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Investigation of the Damping Ratio and Shear Modulus of Soil along Light Rail Transit Route in Megenagna-Hayat Road

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Abstract: Soil vibration may also cause by the movement of heavy vehicles and train, which affect adjacent structures along the route. The response of soils for incoming vibration from the train is measured by the dynamic properties of soils such as shear modulus and damping ratio. These soil parameters are very significant to study the ground motion as well as the site response of soil deposits under cyclic loading and soil-structure interaction. About this, the research study has been sought to give some information about the condition, specifically the shear modulus and damping ratio of the soil along the Addis Ababa light rail transit route from Megenagna to Hayat road. Also, this study was dealt with soil distribution along the route, which was conducted to determine soil properties. The sand replacement method was also utilized to investigate the controlling factors for the dynamic soil properties. From related literature, it was known that the dynamic soil properties are influenced by soil types and location of the soil profile. Five Test pits, designated A, B, C, D & E, were considered randomly for soil sampling to determine the properties of soil. The soil samples were taken from a depth of 2.5m below the surface of the roadside. Aside from the soil laboratory testing for common tests, another test was performed using a simple cyclic shear test for the representative samples. The values of normalized shear modulus and damping ratio are compared with already known curves from literature. The research study found out that the values of normalized shear modulus G/Gmax plotted against the shear strain, showed scattered points when it was compared with the curves of Seed and Idriss. Likewise, for the wet clay from the study area, all measured points were close to the known curve of the plot. On the other hand, the values of damping ratio were also compared to curves provided by Seed and Idriss. The Soil properties from all test pits had almost closer values as seen in the plot. However, the sample collected from test Pit D has the highest value of G/Gmax only, while samples from test Pit C has high values both for Gmax and Damping ratio. Test Pit C showed values of Dry density and liquid limit higher than the other test pits. Based on the comparison of the sand; for the strain less than 1%, all measured points of G/Gmax lying close to the extended curve given by Seed and Idriss. The strain of 0.2%, measured points of G/Gmax is closed to curve plot within the boundary, and it was below the curve given by Seed and Idriss. Likewise, for saturated clay, the measured points are close to the curve of Seed and Idriss. The values of damping ratio obtained for strain less than 1% obtained within the range of either the curves given by Seed and Idriss considers sand or clay soils. For strain, less than and equal to 1% the points lie within a range of clay. Therefore, the controlling factor that affects dynamic soil properties from a comparison of shear modulus and damping ratio curves based on consolidation pressure is the confining pressure, which shows high influence on the values of shear modulus and damping ratio based on the test results of the shear strain amplitudes.

Index Terms—Damping Ratio, Dynamic Properties, Index property, Normalized Shear Modulus, Sand Replacement, Shear Modulus, Shear Strain Amplitude, Simple Cyclic Shear Test.

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1 Introduction

Soil vibration may also cause the movement of heavy vehicles and train, which affect adjacent structures along the route. The response of soils for incoming vibration from the train is measured by the dynamic properties of soils such as shear modulus and damping ratio. Especially vibration from trains passing through cities and towns may cause different damage to a structure. To prevent this from occurring, this research attempted to study the effect of vibration during design and construction to forewarn the affected residential owners and establishments. The study area was conducted in Addis Ababa's light train route. It is located in the growing part of the city and currently, there are so many ongoing construction works in the city which pose a question: "To what degree would a structure sustain damage if vibration occurs?".

To study problems involving soil- structure interaction of the site responses of soil deposits, and possible predictions of the ground motion, it is important to know the dynamic properties such as shear modulus and damping ratios of natural soil deposits. It is known that the effect of vibration is strongly affected by the response of soil deposits and earth structures under seismic loading conditions, of which this research study is conducted to provide some information on the train vibration response of the soil.

There are different laboratory and field techniques available to determine the dynamic properties of the soil, but each technique has their problems and limitations. The laboratory tests behavior into three groups; these are of the strain, small strain and medium strain range depending on the amplitude of the lateral dynamic load it can exert.

Vibrations can be amplified by the passage of trains due to the surface irregularities of wheels and rails, by the rise and fall of axles over sleepers, and by the propagation of deformation patterns on the track and the ground. Such vibrations are transmitted through the track structure, including rails, sleepers, ballast, and sub-layer and propagate as waves through the soil medium [19]. Damage to structures may be caused by the vibration induced differential settlement as well as by vibrations transmitted directly to structures. The complexity of these

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fluctuations related problems makes it difficult to identify the causes of the damages. For the analysis of vibration related problems, it is necessary to consider the combined effect of several factors such as the characteristics of vibration sources, the site characteristics, the propagation of surface and body waves in the ground, and response of structures. The environmental zone, which is effective to reduce the ground vibration amplitude, is often adopted to prevent the vibration damages. However, it was hard to estimate to what degree the amplitude of vibration decreases at a certain distance. The attenuation of vibrations with distance is composed of two factors: geometric damping and material damping. The geometric damping depends on the type and location of the vibration source, and the material damping is related to ground properties and vibration amplitude [19].

The research study was located in Addis Ababa light train project, which starts from Mexico square and stretches to four directions. The train route passes different parts of the city and crossing different geological formations. Since the trains induce vibration load, the dynamic properties such as the damping coefficient and the shear modulus must be deeply investigated to know the performance of the foundation soil, as well as on how it will affect the adjacent buildings. The research study had been sought to answer the following questions to clarify the effect of damping ratio and shear modulus of the soil in a section of Megenagna – Hayat:

- Which type of soils has the highest value of dynamic soil properties?
- What would be the soil response to dynamic load?
- What is the Geotechnical soil parameters that control the dynamic soil properties of the soil?

2 Research Methodology

2.1 Study Area

The study area is located in Addis Ababa City, the largest and most populated cities in Ethiopia. It is found in the Shewa Zone of Oromia at 9°1′48″N and 38°44′24″E. The altitude of the City is 2,355m above the mean sea level. It had a total area of about 527 km2 and subdivided into ten Sub City Administrations. The population of Addis Ababa is estimated to be 3,384,569. Figure 2.1 shows the map of the study area, in which the bold line marked, was the train route under consideration. The newly opened line for Light Rail Transit is in parallel with the existing road on its both sides.

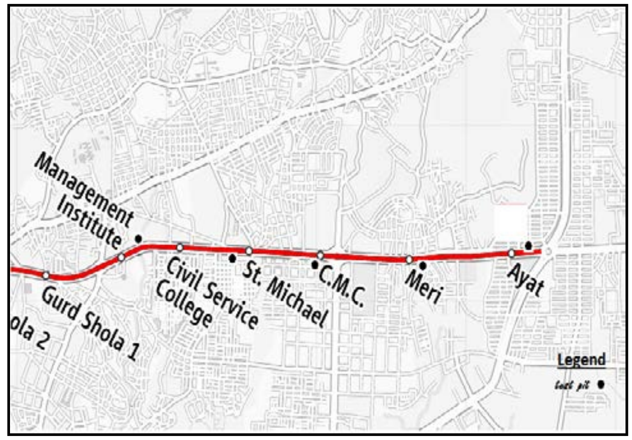

Figure 2.1: Map of the Study Area (Source: Google map)

2.2 Sample Collection

Soil samples were extracted from five selected test pits which are located in Megenagna, Gurd shoal, CMC, Meri and Hayat. The field density is determined using the sand cone replacement method, while the dynamic test is performed by compacting the sample at field density and natural moisture content. The Grain size distribution and index property of the soil are also determined.

2.3 Sample Preparation

The samples were pulverized and used sieve No. 4 (4.75mm), the weight of soil is recorded and mixed with water equal to the percentage of natural moisture content. The specimen is then remolded in a mold to attain the field density as well as the natural moisture content. From this remolded specimen, a 20mm height x 70mm diameter of the sample was prepared; and then placed it in a rubber membrane mounted on the bottom plate of cyclic direct, simple shear machine, which is confined by brass rings to control the lateral deformation of the sample during a consolidation stage.

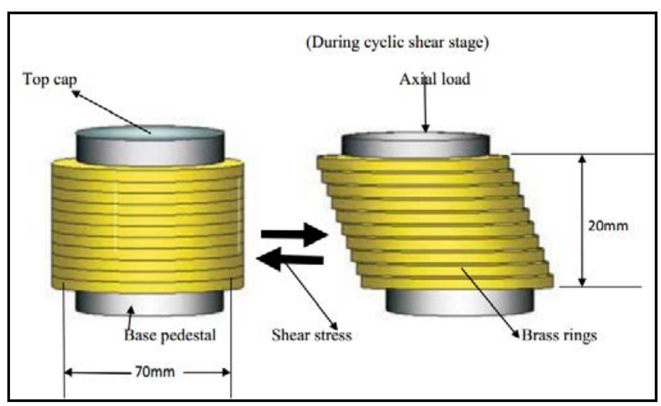

Figure 2.2: Simplified Representation of Lateral Constrain of Specimen Under Cyclic Shear Test (Source: [1])

2.4 Apparatus

To determine the dynamic property of the soil, various

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kinds of apparatus can be used. These include cyclic Tri-axial, resonant column, ultrasonic pulse, piezoelectric bender element, were cyclic shear and cyclic Tensional shear device. In this research study, Cyclic Direct Simple Shear Test was used.

2.4.1 Cyclic Direct Simple Shear Test

The simple shear device consists of either of a rectangle box made of hinged plates or a cylindrical wire-reinforced membrane which surrounds the sample and restrains the sample from expanding laterally in all directions during a consolidation stage but allows the sample to deform horizontally during the cyclic loading test. It is connected to an electronic reading system. The electronic reading system records lateral force and displacement, axial displacement and force. This electronic reading system is governed by a UTS004 software application program that incorporates the functionality to perform consolidation, simple cyclic shear, and linear displacement rate shear. Also, wire-reinforced membrane and electronic reading system, the simple shear device consist of features arranged for applying a constant vertical load or for maintaining a constant sample height while measuring the vertical load and a mechanism for applying a horizontal cyclic shear load as shown in Figure2.3.The cyclic Direct, simple shear test may provide the most accurate representation of the stress state resulting from a vertically propagating shear wave in a horizontally layered soil deposit of any laboratory test; and also the sample is consolidated in Ko state. By applying cyclic horizontal shear stresses to the bottom of the specimen, the test specimen is deformed in much the same way as an element of soil subjected to vertically propagating S-waves. At the top and bottom of the sample, the supporting platens are rough which assists to minimize the non-uniformity of stress conditions. The effects of non-uniformity of stresses can also be reduced by increasing the diameter/ height ratio of the specimen: such effects are small at diameter/ height ratios greater than about 8:1(Kovacs and Leo, 1981). Since the diameter-height ratio of the cyclic simple shear machine present in Addis Ababa Institute of Technology (AAiT) is 7:2, there was an effect of the non-uniformity stress condition. But the plate is rough enough to control the non-uniformity of the stress condition. In addition to the accurate representation of the natural condition of stress state, cyclic direct, simple shear test can measure dynamic soil properties over wide ranges of strain, which is 2% up to 5%.

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Figure 2.3: Cyclic simple shear test apparatus (Photo taken at AAiT Laboratory)

2.4.2 Consolidation Stage

The consolidation stage is simply the application of static axial loading stress to the specimen while the lateral loading (shear) axis are held stationary. In this research study, the axial stresses applied for consolidation are selected, and their values are 100kPa and 400kPa. Axial stress and specimen displacements (axial and lateral) data are measured over time and logged by the system. The consolidation stage is manually terminated once consolidation of the sample has completed.

2.4.3 Simple Cyclic Shear stage

The cyclic shear stage of the test was conducted by applying a lateral cyclic shear force under specified amplitude to the specimen, while the vertical height of the sample is maintained at the constant level. The lateral cyclic shear force tends to slide the rings over each other though the volume of the specimen is unchanged. Since the lower and upper boundary of shear strain to a." for cyclic simple shear testing are 2% and 5 % respectively. The amplitude of the wave from the train is so small, so from the above range some small amplitudes are selected and presented in Table 2.1.

Table 2.1: Selected Amplitude and Shear Strain for Cyclic test

Amplitude(mm)	Shear strain (%)
0.004	0.02
0.04	0.2
0.125	0.5
0.2	1

In this test, both axial and lateral force and specimen displacements are measured for each loading cycle. The measured data are obtained from 50 sample points captured over the cycle period.

2.4.4 Determination of Shear Modulus and Damping Ratio

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The values of both damping ratio and shear modulus are calculated from the following formulas. The calculation is based on shear stress and shear strain that are obtained from the shear force and cyclic shear strain which are the results of the cyclic simple shear test. Normally, there are 40 cycles for single amplitude (Cyclic shear strain), and similar calculation is applied to obtain dynamic soil parameters, shear modulus and damping ratio of soil.

3 ANALYSIS, RESULTS, AND DISCUSION

3.1 Index properties

The physical properties of soil are expressed regarding density, water content, specific gravity, Atterberg's limit, void ratio and behavior of soils under compaction. These physical properties are equally important both under static and dynamic loading condition. Therefore, prior the activity to determine the dynamic soil properties, it is very essential to identify index properties of soils. These have been done in the laboratory. Table 3.1 shows the laboratory test results of index properties of samples collected from Pit A, Pit B, Pit C, Pit D and Pit E. The state of soils is also indicated in Table3.1 which is based on a liquidity index of soil.

Table 3.1: Atterberg's limit results

Sample from	Specific Gravity	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI=LL-PL)
Pit A	2.67	38.5	28.3	10.2
Pit B	2.7	35.5	25.2	10.3
Pit C	2.65	39	34.5	14.5
Pit D	2.68	36.8	27.1	9.7
Pit E	2.7	35	25.6	9.4

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3.2 Soil Classification

The soil sample is classified based on the ASTM D 2487. Table 3.2 shows the classification of soils from the plasticity chart.

Table 3.2: Classification of soils

Sample From	Characteristics of soil passing Sieve No. 40			Plasticity Chart	Soil type
	Liquid Limit	Plastic Limit	Plasticity Index		
Pit A	39.3	28.3	10.2	Below A-line	Plastic silt
Pit B	35.4	25.2	10.3	Below A-line	Plastic Silt
Pit C	49.2	34.5	14.5	Below A-line	Plastic Silt
Pit D	37.6	27.1	9.7	Below A-line	Plastic Silt
Pit E	35.6	25.6	9.6	Below A-line	Plastic Silt

3.3 Result from Cyclic Simple Shear Test

The data obtained from cyclic Simple, the direct shear test was merely raw data which include Axial Lvdt, Axial Force, Ext Axial Lvdt, Lateral Lvdt and Lateral Force of 50 data points for single cyclic loading in the form Microsoft Excel. Since the number of cycle ordered to be done by cyclic machine is 40, for a complete test of any selected amplitude 2000 data points are recorded. From Lateral Lvdt and Lateral force test results, shear stresses and shear strains are evaluated, and the dynamic soil parameters are calculated. Once the shear modulus and damping ratio are calculated, shear modulus and damping ratio versus shear strain were drawn.

3.4 Shear Modulus and Damping Ratio Determination

The values of shear modulus and the damping ratio was determined from stress- strain relationships which are based on raw data obtained from the cyclic shear test as performed in Figure 2.3. From here, there are 50 data points for a single cycle. Using these data points, the hysteresis loop can be drawn. Applying equations 3.1 to 3.6, the values of both damping ratio and shear modulus are computed. A typical calculation is presented in Table 3.3. The calculation is based on shear stress and shear strain that obtain from sheer force and cyclic amplitude which are the results of the cyclic simple shear test. Normally there are 40 cycles for single amplitude (Cyclic shear strain), and similar calculation is applied to obtain dynamic soil parameters, shear modulus and damping ratio of soil [18].

$$\text{Shear stress } () = \frac{\text{Shear force}}{\text{Area of the sample}} = \frac{F}{A} \qquad (3.1)$$

Area of the sample, A = πr^2

$$\text{Shear strain } (\gamma) = \frac{\text{Lateral displacement}}{\text{Height of the sample}} \qquad (3.2)$$

Height of the sample = 20 mm

$$\text{Shear Modulus} = \frac{\tau_n}{\gamma_n} \qquad (3.3)$$

τ_n= difference between maximum and minimum values of shear stress

γ_n= difference between maximum and minimum values of shear strain

$$D(\%) = \frac{\text{Aloop}}{\pi * A_\Delta} \qquad (3.4)$$

Where:

$$A_{Loop} = 0.5 * \sum(\tau_i - \tau_i + 1) * (\gamma_i - \gamma_i + 1) \qquad (3.5)$$

$$\Delta = 0.5 * (L * S) \qquad (3.6)$$

Table 3.3: shows the values of shear modulus and damping ratio

Calculation of shear modulus		Calculation of damping ratio	
τ_{max}	0.0999	A_{loop}= 0.5 * $\sum(_i - _{i+1})$ * $(_i - _{i+1})$	0.000774
τ_{min}	-0.0973		

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τmax-τmin= n	0.197	Δ= 0.5 * (L * S)	0.025
γmax	0.016308	D(%) = (A loop /(4π*Δ))* 100	21.75
γmin	-0.080742		
γmax-γmin= n	0.09705		
Shear modulus() = n / n	2.03		

Table 3.4 shows the values of shear modulus and damping ratio of the sample from Pit A for 400kPa consolidation pressure and 0.02%, 0.2%, 0.5% and 1% cyclic shear strain.

PIT A	Shear modulus for 400kpa				Damping ratio for 400kpa			
Strain %	0.02	0.2	0.5	1	0.02	0.2	0.5	1
No of Cycle								
1	5.45	4.19	3.39	**2.03**	14.82	17.05	20.55	**21.75**
2	5.406	4.14	3.34	1.98	14.63	16.86	20.36	21.56
3	5.33	4.13	3.33	1.97	13.82	16.05	19.55	20.55
4	5.38	4.12	3.32	1.96	13.45	15.68	19.18	20.38
5	5.33	4.07	3.27	1.91	12.96	15.19	18.69	19.89
6	5.17	3.91	3.11	1.75	11.82	14.05	17.55	18.35
7	5.15	3.89	3.09	1.73	11.73	13.96	17.46	18.66
8	5.13	3.87	3.07	1.71	11.39	13.62	17.12	16.68
9	5.11	3.85	3.05	1.69	10.30	12.53	16.03	17.23
10	5.09	3.83	3.03	1.67	8.96	11.19	14.69	15.89
11	5.07	3.81	3.01	1.65	9.46	11.69	15.19	16.39
12	5.05	3.79	2.99	1.63	9.13	11.36	14.86	15.27
13	4.85	3.59	2.79	1.43	8.75	10.98	14.48	15.68
14	4.83	3.57	2.77	1.41	8.63	10.86	14.36	14.77
15	4.81	3.55	2.75	1.39	8.27	10.50	14.00	15.20
16	4.79	3.53	2.73	1.37	9.10	11.33	14.83	16.03
17	4.71	3.45	2.65	1.29	7.83	10.06	13.56	14.76
18	4.69	3.43	2.63	1.27	8.59	10.82	14.32	15.52
19	4.67	3.41	2.61	1.25	7.52	9.75	13.25	14.45
20	4.65	3.39	2.59	1.23	8.27	10.50	14.00	15.20
21	4.63	3.37	2.57	1.21	7.34	9.57	13.07	14.27
22	4.61	3.35	2.55	1.19	7.83	10.06	13.56	14.76
23	4.59	3.33	2.53	1.17	6.99	9.22	12.72	13.92
24	4.57	3.31	2.51	1.15	7.57	9.80	13.30	14.50
25	4.55	3.29	2.49	1.13	6.83	9.06	12.56	13.76
26	4.35	3.09	2.29	0.93	7.23	9.46	12.96	14.16
27	4.33	3.07	2.27	0.91	8.11	10.34	13.84	15.04
28	4.31	3.05	2.25	0.89	7.04	9.27	12.77	13.97
29	4.29	3.03	2.23	0.87	7.82	10.05	13.55	14.75
30	4.27	3.01	2.21	0.85	6.78	9.01	12.51	13.71
31	4.25	2.99	2.19	0.83	7.49	9.72	13.22	14.42
32	4.23	2.97	2.17	0.81	6.71	8.94	12.44	13.64
33	4.21	2.95	2.15	0.79	7.17	9.40	12.90	14.10
34	4.19	2.93	2.13	0.77	6.41	8.64	12.14	13.34
35	4.17	2.91	2.11	0.75	6.88	9.11	12.61	13.81
36	4.15	2.89	2.09	0.73	6.27	8.50	12.00	13.20
37	4.13	2.87	2.07	0.71	6.61	8.84	12.34	13.54
38	4.11	2.85	2.05	0.69	7.39	9.62	13.12	14.32
39	4.09	2.83	2.03	0.67	6.40	8.63	12.13	13.33
40	4.07	2.81	2.01	0.65	7.13	9.36	12.86	14.06

As the values mentioned earlier of shear modulus and damping ratios were computed following the same procedure for all the rest of the cycle as the first cycle and the rest values of shear strain amplitude of the test results.

3.5 Shear modulus and damping ratio curves

To examine the influence of different factors, the values of shear stress, shear modulus, and damping ratio are plotted versus shear strain. These curves are hysteresis loop, shear modulus versus shear strains, shear modulus reduction curves (G/Gmax versus shear strain), damping ratio versus shear strains. Therefore, under this sub-section presentation of a test result is focused by plotting the values of shear stress, shear modulus and damping ratio of soil collected from PitA.

3.5.1 Hysteresis loops

To determine the dynamic properties of soils, the graphs of shear stress versus shear strain, is commonly known as hysteresis loop are plotted. Figure 3.1 shows the hysteresis loop of a sample from Pit A at an axial pressure of 400kPa for 1% shear strains.

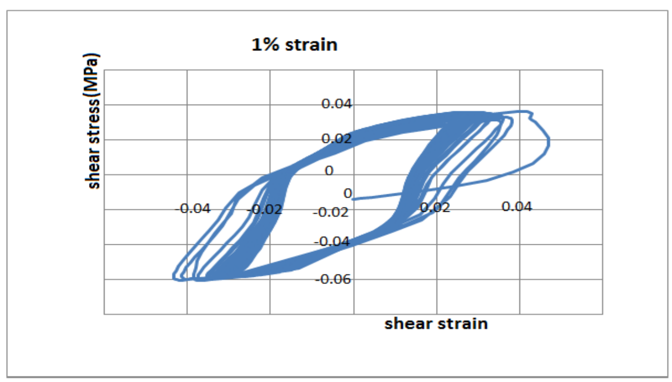

Figure 3.1 Hysteresis loop of sample from Pit A at axial stress of 400kPa for 1% strains

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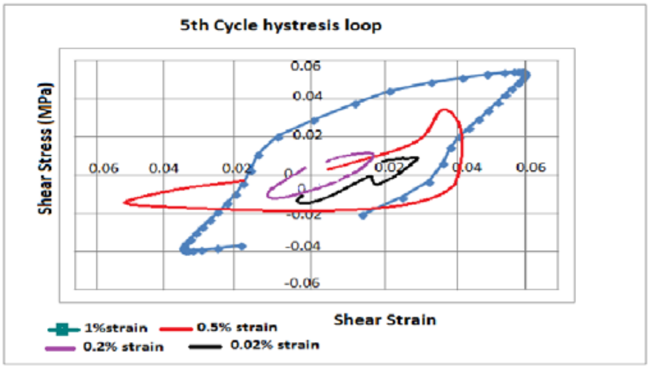

Figure 3.2 Hysteresis loop showing the effect of shear strain amplitude on the hysteresis loop at 400kPa of axial stress

Figure 3.2 is drawn by taking the results obtained from the cyclic simple shear test of shear stress and shear strain of the first cycle of a sample from Pit A for 400kPa confining pressure. The curves indicated the influence of shear strain on the hysteresis loop. The biggest loop corresponds to 1% shear strain and the smallest loop for 0.02% strain.

3.5.2 Dependency of shear modulus and damping ratio of number of Cycles

Table 3.5 contains the values of shear modulus and damping ratio of all Pits for strain 0.02%, 0.2%, 0.5% and 1% under axial consolidation pressures of 100kPa and 400kPa.

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Table 3.5 Values of Shear Modulus and Damping Ratio at 5th Cycle and their average values

Pit A				
	Shear Modulus		Damping ratio	
Axial stress(Mpa)	100	400	100	400
Shear strain				
0.02	3.77	5.46	15.64	12.96
0.2	2.6	4.12	17.75	15.19
0.5	1.97	3.27	20.9	18.69
1	1.79	2.09	22.02	19.89
Pit B				
0.02	4.73	6.21	17.65	14.75
0.2	3.75	4.98	19.61	16.71
0.5	2.77	3.75	21.57	18.67
1	1.79	2.52	22.53	19.63
Pit C				
0.02	4.6	6.12	19.65	18.13
0.2	3.62	5.14	21.61	20.09
0.5	2.64	4.16	23.57	22.05
1	1.66	3.18	24.53	23.01
Pit D				
0.02	4.77	6.29	18.05	16.53
0.2	3.79	5.31	20.01	18.49
0.5	2.81	4.33	21.97	20.45
1	1.83	3.35	22.93	21.41
Pit E				
0.02	4.05	5.57	16.75	15.23
0.2	3.07	4.59	18.71	17.19
0.5	2.09	3.61	20.67	19.15
1	1.11	2.63	21.63	20.11
Average value				
0.02	4.384	5.93	17.548	15.519
0.2	3.366	4.828	19.538	17.534
0.5	2.456	3.824	21.736	19.802
1	1.636	2.754	22.728	20.809

In Figure 3.3 and Figure 3.4 indicate the variation of the values of shear modulus and damping ratio with the number of cycles.

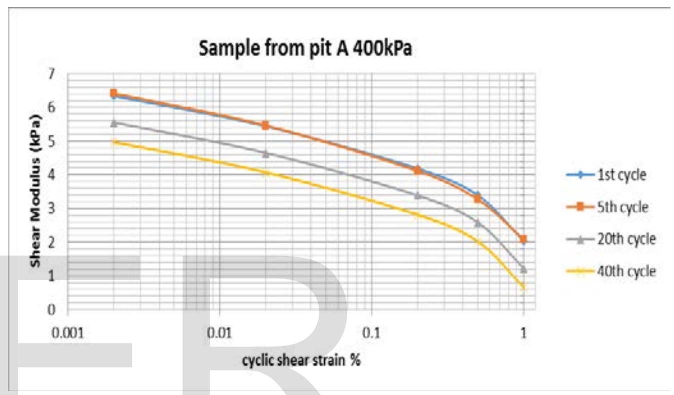


Fig 3.3 Effect of number of cycles on shear modulus of soil

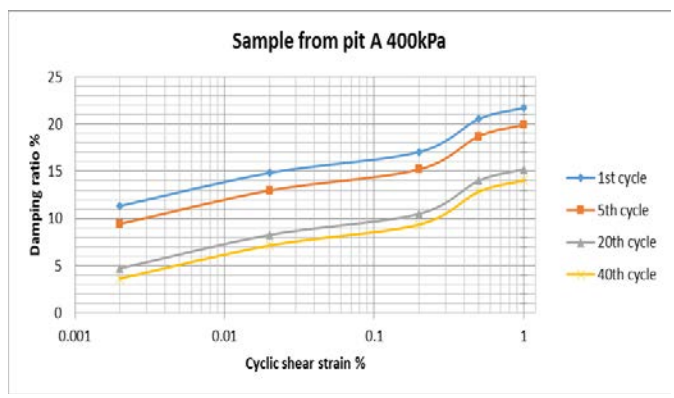


Fig 3.4 Effect of number of cycles on damping ratio of soil

The test result showed that the shear modulus values obtained for specified axial stress at the 5th and 20th cycles differ at most by 40% when the shear strain is minimized (0.02% strain), and the same percentage difference was also noted in the damping ratio of soils. Therefore, it was seen that the value of damping ratio and shear modulus decreases with increasing in no. of cycles. As indicated in Figure 3.3 and Figure3.4, the variation of both shear modulus and damping ratio for the different cycle is almost the same. ASTM D3999 means that the values determined at5th cycle are likely to provide reasonable values for all practical purposes. Thus, in this research, the values determined at 5th cycle are considered for analysis purpose.

3.5.3 Dependency of shear modulus and damping ratio of shear strain amplitude

It is well known that the deformation characteristics of soils are highly nonlinear and this is manifested by the shear modulus and damping ratio, which vary significantly with the amplitude of shear strain under cyclic loading. Figure 3.5 shows the variation of shear modulus and damping ratio of shear strain.

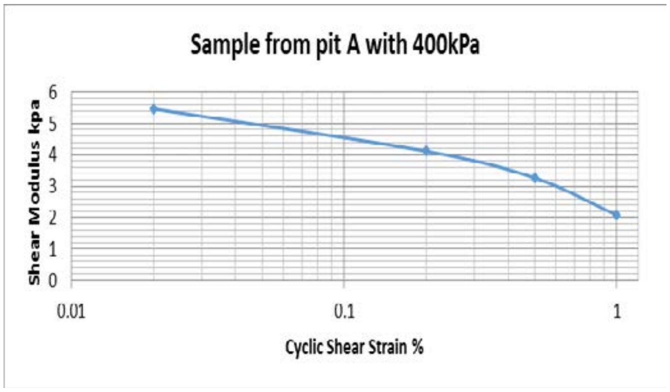
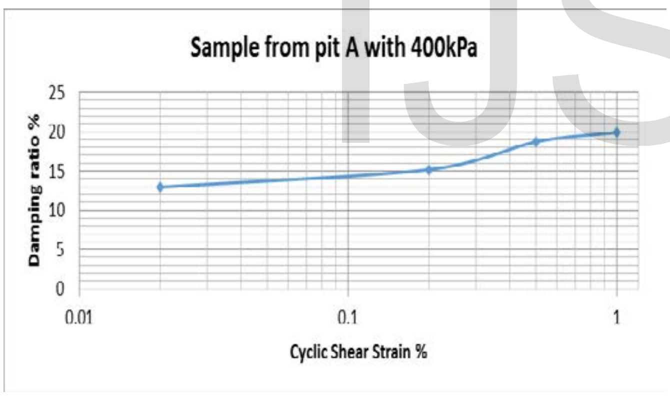


Figure 3.5a: Shear Modulus versus Shear Strain for a sample of Pit A at 400kPa axial stress

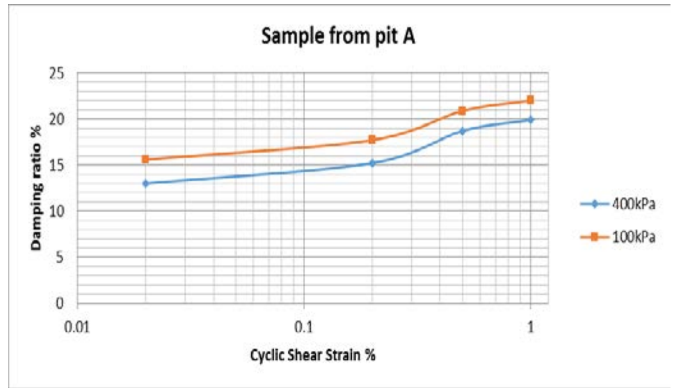


Figures 3.5b Damping ratio versus shear strain for a sample of Pit A at 400kPa axial stress

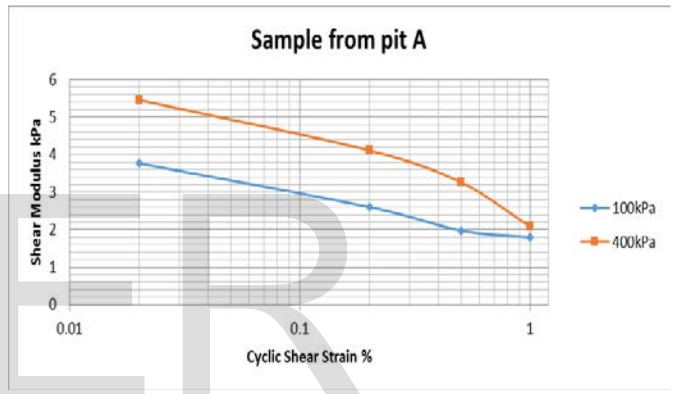
The effect of shear strain amplitude of damp ratio and shear modulus values of soils is shown in Figure 3.5. The shear modulus values decrease for increasing values of shear strain amplitudes. But the value of damping ratio increases as shear strain amplitude increases. This is because of at higher values of shear strain the strength of soils is becoming smaller to resist deformation, and more energy is released to yield substantial deformation.

3.5.4 Dependency of shear modulus and damping ratio on axial stresses

One of the factors which are expected to influence the values of shear modulus and damping ratio of soils is axial consolidation pressure. Figure 3.6 indicates the influence of the axial pressure of 100kPa, 400kPa for strain range from 0.002% to 1%.



Figures 3.6a indicates the influence of the axial pressure of 100kPa, 400kPa for strain range from 0.002% to 1% (Damping ratio).



Figures 3.6b show the influence of the axial pressure of 100kPa, 400kPa for strain range from 0.002% to 1% (Shear modulus).

The values of dynamic properties strongly depend on the values of axial consolidation stresses. The value of shear modulus is higher at higher value of axial stress having the same shear strain, but in a case of damping ratio for the same value of shear strain value damping ratio decreases for increasing value of axial stress.

3.5.5 Dependency of shear modulus and damping ratio on types of soils

The values of shear modulus and damping ratio are influenced by the physical properties of soils such as plasticity index, void ratio or relative density of soils. Figure 3.7 shows the values of shear modulus and damping ratio versus shear strain for samples from Pit A, Pit B, Pit C, Pit D and Pit E at an axial consolidation pressure of 400kPa. As indicated in the figure, the curves are almost identical special at the higher strain. The PI of the sample from Pit A=10.2%, Pit B=10.3%, Pit C=14.5%, Pit D=9.7%, and Pit E=9.4% in which except sample from Pit C others have approximately the same PI value.

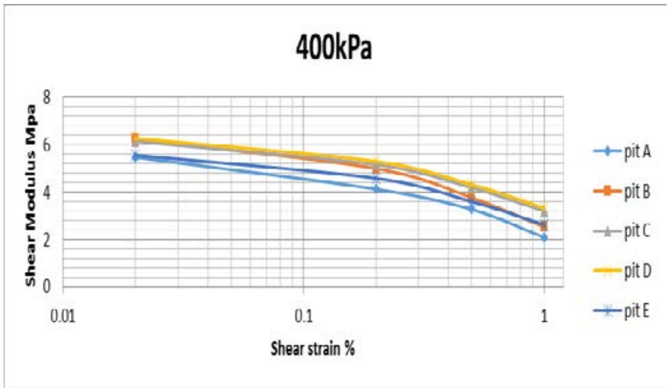


Figure 3.7a: Comparison of values of Shear modulus of sample collected from different test pits

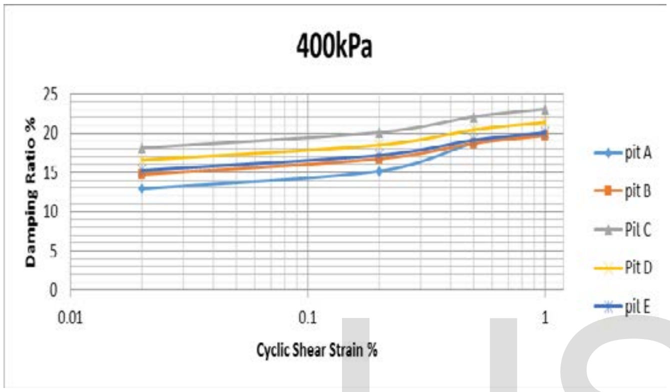


Figure 3.7b: Comparison of values of Damping ratio of sample collected from different test pits

Plasticity index of soils is one of the factors which influence the values of a dynamic property of soils. Plasticity index for fine-grained soils and relative density of coarse-grained soils have the significant influence of the values of shear modulus and damping ratio of soil. Figure 3.7shows a soil having higher no of plasticity index has higher value of shear modulus. Damping ratio values also have higher values for higher values of plasticity index.

Figure 3.8 shows the average values of shear modulus and damping ratio of under axial pressure of 100kPa and 400kPa.

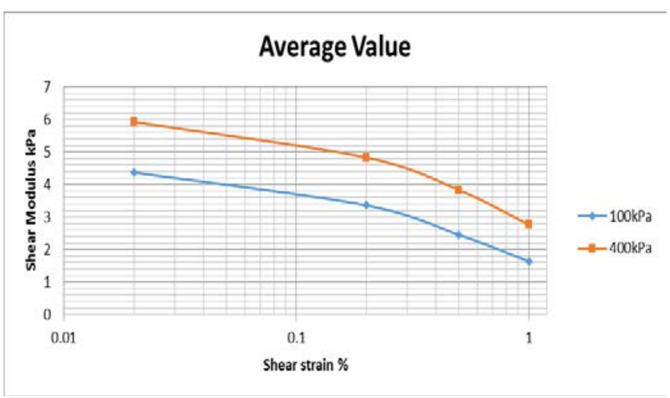


Figure 3.8a: Average values of Shear modulus soils from Five test pits

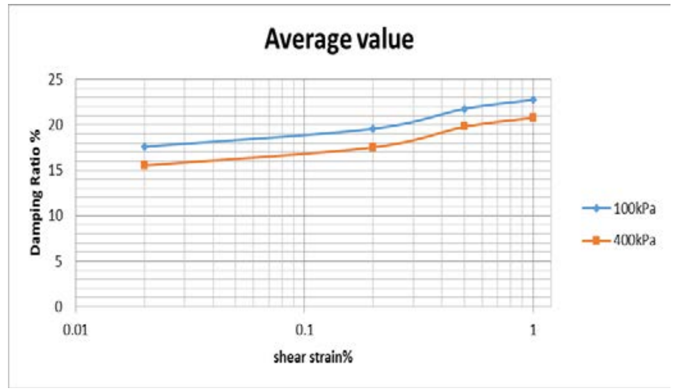


Figure 3.8: Average values of Damping ratio soils from Five test pits

3.6 Determination of initial shear modulus

Maximum shear modulus of any type of soil can be determined using the following equation which is derived by Hardin and Device.

$$G_{max}=14760\,\frac{(2.973-e)2*(OCR)a*(\sigma' m)1/2}{1+e} \quad (3.7)$$

$$\text{Where } e=\frac{G*\rho w}{\rho d}-1 \quad (3.8)$$

G specific gravity

ϱ_d=Dry density of the soil

ϱ_w=Density of water

$$_m=\frac{\sigma'1+\sigma'2+\sigma'3}{3} \quad (3.9)$$

For the condition $'_2='_3$

$K_o=\frac{\sigma 3}{\sigma 1}$, For at rest condition K_o= 0.5, $'_m=2/3*'_1$,

Using K_0 loading condition, lateral stresses can be determined from the applied axial stress as $\varrho_O={}_2=k_{o1}$

K_0 is the coefficient of earth pressure at rest and estimated reasonably at 0.5. From Table 3.6, the value of “a” range from 0 to 0.18 as the PI value goes from 10 to 15. Linear interpolation was used for the determination of a for each test pit (see Table 3.7). Over-consolidation ratio (OCR) for a soil can be defined as $OCR=\frac{P_r}{P_o}$

Pre-consolidation stress is calculated the following equation (Nagaraj and Murti, 1996).

$$\log'_c=\frac{1.322\frac{e_o}{e_l}-0.0463\log\sigma}{0.188} \quad (3.10)$$

And the void ratio at the liquid limit is calculated by the following equation (Nagaraj and Murti,1996).

$$e_L=\left[\frac{LL(\%)}{100}\right] \quad (3.11)$$

Table 3 .6: Values of “a” with respect to Plasticity Index (PI)

PI	“a”
0	0
20	0.18
40	0.30
60	0.41
80	0.48
≥100	0.5

Table 3.7: Calculation of initial shear modulus

Parameters	**Symbol**	**Sample From pit**				
		Pit A	Pit B	Pit C	Pit D	Pit E
Effective vertical pressure	.	100				
Specific gravity		2.67	2.7	2.65	2.68	2.7
Void ratio of effective overburden pressure	e_o	1.4	1.42	1.28	1.48	1.52
Void ratio at liquid limit	e_L	1.05	0.96	0.92	1.02	0.96
	a	0.091	0.096	0.133	0.093	0.09
Over Consolidatio n Ratio		0.68	0.68	0.68	0.68	0.68
Mean principal effective stress		1392.37	1392.37	1392.37	1392.37	1392.37
Max shear modulus	Gma x	548513. 1	529137. 2	657758.3 4	477704. 1	445729. 6
		26.26	25.33	31.49	22.87	21.34
Effective vertical pressure	.	400				
Specific gravity		2.67	2.7	2.65	2.68	2.7
Void ratio of effective overburden pressure	e_o	1.4	1.42	1.28	1.48	1.52
Void ratio at liquid limit	e_L	1.05	0.96	0.92	1.02	0.96
	a	0.091	0.096	0.133	0.093	0.09
Over Consolidatio n Ratio		0.17	0.17	0.17	0.17	0.17
Mean principal effective stress		5569.48	5569.48	5569.48	5569.48	5569.48
Max shear modulus		604.44	598.29	735.63	602.17	599.53
		28.94	28.65	34.75	28.83	28.71

Once the values of Gmax are calculated, one can calculate G/Gmax. Depending on the values of G/Gmax and shear strain amplitude, one can draw normalized shear modulus reduction curves to indicate the influence of confining pressure and types of soils (Plasticity Index). Figure 3.9 shows that the influence of consolidation pressure while Figure 3.10 shows the influence of plasticity of soils for indicating test pits.

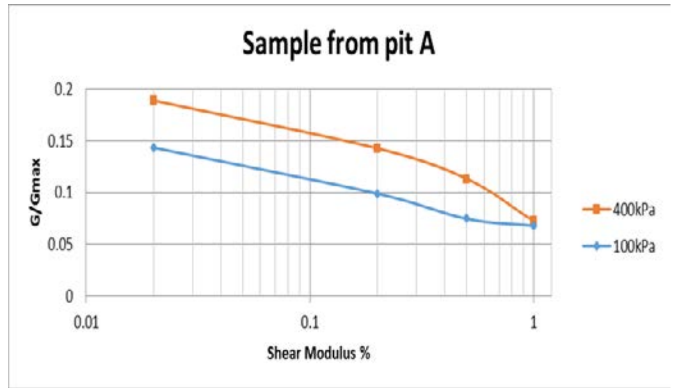


Figure 3.9: G/Gmax versus shear strain amplitude at an axial consolidation pressure of 100kPa, and 400kPa

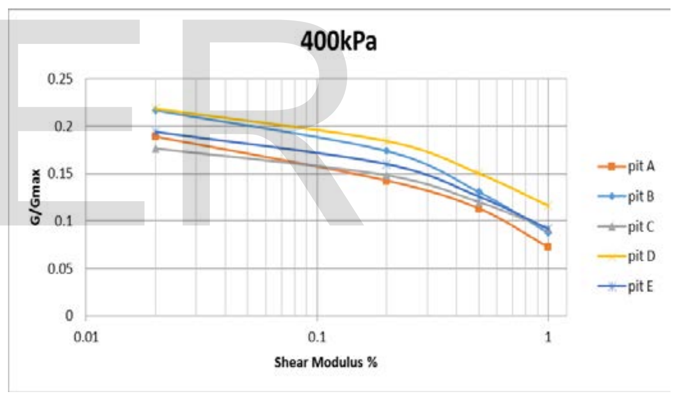


Figure 3.10a: G/Gmax versus shear strain while comparing the values of G/Gmax for soils of different pits at 400 kPa consolidation pressure

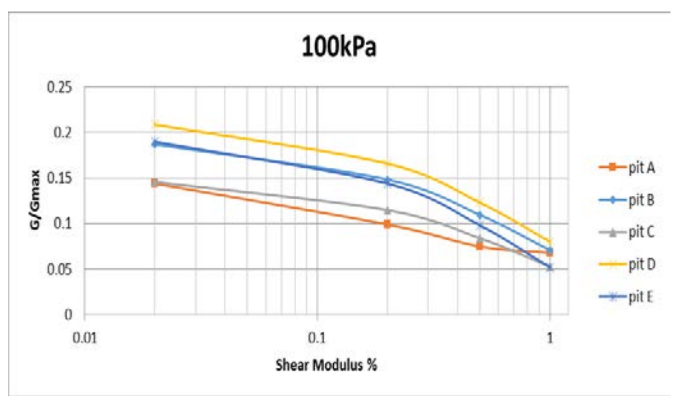


Figure 3.10b: G/Gmax versus shear strain while comparing the values of G/Gmax for soils of various pits at 100kPa consolidation pressure

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3.7 Comparison of results with previous studies

The values of normalized shear modulus and damping ratio are compared with earlier reports of Seed and Idriss. Fig 3.11shows the location of values of G/Gmax of soil for samples from Pit A about sandy soil, while Figure3.12 shows the values of G/Gmax about saturated clay soil.

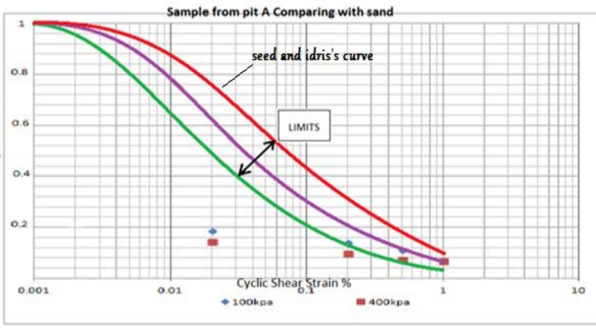

Figure 3.11: Comparison of value of G/Gmax of sample from Pit A with the curves of Seed and Idriss for sand

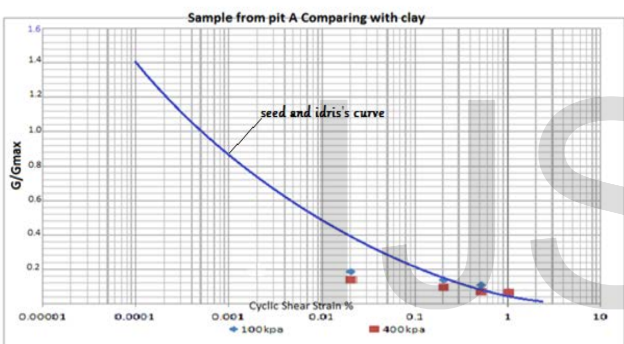

Figure3.12: Comparison of value of G/Gmax of sample from Pit A with the curves of Seed and Idriss for saturated clay

Figure 3.13 and Figure 3.14 also show the location of values of damping ratio Pit A when compared with the curve presented by Seed and Idriss for sand and saturated clay respectively.

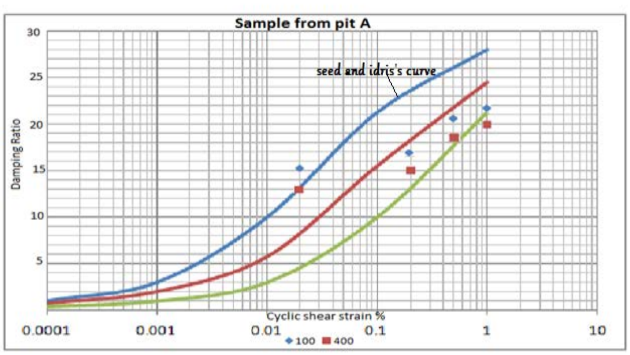

Figure 3.13 Comparison of value of damping ratio of sample from Pit A with the curves of Seed and Idriss for sand

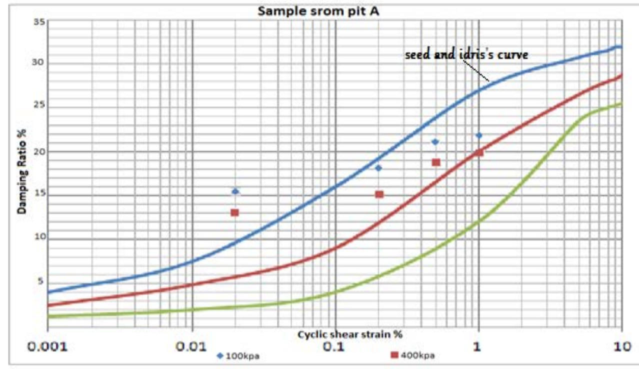

Figure 3.14 Comparison of value of damping ratio of sample from Pit A with the curves of the Seed and Idriss of saturated clay

The results revealed that the soils obtained from the Addis Ababa city are clayey. These test results were compared with previous studies made by Seed and Indris. For sand, the strain was greater than and equal to 0.02%. All measured points of G/Gmax lie close to the extended curves given by Seed and Idriss. Hence the strain of 0.2%, the measured points of G/Gmax were closed to the curve or within the boundary. For a string value of 0.02%, the measured points are below the range given by Seed and Idriss. For saturated clay, the measured points of G/Gmax are close to the curve of Seed and Idriss (Figure 3.11 and Figure 4.12). Comparisons for damping ratio values with curves given by Seed and Idriss, utilizing sand and saturated clay soils. From this comparison, it was observed for strain less than 1%; the measured points the within a range of either the curves given for sand or clay soils. For strain greater than or equal to 1% the points lay within range of clay and outside of sand (Figure 3.13 and Figure3.14). Here, there was a slight variation of values on some measured points from the range given by Seed and Idriss. On the other hand, the value of normalized shear modulus and damping ratio are compared with previous reports of Abu Gemechu Feyisa. The next figure shows lower values of G/Gmax as compared with Abu Gemechu's results.

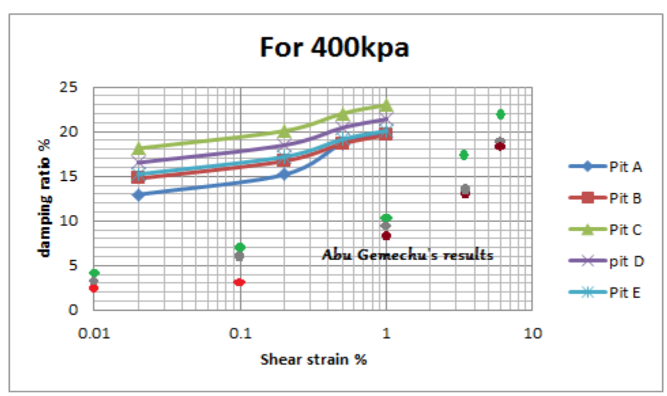

Fig 3.15: Comparison of results using Pit A with the curves of Abu Gemechu Feyisa.

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The result obtained from this research, showed higher values of damping ratio, but less value of G/Gmax as compared with Abu Gemechu Feyisa's results.

4 CONCLUSION

Based on the results of investigations in this research study, the following conclusions had been drawn:

□ The Soil properties from all test pits have almost closer values. However, the sample collected from test pit D has higher values of G/Gmax, while samples from test pit C has higher values of Gmax and Damping ratio. Also, test Pit C has higher values of Dry density and liquid limit. Comparison of the sand showed; the strain less than 1%, all measured points of G/Gmax lying close to the extended curve given by Seed and Idriss. The strain of 0.2%, measured points of G/Gmax were closed to Curve within a boundary. For a string value of 0.02%, the measured points are below the curve given by Seed and Idriss. Likewise, for saturated clay, the measured points are close to the curve of Seed and Idriss. While the sand and clay values of damping ratio obtained for strain less than 1% are located within the range of either the curves given by Seed and Idriss. However, for strain less than and equal to 1%, it could be concluded that the points lie within a range of clay. Moreover, the controlling factors that affect dynamic soil properties from a comparison of shear modulus and damping ratio curves based on consolidation pressure are the confining pressure, which showed high influence on the values of shear modulus and damping ratio based on the test results of the shear strain amplitudes. Therefore, the soil vibration along the study area has the significant effect on the adjacent structures.

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