Investigation to Dynamic Properties of Modjo Town Soils Using Cyclic Simple Shear Machine

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ABSTRACT-*The most important dynamic soil properties are shear modulus and damping ratio which plays a crucial role in prediction and analysis of soil responses in dynamic loadings. The behavior of soils subjected to dynamic loading is influenced by these soil properties. In this study an attempt was done to determine the shear modulus and damping ratio of Modjo town soils by giving emphasis to Modjo Dry Port. The soil samples were collected from Modjo town at four different locations, namely; Modjo dry port (MD), Teklehaymanot church (TK) and Shashemane road exit (SH) and Near minjar road (NMR).*

Investigation of index properties of Modjo soils were done and classified using USCS and AASHTO soil classification system. Based on test results, the soil from MD, TK and SH were highly plastic silt soils and NMR was silty sand. The shear modulus and damping ratio values were determined using cyclic simple shear machine. Strain-controlled cyclic test were conducted at a cyclic loading frequency of 1Hz with a remoulded sample of 70mm diameter and 20mm height. The tests were conducted as a function of cyclic strain amplitude of 0.01%, 0.1%, 1%, 3%, and 5% under axial stresses of 100kPa, 200kPa and 400kPa. The value of shear modulus was in the range of 0.11MPa to 22.98MPa and damping ratio values range between 0.25% and 25.63%.

This study systematically investigates the effect of cyclic shear strain amplitude, confining stress, number of loading cycles, void ratio and soil plasticity on the shear modulus (G) and damping ratio (D) values. As number of loading cycles and confining pressure increase, the shear modulus increases and damping ratio decreases. Shear modulus decreases and damping ratio increases with increase in cyclic shear strain amplitude. The shear modulus values of Modjo soils were normalized to compare with previously developed values in the literature.

Key words:- *Cyclic loading, Shear modulus, Damping ratio, Normalized shear modulus and Cyclic simple shear test.*

1. INTRODUCTION

1.1 Background of the Study

Geotechnical earthquake engineering is a new discipline that was formally defined in the first international conference on geotechnical earthquake engineering in Tokyo in 1995. Soil dynamics is an essential part of geotechnical earthquake engineering. The dynamic properties of natural soil deposits are important to study geotechnical engineering problems involving soil-structure interactions, site responses of soil deposits and prediction of the ground motion.

Two of the most important parameters required for dynamic analysis are the soil stiffness (Shear modulus) and material damping (damping ratio). These soil properties used to evaluate the dynamic response of soils at different strain levels. Dynamic soil responses needed for earthquake analysis, in machine foundation design, wind power plant foundations, fast transportation systems, blast resistant structures, the response of offshore soils and supported structures to ocean wave loads.

Developments of soil dynamics over the last decades have been motivated by the occurrence of catastrophic seismic events. These seismic hazards subjected to seismic loadings include building collapse, bridges failure, failure in slopes and earth retaining structures. Strictly speaking, the concept of dynamic loading of soil refers to the propagation of stress waves through soil layers. The term "cyclic" refers to systems oscillating with constant amplitude and frequency. Cyclic loadings are those loads that exhibit a degree of regularity both in its magnitude and frequency. Characterization of dynamic soil properties required for the analysis of foundation vibrations and geotechnical earthquake engineering problems. Ethiopia is susceptible to Earthquake activities, as it has experienced some recorded earthquake events. Different studies in different places and in different times have been done on dynamic properties of soils in Ethiopia. On red clay soils in Gulelle area of Addis Ababa [7], on red brown clay soils in Kolfe Keraneo area of Addis Ababa [31], silt and silty sand soils of Adama city [17], dry koka sand [57], silty soils of Dessie town [1], Hawassa city soil [19] and Arba Minch town soil [12] and silty and silty sand soil of Ziway town [38] were previously studied.

Even though extensive amounts of earthquake records exist in Ethiopia, the structural damage to infrastructures in the vast past period was obviously very low due to the extreme limitation of built-up environments. Starting from the 1950s and 1960s noticeable building and infrastructure activities were characterized in the seismic-prone areas. In this study, the dynamic soil properties of Modjo town were determined to create awareness and to give dynamic soil information for future proper dynamic load resistance foundation in the town. Special attention was given to large infrastructures like; Modjo dry port, Tannery factories, Leather and Textile industries and the new giant international airport planned to be built around Modjo town. Correct evaluation of shear modulus and damping in soil is very important for both the fundamental understanding of soil behaviour and the practical application of soil modeling.

1.2 Description of the Study Area

Modjo or Mojo is a town in central Ethiopia at 73km from Addis Ababa, named after the nearby Modjo River. Modjo is located in the East Shewa zone of the Oromia region and has alatitude and longitude of 8°39′N 39°5′E with an elevation between 1788 and 1825 meters above sea level. It is the administrative center of Lome woreda. It is not only accessible by road but has been the location of train station of the Addis Ababa –Djibouti railway since the line was extended from Dire Dawa to Akaki in 1915. Based on figures from the Central Statistical Agency in 2005, Modjo has an estimated total population of 39,316 of which 19,278 were males and 20,038 were females. From geographical evidences it is located in the great Rift Valley zone of Ethiopia which is prone to an earthquake activity and classified as seismic zone four [48]. Moreover, it is the center of distribution for the south eastern and central parts of Ethiopia, which exposed for further civil engineering works like high-rise buildings, residential complexes, Factories, large industrial and commercial centers etc.

Modjo town hosts Modjo dry port, two Tannery Factories, one Textile Factory and others. In such high-risk area, it is necessary to have knowledge of the properties of soils subjected to dynamic loads. Therefore, it is necessary to know the ground responses of soil deposits during active volcanic eruptions and other dynamic loadings. In order to understand the ground responses of soil deposits, it is important to know the dynamic soil properties of the area. From previous research works, there were different earthquake activities recorded in different parts of Ethiopia. The Great Rift Valley region of Ethiopia is earthquake prone areas and experienced different magnitude of earthquakes. Nazareth earthquake, which has a magnitude of 5.1, was felt as far as Debre Zeit and Addis Ababa. Modjo, which is 26km from Nazareth, is located in Great Rift Valley of Ethiopia and experiences the Nazareth earthquake.

1.3 Objectives

- Determination of shear modulus and damping ratio of Modjo town soil.
- To provide dynamic soil information for dynamic loading considered foundation designs.
- To assess some of the critical factors of dynamic soil properties.

1.4 Problem Statements

Ethiopia has experienced some recorded earthquake events in the seismic-prone areas (Great Rift Valley regions). Modjo is in Great Rift Valley zone, which is prone to an earthquake activity and classified as seismic zone **four**. It experiences the Nazareth earthquake. To know the response of soil, it is important to investigate the dynamic properties of Modjo soil which were not yet investigated. Pure dynamic loads do not occur in nature, it is always a combination of static and dynamic loadings. Hence, investigation of the behavior soil at static and dynamic state was very important to arrive at rational analysis and design of dynamic loads in the study area soils.

2. LITERATURE REVIEWS

Several researchers have been involved in exploring the complex behaviour of soils under various types of dynamic loading conditions. Damage due to dynamic loadings is influenced by the response of soil deposits and the soil response is governed by the dynamic soil properties. Literature Survey from different available books, research papers, thesis works and test manuals have been done. It serves as a plat form to begin and frame of the study properly.

2.1 Basic Index Properties Required in the Study of Dynamic Soil Properties Basic and important physical (index) properties, which are necessary in the determination of the dynamic soil properties are; field

2.3 Cyclic Loadings and Soil Response

The evaluation of the soil response is one of the most important and the most commonly encountered problems in geotechnical earthquake engineering. Soil response analysis is used to evaluate dynamic stresses and strains and to determine earthquake induced forces that lead to instability of earth and earth-retaining structures. The dynamic soil properties govern the responses of soil subjected to cyclic loadings. Appropriate evaluation of shear modulus and damping characteristics of soils subjected to dynamic loadings is the basic element to accurate seismic response analysis and soil modeling programs [20]. The responses obtained for different cyclic loadings needs to be analyzed to determine the cyclic soil properties. A typical soil subjected to cyclic loading exhibits nonlinear and hysteresis response, which is the result of stress-strain curve as idealized in the Fig.2.1. The hysteresis loop is used for the calculation of shear modulus and damping ratio for each cycle. The area enclosed by the ellipse, A_{loop}, is related to the amount of energy dissipated by the material during a cycle loading. A_{Δ} is the maximum strain energy stored during that cycle. A relation between A_{loop} and A_{Δ} gives the damping ratio. When the materials are deformed, energy is absorbed and dissipated by the material itself. The effect is due to friction between the internal planes, which slip or slide as the deformations take place.density and moisture content, specific gravity, Atterberg`s limits, grain size distribution and compaction tests. These properties are important in cyclic loadings for shear modulus and damping ratio determination [50]. Hence, determination of the dynamic soil properties requires consideration of the above-mentioned influencing parameters.

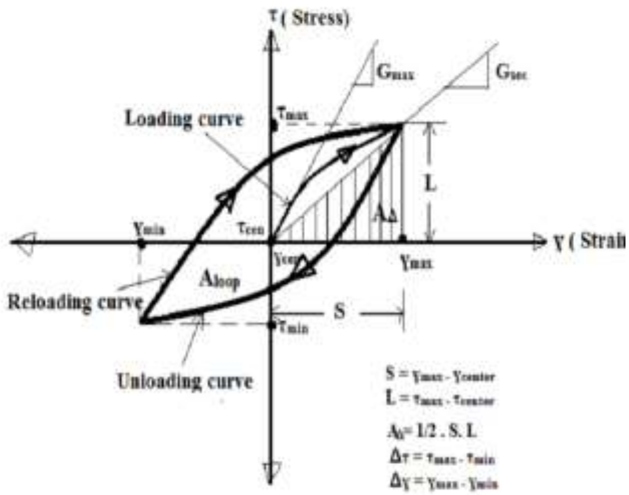


Figure: 2 Hysteris loop

2.6. Factors affecting Shear Modulus and Damping Ratio of Soils

The most important factors that affect the dynamic behaviour of soils divided into two main categories [19]. Firstly, external variables such as stress/strain path, stress/strain magnitude, stress/strain rate and stress/strain duration can affect the dynamic property of soils. Secondly, characteristics of the soil: such as soil type, size and shape of soil particles and void ratio can affect the response of soil to dynamic loadings. These factors are; method of sample preparation in laboratory, confining pressure, methods of loading, over consolidation ratio, shear strain levels, loading frequency, soil plasticity, percentage of fines, void ratio, relative density and soil type. Out these factors: confining pressure, soil plasticity, number of cycles and shear strain levels were discussed in this study.

3. MATERIALS AND METHODOLOGY

3.1 Materials

- Soil samples were collected from four test pits Modjo Dry Port (MD), Teklehaymanot (TK), Shashemane Exit (SH) and Near Minjar Road (NMR) at three different layers each.
- From each layer around 30 kg soil samples were collected for index and cyclic tests.
- For field test, clean uniformly graded sand, sand-cone density apparatus were used.
- For cyclic test, NGI type cyclic simple shear machine and UTS004 software application were used. The machine is found in Addis Ababa Institute of Technology geotechnical laboratory. The general feature of the cyclic simple shear machine is shown in Fig.1.

Figure 1: 31-WF7500 Model cyclic shear machine

3.2 Methodology

Different activities were carried out to meet the objective of the study.

More than 50 literatures on dynamic soil properties were reviewed.

- Soil samples from four test pits were collected.
- Using ASTM standard procedures, the basic index soil tests were conducted.

- The shear modulus (G) and damping ratio (D) of the soil have been determined from cyclic simple shear test.
- Specimen with 70 mm diameter and 20 mm height were used.
- Owing to the difficulties in the prevention of drainage in a simple shear test, the undrained shear tests were carried out as constant-volume tests.

4. TEST RESULTS AND DISCUSSIONS

The laboratory works were done in two parts, the index tests and the cyclic simple shear tests.

4.1 Index Property Tests

The important index property tests done in this study are: field density and natural moisture, Atterberg`s limits, Grain size analysis, Specific gravity and Standard compaction tests.

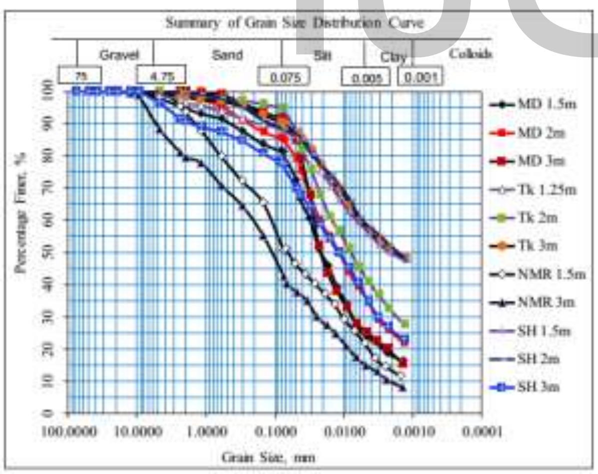


Figure 2: Summary of grain size distribution curves

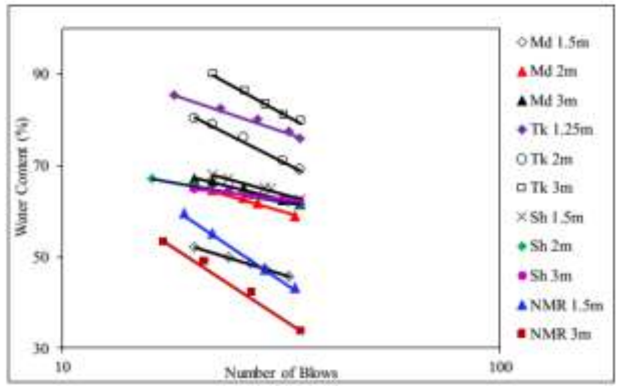


Figure 3: Summary of liquid limit test results

Summary of index test results is shown on Table 1below.

Table 1: Summary of index properties test results

Test Pit		MD			TK			SH			NMR	
Depth (m)		1.5	2	3	1.25	2	3	1.5	2	3	1.5	3
ρ_{bulk} (g/cm^3)		1.21	1.38	1.49	1.38	1.46	1.49	1.39	1.43	1.34	1.53	1.36
ρ_d (g/cm^3)		1.03	1.07	1.16	1.1	1.13	1.16	1.1	1.13	1.14	1.21	1.21
Void Ratio, e		1.56	1.47	1.28	1.39	1.35	1.31	1.29	1.31	1.33	1.22	1.23
w (%)		17.68	29.17	28.82	26.17	29.08	28.43	26.02	26.65	17.27	26.79	12.29
LL (%)		51	63	65	81	76	87	67	64	64	63	29
PL (%)		33	48	45	47	49	48	42	45	44	34	18
PI (%)		18	15	20	31	27	40	24	19	20	30	11
FSI (%)		60	50	45	50	40	30	30	50	40	35	28
G_s		2.64	2.64	2.63	2.62	2.65	2.67	2.52	2.62	2.66	2.69	2.72
Grain Size (%Passing)	Gravel	0.3	0.1	0.1	0.5	1.1	0.1	0.4	0.3	3.8	2.3	2.1
	Sand	18.7	14.79	8.44	11.38	4.33	9.94	11.49	11.5	18.91	50.85	58.37
	Silt	64.74	63.32	76.11	48.2	66.99	51.67	50.79	47.78	54.46	38.79	36.15
	Clay	16.29	21.77	15.39	39.91	27.55	38.28	37.34	40.41	22.85	8.07	3.43
Initial Moisture (%)		13.58	17.03	16.36	15.07	14.3	15.64	14.46	13.64	12.86	9.88	7.45
Soil Type		MH	MH	MH	MH	MH	MH	MH	MH	MH	SM	SM

FSI = Free swell index.

I. Soil Classification

In this study, a combination of particle size and measures of plasticity were used for the soil classifications as shown in Fig.4.
Soil classification was made based on;

- Unified Soil Classification System (USCS) and
- American Association of State Highway and Transportation Officials (AASHTO)

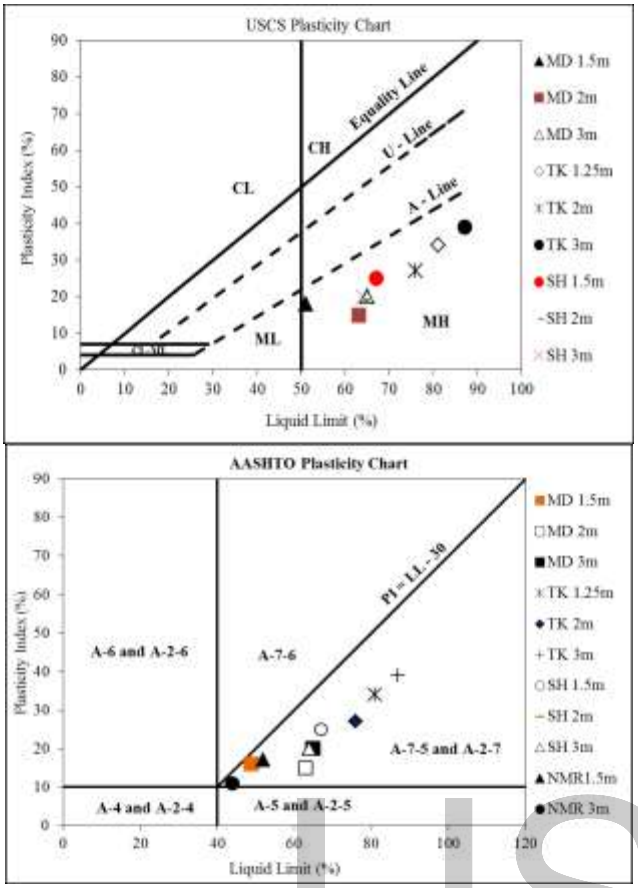


Figure: 4 Soil Classification Results

3.3. Cyclic Simple Shear Test Results

I. Determination of Shear Modulus and Damping Ratio

The dynamic properties were determined from cyclic shear using the hysteresis loop. For single cyclic loading, the cyclic simple shear test gives raw data of Axial Lvdt, Axial Force, Ext Axial Lvdt, Lateral Lvdt and Lateral Force of 50 data points. These data are displayed in the form of wave shapes, charts and tables and logged by the system to an archive data file. Out of these data, Lateral Lvdt (specimen displacements) and Lateral force were used to determine the shear modulus and damping ratio of the soil.

Fig.5 shows the hysteresis loops of TK soil under 100kPa axial pressure and 0.01%, 0.1%, 3% and 5% cyclic shear strain at the 5th cycle.

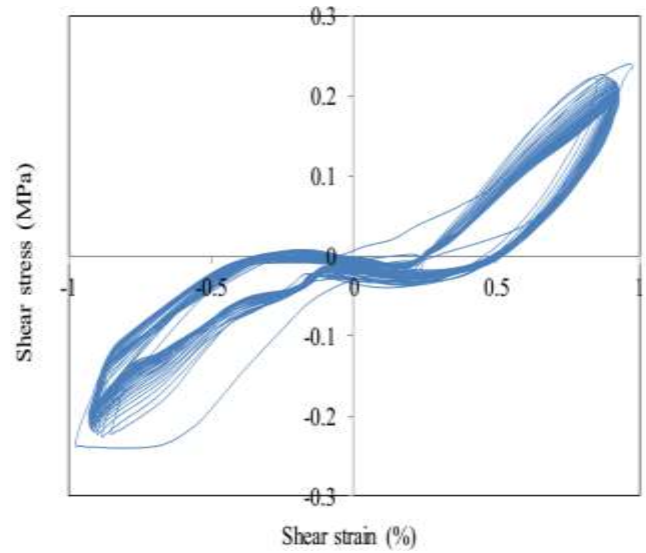


Figure 5: Hysteresis loops from TK under 100kPa axial stress

Table 2: Sample calculation of shear modulus and damping ratio of TK at 100kPa and 5th cycle

Shear Modulus		Damping Ratio	
L	0.092	$A_{loop} = \frac{1}{2}\sum_{i=1}^{n}(\tau_i - \tau_{i+1}) \times (\gamma_i + \gamma_{i+1})$	0.578
S	0.05		
τ_{max}	0.092		
τ_{min}	-0.092		
$\tau_{max} - \tau_{min} = \Delta\tau = 2L$	0.183		
γ_{max}	0.05	$A_s = \frac{1}{2}(S \times L)$	0.0023
γ_{min}	-0.05		
$\gamma_{max} - \gamma_{min} = \Delta\gamma = 2S$	0.10		
$G\ (MPa) = \frac{\Delta\tau}{\Delta\gamma}$	1.83	$D\ (\%) = \frac{A_{loop}}{4\pi A_s} \times 100$	20.13

II. Effects of Shear Strain and Confining stress

The shear modulus and damping ratio of cyclically loaded soils are strongly influenced by the shear strain levels. It was observed that shear modulus decreases and damping ratio increases with increase in shear strain amplitude. Whereas the shear modulus increase and damping ratio decreases with increase in confining pressure as shown in Fig.6 below.

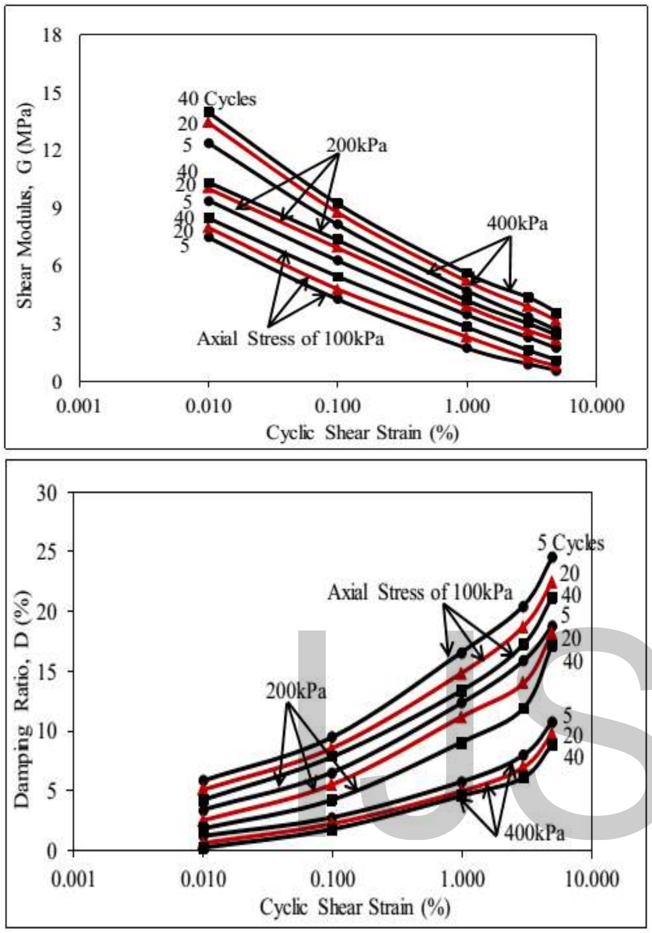


Figure 6: Variation of G and D of MD with shear strain amplitude for a given confining stresses

III. Effects of Soil Plasticity

Soil plasticity has effects on both the shear modulus and damping ratio of soil. As shown in the Fig.7, the normalized shear modulus increase and the damping ratio decrease as the soil plasticity increase with same axial stress.

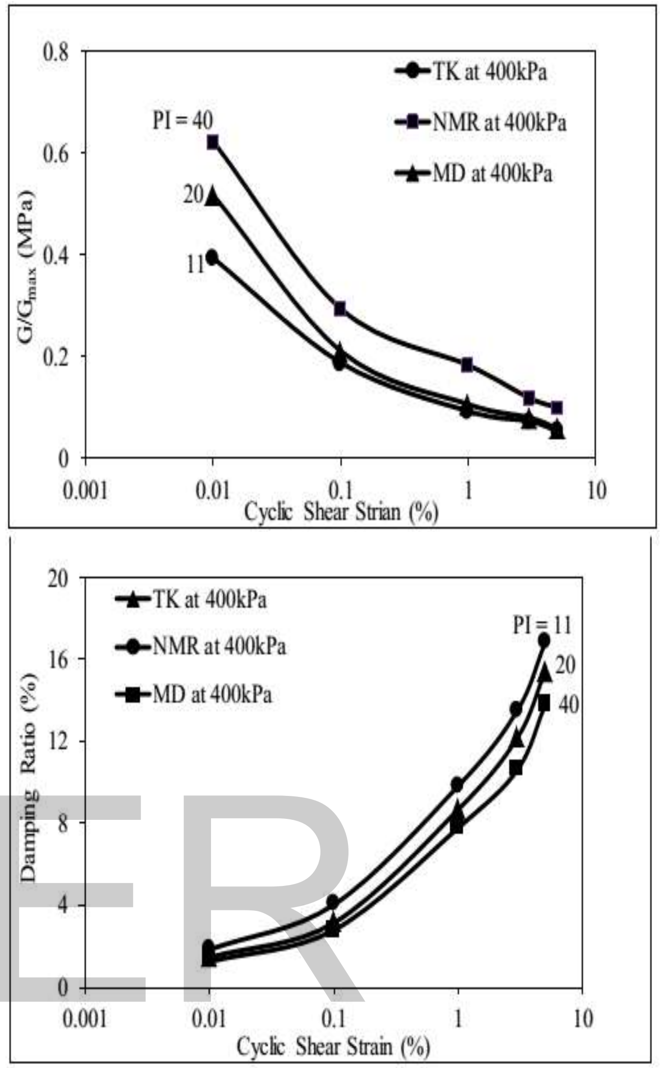


Figure 7: Variation of normalized shear and D of Modjo soil with soil plasticity

IV. Comparison of Cyclic Test Results with Previous Studies

Normalized shear modulus and damping ratio curves of sandy and saturated clay soils developed by Seed H.B and Idriss [49] were used for comparison. For these comparisons, the shear modulus values were normalized (G/G_{max}). The G/G_{max} and damping ratio values of Modjo soil were compared with;

- Sand and saturated clay soil and
- Silt and silty sand soil

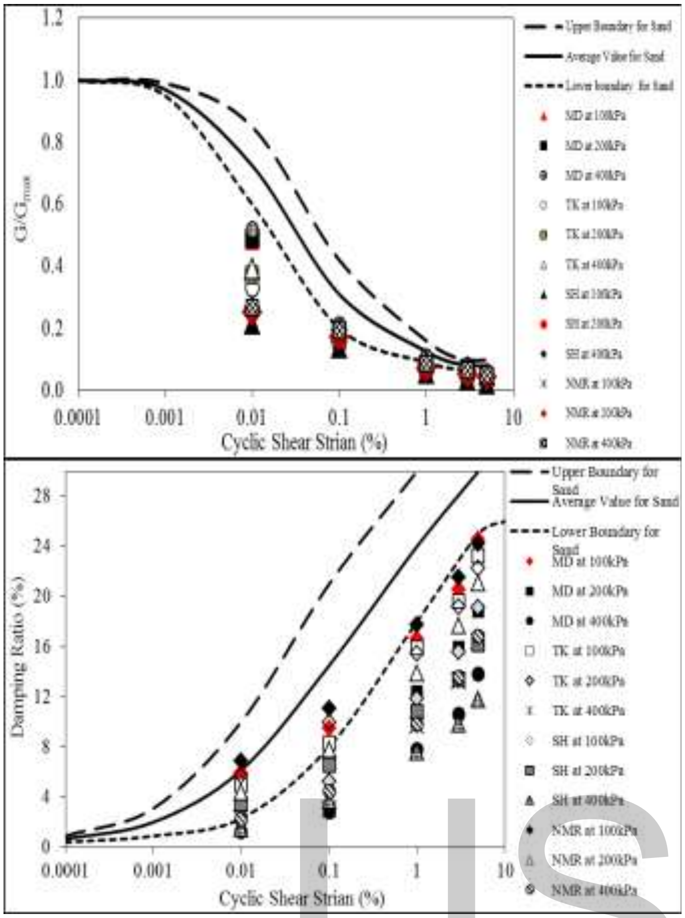
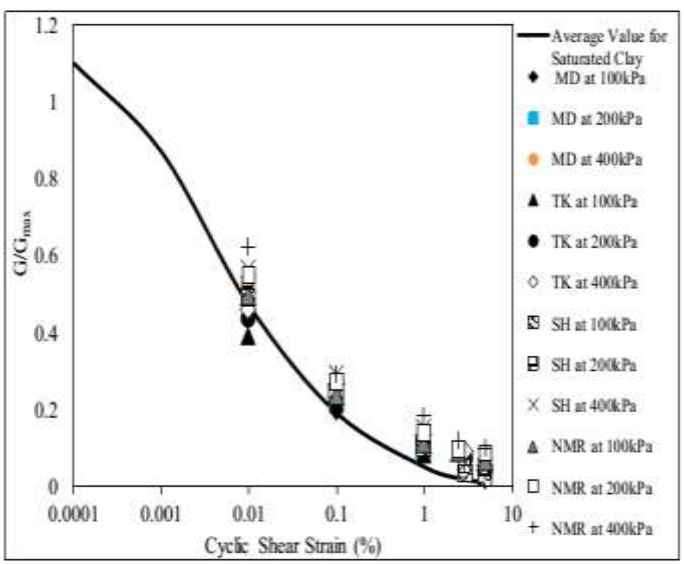


Figure 8: G/G_{max} and Damping ratio values of Modjo soil with sand soil of Seed and Idriss [49].



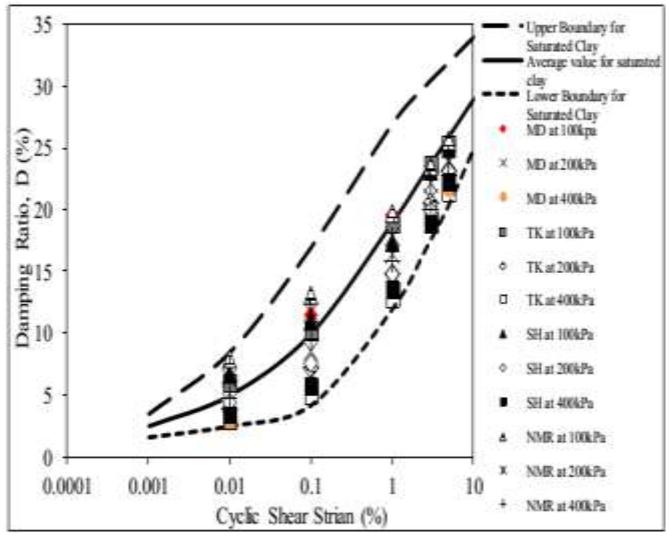


Figure 9: Comparison of G/G_{max} and D of Modjo soil with the saturated clay soil of Seed and Idriss [49]

V. Comparison of Modjo Soil with Local Studies

Comparison of Modjo silt and silty sand soils with Adama and Ziway town silt and silty sand soils were done. The results of normalized shear modulus and damping ratio values of Modjo soils are in a good agreement with silt and silty sand soils of Adama and Ziway towns as shown in Fig.10.

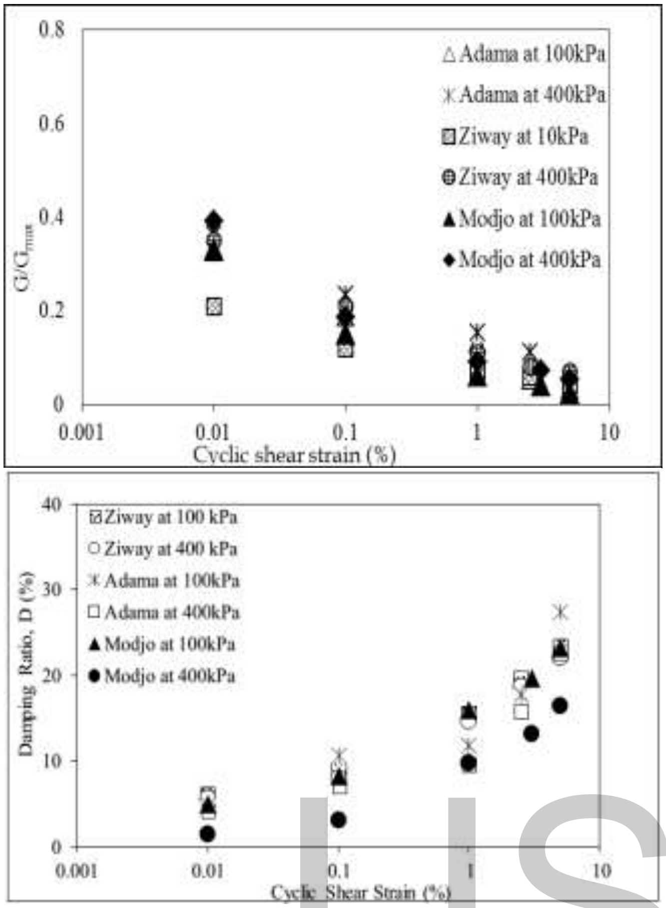


Figure 10: G/Gmax values of Modjo soil with Adama and Ziway silt and sand soils [17]

CONCLUSION AND RECOMMENDATION

Conclusions

Reliable measurement of these soil properties is important for successful analysis of an important class of geotechnical problems such as seismic design and machine foundations. This study investigated the experimental determination of dynamic properties (G and D) of Modjo soil from cyclic simple shear machine. The effects of different factors on the dynamic properties of different soils were also discussed.

- The shear modules values of Modjo soil ranges from 0.11MPa to 22.98MPa
- Damping ratio values ranges from 0.25% to 25.63% and
- Maximum shear modulus values are from 15.41MPa to 68.71MPa, which are acceptable for Modjo soil type based on the literatures.
- There is a good agreement in G/G_{max} values between Modjo and Seed and Idriss soils.
- Some difference was observed between D values and curves of Seed and Idriss. It could be due to sample disturbance, calibration of the machine or imperfect coupling between the top caps and the specimens.
- G and D of Modjo soil showed a good relationship with Adama and Ziway soils.

Recommendations

From the findings of this study, the following points are recommended.

- To obtain a better and comprehensive data more samples have to be tested.
- To observe the effect of saturation, pore-water pressure and degree of compaction on dynamic properties of soil, it is necessary to investigate under saturation condition and under different degree of compaction.
- This study was done using the cyclic simple shear apparatus only. For vertical vibration simulation, it is important to supplement these results by cyclic triaxial test results.

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