DEFORMATION CHARACTERISTICS OF COHESIONLESS SOILS DUE TO VIBRATIONS

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By

RAJENDRA GUPTA

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ROORKEE,
ROORKEE, INDIA

1962

-: CERTIFICATE :-

Certified that the thesis entitled "DEFORMATION CHARACTERISTICS OF COHESIONLESS SOILS DUE TO VIBRATIONS" which is being submitted by Shri RAJENDRA GUPTA in partial fulfilment for the award of the Degree of Master of Engineering in Civil Engineering (Soil Mechanics and Foundation Engineering) of University of Roorkee is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other degree or diploma.

This is further to certify that he has worked for a period of Six months from 20th April to 20th October, 1962 for preparing thesis for Master of Engineering Degree at the University.

S. Prakash/20.11.62.

Dated November, 21 /1962.

(SHAMSHER PRAKASH)
Reader in Civil Engineering,
University of Roorkee,
Roorkee.

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-: SYNOPSIS :-

Attempt has been made to study the possibility of testing cohesionless soil samples under vibrations on a small shaking table in which amplitude and frequency could be adjusted. The veriables considered include frequency of vibration, amplitude, specimen size and loading intensity. The deformations of the samples were measured with dial gauges at various frequencies with time interval of 60 seconds.

The results show that loading stress and intensity of acceleration have remarkable effect on the deformation of samples tested.

A critical review of the available literature on vibratory loading of soils has also been presented.

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INTRODUCTION

A knowledge of the deformation characteristics of soil under dynamic loads at various rates of loading is required to determine the stability of foundation and earth structures when subjected to such loads. Dynamic loads may be imposed by earthquakes, explosions, traffic, machine foundations etc. In earthquakes and bomb blasting, loading is of transient nature (number of repetitions depends upon the nature of earthquakes and blasting), slow repetitional type of loading is produced by heavy wheeled traffic over pavements. Depending upon rapidity of load, application of such loading may also constitute a dynamic load while in machine foundation load is applied in quick succession.

It is necessary to find out to what extent the properties of soils are apt to change under respective dynamic effects. This is particularly important with saturated sands which can loose stability and can be transformed into a liquified state due to dynamic forces. Many cases are known in which structures resting on sands were subjected to more or less serious deformations due to more or less serious deformations due to vibrations. As a rule such phenomenon occured when sands were situated below the water level (Dalmatov 1962)

Investigations, concerning dynamically excited foundations soil system, vibrating compaction of soils, earthquakes and effects of bomb blasts on soils, have contributed to the knowledge of the behaviour of soils under impact and vibratory loading. Both theoritical and empirical approaches to the problem of a vibratory mass, resting on, or surrounded by soils has been reported in the literature.

Casagrande and Shannon (1949) reported their results of transient tests on sands and concluded that the strength of sand increases only slightly with decreasing time of loading, the strength for the fastest time of loading (.02 second) being about 10% greater than that for 10 minutes static tests, and the modulus of deformations of sand was independent of time of loading.

Seed and Lundgren (1954) investigated the effect of transient loads on strength and deformation characteristics of saturated sand and reported that the strength of dense sand under transient loading with failure time of about .02 second was about 40% greater than the normal rates loading in drained tests. The strength in drained and undrained tests in these transient tests was the same. Studies of strength and deformation characteristics of sands under transient loads have been further carried out at M.I.T., and reported by Whitman (1957 a, 1957 b, 1962).

According to Mogami and Kubo (1953) the shearing strength of sand decreases almost to zero as a function of increasing acceleration.

Eastwood (1953) reported that deformation of footings increases with the increase of vibratory load. If severe vibrations are, continued for sufficiently long time, the foundation may fail at a load smaller than the ultimate load for the static loading.

The information available on the subject in the published literature is far from complete and there is considerable scope of investigation of soils subjected to dynamic loads. The basic purpose of the present thesis is to study the possibility of testing cohesionless soil samples, on the small shaking table in the form of columns of different sizes, and to present the result thus obtained. All the available references on vibratory loading have been briefly and critically reviewed.

The variables which are of significance in such an investigations are type of soil, moisture content, specimen size, intensity of acceleration (amplitude and frequency of vibrations) duration of vibrations and vertical stress intensity.

In the present study only one soil at 12% moisture content (slightly above the O.M.C.) was tested at different frequencies and amplitudes. The normal load was varied from zero to 2500 gms. In all 120 samples of cohesionless soil 4" x 4" in plan were tested on the small shaking table. The average axial deformation of sample was measured by means of three dial gauges, to obtain a relation between frequency and deformation for various loading intensities. The results show that the deformation of the tested material increases with increase in axial stress.

Deformation also increases with increase in amplitude for the same frequency and same normal load intensity.

The normal stress intensity to induce specified percentage of deformation depends only on the intensity of acceleration.

Samples of height greater than 4" underwent a tilt on one side and hence could not be tested successfully at that moisture content.

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BEHAVIOUR OF SOIL UNDER VIBRATIONS.

A brief review of the available published literature is presented in this Chapter.

Bendel (1948) reported tests on a loam at water contents of 22%. The size of cylindrical sample for triaxial tests was 20 sq.cm., and 10 cm high. The deformation of the sample was measured with the help of change in resistance of a 0.025 mm wire pasted on to a thin paper in the form of manifold loops.

The samples were subjected to all-round pressure of 1.5 kgm/cm^2 for a number of days and then subjected to dynamic strains in which the frequency of loading varied from 0 to 30.5 cps.

It was observed that at the beginning of the dynamic stress application, the sample underwent a sudden deformation of 2 mm and continued to deform plastically thereafter. At the excitation frequency of 21 cps the sample completely failed by collapse.

Eastwood (1953) presented test results of model footing on a well graded sand. The footings were upto 24" sq. Natural frequency of vibration of model footings was determined with different dead loads acting on them. His settlement observations showed that a footing, with dead load of 47% of static falling load had settled 0.4 in., after 10^6 repetitions of dynamic load and 1.2 in., after 10^7 repetitions of the same dynamic loads, Further, although there was no failure in the ordinary sense of the word, with loads slightly less than 50% of the static ultimate, settlement was so great as to amount to failure after about 12 x 10^6 cycles.

Mogami and Kubo (1953) presented tests data on sand and loam which were filled into a metal box fixed on an electrical vibration table oscilating vertically and sinusoidally. Maximum vibration amplitude was 2 mm., and frequency ranged from 10 cps to 50 cps (800 cm/sec^2 to 20,000 cm/sec^2).

They concluded that shearing strength decreases acceleration as a function of increasing acceleration in a very striking manner. In fact it decreases almost to zero which could justify the liquifaction. They further concluded that the density of the Kumina sand was altered by even a small loading.

Mogami, Yamoguchi and Nakase (1955) reported direct shear tests on undisturbed and remoulded clay with natural moisture content of 110% LL = 110% and P.L. = 50" . The vibrations exerted in this equipment were about 2 mm and frequency of vibration varied from 10 to 50 cps. The specimen of remoulded clay were vibrated for 5 minutes or 1 minute before shearing the acceleration of vibration being 980 cm/sec^2 and frequency 48 cps. The effect of vibration on the shearing strength was negligible which was atributed to insufficient duration of vibrations and disturbance of soil due to hammering action.

In another series of tests shear stresses smaller than failure stress was applied to the soil sample and it was then vibrated. The strength of soil was reduced to 80% of the static strength when vibrated with an acceleration of 980 cm/sec^2 and frequency of 48 cps.

They further performed similar tests on remoulded soil samples vibrated with acceleration of 2g, g and g/2 at frequencies of 48, 30 and 24 cps., and at variable amplitude. They found that shear strength of soils samples depends on a characteristic manner on the magnitude of acceleration.

Mencel and Kazda (1957) presented conclusions of Hermite and Tournon's (1948)of box shear tests according to which the strength during vibration had sunk nearly to zero, while on the other hand Krey (1936) had observed that the angle of the natural slope at vibrations was only about $1\frac{1}{2}^{\circ}$ smaller than the one at rest.

According to Mencel and Kazda (1957) the apparently conflicting results are caused by the fact that in each different case on individual change of normal stresses and shear stresses occur. Both stresses can originate from different phases so there may be a possibility for normal stress to diminish at the same time when the shear grows.

Murayama and Shibata (1960) investigated the effect of vibrations on shearing strength of undisturbed clay in a direct double shear box having two mass oscillator to give vertical vibrating load to the specimen. The frequency range was from

576 to 2970 cpm. The soil had a clay fruction of 50% L.L. 67.3% with a natural water content of 52.3% and a pre-consolidation stress of 1.8 kg/cm^2. The samples were cut in a prismatic shape 4 cms square and 5.5 cms long.

Shearing strength during vibrations was measured by increasing the horizontal shearing force continuously at a suitable rate until the shear failures occured. They showed that the shearing strength decreases linearly with increase in maximum acceleration of vibration and bears a straight line relationship.

Kondner (1961) presented test data for clay samples having L.L. 42%, P.L. = 21% and special gravity = 2.68. The samples were prepared by impact compaction process the wet density being 131 lbs/cft at water content of 18.7%. A constant frequency of 25 cps was used while testing the sample.

Two types of tests were conducted. In one, the amplitude of shear deformation was varied and the corresponding shear forces were measured for constant frequency of vibration. In other tests the specimens were subjected to shear deformation of constant amplitude but with different frequencies of oscillations. The shear force required to maintain constant shear deformation was measured with changes in frequency.

He concluded that strength of clay under vibratory loading is considerably less than under static loading alone. This reduction in strength explained by changes in the energy state of the bound water phase of the clay and further he showed that the elastic response of clay is definitely non-linear.

Kondner (1962) performed vibratory unconfined compression tests at m.c. of 22.7% with wet density of 127 lbs per cft., at frequency at 25 cps. He found that ~~no~~ the maximum stress required to cause failure was 35.2 psi for the conventional test while that of vibratory test was only 8.8 psi., thus the strength under vibratory loading was only one-fourth of that obtained by the conventional test depending upon moisture content value, nature of vibratory parameters and static stress level.

Balakrishna Rao (1961, 1962) presented test data of unconfined compression strength of soil specimen. The specimen were vibrated under steady vibrations and then tested. A Degbo type generator operated by a D.C. Motor was used with range of frequency from 350 rpm to 1200 rpm. The samples were 1½" in diameter and 3" high made of red soil. He concluded that if a standard sample specimen exibits a very high strength, the effect of vibration is to decrease the strength and on the other hand if standard sample exhibites lower strength, the effect of vibration is to increase the strength. Secondly the load carrying capacity of standard and vibrated specimen was found to be a function of total deformation that the specimen could take before failure.

Wolfkill and Buchanan (1962) reported results of triaxial tests on 6" diameter and 12" high samples of Edwards lime stone. Before the conventional triaxial test at a rate of strain of 0.05 in/min., the samples had been subjected to 5,000 and 239,000 repetitions of stress application with lateral pressure of 60 psi. The stress level in the vibratory loading was 50% of the ultimate strength and the rate of loading averaged 27000 psi per second. The increase in strength was 12% after 5000 repetitions and 20% after 239,000 repetitions.

Data on tests similar to these is also reported in which the lateral pressure and number of repetitions of vibratory load was varied.

The conclusions of Mogami, Yamaguchi, and Nakase (1955) Balakrishna Rao (1961,1962) and Wolfskill and Buchanan (1962) in respect to the effect of vibrations on the strength of soils are in apparent conflict with each other.

Thus there is considerable scope for investigation of soils subjected to vibratory loads.

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SOIL TYPE

A highly cohesionless soil which can stand in column of height upto 12" with different cross sections was desired in order to study its deformation characteristics under vibrations. It was desired to obtain such a soil which contains minimum percentage of cohesion yet provides sufficient cohesion for workability.

Six tests were made with different proportions of silty clay and sand to obtain the specified mixture. A larger percentage of clay resulted in a more workable mix but its unconfined compressive strength was high. Thus the loads required at the time of loading in vibratory tests would be high. The lesser percentage of clay gave lesser strength and low workability, giving rise to cracks and failure of the sample before testing.

The samples of all such soil mixes were tested in unconfined compression test with a spring stiffness of 10 lb/in. The samples were taken from mould compacted with standard Proctor's energy.

It was observed that the soil having 15% silty clay (minus 40 fraction) and 85% of locally availble Ranipur sand gave a good workable mix. The grain size distribution for this mix is shown in Fig. 1. Maximum unconfined compressive strength of this soil is about 6 lbs/sq.in. The variation of dry density and unconfined compressive strength with moisture content is shown in Figure 2.

The type of soil according to the Indian Standard Classification is SP - Sand with little fines.

Additional data of this soil are tabulated below :-

Specific Gravity of solids	2.7
Coefficient of uniformity	3.83
O.M.C.	10.6
Maximum dry density	118.3
Degree of Saturation @ O.M.C.	67.4

The silty clay used for cohesion had -

Specific Gravity of solids	2.5
Liquid Limit	36.8
Plastic limit	22.0
Plasticity Index.	14.8

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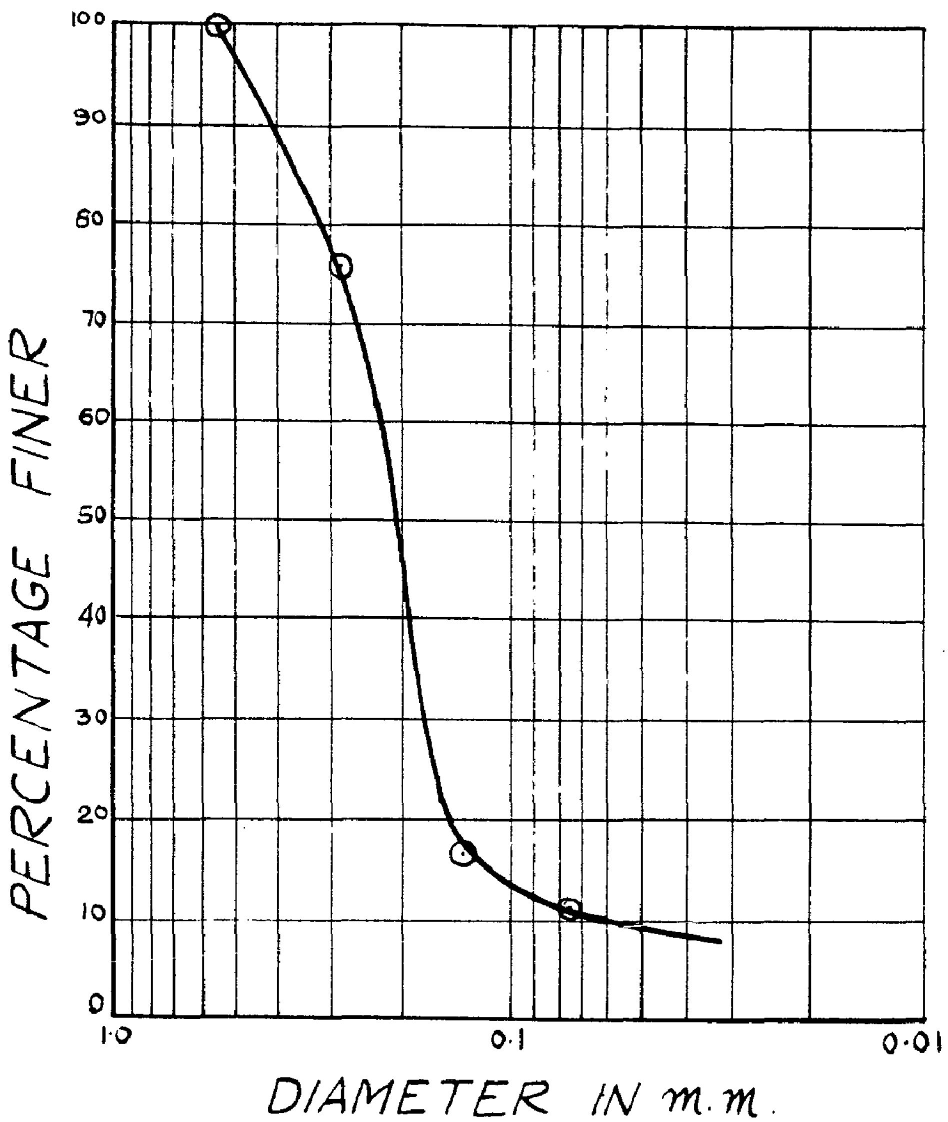


FIGURE 1

GRAIN SIZE DISTRBUTION

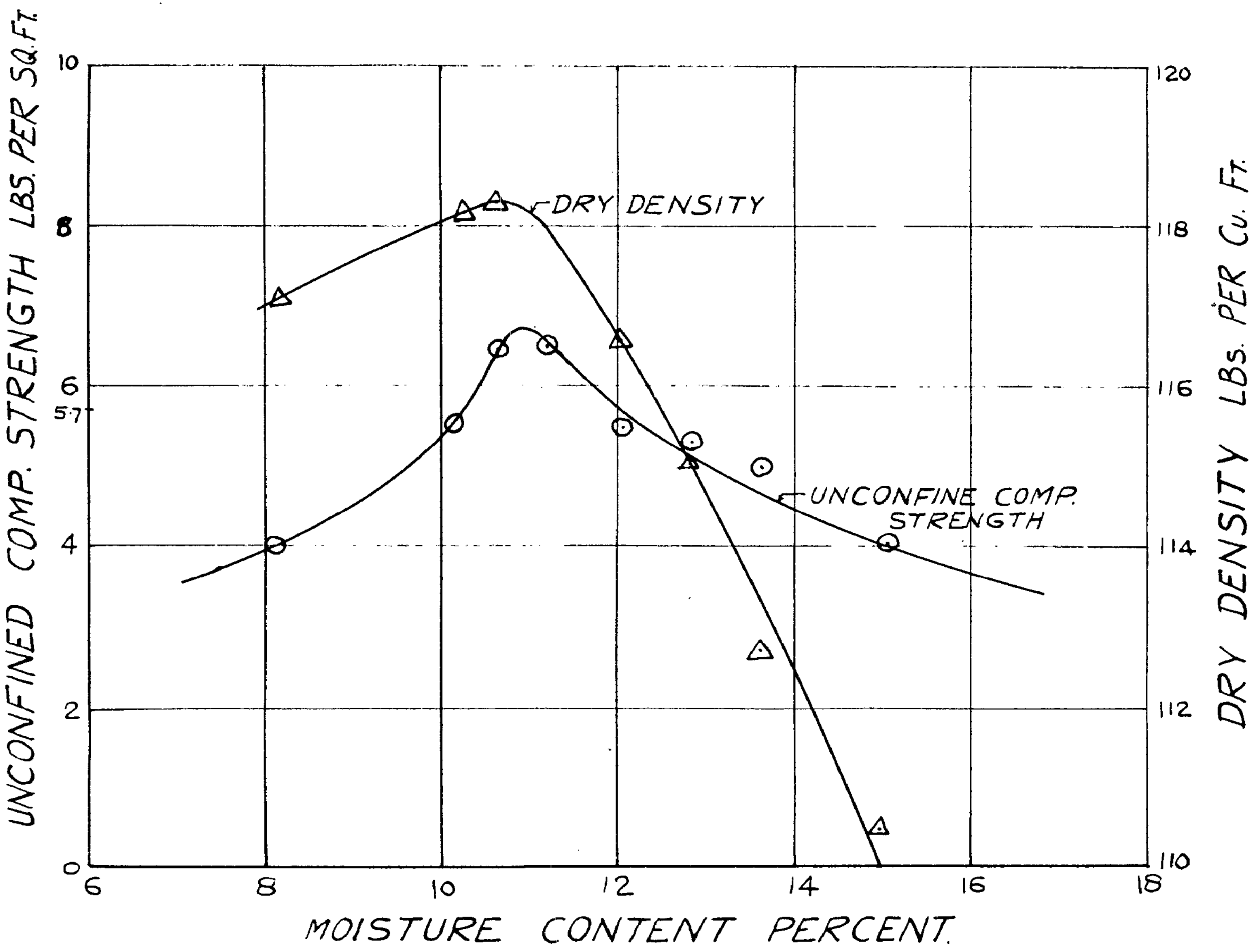


FIGURE. 2
UNCONFINED COMPRESSIVE STRENGTH AND DRY DENSITY VERSUS MOISTURE CONTENT

EQUIPMENT

The equipment employed in carrying out the investigations were as follows :-

1. Small Shaking Table.
2. Hammer
3. Sampler.

1. SMALL SHAKING TABLE :-

It consisted of following parts :-

a) Motor drive and device for changing its speed.

b) Device for converting the rotary motion of the motor to the translatory motion of the platform.

c) Platform and suspension on which the platform rests.

d) Device for changing the amplitude of the platform.

a) Motor Drive and Device for Changing its speed :-

In order to drive the shaking table by a device which is capable of having uniform angular velocity which can be changed continuously and smoothly over a wide range, a commercial available device made by Graham Transmission Co., U.S.A., is used. This is based on the principle of relative movement between two tapered shafts having speed changing capacity from 0 to 3000 rpm. It is driven by a 1 H.P. 3 phase A.C. motor which is a standard commercial device.

b) Device for converting the rotary motion of the motor to the translatory motion of the platform :-

For the above purpose a reciprocating mechanism was used, This mechanism consisted ;

i) A table rod and guide and

ii) A connecting rod,

which have been fully described in Annual Report (1960-61) of the Earthquake School, Roorkee.

c) Platform and its suspension system :-

The platform was 1/4" thick M.S. plate welded on a rectangular welded frame of 3" x $1\frac{1}{2}$" m.s. channel. Stiffners of 1" x 1/8" welded at 6" c/c in both directions, were also used for greater rigidity. The platform rested on four rollers placed at its corners. Each roller was kept between two pads. The top pad was fixed to the platform by means of bolts, and the bottom one was attached firmly to the base frame with adjusting-screws to make minor levelling adjustments of the platform.

d) Device to change the amplitude of the Platform :-

A double ecentric cam in which the positions of the first and the second eccentric plates can be changed was used. By this arrangement it was possible to vary amplitude of vibrations from 0 to 10 mm at the interval of 0.5 mm.

Complete specifications of the table are as follows :-

1.	Maximum acceleration	1 g
2.	Size frequency	0 - 30 cps
3.	Size	$3\frac{1}{2}$' to 2'
4.	Amplitude	0 - 10 mm
5.	Maximum allowable weight of the models	200 lbs.

The movement of the table follows a simple sinusoidal path.

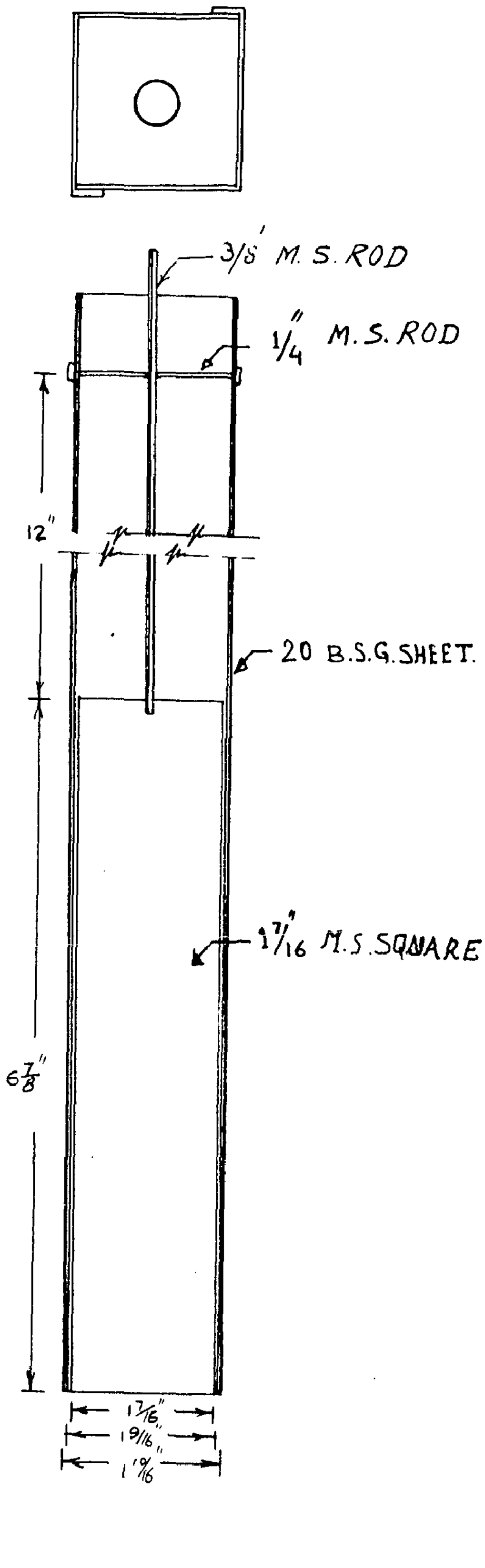
2. HAMMER :-

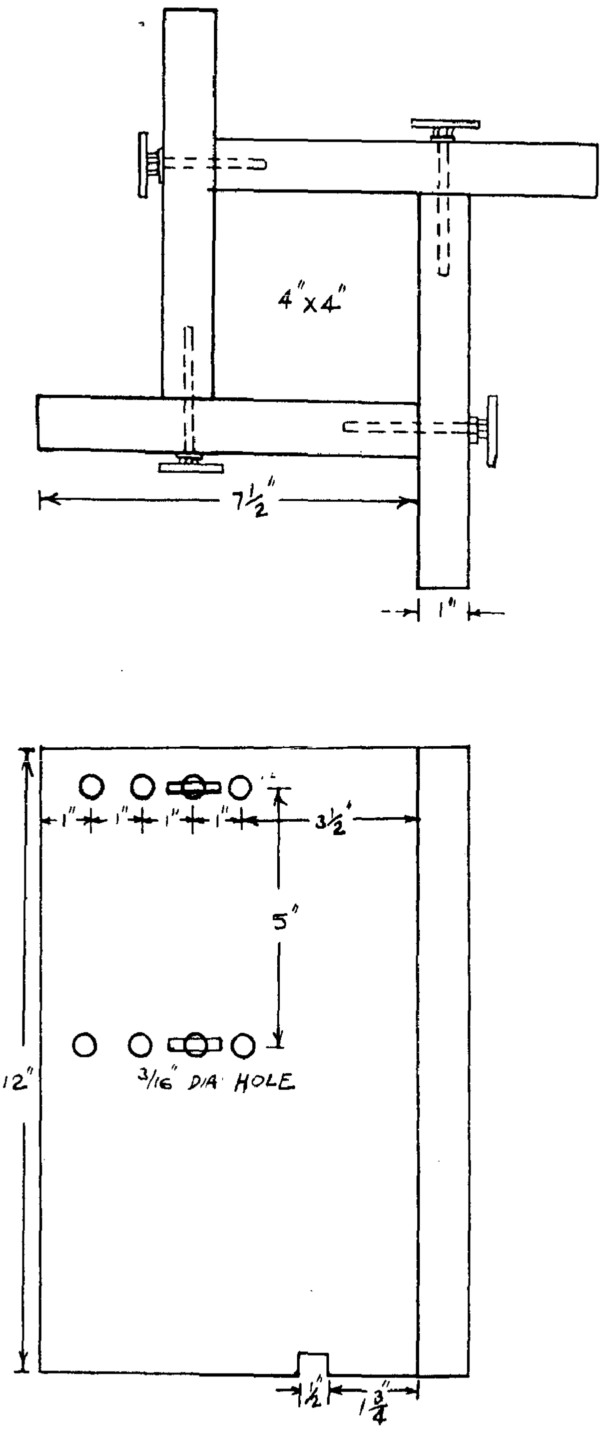
In order to compact the sample with standard Proctor's energy, a square hammer was proposed. The section of square hammer selected was 1½" square to give better compaction at the corners of the square samples prepared (Fig. 3 a).

A 1/4" dia., obstruction rod was kept at 12" distance from the top end of the hammer to give a free fall of 12" every time. The casing cover was about 18" long to provide sufficient allowance to hold it with hand at the top while compacting the sample. The weight of the hammer was exactly 5½" lbs. including the weight of the rod attached to it.

3. SAMPLER :-

A wooden mould Figure 3 -b 12" high was prepared in which the samples of various sizes i.e. 3", 4", 5" and 6" square cross section, could be prepared by adjusting the four cover plates. The mould was made of 1" thick well seasoned timber to give stability. A very thin 26 B.S.G. sheet was fixed all round the sampler in the inner face to avoid the penetration of moisture in the timber fibres.





HAMMER SAMPLER

FIGURE 3

HAMMER AND SAMPLER

CALIBRATION OF FREQUENCY CONTROL :-

Frequency control of the small shaking table consists of a gear system. A disc was mounted on this system, to indicate the frequencies, it was graduated in number of frequency in C.P.S. A pointer indicated a number on the graduated scale corresponding to the frequency of the vibrating table. Although the numbers on the scale should exactly represent the frequency of the shaking table but due to errors in the graduation and wear tear of gears, the pointer did not indicate correct value of the frequency and hence the calibration was necessary.

In this case as shaking table had to and fro motion due to its eccentric connections with a rotating fly wheel calibration was very simple. The revolutions per second of the fly wheel will represent the frequency of vibration of the table. The revolutions of fly wheel in a given time interval were counted with the help of a revolutions counter, when the pointer was set to a certain mark on the graduated disc.

The procedure was followed for several graduated marks and curve was drawn between actual and nominal frequencies, Figure 4. This curve was called as calibration curve as it shows the actual frequency corresponding to every nominal frequency indicated by the pointer of the graduated disc. Every point on this curve is a mean of at least six readings.

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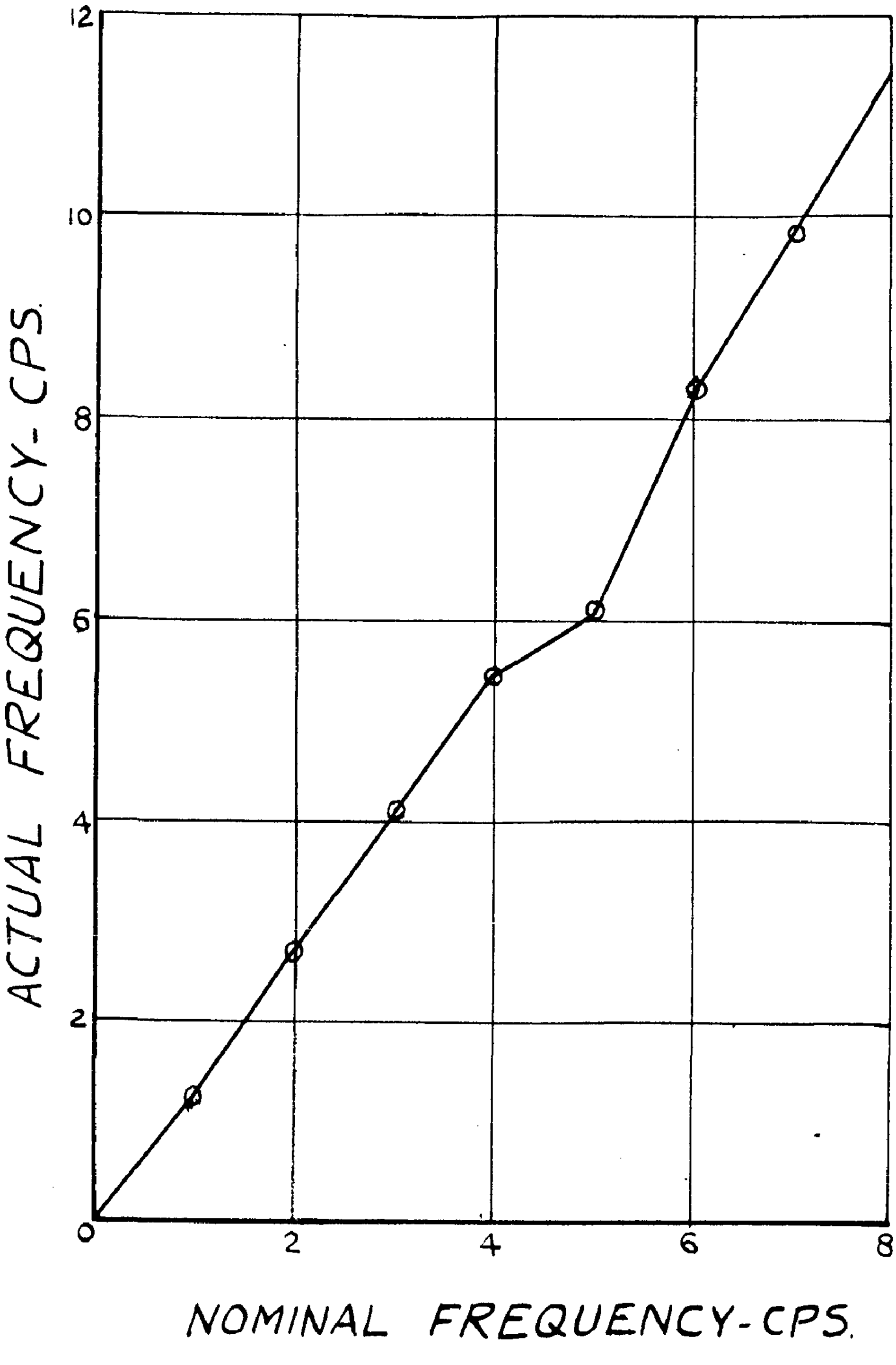

FIGURE 4
CALIBRATION CURVE

TEST PROCEDURE

Samples were prepared from above stated soil mix by means of compaction process with a compaction energy of 12400 ft. lbs/c.ft. of standard Proctor test. 2.5 kg of the mix was taken in a basin and 300 C.C. of water (i.e. 12% slightly more than O. M.C.) was added. The mix was thoroughly mixed with the help of trowel. The material in the basin in three equal parts to compact it in three equal layers in the mould having 4" x 4" cross-section Figure 5,. In order to give Proctor's Energy, 32 blows of 5½ lb. square hammer with a free fall of 12" were given to each layer.The extra height of about ½" was trimmed off to get the sample of 4" nominal height.

In order to avoid disturbances sample was prepared on the platform of the shaking table, itself.

Two m.s. angles 1" x 1" were screwed on the two sides of the sample to hold it firmly while under vibrations. The top of the sample was covered with a simple cover for no load condition and with a loading device for . various loads. Loads of known magnitude were in the form of square blocks of lead 4" x 4", with a slot of ¾" upto the centre.

Three dial gauges reading to .001" and with a travel of 2" were fixed, two on one side and one on the other side of sample. The adjustment was done with the help of magnetic base, as shown in Figure 6.

The predecided amplitude of the vibration was adjusted by the double eccentric cam. Samples were subjected to vibrations in step of one cycle per second with a time interval of 60 seconds, till the sample deformed excessively.

The total axial deformation of the sample was measured by means of the dial gauges. Thus for each loading intensity and for each amplitude of vibration deformations were noted at every frequency. All sets of observations were repeated at least twice to minimise the experimental error. Typical sets of observations on similar samples are shown in Figure 7.

Tested samples before collapse are shown in Figure 8.

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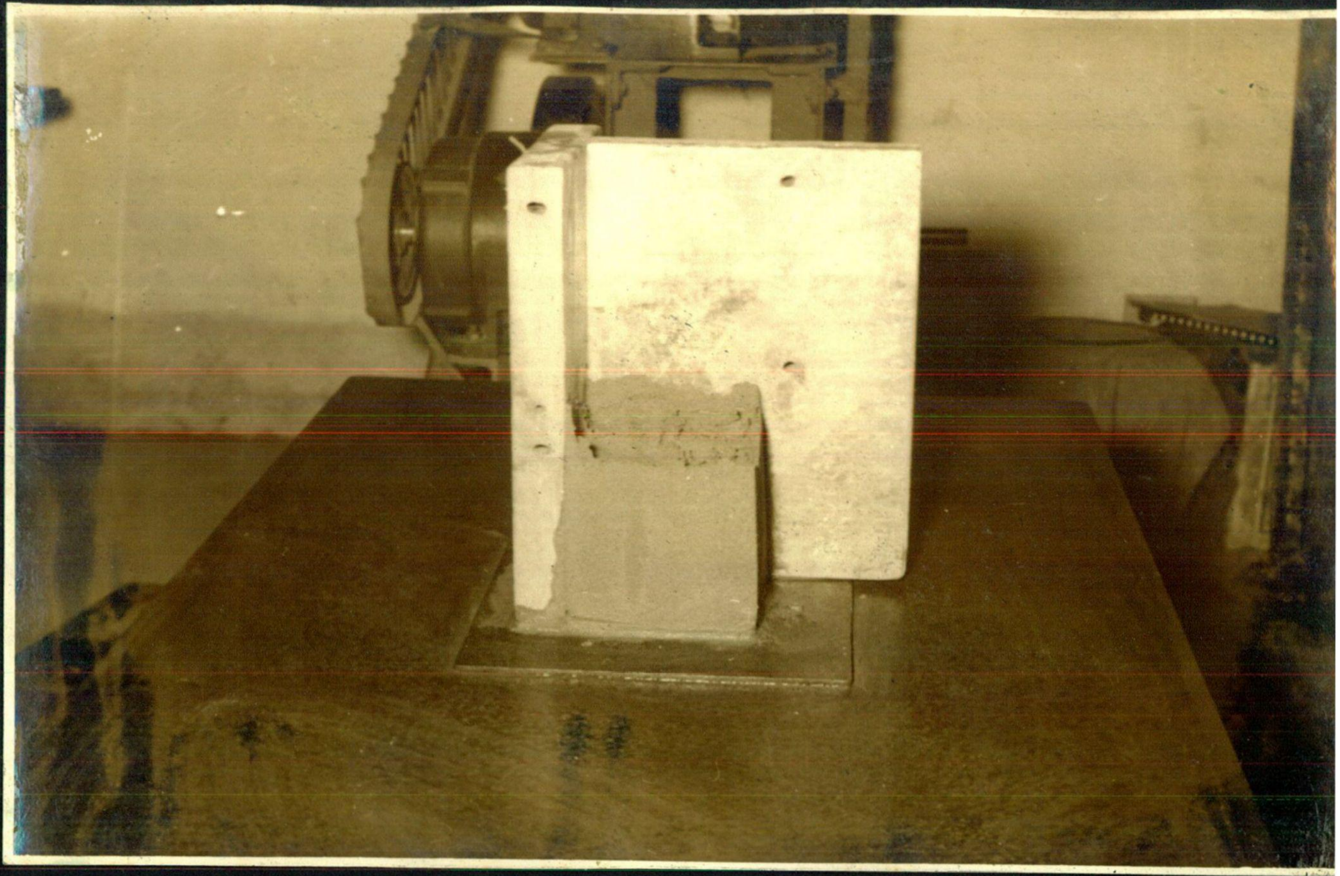


Prep. of Sample
FIG. 5

FIG 6
Expt Set up

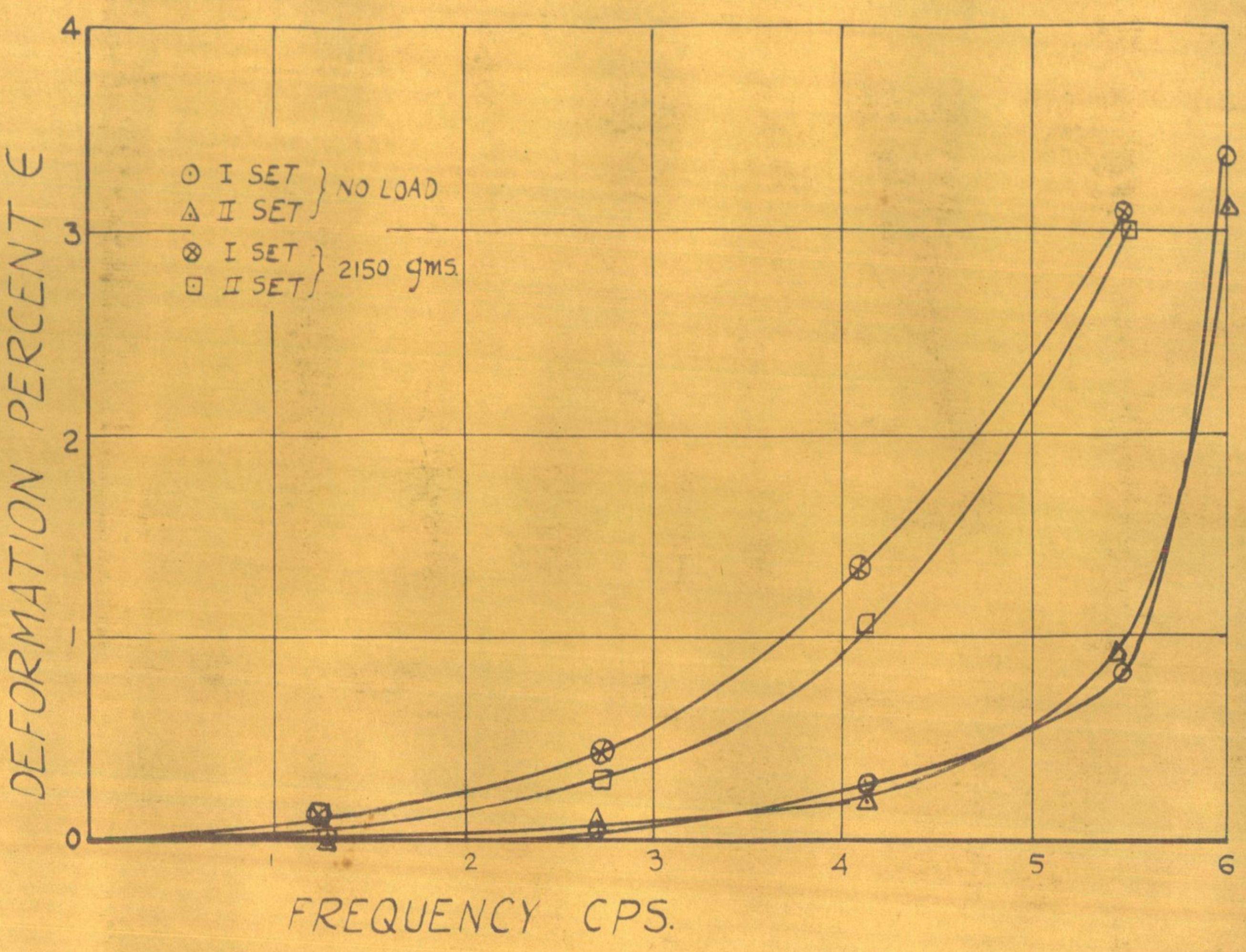


FIGURE 7

FREQUENCY Vs. DEFORMATION
4 m.m. AMPLITUDE

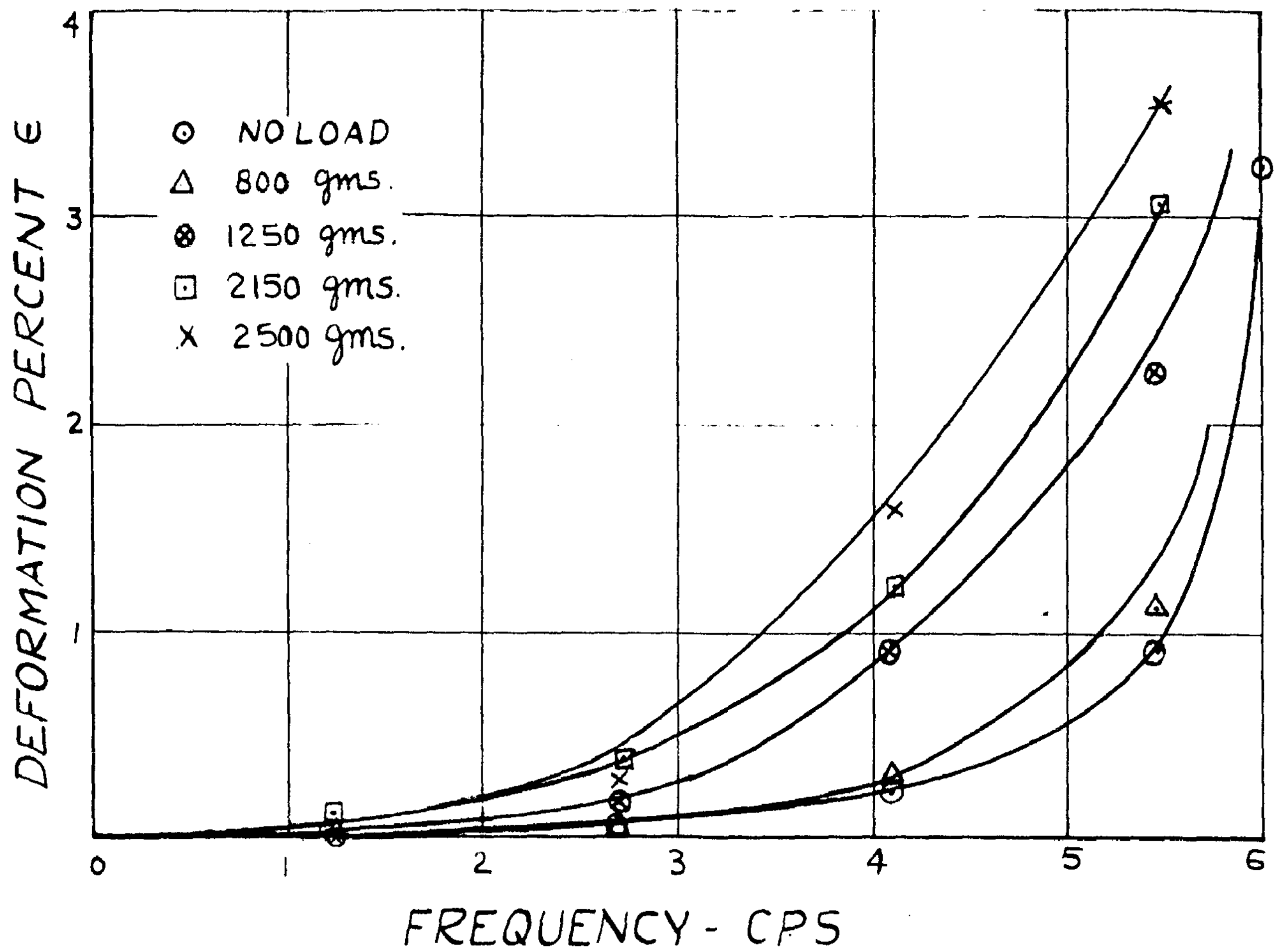


FIGURE 9

FREQUENCY Vs. DEFORMATION

4 m.m. AMPLITUDE

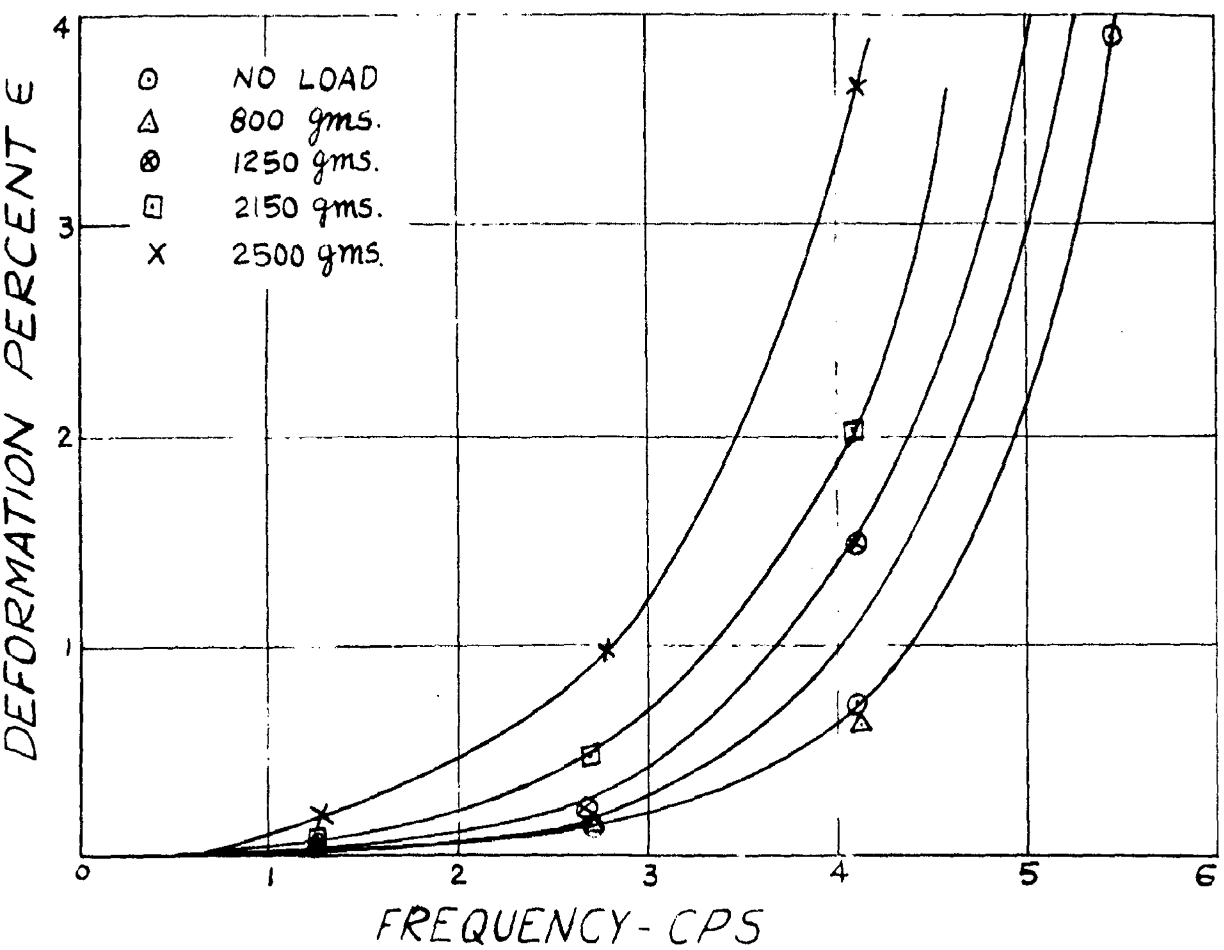


FIGURE 10

FREQUENCY Vs. DEFORMATION

6 m.m. AMPLITUDE

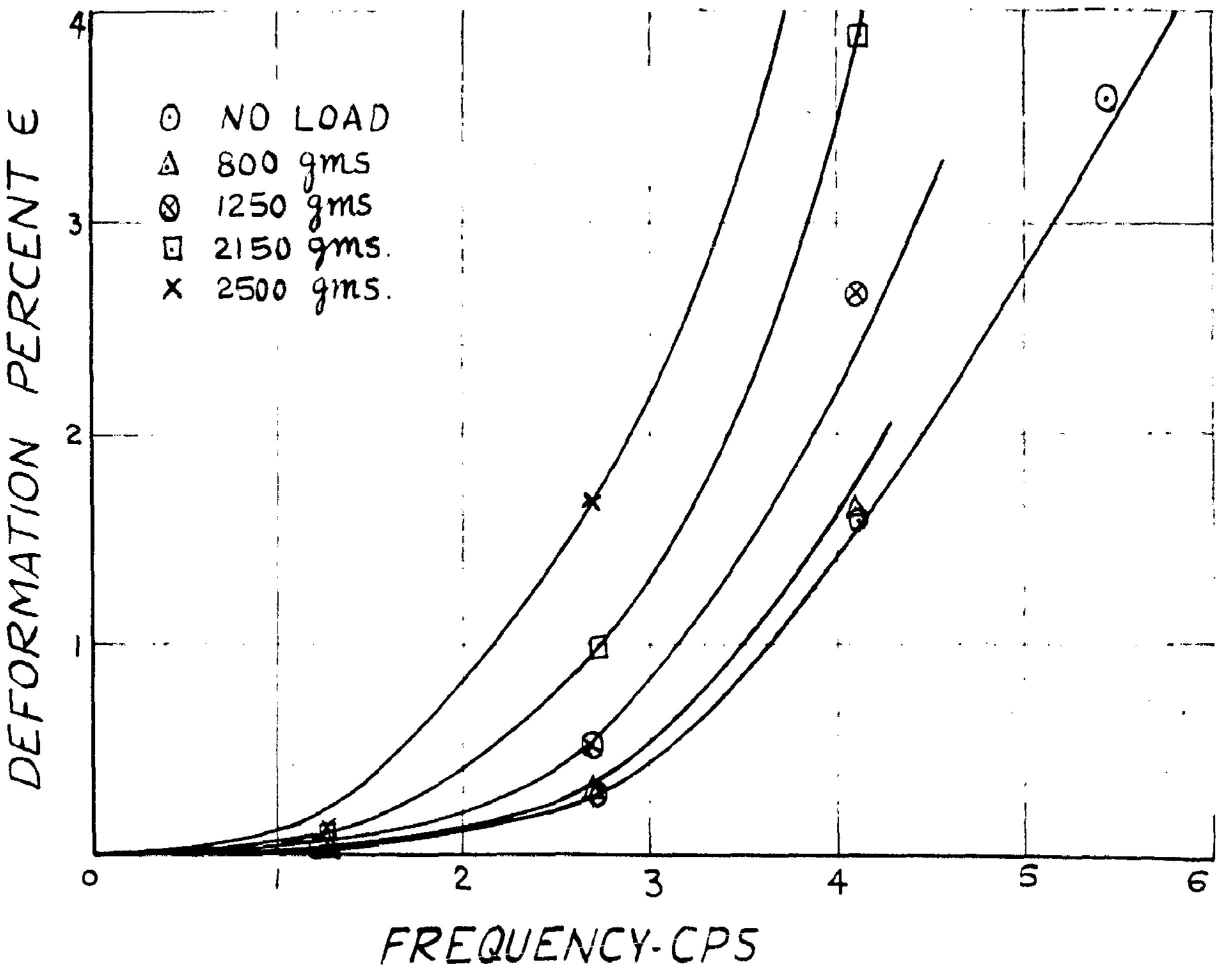
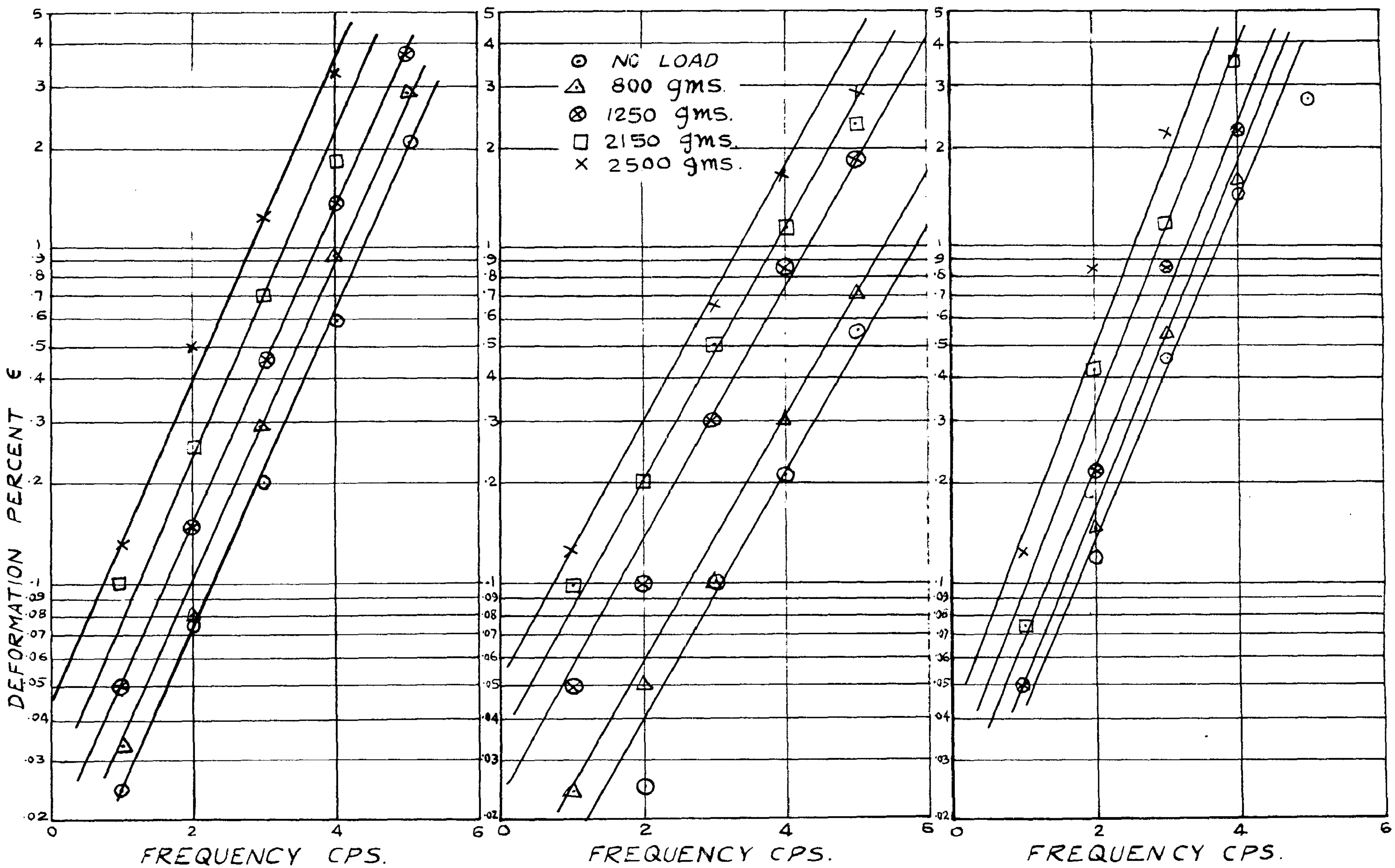


FIGURE 11

FREQUENCY Vs. DEFORMATION

8 m.m. AMPLITUDE



(a) 0.6 CM. AMPLITUDE (b) 0.4 CM. AMPLITUDE (c) 0.8 CM. AMPLITUDE

FIGURE: 12 DEFORMATION Vs. FREQUENCY

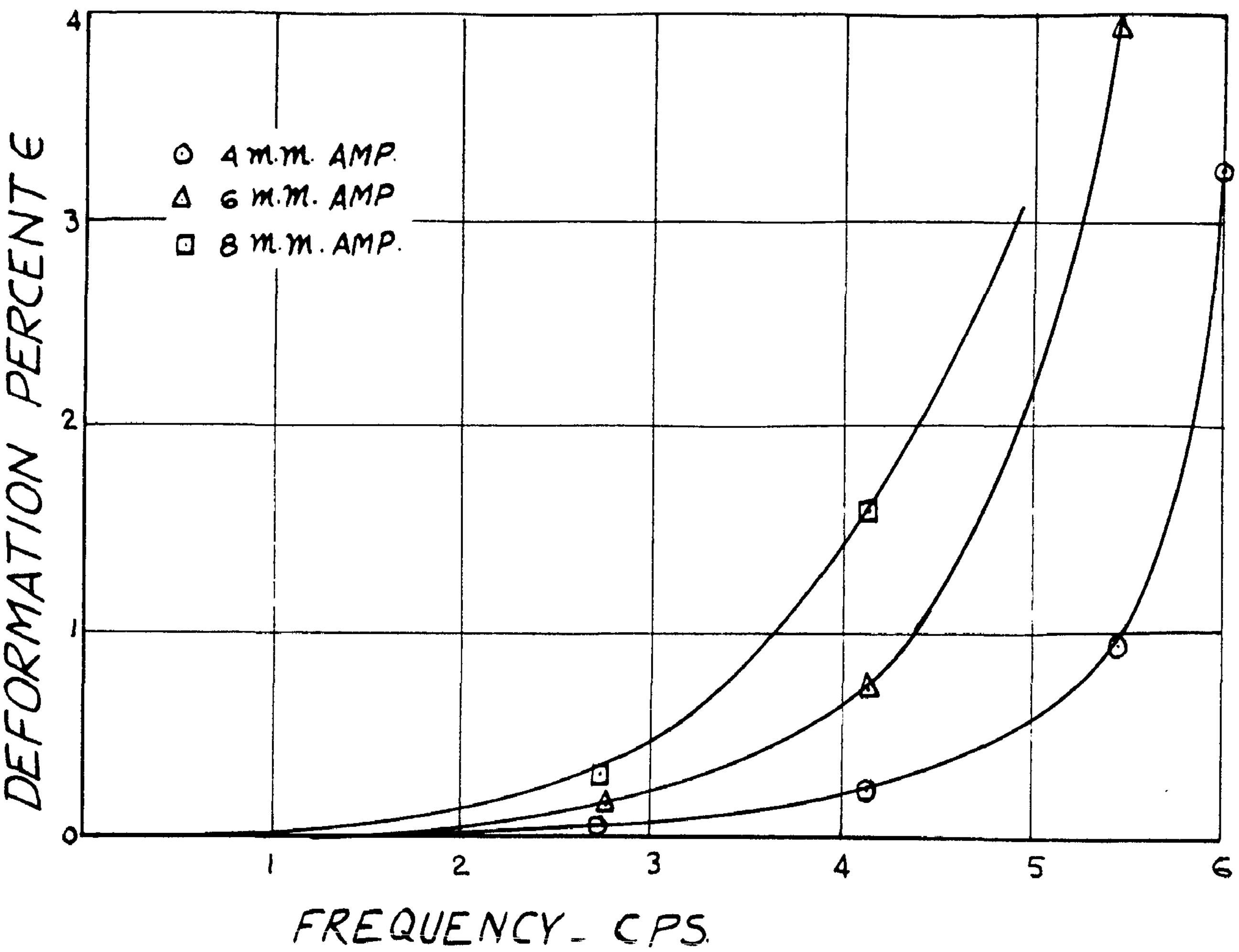


FIGURE 13

FREQUENCY Vs. DEFORMATION
NO LOAD

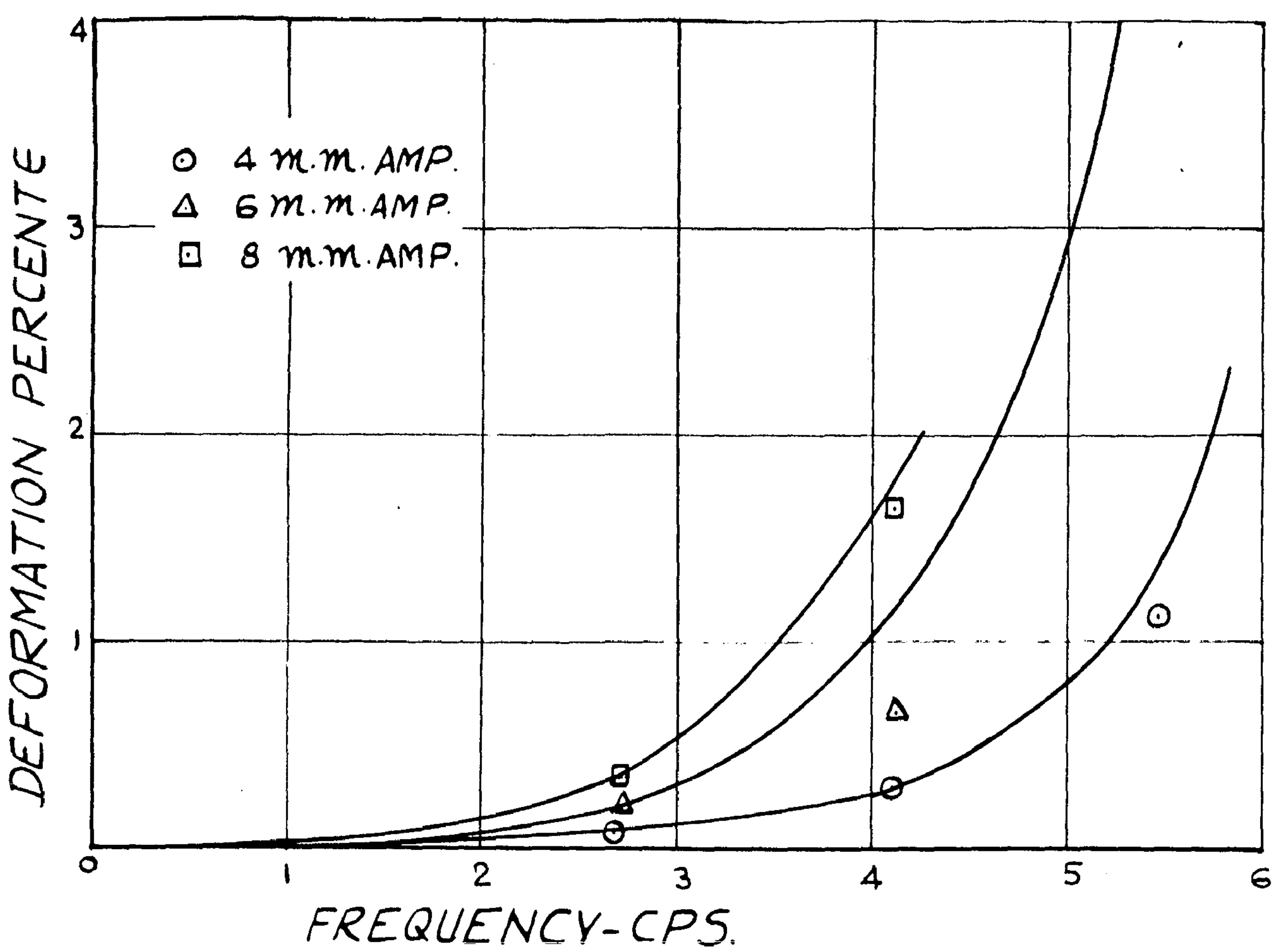


FIGURE 14

FREQUENCY Vs. DEFORMATION
LOAD 800 gms.

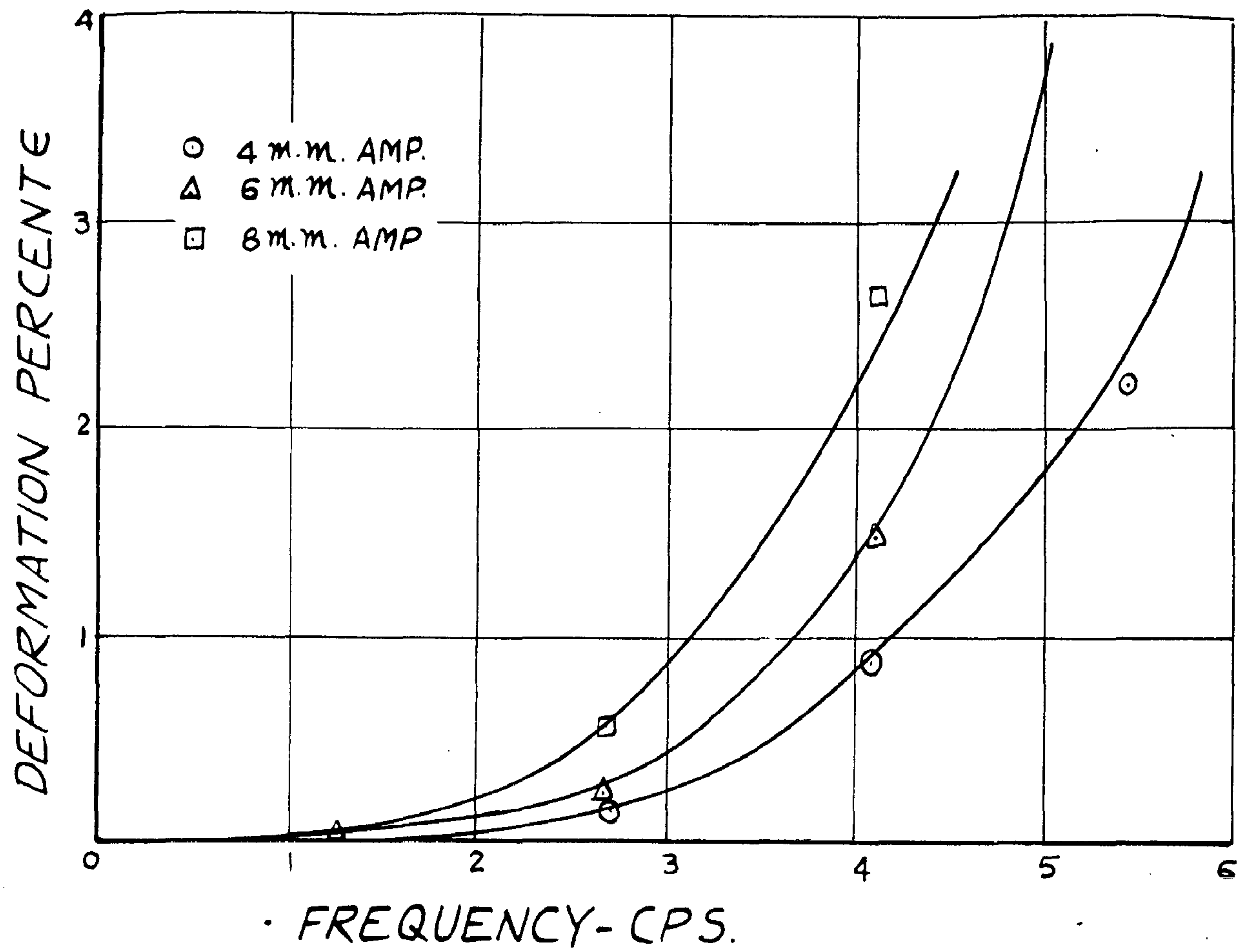


FIGURE 15

FREQUENCY Vs. DEFORMATION
LOAD 1250 gms.

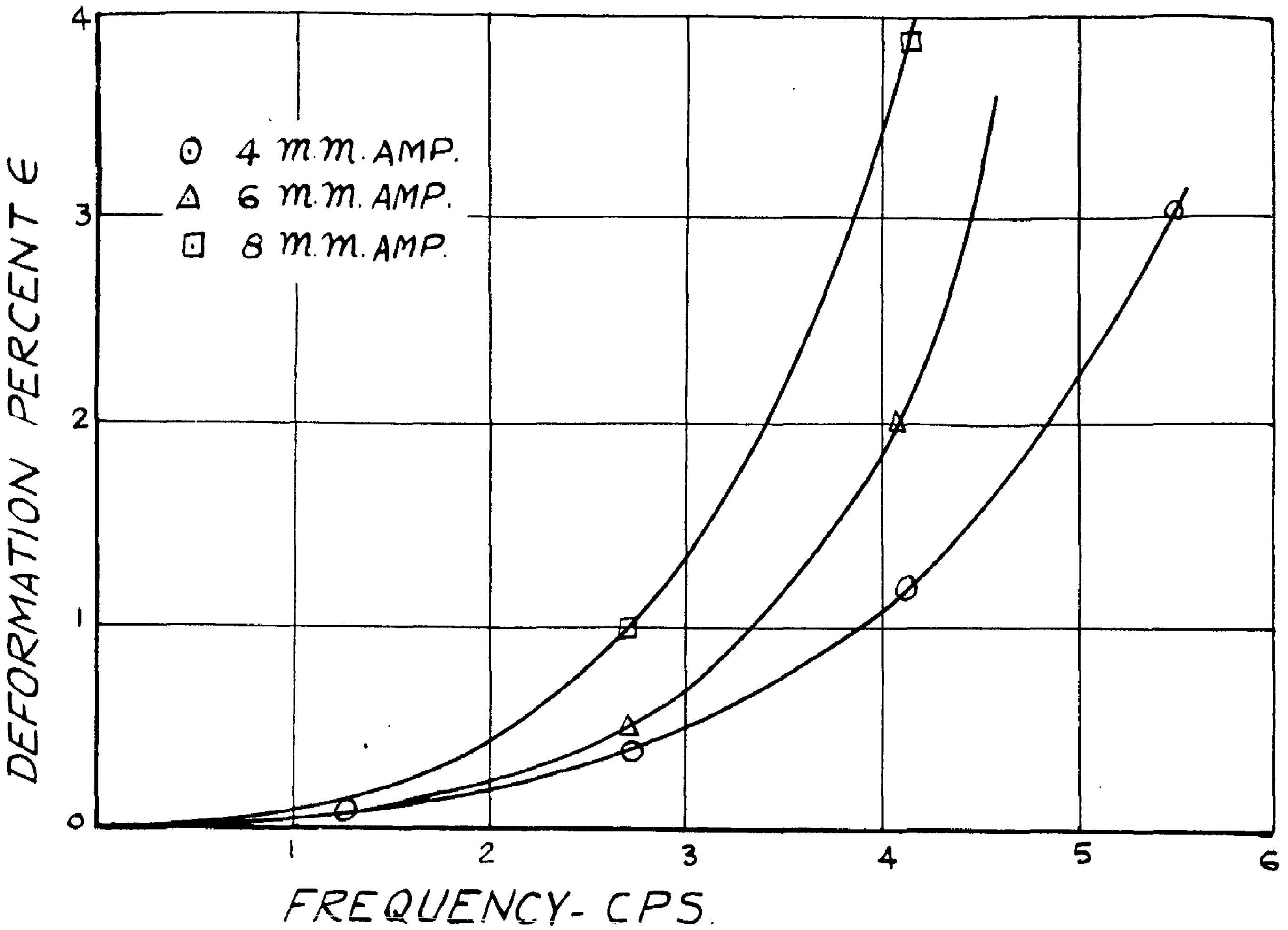


FIGURE 16

FREQUENCY Vs. DEFORMATION
LOAD 2150 gms.

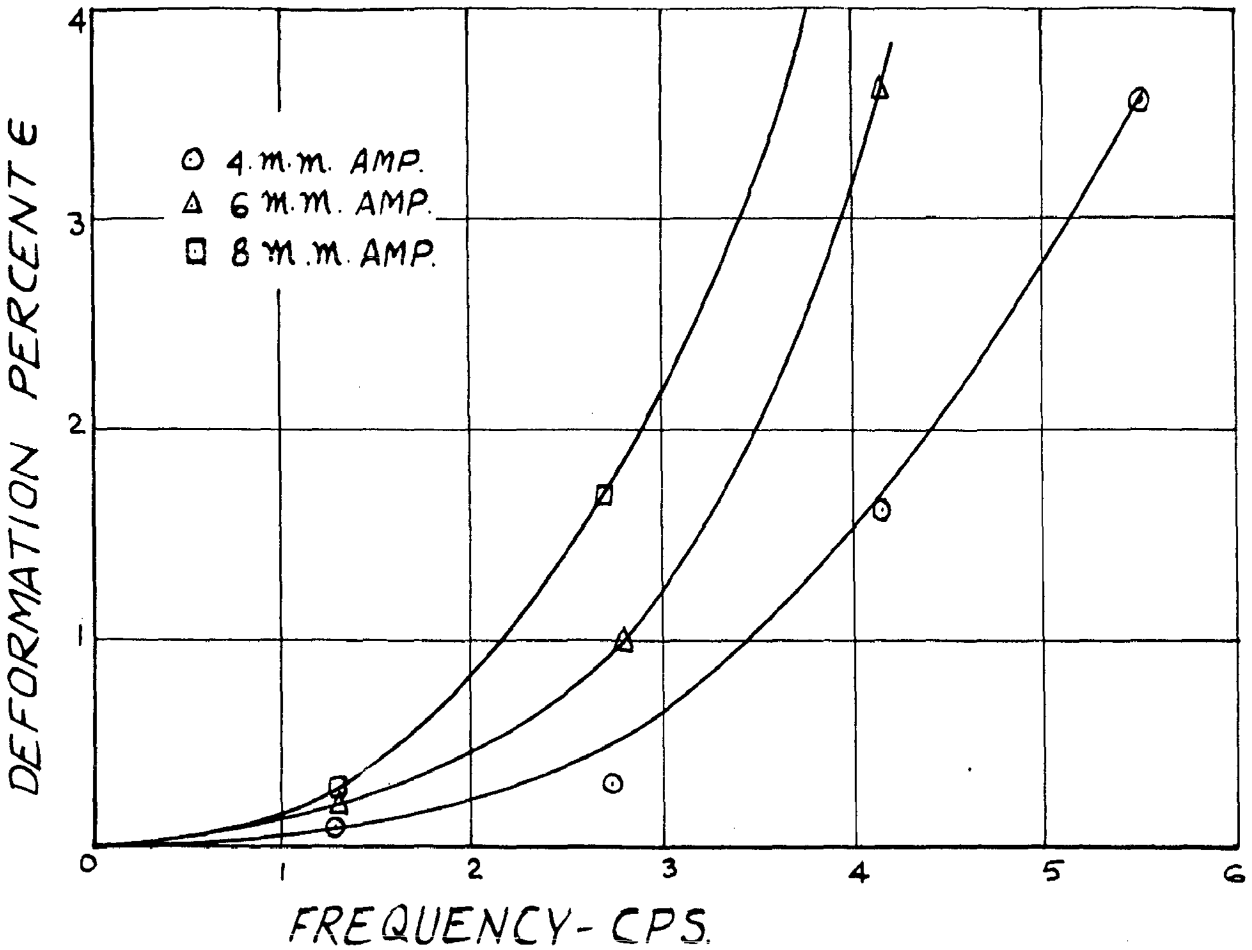


FIGURE 17

FREQUENCY Vs. DEFORMATION
LOAD 2500 gms.

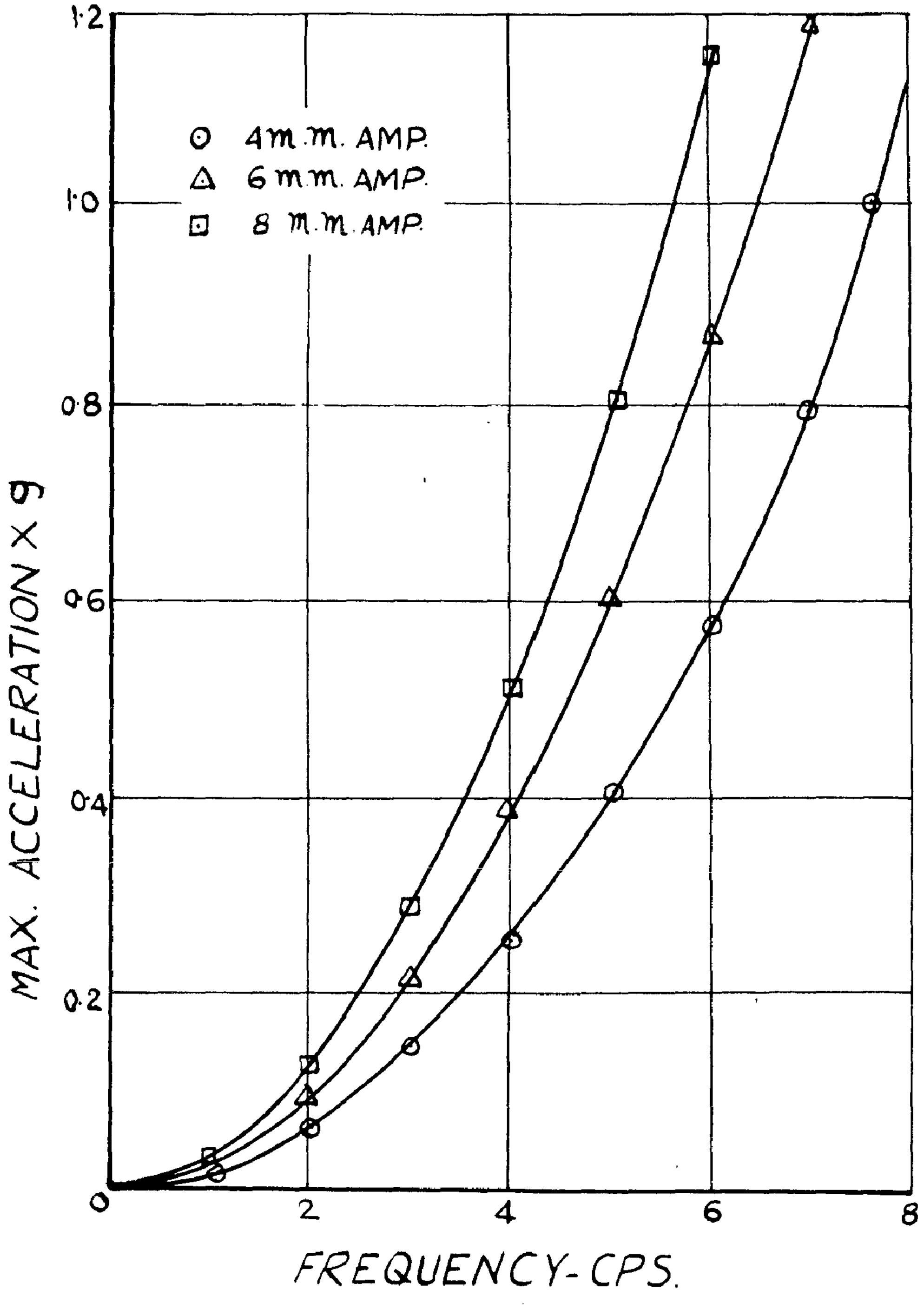


FIGURE 18

FREQUENCY Vs. MAX. ACCELERATION × g

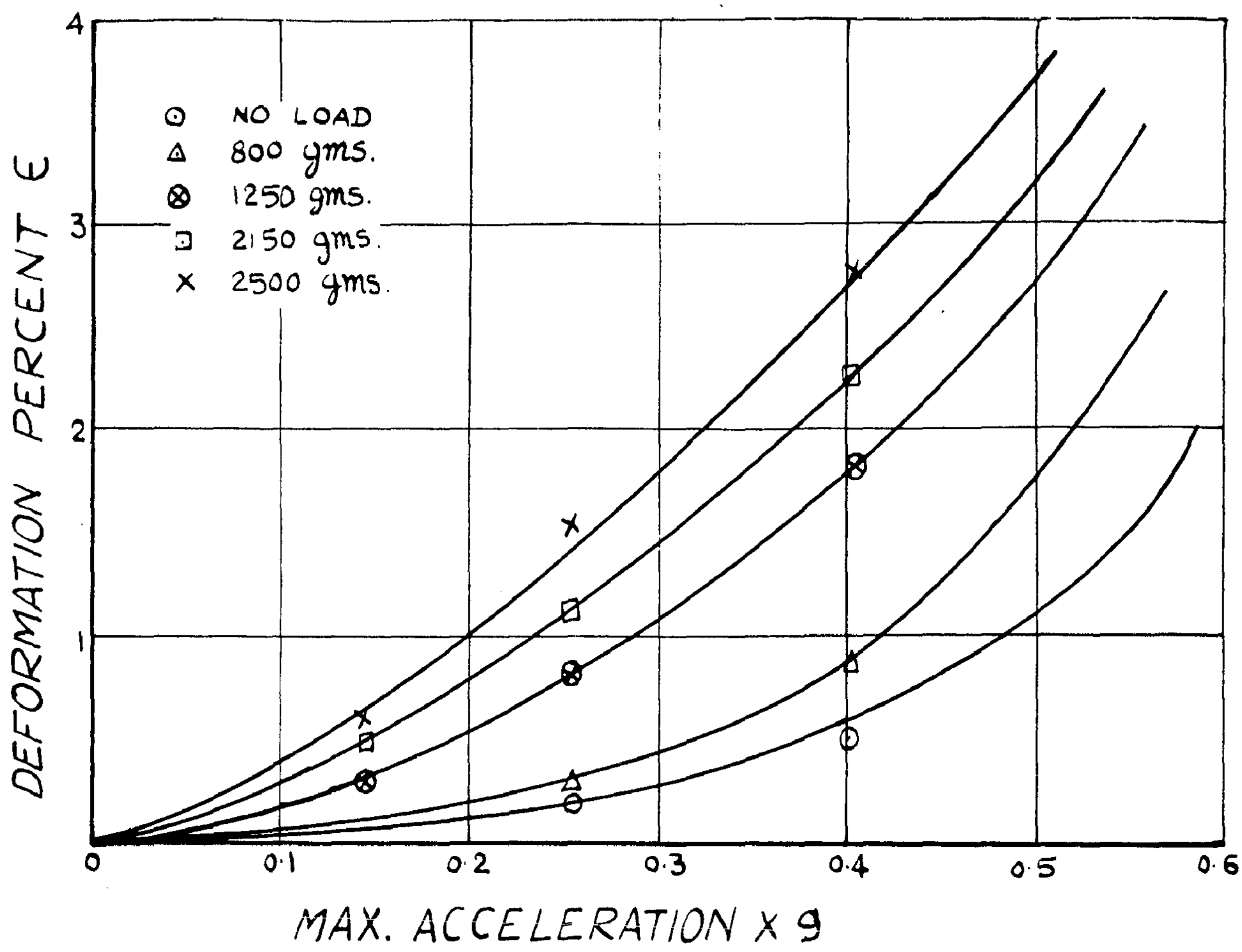


FIGURE 19

MAX. ACCELERATION X g Vs.
DEFORMATION 4 m.m. AMPLITUDE

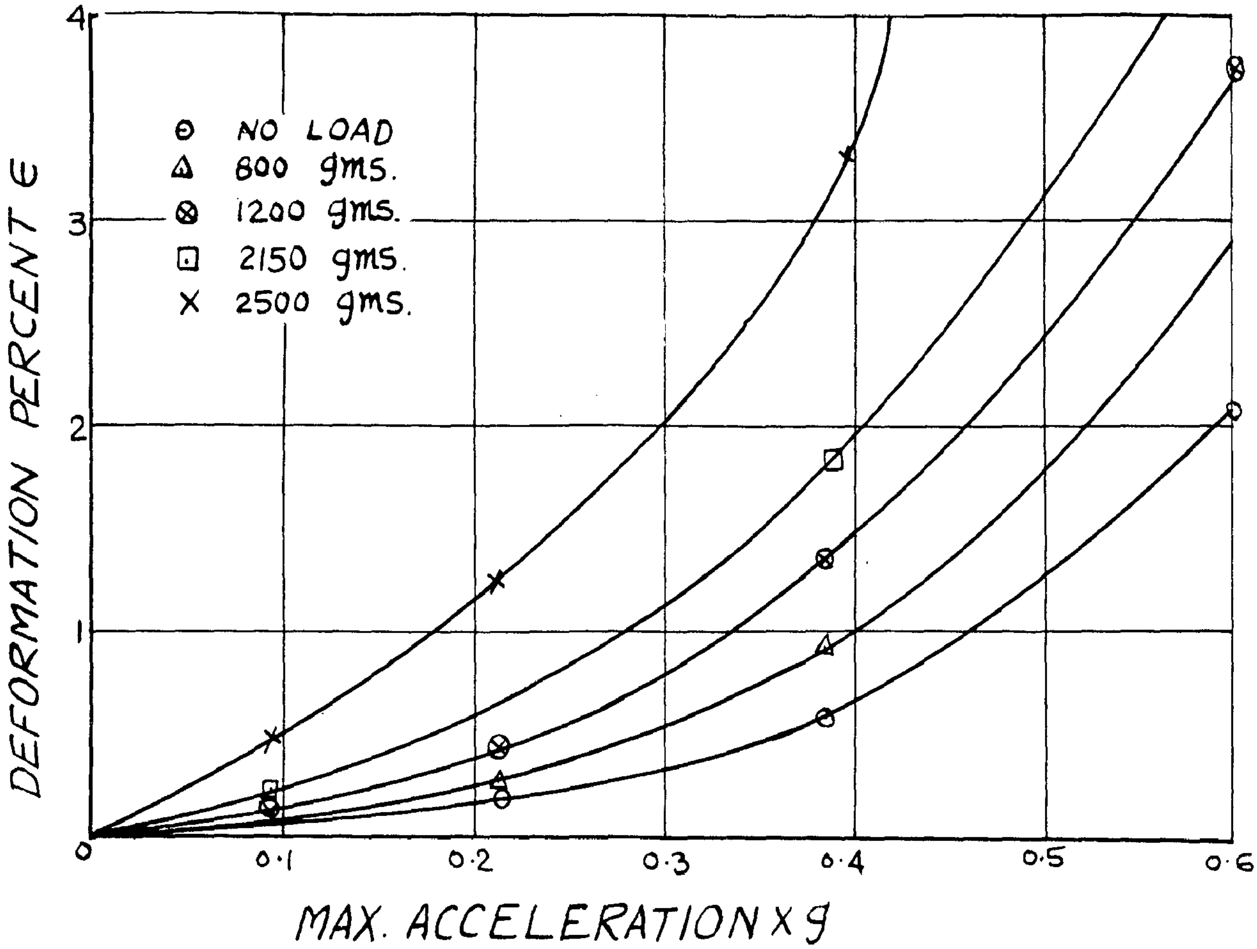


FIGURE 20

MAX. ACCELERATION x g Vs.
DEFORMATION 6 m.m. AMPLITUDE.

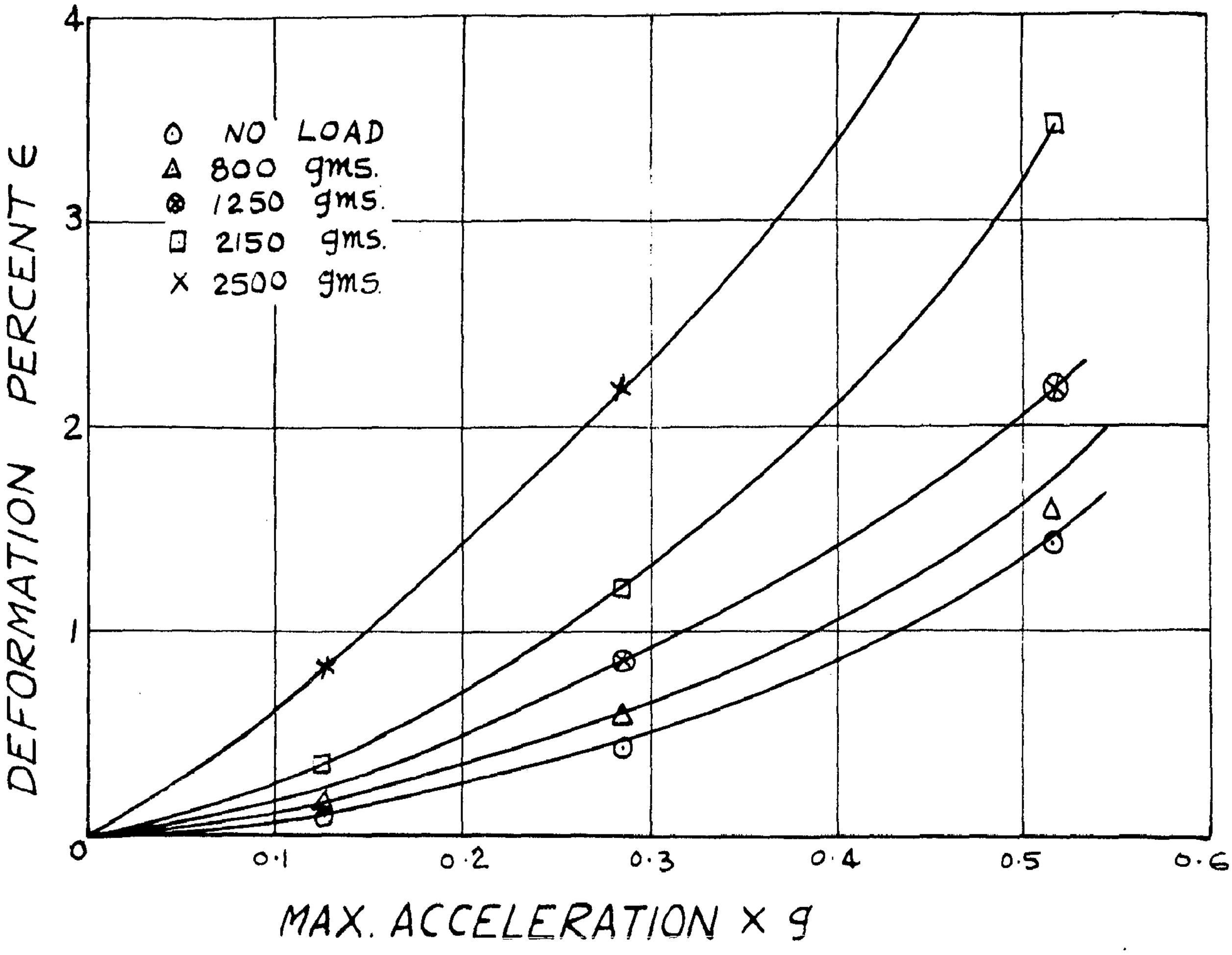
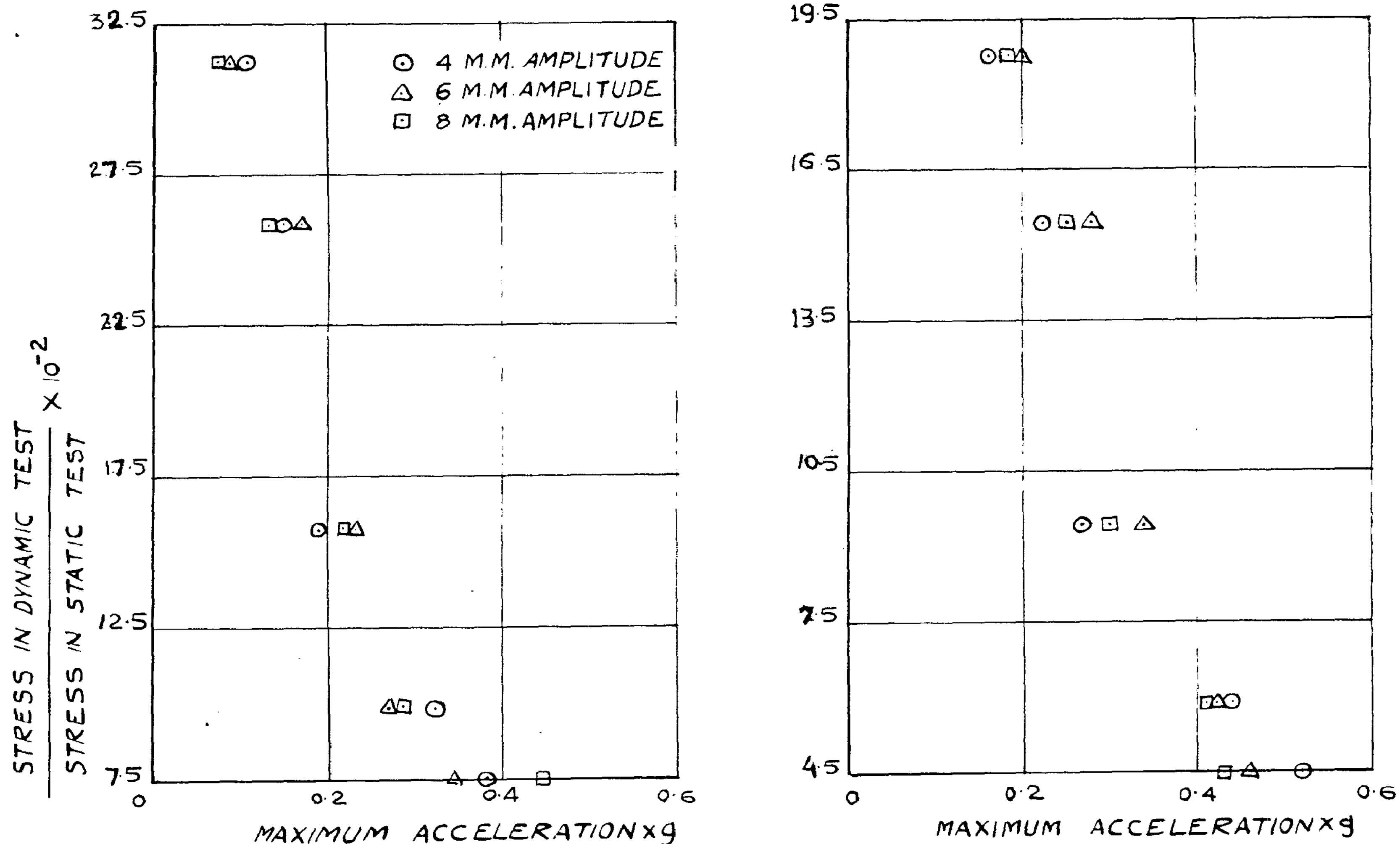


FIGURE 21

MAX. ACCELERATION × g Vs
DEFORMATION. 8 m.m. AMPLITUDE



(a) ½% DEFORMATION

(b) 1% DEFORMATION

FIGURE 22

MAXIMUM ACCELERATION Vs. STRESS

TEST RESULTS AND DISCUSSIONS.

a) Effect of Frequency and Loading Intensity on Deformation:-

Figures 9, 10 and 11 show typical graphs for deformation versus frequency. Figure 9 refers to an amplitude of 4 mm which was kept constant throughout the test. The intensity of vertical loads in these tests was from 0 to 2500 gms.

Similar tests were performed with 6 mm amplitude (Figure 10) and 8 mm amplitude (Figure 11). Each curve is a mean of at least two sets of observations.

These curves indicate that the deformation increases with increase in frequency of vibration at constant load.

Since stress is induced because of horizontal acceleration imparted to the sample, the applied force equals the product of mass of soil and its acceleration. In a sinusoidally vibrating system,

$$F_t = \text{mass x acceleration},$$

where F_t is force at any time t.

Now $x = x_o \sin \omega t$.

where x = displacement.

x_o = amplitude of vibration,

= angular velocity

$$\dot{x} = \omega x_o \cos \omega t$$

$$= \omega x_o \sin (90 + \omega t)$$

and $$\ddot{x} = +\omega 2\ x_o \cos (90 + \omega t)$$

$$= -\omega^2 x_o \sin (180 + \omega t)$$

$$= (2 \pi f)^2\ x_o \sin (180 + \omega t)$$

where f = frequency of vibration.

Thus acceleration is α f^2

i.e. applied acceleration and hence applied force is proportional to the square of the frequency. Therefore, such a result is obvious.

This explanatón is based on the assumption that intensity of acceleration varies along the height of the sample and differential shear stresses are set up along all or almost all the horizontal planes. An examination of the deformed sample indicated bulge on all the four sides, the amount of the bulge being more in the direction of the motion. But the sample definitely showed a tendency to bulge in direction at right angles to that of motion. Thism may be due to the fact that the samples were unconfined and there was no restraint to this bulging effect unlike in a direct shear test. Also, in addition to shear deformations which are taking place, the soil sample is being compacted as well, both under its weight and under additional loads. In a sample of 4" height, the latter effect is probably more predominant and shear deformations are liekly to become predominant as the sample height is increased.

The deformation also increases with increase in load, at the same frequency. This effect is also a manifestation of compaction process.

In Figure 12 the same curves have been plotted on a semi-log scale. The curves are plotted as straight lines in this figure indicating that deformation varies as f^n where f is the frequency of vibration and n is any number (whole or fraction, positive or negative).

b) <u>Effect of Amplitude of Motion on Deformation</u> :-

Deformation versus frequency constant load (No load) is plotted in figure 13, amplitude of 4 mm, 6 mm and 8 mm. Similar curves have been given for loads of 800 gms, 1250 gms and 2150 gms and 2500 gms in Figures 14, 15, 16 and 17 respectively for the same amplitudes of 4 mm, 6mm and 8 mm.

These curves indicate that deformation increases with increase in amplitude of vibration at constant frequency and under the same vertical stress intensity.

Since acceleration is a function of amplitude of vibration, the applied force increases with the amplitude and hence larger deformation with larger amplitude.

c) <u>Effect of Maximum Acceleration on Deformation</u> :-

Maximum acceleration $(2\pi f)^2 \times X_0$ has been plotted as a function of frequency (f) in Figure 18. The curves of Figures 9, 10 and 11 have been replotted as deformation versus maximum acceleration for amplitude of 4 mm (Figure 19), 6 mm (Figure 20) and 8 mm (Figure 21). The curves in Figures 19, 20 and 21 are relatively flat as compared to deformation vs frequency curves (Figures 9, 10, & 11). Since the former can be considered to be $(\text{Frequency})^2$ versus deformation.

d) Effect of Maximum Acceleration on Dynamic Stress :-

Figure 22-a is a plot of ratio of vertical stress in a dynamic test to stress in a Static test at deformation of 0.5% for amplitudes of vibration of 4 mm., 6 mm., and 8 mm. Similar plot has been shown in Figure 22-b, for deformation of 1%. The points corresponding to any value of acceleration and hence different amplitude and frequency of vibration are close to a mean curve (not shown), in both the diagrams. Since stress in a static test is constant at any given deformation, the dynamic stress is a function of acceleration, and not of frequency and amplitude of vibration alone. Similar curve was plotted for the deformation (strain) corresponding to the asymptotic points in frequency versus deformation curves but no satisfactory conclusion could be drawn because of the scatter of the results. This is attributed to the fact that dial gauges could not be read beyond a deformation of 4 - 5% when the sample underwent a sudden collapse.

In plastic soils, where no well defined failure point can be observed on the stress strain plot, the failure stress is taken corresponding to 20% deformation. And this stress has been found to be a function of acceleration alone by Mogami, Yamoguchi and Nakase (1955). No definite conclusion can be drawn regarding such a relationship for sands.

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RELIABILITY OF MEASURED QUANTITY.

UNCONFINED COMPRESSIVE STRENGTH :-

The samples for the purpose of testing them in unconfined, compression were taken from proctor's moulds. The three specimens from the same proctor's mould gave a variation of as much as 10% which is quite reasonable and hence the mean of the three was taken.

MOISTURE CONTENT :-

The quantity of water added was measured by a 500 c.c. measuring flask. Presence of traces of moistures due to humidity could not be taken into account due to the lack of humid chamber. The amount of water content present was about 0.5%.

The loss of moisture content after mixing in the basin was about 0.5%, another about 0.5% after preparation of sample and further about 0.5% after testing the samples. The time interval from the start to completion of the set of observations took about 30 minutes.

FREQUENCY :-

Figure - 4 shows wide variation between the two valuos of nominal and actual frequency. Since the frequency was not changeable in steps but could be varied smoothly, some error in frequency might have been introduced in the result, but this error is only of the second order.

DURATION OF VIBRATION :-

Exactly 60 seconds was the time interval to be elapsed between two consecutive readings. The time was measured by a stop watch (least count 0.4 secs) some error in the observation may be of the order of ± 5 seconds which was duration for noting down the observations.

HEIGHT :-

The nominal height of samples were 4" as measured by a 12" scale. Some 1" of the bottom and one inch of the top of the sample was fixed with angles and cover respectively was not subjected to deformation and hence in calculating the percentage deformation actual height was considered as 2".

DEFORMATION :-

Three dial gauges were adjusted as shown in Figure 6. At lower frequency say upto 3 cps at all amplitudes, it was possible to note down the readings of the three dial gauges simultaneously with an error of ± 1 division (3.3%) but at higher frequencies from 4 to 7 cps, the needles of the gauges vibrate so fast that the mean value recorded may have an error of the order of ± 10 divisions (10%).

Two dial gauges on one end of the sample gave almost identical readings, while the reading in the third dial gauge differed somewhat.

The cause of unequal deformation may be that when acceleration of vibration became large, the load applied vertically on the specimen was shaking violently. Because of this hammering action of the vertical load the result might be influenced.

Thus the measured quantities are fairly reliable but following improvements may be made for further work in this direction.

In order to test the sample of greater height water content may be reduced to avoid tilting. The samples of height more than 4" underwent a tilt at a moisture content fax greater than O.M.C. Such samples are recommended to be tested at water content on the lowerside of O.M.C.

To check the variation in moisture content a humid chamber should be used or even a thin coating of wax or oil may give satisfactory results.

Photographic records or stroboscope may be used for accurate observations.

Confined sample with different time interval may be tested.

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SUMMARY AND CONCLUSIONS.

4" specimen of cohesionless soils at same moisture content were deformed to failure by vibrations at different amplitudes and loading intensities, thus permitting a study of effect of amplitude, frequency, time and loading intensity on deformation characteristics of cohesionless soil due to vibrations.

A review of the literature on behaviour of soils under vibratory loads is presented. Very little information is available on vibratory characteristics of soils. There is considerable scope and need for investigations of soils subjected to vibratory loads.

The following conclusions can be drawn from pilot tests conducted on a silty sand :-

1. The deformation of sample takes place partly because of shear deformations and partly because of compaction of the sample.
2. The deformation is found to increase with the frequency of vibrations. It is found that frequency and the log of deformation have a straight line relationship.
3. The deformation is observed to increase with increase in amplitude.
4. The stress intensity has greater influence on the formation characteristics and is found that with the increase in the intensity the deformation increases.

5. The normal stress intensity to induce specified percentage of deformation depends only on the intensity of acceleration.

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BIBLIOGRAPHY.

ANNUAL REPORT (1960-61) School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee (India).

BALAKRISHNA RAO, H.A. "Behaviour of Soils Under Heavy Machine Foundations and Design of Machine Foundations" Ph.D. Thesis, Indian Institute of Science, Bangalore (India) 1961.

BALAKRISHNA RAO, H.A. "Strength and Deformation of Soil Specimen Under Dynamic Loads". J.Indian National Society of Soil Mechanics and Foundation Engineering, VolI, No.2, April, 1962.

BENDEL, L., "The dynamic triaxial trials", Proc. Second International Conference on Soil Mechanics and Foundation Engineering, Vol. III, pp.131, 1948.

CASAGRANDE, A., & W.L. SHANNON, "Stress-deformation and strength Characteristics of Soils Under dynamic Loads" Proc. Second International Conference on Soil Mechanics & Foundation Engineering, Vol. V, pp. 29.

CASAGRANDES A., & W.L. SHANNON, "Strength of Soil Under Dynamic Loads" Trans. ASCE., Vol.114, pp.755, 1949.

DALMATOV, B.I., "Lecture notes on Seismic Effects and Stability of Sahsated Sands" Deptt. of Geology University of Roorkee, Roorkee, 1962.

EASTWOOD, "The Factors which effects the natural frequency of vibration of foundations and the effect of vibration on bearing power of foundation on sand" Proc. Third International Conference on Soil Mechanics and Foundation Engineering, Vol. I, pp. 119, 1953.

INDIAN STANDARDS INSTITUTION, "Indian Standard on Identification and classification of soils for Engineering purposes" I.S.1498, 1959.

KONDNER, R.L., "Vibratory Simple Shear of a Clay" Proc. Highway Research Board, Vol. 40, p. 647,1961.

KONDNER, R.L., "Vibratory Response of a Cohesive Soil in Uniaxial compression" Preprint, Second Symp.on Earthquake Engg. University of Roorkee, Roorkee, India) 1962.

BIBLIOGRAPHY.

KREY, H., "Erddruck, Erd Widerstand and Tragfaihig keit des Baugrundes" pp. 16, Ernst, Berlin, 1936.

L' HERMITE,M.R., & M.G.TOURNON, "La Vibration du be'ton frais" Annales de l' Institut, Technique, 1948.

MENCEL,V., & J.KAZDA, "Strength of Sand During Vibration" Proc. Fourth International Conference on Soil Mechanics and Foundation Engineering, Vol.I, pp. 382, 1957.

MAGAMI, T., & K.KUBO, "The Behaviour of Soil During Vibrations" Proc. Third International Conference on Soil Mechanics and Foundation Engineering, Vol.I, pp. 152, 1953.

MOGAMI, T., H.YAMAGUCHI & A.NAKASE, "The Dynamical Properties of Soils" 2nd report, Reports of the Institute of Science and Technology, University of Tokyo, Vol.9, No.1, March, 1955.

MURAYAMA,S., AND T. SHIBATA, "On the Dynamic properties of clay" Proc. Second World conference on Earthquake Engineering, Vol.I, pp. 297, 1960.

SEED,H.B., & R. LUNDGREN, "Investigation of the Effect of Transient loading on the strength and deformation characteristics of saturated sands" Proc. ASTM., Vol. 54, pp. 1288, 1954.

WHITMAN, R.V. "The Behaviour of soils under transient loads" Proc. Fourth International conference on Soil Mechanics and Foundation Engg., Vol.I, pp.207, 1957-a.

WHITMAN, R.V. "Testing of Soils with transient loads" ASTM Special Techical Publication No.232,pp.242, 480, 1957-b.

WHITMAN,R.V., "Shear Strength of Sands During Rapid Loadings" Proc. AS.C.E., Vol.88, SM 2, april, 1962.

WOLFSKILL, 4A, and S.J. BUCHANNAN, "Dynamic Stress-Strain Characteristics of Granular Materials" Delivered at the National Convention of ASCE, FEBRUARY, 1962.

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