

THE SIMPLE METHOD OF SHEAR WAVE VELOCITY PROFILE FROM EXPLOSION SOURCE IN SURIN, THAILAND

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ABSTRACT: This study aimed to propose a correlation of shear wave velocity (V_s) derived from explosives using the Simple Method (SM). The SM is a technique for surveying shear wave velocity and is used to analyze vibration records at the surface through an established dispersion curve. The seismic wave was generated below ground surface. The shear wave emanates from the source is detected by a geophone at the ground surface and measure traveling time of shear wave for calculated shear wave velocity to estimate soil layer. The tested site was in Surin Province, northern Thailand (large-scale underground petroleum seismic survey area). In the present study, the SM technique was adopted to evaluate the shear wave velocity profile from underground explosives. The results showed that the SM agreed with those obtained from the Downhole Seismic Test (DH). The DH is geophysical surveys for determining shear wave velocity. Required parameters were then obtained through calibration with the results from the DH test. Subsequently, the shear wave velocity profiles from SM using explosives in the test area were then obtained. The SM has been used for vibration and shear wave velocity analysis of soil.

Keywords: Simple method, Shear wave velocity, Explosives, Vibration

1. INTRODUCTION

Shear wave velocity (V_s) is an important factor in measuring the dynamic and cyclic responses of subsoil layers. Advanced laboratory procedures have been developed over decades to determine the shear wave velocity in a soil sample; i.e. the resonant column test, cyclic torsional and triaxial tests, bending element test, etc. The results of these advanced laboratory tests have played a crucial role in establishing various important correlations between shear wave velocity, states of stresses, density, etc. At the same time, shear wave velocity field measurements have also been vastly improved; i.e. downhole and cross-hole seismic tests, seismic cone penetration test, etc. Although field measurement has grown in popularity, the attempt to apply well-established laboratory correlations to field measurement has not been successful [1]-[7].

2. METHODOLOGY

2.1 General Site Information

Figure 1 shows the general subsoil profile in the study area (Latitude 15°21'32.8"N, Longitude 103°23'55.6"E). There are 4 main soil types at the site as follows: First, Silty sand layer (SM): the layer extends from the surface to a depth of about 4.5 m. It mostly contains silt mixed with very fine sand. The relative density measured using split spoon ranged from medium to dense. Second, Fine

to coarse sand layer (SP, SP-SM): this layer of medium to dense coarse sand is found beneath the top silty sand layer. It extends to a depth of about 15 m from the surface. Third, Silt-coarse sand layer (SM, SP-SM): this silty sand is found between 15 m to 25 m from the surface. The relative density ranged from medium to very dense. Fourth, Cemented coarse sand layer: this very dense cemented coarse sand lies beneath the site to a depth of 32 m (end of boring).

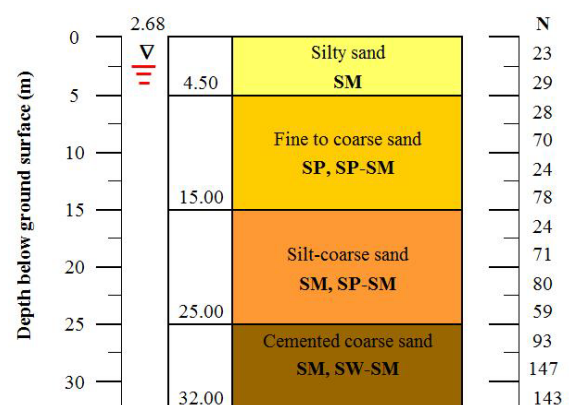


Fig. 1 Soil profile in Surin province

2.2 Field Measurement

In the present study, the Simple Method (SM) was adopted to analyze the surface waves generated from underground explosives. The tested

site in Surin province was under a large scale underground petroleum seismic survey. The explosives used were single hole shot point at approximately 13 m depth. The explosive was 4 kg of ammonium nitrate emulsion Emulex 700 (Figs. 2 and 3). A series of sixteen well calibrated 4.5-Hz vertical-component geophones were placed on the surface at various distances from selected explosives to record the ground surface motions. The maximum investigation depth of the project was around 30 m. The nearest offset to first geophone (X_1) was 10 m with an interval of 20 m (d), 300 m (D), and total spread (Table 1 and Figs. 4-5). The maximum investigation depth is normally half of the longest wavelength. Figures 6 and 7 show the field blasting and path of the wave, which is used to determine shear wave velocity.

Table 1 Geophone array in Surin province

| Geophone, X_1 (m) | Explosive (kg) | d (m) |
|---------------------|----------------|-------|
| 10 | 4 | 20 |

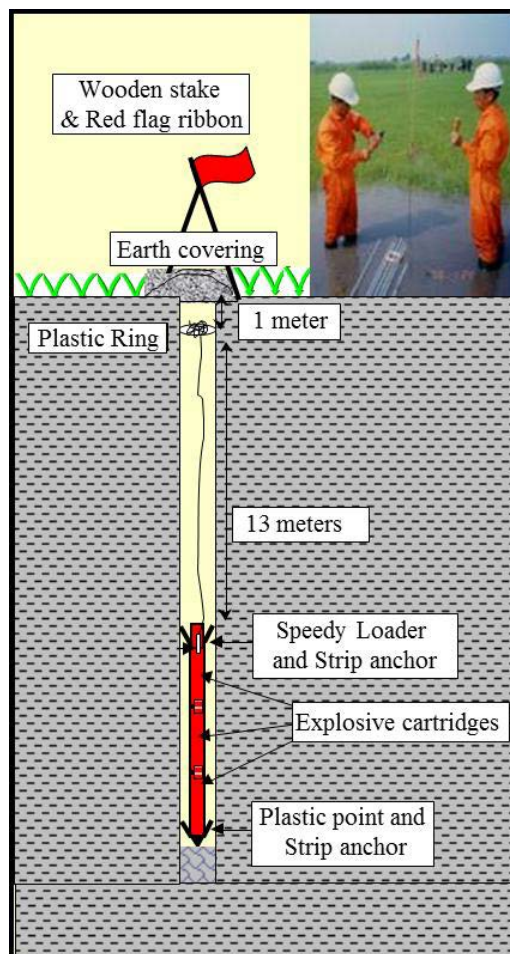


Fig. 2 Emulex-700 Ammonia Nitrate Emulsion



Fig. 3 Explosive installation

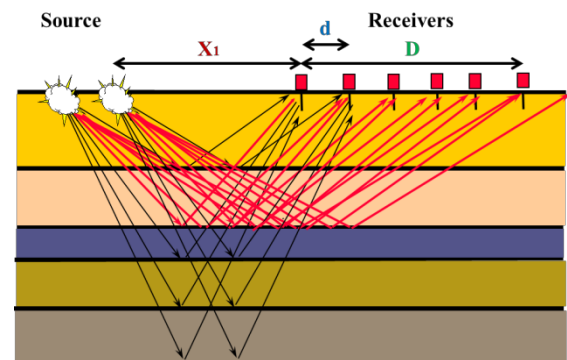


Fig. 4 Geophone array



Fig. 5 Geophone installation



Fig. 6 Blasting shot point

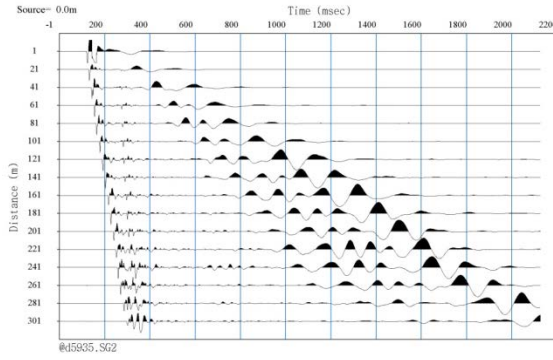


Fig. 7 The typical record of wave arrival

2.3 Simple Method (SM)

A simple Method is a new approach to analyzing the characteristics of the primary wave (S_1) and surface wave (S_2 to S_6). First, shot data is gathered and converted to period by Eq. (1) as shown in Fig. 8 and converted to dispersion curve technique ($v-f$) by Eqs. (2) - (3) as shown in Fig. 9. Shear wave velocity can be derived by Eq. (4) and inverting the depth of the soil layer by Eqs. (5) - (6).

$$T_i = S_i \quad (i = 2-6) \quad (1)$$

$$f = 1/T_i \quad (2)$$

$$v = \Delta x / \Delta t \quad (3)$$

$$V_s \approx 1.1v \quad (4)$$

$$\lambda = v / f \quad (5)$$

$$Z \approx \lambda / 2 \quad (6)$$

Where S_i is time (s); T_i is period (s); f is frequency (s^{-1}); x is geophone array (m); v is phase velocity (m/s); λ is wavelength (m); V_s is shear wave velocity (m/s) and Z is depth (m)

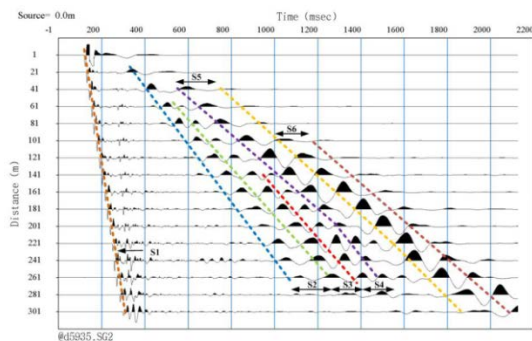


Fig. 8 Interpretation of SM

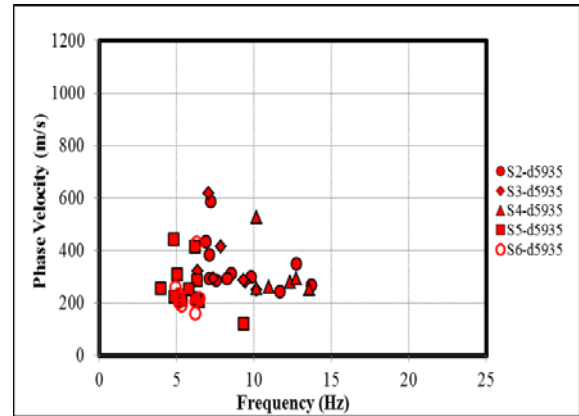


Fig. 9 The dispersion curve technique ($v-f$)

2.4 Downhole Seismic Test (DH)

A Downhole Seismic Test is performed by installing a movable seismic receiver in the borehole and measuring excitation at the surface (Fig. 10) [8]-[10]. The recorded waves arriving at different depths are then analyzed to compute the shear wave velocity of the corresponding soil in Eqs. (7) - (8). A typical record of wave arrival in the DH test is shown in Fig. 11.

$$t_c = \frac{D \cdot t}{R} = \frac{D \cdot t}{\sqrt{D^2 + H^2}} \quad (7)$$

$$V_s = \Delta D / \Delta t_c \quad (8)$$

Where t is measured travel time (s); D is the testing depth from the surface (m); H is the distance between the source and receiver in the horizontal path (m); R is the distance between the source and receiver in the inclined path (m); t_c is corrected travel time (s) and V_s is shear wave velocity (m/s) (Fig. 12)

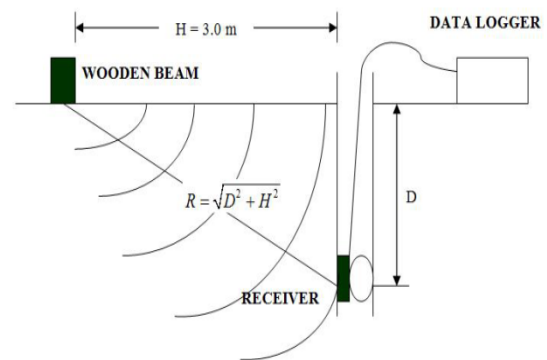


Fig. 10 Field measurement of DH

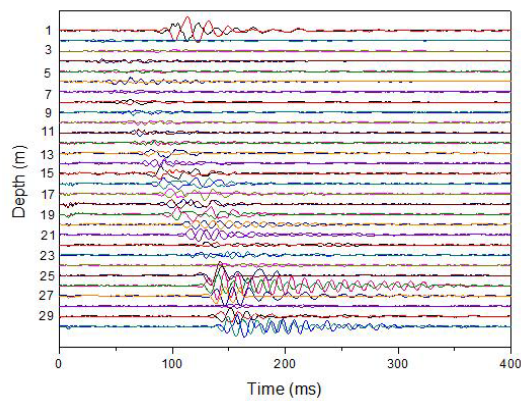


Fig. 11 A typical record of wave arrival in the DH

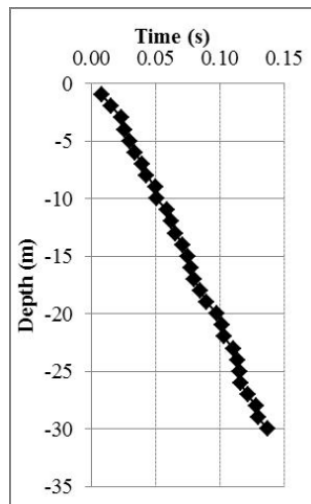


Fig. 12 Interpretation of DH

3. RESULTS AND DISCUSSION

3.1 Simple Method (SM)

Figure 13 shows that analysis of the data using the Simple Method established the relationship between the phase velocity and frequency (Fig. 9 and Table 2), with inversion to determine the shear wave velocity at the depth of the soil layer. The results established an empirical correlation between shear wave velocity and depth as shown in Eq. (9).

Table 2 Inversion of Simple Method (S2-d5935)

| f | v | V_s | Z |
|-------|--------|--------|-------|
| 13.72 | 267.02 | 293.72 | 9.73 |
| 12.74 | 349.65 | 384.62 | 13.72 |
| 11.68 | 243.90 | 268.29 | 10.44 |
| 9.83 | 301.20 | 331.33 | 15.32 |
| 8.52 | 311.04 | 342.15 | 18.26 |
| 8.26 | 294.99 | 324.48 | 17.85 |

Table 2 continued

| f | v | V_s | Z |
|------|--------|--------|-------|
| 6.91 | 433.84 | 477.22 | 31.41 |
| 7.11 | 383.88 | 422.26 | 27.01 |
| 7.10 | 294.99 | 324.48 | 20.77 |
| 7.18 | 588.24 | 647.06 | 40.94 |
| 7.56 | 288.60 | 317.46 | 19.08 |

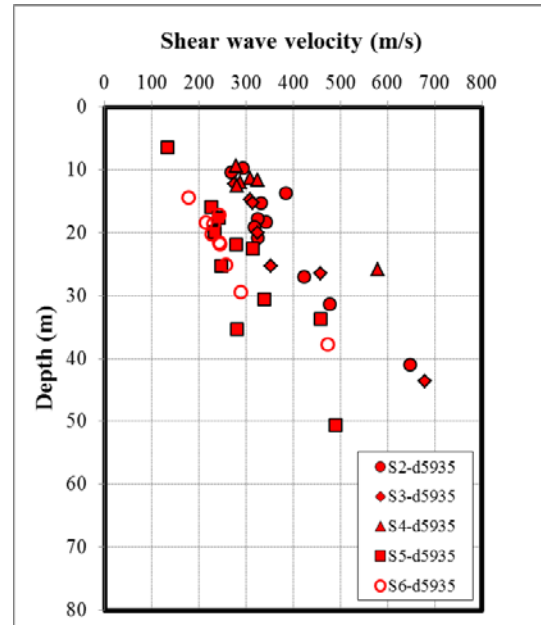


Fig. 13 Shear wave velocity profile by SM

$$V_s = 10.32Z + 79.66 \quad (9)$$

Where Z is the depth from the surface (m) and V_s is shear wave velocity (m/s)

3.2 Downhole Seismic Test (DH)

Figure 14 shows the result of analysis of the Downhole Seismic Test data in Eqs. (7) and (8). The V_s can be calculated by the traveling time (Fig. 12 and Table 3). The calculation must be done sequentially from the top to the bottom of the borehole. The results established an empirical correlation between shear wave velocity and depth as shown in Eq. (10).

Table 3 Inversion of Downhole Seismic Test

| ΔD | Δt_c | V_s | Z |
|------------|--------------|-------|-----|
| 1 | 0.0082 | 122 | 1 |
| 1 | 0.0154 | 138 | 2 |
| 1 | 0.0238 | 119 | 3 |
| 1 | 0.0258 | 505 | 4 |
| 1 | 0.0303 | 219 | 5 |
| 1 | 0.0340 | 270 | 6 |

Table 3 continued

| ΔD | Δt_c | V_s | Z |
|------------|--------------|--------|----|
| 1 | 0.0392 | 193 | 7 |
| 1 | 0.0432 | 252 | 8 |
| 1 | 0.0498 | 152 | 9 |
| 1 | 0.0509 | 907 | 10 |
| 1 | 0.0593 | 118 | 11 |
| 1 | 0.0625 | 308 | 12 |
| 1 | 0.0655 | 338 | 13 |
| 1 | 0.0708 | 187 | 14 |
| 1 | 0.0748 | 254 | 15 |
| 1 | 0.0774 | 379 | 16 |
| 1 | 0.0798 | 416 | 17 |
| 1 | 0.0851 | 191 | 18 |
| 1 | 0.0898 | 212 | 19 |
| 1 | 0.0981 | 120 | 20 |
| 1 | 0.1021 | 248 | 21 |
| 1 | 0.1034 | 796 | 22 |
| 1 | 0.1105 | 141 | 23 |
| 1 | 0.1139 | 293 | 24 |
| 1 | 0.1157 | 567 | 25 |
| 1 | 0.1162 | 1887 | 26 |
| 1 | 0.1218 | 179 | 27 |
| 1 | 0.1286 | 147 | 28 |
| 1 | 0.1298 | 851 | 29 |
| 1 | 0.1377 | 127 | 30 |
| V_{s30} | | 354.40 | |

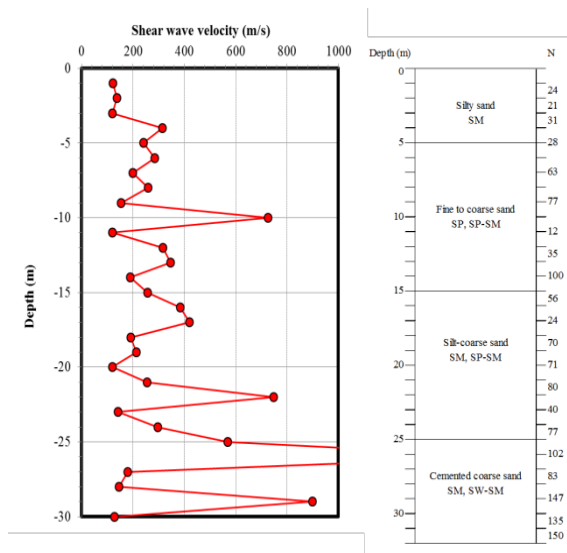


Fig. 14 Shear wave velocity profile by DH

$$V_s = \sum_{i=1}^n (V_{s_i} / \Delta D_i) \quad (10)$$

Where V_s is shear wave velocity (m/s); i are measurement stations = 1, 2, 3, . . . , n ; n is the

number of the layer under consideration

Based on V_s profile from the Surin test sites, the average shear wave velocity at 30 m (V_{s30}) with the Simple Method (SM) was calculated by Eq. (9) and compared with the velocity with the Downhole Seismic Test (DH) was calculated by Eq. (10) as shown in Fig. 15. The Shear wave velocity from the explosives was about 10% higher with the SM than that from DH as shown in Table 4.

Table 4 Comparison of V_{s30} between SM and DH

| Site area | V_{s30} (m/s) | | Different of SM and DH (%) |
|-----------|-----------------|--------|----------------------------|
| | SM | DH | |
| Surin | 389.26 | 354.49 | 9.81 |

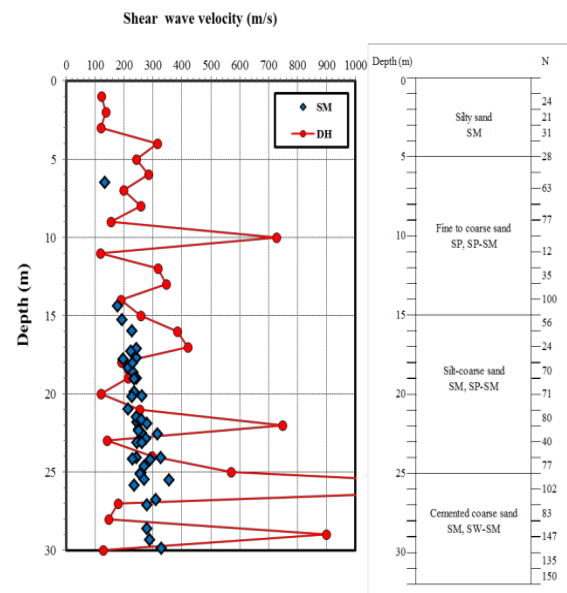


Fig. 15 A comparison of shear wave velocity

4. CONCLUSIONS

This research compared the relationship between shear wave velocity and depth obtained from the SM with underground explosives and DH. Since there is an abundance of ground motion records from seismic surveys; i.e. the petroleum source survey, the shear wave velocity profile can be easily obtained as a byproduct from such projects. The Simple Method (SM) has been used for vibration and shear wave velocity analysis of soil. Based on V_s profile from the Surin test sites, the average shear wave velocity at 30 m (V_{s30}) with the Simple Method (SM) was calculated and compared with the velocity with the Downhole Seismic Test (DH). The Shear wave velocity from the explosives was about 10% higher with the SM than that from DH.

5. ACKNOWLEDGMENTS

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