I-B 243 BEAMFORMED GREEN FUNCTION METHOD FOR THE SYNTHESIS OF STRONG GROUND MOTIONS - APPLICATION IN THE AKASHI KAIKYO AREA

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1.- INTRODUCTION

For the seismic design of large-scale structures it is of great importance to consider the spatial variation of free-field ground motions, because a simple base excitation cannot represent adequately the multiple-input effects. In this research, aftershock data of the 1995 Hyogo-ken Nanbu Earthquake, recorded by the Akashi Kaikyo Array Observation System (Fig. 1), are used to estimate the seismic inputs at the Akashi Kaikyo bridge's supports. For this purpose, the Beamformed Green Function method, to estimate multiple seismic inputs for large-scale structures induced by near-field earthquakes, is proposed.

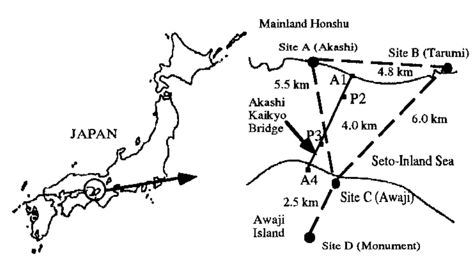

Fig. 1: Location of Array Observation System and Akashi Kaikyo Bridge.

2.- BEAMFORMED GREEN FUNCTION METHOD

The Beamformed Green Function method presented here, is intended for synthesizing multiple seismic inputs for large-scale structures induced by near-field earthquakes, based on a set of array records of aftershocks. This procedure consist in generating the empirical Green functions corresponding to each support point, at the location of each fault plane's sub-element. Thus, the small event's signals recorded by an array observation system are beamformed using the Delay-and-Sum beamforming algorithm to generate the empirical Green functions; then, the Irikura's method (Irikura, K., 1986) is used to synthesize the strong ground motions at the beamforming origin of coordinates (Fig. 2). With this method, the geometrical effect of near-field earthquake can be taken into account.

The Delay-and sum beamforming algorithm consists in applying appropriate delays to the signals recorded by each sensor of an array, and adding them together to obtain a reinforced signal. The delays are directly related to the length of time it takes for the signal to propagate between sensors. When the source is located in the array's near-field it is assumed the signal *s(t)* spreads spherically into space. Then, by the spherically symmetric solution of the wave equation, the signal $y_m(t)$ recorded by the *mth* sensor has the form

$$y_m(t) = s\left(t - \frac{r_m^o}{c}\right) \Big/ r_m^o \qquad (1)$$

where, r_m^o is the distance between the source and the sensor, and c represents wave propagation velocity. By choosing the delay

$$\Delta_{m,ij} = \frac{r_{ij}^o - r_m^o}{c} \qquad (2)$$

we can stack the signal replicas captured by all M sensors so that they reinforce each other. Therefore the beamformer's response to a spherically propagating wave becomes:

$$u_{ij}(t) = \sum_{m=0}^{M-1} w_m \frac{r_m^o}{r_{ij}^o} y_m\left(t - \Delta_{m,ij}\right) \qquad (3)$$

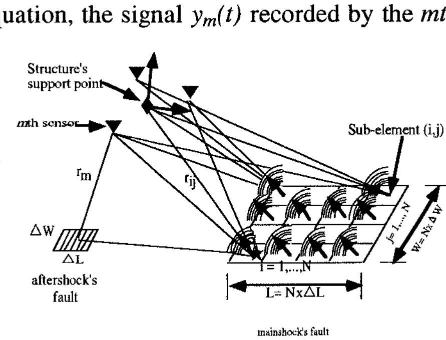

Fig. 2: Empirical Green functions are generated by beamforming algorithm at each fault's sub-element, and strong ground motions are obtained by Irikura's method.

where, r_{ij}^o is the distance between the source and a particular spatial location (i.e. beamforming origin of coordinates), and w_m is the *mth* sensor's weight used for optimizing the array gain.

This equation is used to generate the empirical Green functions at each fault's sub-element. Then, the synthetic strong ground motion $U(t)$ for the large event is given by:

$$U(t)=\sum_{i=1}^{N}\sum_{j=1}^{N}\left(\frac{r}{r_{ij}}\right)F\left(t-t_{ij}\right)*u_{ij}(t) \qquad (4)$$

where, the notation * represents convolution,

$$F(t)=\delta(t)+\frac{1}{n'}\sum_{k=1}^{(N-1)n'}\delta\left[t-\frac{(k-1)\tau}{(N-1)n'}\right] \quad (5), \quad \text{and} \quad t_{ij}=\frac{r_{ij}}{V_c}+\frac{\sqrt{\xi_i^2+\eta_j^2}}{V_r} \quad (6)$$

r and r_{ij} are the distance from the hypocenter of the small earthquake and from the (i,j) element to the site respectively; V_c and V_r are the wave propagation and the rupture propagation velocities τ is the rise time of the target event, and n' is an appropriate integer number to shift the fictitious periodicity $\tau/(N\text{-}1)$ into a high frequency out of the range of interest.

3.- SYNTHETIC SEISMIC INPUTS AT THE AKASHI KAIKYO BRIDGE'S SUPPORTS

A multi fault rupture model composed of three fault planes and two aftershocks, the February 18, 1995 (M_{JMA} 4.9) and the January 23, 1995 (M_{JMA} 4.5), were used for the analysis (Fig. 3). A constant sensor's weight w_m=0.25 was assumed for the beamforming analysis, and the stress drop ratio between large and small event was assumed to be C=1 in the synthesizing procedure.

The synthetic seismic inputs obtained by this procedure, have peak acceleration ranging from 300 to 600 gal in their horizontal components and around 100 gal in their vertical component. Figure 4 shows the acceleration, velocity, and displacement time histories of the NS component of the seismic input obtained at the bridge's abutment A1, located on the Akashi side, and Figure 5 shows the acceleration response spectrum of this synthetic seismic input along with those of the El Centro and JMA-Kobe records. As can be seen in this figure, the synthetic signal presents larger amplitudes than El Centro record in almost all the frequency range.

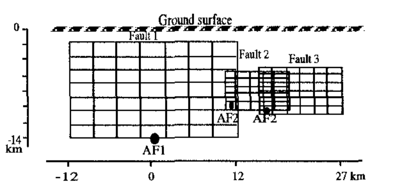

Fig. 3: Multi-fault rupture model and location of rupture starting points (Source mechanism after Kikuchi, 1995)

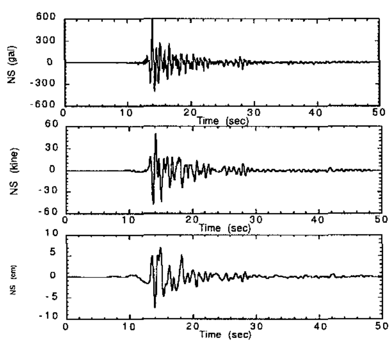

Fig. 4: Synthetic seismic input at Abutment A1 obtained by BGF Method.

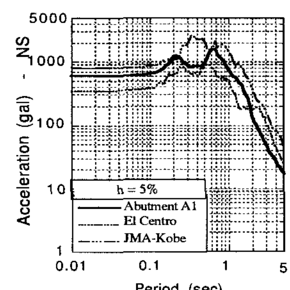

Fig. 5: Acceleration response spectra of synthetic seismic input at abutment A1, and of El Centro and JMA-Kobe records

4.- CONCLUSIONS

- The Beamformed Green Function method, for synthesizing strong seismic ground motions induced by near-field earthquakes, is presented. With this procedure it is possible to generate different seismic inputs for large-scale structures, allowing to perform a more realistic response analysis for the case of near-field earthquakes.
- The seismic inputs obtained at the Akashi Kaikyo bridge's support present high intensity, short duration, and high frequency content, which are characteristics of near-field earthquake ground motions. Furthermore, their peak accelerations are comparable with those observed in the surrounding area.

REFERENCES

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