CONSIDERATION OF 1- TO 10-SEC SURFACE WAVES IN EVALUATION OF SEISMIC INPUT MOTIONS FOR LARGE-SCALE STRUCTURES

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SUMMARY

An investigation on 1- to 10-sec surface waves in thick sedimentary layers was carried out in order to evaluate their engineering significance. Surface wave severity was estimated on the basis of records of moderate earthquakes. A method for synthesis of ground motion models, which include surface waves, was examined, and several models were calculated. Effects of surface waves on manmade structures were evaluated by meand of earthquake response simulations in which the synthesized ground motions were applied. Structural types which are vulnerable to surface waves were identified, and a basic procedure for accounting for 1- to 10-sec surface waves in earthquake input motions was proposed.

INTRODUCTION

In recent years, a great number of large-scale structures have been constructed. Their natural periods are far longer than those of usual ones, i.e., longer than 1-sec and up to 10-sec. It has been pointed out that 1- to 10-sec components from shallow faults are composed mainly of surface waves, but their engineering significance is not obvious yet. Elucidation of the nature of 1- to 10-sec surface waves and their effects on manmade structures, which are followed by a proposal for consideration of them in evaluation of seismic input motions, are the objectives of this study.

Surface waves in the Kanto plains, Japan, which has thick (about four kilometers) sedimentary layers composed mainly of Tertiary deposits, were investigated. On the basis of this investigation, general ideas for accounting for surface waves were derived.

SURFACE WAVE SEVERITY

Displacement records obtained from low-magnification seismographs having natural period of 6- to 110-sec and installed in the Kanto plains (down town Tokyo) were analyzed by Tanaka (Ref. 1). Characteristics of the earthquake ground motions in the period range from 1- to 10-sec were investigated. Analyzed earthquakes are of magnitude greater than 6.

Frequency-time characteristics of the ground motions were analyzed, and several wave groups having evident dispersive characteristics were recognized. For nine records, the maximum amplitude of Fourier acceleration spectra (converted from Fourier displacement spectra) in the period range from 4- to 10-sec are plotted versus peak acceleration amplitude in Figure 1. Peak acceleration amplitude was estimated from seismic intensity reported by Japan Meteorological Agency at Tokyo.

Peak acceleration amplitude is expected to be given by the short period s-waves. It can be regarded as an indicator of body wave severity. On

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the other hand, maximum spectral amplitude can be regarded as that of surface wave severity. A ratio of maximum spectral amplitude to peak acceleration amplitude represents the severity of surface waves in comparison with that of body waves.

Probable upper bound of the ratio, derived from the actual ground motions in the Kanto plains, is shown by a thick solid line in Figure 1. Though physical background of the probable upper bound is hard to be discussed exactly, we adopt it for convenience in order to complete the present investigation.

In an earthquake response simulation, which is a conventional technique for aseismic design of structures, actual accelerograms have been applied as input motions. When such a method is applied to the aseismic design of large-scale structures, careful attention to 1- to 10-sec component in the accelerograms is important. One- to 10-sec component severity of a few conventional design accelerograms are shown in Figure 2. Amplitude of 1- to 10-sec ground motions contained in these accelerograms are far smaller than those of surface waves recorded in thick sedimentary layers. They are not appropriate as input motions for large-scale structures.

GROUND MOTION MODELS INCLUDING SURFACE WAVES

Studies in earthquake engineering have concentrated in short period ground motions, and data of 1- to 10-sec ground motions are not sufficient today. The nature of 1- to 10-sec surface waves is not expected to clarified from only empilical studies, at least in the near future. Utilization of theoretical studies are reasonable in such circumstances. In the last ten or so years, the dynamics of a seismic fault has been remarkably developed. It is confirmed that ground motion models of 1- to 10-sec surface waves can be reasonably interpreted by means of an appropriate fault model and a deep underground structural model.

In the estimation of ground motions in the shorter period range, apprecation of a fault model is inadequate yet. Detailed information of source and path can not be disregarded in the theoretical estimation. However, considerable observation in the period range less than 1-sec have been made, and the stored data were applied to statistical reduction. Reliable empirical equations of peak acceleration amplitude, spectral amplitude and so on are constructed in terms of magnitude, epicentral distance and site soil conditions. Application of such empirical equations is suitable in the synthesis of short period body wave component.

A mathematical method of synthesis of surface waves in the period range from 1- to 10-sec was proposed by Kudo (Ref. 2). There are three essential points. (1) The basic idea owes the theory of surface waves from a point couple force in multi-layered media given by Harkrider (Ref. 3). (2) The spectral source function (source spectrum) is determined by source time function, rupture propagation characteristics and seismic moment. (3) The effect of thick (several kilometers) sedimentary layers is taken into account. An equivalent layered half-space model, which is establised so as to agree theoretical and observed group velocity dispersion, is introduced.

A fault model and a deep structural model used in this study are shown in Figure 3 and 4, respectively. A symmetrical, bi-lateral fault is chosen, and the station direction is of orthogonal to the fault trace. The deep structural model includes thick sedimentary layers.

Fundamental Love waves were calculated as typical surface waves. Higher mode Love waves and Raileigh waves were not included. An example of a set of time histories of surface wave ground motions is shown in Figure 5.

S-wave ground motion models were calculated in the following two steps. (1) Target spectra were evaluated on the basis of a conventional empirical equation. (2) Target spectra were converted into time histories in terms of superposition of harmonic functions with random phase. Empirical equations proposed by Iwasaki et al. (Ref. 4) for an Alluvial soil site was used. Body wave ground motion models are shown in Figure 6.

Body and surface wave ground motions were superimposed to make a realistic ground motion model. Maximum amplitude of Fourier acceleration spectra in the period range from 4- to 10-sec (surface wave severity) are plotted versus peak acceleration amplitude (body wave severity) in Figure 7. Surface wave severity of the ground motion models is consistent with that of the actual records. They can be used as input motions in a structural response simulation to examine the effects of surface waves.

STRUCTURAL RESPONSES AND PROCEDURE FOR CONSIDERING SURFACE WAVES

Response spectra for the synthesized ground motion models (M=8, r=50 km and δ=20°), with and without surface waves, are shown in Figure 8. Structures of which natural periods agree with the period of surface waves, have large responses. In Figure 8, current design spectra in Japan are also shown. A structure designed under the guidance of the recommendations is safe from body waves, it its natural period is longer than 1- or 2-sec. However, when a structure is to be constructed on thick sedimentary layers and an occurrence of an earthquake with a shallow focus is expected, the safety of the structure must be discussed by means of a comparison with a response spectrum for ground motions including surface waves. An undesirable situation that the structure may suffer from acceleration almost comparable to or greater than that of the design spectra, is predicted.

Natural period of manmade structures, particularly their upper bounds, depends on the structural type and material. Structure having natural period in the predominant period range of surface waves are large fluid tanks (Sloshing of their contents) and large-scale steel structures, i.e., high-rise buildings and long-span bridges.

A procedure to distinguish structures that must be designed with due consideration of surface waves, from the others that can be designed by conventional input motions, is shown in Figure 9. Distinction is made in terms of the natural period of the structures. As mentioned above, structures vulnerable to surface waves are steel structures and liquid tanks (sloshing of their contents). Timber, block, R.C. and S.R.C. structures have natural periods far shorter than the surface wave periods. They are free from consideration of surface waves. In cases of steel structures and tanks, further examination is needed to know whether consideration of surface waves is necessary or not. When the natural period of the structure is in the period range where surface waves predominate, the aseismisity of the structure must be examined by means of earthquake inputs including surface waves.

Fundamental ideas to synthesize surface wave ground motion models are summarized as follows. Mathematical theories on surface waves is as seen in the previous section. Fault models are constructed after some geophysical investigations, i.e., seismic activity and crustal movement. Deep soil models are expected in earthquake engineering studies.

CONCLUDING REMARKS

Engineering significance of 1- to 10-sec surface waves in thick sedimentary layers was investigated. Results of this study are:

(1) A probable upper bound of 1- to 10-sec surface waves was estimated.
(2) Severity of 1- to 10-sec component in accelerograms, which have frequently been used in earthquake response simulations, as say El Centro, 1940, is not appropriate to examine the effects of surface waves on large-scale structures.
(3) A method for synthesis of earthquake ground motion models, which include surface waves, was discussed, and several models in thick sedimentary layers were calculated. Also, it was confirmed that the surface wave severity in the synthesized ground motions was reasonable.
(4) Synthesized ground motions were used in structural response simulations, and it was found that the acceleration of a structure may sometimes exceed the design acceleration (design spectrum) specified in current Japanese building codes.
(5) Structural types which are vulnerable to surface waves were identified, and a basic procedure for accounting for 1- to 10-sec surface waves in an earthquake input motion was proposed.

In this study, engineering significance of 1- to 10-sec surface waves was evaluated consistently. However, it can not be denied that some theoretical examinations are first approximations. Attention was concentrated only on fundamental mode Love waves. Investigation on Rayleigh waves and higher mode surface waves are desired. More sophisticated models of manmade structures, i.e., non-linear ones, call for further studies.

ACKNOWLEDGEMENTS

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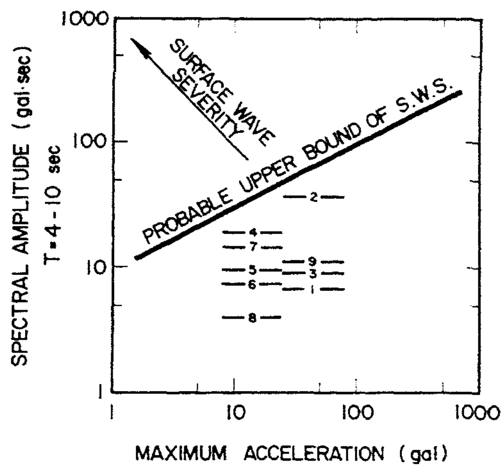


1. Off Boso peninsula, 1916
2. Kita-Izu, 1930
3. Nishi-Saitama, 1933
4. Imaichi, 1949
5. Tokachi-oki, 1968
6. Middle part of Gifu, 1969
7. Off Izu peninsula, 1974
8. Near Hachijyojima island, 1974
9. Near Izu-ohshima island, 1978

Figure 1. Plot of maximum Fourier amplitude in the period 4- to 10-sec versus peak acceleration amplitude.

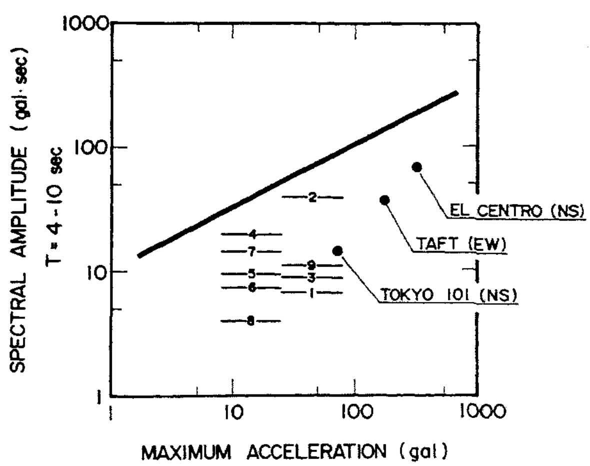
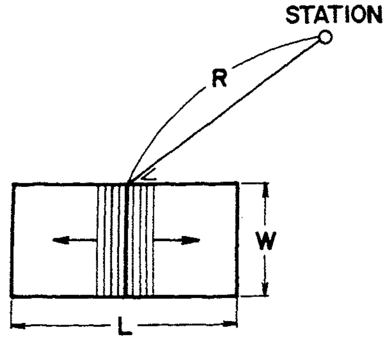


Figure 2. Comparison between surface wave severity in the Kanto plain data and long-period severity of accelerograms frequently used in response simulations.



dip angle δ=90°, slip angle λ=0°
rupture velocity v_R=2.0 km/sec

M=6	length	l=15.8 km
	width	w= 7.9 km
	critical time	T=0.61 sec
	seismic moment	Mo=1.0×10^{25} dyne-cm

M=7	l=50.0 km	M=7	l=158 km
	w=25.0 km		w=79.0 km
	T=1.9 sec		T=6.1 sec
	Mo=3.2×10^{26} dyne-cm		Mo=1.0×10^{28} dyne-cm

Figure 3. Fault model and fault parameters.

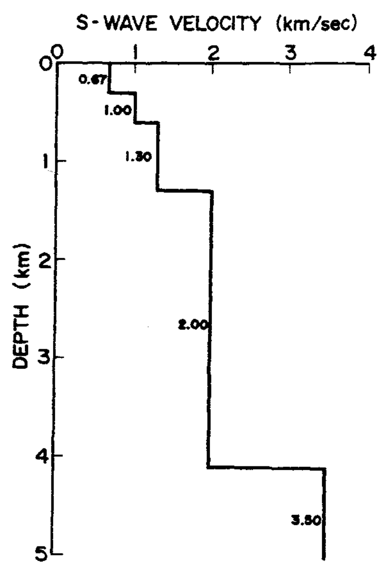


Figure 4. Deep soil structure.

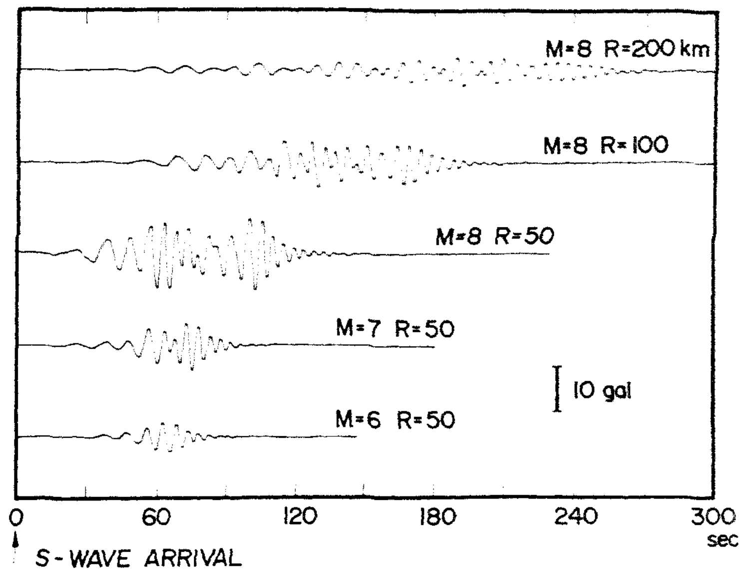


Figure 5. Surface wave ground motion models.

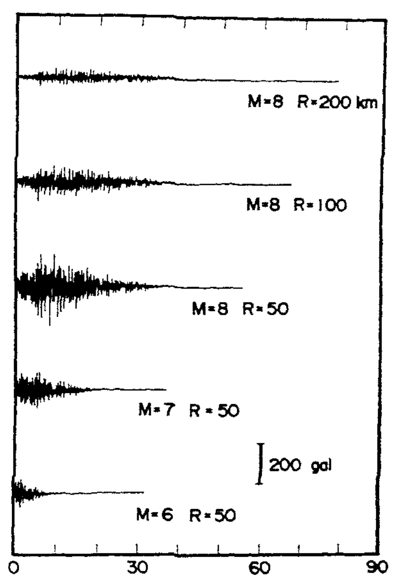


Figure 6. Body wave ground motion models.

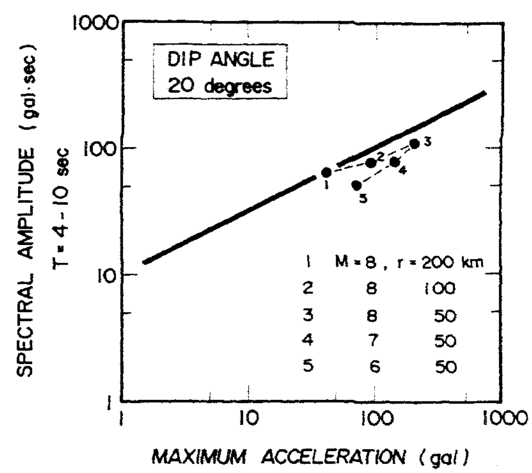


Figure 7. Surface wave severity (Ground motion models).

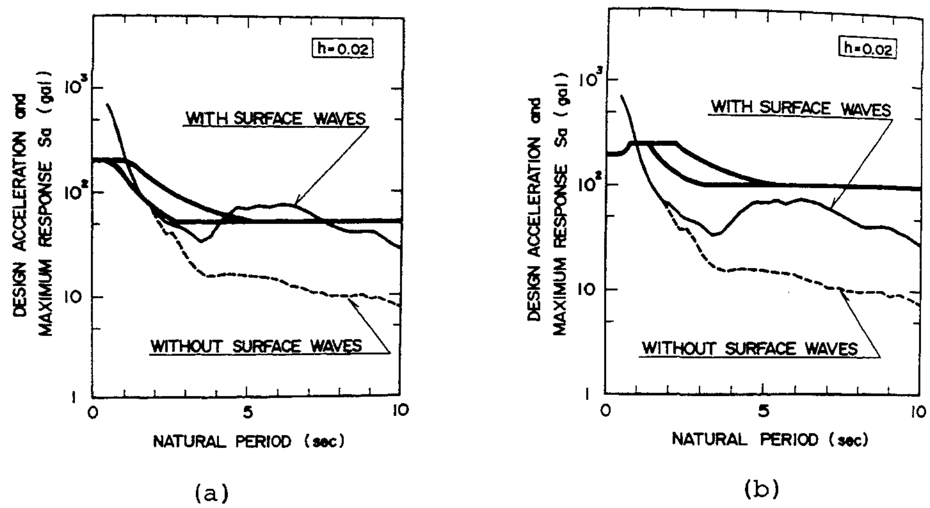


Figure 8. Response spectra and design spectra.
Design spectrum
(a)
for buildings in Building Code of Japan
(b)
for road bridges by Japan Road Association

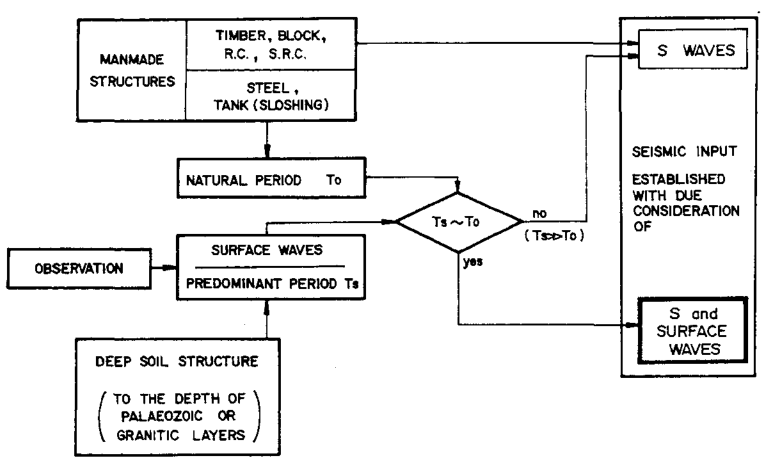


Figure 9. Selection of seismic input motions
(with and without surface waves)
including structural type.