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Determination of mean shear wave velocity to 30 m depth for site classification using shallow depth shear wave velocity profile in Korea

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ABSTRACT

The mean shear wave velocity to a depth of 30 m (V_S30), established in the western United States, is the current site classification criterion for determining the seismic design ground motion, taking site amplification potential account into. To evaluate V_S30 at a site, a shear wave velocity (V_S) profile extending to a depth of at least 30 m must be acquired using in situ seismic tests. In many cases, however, the obtained V_S profile does not extend to a depth of 30 m due to unfavorable field conditions and limitations of testing techniques. In this study, V_S30 and the mean shear wave velocity to depths less than 30 m (V_SDs) were calculated using V_S profiles of more than 30 m obtained by seismic tests at 72 sites in Korea, and the correlation between V_S30 and V_SDs was drawn based on the computed mean V_S data. Additionally, a method for extrapolating the V_S profile from shallow depths to 30 m and bedrock was developed by building a shape curve based on the average data of all V_S profiles. These two methods of extrapolating V_S30 from shallow V_S profiles, using V_SDs and a shape curve, resulted in less bias than the simple method in which the lowermost V_S value obtained is extended to the depth of 30 m. These two extrapolation methods are useful for V_S profiles extending to depths of at least 10 m. Furthermore, the shape curve method developed in this study may be useful in the western United States as well as in Korea.

1. Introduction

The dynamic characteristics of a site can be represented by shear wave velocity (V_S). Current earthquake-resistant design codes [1–5] suggest that the mean V_S of the upper 30 m (V_S30) be used to characterize site conditions [6–8]. Site coefficients (or site amplification factors), which quantify local site effects, can be determined based on the site classification system according to V_S30 [9–12]. Design ground motion is estimated by combining the reference rock motion and the site coefficients for short-period (F_a) and mid-period (F_v) associated with seismic amplification effects [9,11,13]. The most important factor in these determinations is the V_S profile with depth at the site.

Site conditions can be characterized into five categories (denoted by A through E) according to the V_S30 described in current seismic design codes, as listed in Table 1 [1,2,5]. Although a depth of 30 m (100 ft) is very shallow in seismological terms, it is the depth of conventional borehole drilling and of detailed geotechnical studies in the western United States (US), where the depth to bedrock (H) is comparatively large [14]. The geological conditions and dynamic properties of material near the ground surface contribute significantly to seismic site responses [15,16], so V_S30 is very useful for earthquake engineering [17–19]. V_S30 is calculated from the time taken by a shear wave to travel from a depth of 30 m to the ground surface. For a profile consisting of n soil and/or rock layers, V_S30 can be calculated as

$$V_S30 = 30 / \sum_{i=1}^{n} \frac{d_i}{V_{Si}} \qquad (1)$$

where d_i and V_{Si} are the thickness and the V_S of each soil or rock layer to a depth of 30 m ($30\ \text{m} = \Sigma d_i$), respectively. To use V_S30 in seismic site categorization, the V_S distribution to a depth of more than 30 m should be acquired from seismic tests in the field. Despite the requirement for the V_S profile to have a considerable depth, V_S30 has been applied widely as the sole criterion for classifying site conditions in most current earthquake-resistant design codes because of its simplicity and lack of ambiguity [20,21].

Several in situ seismic testing techniques have been developed to determine V_S profiles worldwide [22–24]. In Korea, existing techniques are being improved by incorporating the ability to include local field conditions [25,26]. To determine V_S for earthquake-resistant applications in a particular area using seismic testing, a V_S profile that

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covers a depth of at least 30 m from the ground surface must be acquired. However, testing that extends beyond 30 m may result in unreliable variables because of incomplete knowledge of the subsurface environment. Furthermore, a particular in situ testing method or instrument may be useful for only a limited range of ground conditions and depths [11]. Recently, geotechnical and geophysical testing techniques, including in situ seismic survey methods, and hybrid in situ testing techniques such as the seismic piezocone penetration test (SCPTu) and the seismic dilatometer test (SDMT), have been successfully combined to evaluate various geotechnical characteristics [27,28]. Penetration tests, however, remain limited in the depth to which they can provide meaningful V_S data.

Table 1
Site classification system with V_S30 of the current earthquake-resistant design guidelines [1–3,5].

Site class (soil profile type)	Generic description	Mean V_S of top 30 m, V_S30 (m/s)
A (S_A)	Hard rock	$1500 < V_S30$
B (S_B)	Rock	$760 < V_S30 \leq 1500$
C (S_C)	Very dense soil and soft rock	$360 < V_S30 \leq 760$
D (S_D)	Stiff soil	$180 < V_S30 \leq 360$
E (S_E)	Soft soil	$V_S30 \leq 180$
F (S_F)	Requires site-specific evaluation	

The V_S profiles acquired from different in situ seismic tests are used to determine near-surface earthquake ground motion. The two most commonly used methods for determining the ground motion are site classification based on V_S30 and site-specific seismic response analysis using the V_S profile of soil strata and the unique V_S of infinite-assumed bedrock. Recently several researchers [13,24,29,30] have proposed another method of site classification that uses the predominant (or fundamental) site period (T_G) determined using Eq. (2), but this method has not yet been officially sanctioned in earthquake-resistant design guidelines. The site period is based on the thickness of the soil layers overlying the bedrock at each site and their V_S

$$T_G = 4\sum_{i=1}^{n}\frac{D_i}{V_{Si}} \tag{2}$$

where D_i and V_{Si} are the thickness ($H=\sum D_i$) and V_S, respectively, of the ith layer above bedrock. Regardless, all of these methods require V_S profile data.

As a result of the complex factors discussed above, V_S profiles to a depth of 30 m might not be obtainable for a given site [11,17]. To determine earthquake ground motion in the context of current seismic design guidelines [31], it is necessary to calculate V_S30 (the criterion for site classification), which means that sites with V_S data that do not extend to a depth of 30 m cannot be evaluated properly [11,32]. Several studies [17,33,34] have used V_S profiles of

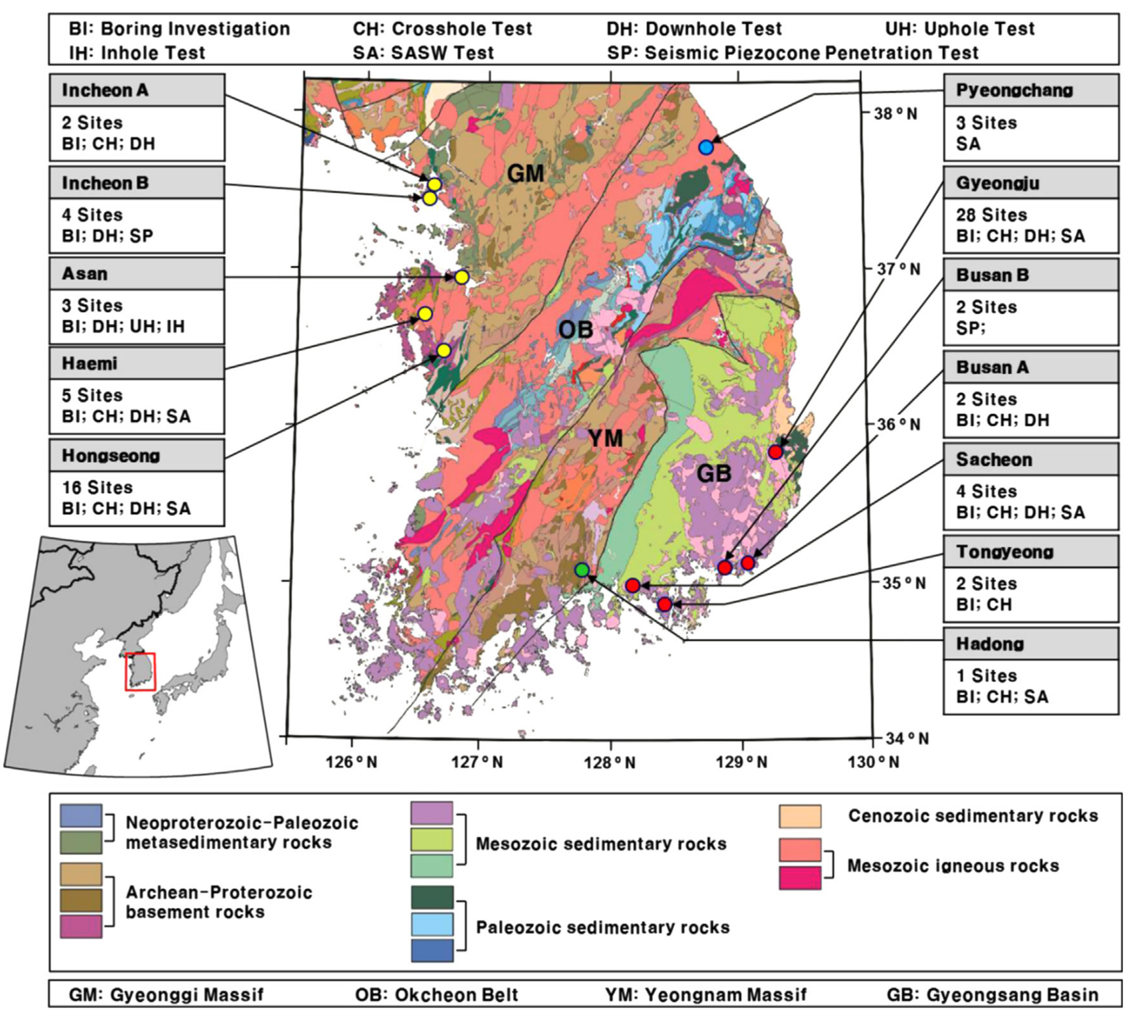

Fig. 1. Geographic locations of study areas and contents of site investigation. The geological setting of the Korean Peninsula is presented as the base map. Within the box for each study area, the first line is the name of the study area and the second and third lines are the number of site locations and the in situ investigation methods adopted in the study area, respectively. In total, the target area of this study contains 12 study areas and the associated 72 test sites.