Application of wave propagation modeling to earthquake strong motion records of buildings

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Introduction. Earthquake motions recorded in buildings are the only source of experimental data that contains all uncertainties inherent to the earthquake behavior of buildings. But because of complexity of the recorded motions, engineering features of the earthquake ground motion, its effects on structures and response behavior of buildings cannot be seen directly from the records. Most frequently used and conventional methodologies for the study of structure's response due to the earthquake strong motions are system identification method and spectral ratio analysis. Also there are many methods for obtaining the wave propagation properties of the linear system by using the actual ground motions. Because the wave propagation velocity is much dependent on body's characteristics through which wave propagates, it was realistic to use such a method in the building response investigation.

NIOM method. One of the methods for wave propagation modeling is Normalized Input Output Minimization Method (NIOM, H.Haddadi and H.Kawakami, 1998) and adopted in this work. This method is capable of revealing the arrival times of incident and reflected waves as well as their relative amplitudes in multiple linear system. The procedure of the NIOM method is, at first the actual ground motion input and output are used to compute the transfer function, which relates simplified input and output models. Transfer functions depend only on physical properties of the systems. Therefore the same transfer function that defines the relation of the actual input and output motions should satisfy the relation of the input model and output model. Then by minimizing the square values of Fourier amplitude spectra at the input level and at the output level when the constraint is in existence get the simplified input and output models, which illustrate the statistical correlation between two motions.

Building records. The records of 21 buildings from San Fernando earthquake (1971), record of one building from Whittier Narrow earthquake (1987), four buildings from Loma Prieta earthquake (1989), 13 buildings from Northridge earthquake (1994) (all in California, USA), and records in 2 buildings recorded during 1995 Hyogo-ken Nanbu earthquake, Japan, are analyzed. Buildings of different structural systems and heights, which have records at least three different levels were selected for our investigation.

Record analysis. In the record analysis, the response time histories at top floors are considered as input and response time histories at the other floors are considered as output in order to suit the NIOM method modeling. The analysis results by using horizontal components in two buildings are shown in **Figure 1**. As seen from the figure the outputs show two clear peaks, which correspond to the incident (1) and reflected waves (2) and time arrivals of incident and reflected waves are determined from these results. Analysis result of the 1640 S.Marengo building record gives 0.22 sec of incident and 0.26sec of reflected waves arrival times at the 1st floor in direction N038E (NS). In case of the 8639 Lincoln Avenue building it gives same 0.16 sec of arrival times for the both incident and reflected waves at the subbasement in direction S045E.

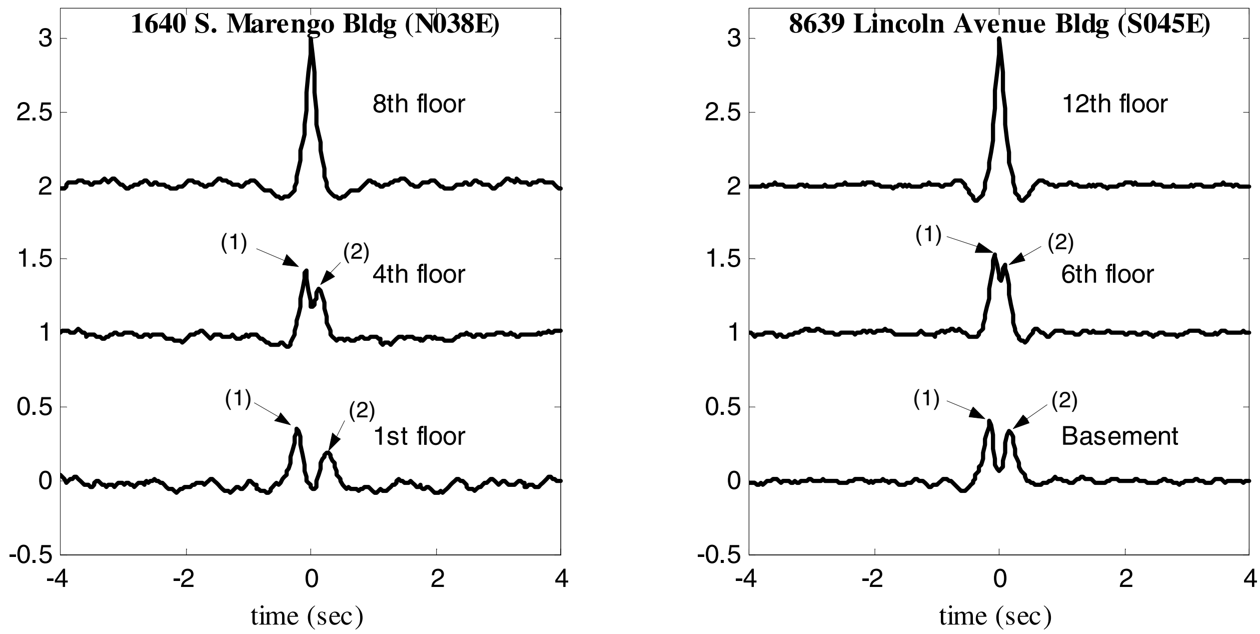

Figure 1. NIOM analysis result of strong motion records by using horizontal components,

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The analysis results of the building records were obtained by changing the weighting constant, which determines the contribution of frequency band in the analysis process, but the results always showed two peaks and wave arrival times are same for the different values of weighting constant. Two peaks in the analysis results give us wave-propagating time through building and relative wave amplitudes. Wave arrival times and wave amplitudes at the basement/ground floors determined from the NIOM method analyses results by using horizontal components are shown in **Figure 3**. One can see the relationship between arrival times of incident and reflected waves and their amplitudes. It is found that the reflected wave amplitude is smaller than incident wave amplitude in all cases and it can be explained by the multiple reflection theory or damping of a structure. From the analytical building model analysis it is concluded that the wave amplitude ratios could be employed for the determination of structural damping.

Wave arrival times at basement/ground floors are used for the determination of fundamental vibration periods of buildings and it is 0.96 sec for the 1640 S.Marengo building and 0.64 sec for the 8639 Lincoln Avenue building. Damping ratios determined by using amplitudes ratio are 0.075 and 0.017 respectively.

Analyses results by using the vertical components of the records in two buildings are shown in **Figure 2** and one can see single peak at the output levels. It verifies that buildings are much stiffer in the vertical direction than horizontal direction.

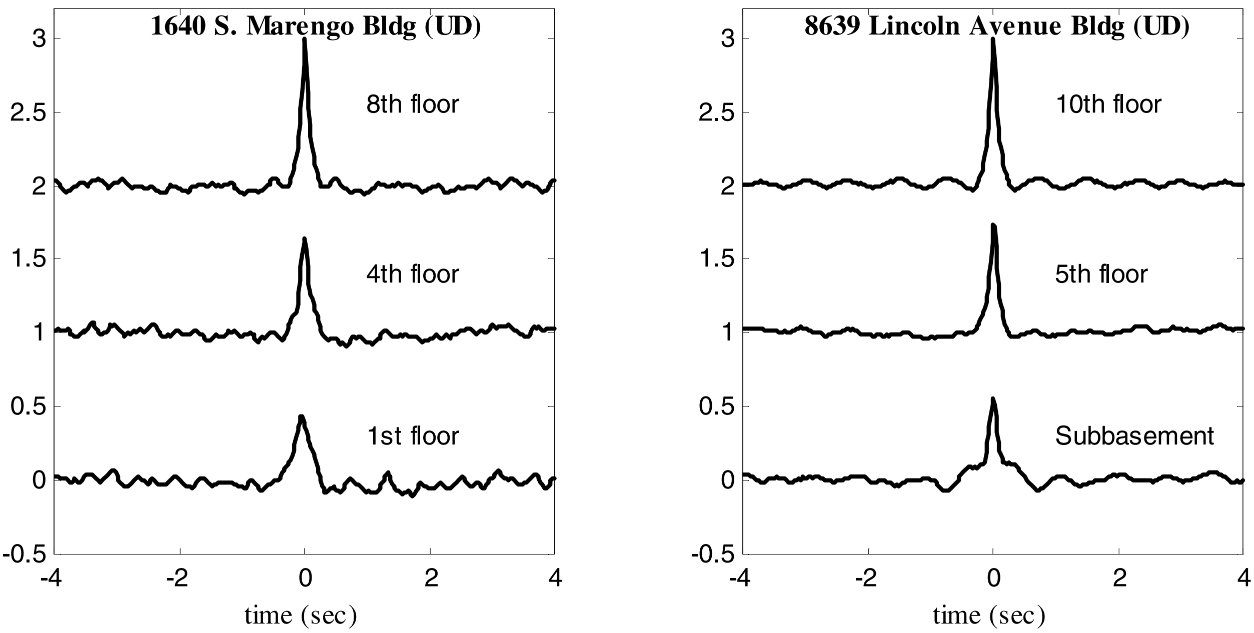

Figure 2. NIOM analysis result of strong motion records by using vertical components,

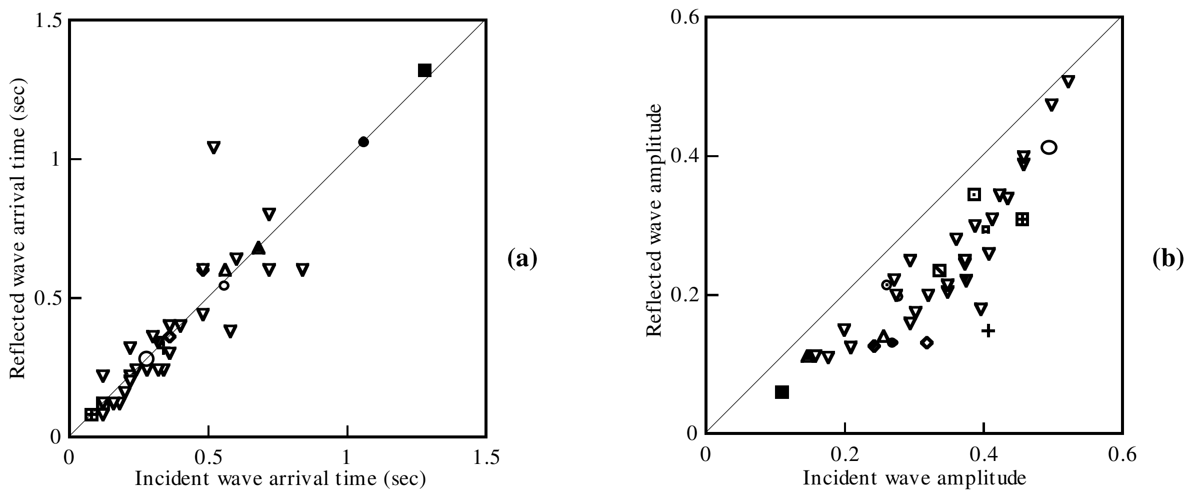

Figure 3. Relationship between **(a)** wave arrival times, **(b)** amplitudes of incident and reflected waves in NS direction

Conclusion. Incident and reflected waves arrival times at outputs are mostly symmetric and use of the wave arrival time at the basement/ground floors gives reasonable value of the fundamental period of a building. Reflected wave amplitude is always smaller than incident wave amplitude and ratio of the wave amplitudes at the basement/ground floors can be used for the approximation of damping ratio of a building during particular earthquake. Wave propagation modeling method such as NIOM method could be employed effectively for the building response investigation by using strong motion records.

References. **1.** Haddadi, H.R & H.Kawakami 1998a. Modeling wave propagation by using Normalized Input-Output Minimization (NIOM) method for multiple linear systems. *J. Struct. Mech.Earthquake Eng., JSCE.* 584/I-42. **2.** Kawakami, H & H.R.Haddadi 1998a. Modeling wave propagation by using normalized input output minimization (NIOM). *Soil Dyn. and Earthquake Engrg. 17: 117-126.*