYSTEMS FOR STRUCTURAL CONTROL

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ABSTRACT: There has been steady progress in research and development of earthquake early warning systems and its application to structural control. In this paper our proposed methodology about forecasting frequency contents of strong motion is first introduced, then its application to feed forward structural control with the usage of semi active control devices is simulated, and lastly it is showed that non-resonance structural control can be achieved before the strong motion of an upcoming earthquake reaches to a building of interest.

Key Words: Earthquake early warning systems, structural control, artificial neural networks, active variable systems, Miyagi-ken offshore earthquakes

INTRODUCTION

Several methods and developments in earthquake early warning systems in active seismic zones such as Japan have been proposed recently. Most of them are related to backcasting, which investigates methods for calculating source parameters of earthquakes. On the other hand, the issue of forward prediction which forecasts the amplitude of ground motion, in far site has not been discussed adequately from the engineering point of view (Fig. 1). The usage of the newest technology and its engineering applications need urgent investigations. Next generation Earthquake Early Warning Systems (EEWS) will provide information to control structures equipped with active/semi-active devices or critical systems to protect them from the destructivity of earthquake ground motion.

In order to mitigate the earthquake hazard, apart from warning society and taking the proper actions for damage reduction such as automatic shutdown systems of gas lines, slowdown of bullet trains etc, the attention focuses on the transmission of the necessary information to special or critical buildings, and the usage of the active or semi-active control devices in intelligent structures before the destructive energy of an earthquake reaches. Before transmitting the required information, there are some questions needed to be answered from the structural point of view, such as; what kind of parameters or functions and how these Earthquake Early Warning (EEW) information can be applied to the structures and, above all, much critically, how or which methods should be used to find the desired functions in real-time.

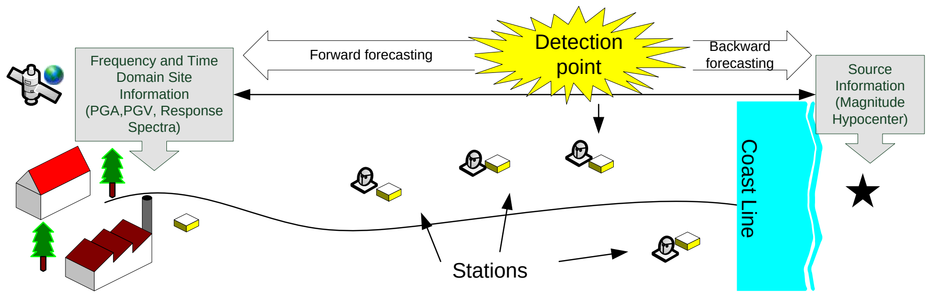

Fig. 1 Illustration of backcasting and forecasting

The perception of forward forecasting encompasses time domain such as Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), duration etc. and spectral (Fourier spectra and response spectra) quantities. Except Fourier Amplitude Spectra (FAS), other single parameter forecasting or response spectra are insufficient functions for implementation to real-time seismic control of structures at this moment. Moreover, FAS is a critical tool to describe ground motions during wave propagation and to control the structures for EEWS applications. It is widely used in seismological studies such as estimating seismic hazard and ground motion prediction (Sokolov et. al. 2000) and engineering studies (Akkar and Bommer 2007). Several researchers tried to predict FAS (Sokolov et. al. 2000, Trifunac and Lee 1989) using source information of earthquakes with multi-regression analysis without any consideration of the EEWSs. It is basically suggested that FAS of strong motion accelerations can be scaled in terms of earthquake source parameters, and geological site conditions without any consideration of waveform information. Several regression models have been developed considering different parameters in frequency domain (Trifunac and Lee 1989). Bose also tried to predict FAS based on the Early Warning Information (EWI) using artificial neural networks (Böse 2006).

With the present advances in the EEWS technology it is inevitable to integrate sophisticated EEWS and control devices for real time structural control. In this stage, a frequency dependent structural control device like active variable stiffness (AVS) is a good candidate for this purpose. They can actively control structural stiffness of a building to seek a non-resonant state against earthquake excitation. Although a non-resonance control systems has been proposed early 1990s (Kobori et al. 1993); unfortunately they were not designed for EEW applications and unable to use EEW information. However then, the usage of AVS system was investigated (Pnevmatikos et al. 2004) for a given frequency content of upcoming ground motion to eliminate resonance/near-resonance phenomena in structures considering EEW applications. It is numerically proven that control can be achieved in cases when the FAS are assumed to be known. However, question is not yet answered on how the FAS could be estimated. Up until now all the methods and attempts to forecast FAS as well as response spectra were very rough (or much smoothed) and far from distinguishing the fundamental frequency.

Generally the estimations of the parameters of ground motions are done either by empirical relations that link these to source parameters, path effect, and soil conditions (so called attenuation relations or source scaling) or mathematical modeling for single (PGA), or certain frequency quantities. However, attenuation relationships refer to the only certain site conditions and all have a constant standard (deviation) error of the logs with respect to magnitude and distance. Recently artificial neural network methodology is used different from attenuation relationships in order to calculate the smoothened FAS (in range 0.25 to 11.25 Hz) using source parameters and cumulative absolute velocity (Bose et al. 2006). Indeed, this was a superior idea because advantages of the Artificial Neural Network (ANN) usage are very helpful in all respects including dealing with missed data, false alarm etc. (Kuyuk and Motosaka 2008). Unfortunately, so far the studies of the FAS forecasting have not yet taken into account the frequency content of initial ground motion and frequency dependent soil amplification factors at the sites of interest. Therefore, there is an emerging need for a reliable method that is fast enough considering real time applications and takes into account source parameters together with the above specifications to forecast spectral functions for advanced civil engineering.

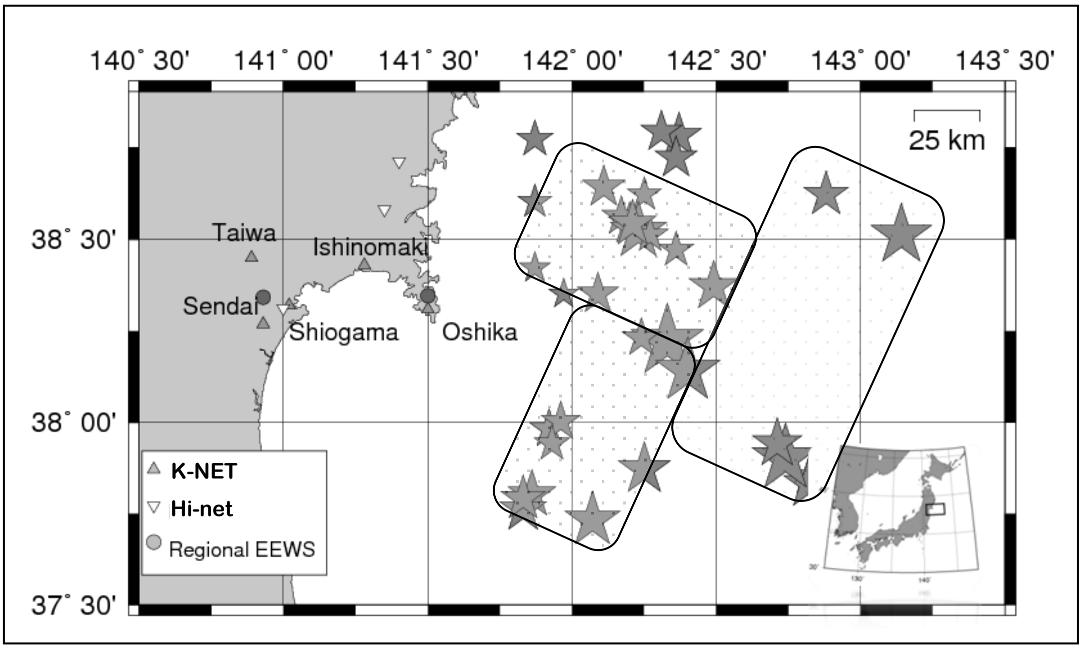

Fig. 2 Location of Miyagi prefecture and EEWS configuration

At the present no EEWS is providing initial ground motion for engineering purposes, even the most advanced system in Japan. Provided information is limited to Japan Meteorological Agency (JMA) intensity, time of upcoming S-wave, and source parameters which are not adequate to mitigate the earthquake hazard and, especially, to control building response. The authors are using this system since 2006 and they have developed an independent regional warning system in Sendai, Miyagi prefecture, where one of the most seismically active zones is located (Miyagi subduction zone) in Japan, to increase reliability and supplement the national EEW configuration. The system has multi purposes such as structure health monitoring, real time application for structures and furthermore provides waveform to clients (Motosaka et al 2008). It is the fastest EEWS that can serve waveform with variable packets (set for this application as 0.2 sec packet) to client with transmission speed less than 0.2 sec for each packet. Two separate systems are integrated to be mutually beneficial for the advanced engineering application purposes. The configuration of the overall system is shown in Fig. 2, circle symbols represent the regional configuration, triangles are the Kyoshin network (K-NET) along the main towns in the area and reversed white triangles are the High network (Hi-net) data (national EEWS).

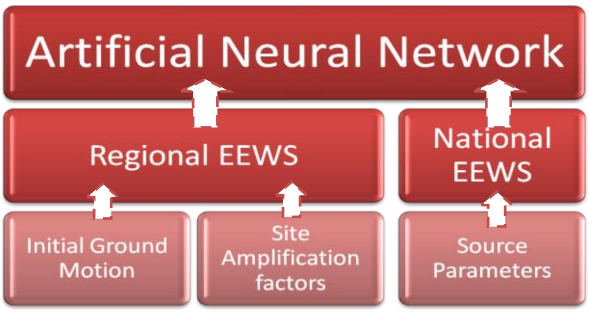

Fig. 3 Illustration of the methodology

With consideration of the above, our previously developed methodology to forecast Fourier amplitude spectra is first described and furthermore the utilization of the feed forward approach in structural control is simulated for the August, 2005 Miyagi-ken Oki earthquake. Source parameters of an earthquake, initial ground motion in the near field and the site amplification in frequency domain which are provided by two separate EEWS, are used with artificial neural network (Fig. 3).

METHODOLOGY

Artificial Neural Network

ANN is a computational tool, which challenge to simulate the architecture and internal operational characteristics of the human nervous system. It has been used to model or solve nonlinear complex engineering problems. However, it is not widely used in seismology. And especially earthquake engineering applications for EEWS are quite new. The great characteristic of the ANN is the ability to learn from experience and examples as well as the adaptability with the varying environments.

One of the general definitions of ANN is: a computational process which represents and evaluates mapping from one space to another by a set of data that represents mapping (Garret 1994) which is actually employed from Oshika to other sites in this particular study. Namely, ANN methodology is trying to find relations that maps from a set of given patterns (input data) to an associated set of known values (target output data). This is done by a number of simple, highly interconnected processing elements by adjusting weights of these neurons and optimizing errors between estimated outputs and target outputs. Satisfactorily trained and tested network is able to generalize rules and respond unknown situations to forecast required result.

Artificial Neural Networks based methodology is used to combine all information considering past earthquakes occurred in Miyagi-ken Oki. Common feed-forward network architecture is used and three hidden layer networks are challenged to get the best results. Statistical verification is used to determine optimum design of ANN. We carry out simultaneous analysis for all 156 records of FAS at 40 selected set of discrete frequencies for the interval from 0.1 to 10 Hz which is adequate for engineering applications. Among the 639 trials of different architecture of ANN three-hidden layer is selected depending on the test results. For each frequency of 39 earthquakes 40 different ANN structures are used for each frequency value including all of the 156 datasets. It took several weeks to conduct such a huge training on the supercomputer of Tohoku University. Weights are initiated randomly and adjusted in learning process. As an activation function, a common type sigmoid transfer $S(\vec{x})$ function in the hidden neurons is used;

$$S(\vec{x}) = 1 / (1 + e^{(-z_i)}) \tag{1}$$

where

$$z_i = \sum_{j=1}^{n} w_{ij} * x_j \tag{2}$$

x_j is the action of the j input neuron and $S(\vec{x})$ is the action of the i^{th} hidden layer neuron. Training is successfully accomplished after about 6000 epochs. The procedure implemented for ANN here is done in the following 8 steps.

Step 1: Nuumbers of the input neurons that have influence on the particular problem and output neurons are determined. For this case the followings are used as input parameters: a) source parameters (magnitude, epicenteral distance, depth and azimuth), b) amplitude and frequency of the initial simplified waveforms, c) site amplification for the particular frequency; and as output- frequency amplitude for corresponding frequency.

Step 2: Input variables of the training and testing are calculated.

Step 3: Input data is normalized.

Step 4: Network is designed with three-hidden layer. For each layer, the configuration of 20-15, 15-10, 10-5 neurons are tested.

Step 5: The specification of training algorithm is decided (sigmoid function, training rate, maximum error, number of maximum iteration, etc).

Step 6: The training is initiated with described topology.

Step 7: The outputs are unnormalized and network is tested with unseen test data.

Step 8: The decision algorithm is executed according to test results using statistical methods. In order to find out optimized design, average and standard deviations of results in each test data variables are searched. Once the optimum architecture is determined then in the real implementation when the inputs (mentioned in step one) are fed to ANN, results are calculated in negligible time (a few milliseconds).

Database

Several studies on parameter prediction are based on simulated ground motion time series (Bose 2006, Yamada 2007) in the field of EEW. The comparisons between the simulated and observational data are always biased and waveform simulations can not represent the recorded waveforms, especially with respect to underestimation of site effects. Due to practical considerations present methodologies and results should need to be proved by real recorded data. In contrast, here 195 accelerometer records resulted from 39 earthquakes in the east-west Japan (Miyagi Prefecture, Taiwa MYG009, Ishinomaki MYG010, Oshika MYG011, Shiogama MYG012, Sendai, MYG013) that were recorded by the K-net during January, 1996 to September, 2007 are utilized.

Earthquakes that occurred in a window bounded by 37.5N-38.8N latitude to 141.7 to 150 degrees longitude in the region are located in Fig. 2. In order to achieve a high quality of modeling and accurate training, the range of the earthquake parameters is limited to 4.1-7.2 for magnitude (M), 43-532 km for epicenteral distance (E) and 14-99 km for depth (D). 195 different ground motions (N-S component) in five locations are considered and 156 FAS is prepared at four far sites (extracting the nearest location) and thought to the ANN. The specification of earthquakes as an input data of ANN structure is given in Table 1.

Modeling Initial Ground Motion

Some methods have been proposed for last two decades concerning real time evaluation of initial ground motion. Almost all of them are for estimation of source parameters to deterministically prove the correlation of fundamental frequency and the earthquakes magnitude (Wu and Kanamori 2005, Nakamura 1985). Different from these approaches, a new and easy applicable methodology which describes the content of initial ground motion in near field is needed to forecast the frequency dependent FAS. One parameter derived from the early portion of waveform (fundamental frequency or time dependent PGA) are not sufficient for this purpose. Primary motion can be described combining simplified waveforms as the sum of sinus functions as in Eq. (3);

$$y = \sum_{i=1}^{n} a_i * \sin\left(b_i * x + c_i\right) \tag{3}$$

where a is the amplitude, b is the frequency and c is the phase constant for each wave term. They selected n as 8 due to sufficient representation of the motion (Fig. 4). It is considered that the parameters of sinus waves basically represent or describe the frequency content of initial ground motion (Kuyuk 2008).

Table 1 Earthquake source parameters used as input data

No	Date and time	Earthquake Source Information			
		M	E	A	D
1	00:08:28-17:20	4.8	199	117	41
2	01:10:02-17:20	5.4	49	157	41
3	02:05:06-17:12	5	101	72	40
4	02:10:12-19:59	5.6	198	118	29
5	02:12:05-00:50	5.2	128	57	40
6	02:12:05-00:53	4.9	119	55	37
7	03:01:05-18:51	4.4	49	27	99
8	03:03:03-07:47	5.3	44	160	41
9	03:10:31-10:06	6.8	187	116	33
10	04:05:29-12:47	5.9	81	148	38
11	04:07:05-18:22	4.7	57	144	42
12	04:12:29-22:59	5.5	106	75	39
13	05:03:30-04:12	4.4	109	66	61
14	05:08:16-11:46	7.2	122	104	42
15	05:08:24-19:15	6.3	249	83	14
16	05:08:31-03:11	6.3	311	86	22
17	05:09:06-18:13	4.1	65	94	45
18	05:09:12-04:28	4.7	107	105	42
19	05:10:12-13:30	4.7	57	144	43
20	05:10:18-03:48	4.8	64	139	43
21	05:10:24-18:35	4.8	97	68	39
22	05:11:15-06:39	7.1	532	95	83
23	05:12:02-22:13	6.6	133	109	40
24	05:12:05-07:20	5.5	181	115	25
25	05:12:17-03:32	6.1	106	75	40
26	06:01:18-23:25	5.7	109	133	36
27	06:02:01-04:23	4.5	126	82	36
28	06:02:03-13:03	4.5	59	146	42
29	06:04:02-16:23	4.4	49	47	50
30	06:04:22-23:36	4.6	50	32	66
31	06:05:06-20:45	4.5	113	76	38
32	06:07:01-08:28	5.3	102	72	40
33	06:09:09-19:36	4.9	83	93	67
34	06:10:02-02:07	5.2	208	76	56
35	07:06:13-10:49	4.2	49	80	66
36	96:05:23-18:36	5	127	61	39
37	97:12:07-12:50	5.2	43	160	83
38	98:05:21-06:54	5	88	59	84
39	99:11:15-10:35	5.5	146	90	49

M: JMA magnitude, E: epicenter (km), A: azimuth, D: depth (km)

Effect of Site Condition

Site amplification characteristics are indispensable for evaluating ground motion and this issue has to be considered for EEW applications at specific sites as well. The engineering bedrock of Sendai basin is a Pliocene layer where the S-wave velocity is larger than 500 m/sec and SPT value (N) is greater than 50 and seismological bedrock is the pre-Tertiary intact rock with the 3 km/sec S-wave velocity (Satoh et al. 2001). Velocity structure of Sendai basin is reported and available in the Earthquake Damage Survey Report for Sendai city (Earthquake Damage Survey Report for Sendai City 2003). We calculated site-amplification factors from the seismological bedrock to engineering bedrock by the linear one-dimensional wave propagation theory for obliquely incident S-wave. The S-wave velocity of the seismological bedrock is assumed to be 3000 m/sec based on the refraction survey in the Kitakami Mountains (Iwasaki 1994), about 100 km away from Sendai City, and this deep structure is basically represented by four sedimentary layers. Then amplification factors from engineering bedrock to surface outcrop are calculated by nonlinear one-dimensional program - the SHAKE code (Schnabel 1972). The normalized shear modulus G/G_{max} and damping ratios with respect to shear strain and soil profiles are adopted from (Earthquake Damage Survey Report for Sendai City 2003). Lastly, the two site amplification factors are combined for each site. Nonlinearity depends on the ground motion taken into account in frequency domain in four sites for each 39 earthquake.

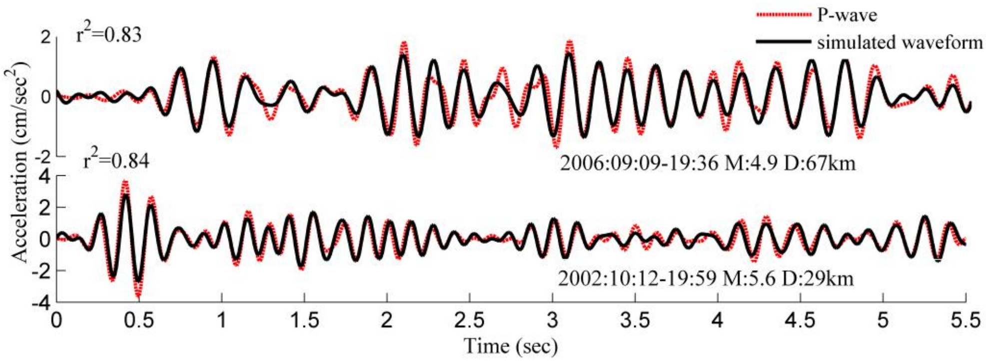

Fig. 4 Simulated initial ground motion

Structural Resonance Theory

Resonance against seismic ground motion in structures can be describe as the tendency of a vibrating system to respond most strongly to a seismic force whose frequency is close to the structures natural frequency of vibration. Basically, let us assume that for a given structure three stiffness types may

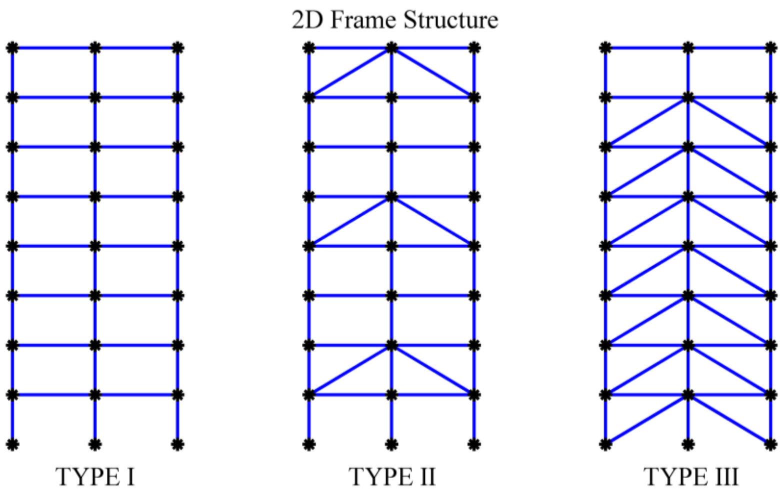

Fig. 5 Modeled frame structure with three stiffness type

arise; soft, normal and stiff types which are shown in Fig. 5 by locking and unlocking the AVSs devices at the diagonal bracings. Let M and K are the mass and stiffness matrices of the structure and the solution of the Eigen-value problem described by Eq. (4) for each of the structure types I, II and III, yields the corresponding first natural frequencies f_1^I, f_1^{II} and f_1^{III}

$$\left|K - w^2 M\right|_{n\times n} \Phi = 0 \Rightarrow \left|K - w^2 M\right| = 0 \tag{4}$$

where $w_1, w_2, w_3 ..., w_{n-1} \rightarrow f_i = w_i / 2\pi \quad i = 1\,,\, 2\,,\, .n -,$
and Φ is the eigenvectors. By construction of the frame, the frequencies also hold:

$$f_1^I < f_1^{II} < f_1^{III} \tag{5}$$

In order to avoid building resonance during the earthquake the condition that should be satisfied is:

$$f_1^{input}, f_1^{input}, ...f_k^{input} \neq f_k^I, f_k^{II}, f_k^{III} \tag{6}$$

where f_k^{input} are the dominant spectral frequencies of the seismic ground motion. The inequity of the above equation is used in an exact sense, the contribution in case of the near resonance should be considered as well. In case of high-rise buildings, where the higher modes may contribute more to the dynamic response, equation should satisfy for each natural frequency of modes.

Results and Discussion

Consistent and continuous spectral representation of earthquake wave amplitude for the usage of advance civil engineering structures would help in controlling structural responses. It is well known that the shape of the FAS can not be modeled accurately by only basic source information such as magnitude and site-to-station distance. Hence, from a practical point of view, it is worthwhile to consider only those parameters which are readily available in EEW application regarding structural control. The advantage of this approach is that, without a complete and possibly indecisive analysis, the approximate FAS can be estimated for a given expected earthquake using online obtainable information.

The methodology is presented by a scenario earthquake for the ANN approach, which is applied to four main locations in the Miyagi area of interest; Shiogama, Ishinomaki, Taiwa and Sendai stations. Fourier amplitude spectrum of a magnitude 7.2 earthquake is given in Fig. 6. Gray lines represent the observed Fourier amplitude (FA), the red lines are the forecasted FA. Forty circles in each FA are the forecasted amplitude corresponding to the frequency set. To combine the discrete points, a piecewise-polynomial approximation is used. The cubic spline data interpolation is performed using spline algorithm (Matlab 2007). Basically, for the coefficients of the cubic polynomials, which make up the interpolating spline, a tridiagonal linear system is constructed and is being solved for the required intervals. We think that this method is beneficial and applicable to similar studies due to the simplicity of its construction, ease, and accuracy of evaluation, especially its capacity to approximate complex shapes through curve fitting. The difference between computed and observed Fourier spectra in Fig. 6 clearly shows that the scaling characteristic of earthquake ground motion in terms of earthquake source, initial ground motion, and site amplifications can be expected to yield satisfactory answers in all cases for Miyagi-ken oki earthquakes. This figure is the capture of the FAS in 5.5 sec after the first detection of P wave in Oshika. Based on our experience, the national

EEWS information reaches the Disaster Control Research Center (Tohoku University, Sendai) in 5.5 sec average after detection of an earthquake in the nearest point. This delay reflects the transmission delay that is caused due to the distance between Sendai and Tokyo where the JMA/NIED (National Institute of Earthquake Disaster) center is located. Therefore, in our hybrid approach the source information is known after detection of earthquake in 5.5 sec and then further information and calculations are provided by our regional system.

An error can be seen in Taiwa(MYG09) between 3 to 4 Hz which is basically due to the limitation of forecasted points. In case the peak amplitude is in the middle of the forecasted points, these errors are unavoidable. Although it is adequate in here as a preliminary study, increase in the frequency of data set for prediction by at least two times could be a solution. With the increasing points which are accompanied with increase in computation efforts, the compatibility of high frequency ranges will also be better. Since high frequency ground motion attenuate faster than low frequency with distance, high frequency ranges are biased in Taiwa city, which means prediction of high frequencies in far ranges become rather difficult. However, it is no more important to predict high frequencies in far ranges such as Taiwa city, since low frequency motions become more critical, especially for high rise buildings with long periods (as seen the fundamental frequency is unclear in the graph).

All the peak values, except in Taiwa (MYG09), are forecasted satisfactorily. The authors think such error in Taiwa is in fact acceptable. Due to resonance/near-resonance phenomena, the control algorithm will arrange a stiffness of the structure in order to adjust the natural frequency of the structure and shift the building frequencies as far as possible from the ground motion dominant frequency. For instance, the content of FAS motion message will be served to a AVS-equipped structure so that it would allow for a small but satisfactory window for moving the hydraulics of the AVS system to compensate for the frequency content of the arriving seismic signal.

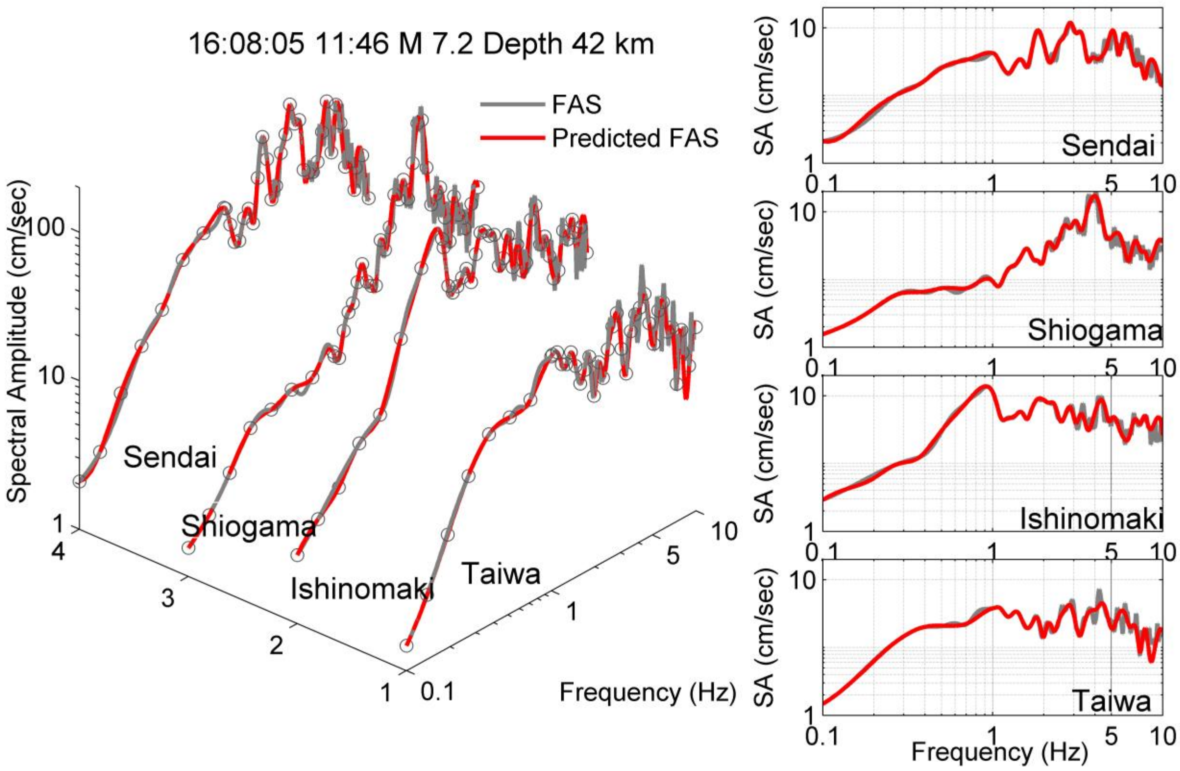

Fig. 6 August 16, 2005 earthquake (7.2 magnitude), predicted and real FAS in four site

Overall, the agreements between the observations and forecasts are seen clearly at four sites. It can be said that the ANN methodology forecasted well enough for an unseen and new earthquake. The test so far suggests that the forecasted FAS are very realistic for 4.1 < M < 7.2 and for horizontal ground motion. To understand these amplitudes we need more accelerometer records in the same area and so we must patiently wait for this data to become available. On the other hand, in different locations, like California, where there is more data available, the same methodology could be applied.

Numerical Example

Using the outlined process, it is now possible to deliver the frequencies of upcoming ground motions to intelligent structures. Here, the eight story, two-bay, steel frame, shown in Fig. **5** is simulated to describe how the methodology can be effectively used. The structure is analyzed under the base motion corresponding to the August 16, 2005, earthquake in Miyagi prefecture. Three structure types were chosen; the first type with all braces open and the others are closed according the Fig. **5**. As can be seen from the Fig. 7 the spectra of the records in each station have different frequency contents (To better recognition, Fourier amplitude spectrums of displacement are normalized according to their maximum values).

In time history analysis of the buildings, August 2005 Miyagi earthquake records from four locations, Taiwa, Ishinomaki, Shiogama and Sendai were used. The structures are assumed to be fixed base (without soil-structure interaction) with damping ratio of C=0.001*M+0.02*K and the floors as rigid diaphragms with infinite in-plane stiffness. The sections and dimensions of the structure elements are kept constant for all floors as for the columns IPE100 and the beams IPE80. The storey heights of the frame are assumed to be constant with 3 meter and the bays are 5 meter. The modulus of elasticity for the structural elements $E = 30\,kN/mm^2$, Poisson's ratio $\upsilon = 0.20$ and mass density $\rho = 25\,kN/m^3$ are assumed and for the illustrated braces bar elements are assumed with the $E = 200\,kN/mm^2$ and 10 mm^2 cross section.

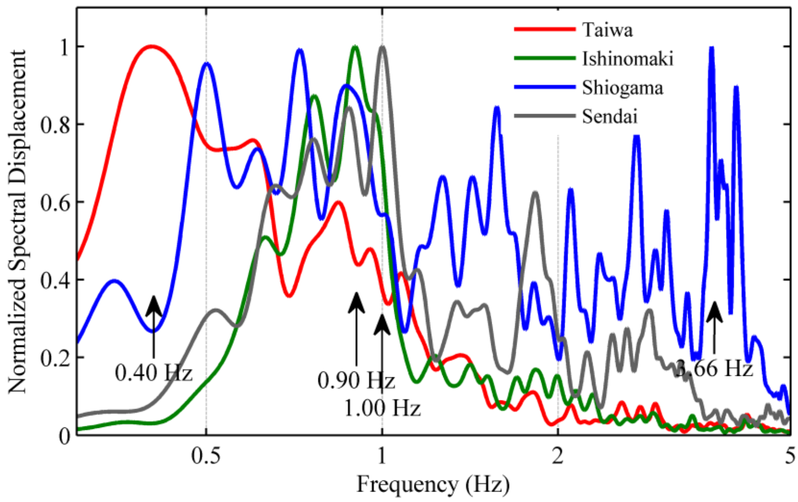

Fig. 7 Displacement frequency content of August 16, 2005 earthquake

Dynamic analyses of the structure subjected to earthquake were carried out by a Matlab software program for finite element analysis. The second order differential equation is solved by the Newmark method and for the natural frequencies of each type Eigen-value analysis is performed. First four modes are given in Table 2. The displacement and acceleration at the top of the buildings with stiffness types I, II and III are shown in Fig. 8 and Fig. 9.

Horizontal displacements on the top of the frame structure in Taiwa showed that due to near resonance phenomena (first natural frequency of Type I is 0.53 Hz where seismic record is 0.40 Hz) the peak displacement of softest type was three times more than Type III. In Ishinomaki, above explanation was valid for Type II which natural frequency is 0.91 Hz and the record was 0.90 Hz. In this station it is clear that because of the resonance stiffer configuration, Type II was 8.4 cm while Type I was about half of it. Again the stiffest, Type III was the best choice for the smallest response regarding to displacement. However, in Shiogama fundamental frequency of upcoming ground motion was 3.66 Hz where natural frequency of Type III was also 3.88 Hz which indicated that the stiffest structure's replacement was the largest and, contrary Type I was the smallest value. Nevertheless, the difference in displacement of the three types were not significant, this was due to the contribution of low frequencies in the area. In Sendai similar result can be seen like Ishinomaki city that the peak displacement was occurred in Type II.

Table 2 Natural frequency of frame structure

Modes	Natural Frequencies		
	Type I	Type II	Type III
1st	0.53	0.91	3.88
2nd	1.68	2.54	6.02
3th	3.08	3.98	14.92
4th	4.82	8.37	15.26

These results are interesting because, even though a structure designer considers the response spectrums and the amplification factors of ground in design stage; there is a possibility that the structure can get resonance due to frequency content of impending ground motion which is caused by rupture process of earthquake. At the end, evaluating the displacement results on top of the structure by itself, it can be said that, Type III, Type III, Type I and Type III are the chosen configuration in Taiwa, Ishinomaki, Shiogama and Sendai cities respectively.

On the other hand, these selections did not stand for the acceleration response. As can be seen in Fig. 9 the peak accelerations for Type III took the biggest values at four locations. Especially in Shiogama this was obvious that peak acceleration was six times larger for Type III. In Ishinomaki, the peak displacement between Type I and III is about two times however this is vice-verse for the peak acceleration. Here the decision algorithm became very important. In case the structure could resist the peak displacement in every configuration, the best options turns to Type I acceleration records. The authors are aware that this frame structure is not adequately representing the common resistant buildings; however this was a good example to indicate that the frequency content of the seismic motion is also crucially important and in case of forecasted frequency in far sites, it is not impossible now to avoid resonance in structures due to the uncertainty of input seismic ground motion.

The innovation of this study shown in the example could be highlighted as; the best configuration of the structure could be selected even the P-wave has not reached in Sendai and Taiwa cities. This decision could be made 5.5 second after the detection of the earthquake. The authors ignored the process time of FAS prediction which needed for ANN methodology due to negligible process time (a few milliseconds). Therefore the methodology is very efficient in order to build securer, more reliable residents.

CONCLUSIONS

Application of earthquake early warning systems currently focuses on providing information to the public services; however, next generation EEWS will provide information to control critical systems or structures equipped with active/semi-active devices from the destructivity of earthquake ground motions. Providing consistent and continuous spectral representations of earthquake wave amplitudes for the usage of advance civil engineering applications would definitely help to reduce seismic response.

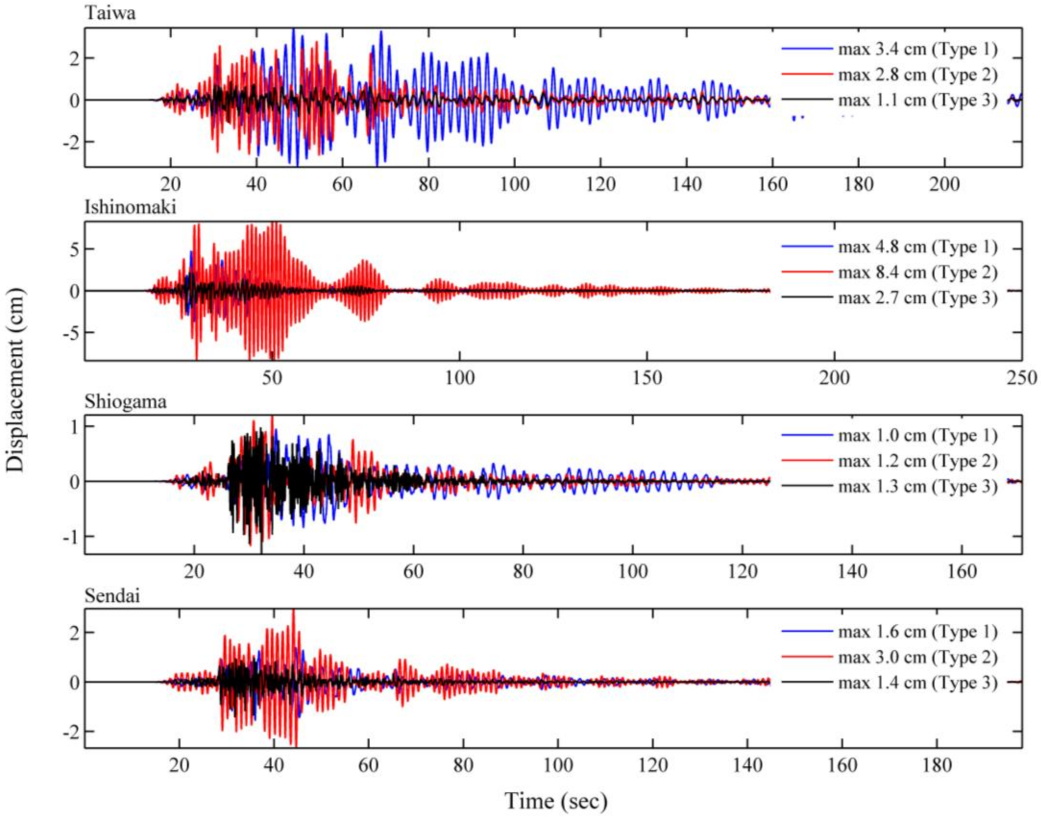

Fig. 8 Top displacement records of three type structure at four stations

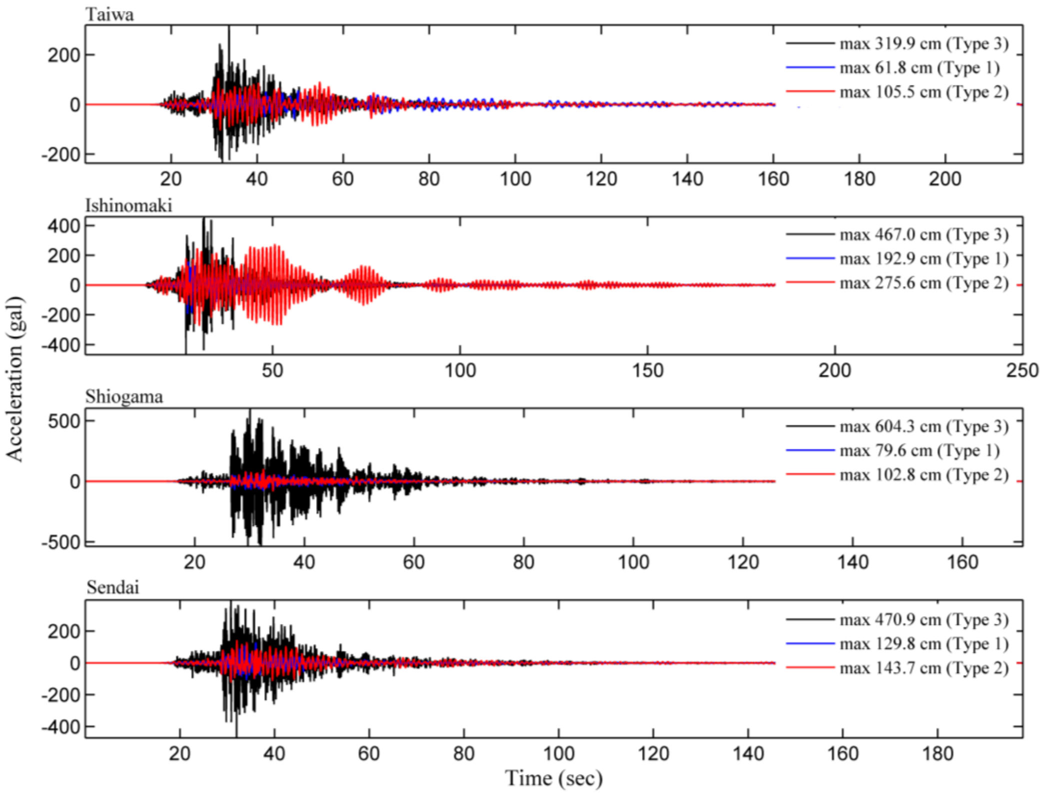

Fig. 9 Top accleration records of three type structure at four stations

In this study it is proposed that Fourier amplitude spectrum of earthquake ground motion can be forecasted in far-site ranges after detection of an earthquake in terms of initial ground motion, source parameters, and site amplification in frequency domain which are provided by different EEWSs. For this purpose, the authors have developed a regional warning system which integrated with the JMA/NIED, national Japan EEWS in Miyagi Prefecture against Miyagi-ken Oki earthquakes. Our system is providing a real-time online waveform data from the nearest inland point to the Miyagi subduction area to the center located in Tohoku University, Sendai. Artificial neural network methodology is used to integrate the information from the hybrid configuration. Numerical simulations have been performed for verification in structural control. The results indicated that the methodology of FAS forecasting will provide great contribution to structural control considering non resonance phenomena with the usage of feed forward control algorithms

Numeric simulations have been proving that structural control can be effectively achieved if the content of propagating waves is known before arriving at the building of interest. It is therefore particularly valuable to forecast Fourier Amplitude Spectrum in this respect for real time engineering applications.

ACKNOWLEDGEMENTS

The K-NET data were used in this study. The authors are grateful to the concerned persons of National Research Institute for Earth Science and Disaster Prevention (NIED). We also thank Mr. Makato Homma for his fruitful discussions with us. The authors also express their sincere gratitude to three anonymous reviewers for their constructive critiques during the review process.

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(Submitted: May 30, 2008)
(Accepted: March 2, 2009)