DYNAMIC PROPERTIES OF A WEATHERED ROCK

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SUMMARY

Relatively little information is available in the literature regarding the dynamic properties of weathered rocks. This paper describes the dynamic properties of the weathered in-situ foundation soils and rocks for a nuclear power plant being constructed in Asia.

The laboratory dynamic testing performed included cyclic triaxial tests and resonant column tests to estimate the shear moduli and damping ratios of the weathered rocks. The variation of the moduli and damping ratios with strain level and confining pressures is discussed in the paper. The effect of sample disturbance on the moduli of the weathered rocks was investigated by comparing the shear wave velocity obtained for the laboratory "undisturbed" sample with that obtained in the field. The results are discussed.

The dynamic shear moduli and damping characteristics of the weathered rocks are compared with data for sedimentary sands and clays available in the literature.

INTRODUCTION

A substantial body of information is available in the literature regarding the dynamic properties of sedimentary soils, both in their in-situ or reconstituted state when used as backfill (e.g., Hardin and Drnevich, 1972, and Seed and Idriss, 1970). Sowers (1963) and Deere and Patton (1971) had made many detailed studies of the static strength characteristics of residual soils and weathered rocks. References in the literature to the dynamic properties of weathered rocks are, however, very sparse.

This paper describes the dynamic properties of the foundation soils and rocks for a nuclear power plant being constructed in Asia. The site is located in an area of high seismic activity, with a horizontal design acceleration of 0.4g. To ensure the proper design of the power plant, it was very important that the dynamic characteristics of the foundation soils and rocks be evaluated in order to provide the correct input for use in the seismic soil-structure interaction analyses and plant structure design.

SUBSURFACE CONDITIONS

The subsurface materials at the site are predomoninantly weathered pyroclastic rocks. These pyroclastic rocks consist of interlayers of volcanic breccia (with fragments larger than 32 mm), lapilli tuff (with fragments 4 mm to 32 mm in diameter) and tuff (with fragments smaller than 4 mm).

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The pyroclastic rocks encountered at the site are variable and their properties are dependent upon the degree of weathering. For engineering purposes the subsurface materials can be classified as soil-like saprolite, rock-like saprolite, moderately weathered rock and slightly weathered to fresh rock.

In order to aid in field classification, the material is classified as a soil-like saprolite if it could be sampled using a split-spoon sampler. Rock-like saprolite is distinguished from soil-like saprolite by the fact that a split-spoon sampler would encounter refusal in it, but a sample could be obtained by coring. The moderately weathered and slightly weathered rocks are classifed on the basis of the degree of weathering and RQD.

Soil-like saprolite is completely weathered from the volcanic rock into a friable condition with soil-like characteristics, but the rock texture and structure of parent rocks are preserved. Rock-like saprolite is a highly weathered rock and the weathering extends throughout the rock mass; the rock mass is partly friable and of low hardness. Moderately weathered rock is of moderate to high strength. From the extent of weathering, moderately weathered rock can be visually distinguished from rock-like saprolite. For slightly weathered rock, weathering is only developed on the joint surfaces and signs of weathering are less apparent.

INDEX AND STATIC PROPERTIES

A large number of index property tests and static tests were performed on the weathered rocks. The index property tests included density, natural water content, specific gravity, Atterberg limits and grain size analyses. Static tests included one-dimensional consolidation tests, unconfined compression tests, unconsolidated undrained and consolidated undrained triaxial compression tests on selected samples of the weathered rocks.

Results of the index property tests are summarized in Table 1. As one may expect, the average dry density increases and the average moisture content decreases as the degree of weathering decreases. For example, the average total density and moisture for the soil-like saprolite are $1.5\ t/m^3$ and 45 percent, but for the slightly weathered rock, they are $1.8\ t/m^3$ and 19 percent. The unconfined compressive strengths of the weathered rocks are shown in Fig. 1, along with the weathering profile.

DYNAMIC MODULI AND DAMPING RATIOS

To measure the dynamic shear moduli and damping ratios, samples of the weathered rocks were subjected to cyclic triaxial and resonant column testing in the laboratory. Method of cyclic triaxial testing for measuring dynamic stress-strain properties is well discussed in the literature (e.g., Lee and Seed, 1967, and Park and Silver, 1975). Because the cyclic triaxial testing suffers from a lack of sensitivity at a strain level of less than 10^{-3} to 10^{-2} percent supplementary tests were performed using the resonant column device to provide data at these lower strain levels.

TABLE I
INDEX PROPERTIES OF WEATHERED ROCKS

	Average Total Density t/m^3	Average Water Content %	Porosity %	Core Recovery %	RQD %
Soil-like Saprolite	1.5	45	-	-	-
Rock-like Saprolite	1.5	49	0.63	43-89	15-61
Moderately Weathered Rock	1.7	27	0.45	89-100	45-81
Slightly Weathered to Fresh Rock	1.8	19	0.37	84-100	54-89

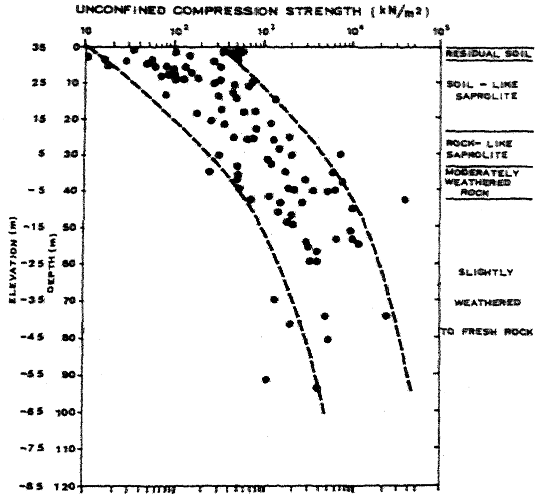


FIG. 1 UNCONFINED COMPRESSIVE STRENGTHS OF WEATHERED ROCKS

The resonant column tests were performed using the Hardin apparatus discussed in Hardin and Music (1965). The combined results from the strain controlled cyclic triaxial tests and resonant column tests thus provide a good estimate of the dynamic shear moduli and damping characteristics of the weathered rocks over the full range of strains of interest in the soil-structure interaction analyses.

A series of cyclic triaxial tests and resonant column tests was performed at different confining pressures. To establish their interrelationship, the maximum dynamic shear moduli (at a low strain of 1×10^{-4} percent) were plotted against confining pressures on a log - log scale based on standard procedures. From these plots, it is established that the maximum dynamic shear modulus G_{max} varies with the effective confining pressure $\bar{\sigma}_c$ according to the formula

$$G_{max} = A \, \bar{\sigma}_c^{\,n} \text{..............Eq. 1}$$

where A is a constant and the exponent n varies from 1/6 to 2/5. Table 2 presents the constants A and exponents n for the four types of weathered rocks encountered at the site.

The variations of the dynamic shear moduli and damping ratios with shear strain are shown in Fig. 2. The shear strain is single amplitude strain. Following established procedures, the scale used for the shear strain in Fig. 2 is logarithmic. The shear modulus, G, is expressed in an dimensionless form as $K = G/G_{max}$.

MODULI FROM FIELD GEOPHYSICAL TESTING

It is generally recognized that laboratory testing frequently underestimates the strength and moduli of soil samples because of effects of sample disturbance. More recently, Murphy, et al (1978) has shown that duplication of the stress conditions in the laboratory to account for past stress history experienced by sedimentary soils would lead to a higher modulus than that provided by conventional laboratory testing.

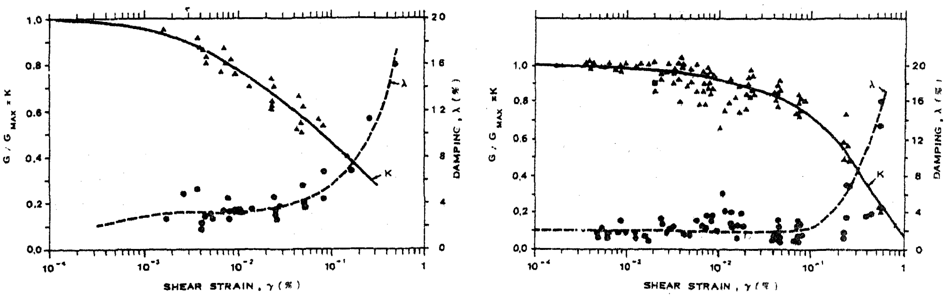
Stress history simulation in the laboratory testing of the weathered rock materials is not possible due to the extremely complicated effects of weathering. As is common in relatively weaker rocks, the microstructure of the material is affected by the "disturbance" due to coring, handling and relief swelling and tends to reduce the properties measured in the small samples used for laboratory testing. The properties most sensitive to microstructure disturbance are the elastic moduli. Therefore, reliance was placed on field geophysical testing for the determination of the in-situ shear modulus for the weathered rock mass. The field geophysical testing included up-hole and cross-hole shear wave velocity measurements. Thus, in order to incorporate the in-situ stiffness of the rock mass, in the nuclear plant design, a correction factor based on the ratio of field to laboratory shear wave velocity measurements were developed. These correction factors (CF) were used to adjust the laboratory moduli to in-situ conditions for the full strain range, while the decaying

TABLE 2
PARAMETERS IN EQUATION FOR SHEAR MODULUS

	A* kN/m^2	n*	CF*
Soil-Like Saprolite	5.5x10^4	1/4	1.75
Rock-Like Saprolite	15.1x10^4	1/6	2.5
Moderately Weathered Rock	15.3x10^4	1/4	3.0
Slightly Weathered to Fresh Rock	14.2x10^4	2/5	4.0

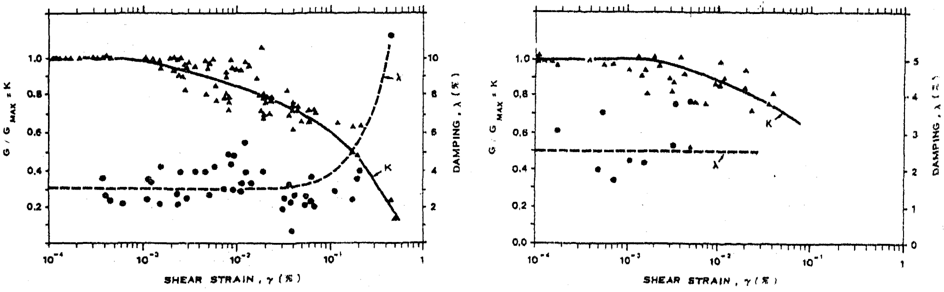
*Note: As in $G_{in-situ} = K A (\bar{\sigma}_c)^n$ (CF)

Where G and $\bar{\sigma}_c$ are in kN/m^2



a. SOIL – LIKE SAPROLITE

b. ROCK – LIKE SAPROLITE



c. MODERATELY WEATHERED ROCK

d. SLIGHTLY WEATHERED TO FRESH ROCK

FIG. 2 DYNAMIC SHEAR MODULI AND DAMPING RATIOS OF WEATHERED ROCKS effect of the moduli characteristic curve determined from laboratory testing is believed to remain unchanged. These CF values are presented on Fig. 3. Substituting $G = KG_{max}$ in Eq. 1, the in-situ modulus of the weathered rock mass is thus:

$$G_{in-situ} = KA\ (\bar{\sigma}_c)^n\ (CF) \ldots\ldots\ldots\ldots\ldots \text{Eq. 2}$$

COMPARISON WITH SEDIMENTARY SOILS

The variation of the moduli and damping ratios with strain level for typical sedimentary deposits have been reported by Seed and Idriss (1970) and Hardin and Drnevich (1972).

For comparison, the curves showing the variation of the moduli, and damping ratios of the weathered rocks are summarized on Fig. 4, on which are also shown the typical curves showing the variations with strain of the moduli and damping ratios for sands and for clays of sedimentary origin. It can be seen from Fig. 4 that the reduction with strain of the moduli is less for the weathered rocks than it is for either sands or clays.

It can also be seen from Fig. 4 that the increase at higher strain levels in the damping ratios of the weathered rocks is much less than those for either sands or clays of sedimentary origin.

DISCUSSIONS AND CONCLUSIONS

This paper has summarized the dynamic properties of the weathered rock materials at the site of a nuclear power plant being constructed in Asia. The interrelationship between shear modulus, confining pressure and shear strain, and that between damping characteristics and shear strain were presented.

It was determined that the in-situ moduli of the weathered rock materials are significantly higher than the laboratory determined moduli. Thus, in order to incorporate the actual stiffness to be experienced in the in-situ rock mass, correction factors were applied to adjust the values of the shear modulus determined in the laboratory to field condition. The correction factors, ranging from 1.75 to 4.0, were based on the ratio of the shear wave velocities determined in the field and in the laboratory.

The variations of the moduli and damping characteristics with shear strain of the weathered rocks were compared with those of typical sedimentary deposits reported in the literature. The reduction with strain of the moduli is less for the weathered rocks than it is for either sands or clays. The increase at higher strain levels in the damping ratios of the weathered rocks is much less than those for either sands or clays of sedimentary origin.

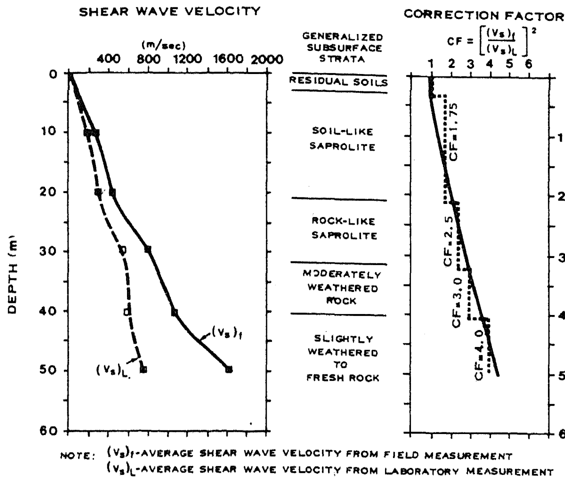
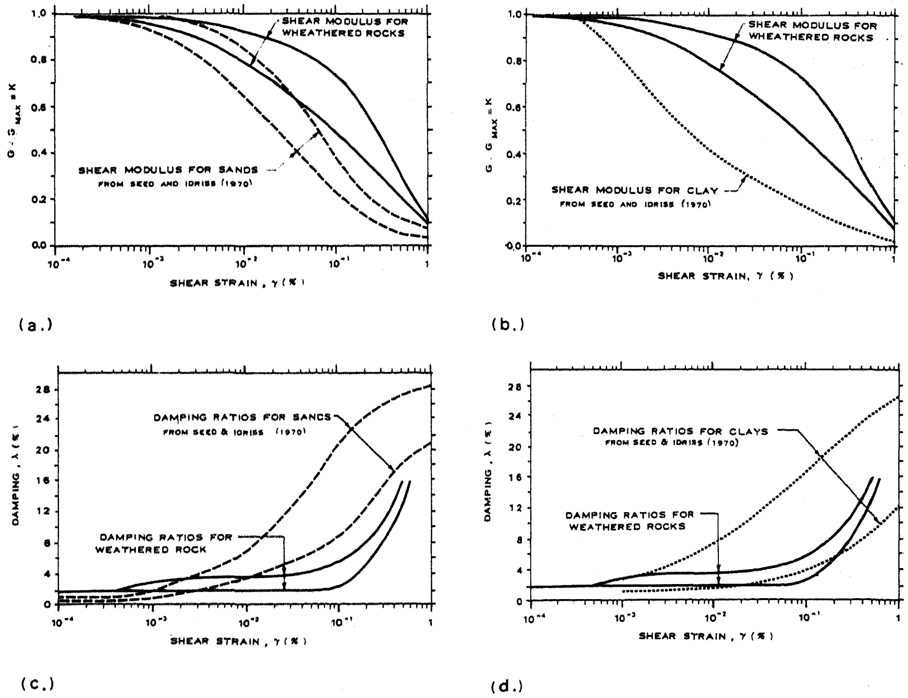


FIG. 3 SHEAR WAVE VELOCITIES AND CORRECTION FACTORS FOR MODULUS



(a.) (b.)

(c.) (d.)

FIG. 4 COMPARISON OF MODULI AND DAMPING BETWEEN WEATHERED ROCKS AND SEDIMENTARY SOILS

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