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INFLUENCE OF SOIL FABRIC ON DYNAMIC PROPERTIES OF SAND: AN EXPERIMENTAL STUDY

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Natural field sites originate under the action of external sources such as rivers, wind, or marine environments. These sources are responsible for constituting a variety of soil fabrics, which ultimately modify the deformation characteristics. Additionally, the dynamic properties of a site present the characterization of a region and have been profusely utilized by field engineers and researchers. In the present study, the dynamic properties of soil specimens have been evaluated for specimen preparation techniques, namely, air pluviation (AP) and water sedimentation (WS). The cyclic triaxial tests were conducted on the strain-controlled consolidated undrained specimens at a frequency of 0.1 Hz. This frequency has been used in several studies to replicate earthquake or liquefaction scenarios. The calculation of shear modulus (G) and damping ratio (D) was performed using symmetric hysteresis loops generated through cyclic loadings. The outcomes suggest that the specimen prepared using the WS technique possesses a larger shear modulus value than AP ones. The reason behind this observation was the lower degradation characteristics of the WS-prepared specimens. Additionally, the liquefaction susceptibility of the specimens has been noticed for different specimens.

Keywords: Shear modulus, Earthquake, Specimen preparation, Cyclic loading.

1 INTRODUCTION

The dynamic properties of soil mass assist in site characterization and therefore, are useful in the response analysis of the disastrous seismic effects. Hardin (1965) provided analytical solutions for calculating the dynamic properties of soil after performing free vibration and static torsion tests. Several researchers developed analytical correlations for evaluating the shear modulus and damping ratio of soil mass (Seed and Idriss 1970, Hardin and Drnewich 1972). Many research studies (Vucetic and Dobry 1991, Sun *et al.* 2012, Chattaraj and Sengupta 2016) noticed that the confining stresses, void ratio, plasticity, and atmospheric pressure could affect the degradation characteristics of sandy strata. The resonant column and cyclic triaxial tests on sandy-silty clay and sand-gravel mixture provided a clear idea about the seismic analysis of earth dams (Xenaki and Athanasopoulos 2008). Jain *et al.* (2023b) calculated the dynamic properties of fine sand reinforced with plastic fibers and correlated them with the degradation index. Previously, much research has been performed to understand the stress-strain response of the specimen with various fabrics. Ladd (1974) performed cyclic triaxial tests on cohesionless soil after utilizing different specimen preparation techniques to understand the influence of fabric. In a study performed by Mulilis *et al.*

(1977), the undisturbed specimens depicted more resistance than the specimens prepared by moist tamping. The authors investigated the electrical conductivity and fabric-related tests to understand the critical role of the arrangement and orientation of soil grains. Many research studies suggested that replicating soil deposits nearby rivers, beaches and coastal dunes is possible using the water sedimentation technique for preparing the specimens (Vaid and Sivathayalan 1999). A series of cyclic triaxial tests were performed by Sze and Yang (2014) to understand the influence of specimen preparation techniques on the deformation characteristics, the response of pore-water pressure, stress-strain behavior, and the liquefaction resistance of saturated sand. Kiyota *et al.* (2019) correlated the response of in-situ soil with the reconstituted specimens after performing several cyclic triaxial tests to understand the role of different specimen preparation techniques. The authors also compared the liquefaction resistance of the soil specimens with different cases. Jain *et al.* (2021) conducted strain-controlled tests on the specimens prepared with air pluviation and water sedimentation techniques. Most of the previous studies on fabric change understood the pore pressure response and deformation characteristics of soil specimens. However, further investigation is needed to understand the changes in stiffness characteristics for different fabric orientations. The present research work attempts to explore the variations in the dynamic properties of fine sand specimens prepared using WS and AP techniques. The outcomes suggested a higher stiffness of the fabric formed by WS specimens than the AP-prepared ones. Also, the variations in the dynamic properties of a specimen may further assist practicing engineers and geotechnical researchers.

2 MATERIALS, METHODOLOGY AND PARAMETERS CONSIDERED

In the present research work, fine sand collected from the Solani River (Roorkee, India) has been used for testing. This Roorkee region lies in zone IV as per the seismic zonation map of India; therefore, the outcomes based on the dynamic properties and liquefaction behavior of sand used are critically important (Jain *et al.* 2022, Jain *et al.* 2023a). A series of undrained strain-controlled cyclic triaxial tests were performed. The adopted frequency for all these tests was 0.1 Hz which has also been utilized by previous researchers in liquefaction-related studies (Hussain and Sachan 2019, Jain *et al.* 2021). The necessary details of the utilized cyclic triaxial apparatus can be obtained from Jain *et al.* (2023b). To observe the changes in shear modulus due to strain rates, two different strain rates of 0.4% and 0.6% were considered. After preparing the specimen using desired specimen preparation technique, carbon-di-oxide was passed through the specimen, followed by water flushing. In the next step, the specimen was saturated using the combination of confining and back pressure with an increment of 20 kPa. The specimen was considered saturated when the skempton's coefficient (B) crossed the 0.95 mark. Then, the specimen was consolidated at an effective confining stress of 100 kPa and loading was applied.

3 CALCULATION OF DYNAMIC PROPERTIES

In this study, the shear modulus and damping ratio of soil specimens have been calculated using strain-controlled cyclic triaxial tests. The inclination of the hysteresis loop governs the stiffness characteristics of soil mass, which can be explained at any stress-strain data point during the cyclic loading (Kramer 1996). Also, the breadth of the hysteresis loop is dependent on the area under the curve, which defines energy dissipation and can be described by the damping ratio (D). As per ASTM D3999 (ASTM 2012), the dynamic properties of soil specimens can be evaluated using a symmetric hysteresis loop (SHL), as shown in Figure 1. The calculation of dynamic properties can be achieved using Eqs. (1) to (4).

$$E_{sec} = \sigma_d/\varepsilon = (\sigma_{d,max} - \sigma_{d,min}) / (\varepsilon_{max} - \varepsilon_{min}) \quad (1)$$
$$G = E_{sec} / [2(1+v)] \quad (2)$$
$$\gamma = (1+v)\varepsilon \quad (3)$$
$$D = (A_{o\text{-}b\text{-}d\text{-}a}) / (4\pi \times A_{o\text{-}b\text{-}c}) \quad (4)$$

where E_{sec} = tangent elastic modulus, $\sigma_{d,max}$ = maximum deviator stress, $\sigma_{d,min}$ = minimum deviator stress, G = shear modulus, D = damping ratio, ε_{max} = maximum axial strain, ε_{min} = minimum axial strain, $A_{o\text{-}b\text{-}d\text{-}a}$ = area under the hysteresis loop, $A_{o\text{-}b\text{-}c}$ = area under the triangle obc, γ = shear strain, v = Poisson's ratio (may be taken as 0.5 for saturated undrained specimens as suggested by Rollins *et al.* (1998).

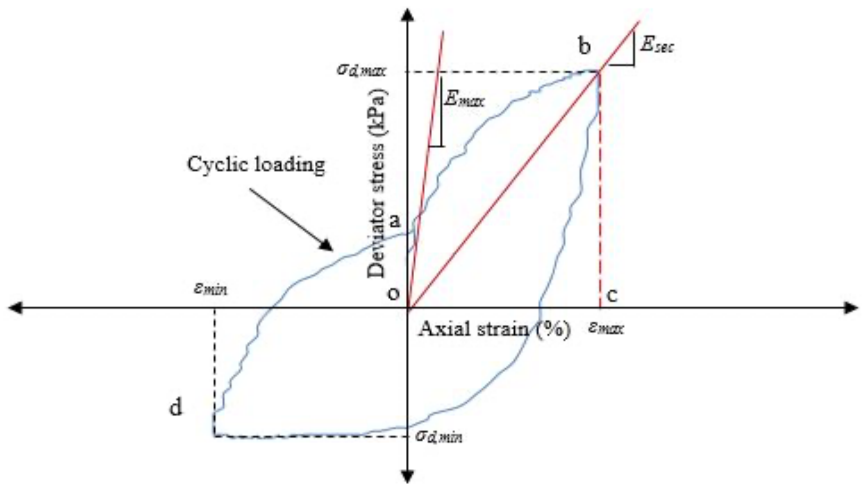


Figure 1. Hysteresis loop used for the calculation of dynamic properties.

4 RESULTS AND DISCUSSION

4.1 Effect of Soil Fabric on Stiffness Characteristics

In order to replicate the formation of soil strata due to several external agencies like wind, rivers, or lakes, the specimens have been prepared using different techniques (Ladd 1974, Wood *et al.* 2008, Jain *et al.* 2021). In Figure 2(a), the variation of shear modulus is presented for the fabrics formed by water sedimentation and air pluviation.

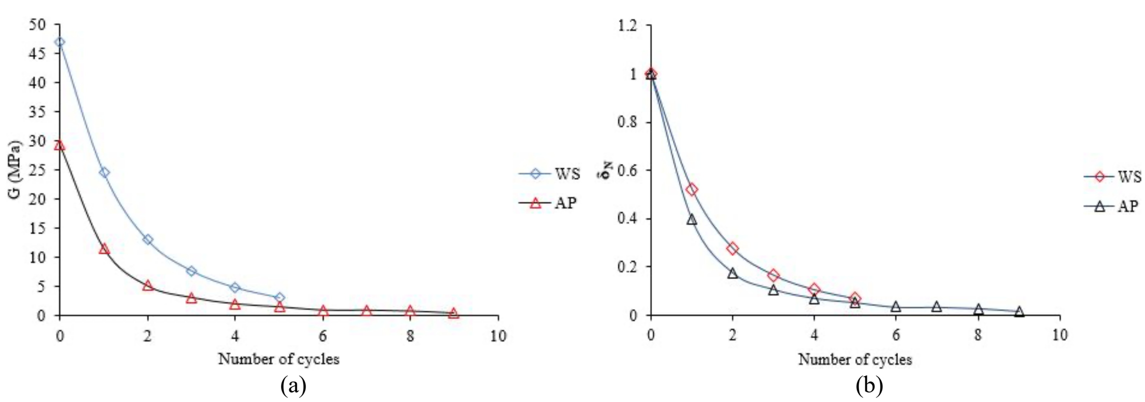


Figure 2. Influence of specimen preparation technique on dynamic properties.

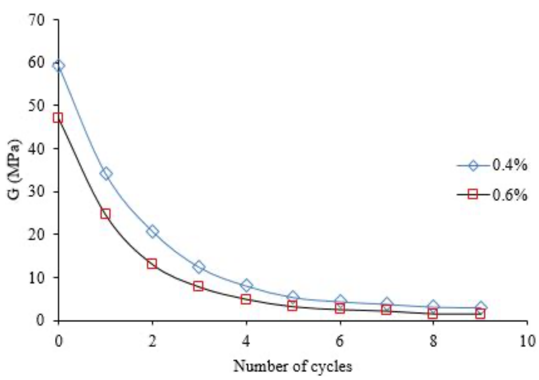
It can be observed that specimens prepared by WS depicted higher values of shear modulus (G) than that of the AP specimens. The value of shear modulus for WS cases was 2.6 times the AP specimens. Also, a representation of the degradation index is provided in Figure 2(b) for different specimen preparation techniques. The term degradation index (δ_N) can be defined as the ratio of the shear modulus in the 'N' cycle to the shear modulus in the first cycle (Hussain and Sachan 2019), which can be noticed in Eq. (5).

$$\delta_N = \frac{G_N}{G_1} \tag{5}$$

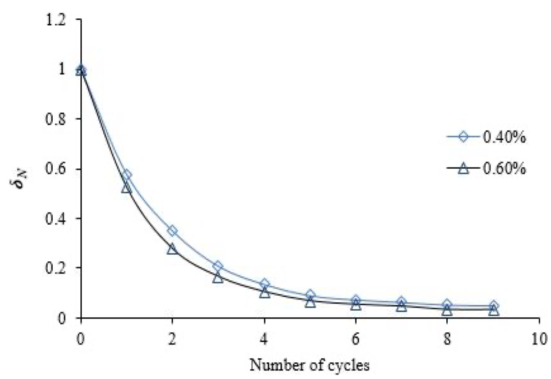
In Figure 2(b), it can be observed that the degradation of the specimens was quick in the AP specimens. Within two loading cycles, the degradation index of the WS specimen was 58% higher than those of the AP specimens. The reason behind this outcome is the better stiffness characteristic of soil fabric prepared by the WS technique.

4.2 Effect of Strain Rates on Stiffness Characteristics

With an increase in strain rate, the specimen depicted a higher rate of degradation and ultimate failure. Therefore, Figure 3 presents the shear modulus variation of the specimens prepared using the water sedimentation technique at different strain rates. As shown in Figure 3(a), the curves of shear modulus at a strain rate of 0.4% and 0.6% follow a similar path. At a larger strain rate, the degradation of soil specimens happens quickly, which is responsible for causing the loss of stiffness in early cycles. Therefore, the shear modulus (G) at a strain rate of 0.4% was 2.8 times that of the G value at 0.6% within two load cycles. The degradation index variation in Figure 3(b) also suggested an increased rate of stiffness degradation.



(a)



(b)

Figure 3. Influence of specimen preparation technique on dynamic properties.

4.3 Comparison with Modulus Reduction Curve

In Figure 4, the modulus reduction curves have been presented for the specimens prepared with different specimen preparation techniques, namely, water sedimentation and air pluviation. The data points of WS specimens resided in the curve's upper regions due to the higher stiffness characteristics of the fabric produced by water sedimentation. It could be noticed that the data points of the present study lie nearby the curve of Seed and Idriss (1970) which justifies the results obtained in the present research work.

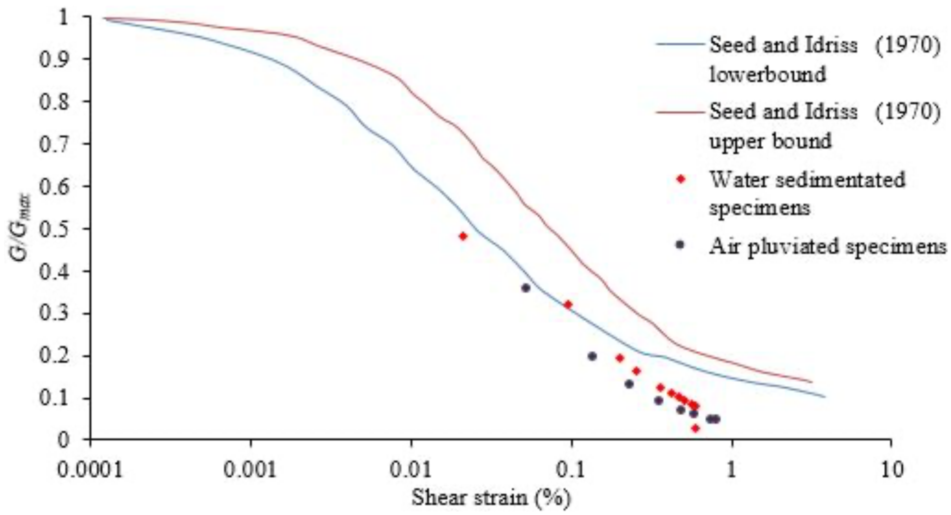


Figure 4. Modulus reduction curve.

5 CONCLUSIONS

Dynamic properties of soil specimen are very critical for assessing site response analysis in any project. It can be observed that the specimen prepared using the water sedimentation technique depicted larger values of shear modulus values than the air-pluviated specimens. This is because of the development in better stiffness properties of soil fabric in WS specimens. Additionally, the degradation index of the WS specimen was 58% higher than that of the specimens prepared using the AP technique. The calculation of the degradation index and modulus ratio has been achieved. Also, the validations of the present work have been performed based on the modulus reduction curves of previous studies. These outcomes are truly valuable for site engineers and researchers to understand the crucial role of soil fabrics.

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