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FORMULATION OF LEVEL 2 EARTHQUAKE MOTIONS FOR CIVIL ENGINEERING STRUCTURES

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ABSTRACT

The Proposal issued by the Japan Society for Civil Engineers (JSCE) following the 1995 Hyogoken-nanbu earthquake requires to consider Level 2 (L2) motion in seismic design of civil engineering structures. The L2 motion addresses input motions of extremely high intensity like that experienced in Kobe city during the 1995 earthquake. Based on discussions in a task committee of JSCE, this paper describes about definitions and features of the motion, procedures to select scenario earthquakes followed by evaluation of the motion, and its lower bound.

INTRODUCTION

Following the 1995 Hogoken-nanbu earthquake, the Japan Society of Civil Engineers (JSCE) issued twice the "Proposal on Earthquake Resistance for Civil Engineering Structures[1]"; the first in May, 1995, and the second in January, 1996. One of the requirements of the proposals is to consider two levels of input earthquake motion for seismic design of structures. Level 1 (L1) motion covers motions of moderately high intensity while Level 2 (L2) addresses motions of extremely high intensity of the nature of the strong motion experienced in Kobe city during the Hogoken-nanbu earthquake. The selection of the L1 and L2 motions is implicitly based on the expectation that the L1 motion will be experienced once or twice during the lifetime of the structure while the L2 motion has a very low probability of being experienced by the structure. The underlying design assumption is that the intensity of the L1 motion is comparable to the seismic loadings traditionally used in Japanese seismic codes for which structures are to remain within their elastic limits; for the L2 motion, structures are allowed to undergo plastic deformations as long as collapse and loss of life are prevented. For most Japanese seismic codes for civil engineering structures, the L2 motion is a new type of input earthquake motion to be considered in design. For this reason, in the above mentioned proposals, a main focus was placed on the L2 motion.

In Japan, L2 motion can most likely be caused by two types of earthquakes: interplate earthquakes occurring under the ocean and intraplate earthquakes associated with inland active faults. Regardless of the earthquake type and the difficulties associated with implementation, the proposal requires the L2 motion to be determined from the rupture process of the relevant faults affecting the structure considered.

As a whole, the concept of L2 motion as described in the proposals appears to be too general to be applied directly in design. For practical applications, more detailed guidelines are required for the estimation of the L2 motion, such as how to select scenario earthquakes and how to deal with the uncertainty inherent in the fault rupturing mechanism of future events. To respond to this need, a task committee formed by the JSCE two years ago clarified a number of these points. The committee's recommendations have been summarized in a recent report[2].

This paper is based on work done by the JSCE committee on Level 2 Earthquake Motion. Any opinions, findings and conclusions or recommendations expressed in this paper are those of the author and do not necessarily reflect the views of the JSCE and the committee.

DEFINITIONS AND FEATURES OF THE L2 MOTION

In general, the concepts of intensity and probability of occurrence are not differentiated from one another when one refers to "level" in Level 2 Earthquake Motion. This tends to create some confusion considering the two types of earthquakes contributing to the L2 motion, i.e. interplate and intraplate events. These events have different return periods and different potential intensities. Intuitively one would expect long return period events to have higher intensities than shorter return period events. This is not necessarily the case for Japanese interplate and intraplate events. The interplate or subduction earthquakes of large magnitude have relatively short return periods (of the order of a few hundred years) while the intraplate earthquakes of moderate to large magnitude caused by active faults have very long return periods (of the order of thousand years). However, the more frequent interplate events are capable of more intense shaking than the longer return period intraplate events.

To eliminate this potential source of confusion, this paper refers to "level" as a measure of the intensity only and defines Level 2 Earthquake Motion as follows:

The Level 2 Earthquake Motion to be used as an input motion for the seismic design of a specific civil engineering structure is the maximum intensity earthquake motion to be reasonably possible at the site for the structure considered.

This definition for the L2 motion implies the following:

- L2 motion is dependent of the seismic environment and geology of the site, but is independent of social factors such as importance of the structure
- The L2 motion is a "so-called" source specific, site specific and structure specific motion.
- A preferred procedure to determine the L2 motion consists of selecting a set of scenario earthquakes based on the tectonic setting of the region, to evaluate the respective ground motions at the site taking into account the site soil characteristics and finally to select the most critical of these inputs based on the response of the structure considered.
- It is desirable to formulate the L2 motion from observed earthquake motions compatible with the points presented above by using a semi-empirical method
- A lower bound of L2 motion is given by moderate local earthquakes (about M_J 6.5) caused by blind faults, which are assumed to occur uniformly throughout Japan.

SELECTION OF SCENARIO EARTHQUAKES

A standard procedure to estimate L2 motion is shown in Fig. 1. The first step consists of selecting a set of realistic earthquakes that provide the greatest seismic threat to the structure. Taking into account all information available, one or more scenario earthquakes are selected by comparing intensity of ground motion resulting from every seismic source affecting the site under investigation. In this comparison process, empirical attenuation relationships are often used to estimate ground motion intensity in terms of peak acceleration, peak velocity, JMA seismic intensity or response spectrum.

In general, candidates for the scenario events are repeats of devastating historical earthquakes and potential large earthquakes on active faults. Hence, a large database containing in-depth information about active faults and historical earthquakes facilitates the selection of the scenarios to be considered. It should be noted that scenario earthquakes for a given structure may not be applicable to nearby structures if the structures have significantly different response characteristics. Accordingly, the structure's natural period is one key factor entering into the selection of the scenario earthquakes.

EVALUATION OF L2 MOTION FROM SCENARIO EARTHQUAKES

Once a set of scenario earthquakes has been selected, the L2 motion can be estimated by various methods. As shown in Fig. 1, these methods can roughly be classified into three groups: empirical, semi-empirical and theoretical. Since each of these methods have their own advantages and limitations, it is necessary to adapt them adequately. For example, at the present state, the empirical methods are applicable to a period range shorter than 1 or 2 sec, while the theoretical methods are applicable to the range longer than 1 or 2 sec. The semi-empirical methods [3], which use observed ground motion of small or medium size earthquakes are the most appropriate for the present purpose of L2 motion estimation. The main advantage of the semi-empirical methods is twofold: if properly applied, they appropriately reflect, without much effort, the wave propagation path and the local site effects of the L2 motion and they are adaptable to both the short and long period ranges. These methods however require observed earthquake motion at the site. Hence, the availability of a recorded earthquake motion at the site prior to the planning and design process greatly facilitates the L2 motion estimation.

In the absence of recorded time histories at the site, empirical or theoretical approaches can be used.
As long as a seismic source and the subsurface soil condition are given, the associated ground

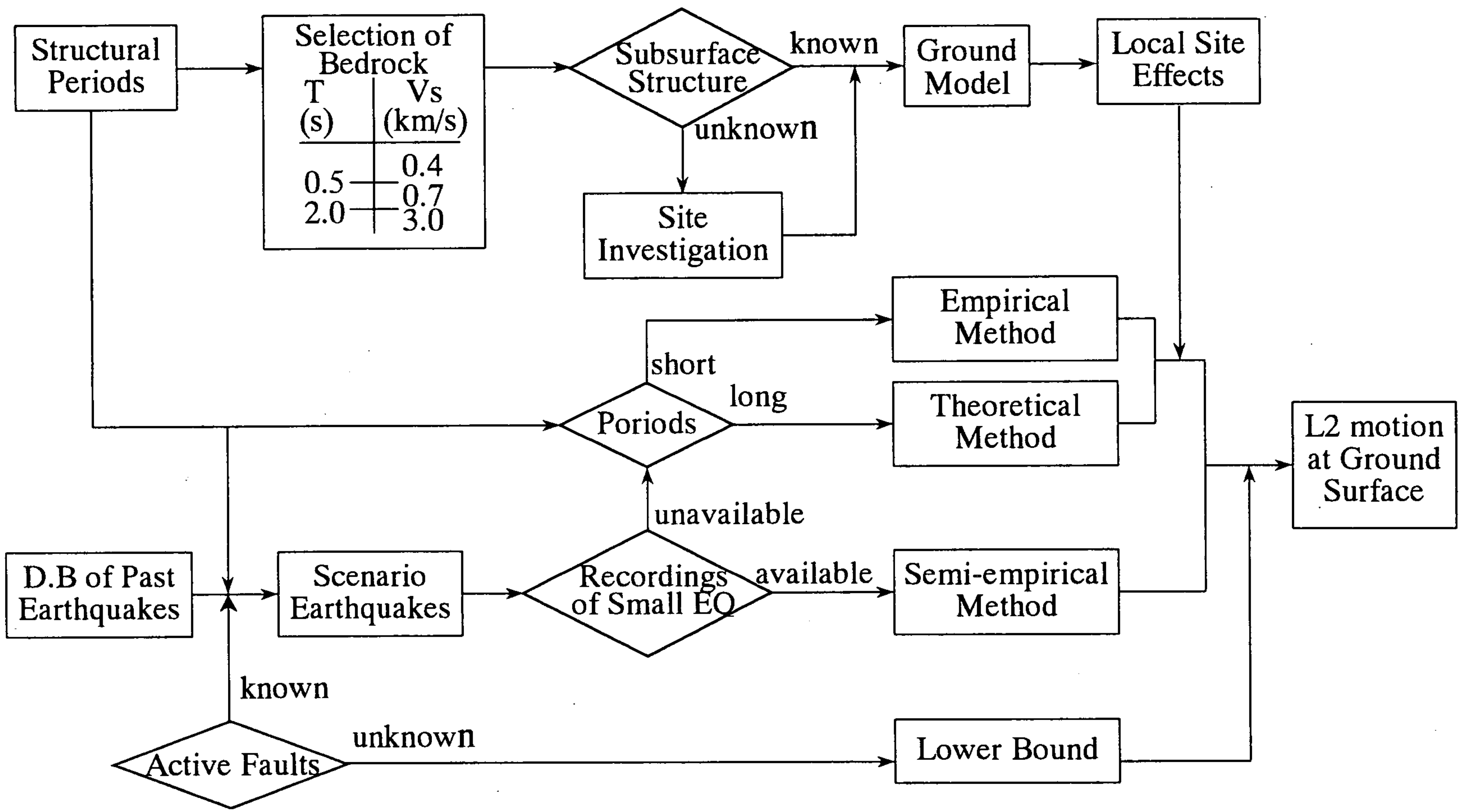

Fig.1 Flowchart to Formulate L2 Motion

motion for different periods can be evaluated to a satisfactory level of accuracy by numerical simulation. As an example of a numerical simulation[4] of the 1995 Hyogoken-nanbe earthquake using a 3-D boundary element method is shown in Figs. 2 and 3. In Fig. 2, a two-layered ground model used for the simulation is shown. The simulated area extends from the epicenter to Amagasaki and Takarazuka cities in the EW direction and from Rokko mountains to Osaka Bay in the NS direction. The source model presented by Ide et al.[5] was simplified and used in the simulation together with a source time function simplified as a ramp function having a rise time of 1.0 sec. The ground motion of periods longer than one second was simulated for comparison with the strong motion records. Comparisons of velocity time histories and their spectra at Kobe University for the NS, EW and vertical components are presented in Fig. 3. Some differences can be seen in the time histories, but inspection of the spectra indicates that they are mainly due to the shorter period components that were not considered in the simulation.

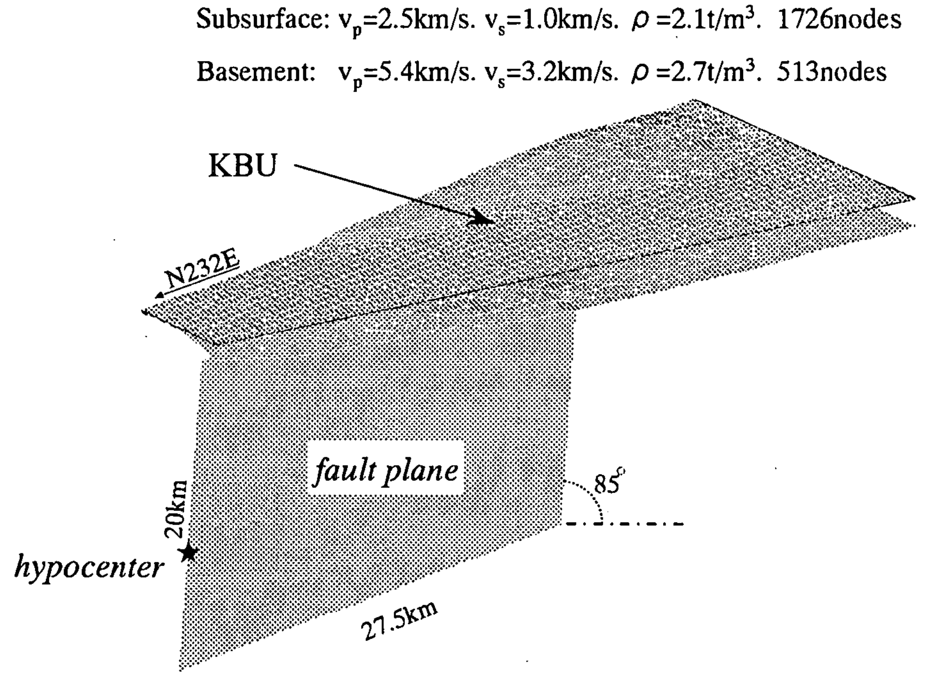

Fig.2 3-D numerical model to simulate the 1995 Hyogoken-nanbu earthquake[4]

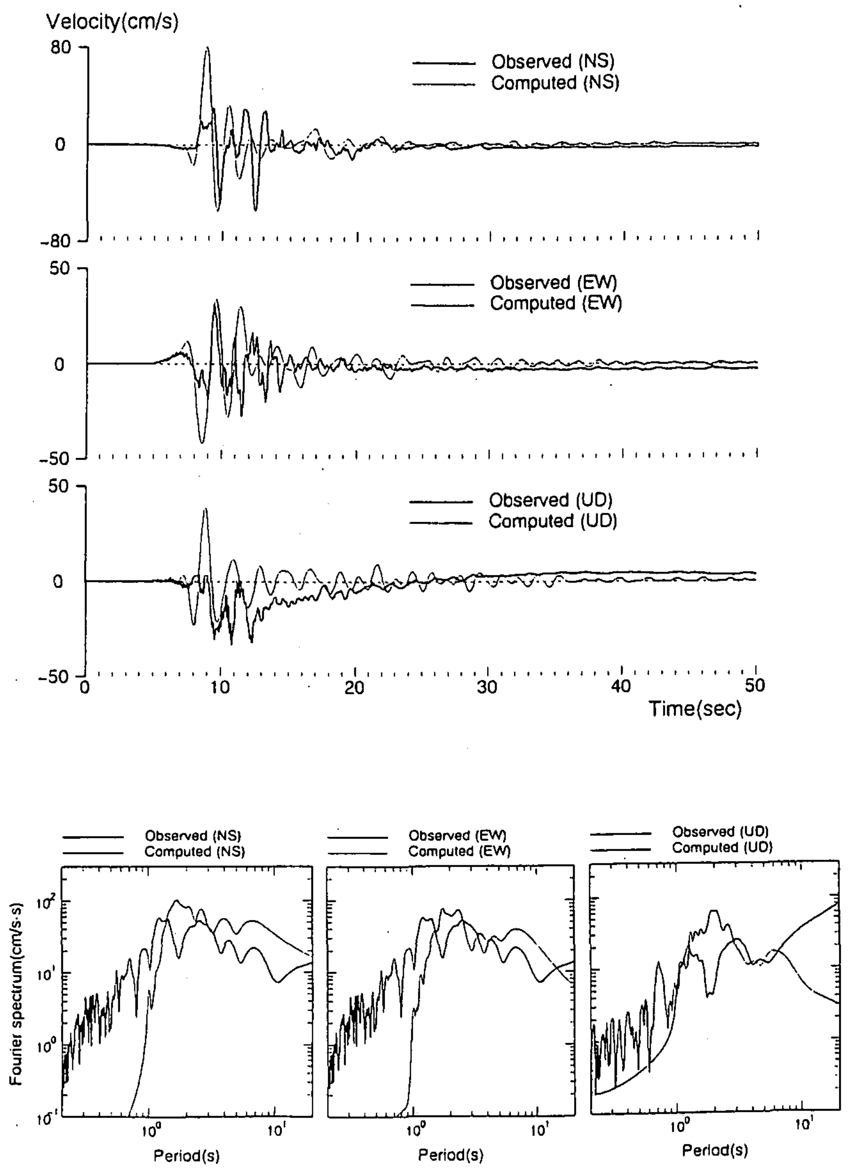

Fig. 3 Comparison of simulated and bserved strong motions at Kobe university [4)]

LOWER BOUND OF L2 MOTION

Uncertainty is inherent in the formulation of L2 motion. The uncertainty lies not only in the rupture process of future seismic faulting, but also in the location of active faults. As a matter of fact, present maps of active faults do not contain blind faults. However, inland earthquakes caused by blind faults have often affected various civil engineering structures.

In Fig .4 the solid short lines indicates the locations of the large active faults[6)] known as of today. As shown in Fig. 4, active faults are mapped mostly in the middle part of Japan, while shallow crustal events have occurred in many instances outside known fault zones. It seems safe to say that inland earthquakes are likely to occur anywhere in Japan, no matter whether they are caused by known active faults or blind faults.

Fig. 4 Distribution of active faults in Japan [6)]

In addition, according to recent studies [7)], inland earthquakes of magnitude M_J smaller than or equal to 6.5 are not likely to reveal their fault traces on the ground surface, even if the surface is not covered with sedimentary layers. On this basis an inland earthquakes of M_J 6.5 is thought to be a scenario earthquake that gives a lower bound for L2 motion. Trial calculations have shown that ground motion intensity produced by M_J 6.5 earthquakes is 6- on the JMA instrumental intensity scale for most part of Japan except for exposed hard rock sites. Similar calculation results are shown in Fig. 5 in terms of acceleration response spectra, for which a subsurface ground structure for Hanshin area shown in Table 1 was used with a vertical 10km × 10km seismic fault of either a strike-slip or a dip-slip type located variously. Judging from Fig. 5, the lower bound of the L2 motion is related to acceleration response of 1G at the ground surface in the period range of 0.1 ~1.0 sec, in which G denotes acceleration of gravity.

Table 1. Subsurface ground structure

Layer	S-wave velocity Vs(km/s)	P-wave velocity Vp(km/s)	Density ρ (t/m^3)	Q	Thickness (km)
1	0.35	1.6	1.7	15	0.20
2	0.55	1.8	1.8	25	0.30
3	1.00	2.5	2.1	35	0.50
4	3.20	5.40	2.6	37	----

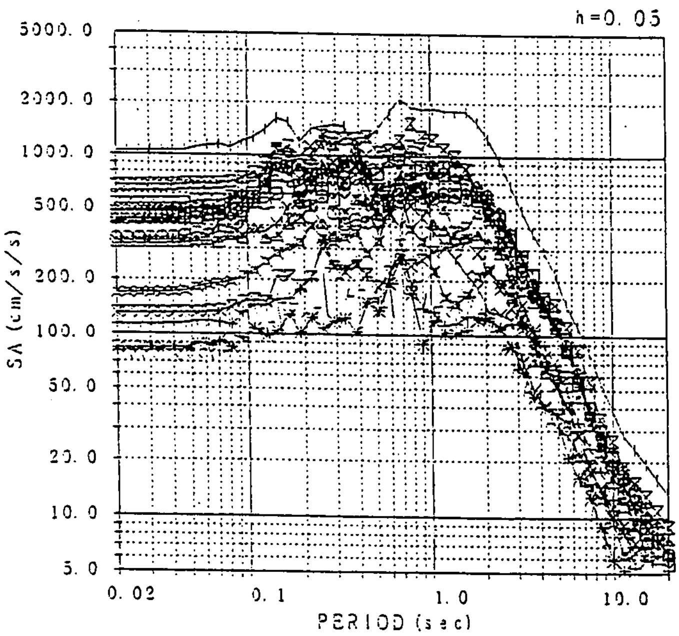

Fig. 5 Acceleration response spectra in near-field of M_J 6.5 earthquakes [2)]

CONCLUSIVE REMARKS

Since the JSCE Proposal was issued, various efforts have been made to facilitate practical application of the L2 motion. The efforts include detailed description about definitions and features of the motion, and a trial evaluation of its lower bound. In a word, the L2 motion is evaluated as a source-specific and site-specific motion. However, in designing a structure of less importance, a simplified procedure may be needed for practical application. In such a case, the lower bound of the L2 motion evaluated on a site-specific basis can be a substitute. This is because the L2 motion is much associated with the so-called performance-based design where the importance is taken into account in the structural performance under input earthquake motions, but not in evaluation of the motions.

There still remains much room for full implementation of the Proposal as regards:

1) The L2 motion should be described in terms of probability of occurrence in order to be widely used in the performance-based design.
2) Similarly, the L1 motion should be defined in a similar context as the L2 motion.
3) A subsurface ground structure extending to seismic bedrock should be explored throughout Japan as soon as possible.
4) Causes and effects of active faults should be studied from civil engineering points of view.
5) Rupture process of seismic faults should be characterized in detail to reduce uncertainty in evaluation of the L2 motion.

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