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DETERMINING A PROFILE OF SHEAR WAVE VELOCITY USING LABORATORY MEASUREMENTS: APPLICATION TO THE SCALE EFFECT

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ABSTRACT

Most of the liquefaction assessment methods are based on penetration tests; few works can be found in the literature about the methods based on shear wave velocity. In this paper, a preliminary method of field shear wave velocity determination using laboratory measurements is presented. The laboratory tests were performed using bender elements. The effects of sample dimension, water content and isotropic pressure were examined. The application of this method to field condition showed that it is necessary to consider a scaling factor for the variability of soil at different depths. However, the whole procedure will be validated only when more in situ and laboratory tests are conducted.

Keywords: loess, bender element, shear wave velocity, scaling factor

INTRODUCTION

In the last two decades, the use of shear wave velocity V_s in the evaluation of liquefaction risk as a promising alternative and/or a supplement to the methods based on the penetration tests (SPT or CPT), has not ceased growing. In field condition, V_s can be measured either directly using the techniques of spectral surface wave analysis (SASW), or indirectly using the dynamic penetration test (SCPT), dynamic dilatometer test (SDMT) etc. However, sometimes it is difficult to perform field tests especially in urban zones where usually, traffic is dense and working place is not wide enough. On the other hand, V_s can be determined in laboratory using techniques such as resonant columns and piezoceramic transducers (Bender element). Theoretically, it is possible to determine the shear wave velocity profile using measurements in laboratory. This could constitute a good alternative to the measurement using field tests.

In this work, V_s in a loess from northern France is measured. The results showed a significant effect of isotropic pressure and water content. A new evaluation method was proposed, taking into account this effect. This method was confronted to the direct measurement by SASW in Beugnâtre site, near Picardie station (France). The comparison showed that, for a more accurate prediction, it is necessary to consider a scaling factor in the method. This factor can be function of void ratio or carbonate content.

MATERIAL

The studied material is a loess from northern France. Sampling was carried out according to the French standard NF XP 94-202 in a trench of 1.5m x 9m located at 140 km North of Paris and 25m far from the line of Large Velocity Train (TGV). Four various depths (1.2, 2.2; 3.5; and 4.9 m) were considered. The geotechnical properties were presented by Cui et al. (2004, 2005) and are presented in Table 1. The liquid limit is comprised between 26 and 30; the index of plasticity varies from 6 to 9; the dry density is rather low (ρ_d = 1.39 to 1.55 Mg/m^3); the carbonate content is quite high (5% to

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15%). The suction measured using filter paper method is not very high, ranging from 13.8 to 34.1 kPa, even though the natural degree of saturation is quite low, ranging from 53 to 82%. The grain size distribution analysis showed that the clay fraction (%<2 mm) is comprised between 16 and 20%. X-ray diffractometry showed that the clay fraction involves kaolinite, illite and interstratified illite-smectite.

Table 1. Geotechnical properties of the studied loess (Cui et al., 2004, 2005)

Depth ***(m)***	ρ_s **(Mg/m^3)**	**% < 2µm**	w_L **(%)**	I_p	ρ_d **(Mg/m^3)**	w_{nat} **(%)**	S_{rnat} **(%)**	**CaCo$_3$ (%)**	**Suction (kPa)**
1.20	2.719	20	30	9	1.52	**19**	66	5	20.1
2.20	2.714	16	28	6	1.39	**18.1**	53	6	34.1
3.50	2.713	16	26	6	1.54	**16.6**	55	15	27.5
4.90	2.712	18	30	9	1.55	**23.6**	82	9	13.8

EXPERIMENTAL SETUP AND TEST PROCEDURE

As Lings & Greening (2001), a triaxial cell equipped with embedded piezoceramic bender extender element was used to measure V_s under different isotropic pressure. Two cell bases were adopted, 50mm and 80mm respectively. A voltage excitation of sinusoidal or square type was generated using a function generator, and applied to the transmitter element. The technique adopted for the measurement can be found in Viggiani & Atkinson (1995), Jovicic et al. (1996), Brignoli et al. (1996) Arulnathan et al. (1998), Rinaldi & Brocanelli (1998) Blewett & Woodward (1999, 2000), Dano & Hicher (2003), Greening et al. (2003) and Lee & Santamarina (2004). A schematic view of the overall test apparatus is presented in Figure 1.

Bender elements were excited by sinusoidal input signals with a frequency of 10 kHz and a voltage of 14 V.

Figure 1. Schematic view of a triaxial cell equipped with bender elements

Cylindrical specimen were cut and trimmed to different desired dimensions (various ratio of height to diameter, H/D). The cables of bender elements were grounded to avoid electrical cross talk. Tests were conducted on dried and humidified samples. Drying was done by leaving the samples in contact with air and humidification was done by adding water using a spray gun. All samples have followed the loading program as:

- isotropic loading from 2 kPa to 650 kPa;
- isotropic unloading from 650 kPa to 2 kPa.

EXPERIMENTAL RESULTS

Effect of the ratio of height to diameter (H/D)

Measurements of the shear wave velocity on dry samples with various heights for the same diameter (the densities were almost equal) were carried out. As shown in Figure 2, for a sample height of 3.7cm for example, the S wave arrival is represented by point A corresponding to the first amplification of the response. However, for a greater height, 13.8cm for example, the amplification starts at point A'. Before this point, only reflected P waves were observed. The bender elements generate by vibration two side lobes of P waves which are normal to their propagation plane (one wave is in compression and the other is in rarefaction), and a frontal lobe of S wave (Lee and Santamarina, 2004). This phenomenon is known under transversal and longitudinal directivity. Hence, the effect of directivity seems to be amplified with the increase of height: the higher the sample, the more the effect of reflected compression P waves on the arrival of shear wave (S wave). Therefore, in order to reduce such a problem, it is necessary to use samples with small H/D ratio. A ratio H/D≤1 is recommended.

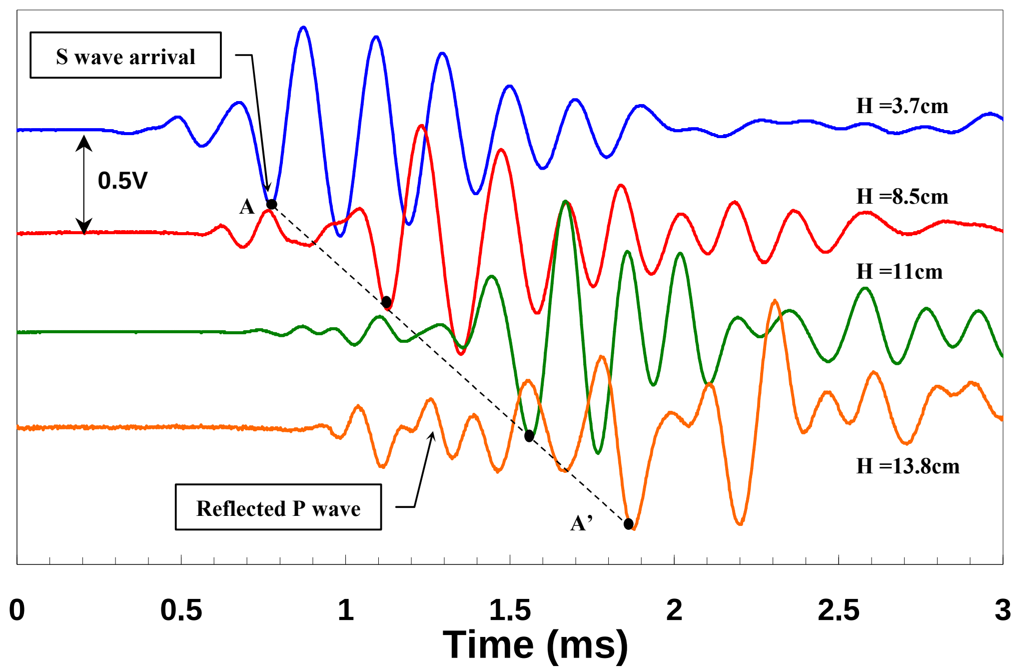

Figure 2. Effect of H/D ratio

Effect of water content and isotropic pressure

In order to understand the effect of degree of saturation and isotropic pressure on shear wave velocity, 5 samples taken at 2.20 m depth were loaded to various isotropic pressures at different water content; V_s was measured under each pressure. Two samples were air dried to 1% and 10% water content respectively, two other samples were humidified to 23% and 33% water content respectively, the fifth being kept at its natural water content, 17%. The results during loading are presented in Figure 3 in a logarithmic scale, showing that there is a significant effect of water content and pressure: V_s increases with pressure increase and water content decrease. It can be also observed that all the five curves are nearly parallel. This enables the formulation of V_s as a function of pressure and water content by curve fitting, as follows:

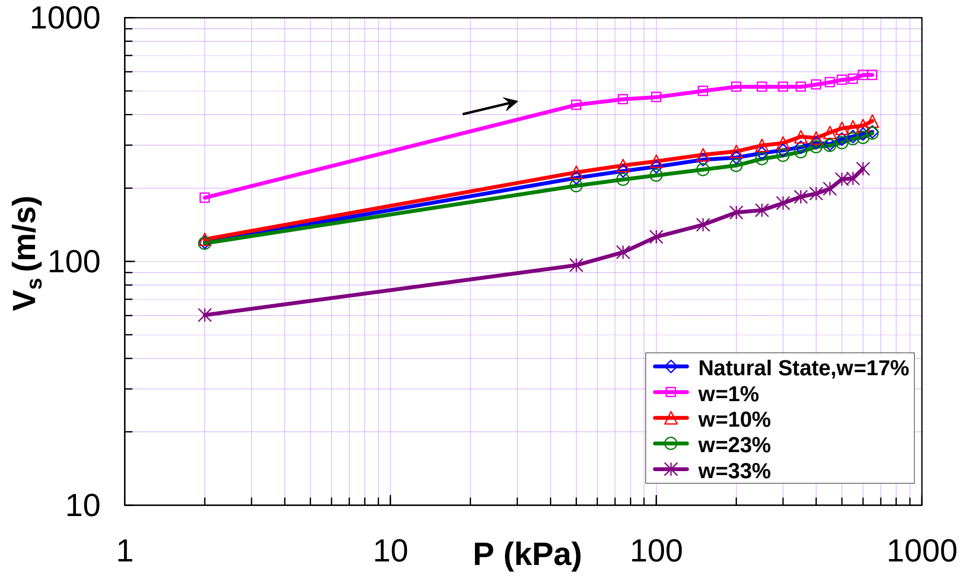

Figure 3. Effect of water content and isotropic pressure on V_s for the loess taken at 2.20 m

$$V_s = \lambda(w) \times P^{\theta(w)} \quad (1)$$

where
V_s is shear velocity in m/s,
P is isotropic pressure in kPa
w is water content in %
$\lambda(w) = -0.0188\, w^3 + w^2 - 17.218w + 202.22$
$\theta(w) = 10^{-5} \times w^3 - 5\times10^{-4} \times w^2 + 4.4 \times 10^{-3} \times w + 0.1774$

APPLICATION TO BEUGNÂTRE SITE

In order to check the relevance of the developed method, Eq. 1 was used to determine the V_s profile in Beugnâtre site; the calculated profile was then compared with that obtained using SASW technique. For the SASW measurement, 48 geophones of 10 Hz was installed; a hammer of 10 kg was used as a dynamic source. The distance between the source and the first geophone is 10 m. The geotechnical parameters (density ρ and Poisson coefficient ν) used to calculate V_s by back analysis in the SASW method are presented in Table 2. It should be mentioned that for depths greater than 5 m, the parameters were estimated. A comparison between the two profiles is presented in Figure 4. It is observed that the proposed method overestimated V_s, especially for depths greater than 4 m. This difference is mainly due to the fact that the samples studied in laboratory were not always representative of the large layer considered where the geotechnical properties may vary significantly with depth (see Table1). Hence, a correction of the calculated profile must be made by introducing a scaling factor SF. This factor should be dependent of the soil properties such as void ratio and carbonate content; its determination needs further analysis. The corrected V_s can be then expressed as:

$$V_{s\,cor} = V_{s\,cal} \times SF \quad (2)$$

Table 2 :Geotechnical parameters used to determine the profile of the shear wave velocity by the SASW method on the site of Beugnarte (SNCF, 2005)

Depth (m)	V_s *(m/s)*	ρ *(g/cm³)*	ν
0.0	122.2	1.7689	0.4265
1.2	133.9	1.7689	0.4297
2.4	167.4	1.7689	0.2937
3.6	233.7	1.7689	0.3670
4.8	243.5	1.7689	0.3919
6.0	166.3	1.7689	0.4654
7.2	79.7	1.7689	0.4682
8.4	223.2	1.7689	0.4187
9.6	166.6	1.7689	0.4717
10.8	133.9	1.7689	0.4711

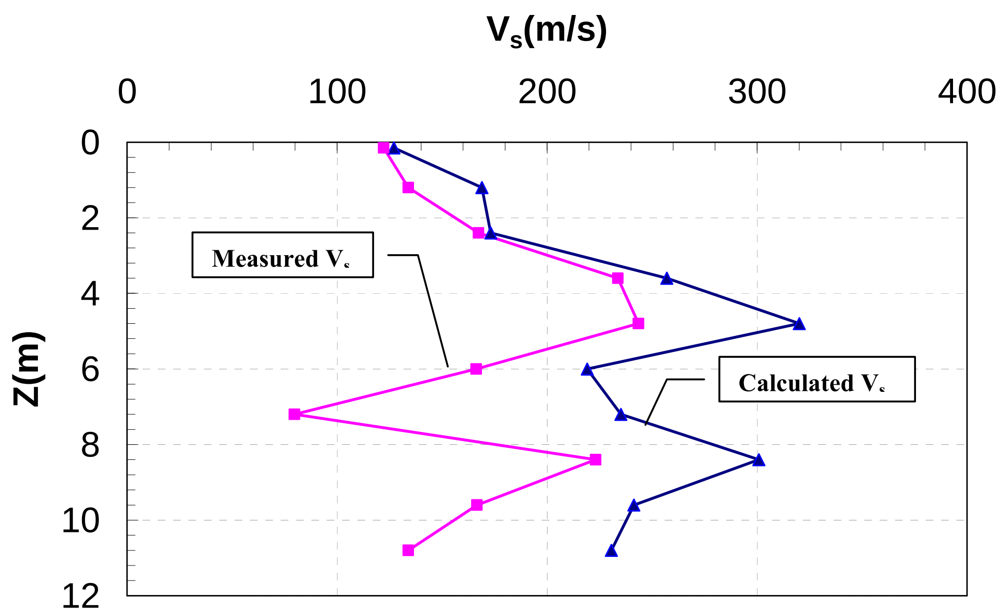

Figure 4. Comparison between calculated and measured V_s profiles

For the studied loess, examination of Figure 4 resulted in the following expression:

$$S.F. = 0.96 \times \exp(-0.0381 \times Z) \quad (3)$$

Where Z is the soil depth in m.

The corrected profile is plotted in Figure 5. The only difference that we can observe is at 7 m depth. This could be attributed to the lack of accuracy of SASW technique for great depths. Indeed, because of the analysis method which considers a larger and larger soil layer when going to deeper soil, the SASW technique is less accurate when getting deeper. It will be interesting to make more measurements in this layer.

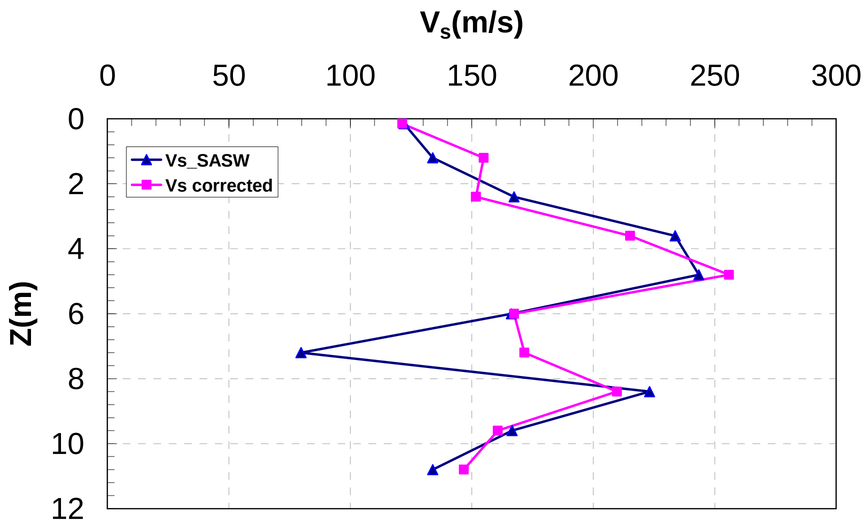

Figure 5: Corrected V_s profile after introducing the scaling factor

CONCLUSION

A triaxial cell equipped with bender elements was used to examine the shear wave propagation in a loess taken from northern France. The effect of isotropic pressure and water content was examined. It was observed that shear wave velocity (V_s) increases with pressure increase or water content decrease. Based on the experimental results, a new but preliminary correlation method was proposed which considers the effect of pressure and water content. This method was applied to Beugnâtre site and the calculated V_s values were compared to that obtained using SASW technique. It was observed that in order to consider the soil variability along the depth, it is necessary to introduce a scaling factor that is dependent of the soil geotechnical properties such as void ratio and carbonate content. Finally, some in situ parameters where estimated for depths greater than 5m, therefore and in order to validate this correlation, the authors suggest that more in situ and laboratory tests should be conducted.

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