A LABORATORY STUDY OF E, POISSON'S RATIO AND FATIGUE CHARACTERISTICS OF LEAN CONCRETE

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
CIVIL ENGINEERING
(Transportation Engineering)

By

S. S. V. CHALAM

TRANSPORTATION ENGINEERING DIVISION
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE - 247667 (INDIA)

MARCH, 1986

CANDIDATES DECLARATION

I hereby declare that the work which is being presented in the thesis entitled 'A LABORATORY STUDY OF E, POISSON'S RATIO AND FATIGUE CHARACTERISTICS OF LEAN CONCRETE' in partial fulfilment of the requirement for the award of degree of MASTER OF ENGINEERING in Transportation Engineering, submitted in the Department of Civil Engineering of University of Roorkee is an authentic record of my own work carried out during a period from August 1985 to March 1986 under the supervision of Dr. A.K. Gupta and Sri A.K. Mahendru of Transportation Engineering Division of University of Roorkee. The matter embodied in this dissertation has not been submitted for the award of any degree or diploma.

(S.S.V. Chalam)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

(A.K. Mahendru)
Lecturer
Transportation Engg. Division,
Department of Civil Engineering,
University of Roorkee,
Roorkee

(A.K. Gupta) 24/08/86
Professor & Coordinator,
Transportation Engg. Divn.
Department of Civil Engg.,
University of Roorkee,
Roorkee

ACKNOWLEDGEMENT

The author wishes to express his sincere heartfelt gratitude to Dr. A.K. Gupta, Professor and Coordinator of Transportation Engineering Division and Sri A.K. Mahendru, Lecturer of Transportation Engineering Division for supervising this dissertation and the valuable suggestions at different stages of this work and their painstaking efforts in going through the manuscript for improving it.

The author desires to acknowledge the help extended by Sri Satish Chandra, Lecturer in Transportation Engineering Division, Dr. P.C. Jain of Structural Engineering Division and Mr. P.P. Bajaj of Transportation Engineering Division.

The author is also extending his heartfelt gratitude to all the faculty members of Transportation Engineering Division, Civil Engineering Department, University of Roorkee for their suggestions during the period of M.E. Course.

The author wishes to thank his parents for their encouragement and inspiration at all stages of this course.

The author is also thanking the people of C.R.R.I., Delhi for their valuable suggestions during the course of study.

The author is also thankful to the Highway Engineering Laboratory staff for their help in conducting various experiments.

Finally thanks are due to Sri A.K. Agrawal and Sri S.C. Sharma for their neat typing and drafting respectively.

S.S.V. CHALAM

ABSTRACT

For a rational design and evaluation of various pavements need modulus of elasticity and Poisson's ratio of a pavement material. Existence of heavier wheel loads makes an highway engineer to think in terms of fatigue of pavement material. There are several methods available for estimation of above properties under various conditions for different materials. The planning and implementation group of Ministry of Shipping and Transport of India, identified a research project entitled R-24 'Determination of E and Fatigue Characteristics of Asphaltic Concrete, Lime Flyash Aggregate, Lime gravel and lean cement concrete in laboratory'. In the present investigation Lean Cement Concrete material was selected for estimation of above properties, which is a part of above research project.

In the current study, three lean concrete mixes of 1:4:8, 1:5:10 and 1:6:12 (Cement:Sand:Aggregate) were selected for finding modulus of elasticity, Poisson's Ratio and Fatigue by using various techniques in the laboratory. Tests were conducted on various samples including cubes, cylinders, beams and slabs. The E value was estimated from 5 different tests which included both destructive and non-destructive tests. The fatigue of lean cement concrete was determined by using beam specimens with the help of machine developed by CRRI. The results were compared and discussed with that of other investigators.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF NOTATIONS

a	Radius of loaded area in cm
a_1	Distance between line of fracture and nearer support on tensile side, cm
D	Distance between Transducers in surface wave propogation techniques, cm
d	Unit weight of material kg/cm^3
E	Modulus of Elasticity, kg/cm^2
E_c	Modulus of Elasticity in compression, kg/cm^2
E_d	Dynamic modulus of elasticity, kg/cm^2
E_{d1}	E_d from pulse velocity technique, kg/cm^2
E_{d2}	E_d from longitudinal resonance technique, kg/cm^2
E_{d3}	E_d from surface wave propogation technique, kg/cm^2
E_{PL}	E from plate load test, kg/cm^2
E_s	E of subgrade, kg/cm^2
F_2	Dimensionless deflection factor in Burmister's method
f	Resonance frequency, Hzs or cycles/sec
f_b	Flexural strength, kg/cm^2
g	Acceleration due to gravity, cm/sec^2
h	Pavement thickness, cm
K	Modulus of subgrade reaction, kg/cm^3
L	Length of sample, cm

l	Radius of relative stiffness, cm
P	Design wheel load in kg,
V	Velocity of waves, cm/sec
T	Transit time in micro seconds
Δ	Wave length, cm
Δ_1	Design deflection in Burmister's method, cm
γ	Poisson's ratio

CHAPTER I

INTRODUCTION

1.1 GENERAL

For a rational design and evaluation of pavement requires the fundamental properties of various materials. These fundamental properties include modulus of elasticity, poisson's ratio and fatigue characteristics. Existence of larger and heavier wheel loads makes an highway engineer to estimate the properties relating to fatigue. There are several methods available for estimation of the above stated properties for different materials under various conditions. So in order to use lean cement concrete as a pavement material the above stated properties are to be estimated accurately. So there is a need to study the suitability of methods available for testing quality concrete, for applying to lean concrete. Lean cement concrete consists of ordinary portland cement, coarse aggregate and fine aggregates with water cement ratio greater than 1. Lean cement concrete is a semi rigid material having distinctly superior load spreading characteristics as compared to conventional granular bases and subbases like water bound macadam. Besides superior load spreading properties, lean cement concrete is resistant to softening action of water and can serve as a good working platform on softer foundations. This material is very useful in heavy rain fall areas and black cotton soil areas. In the present study, the fundamental properties of lean cement concrete are determined by using both destructive and non destructive tests and more emphasis was placed on later methods.

1.2 DEFINITIONS OF VARIOUS PARAMETERS

1.2.1 Modulus of elasticity

From theory of elasticity, modulus of elasticity is the ratio of stress and strain (3). This stress-strain relationship is linear for purely elastic material. As the pavement materials are not purely elastic, the relation is rather curved in nature. When no straight portion is available it is determined by drawing tangent to the curve at any specified point on stress-strain curve. For cement concrete, this specified point is taken as either 25% or 50% to 60% of compressive strengths. A typical stress-strain curve for cement concrete was shown in fig. 1.1. Generally elastic modulus is represented as secant modulus or tangent modulus.

(a) Secant Modulus: This cuts the characteristic curve at a point and is equal to the tangent of the angle subtended by the secant drawn from origin to the point considered. This secant modulus is used very much in research work, indeed when used as multiplying factors for experimentally measured strains, the equivalent stress is obtained directly.

(b) Tangent Modulus: This one equals to the trignometric tangent of the angle subtended by the geometric tangent at the characteristic curve with the x-axis. This tangent modulus is closer to the theoritical definition of elasticity.

Generally, the modulus of elasticity is denoted by the letter 'E'. E value is again classified as 'E' in static - in which loads are applied to specimens and the resulting strains were measured - and E in dynamic - involving stress - wave velocity and vibration methods.

1.2.2 Poisson's Ratio

Poisson's Ratio, 'γ', is defined as the ratio of lateral to longitudinal strain by a load parallel to the axis in which axial strain is measured.

$$\gamma = e_l/e_a \qquad (1.1)$$

e_l = Lateral strain

e_a = Longitudinal or axial strain

'γ' is again classified as static 'γ' (γ_s) or dynamic 'γ' (γ_d) similar to E.

1.2.3 Fatigue

Some of the impartant definitions to fatigue are (2,15) -

'The process of progressive localized permanent structural change occuring in a material are subjected to conditions which produce fluctuating stresses and strains at some point or points which may culminate in cracks or complete fracture after a sufficient number of fluctuations'.

'Phenomenon of a fracture under repeated or fluctuated stress having a maximum value less than tensile strength of the materials'.

'Fatigue is a kind of distress in pavements and is none other than load associated cracking'.

1.3 SIGNIFICANCE OF MODULUS OF ELASTICITY AND POISSON'S RATIO

1.3.1 Flexible pavements

In order to use Ulrey and Ahlvin (28) equations for finding stresses, strains and deflections at any point in a homogenous layer, E and γ are required.

$$\sigma_r = p(2\gamma A + C + (1-2\gamma)F) \quad (1.2.1)$$

$$\sigma_t = p\,(2\gamma A - D + (1-2\gamma)E_1) \quad (1.2.2)$$

$$e_z = p\,\frac{(1+\gamma)}{E}\,[(1-2\gamma)\,A + B] \quad (1.2.3)$$

σ_r = Radical horizontal stress

σ_t = Tangential horizontal stress

e_z = vertical strains

In the above equations A,B,C,D,E_1 and F are functions of both depth and offset distances in terms of (z/a, r/a).

In order to find the deflections in a two layer system by using Burmister's equations (28) needs E.

$$\Delta_1 = 1.5 \frac{p_a}{E_s} F_2 \qquad \text{flexible plate} \qquad (1.3.1)$$

$$= 1.18 \frac{p_a}{E_s} F_2 \qquad \text{Rigid plate} \qquad (1.3.2)$$

With known values of modulus of elasticity of subgrade E_s and pavement material E_p, yielded pressure p, and radius of loaded area a, deflection Δ_1 in the pavement or subgrade is computed, after knowing F_2 (dimensionless deflection factor) from graph 1.2, which was established between F_2, h/a (pavement thickness/radius of loaded area) and E_s/E_p ratio.

E is needed to find stresses in a multilayered system by using equations developed by Fox and Accum (28).

$$\sigma_{z1} = p(zz_1) \qquad (1.4.1)$$

$$\sigma_{z2} = p(zz_2) \qquad (1.4.2)$$

where zz_1 and zz_2 are function of $K_1 = E_1/E_2$ and $K_2 = E_2/E_3$, $A = a/h_2$, $H = h/h_2$ where 1,2,3 are suffices indicate various layers in a multilayer system.

Triaxial method of flexible pavement design to find thickness of pavement layer, T_p, requires E of pavement material. (14)

$$T_p = \left[\left(\frac{3pxy}{2 \times 3.14 \times E_s \times \Delta_1}\right)^2 - a^2\right]^{0.5} (E_s/E_p)^{1/3} \qquad (1.5\ \ )$$

x,y coefficients depending on traffic and rain fall.

p = design wheel load in kg

Burmisters method of designing flexible pavements requires E_s and E_p for a design deflection of 0.25 or 0.5 cm by using equations 1.3.1 and 1.3.2 and fig. 1.2.

1.3.2 Rigid pavements

Either to design or analysis of rigid pavements, the important parameter is radius of relative stiffness 'l'. This parameter is defined by Westergaard as

$$l = [E h^3/12 (1-\gamma^2)K]^{0.25} \qquad (1.6)$$

where K = modulus of subgrade reaction

h = pavement thickness

Radius of relative stiffness is required for computation of stresses due to wheel load, at centre, corner, edge by using Westerguard eqs., Badburry, Gerald, Pickett, Kalley, Spangler equations and IRC charts. E and γ are needed to find wrapping stresses in the pavements due to temperature changes. To estimate load carrying capacity of slabs or to find breaking load of slabs at various points by using Mayerhoffs theory (22), requires l value, The following few equations give an idea of significance of l.

$$S_c = \frac{3P}{h^2}\left[1-(a\sqrt{2}/l)^{1.2}\right] \quad (1.7.1)$$

$$S_{t(c)} = \frac{Eet}{3(1-\gamma)}\left[(a/l)^{0.5}\right] \quad (1.7.2)$$

S_c = stress in the pavement due to a wheel load p at corner

$S_{t(c)}$ = Wrapping stresses at corners due to temperature changes

e = Thermal coefficient of concrete

t = Temperature difference between top and bottom layer

1.3.3 E in overlay design

Navy method (23) to find the rigid overlay thickness requires E as a parameter.

$$R_1 = R_0 E_1 h^3/(E_1 h_o^3 + E_2 h^3) \quad (1.8.1)$$

$$R_2 = R_3 E_2 h^3/(E_1 h_o^3 + E_2 h^3) \quad (1.8.2)$$

R_0 = Maximum tensile stress in the upper layer when the upper slab does not exist and the new slab takes its place and rests.

R_1 = Maximum tensile stress in the upper slab when the older is under it.

R_2 = Maximum tensile stress in the lower slab when it lies under the upper slab.

R_3 = Maximum tensile strress in the lower slab when the upper slab does not exist.

1.4 SIGNIFICANCE OF FATIGUE

1.4.1 Concept of fatigue used in PCA method of pavement design

The application of fatigue principle to the design of cement concrete pavement (15, 28) in terms of flexural strength and the wheel load repetitions likely to occur in its estimated life has been given in this method. In this method it is assumed that when the repeated stress is not greater than 50 percent of ultimate strength in flexure, concrete will withstand unlimited number of repetitions.

1.4.2 Concept of load repetitions in AASHO Road test formula

This is a design method which accounts for anticipated number of repetitions of a load causes fatigue in pavement (28). During the test, a method of rating pavements and determination of their service period was originated. The rating obtained by this method is called percent serviceability index (PSI).

The PSI was established on a scale from 5 (best) to 9 (worst). The average pavement on the test road had PSI rating 4.5 for rigid type and 4.2 for flexible type. Many engineers felt however that pavements with PSI of 2.5 were justified with heavy maintenance expenses. For this reason AASHO data are generally presented on the basis of 2.5 PSI.

Results of flexible pavement test indicates that for a given material, climatic conditions and construction of the best road, the thickness of the structural section varies with weighted axle and number of load repetitions.

From the above discussion it can be seen that the fatigue response of pavement material and load repetitions play a significant role in pavement performance and inturn designing the pavement structure.

1.5 OUTLINE AND SCOPE OF PRESENT STUDY

The main aim of the present investigation is to develop a technical knowledge for finding E, γ and fatigue of lean cement concrete, but not the characterisation of material. The Chapter II of this report contains the work performed by various investigators Abroad, at Central Road Research Institute of India (CRRI) and Transportation Engineering Division of University of Roorkee to find the above stated properties, while Chapter III describes the methods adopted, which includes selection of mixes, samples, description of various experimental setups and their procedures. In the Chapter IV the analysis of results are carried out and discussions are presented by comparing with the results of other investigators. Conclusions are drawn based on the experimental results and some recommendations are given for further work in Chapter V.

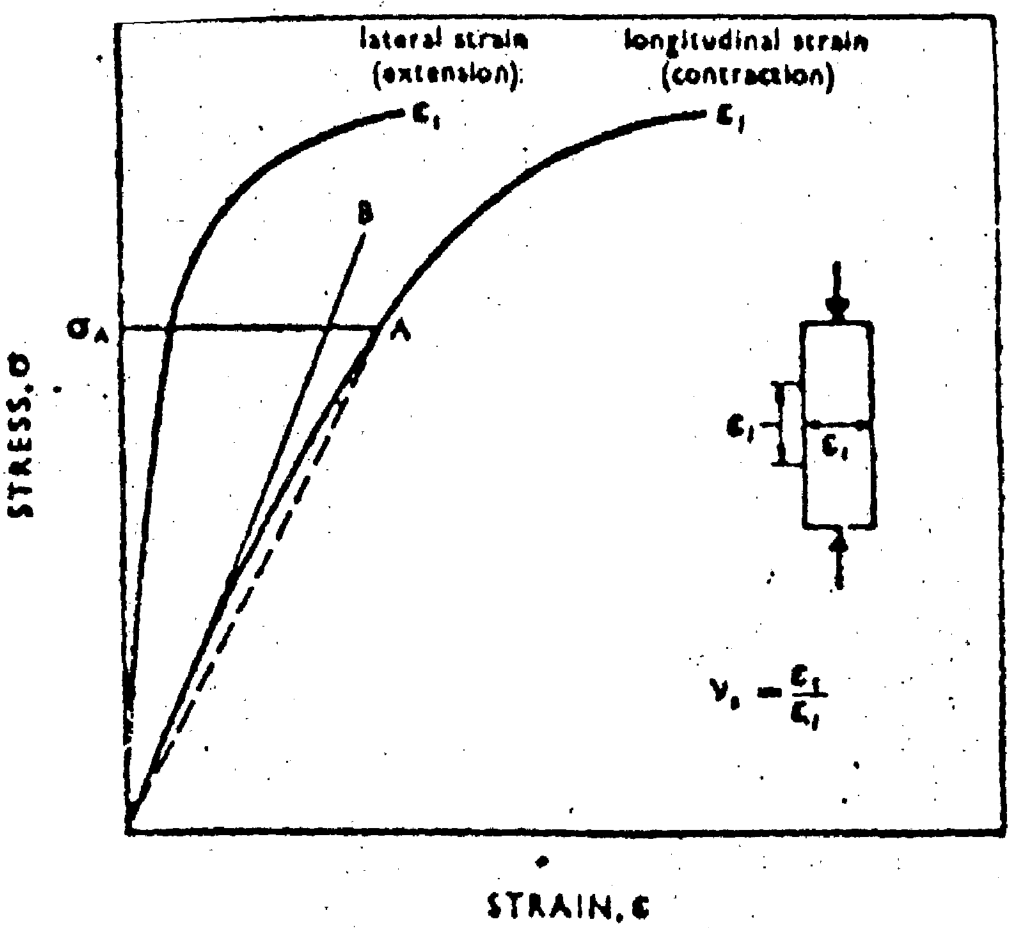


Fig. 1.1 Stress-strain curves for a typical concrete loaded uniaxial compression

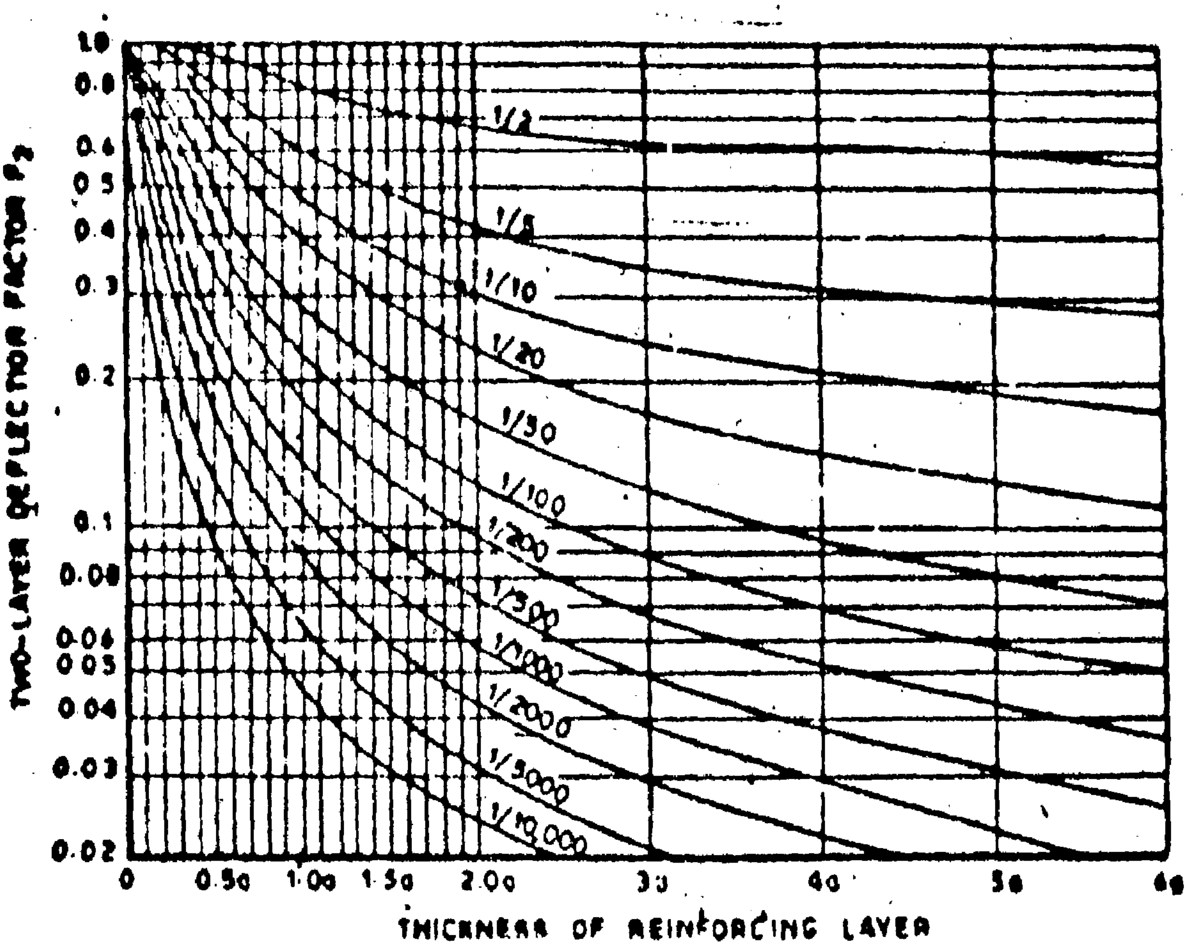


Fig. 1.2 Relationship of F_2 and h in a two layer system (Burmister method[2])

CHAPTER II

LITERATURE REVIEW

The available or reported literature on Lean Cement Concrete was very limited. Since the behaviour of lean concrete was similar to the rich concrete, some of the reported literature of cement concrete was included in this present review.

2.1 DETERMINATION OF MODULUS OF ELASTICITY

2.1.1 Destructive Tests

Most of the work available for determination of E of lean cement concrete was in compression. Very few investigators determined E in tension.

J.M. Galloway (6) conducted tests on both quality concrete and lean cement concrete and determined E in compression as well as in tension. The tests were conducted on specimens having 76 mm square section at centre and 229 mm length which were prepared from 508 x 102 x 102 mm beam moulds to give a slenderness ratio of 3. The specimens were compacted by electric vibrating hammer and were tested after curing for 26 weeks. They conducted tests in compression, tension and compression - tension. They did not observe much change in E value of quality concrete and lean cement concrete.

CRRI (7) also conducted test in compression on 1:4:8 lean cement concrete and obtained a value of 1.07×10^5 and

1.05×10^5 kg/cm^2 at 25% and 50% compressive strengths respectively. The tests were conducted on cylinderical specimens.

In University of Roorkee the E value of other materials like lime fly ash aggregate (22), and cement concrete (18) as a building material were determined in compression. Few investigators (26) determined E value by conducting plate load tests on slabs of lime fly ash concrete.

Dr. Ramaswamy et al (20) conducted tests on standard samples of cement-concrete in compression and developed equations for computation of E after knowing either cylindrical strength R_c or cube strength f_c.

$$E = 7.815 \times 10^6 \left(\frac{f_c}{f_c + 1700}\right) \text{ PSI} \qquad (2.1.1)$$

$$= 4.17 \times 10^6 + 300\, R_c \text{ PSI} \qquad (2.1.2)$$

2.12 Nondestructive tests

People adopted these non-destructive techniques especially pulse velocity and longitudinal resonance tests on cement concrete. The progress of using these equipments was significant. The latest trend was the use of vibratory techniques on existing pavements.

J.C. Simons (25) worked with Pulse velocity techniques and longitudinal resonant tests by using cement concrete beams of 18" x 4" x 4". R. Jones (13) also used above techniques on lean concrete test specimens that were subsequently broken for determination, compressive and flexural strengths.

They computed E value from the following equations:

Pulse velocity technique $E_{d1} = \frac{(1+\gamma)(1-2\gamma)}{(1-\gamma)} V^2 \frac{d}{g}$ (2.2)

Longitudinal Resonance Technique

$$E_{d2} = \frac{4 \times f^2 \times L^2 \times d}{g} \quad (2.3)$$

V = Pulse velocity in cm/sec

d = unit weight of specimen in kg/cm^3

g = acceleration due to gravity in cm/sec^2

f = frequency at resonance in Hzs

L = Length of sample in cm

R. Jones multiplied eq. 2.3 with a factor T_1^2, where $T_1 = 1.05$ (a correction for infinite cross-section).

In India, these techniques were used for determination of E value of cement concrete, cement flyash concrete and lime fly ash concrete (22).

The vibrational testing of roads and runways originated in Germany, in between 1928 and 1939, where mechanical vibrators were used to investigate the mechanical properties of different types of soils. R. Jones (12) reviewed the state of use of vibrational techniques between 1928 to 1960 and the subsequent progress. According to this paper most of vibrators used in early stages were of lower frequency ones (10 to 80 cycles/sec) and investigations were made on soils to find their properties.

In later stages people acquainted with the high frequency vibrators having frequencies ranging from 10 to 30000 cycles/sec. These high frequency vibrators were used for finding the mechanical properties of pavement layers. The main principle of this technique was determination of E using correlations between velocity of wave propogation and elastic constants. In the same paper, A.A. Maxwell (17) described the computations to be done for finding E using these vibrators.

$$V = f \Delta \quad \text{cm/sec} \tag{2.4}$$

$$E_{d3} = (1+\gamma)\, V^2 \frac{d}{g} \cdot \text{cm/sec}^2 \tag{2.5}$$

Δ = Wavelength in cm

f = frequency of vibrator in cycles/sec

R. Jones observed that the E value was not affected very much by change in Poisson's Ratio and unit weight of material.

In India, CRRI (15,25) used the vibratory techniques for evaluation of pavements. They conducted tests at NH_2, near CRRI with the help of a vibrator having a frequency range of 200 Hzs to 10,000 Hzs. The wavelength was determined in the following manner. The phase angle was measured at an interval of 20cms and 10 cms for lower and higher frequencies respectively with the help of a phase-difference-meter. The wave length Δ, was computed by plotting graph between cumulative phase angle and distance. The corresponding distance for a phase difference of 360° was taken as wave length. They also plotted a graph between velocity, V and wave length Δ, for various frequencies and observed a discontinuity, essentially corresponding to the distinctly different layers. They took the velocity to zero wave length of enveloping curve as shown in fig. 2.1 and 2.2 and it was seen to correspond with the phase velocity for the top layer. The other two segments were seen to have relatively little steepness and their values (shear waves) correspond to the elastic characteristic curves of bottom layers. They computed E value from the following equations.

$$V = f\Delta \tag{2.4}$$

$$E_{d3} = \frac{2(1+\gamma)\, V^2}{P^2} \frac{d}{g} \tag{2.6}$$

P = 1 for shear wave

= 0.91 to 0.96 for Raylegh's wave

They also developed a nomogram for obtaining Young's modulus conveniently. This nomogram was shown in fig. 2.3. The phase velocity V, in the nomogram was shear wave velocity (P=1.0). For Raylegh wave velocity the value obtained from the nomogram was to be adjusted. The E values obtained for different materials were shown in Table 2.1. A comprehensive review of literature was available in a preliminary report (29) on surface wave propogation techniques.

2.2 DETERMINATION OF POISSON'S RATIO

The ratios such as stress-strain, longitudinal to lateral deformations were very much dependent on type of loading. People used to assume γ for cement concrete as 0.15, but there is a necessary to find the value of γ directly. Similar was the case for lean concrete. As per P.S. Pell (19), Kolias conducted tests on lean concrete and got a value of 0.15 in static tests and 0.2 in dynamic tests.

2.2.1 Destructive tests

A comprehensive review of the information available. Concerning Poisson's ratio of concrete made with gravel aggregate has been given by M. Anson (1) in static tests. The literature review was carried in detail under various conditions (compression tension, biaxial compression tension), on various samples (cylinders, beams, prisms) etc.

CRRI (7) also conducted tests on lean cement concrete in compression on (10 x 10 x 25) cms prisms and the strains were measured by using strain gauges of 7.5 cm long. They obtained a value of 0.25 and 0.27 at 25% and 50% compressive strengths respectively.

2.2.2 Non-destructive tests

Most of the investigators (1,24) determined Poisson's Ratio by using both Pulse velocity technique and longitudinal resonant tests on beam specimens. The γ value was determined by equating eq. 2.2 and eq. 2.3.

$$\frac{(1+\gamma)\ (1-2\gamma)}{(1-\gamma)} = \frac{4\ f^2\ l^2}{V^2} \qquad (2.7)$$

2.3 DETERMINATION OF FATIGUE

Research into the fatigue behaviour of concrete under repeated loading has been conducted over a period of 90 years. K.D. Raith by (27) reviewed the available literature on fatigue properties of cement concrete by dividing into two categories.

1. Axial loading on cylindrical or prismatic specimens usually under compressive loading
2. Flexural tests on simply supported beams

He covered the reported literature under the following sub-headings.

(a) Constant amplitude tests.

(b) Time dependent effects (i.e. rate of loading, specimen age, rest periods etc)

(c) Stress interaction including previous stress history and cumulative fatigue damage

(d) Mechanism of fatigue failure (crack propogation, stress-strain relationships, fracture mechanics.)

M. Saito et al (21) determined fatigue of concrete by using frictional grips as shown in fig. 2.4 on tampered beams as shown in fig. 2.5 at the age of 8 weeks in tension.

H.A.N. Cornelissen (4) conducted tests on cement concrete under constant amplitude loading in tension. The tests were performed on cylindrical specimens (120 mm ∅ x 300 mm) casted vertically in steel moulds.

In India CRRI (7) performed fatigue tests on 1:4:8 lean concrete mixes in flexture. They tested the samples by applying the load at the rate of 70 cycles / min. on beams of (50 x 10 x 10) cm after curing them for 28 days. The results were shown in fig. 2.6.

In University of Roorkee, fatigue property of other material lime fly ash aggregate (2), soil cement (15) and other materials were determined using the equipment developed by CRRI.

2.4 NEED OF PRESENT STUDY

As it was observed from the above literature review, that not much technical knowledge was reported for lean cement concrete. Even CRRI also reported only for 1:4:8 mix. From the first Chapter the importance of lean concrete as pavement material was discussed and the need to find E, γ and fatigue of materials was discussed. So far using lean cement concrete as a pavement material, the above properties are to be estimated accurately and the suitability of methods available for other materials and their application to lean concrete upto 1:6:12 are to be studied.

TABLE 2.1

DYNAMIC YOUNG'S MODULUS VALUES DETERMINED USING SURFACE WAVE PROPOGATION TECHNIQUE (5)

Pavement layers	Wave velocity m/s	Edyn. value $kg/cm^2 x 10^5$
Cement Concrete	2412	4.204
W.B.M.	1010	0.641
Stone Soling	750	0.369
Cement Puzzolane Concrete	2247	3.648
W.B.M.	860	0.464
Stone Soling	600	0.236
Cement Concrete	2393	4.138
W.B.M.	940	0.555
Stone Soling	600	0.236
Cement Concrete	2245	3.642
W.B.M.	810	0.412
Stone Soling	640	0.269
Asphaltic Concrete	1075	0.874
W.B.M.	600	0.226
Stone Soling	405	0.108
Asphaltic Concrete	1230	1.144
W.B.M.	580	0.211
Stone Soling	480	0.151
W.B.M. Surface Course	220	0.030
Soil Subgrade (only)	165	0.014

Notes:

1. The wave velocity values given above were obtained as under:
   - for subsurface layers, the values were read directly from the dispersion curve plot as shear wave velocity.
   - for the top layer, the Rayleigh wave velocity was read directly from the dispersion curve & then adjusted as per the least square method.
2. The measurements relate to air shade temperature in the range of 20-25°C. Moisture was not monitored, generally.
3. The Young's modulus was determined for the following values of Poisson's ratios:
   - Cement concrete and puzzolona cement concrete–0.25
   - Asphaltic concrete – 0.35–W.B.M. – 0.40
   - Stone soling – 0.40 – Subgrade Soil – 0.45

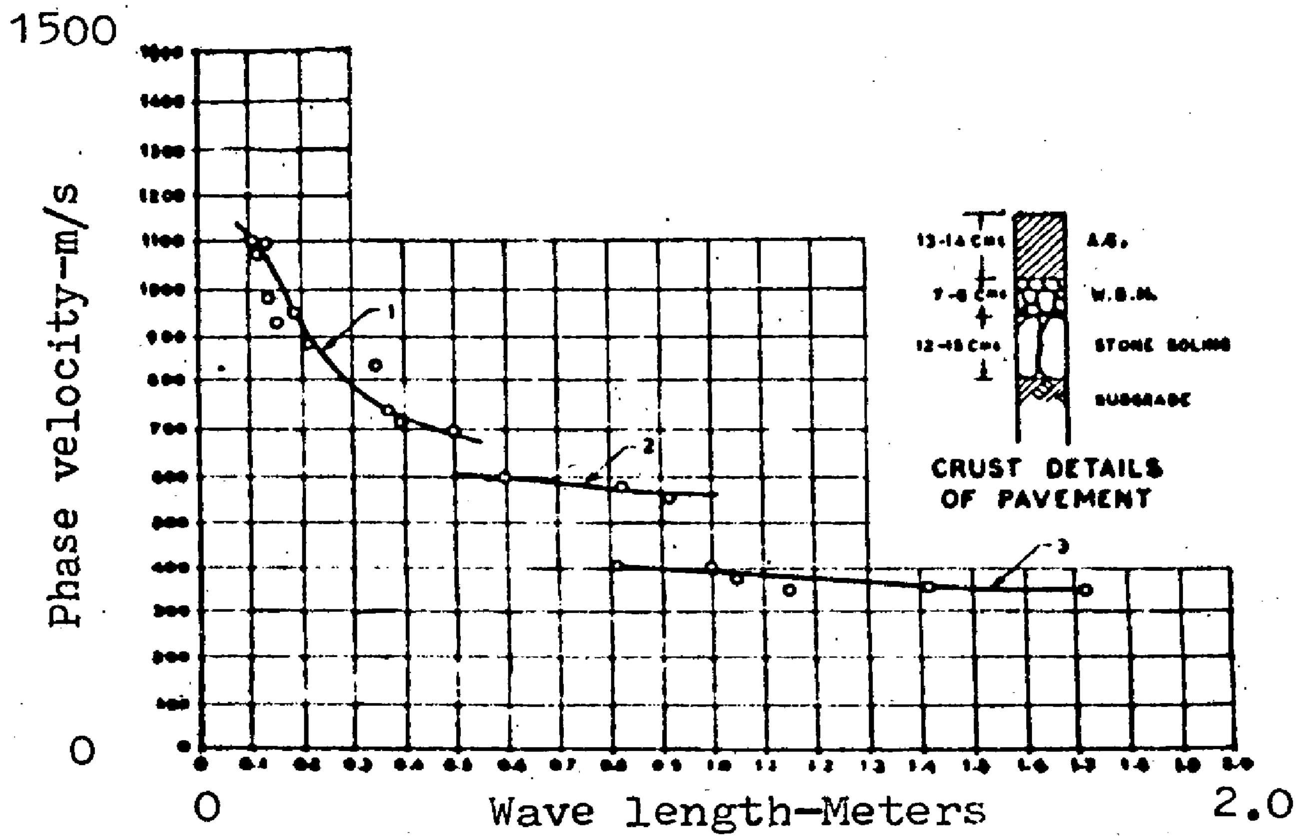


FIG. 2.1 DISPERSION CURVE FOR FLEXIBLE PAVEMENT

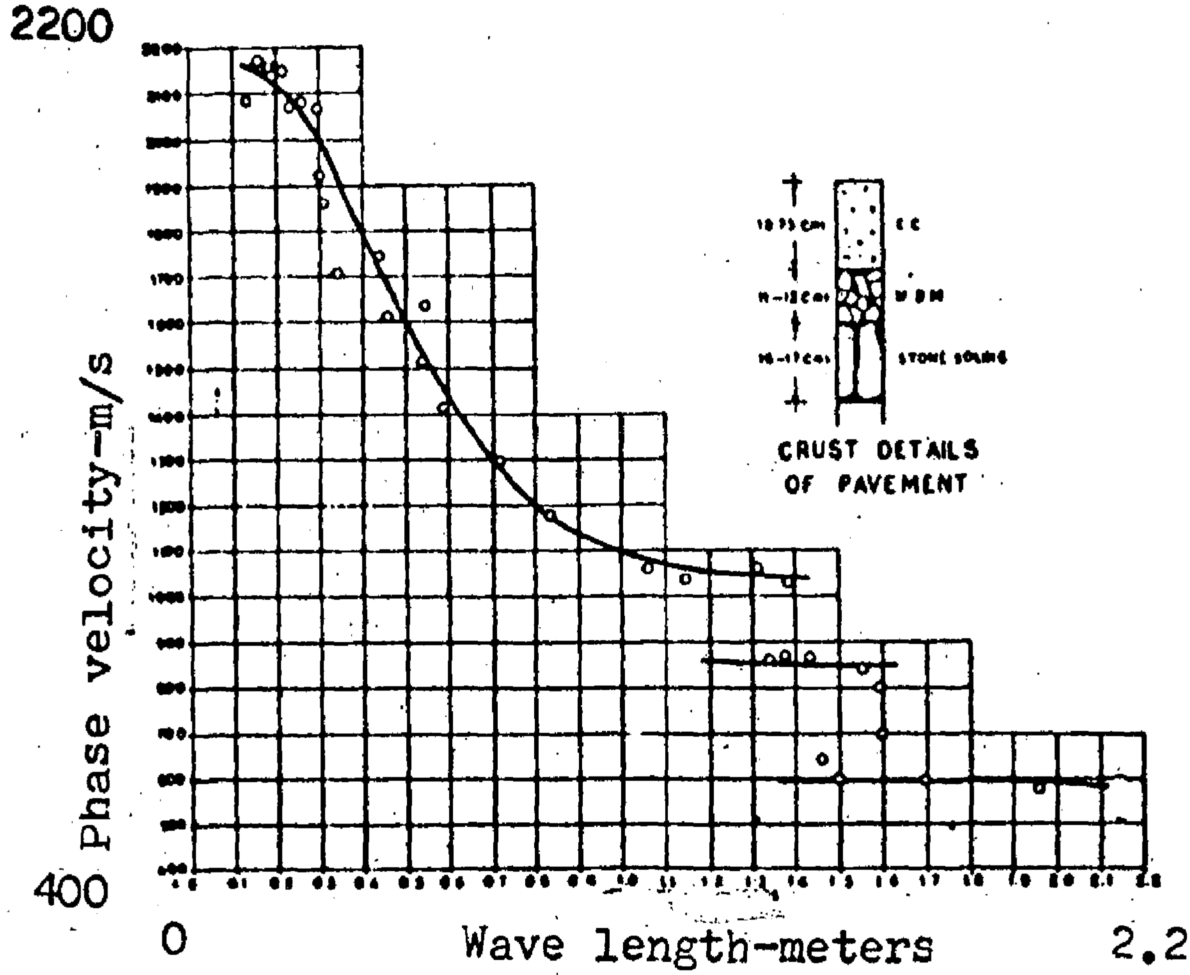


FIG. 2.2 DISPERSION CURVE FOR PUZZOLANA CONCRETE PAVEMENT

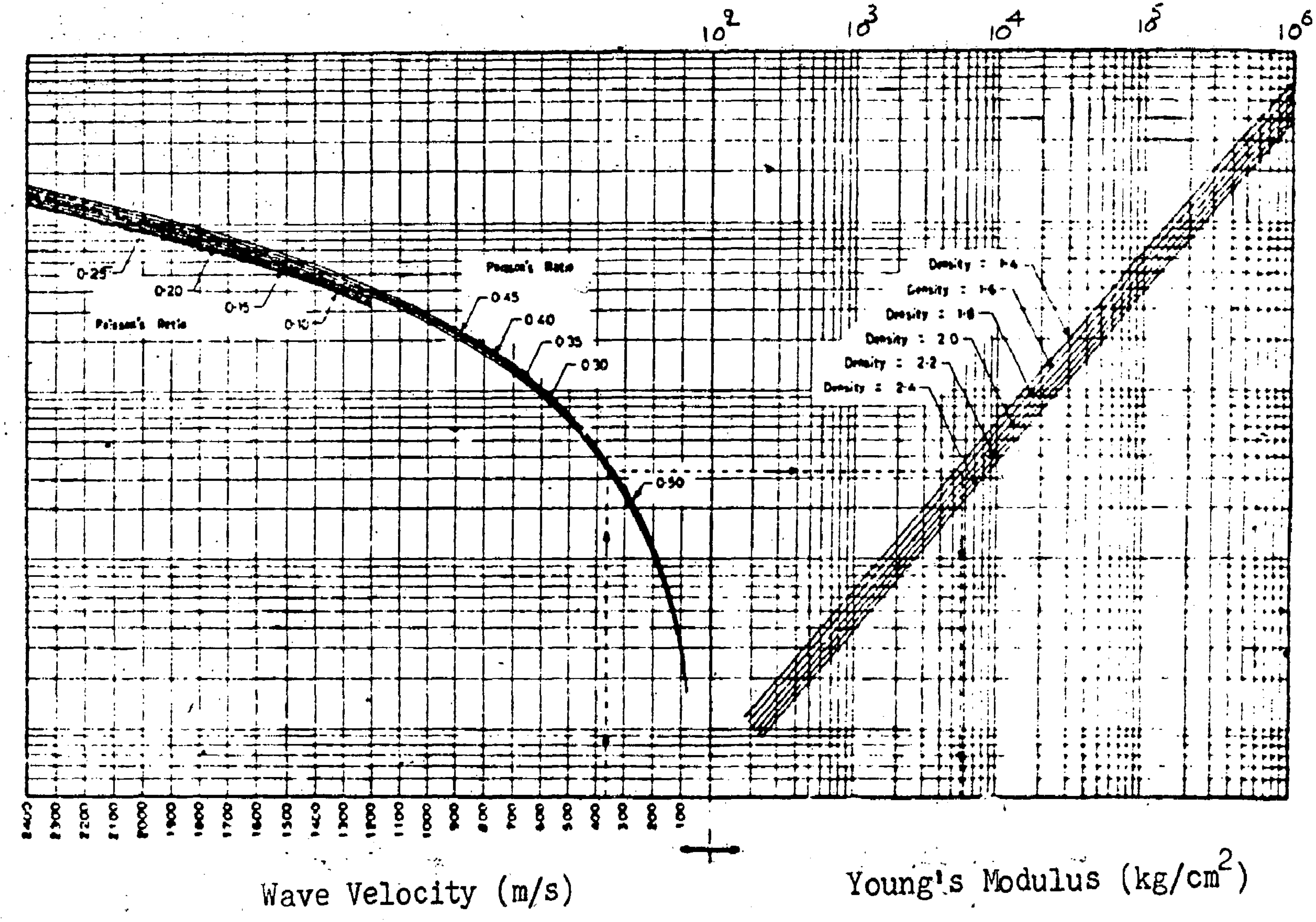


Fig. 2.3 Nomogram correlating Young's modulus, Poisson's ratio, density and wave velocity

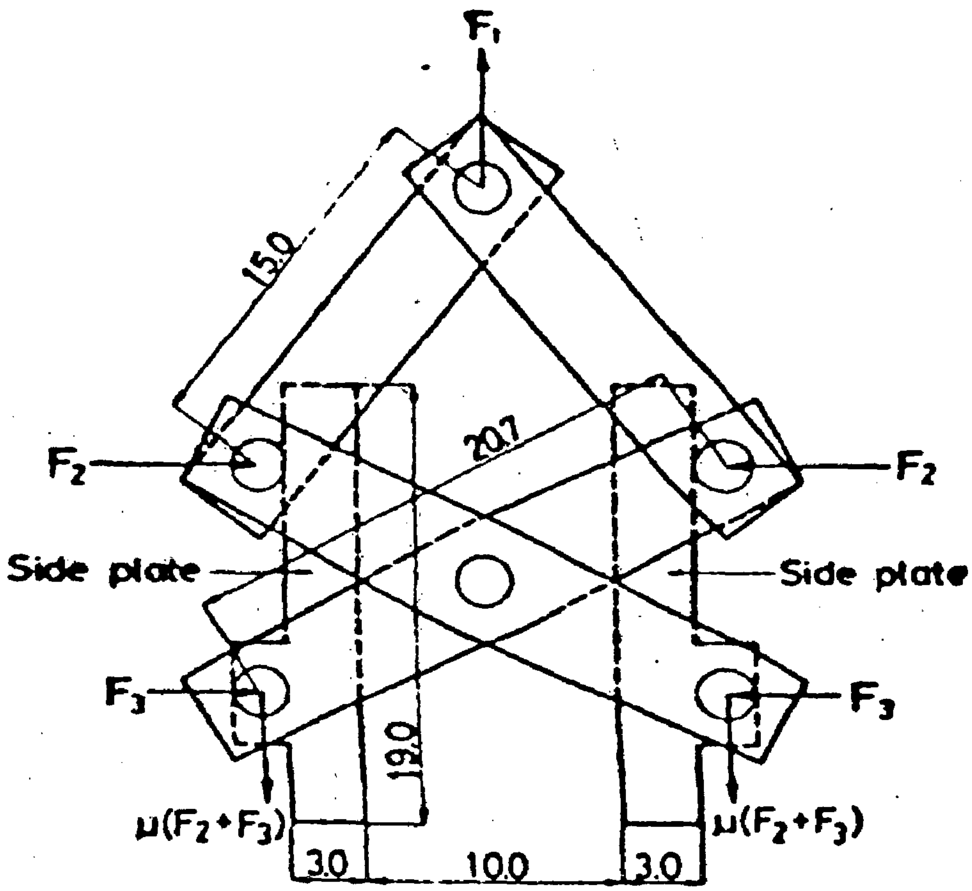
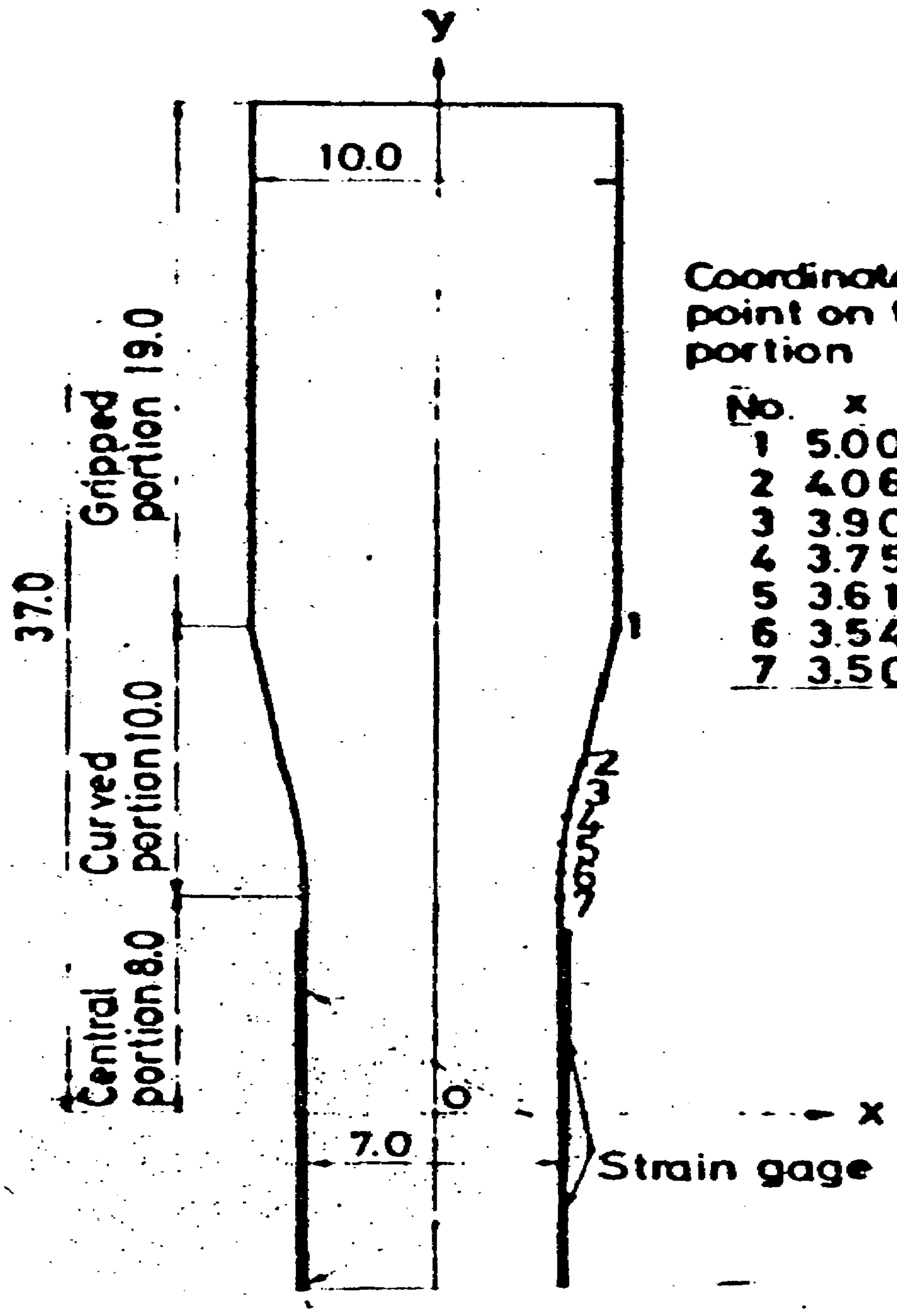


Fig. 2.4 Details of friction grip



Coordinate of each point on the curved portion

No.	x	y
1	5.00	18.00
2	4.06	13.00
3	3.90	12.00
4	3.75	11.00
5	3.61	10.00
6	3.54	9.00
7	3.50	8.00

Fig. 2.5 Direct Tensile Specimen

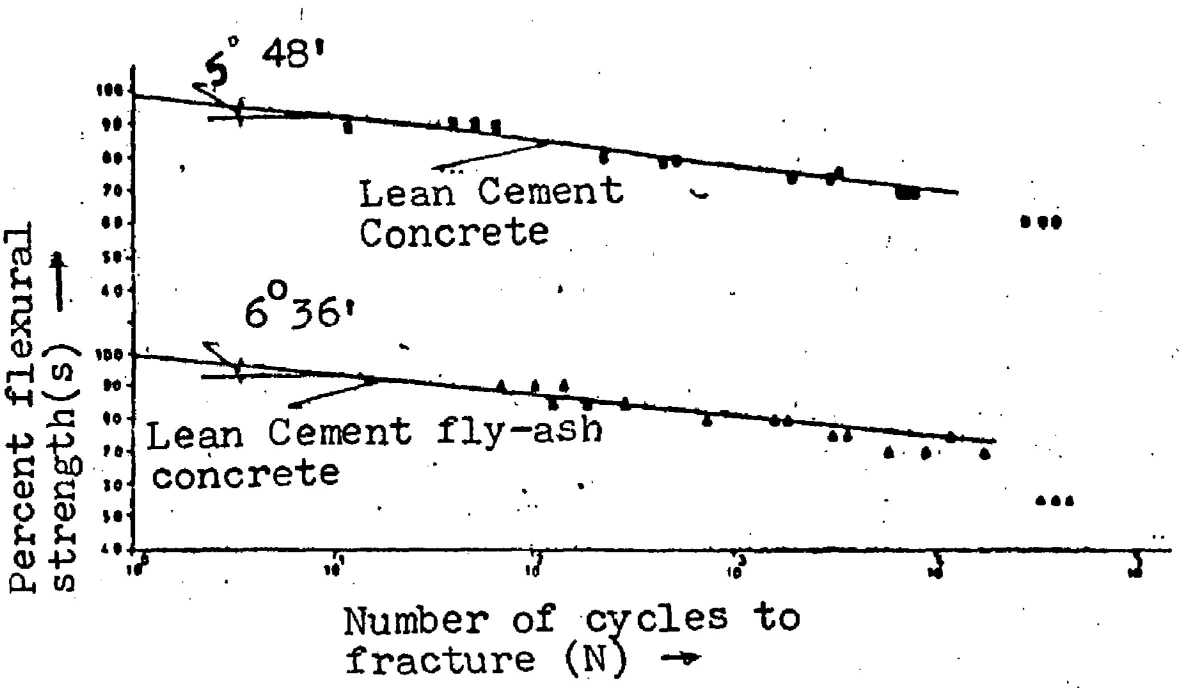


FIG. 2.6 RELATIONSHIP BETWEEN PER CENT FLEXURAL STRENGTH AND LOGARITHM OF NUMBER CYCLES TO FRACTURE

CHAPTER III

EXPERIMENTAL STUDII

3.1 SELECTION OF MATERIALS

Cement, sand and aggregate were chosen in the following manner:

(a) Cement: Ordinary Portland cement was used in the present study.

(b) Sand: Locally available sand was chosen.

(c) Aggregate: The maximum nominal size of the aggregate was kept as 20 mm. Material passed through IS 25 mm and retained on IS 150 microns was selected.

(d) Water: Portable water was taken because it did not contain any deliterious materials.

3.2 Mix Selection

As per IRC-74 (9) nominal mixes were selected as shown in Table 3.1. All the materials were taken by weight and water/cement ratio was selected per eeach mix from workability point as shown in Table 3.1. The water cement ratio was kept constant for entire study.

3.3 DETAILS OF SAMPLES

The following samples were selected to conduct various tests:

1. Compressive strengths were determined by using (15 x 15 x 15) cm samples. Four samples were prepared for each mix.

2. Flexural strengths were determined by casting (50 x 10 x 10) cm beam specimens.
3. 15 cm ϕ x 30 cm ht cylindrical specimens were selected for finding E in compression. Four samples for each mix were selected.
4. (50 x 10 x 10) cm samples were chosen for conducting fatigue tests.
5. One slab of (200 x 200 x 10) cm were casted for conducting plate load test and to study vibrational techniques. So a total 3 slabs were casted.
6. Pulse velocity and longitudinal Resonance tests were conducted on samples prepared for previously mentioned destructive tests.

3.4 PREPARATION OF SAMPLES

Preparation of samples included mixing, compaction and curing of specimens. These operations were carried as per IS-516 (10). All the materials were taken in dry condition in predetermined propertions by weight. The materials were thoroughly mixed till a uniform colour is achieved. The material was again mixed in wet condition after placing the required amount of water. Steel moulds of standard sizes were selected for casting various samples. The moulds were greased well in order to make demoulding operation easier. The material was placed in three equal layers per cylinders and cubes and in two layers for beams. Each layer was compacted with the help of standard tampering rod and thirtyfive blows per cubes, beams and cylinders were given and the blows were distributed uniformly. After compaction, the sides of the moulds were tampered to close the voids. The top surface was levelled and the moulds were left in the atmosphere at room temperature. The samples were taken after 48 hours from the moulds. The samples were marked and kept in the curing tank. The samples were tested after 14 days curing.

3.5 PREPARATION OF SUBGRADE

As the existing subgrade in the pavement testing hall was in good condition, water was sprinkled and was compacted uniformly by ramming. After compacting, the top surface was levelled and finished.

3.6 CASTING OF SLABS

As per IRC-74 (9), the slab thickness was chosen as 10 cms. On the prepared subgrade, the wooden form work was fixed rigidly as per required dimensions. The material required for casting the slab was taken in predetermined propertions by weight. As the quality of material was very high weighing was done by batching. All the slabs were casted in two equal layers of each 5 cms thickness. After weighing various constituents, they were mixed thoroughly in dry as well as wet condition by hands till a uniform colour was achieved. Then the material was transferred immediately into the form work and was spread on the levelled subgrade.

Compaction was done by ramming and the compaction was continued till a uniform thickness was achieved and top surface was levelled. On this layer, the second layer was placed immediately and the above operation was repeated. The entire procedure was repeated for all the slabs. After 48 hours, the wooden form work was removed and placed 30 cm away from the first slab to cast second slab. Curing was done by placing wet sand and water was sprink-illed regularly.

3.7 DESCRIPTION OF VARIOUS TEST SETUPS

The following arrangements were made for finding various parameters:

3.7.1 Compressive tests: This one is carried by using universal compressive testing machine as per IS-516 (10).

3.7.2 Flexural Tests

Flexural tests were conducted by using 10 ton universal machine by using third point loading, as shown in Photo 1.

3.7.3 Modulus of elasticity

(a) Compression Test

The E value in compression were determined by using 12 ton Amsler testing machine. The load was measured from the dial gauge on the machine and vertical deformations were measured by using dial gauges of sensitibility 0.001 cms as shown in Photo 2.

(b) Plate Load Test

Plate Load tests were conducted on subgrade and slabs. 75 cm ∅, 45 cm ∅ and 30 cm ∅ set of plates were used for subgrade and 30 cm ∅ plate was selected for testing of slabs. Loads were transferred through the reaction of a jack, which was placed below the proving wing. The loads, on to the plates were measured with the help of proving rings. A loaded trolley was used for supplying the required reaction. Three dial gauges were placed on the outer perphery of the plates to record the deformations. The dial gauges were 0.001" sensitive. The arrangement of plate load test was shown in Photo 3.

(c) Pulse Velocity Technique

Ulstrasonic equipment was used to apply the pulse velocity technique. This equipment was supplied by Saraswati Engineering Agency of Roorkee, which was shown in Photo 4. This equipment can provide pulses at 3 pulse/sec and 100 pulse/sec. By using this equipment the travel time of the pulse from one end to the opposite end can be measured in microseconds directly. The following connections were to be made before using the equipment (16).

1. The power cable of the tester was connected to the 230 V. A.C. supply line.
2. The power on switch was thrown to on position.
3. The probes were connected to transmitter and receiver sockets marked trans or REC terminals. Either probe can be connected to TRANS or REC terminals.

4. The sensitivity control was kept at almost minimum position.
5. The pulse rate was selected as 3.

The line diagram of these connections were shown in fig. 3.1 and Photo 4, provides clear view of these connections. This equipment is capable of working under Battery.

(d) Longitudinal Resonance Technique

This technique was adopted by using sonic apparatus developed by M/s Cawkers Ltd., London. By using this equipment, frequency of a sample at resonance can be recorded. The equipment consists of audio frequency oscillator with frequency range of 100 cycles/sec to 10000 c/s and an amplitude of 3 watt output, coupled to a moving coil vibrator for exitation of sample. The vibrations from the specimens were picked up by a Piezoelectric crystal pickup and fed to a meter graduated in microvolts. The specimens were clamped at their mid length and excited under forced vibrations. The setup was shown in Photo 5, while the line diagram showing various connections were shown in fig. 3.2 (16).

(c) Surface wave propogation technique

These tests were conducted by using electro dynamic test system, supplied by Saraswati Engineering Agency, Roorkee. The main components used in this test were a vibrator, exitation amplifier for setting the required frequency, and phase difference meter for measuring phase differences and transducers for picking vibrations on slabs, which were finally connected to phase difference meter. The vibrator with transducers were shown in photo 6, while the photo 7 contains excitation amplifier and phase difference meter. The following connections are to be made before using the equipment, which were shown in fig. 3.3 (16).

1. The test vibrator was placed on the slab and was connected to excitation amplifier which in turn connected to A.C. supply line.

2. Transducers were then connected to phase difference meter, phase meter can work with A.C. as well as battery.

The vibrator can provide vibrations in the range 10 to 10000 cycles/sec. Though the markings were made as 10 to 10000 c/sec, this can only supply between 50 to 1000 c/s. In order to avoid damages to the equipment, the equipment was operated at higher frequencies first and then gradually decreased to lower frequencies. The equipment was stopped after operating for half an hour continuously.

3.7.4 Poisson's Ratio

Both pulse velocity techniques and longitudinal resonance equipments were used for finding γ, which were described in the articles c and d of 3.7.3. respectively.

3.7.5 Fatigue

The fatigue tests were conducted by the equipment developed by CRRI under third point loading. The view of this equipment was shown in photo 8. The load was applied through a piston oscillating in a vertical plane and connected to a ecentric through a connecting rod. The ecentric can be adjusted to provide desired magnitude of load. Load on the beams was applied through a loading plate. The actual load coming on to the plate was determined by pasting a 2.5 cm strain gauge under the bottom of the plate. The strains were measured for corresponding load by using a strain measuring bridge. The load was then measured from the calibration chart, which was established before conducting the test.

As there was no sufficient clearance between the plunger and the base plate of fatigue testing machine to accommodate 10 cm high beams, a hole of 10 cm diameter was made in the base of machine and a new elongated plunger was used. Beams to be tested were raised to a required height by providing a temporary support. Arrangements were made to stop the machine automatically when the beams failed. To support the beam, while testing for fatigue two steel rollers were welded to a heavy mild steel plate exactly at a distance of 40 cms only for applying the load exactly at middle third, two V shaped grooves were made on the underside of the plate exactly at 13.33 cms. In these V grooves two mild steel rollers were placed. These arrangements were shown in photo 9. Thus the load from the plunger was transferred to the beam. It was not possible to adjust the required amount of load exactly by ecentricity only. This was done by adjusting the length of plunger to the required amount, and the exact load was noted from calibration chart after knowing the strain measuring bridge readings.

This machine can apply the load repetitions at 70 cycles/minute. A rest period of 10 minutes was given for cooling after working continuously for six hours. The rest period did not have any impact as per the observation carried by Mehmel, Yoshida and Kesler (15, 27). The tests performed on cement concrete indicate that the rest period larger than 5 minutes has no effect in the improvement of fatigue strength.

3.8 PLATE LOAD TEST ON SUBGRADE

Before laying the slab, plate load test was conducted on subgrade to find the modulus of subgrade reaction and modulus of elasticity of subgrade. After making arrangements as mentioned in article 3.7.3 the following observations were taken. A seating load of 0.07 kg/cm^2 (320 kg) was applied and released after a few seconds and adjust the dial gauge readings to show zero. A sufficient load was applied to cause approximately 0.025 cm settlement and when there was no perceptile settlement or the rate of settlement was less than 0.0025 cm/min, the readings of deformation dial gauges were noted and the corresponding readings of proving ring dial gauge was noted. Then the load was increased till the settlement was increased by further 0.025 cm and the readings were noted as discussed above. This procedure was repeated till the net settlement was 0.175 cm. This test was conducted at three central positions where the slabs were to be casted.

3.9 TESTS ON PAVEMENT MATERIAL (LEAN CEMENT CONCRETE)

3.9.1 Compressive strengths

Compressive strengths of each mix were determined by applying the load at 140 $kg/cm^2/min.$ on cubes. The loading was continued upto a point beyond which the specimen could not take any more load. This test was performed as per IS-516 (10). Three specimens per each mix were tested.

3.9.2 Flexural strength

Flexural strengths of each mix was again tested by using the method specified by IS-516. The load was applied by using third point loading method. In these tests the specified load on the specimens was increased gradually at the rate of 180 kg/min. upto failure point.. The maximum failure load P, and the distance between line of fracture to the nearer support a_1 , were noted.

3.9.3 Modulus of elasticity

(a) Compression Test

E value was determined as per code No. IS-516 on cylindrical specimens. As the load carrying capacity of specimens were low, the rate of loading was decreased to 100 $kg/cm^2/min.$ Deformations were noted at regular intervals of load increaments and the procedure was continued upto (C+5) kg/cm^2 where C is the 1/3 of average compressive strengths. The specimens were tested in wet condition.

(b) Plate Load test

The plate load test was conducted at the centre of the slab by using 30 cm diameter plate. After making arrangements as mentioned in article 3.7.3, a static load of 0.2 kg/cm^2 was applied for few seconds and released immediately. Then the load was increased gradually and the loads at every 0.05 cm deformation were noted upto a minimum deformation of 0.25 cm. The slabs were tested upto the ultimate load carrying capacity.

(c) Pulse velocity technique

This test was conducted on all types of samples i.e. cylinders, cubes and beams which were prepared for other tests. The main principle involved in this method was that the velocity of the pulse travelling in a media was dependent on density and elastic properties of the material. After giving necessary connections as discussed in 3.7.3. and switched on the instrument. Grease was applied on the probes and the initial reading was adjusted to zero by using sensitivity control by making the probes touching to each other. The specimens were taken out from the curing tank and grease was applied on the opposite faces of the specimen. Then two probes were pressed uniformly against and at the centre of faces axially and the corresponding transit time in microseconds was noted. The distance between the faces was noted. The weight of the sample was also measured.

(d) Longitudinal resonance test

This test was performed only on beams specimens that were prepared for destructive tests. After giving the necessary connections as discussed in the articles 3.7.3, the equipment was allowed to warm up for one hour. The beam was clamped at the centre and the vibrator and pickups were made to contact at the centre of each ends properly. The output of the amplifier was kept as low as possible, compatible with a resonance meter reading, in order to avoid the distortion of the signal fed to the vibrator. The frequency of the oscillator was then changed and its value giving maximum output, on the output meter was recorded as the resonance frequency of the clamped specimen in KHzs. Any increase or decrease of the oscillator reading from resonance frequency resulted in decrease on the output meter reading. This one helped in noting the resonance frequency accurately.

(e) Surface wave propogation technique

In this method, the vibrator was placed at the centre of the test slab and directions were marked along which the observations were taken. The various components of the equipments were connected as discussed in 3.7.3. The required frequency was selected by using frequency selector and fine frequency control. Then the equipment was started the transducers were kept slightly away from the vibrator and as close as possible and without touching each other. The corresponding phase difference meter reading was noted and was designated as initial reading. Then one of the transducers gradually moved such that phase difference meter reading was (initial $\pm$ 90^{o}). The distance between the transducers were noted as D. Similarly D was noted in the other directions. The entire procedure was repeated at various frequencies and the corresponding D's were determined.

3.9.4 Poisson's Ratio

Poisson's Ratio was mainly determined by using both pulse velocity and longitudinal resonance tests. The transit time from ultrasonic apparatus and the frequency at resonance were determined for a single beam as discussed in determination of E. The computations of γ were discussed in the succeeding chapter.

3.9.5 Fatigue

Fatigue tests were conducted by using equipments developed by CRRI. After removing from the curing tank, the specimens were placed under the fatigue machine exactly at centre. The load to be applied was selected as 60 to 90% of failure load and the exact load was adjusted as discussed in 3.7.5. The load repetitions on the specimen were continued till the specimen failed or the number of repetitions were more than 50,000. The procedure was repeated for 3 beams at each stress level for each mix. The failure of the specimen after certain number of repetitions were shown in photo 10. The distance of line of fracture from the nearer support was also recorded.

touching each other. The corresponding phase difference meter reading was noted and was designated as initial reading. Then one of the transducers gradually moved such that phase difference meter reading was (initial ± 90°). The distance between the transducers were noted as D. Similarly D was noted in the other directions. The entire procedure was repeated at various frequencies and the corresponding D's were determined.

3.9.4 Poisson's Ratio

Poisson's Ratio was mainly determined by using both pulse velocity and longitudinal resonance tests. The transit time from ultrasonic apparatus and the frequency at resonance were determined for a single beam as discussed in determination of E. The computations of γ were discussed in the succeeding chapter.

3.9.5 Fatigue

Fatigue tests were conducted by using equipments developed by CRRI. After removing from the curing tank, the specimens were placed under the fatigue machine exactly at centre. The load to be applied was selected as 60 to 90% of failure load and the exact load was adjusted as discussed in 3.7.5. The load repetitions on the specimen were continued till the specimen failed or the number of repetitions were more than 50,000. The procedure was repeated for 3 beams at each stress level for each mix. The failure of the specimen after certain number of repetitions were shown in photo 10. The distance of line of fracture from the nearer support was also recorded.

TABLE 3.1

DETAILS OF VARIOUS MIXES

Sl. No.	Proportions of materials by weight			Water/Cement
	Cement	Sand	Aggregate	
1	1	4	8	1.2
2	1	5	10	1.73
3	1	6	12	1.82

TABLE 3.2

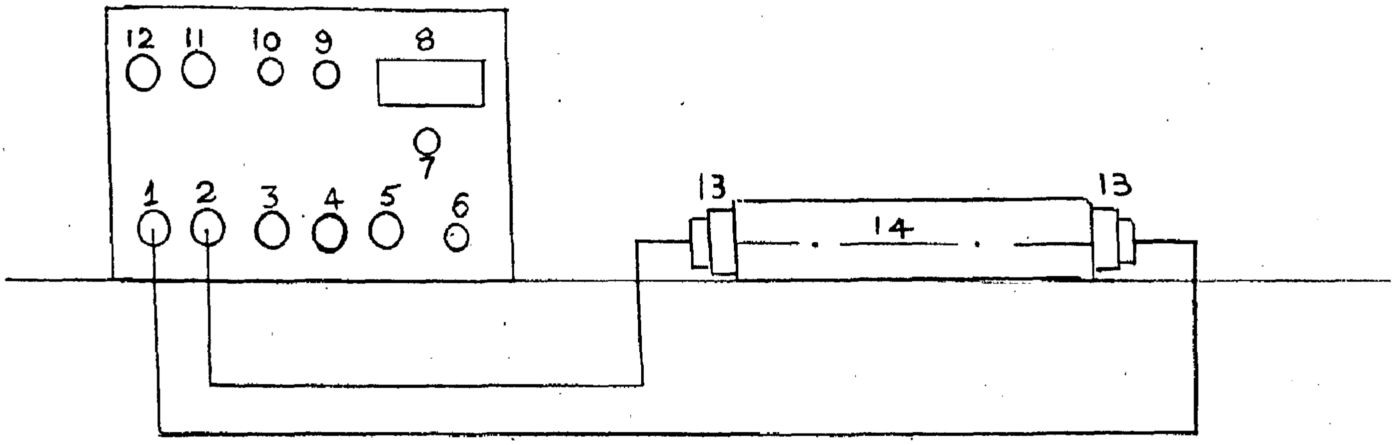
SUMMARY OF DETAILS OF VARIOUS SAMPLES TESTED FOR EACH PARAMETER

Type of test	No. of samples per each mix			
	Cubes	Cylinders	Beams	Slabs
Compression test	3	–	–	–
Flexural test	–	–	3	–
Modulus of elasticity	3*	3	3*	1*
Poisson's Ratio	–	–	3*	–
Fatigue	–	–	15	–
Extra samples prepared	1	1	3	–
Total	7	4	27	1
Grand total for all mixes	21	12	81	3

* Samples prepared for destructive tests were used in non-destructive tests.

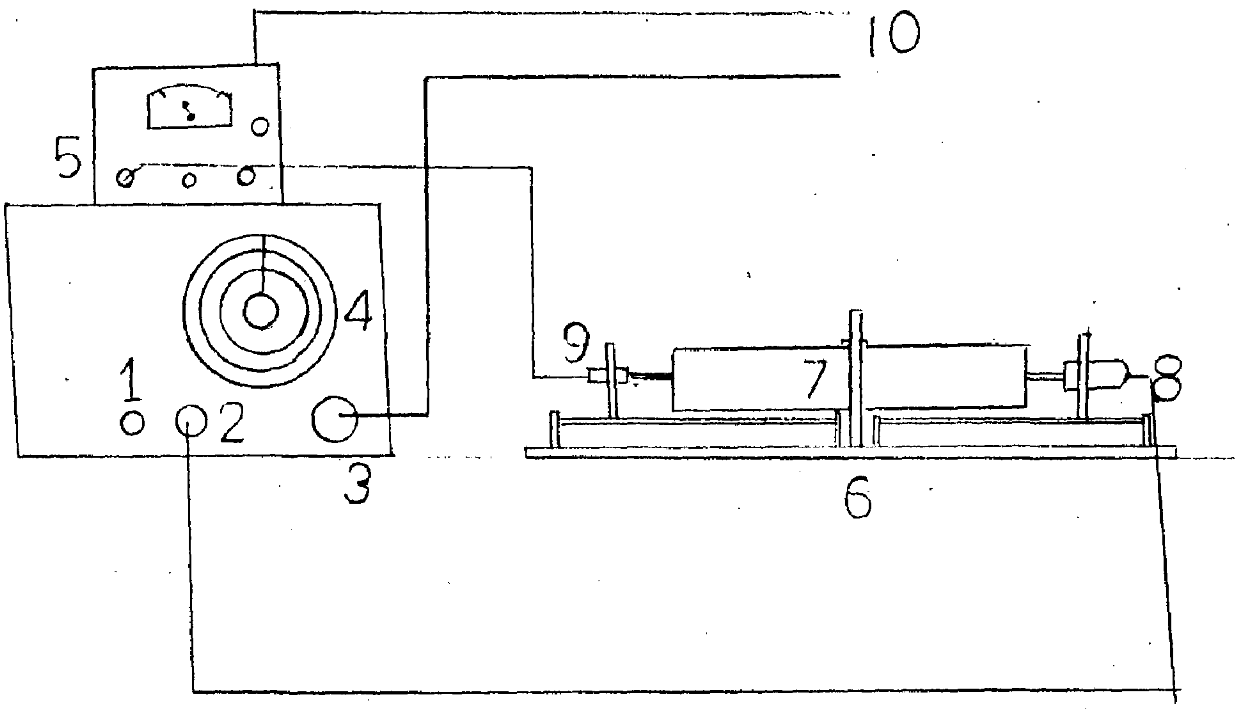
Total No. of Samples prepared

Cubes:	12
Cylinders	12
Beams	54
Slabs	3



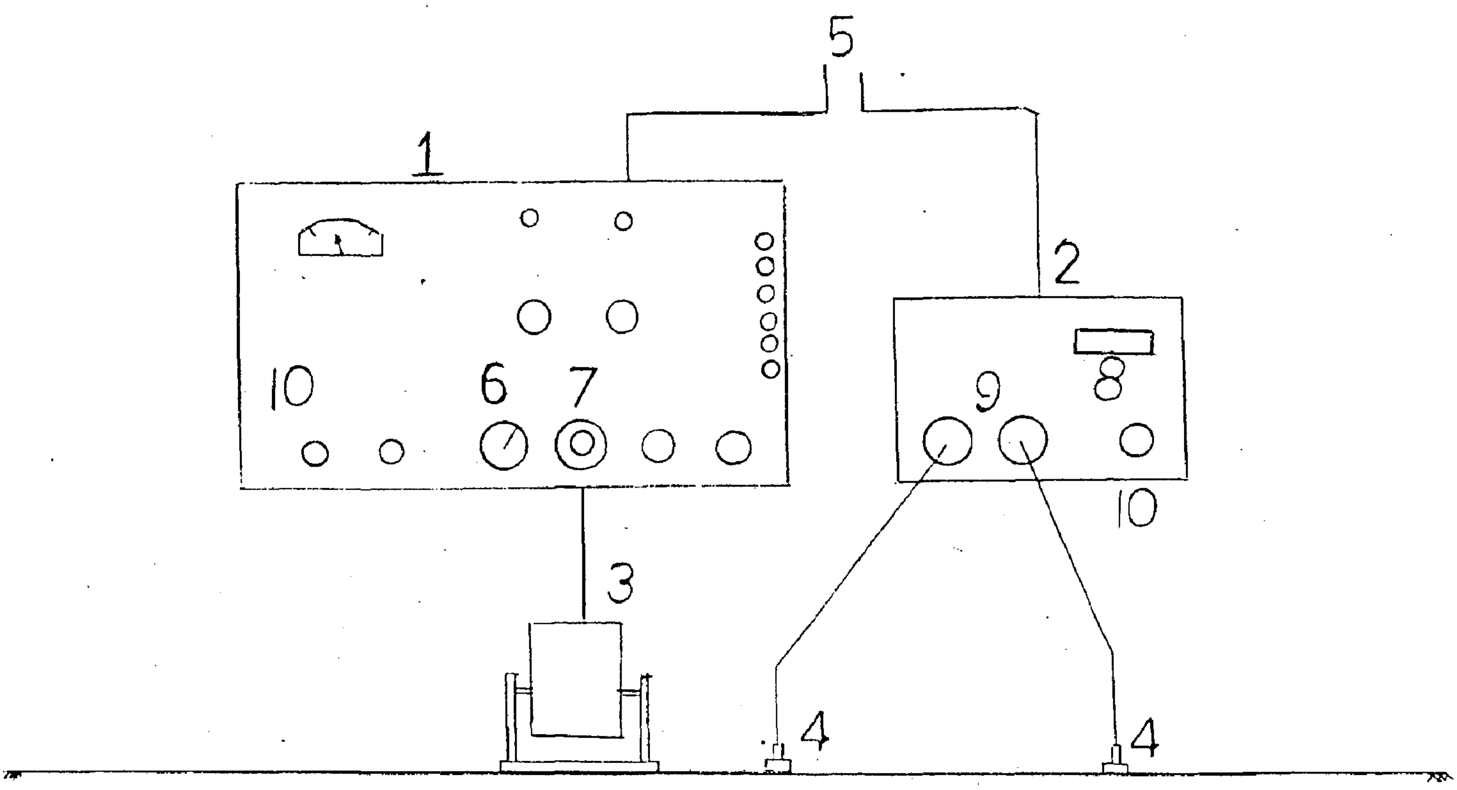
1. Socket for Transmitter (Trans)
2. Socket for Receiver (Rec)
3. SYNC
4. Signal
5. Hold
6. Poweron
7. Zero Adjuster
8. Time Displayer
9. Pulse Rate Selector
10. Low, High Selector
11. Adjuster
12. Sensitivity
13. Probes
14. Specimen

Fig. 3.1 SCHEMATIC VIEW OF ULTRASONIC EQUIPMENT



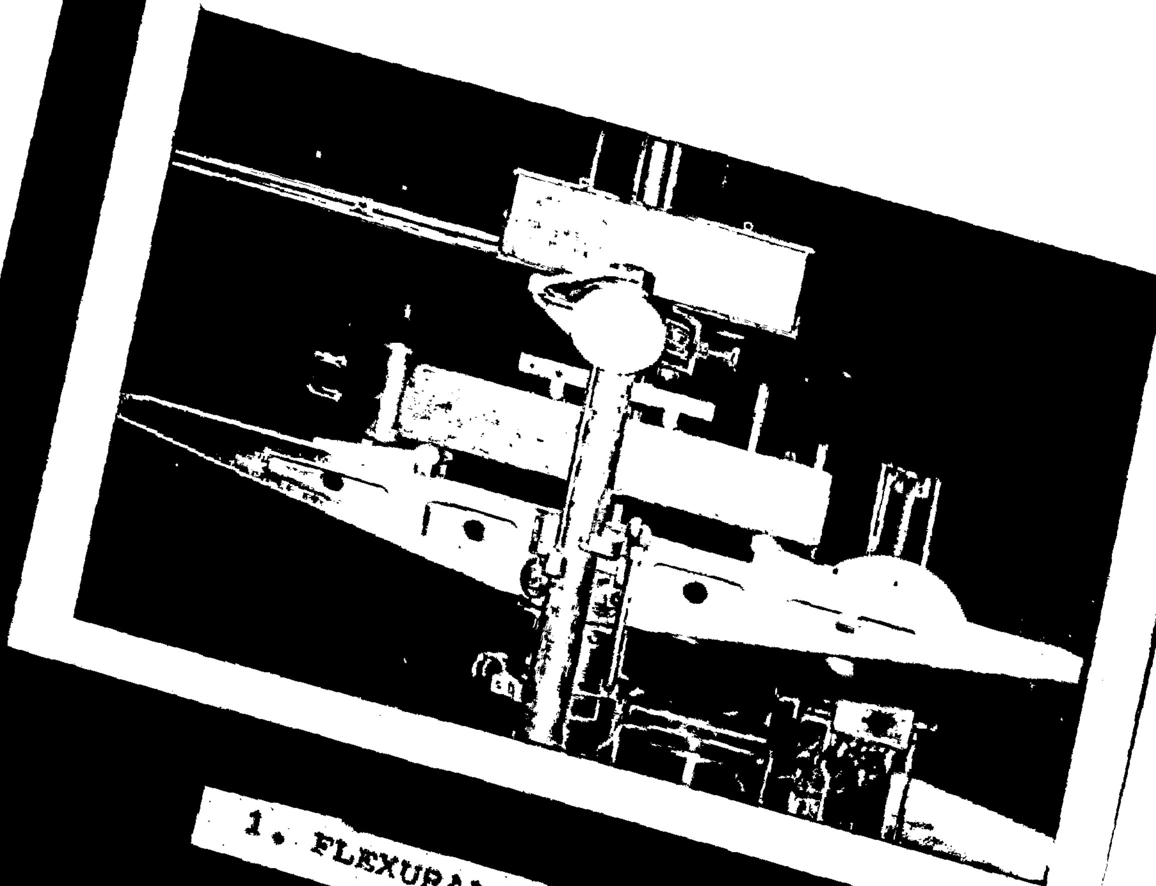
1. Output Gain Control
2. Point for Connecting Vibrator
3. Socket for Connecting Powerline
4. Oscillator
5. Amplifier
6. Mechanical Jig
7. Beam Specimen
8. Electro Mechanical Vibrator
9. Pickup
10. Power Supplier

Fig. 3.2 SCHEMATIC VIEW OF LONGITUDINAL RESONANCE EQUIPMENT

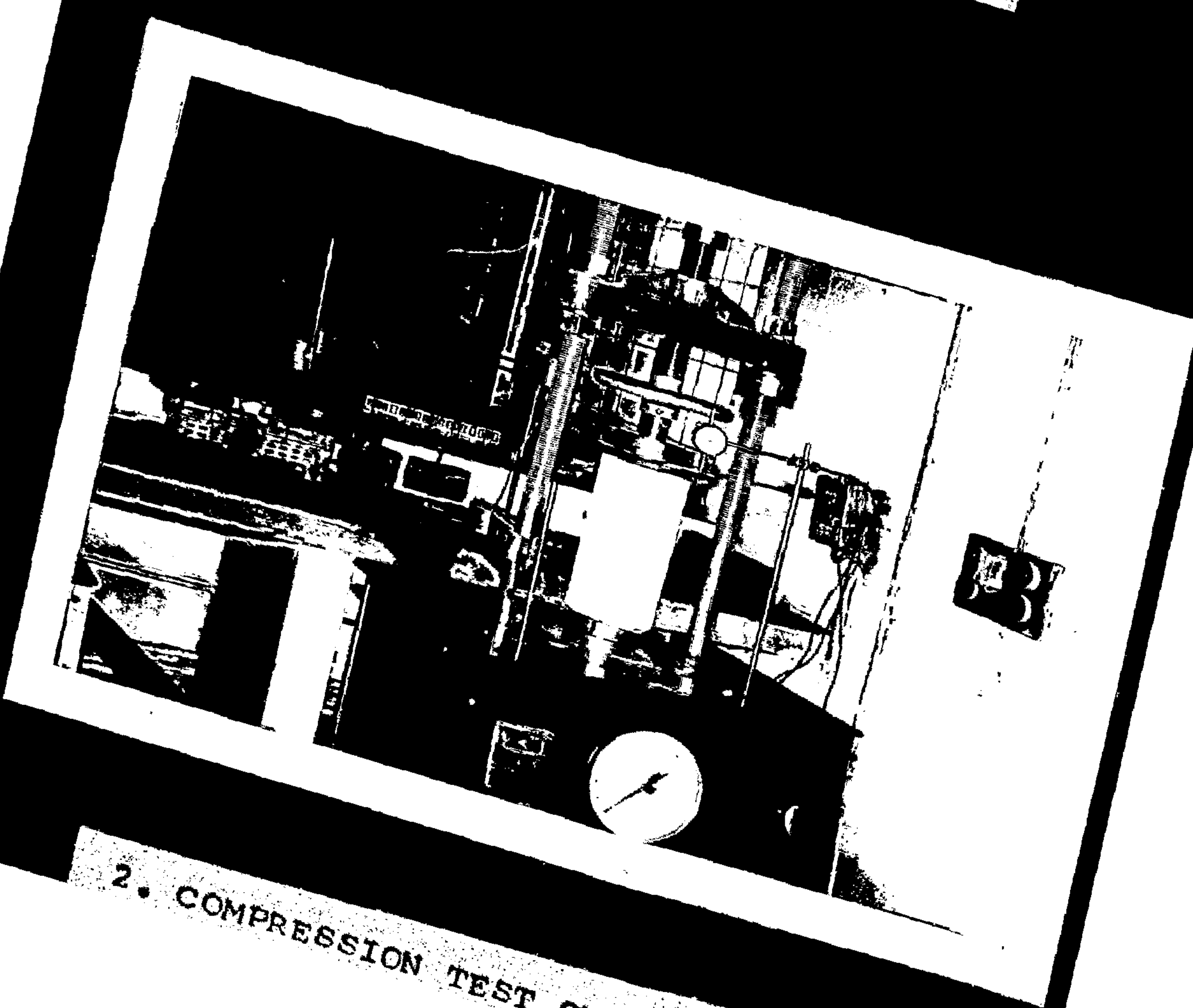


1. Excitation Amplifier
2. Phase Difference Meter
3. Vibrator
4. Transducers
5. Power Supplier
6. Frequency Selector
7. Frequency (fine) Controller
8. Phase Angle Displayer
9. Sockets for connecting Transducers
10. Power on Switches

Fig. 3.3 SCHEMATIC VIEW OF VIBRATING TEST SYSTEM



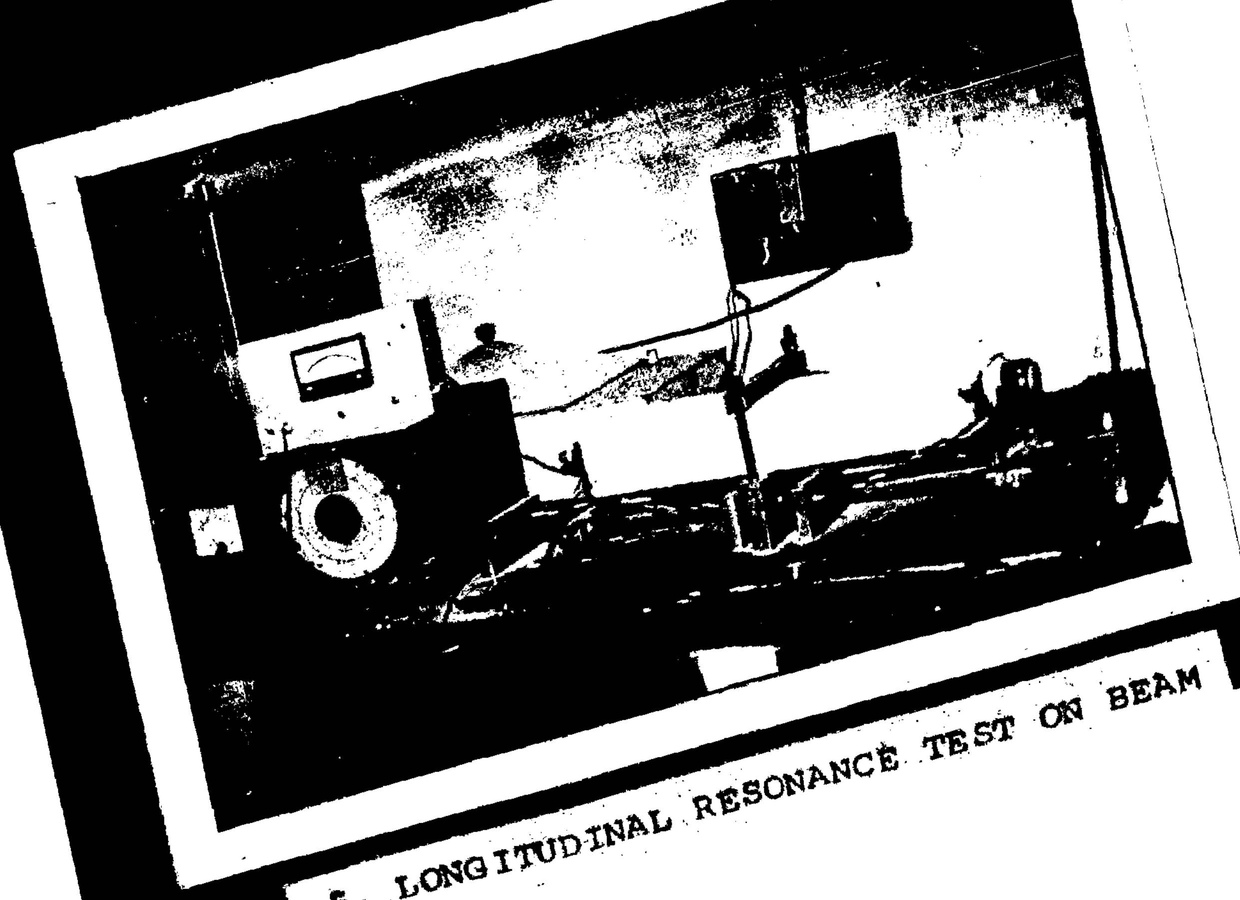
1. FLEXURAL TEST ON BEAM



2. COMPRESSION TEST ON CYLINDER

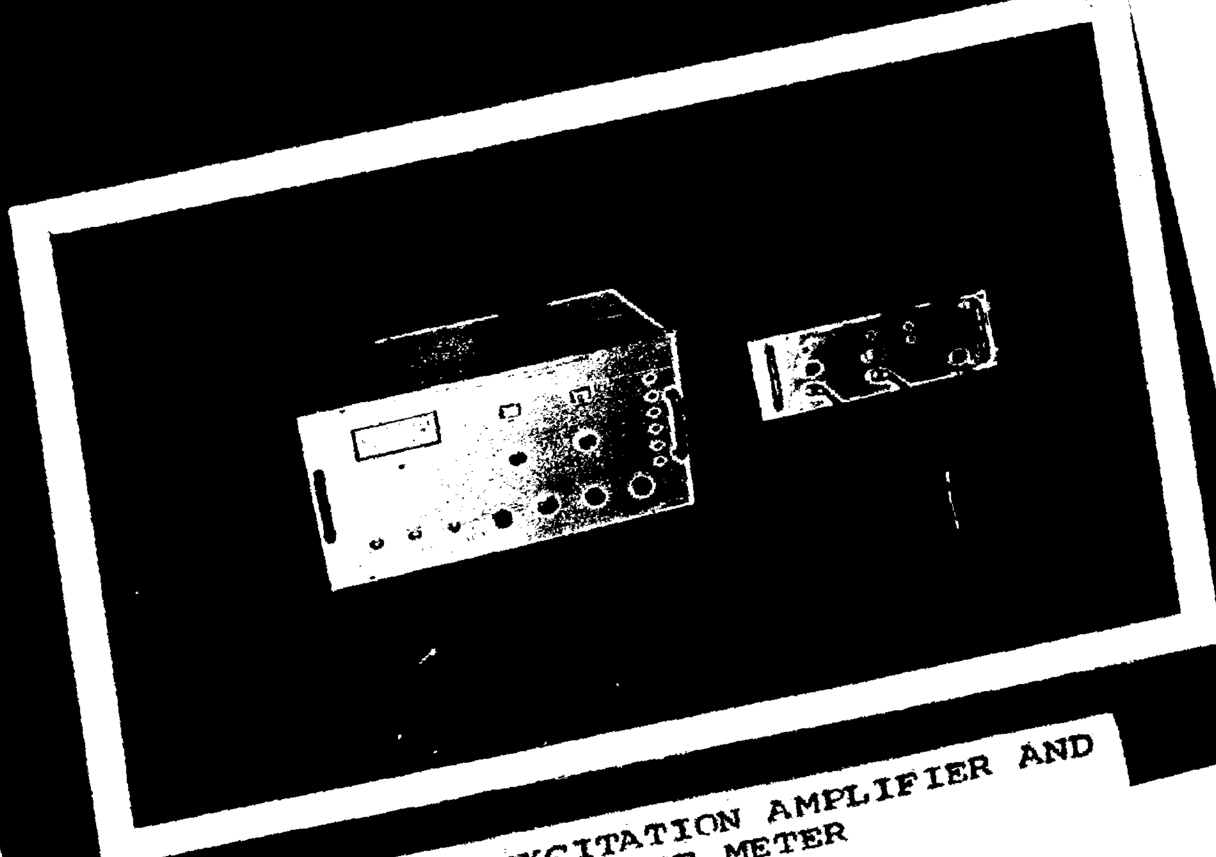
3. PLATE LOAD TEST ON SLAB

4. ULTRASONIC TEST FOR BEAM

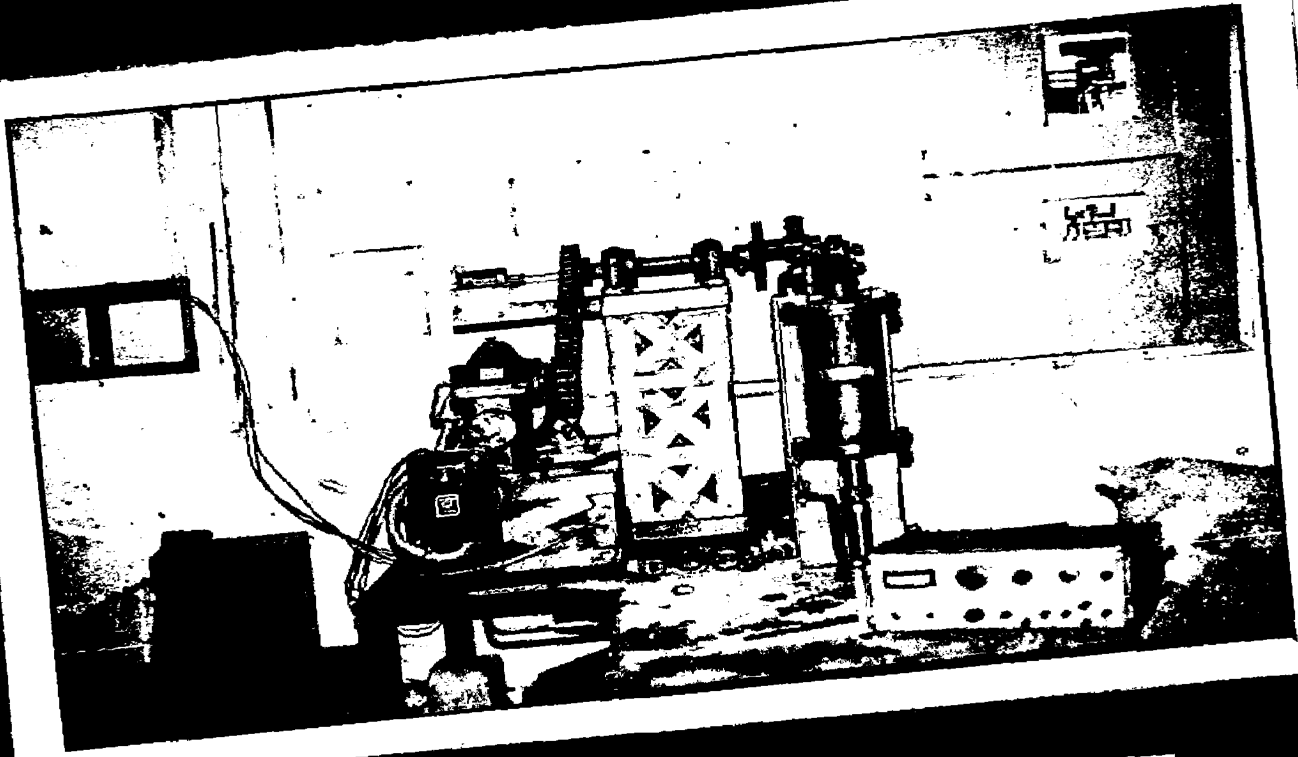


5. LONGITUDINAL RESONANCE TEST ON BEAM

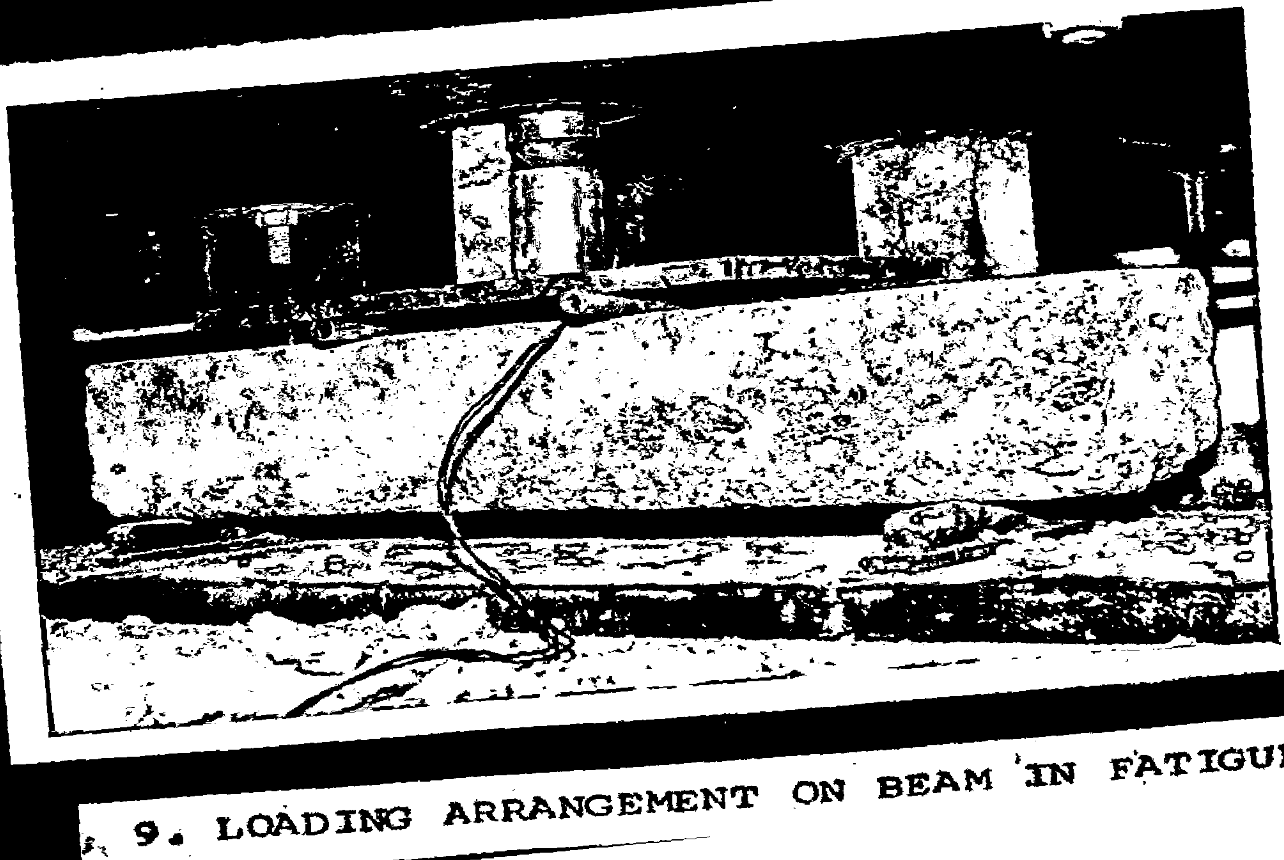
6. VIBRATOR TESTING OF SLAB



7. VIEW OF EXCITATION AMPLIFIER AND PHASE DIFFERENCE METER



8. FATIGUE TESTING MACHINE FOR BEAM



9. LOADING ARRANGEMENT ON BEAM IN FATIGUE

10. BEAM AFTER FRACTURE IN FATIGUE

CHAPTER IV

ANALYSIS AND DISCUSSION OF RESULTS

The results obtained through experimental study have been analysed for the following values, and are presented as under:

4.1 COMPRESSIVE STRENGTH

When the compression tests were conducted on cubes, the following strengths were observed at the age of 14 days.

Mix	Compressive strength
1:4:8	36 kg/cm^2
1:5:10	30 kg/cm^2
1:6:12	27 kg/cm^2

These strengths were about 75% of the strengths achieved by CRRI (7) for same proportions.

4.2 FLEXURAL STRENGTHS

Flexural strengths of various mixes were computed in the following manner.

$$f_b = \frac{P l}{bd^2} \quad \text{If } a_1 > 13.3 \text{ cms} \qquad (4.1.1)$$

$$= \frac{3 P a_1}{bd^2} \quad \text{If } 11 > a_1 > 13.3 \text{ cms} \qquad (4.1.2)$$

where a_1 = distance between line of fracture and nearer support in cm

b = width of beam in cm

L = length of span on which the specimen was supported

d = average depth of beam in cm

P = Maximum load at failure in kg

When a_f was less than 11 cms the results were discarded. The flexural strengths of mixes 1:4:8, 1:5:10 and 1:6:12 are respectively 6.2 kg/cm^2, 5.7 kg/cm^2 and 5 kg/cm^2, at the age of 14 days. The strength observed by CRRI (7) was 14.1 kg/cm^2 at the age of 28 days for mix 1:4:8.

4.3 MODULUS OF SUBGRADE REACTION

The modulus of subgrade reaction is given by the equation

$$K = \frac{P}{0.125} \text{ kg/cm}^2\text{/cm} \qquad (4.2)$$

K = Modulus of subgrade reaction in kg/cm^3

P = The pressure to cause a settlement of 0.125 cm in kg/cm^2.

For evaluation of K, stress deformation curves to be plotted as shown in fig. 4.1 and the stress corresponding to 0.125 cm was taken. As the points of subgrade under slab 1:5:10 were lying between 1:6:12 and 1:4:8, the curves were plotted for the two positions only and the average value of K was observed as 5.48 kg/cm^3 which was within the values specified by IRC 58 (8). The observations are presented in the Table 4.1.

4.4 MODULUS OF ELASTICITY

4.4.1 Subgrade

The E value of subgrade was determined by the following equations :

$$E_s = 1.18\ Ka \qquad (4.3)$$

a = radius of plate used

= 37.5 cms in the present case

$$E_s = 1.18 \times 2.45 \times 37.5$$

$$= 245\ kg/cm^2$$

4.4.2 Pavement material (lean concrete)

(a) Compression

The E value in compression was determined by plotting stress-strain relations which were shown in fig. 4.2. The recorded observations are shown in 4.2. The tests were performed at the age of 14 days. The E value in compression was computed for 25% compressive strength and the following values were obtained.

Mix	E_c in compression at 14 days kg/cm^2
1:4:8	1.544×10^4
1:5:10	1.339×10^4
1:6:12	1.216×10^4

CRRI (7) observed a value of 1.07×10^5 kg/cm^2 and 1.05×10^5 kg/cm^2 at the age of 28 days for 1:4:8, when measured at 25% and 50% compressive strengths respectively. From the fig. 4.2 it was observed that the behaviour of mixes was similar in compression. The strains for 1:6:12 were rather high at higher loads and this variation was less at initial stages of loading. The stress-strain relations were curve linear for these mixes.

(b) Plate load test

Plate load tests were conducted at the age of 35 days on the slabs after curing 14 days. The E value was computed by using Burmister's equation 1.3.2 for rigid plate. Generally the pavement thickness was computed by using the Burmister's equations for a value of 0.25 cm or 0.5 cm design deflections for known values of E_s and E_p. But the present case was reverse in which the pavement thickness was known and the value of E_p of pavement material was to be computed. So again a design deflection of 0.25 cm was selected for computing E_p. A graph was plotted between stress and deformations as shown in fig. 4.3. These curves also indicate that the behaviour was same for all the mixes and the deformations suffered by 1:6:12 mix were higher than the two mixes indicating the mix was more flexible in nature. The E value was computed in the following manner.

$$\Delta_1 = \frac{1.18\ Pa}{E_s} F_2 \qquad (4.4.1)$$

$$F_2 = \frac{E_s\ \Delta_1}{1.18\ Pa} \qquad (4.4.2)$$

A,B,C suffixes in the following computations indicate slabs 1:4:8, 1:5:10 and 1:6:12 respectively. The following thicknesses of slabs were observed for each mix.

h_A = 10.5 cm $\qquad$ h_B = 11 cm $\qquad$ h_C = 10.5 cm

$\frac{h_A}{a}$ = 0.7 $\qquad$ $\frac{h_B}{a}$ = 0.73 $\qquad$ $\frac{h_C}{a}$ = 0.7 a

For Δ_1 = 0.25 cm P_A = 13.1 kg/cm^2 P_B = 12.2 kg/cm^2

P_C = 10.9 kg/cm^2 from fig 4.3

$$F_{2A} = \frac{0.25 \times 245}{1.18 \times 13.1 \times 15} = 0.275$$

$$F_{2B} = \frac{0.25 \times 245}{1.18 \times 12.2 \times 15} = 0.284$$

$$F_{2C} = \frac{0.25 \times 245}{1.18 \times 10.9 \times 15} = 0.317$$

∴ For h/a, and F_2, E_s/E_p from graph fig. 1.2 were calculated.

$$\frac{E_s}{E_{PA}} = \frac{1}{150} \qquad E_s = 150 \times 245$$

$$= 368 \times 10^4 \text{ kg/cm}^2$$

$$\frac{E_s}{E_{PB}} = \frac{1}{120} \qquad E_{PB} = 120 \times 245 = 2.94 \times 10^4 \text{ kg/cm}^2$$

$$\frac{E_s}{E_{PC}} = \frac{1}{80} \qquad E_{PC} = 80 \times 245 = 1.96 \times 10^4 \text{ kg/cm}^2$$

Mix	E_{PL} kg/cm^2 PL = plate load test
1:4:8	3.68×10^4
1:5:10	2.94×10^4
1:6:12	1.96×10^4

E value in compression was about 50 to 60% of above values.

The load deformations observations of various slabs were given in Table 4.3. However the E values were less than the values from non destructive tests.

(c) Pulse velocity technique

The test was conducted on all types of samples to study the effect of size of samples. In these observations the unit weight of the material is varying between 2280 kg/m^3 to 2320 kg/m^3. So a value of 2300 kg/m^3 was taken for all observations. After knowing the pulse travel time or transit time, T, the velocity was computed from the relation.

$$V = \frac{L}{T} \tag{4.5}$$

L = distance travelled by pulse in cm

T = Transit time in seconds

Then E_d was computed by eq. 2.2.

$$E_{d1} = \frac{(1+\gamma)\ (1-2\gamma)}{(1-\gamma)}\ V^2\ \frac{d}{g} \tag{4.6}$$

γ value was taken as 0.2 for all mixes as per reference (19).

Substitute $\gamma = 0.2$, $d = 2{,}300 \times 10^{-6}\ kg/cm^3$

$g = 980\ cm/sec^2$

$$E_{d1} = 2.11224 \times 10^{-6}\ V^2$$

The computations of E_{d1} are given in Table 4.4. A graph was plotted as shown in fig. 4.4 between E_d and distance between the faces on which transprotes were placed to know the variation E_d w.r. to size of sample. It was observed the variation was less for cubes and cylinders when compared to beams. Some trends were observed in all the mixes. These E_d values were very high compared to E values from compression and plate bearing tests. Simon's (24) observed that E value from non-destructive tests was higher than destructive tests. He observed that E in static condition was 70 to 80% of E dynamic.

(d) Longitudinal Resonance tests

After knowing the natural frequency of the beams at resonance the analysis was carried out in the following manner:

$$E_{d2} = 6\, f^2\, L^2\, \frac{d}{g} \qquad (4.7)$$

which was a slightly modified version of eq. 2.3.

f = frequency at resonance in cycles/sec

L = length of sample in cm

d = unit weight of sample in kg/cm^3

g = acceleration due to gravity cm/sec^2

The computations of E_{d2} were shown in Table 4.5. The average E value of samples were 1.7245×10^5, 1.6×10^5 and 1.365×10^5 kg/cm^2 for 1:4:8, 1:5:10 and 1:6:12. These values are almost matching with the values determined by pulse velocity technique, and however higher than the E in compression.

(e) Surface wave propogation technique

In this test, the E value was to be determined by correlating velocity of waves. The velocity V was computed by eq. 2.4.

$$V = f\Delta \text{ cm/sec} \qquad (4.8)$$

f = frequency in c/s

Δ = wave length in cm/sec

The wave length Δ at every frequency was computed by interpolating the distance D to 360^{o} phase difference which was measured for 90^{o} phase difference. Then the velocity of waves at each frequency were determined and dispersion curves between velocity and wave length were drawn as shown in fig. 4.5. A discontinuity was observed in the curves indicating change in layer media. Segments 1,2,3 were corresponding to slabs 1:4:8, 1:5:10 and 1:6:12 and 4,5,6 were that of corresponding subgrades. The peak velocities on each curve was taken as the velocity for computation of E of that layer.

$$E_{d3} = \frac{2(1+\gamma)\ V^2 d}{P^2 g} \tag{4.9}$$

P = 1 and assumed waves as shear waves.

The above equation was slightly modified vertion of eq. 2.5. The poisson's ratio values were taken as per Table 4.5.

Mix	Poisson's ratio	Velocity m/sec	E_{d3}
1:4:8	0.15	84 0	3.81×10^4 kg/cm^2
1:5:10	0.15	76 0	3.12×10^4 kg/cm^2
1:6:12	0.23	69 0	2.75×10^4 kg/cm^2

In order to compute the values by using Raylegh wave velocity. The curves were to be interpolated for wavelength equal to zero, which could be possible only when the equipment can provide still higher frequencies i.e. greater than 1000 cycles/sec. The values obtained in this method were much lower than the values from other two non-destructive methods but higher than destructive values. The various observations on slabs has been shown in Table 4.6.

The summary of E values for each mix are presented in Table 4.7. A graph was also plotted by taking E value in compression on x-axis with E value from other tests on y-axis which was shown in fig. 4.6. The graph indicates certain calibration was needed to convert E dynamic values to static values. In the case of ultrasonic tests it was observed as 0.095 and the longitudinal resonance frequency tests requires a multiplication factor of 1/11 to 1/13 in the current study, The E values for plate load test and wave propogation techniques were almost matching to each other.

4.5 POISSON'S RATIO

The poisson's ratio was computed by finding pulse travel time or transit time and frequency at resonance with the help of ultrasonic and sonic apparatus on beam specimens, then γ value was evaluated by solving equations 4.5 and 4.6.

$$E_{d1} = \frac{(1+\gamma)\ (1-2\gamma)}{(1-\gamma)} V^2 \frac{d}{g} \qquad (4.5)$$

$$E_{d2} = 6 \times f^2 \times L^2 \times \frac{d}{g} \qquad (4.6)$$

$$\frac{(1+\gamma)\ (1-2\gamma)}{(1-\gamma)} = \frac{6 \times f^2 \times L^2}{V^2}$$

$$\text{Let } K = \frac{6 \times f^2 \times L^2}{V^2}$$

$$(1+\gamma)\ (1-2\gamma) = K\ (1-\gamma)$$

$$1 - \gamma - 2\gamma^2 = K - K\gamma$$

$$2\gamma^2 + \gamma\ (1 - K) - C\ (1 - K) = 0$$

$$\text{Let } z = (1 - K)$$

$$2\gamma^2 + \gamma z - z = 0$$

$$\gamma = \frac{-z + (z^2 + 8z)^{0.5}}{4}$$

The computations were presented in Table 4.5. The average poisson's ratio of 1:4:8 and 1:5:10 were 0.15 while that of 1:6:12 was 0.23. These tests were performed at the age of 14 days. CRRI (7) observed poisson's ratio of 1:4:8 as 0.25 and 0.27 at 25% and 50% compressive strengths. The values assumed for computation of E_d by using pulse velocity technique also hold gord. A graph was plotted between average E_{d2} and poisson's ratio, as shown in fig. 4.7 and observed as E_{d2} increased, there was a decrement in the value of γ. Similar type of trend was observed by Simons (24) for cement concrete.

4.6 FATIGUE

Fatigue tests were conducted on beam specimens. The stress for a particular application of load was computed by using equations 4.1.1 and 4.1.2. The stress level was computed by dividing the applied load with the corresponding flexural strength of mix. The stress levels were selected in between 60 to 95% of flexural strengths. After noting the number of repetitions at failure, the results were plotted in S-n form where S is the stress level on y-axis and n is number of repetitions at failure as shown in fig. 4.8. It was observed as the behaviour of mixes for fatigue was similar. At 75% stress level the number of repetitions at failure was between 1000 to 2000 for mixes 1:6:12 to 1:4:8. The number of repetitions at 75% stress level was 2×10^3, when the tests were performed by CRRI (7) on 1:4:8 mix. The observations on each mix were presented in the Table 4.8.

TABLE 4.1

PLATE LOAD TEST ON SUBGRADE

Position under slab	Proving Ring Readings	Load kg	Stress kg/cm²	Dial gauge readings 1	2	3	Average	Deformation in cm
1	2	3	4	5	6	7	8	9
1:4:8	0	0	0	0	0	0	0	0
	14	448	0.101	18	1	4	7.7	0.0195
	38	1216	0.275	20	21	15	18.7	0.0474
	58	1856	0.42	30	32	25	29.0	0.737
	73	2336	0.53	40	41	31	37.3	0.0949
	94	3008	0.68	50	51	39	46.3	0.01185
	118	3776	0.86	60	62	49	57.0	0.0145
	138	4416	0.99	70	65	57	67.3	0.1710
	155	4960	1.12	80	69	65	71.3	0.1812
1:5:10	0	0	0	0	0	0	0	0
	19	608	0.14	10	8	9	9.0	0.0228
	31	992	0.23	20	14	17	17.0	0.0432
	43	1376	0.31	30	21	24	25.0	0.0635
	66	1792	0.41	40	29	31	33.3	0.0847
	71	2272	0.51	50	36	39	41.7	0.106
	91	2912	0.66	60	43	47	50.0	0.127
	112	3584	0.81	70	50	57	59.0	0.149
	131	4192	0.95	80	56	65	67.0	0.170

Table contd..

Table 4.1 (Contd.)

1	2	3	4	5	6	7	8	9
1:6:12	0	0	0	0	0	0	0	0
	21	672	0.152	10	7	16	11.0	0.279
	35	1120	0.254	18	15	20	17.7	0.045
	46	1472	0.333	31	20	30	27.0	0.068
	68	2176	0.493	47	30	40	34.0	0.086
	89	2848	0.645	62	39	50	50.3	0.128
	109	3488	0.789	76	48	60	61.3	0.156
	135	4320	0.977	89	56	70	71.7	0.182
	163	5216	1.18	103	68	80	83.7	0.213

TABLE 4.2

STRESS-STRAIN OBSERVATIONS ON CYLINDRICAL SPECIMENS OF 15 cm ∅ x 30 cm ht

Mix	Load t	Stress kg/cm^2	Dial gauge Readings 1	2	3	Average	Deformation cm	Strain
1	2	3	4	5	6	7	8	9
1:4:8	0	0	0	0	0	0	0	0
	0.5	2.7	4	6	4	4.7	4.7×10^{-3}	1.6×10^{-4}
	1.0	5.6	9	10	11	10.0	10×10^{-3}	3.3×10^{-4}
	1.5	8.4	12	16	14	14.0	14×10^{-3}	4.7×10^{-4}
	2.0	11.3	22	26	27	25.0	25×10^{-3}	8.4×10^{-4}
	2.5	14.1	29	34	33	32.0	32×10^{-3}	10.7×10^{-4}
	3.0	16.9	44	47	44	45.0	45×10^{-3}	15×10^{-4}
1:5:10	0	0	0	0	0	0	0	0
	0.75	4.2	9	10	6	9	9×10^{-3}	3×10^{-4}
	1.5	8.4	20	24	13	19	19×10^{-3}	6.4×10^{-4}
	2.0	11.3	28	30	20	26	26×10^{-3}	8.8×10^{-4}
	2.5	14.1	46	42	32	40	40×10^{-3}	13.3×10^{-4}
1:6:12	0	0	0	0	0	0	0	0
	0.75	4.2	12	9	12	11	11×10^{-3}	3.6×10^{-4}
	1.5	8.4	24	19	23	22	22×10^{-3}	7.3×10^{-4}
	2.0	11.3	31	26	30	29	29×10^{-3}	9.7×10^{-4}
	2.5	14.1	48	44	46	46	46×10^{-3}	15.3×10^{-4}

TABLE 4.3

PLATE LOAD TEST ON SLABS

Mix	Proving ring readings	Load kg	Stress kg/cm^2	Dial gauges readings				Deformation cm
				1	2	3	Average	
1:4:8	14.5	2900	4.1	20	20.5	20	20.1	0.051
	24.5	4900	7.0	39	41	40	40	0.10
	34.0	6800	96.0	58	61	60	59.7	0.151
	40.5	8100	11.4	78	81	83	80.7	0.205
	46.5	9300	13.1	99	100	99	99.3	0.251
	49	9800	13.9	112	117	115	114.7	0.291
	50.5	10100	14.2		132	132	131.3	0.34
1:5:10	12.5	2500	3.6	20	19	21	20.0	0.05
	22	4400	6.2	40	38	39	39.0	0.099
	30.5	6100	8.6	60	61	61	60.7	0.154
	39	7800	11.1	81	80	80	80.3	0.204
	44	8800	12.4	98	97	100	98.3	0.249
	45.5	9100	12.9	110	109	113	110.7	0.281
1:6:12	11	2200	3.1	20	18	18	18.7	0.048
	19	3800	5.4	40	40	38	39.3	0.99
	28	5600	7.9	60	61	60	60.3	0.153
	33.5	6700	9.5	80	81	75	78.7	0.199
	38.5	7700	10.9	101	100	96	99.0	0.251
	40.5	8100	11.5	120	119	115	118.0	0.299

TABLE 4.4

PULSE VELOCITY TECHNIQUE FOR E_d

Mix	Type of sample	Length of sample L cm	Transit time T sec x 10^{-6}	Velocity V = L/T cm/sec	V^2 x 10^{10}	E_d = 2.11224 x 10^{-6} x V^2 kg/cm^2	Average
1	2	3	4	5	6	7	8
1:4:8	Cubes	15	50.5	297030	8.82266	1.864x10^5	1.673 x 10^5
	Cylinders	30	105.5	284361	8.08767	1.708x10^5	
	Beams	50	191	261780	6.85388	1.448x10^5	
1:5:10	Cubes	15	56	267857	7.1747	1.5155x10^5	
	Cylinders	30	113	265486	7.048	1.4888x10^5	1.405 x 10^5
	Beams	50	209	239234	5.7233	1.2089x10^5	
1:6:12	Cubes	15	59	254237	6.464	6.3653x10^5	
	Cylinders	30	124.5	241935	5.854	1.2364x10^5	1.2534 x 10^5
	Beams	50	213.5	234192	5.485	1.1585x10^5	

TABLE 4.5

SONIC & ULTRASONIC OBSERVATIONS FOR FINDING POISSON'S RATIO

Mix	Beam No.	f cycles/sec	$Tx10^{-6}$ sec	V=L/T cm/sec	γ	$E_{d1} = 2.11224 \times 10^{-6} V^2$ kg/cm^2	$E_{d2} = 6f^2 L^2 d/g$ kg/cm^2
1	2	3	4	5	6	7	8
1:4:8	1	2525.5	176	284091	0.156	1.705×10^5	1.786×10^5
	2	2287.5	174	287356	0.150	1.744×10^5	1.842×10^5
1:5:10	1	2177	180	277778	0.139	1.623×10^5	1.668×10^5
	2	2165	183	273224	0.157	1.576×10^5	1.65×10^5
1:6:12	1	1951	199	251257	0.196	1.333×10^5	1.339×10^5
	2	1925	198	252525	0.223	1.346×10^5	1.305×10^5
	3	2000	193	259068	0.205	1.418×10^5	1.408×10^5

f = frequency from sonic apparatus

T = Pulse Travel time in micro seconds

TABLE 4.6

VIBRATIONAL TECHNIQUES ON SLABS

Mix	Frequency cycles/sec	Wave length Δ cm	Velocity V m/sec
1	2	3	4
1:4:8	850	97.4	830
	750	94.1	770
	500	127.7	640
	400	147.5	590
	250	156.0	390
	200	160	320
1:5:10	1000	84	840
	900	85	760
	800	92.2	740
	400	123	490
	300	132	396
	200	140	280
1:6:12	800	111.5	890
	750	93	690
	500	107	535
	400	122.5	490
	300	140.5	421.5
	200	155.6	311.2

TABLE 4.7

SUMMARY OF MODULUS OF ELASTICITY VALUES FROM DIFFERENT TESTS

Sl. No.	Modulus of Elasticity from	Mixes 1:4:8	1:5:10	1:6:12
1	Compression E_c kg/cm^2	1.544×10^4	1.339×10^4	1.216×10^4
2	Plate load test (E_{PL}) kg/cm^2	3.68×10^4	2.94×10^4	1.96×10^4
3	Pulse velocity technique E_{d1} kg/cm^2	1.673×10^5	1.405×10^5	1.2534×10^5
4	Longitudinal Resonance Technique E_{d2} kg/cm^2	1.814×10^5	1.659×10^5	1.351×10^5
5	Vibrational technique E_{d3} kg/cm^2	3.81×10^4	3.12×10^4	2.75×10^4

TABLE 4.8

FATIGUE OBSERVATIONS ON BEAMS

Mix	Applied Load kgs	Average stress level	DAverage Repetitions at failure
1	2	3	4
1:4:8	160	96.5%	255
	145	83.6%	800
	136	72.8%	2980
	102	62.2%	25680
1:5:10	150	95%	15
	136	86.2%	500
	115	74.2%	1510
	95	63.5%	20120
1:6:12	136	97.4%	3
	114	82.9	30
	102	75.4%	795
	76.5	59.3%	19200

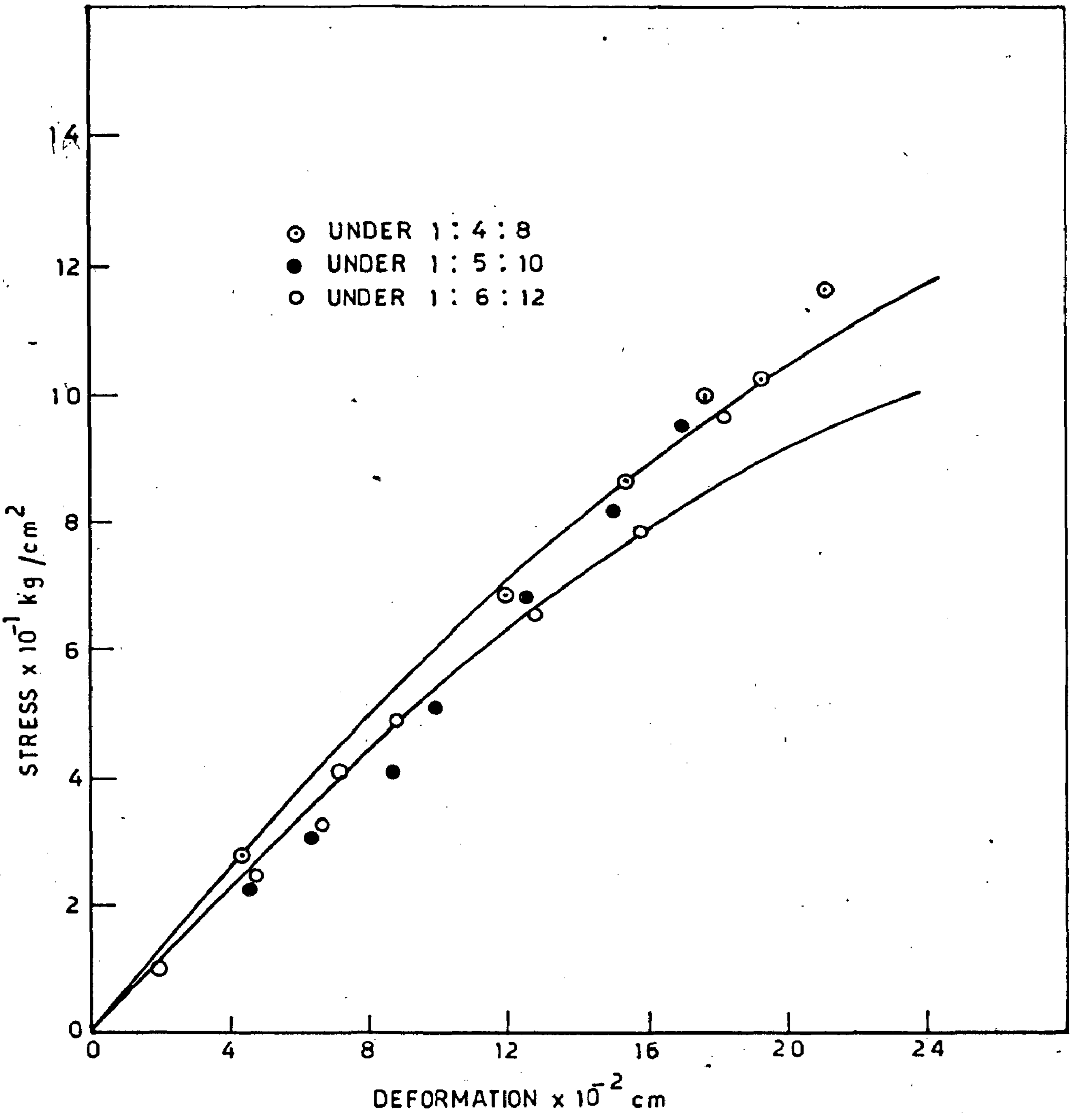


FIG. 4.1 _ PLATE LOAD TEST ON SUBGRADE WITH 75 cm DIAMETER PLATE

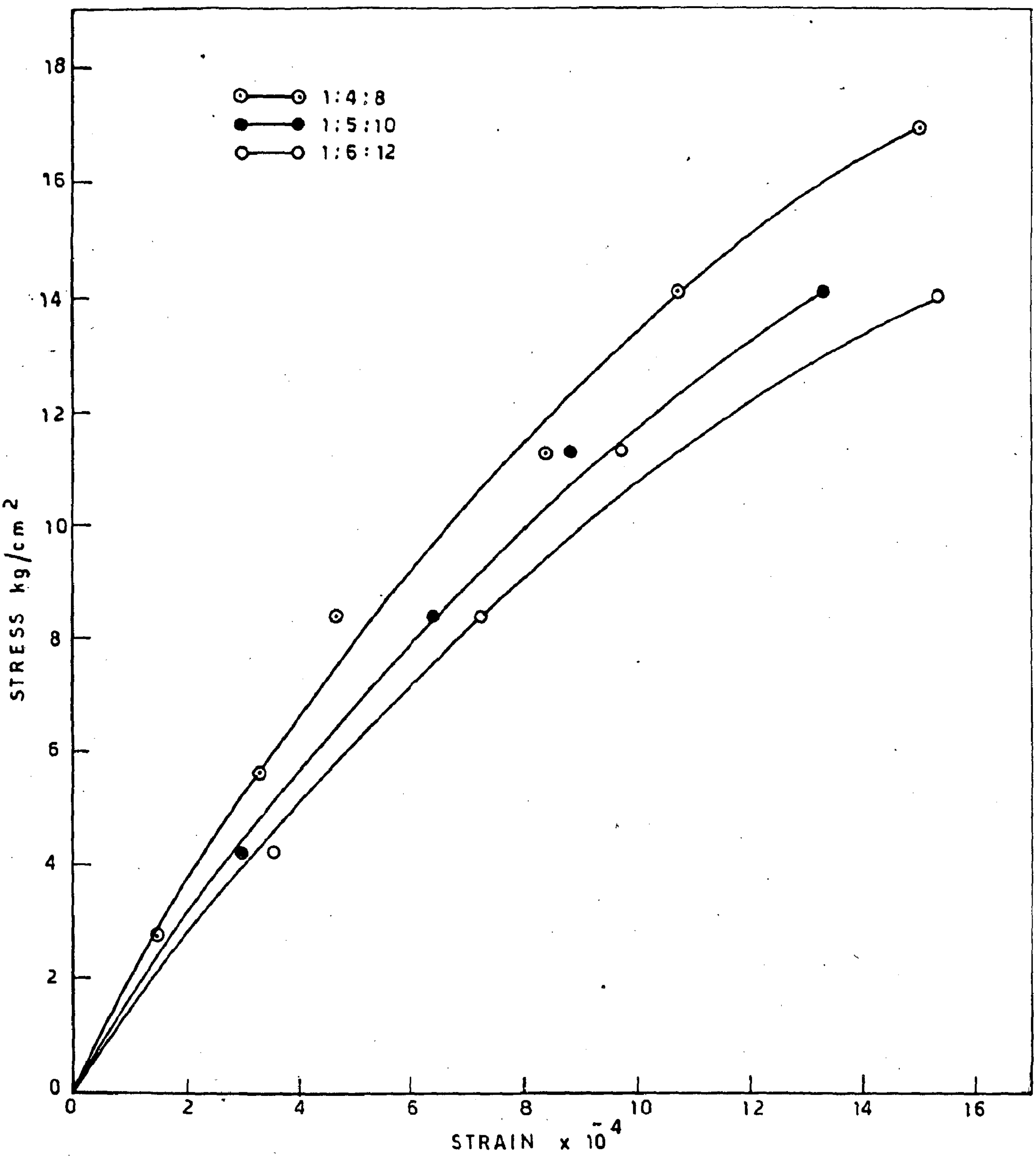


FIG. 4.2 _ STRESS- STRAIN CURVES FOR LEAN CONCRETE MIXES

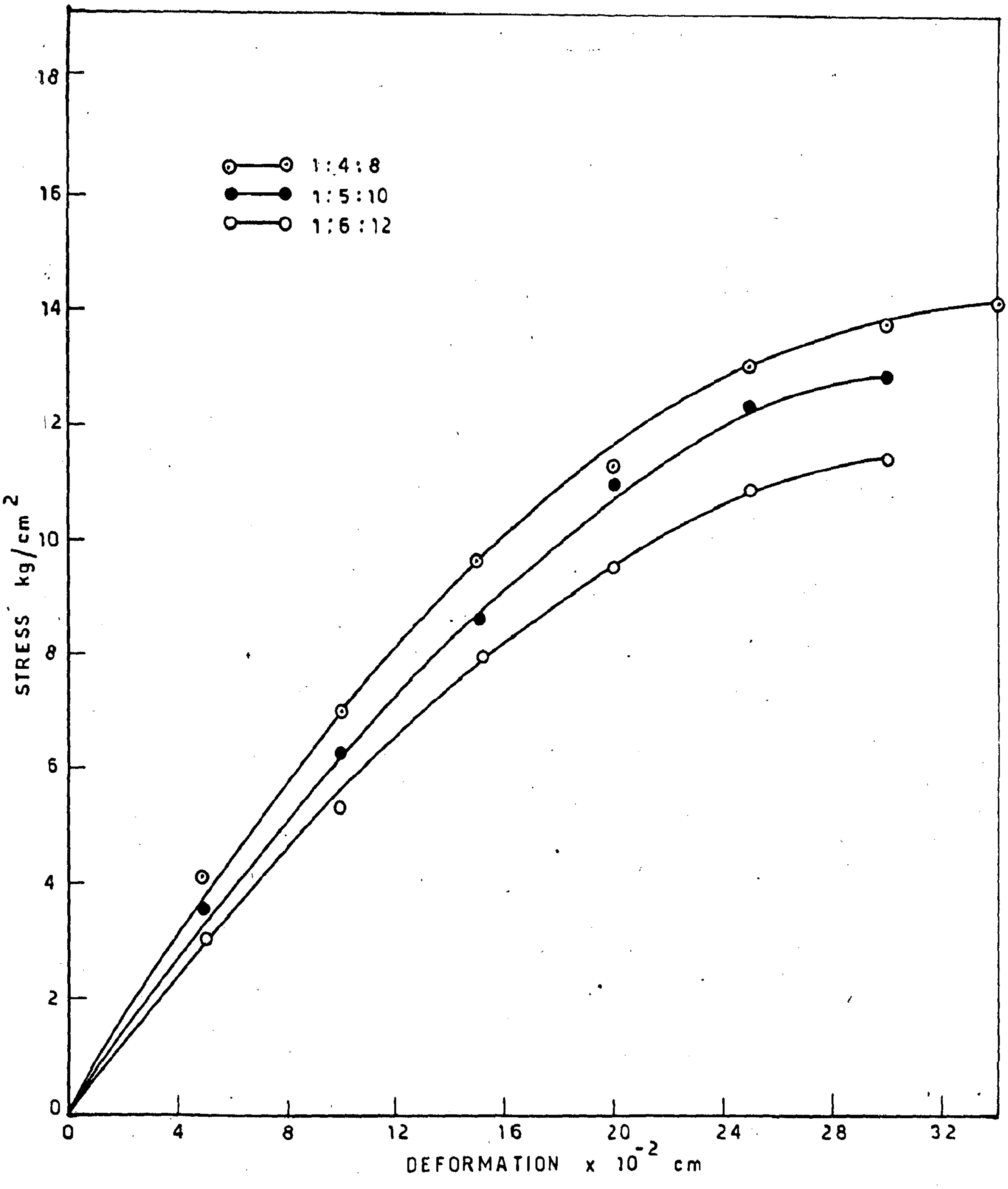


FIG. 4.3 _ PLATE LOAD TEST ON SLAB WITH 30 cm DIAMETER PLATE

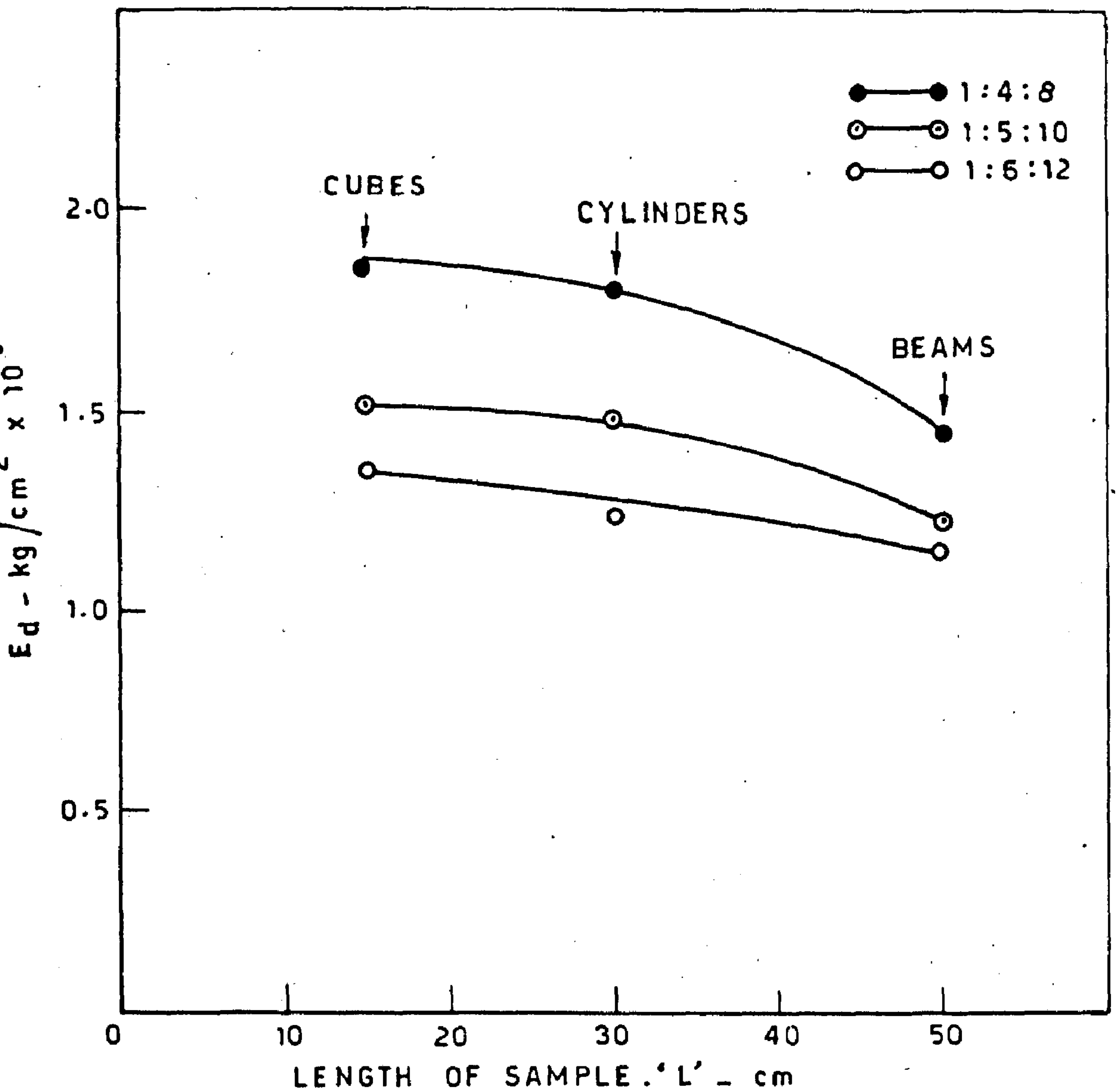


FIG. 4.4 _ VARIATION OF E_d WITH LENGTH OF SAMPLE

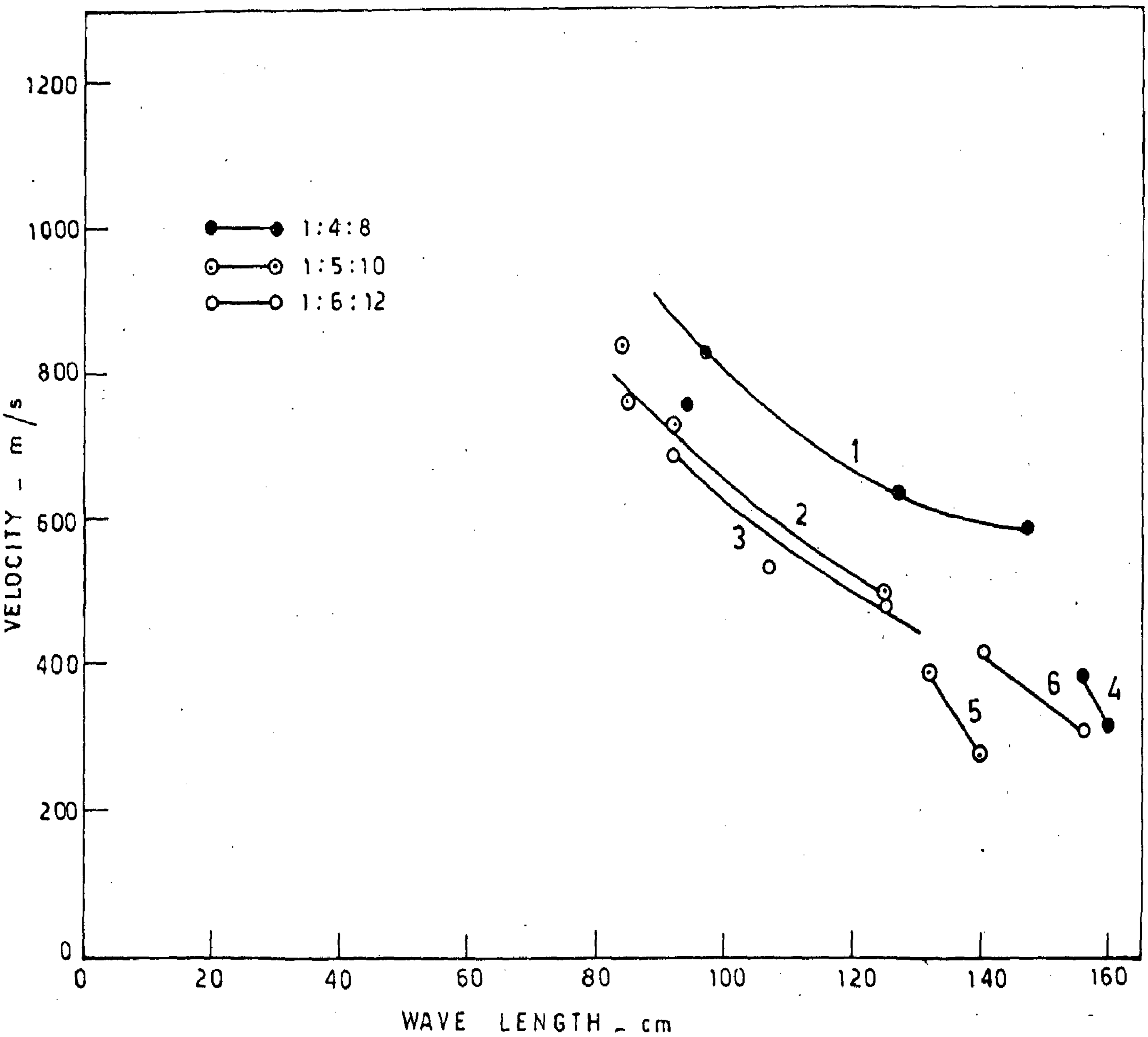


FIG. 4.5 _ VELOCITY - WAVE LENGTH CURVES FOR SLABS

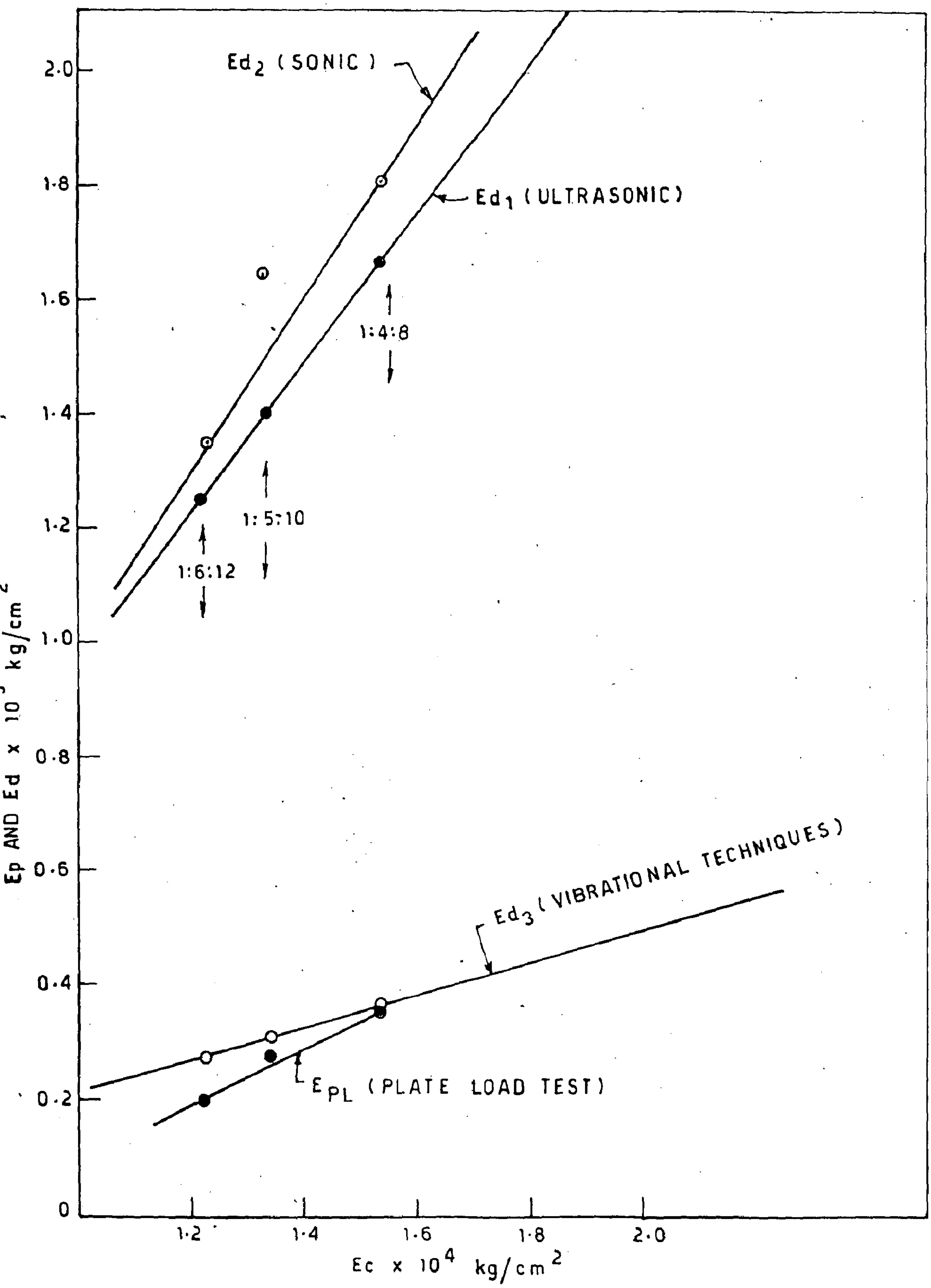


FIG. 4.6 – COMPARISON OF Ed AND Ep WITH Ec

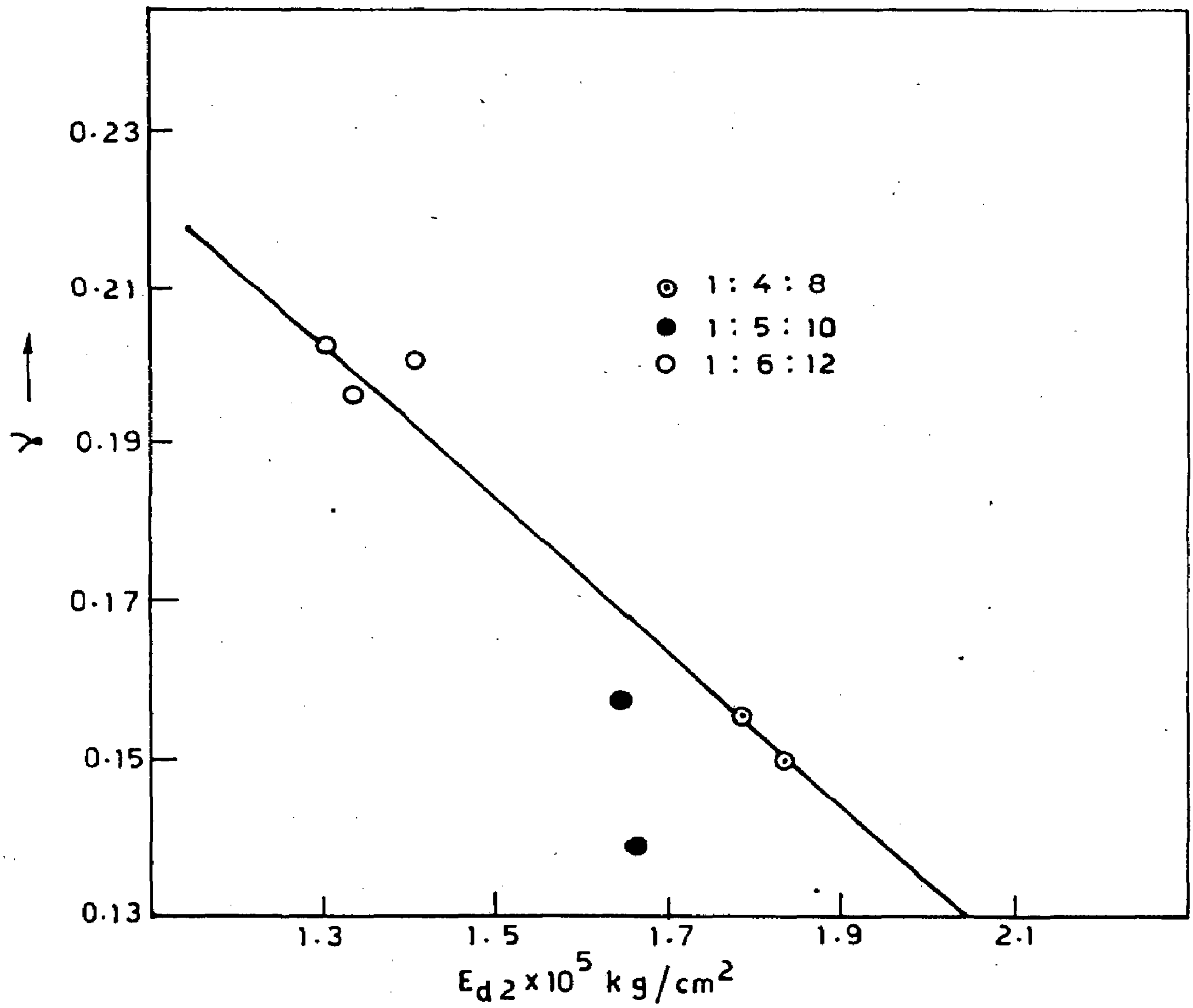


FIG. 4.7 – E_{d2} POISSON'S RATIO γ

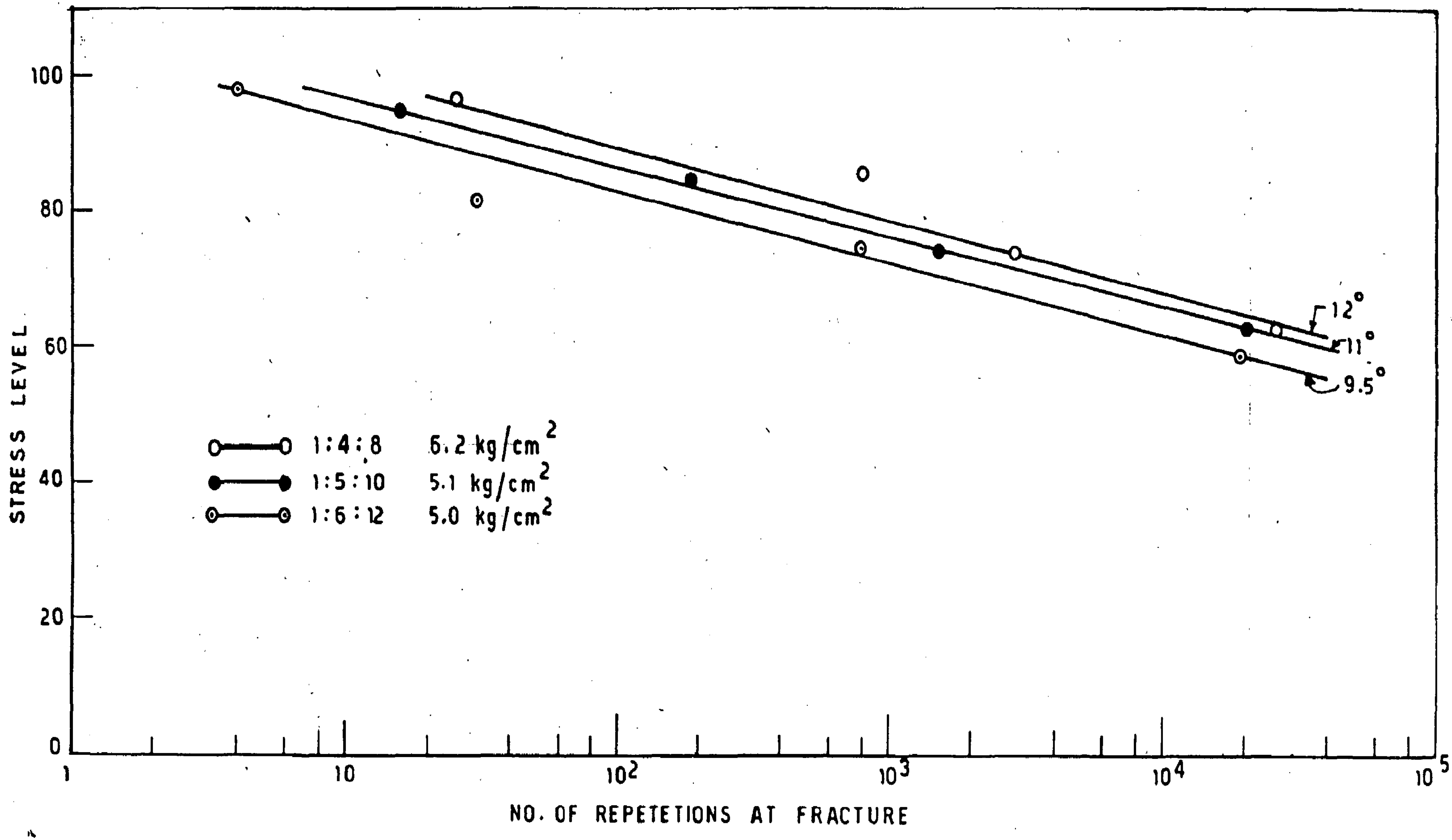


FIG. 4.8 _ STRESS LEVEL - REPETETIONS AT FAILURE

CHAPTER V

CONCLUSIONS

Based on the discussions of the previous chapters of this study, the following conclusions can be drawn.

1. The amount of reported literature for finding modulus of elasticity 'E', Poisson's ratio γ and fatigue characteristics is very limited, especially when compared with the availability of other materials such as quality concrete, Lime fly ash aggregate etc.

2. The advancement of non-destructive tests for estimation of 'E' and γ is rather good, however a lot of work has to be done for incorporating these dynamic properties in designing and analysis.

3. The vibrational testing of pavements to estimate the above properties for various compositions of materials seems to be a very viable field for detailed study and investigation.

4. In the current investigation lot of variations are observed in E values from different tests. The estimated values of E from pulse velocity technique and longitudinal resonance tests are very high when compared with other tests. The low values of E_C in compression are due to the selection of nominal mixes, type of

compaction and curing period. The variations in E_d from sonic and ultrasonic tests are not significant. The value of E from plate load test is dependent on subgrade properties. The relation between E_d and E_c appeared to be linear.

5. It was expected that the dual observations with the phase-angle meter and cathode ray oscilloscope (CRO) greately improves the reliability of measurements. However, the transducers should have a point contact on the pavement to have a more stable and accurate determinations and readings.

6. The assumed value of 0.2 for poisson's ratio to compute E_d from pulse velocity technique was found to be good enough because test results of poisson's ratio show a value of 0.15 for 1:4:8 and 1:5:10 and 0.22 for 1:6:12 and 0.2 may be assumed to be a good central tendency.

7. The effect of poisson's ratio and unit weight of materials was not very significant on computations of E value.

8. The poisson's ratio and modulus of elasticity are inversely proportional to each other.

9. Though the relationship between stress level and logarithm of load repetitions was linear the mixes were taking smaller number of repetitions at lower stress levels. The flexural strengths of the mixes were also lower than the values obtained and reported (7) values by CRRI.

Some reasons explained for lower results of E values also seem to be applicable here.

SUGGESTIONS FOR FUTURE WORK

1. There is a lot of scope to continue further work on these mixes especially for improving strength characteristics.
2. The study of modulus of elasticity, Poisson's ratio and fatigue characteristics under various test conditions. These different test conditions includes curing period, type of compaction and type of loading pattern.
3. The available vibrator test system is to be modified for taking accurate observations (provisions are to be made for taking readings using both CRO and Phase differencemeter simultaneously and imprrovement in the contact of transducers).
4. There should be some provisions for estimation of fatigue property at any rate of load repetitions instead of only at 70 cycles/minute.
5. Some more methods are to be developed for incorporating fatigue property in design of pavements.

REFERENCES

1. Anson M., 'The effect of mix proportions and method of testing on Poisson's Ratio for Mortors and Concretes', Magazine of Concrete Research, Vol. 28(56), 1976.

2. Arora M.G., 'Strength Characteristics of pozzolanic mixtures and base course',Ph.D. Thesis, University of Roorkee, Roorkee, 1973.

3. Avram C., et. al., A Test Book on 'Concrete Strength and Strains', 1981.

4. Cornelissen H.A.N., 'Uniaxial tensile fatigue failure of concrete under constant amplitude programme loading', Magazine of Concrete Research, 1968.

5. Dhir M.P. (Dr.) et.al., 'Study of Pavements using surface wave propogation technique', Indian Geotechnical Journal, Vol. 10, No. 4, Oct. 1980.

6. Gallowway J.W. et.al., 'Elastic moduluii of Lean and Pavement quality concrete under uniaxial compression and tension', RILEM Structures and Materials, Vol. 9 (49), 1976.

7. Ghosh, R.K. (Dr.) et.al., 'Laboratory study on lean cement-fly ash concrete as construction material', CRRI Road Research Paper No. 84, 1982.

8. IRC-58, 'Tentative guidelines for design of rigid pavements for Highways', 1974.

9. IRC-74, 'Tentative guidelines for lean cement concrete and lean cement fly ash concrete as pavement base or sub base.

10. IS-516, 'Methods of test for cement concrete', 1959.

11. Jain O.P., A Text Book on 'Plain & Reinforced Concrete', Vol. I.

12. Jones R. et.al., 'A survey of dynamic methods of testing roads and runways',HRB Bulletin No. 277, 1960.

13. Jones R. et.al., 'Measurement of elastic and strength properties of cemented material in road bases', Highway Research Record, 1966.

14. Justo C.E.G., et.al., A Text Book on 'Highway Engineering'

15. Mahendru A.K., 'Fatigue life prediction of base course material', M.E. Thesis, 1975.

16. Manuals on Sonic Apparatus, Ultrasonic and High frequency vibrator with low excitation.

17. Maxwell A.A., 'Non-destructive testing of pavements' HRB Bulletin No. 277, 1960.

18. Nautiyal B.D., 'Time dependent properties of fly-ash concrete' Ph.D. Thesis, University of Roorkee, Roorkee, 1975.

19. Pell P.S., A Text Book on 'Developments in Highway Pavement Engineering', Vol. 1.

20. Ramaswamy, G.S. (Dr.)et.al., Relation between the compressive strength and its elastic modulus', Indian Concrete Journal, Vol. 34, 1964.

21. Saito, M., et.al., 'Direct tensile fatigue of concrete by the use of friction grips', American Concrete Institute Journal.

22. Satish Chandra, 'Parametric Study on some rigid pavement model slabs using calcite/dolimite lime', M.E. Thesis, 1985.

23. Sharma B.G., 'Laboratory Study of Concrete Overlays', M.E. Thesis, 1963.

24. Simons J.C., 'Poisson's Ratio of Concrete: a comparison of concrete research', Vol. 7 (21), 1957.

25. Swaminathan (Prof.), 'Surface wave propogation technique - A non-destructive method for pavement evaluation', IRC Journal, Vol. 40-1, 1977.

26. Vason R.M., 'Strength characteristics of lime fly ash soil mixtures for road construction! M.E. Thesis, 1968.

27. Whiffin A.C., Raithby K.D., 'Failure of concrete under fatigue loading - A review of current knowledge', TRRL LR-231, 1968.

28. Yoder E.J. et.al., A Text Book on 'Principles of Pavement Design', Second Edition.

29. Preliminary Report of R-23, 'Determination of E of pavement layers and subgrade by vibrational techniques in the field', Nov. 1984.