CROSSHOLE SURVEY AT A NUCLEAR POWER PLANT SITE

H. Turan Durgunoğlu[1], Semih S. Tezcan[2], Selçuk Erden[3], Yalçın Acar[4]

SUMMARY

For the purpose of obtaining reliable data on shear wave velocities of subsurface formations at Akkuyu Nuclear Power Plant (ANPP) site in Turkey, an intensive crosshole survey has been employed. The modifications incorporated to the standard crosshole testing procedure due to fractured dolomitic limestone formations encountered at the site proved to be very practical and economical.

Considerable large range of values for both shear and compressional wave velocities are measured. The results obtained were especially useful in determining the weak zones in the form of the low velocities, since it was not possible to obtain core-samples in weak zones due to fractured nature of the subsurface. Furthermore, it is shown that the shear wave velocity is much more sensitive than the compressional wave velocity to the variations in the formational characteristics of the subsurface.

INTRODUCTION

The highly sensitive characteristics of nuclear power plants demand extensive insitu and laboratory investigations of the subsoil conditions. Therefore, determination of soil parameters by several methods is very important. On the other hand, performing several techniques to measure a specific subsurface property is costly and time consuming. Therefore, deciding the scope and extent of the techniques best suitable for the specific characteristics of the site of a nuclear power plant requires considerable expertise and engineering judgement.

The most important factor in dynamic foundation behaviour and earthquake analysis is the dynamic shear modulus, G, which may be defined as,

$$G = \frac{\gamma_t}{g} v_s^2 \qquad (1)$$

where, γ_t =total unit weight of soil, g = acceleration of gravity, and v_s = shear wave velocity. Among the parameters defining the dynamic shear modulus, γ_t may be determined very easily on samples obtained from the field. On the other hand, knowledge of the correct value of the v_s is extremely important in the calculation of shear modulus from Equ. 1. It is usually very hard to estimate the v_s profile of a subsoil with reliable accuracy, without employing recent measurement technique of crosshole method.

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[1] Associate Professor of Civil Engineering, Boğaziçi University, Istanbul

[2] Professor of Civil Engineering, Boğaziçi University, Istanbul

[3] Associate Professor of Civil Engineering, Boğaziçi University, Istanbul

[4] Research Assistant of Earthquake Engineering Research Institute, Boğaziçi University, Istanbul

A further importance of the direct measurement of shear wave velocity is based on the fact that this type of a wave cannot propagate in a liquid environment. On the other hand, the pressure waves, which are commonly measured in seismic studies, can move through *both solid and liquid media*. Therefore, in addition to the quantitative difference in shear and pressure wave velocities, there is also a qualitative difference due to the characteristics of the two types of waves and direct measurement of v_s must be employed at locations below the ground water table.

Under the light of all the points mentioned above plus the added importance of dynamic soil-structure interaction analyses for foundations of nuclear power plants, it may be concluded that reliable insitu determination of shear wave velocity profiles in field must be performed. Among the techniques developed for this purpose in the last decade, the crosshole method has been widely accepted as most reliable and practical technique to measure insitu shear wave velocities. Stokoe and Woods (1972), Ballard (1976) and Auld (1977).

CROSSHOLE TESTING SETUP AT THE SITE

The basic testing setup of crosshole technique was described earlier by Stokoe and Woods (1972). In the crosshole testing program for Akkuyu Nuclear Power Plant (ANPP) site, although the basic principles of the technique, as described by Stokoe and Woods were used, several modifications were also made which were necessitated due to the characteristics of the special subsoil conditions.

The subsoil conditions at the site is determined to be mainly fractured dolomitic limestone with interbedded shale layers. Therefore, it would have *been extremely time consuming and uneconomical to follow tha standard crosshole* testing procedure of drilling, testing and drilling again. In view of this difficulty it is decided that the tests to be conducted in previously drilled boreholes. Testing was started at the bottom of the holes and proceeded towards the surface by filling the holes with compacted sand to desired levels.

Furthermore, a microphone, rather than a vertical velocity transducer was attached to the top of the impulse rod to activate the signal on the oscilloscope screen. This variation was both practical and economical in the sense that the replacement of this microphone, in case of a breakdown, required negligible cost and time. A third variation from the standart procedure was the use of a steel cable, instead of a continuous rod, attached to a short rod containing the recording transducer. This modification is proved to be time saving since the depths involved were as high as 50 meters, and by means of a steel cable, the lowering and raising of the recording transducer were easier and faster compared to the lowering and raising of a steel rod.

Finally, an amplifier was connected in between the recording transducer and the oscilloscope to determine the arrival time more accurately. Impact was imparted to the subsoil by the use of a sledge hammer, and the record stored on the oscilloscope screen was photographed.

The only difficulties met during the shooting program were those due to the physical characteristics of the boreholes. The casing left in some boreholes in order to prevent borehole cavings were sometimes hard to pull up.

locations and to develop a technique which accounts for the effects of refraction of waves from high velocity layers.

It is determined that the refraction factor defined as v_{15}/v_{30}, where v_{15} = velocity value for spacing of 15 m. and v_{30} = velocity value for spacing of 30 m, for the shear wave velocity is on the average, about 0.7 for depth range of 35.0 m from surface. The corresponding distortion factor for the compressional wave velocity, v_p is, on the average about 0.9 in the same range of depths. Below this depth the velocities do not change considerably as were in the independent measurements of deep shooting and surface refraction studies and therefore the distortion factor may be taken as unity.

All the measurements were conducted below the water table, it is determined that compressional waves velocities measured are higher than 1600 m per sec which is the compressional wave velocity in water. Therefore, the values of Poisson's Ratio can be calculated from the following relationship:

$$\mu = \frac{1 - 2(v_s/v_p)^2}{2 - 2(v_s/v_p)^2} \qquad (4)$$

where, μ= Poisson's Ratio, v_s= Shear wave velocity, v_p= Compressional wave velocity.

EVALUATION OF THE MEASUREMENTS

The shear and pressure wave velocities determined from field measurements in the form of velocity profiles are given in Fig.2. In general both the shear and compressional wave velocities are consederably different from one location to another. It is seen that, in general both shear and pressure wave velocities increase with depth.

It is also seen in Fig.2. that both shear andcompressional wave velocities for every depth interval decreases towards Borehole 44C. This is mainl due to inhomogeneous subsurface bedrock conditions encountered between 33 and 44C. It may also be observed that the difference in v_s values are great than the difference in v_p values. This condition is reflected by the increas in Poisson's Ratio values from Boring 33 to 44C.

The velocity profiles along the axis between Boreholes No. 44C and 46 is also given in Fig.2. In this part of the site the measurements are concentrated for the top 30.0 meters from the ground surface.

It may be seen that there is a big decrease in wave velocities within this region in comparison to region located between the Borings 33 and 44C.

The variation of shear wave velocity together with poisson's ratio along the axis of 33-46 are given in Fig.3. It may also be seen from this figure that there is a considerable difference in measured values from Boring 33 to Boring 46. It is calculated that the average ratio of change in v_s value to average shear wave velocity ($\Delta v_s/\bar{v}_s$) from Boring 33 to Boring 46 is nearly equal to 1.0.On the other hand average $\Delta v_p/v_p$ value is measured as 0.33. This is a very good indication that the shear wave velocities of the formations is much more sensitive to the variations in formational characteristics,than the compressional wave velocities especially under ground water table. In view of the subsurface geotechnical investigations the drop in v_s and v_p values may be explained in terms of gradual change of formations from dolomite to fractured dolomite and to mainly shaly mylonite along the axis of 33-46.

The shear wave velocites, in fact, the lowest values in the whole investigations was observed especially around Borehole 46A. The shear wave velocities were observed to be as low as 500 m/sec within a depth of 10.0 to 20.0 m from the ground surface. Such a relatively weak zone was also observed during subsurface geotechnical investigations and, consequently additional borings had been drilled around Boring 46 to investigate the lateral extent of this weak zone. The crosshole measurements are also utilized in these borings and velocity profiles for these measurements are also given in Fig.2. It may be seen that this weak zone is the closest to the surface in between Borings 46A and 46, and reaches to greater depths, about 20 m below the surface inbetween Boreholes 46A and 46D. In between Borings 46A, 46B, and 46C, the low velocity zone seems to be closer to surface. However, the most critical zone, as far as the low shear wave velocities are concerned, is inbetween Borings 46A and 46. This is in very good agreement with the results of geotechnical investigations.

CONCLUSIONS

1. The crosshole testing program undertaken at the ANPP site provided very useful information concerning the dynamic properties of the subsurface formations. This method was especially useful in detecting the weak zones in the form of low velocities, especially since it was not possible to obtain core samples in weak zones due to the fractured nature of the soil.

2. The crosshole testing scheme performed in this study with the modifications incorporated to the standard crosshole testing procedure, namely starting at the bottom of existing boreholes and moving upwards, the use of a microphone rather than a transducer to initiate the signal, and the use of a steel cable rather than a continuous rod to lower the recording transducer into the hole proved to be very pactical and economical.

3. It is generally obtained from velocity profiles that both shear and compressional wave velocities increase with depth.

4. Considerable large range of values for both shear and compressional wave velocities are measured. Along the axis 33-46, the average values of v_s and v_p for the depth range of 10.0 to 20.0 meters are 1200 m/sec and 2890 m/sec respectively . The average wave velocities increases to 1380 m/sec and 3400 m/sec in depth range of 20.0 to 30.0 meters.

5. The shear wave velocity is much more sensitive to the variations in formational characteristics of the subsurface than the compressional wave velocity, especially under saturated conditions.

6. The calculated Poisson's ratio values were within the range of 0.21 to 0.47 having average values of 0.36 and 0.38 for the depth of 10.0 to 20.0 meters and 20.0 to 30.0 meters depth ranges respectively.