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EFFECT OF INPUT PARAMETERS ON DYNAMIC CHARACTERISTICS OF CLAYEY SOIL THROUGH DYNATOR – A NON-DESTRUCTIVE TEST

SADIA MOIN*
Currently Pursuing Doctoral Degree in Civil Engineering from NED University of Engineering and Technology, Pakistan and serving as a Lecturer there.
*Corresponding Author Email : sadiamoin@cloud.neduet.edu.pk

Dr. AMANULLAH MARRI
Professor, Department of Civil Engineering, NED University of Engineering & Technology, Karachi, Pakistan.

Dr. SADAF QASIM
Associate Professor, Department of Civil Engineering, NED University of Engineering & Technology, Karachi, Pakistan.

Abstract

Currently dynamic loading and its effects on foundation is quite a hot topic in the field of geotechnical engineering which occurred due to vibration effect on soil, and it is quite challenging to observe. This study was performed on the Resonant column equipment accompanied by the software Dynator. The usage of software needs a proper understanding and its effects on the testing properties of soil. The previous studies of dynamically loaded soil studied through resonant columns majorly are in the range of 1 to 2 Hz with free vibration and forced vibration, but to start work with the soil sample and to relate the loading properties with the literature is difficult because of the input parameters of dynamic loading. The objective of this study is to provide how much difference occurred in the values of shear modulus *(G)*, damping ratio *(D),* and peak strain amplitude *(γ)* on minor changes of input values. The outputs of this research show that shear modulus values increase linearly on change of values of initial frequency and peak strain amplitudes decreases, while there is a minor decrease in the Damping ratio. The acquisition channel gives linear straight values of damping on angular and in the channel of acceleration it provides the wave type variation in values of damping ratio.

Keywords: Clay, Frequency Range, Shear Modulus, Damping Ratio, Maximum Strains, Confining Pressure, and Acquisition Channel.

1. INTRODUCTION

Soft soils are considered problematic soils[1] but most of the areas in *Pakistan* are rich in different types of soft soils[2]. On the other side, dynamic loads such as traffic loadings, machine vibrations, seismic loading, etc. are also considered a big threat to the different structures built on these types of soil[3]. The dynamic characteristics of soil which are quite important for clayey soils are the Damping ratio (D) and shear modulus (G). This study also focused on the said two properties and these are measured through the equipment of Resonant column and torsional shear (RCTS) provided by Wykeham Ferrance, Italy (W8500).

The RCTS equipment comes with the software DYNATOR, that software having four modes of the testing sweep, chirp (continuous), free vibration decay, and torsional shear, all four modes require inputs in terms of frequency and shear strains and then provide different parameters of dynamic characteristics, like the values of shear modulus,

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damping ratio, and peak strains. The objectives of this study are to observe the dynamic response of low plastic clay soil in its untreated condition on the input of different initial and final frequency values (but having the same difference), shear strains, acquisition channel, and cell pressures and validate the results of damping ratio with previous research.

2. LITERATURE REVIEW

Design of machines and buildings heavily relies on dynamic evaluations of material properties, and advancements in dynamic analysis techniques in lab Tests are becoming commonplace. It has made it feasible to resolve difficult dynamic challenges involving soil and structural cooperation. [4]. The dynamic characteristics of soil at various shear strain amplitudes can be determined using a variety of laboratory and field testing techniques. To determine the dynamic properties of soil at a specific strain level, laboratory testing methods like bender and extender element testing and ultrasonic pulse velocity testing are helpful. On the other hand, cyclic torsional shear test, cyclic direct shear test, cyclic triaxial test, and resonant column apparatus testing techniques provide the dynamic properties of soil for different strain levels with different frequency ranges. [5].

The resonant column testing method is widely used in geotechnical engineering since the 1930s and Japanese engineers Ishimoto and Iida developed the resonant column testing method. [6], [7]. But still, there are some challenges in performing resonant column tests. [8] A cylindrical sample with dimensions of 50 mm in diameter and 100 mm in thickness is anchored at the base and free to rotate on the head of the combined Resonant Column/Torsional Shear device *Figure 1* The specimen's free end is subjected to a torsional force using an electromagnetic motor made up of 4 magnets and 8 coils. Each sample receives torsional inputs that are regulated by amplitude and frequency. To find the sample resonance frequency f_n, to which G and D are connected, the excitation frequency is modified for each amplitude. In particular, the specimen density is used to derive G through the equation $G = \rho V_s^2$, where V_s is the shear wave velocity connected to f_n, and the half-power bandwidth is used to determine D from the applied frequency-response curve. The tests were performed by varying the input amplitude, to investigate the behavior of the soil on different shear strains ranging between 0.0001 and 1%. As usual, the tests were interpreted in terms of *G- γ* and *D- γ* curves. [9]

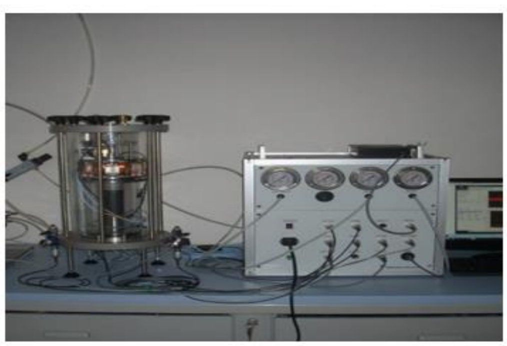

Figure 1: Resonant Column Equipment

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This study was done through a Resonant column W8500 device which is fixed-free and has 4 modes of testing i.e. sweep, chirp, free vibration decay (FVD), and torsional shear (TS). RC sweep is considered a conventional method with only forced vibrations while chirp is a new and innovative technique, [4], [8] while the sample can be tested alone in free vibrations by FVD and in torsional mode through torsional shear test for up to the frequency of 50 Hz but in the other 3 methods frequency input can go up to 300 Hz.

Most of the researchers used the Resonant column discrete/ sweep method for forced vibration technique or free vibration decay in free vibration mode to observe the behavior of soil under dynamic loading conditions because these are considered conventional methods, but the input parameters in terms of the frequency range are not clear, although most of the studies focused on 0.5, 1 or 2 Hz frequency level with small strain the range of initial and final frequencies is not mentioned.[10]–[14]

It is important to step towards improving the long-term performance and design of geotechnical structures that benefit the mechanical response of stabilized soil under dynamic loading circumstances[15].

This study helps the new researcher to perform the test on said equipment with confidence and provides an understanding that what are the effects of testing if didn't understand the soil behavior and frequency phenomenon before testing.

3. MATERIALS AND METHODS

The collected sample's optimum content and maximum dry density have been determined through the Proctor test. Specific gravity, plasticity index, and soil classification are done through the designated ASTM standards and the Unified soil classification system. The results are given in Table 1.

Table 1: Soil Sample Properties

Specific Gravity	2.68
Optimum Moisture Content	17%
Maximum Dry Density	1.81 gm/cc
Liquid Limit	27.48%
Plastic Limit	19.36%
Plasticity index	8.12%
Soil Classification	CL-ML

To achieve the objectives, different frequency ranges were applied under constant cell pressure of 500 KPa and strains (0.0001%), the same frequency ranges were also applied with different cell pressures (100 and 300 KPa), although the difference of initial and final frequencies remains constant which is 60 Hz. Table 2 provides a methodology to achieve the said objectives.

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Table 2: Methodology adopted to identify differences

Testing Conditions	Constant values	Variable	Observations
1	Confining pressure and strains	Initial and final frequency	*G, D, and γ*
2	Strains	Cell pressure, Initial and final frequency	*G, D, and γ*
3	Confining pressure, strains	Acquisition channel	*D (from FVD)*
4	Cell pressure and frequency	strains	*D (from RC sweep)*

To validate the results, the same methodology has been adopted which is adopted by Mog & Anbazhagan. [16]. The literature predicted the results that an increase in strains leads to a reduction of shear modulus while the increase in damping ratio. [9], [16]. The validation of the damping ratio is done by the conductance of a series of different tests with the specified inputs and mode. FVD gives the value of the Damping ratio while the shear modulus is checked through back-calculation by estimation of shear wave velocity. [10], [16]

The situation of high frequency and low strains is considered to match the criteria of soil experiencing vibrations due to machine foundations.

4. RESULTS

4.1 Effect of Frequency Range with Constant Cell Pressure and Amplitude Strains

Table 3: observed values under constant cell pressure and strains

Frequency range (Hz)	Strains (%)	Shear modulus (MPa)	Damping Ratio	Peak Strain achieved (γ)(%)
10 to 70	0.0001	1.53	0.628	0.0265
20 to 80	0.0001	4.06	0.587	0.00652
30 to 90	0.0001	8.6	0.573	0.00283
40 to 100	0.0001	15.37	0.559	0.00161

the initial and final point of the frequency range shows minor changes in the values of the damping ratio while the shear modulus increase linearly. On the other side Peak strain achieved on 10 to 70 Hz gives more value as compared to the frequency range of 40 to 100 Hz. The comparative analysis is mentioned in *Figure 2.*

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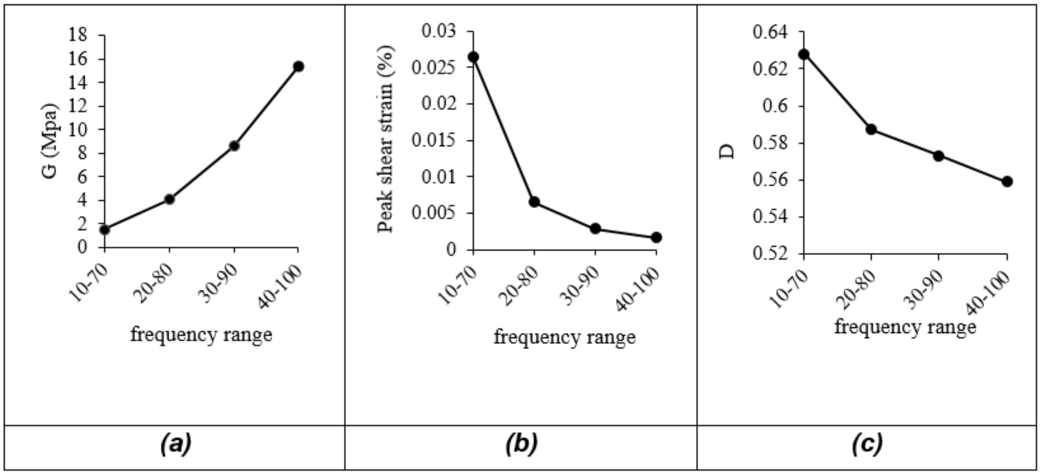

Figure 2: Effect of frequency range (a) shear modulus (b) strains (c) damping ratio

4.2 Effect of Cell Pressure with Different Frequency Ranges and Constant Shear Strains

Table 4: Observed values under different cell pressure and frequency range

Cell pressure (KPa)	Frequency range (Hz)								
	20 to 80 Hz			30 to 90 Hz			40 to 100 Hz		
	G	D	γ	G	D	γ	G	D	γ
100	3.21	0.6182	0.00605	8.87	0.5801	0.00201	15.36	0.5705	0.00112
300	3.93	0.5930	0.00628	8.9	0.5853	0.00246	15.5	0.5615	0.00147
500	4.06	0.5870	0.00652	8.6	0.5732	0.00283	15.37	0.5590	0.00161

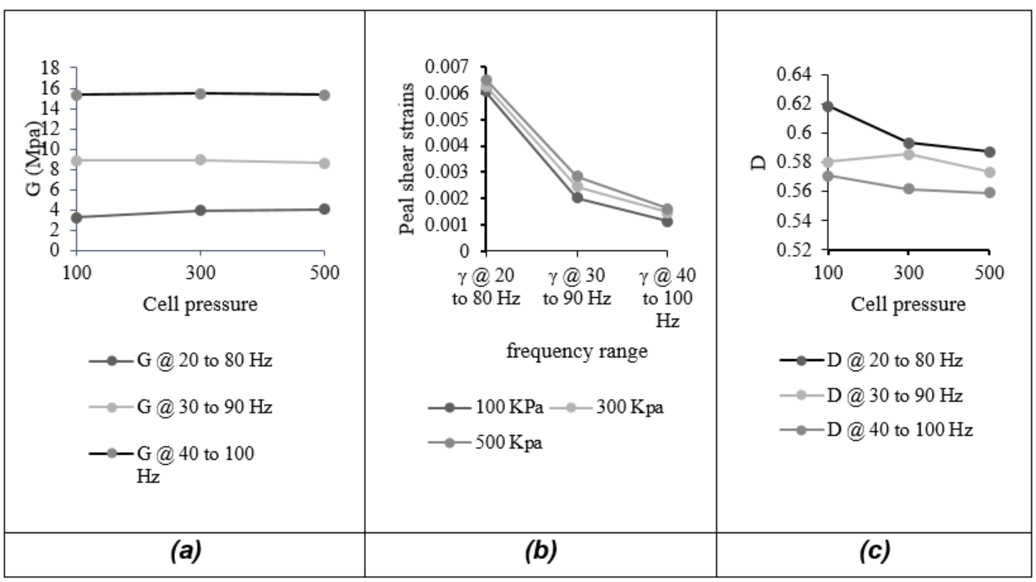

Figure 3: effect of change in confining pressure on (a) shear modulus (b) strains (c) damping ratio

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4.3 Effect On G And D Due To Acquisition Channel

To find out the effects the soil was tested under the frequency of 30 Hz with 20 no. of vibration cycles and differences were observed on applying different strain levels. Results are listed in Table 5

Table 5: Observed values on Damping ratio due to acquisition channel

Amplitude Strain (%)	Acquisition Channel	
	D at Acceleration	D at Angular
0.001	0.613	0.496
0.002	0.328	0.516
0.004	1.472	0.597
0.005	1.491	0.618

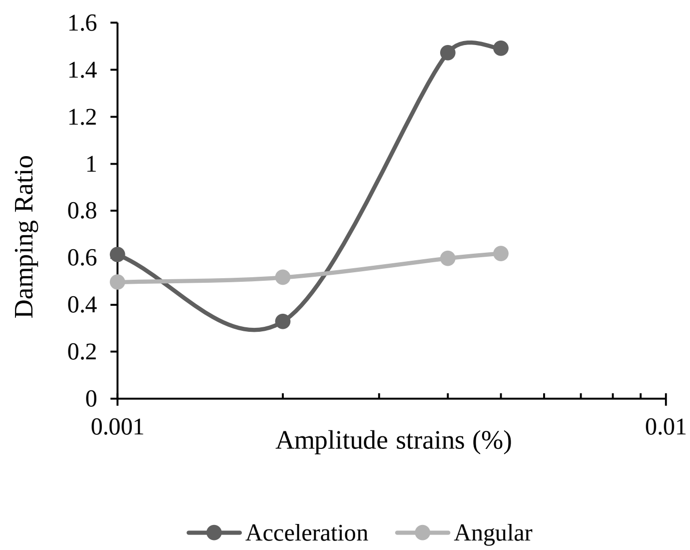

Figure 4: Effect of change in acquisition channel

4.4 Validation

4.4.1 For Damping Ratio

The soil tested in the range of 1 Hz with 50 KPa at different strain levels with free vibration decay on 2 cycles, the table provides the results of the above methodology. Results are plotted in the below figure which also lies in the average range of previously observed damping ratios.

Table 6: Observed Damping Ratio on different strain levels for validation

Shear Strains (%)	Damping ratio	Shear Strains (%)	Damping ratio
0.0001	0.231	0.002	1.386
0.0002	0.997	0.003	2.253
0.0005	1.028	0.004	2.386
0.0008	1.042	0.005	2.453
0.001	1.22	0.01	2.697

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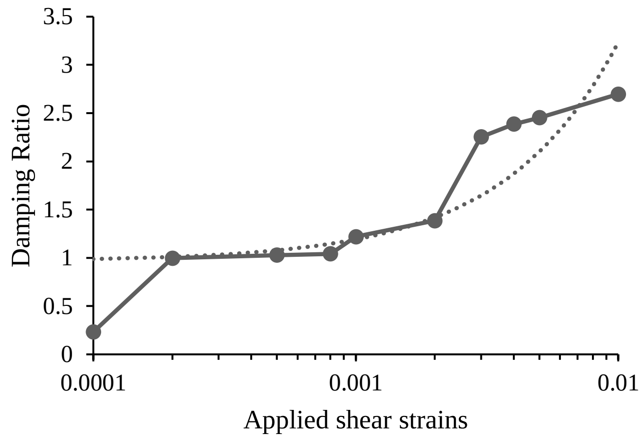

Figure 5: Observed Relationship between damping ratio and strains from the current study

The same trends for various soil types observed in the past research with low frequency and strains through resonant column test and the observed values of control test lie in the same trends which gives a comparison of the damping ratio of sands and cohesive soil in Figure 11 [16] the observed results of this study lie closely to the trends which observed by Darendeli 2001 [17]and the Kunjari Mog.

4.4.2 FOR SHEAR MODULUS (G)

Atkinson [18] observed in the study that the shear modulus will remain the same on small strains and shows an inverse relationship with the strains. On the other side, the value of shear modulus is calculated through the shear wave velocity and density, and the value of shear wave velocity is obtained through the experimental results and calibration of the resonant column test. The value of shear wave velocity is dependent on the factor "Beeta" (β) which is obtained through the calibration of equipment. It also shows the value of β in each test. After identifying the values of shear wave velocity, one can find out the values of shear modulus from the following calculations.

Back calculation of shear modulus from RC Sweep test

The formula for shear modulus and shear wave velocity is listed in the equation

$$G = \rho V^2$$

$$V = 2\pi frL/\beta$$

Where;

G= Shear modulus (MPa)

ρ = density (KN/m^3)

V= shear wave velocity

f_r= resonant frequency

L= length of the sample

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Figure 6 provides input parameters and results of the RC sweep test for 10 to 70 Hz at a cell pressure of 500KPa. By putting values in the above-mentioned equations, the same results were obtained.

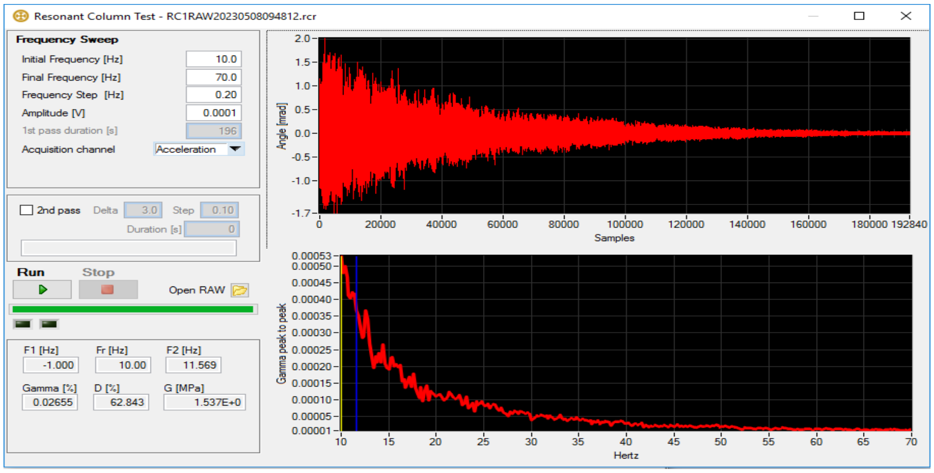

Figure 6: Screenshot of resonant column sweep test (forced vibration)

CONCLUSION

The result of this study gives us a clear idea that input of frequency values has a great effect on the observed maximum strain range, as the strain range is having a quite big effect on the shear modulus and damping ratio, while the damping ratio not experiencing any significant effect and shear modulus value increased linearly which shows that the if the initial range of frequency increased then shear modulus value will also increase linearly. But to check the effect on *G* with any one value of frequency, it is suggested to start the range near to that value.

The increase in confining pressure increased the values of shear modulus while damping ratio values are almost constant and an increase was also observed in the values of maximum strain amplitudes. The same trends were observed in past studies through various methods or equipment. [3], [19], [20]

The effect of the acquisition channel shows that the if selects angular instead of acceleration, the values of the damping ratio are estimated lower as compared to the accelerated acquisition channel. It may be due to the behavior of soil rigidity.

To validate the values of experimental work the free vibration decay test was performed with the same frequency and strains on the same soil which is having the same index properties and the estimated values lie in the same range as identified in previous studies which was summarized by K. Mog and P. Anbazhagan. [16]

This study recommends that for a safe design consider the initial and final frequency values of the desired range which gives the maximum values of peak strain as recommended by K.Mog [16] and near to desired frequency value. Find out the value of the damping ratio and consider the value of shear wave velocity to determine the value of shear modulus.

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Research Significance

The title indicates that it gives information on how input parameters affect the dynamic properties of soil. Most researchers chose the free vibration decay test in the resonant column test because it only required them to enter a single value of frequency while the other required them to select a frequency range and channel input, which could change the shear modulus and damping ratio values and due to this data were abundant in the literature on strains and frequencies about the resonant column test. It is crucial to comprehend that the updated resonant column equipment offers testing methods for combining forced and free vibration data.

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