STUDY OF EFFECTS OF REPEATED LOADING ON SOIL-CEMENT SPECIMENS

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CERTIFICATE

Certified that the dissertation entitled "Study of Effects of Repeated Loading on Soil-Cement Specimens" which is submitted by Shri G.K. Vasishtha in partial fulfilment for the award of the degree of Master of Engineering in Highway Engineering of the University of Roorkee is a record of the student's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation 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 Seven months from January 1970 to July 1970 for preparing this dissertation at this University.

14.11.70.

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G. K. Vasishtha

C O N T E N T S

SYNOPSIS

Rationalisation of design concepts for soil-cement base courses is a problem engaging the attention of Highway Engineers, and repeated loading tests are expected to provide a realistic means of assessing soil-cement properties in the laboratory for predicting its field behaviour under repetitive traffic loads. An attempt has been made to study the effects of repeated applications of stress on the strength and deformation characteristics of soil-cement specimens. An indigenous repeated load equipment is locally fabricated for the purpose. Compressive and flexural strengths being main characteristics of soil-cement, cylinderical and beam specimens are tested under repeated load for different levels of statically applied ultimate stress. Effect of curing conditions on the strength of specimens is also observed. At low stress-levels both compressive as well as flexural strengths of specimens are found to increase due to repeated load application. However, the relation between applied flexural stress and number of load repetitions is not found to be linear as it is in case of concrete.

CHAPTER I

INTRODUCTION

1.1 DEFINITION AND USE

Soil-cement can be defined as "a mixture[1] of pulverised soil and measured amounts of portland cement and water, compacted to a high density and protected against moisture loss during a specific curing period". This material has been used in Civil Engineering in a variety of modes of construction e.g. strengthening of soil below large foundations and floors; construction of low cost houses[2,3]; paving of slopes and lining of ditches, reservoir and tank-bases, linings and bank protection; as an insulator for cold storage premises; strengthening of open spandrel arch bridges, abutment blocks and abutments for beam bridges and for Highway bases and parking areas.

The first road-bases of cement treated soil were built in South Carolina[4] in 1932. This successful project was followed by the construction of similar roads in other states in U.S.A. New techniques were developed, controls were established strength and durability were improved and methods of determining optimum cement content were devised. Using these controls and test methods many highways, streets, parking lots and air fields have since been built using soil-cement as base or sub-base course. In the last decade the use of soil-cement has increased rapidly. Studies reported by F.A.A.[5] and AASHO road test[6] bear the testimony to the fact that flexible pavements containing cement treated layers give better performance under traffic loads than untreated gravel bases of the same thickness. Nussbaum and Larsen[7] established from the results of plate load tests that untreated gravel bases may deflect from 1.6 to 3.3 times as much as under a given load as an equal thickness of soil-cement. In rigid pavements, cement treated bases reduce the hazardous effect of pumping at the joints. In another study[8] conducted by P.C.A. lab, it was brought out that for constant edge deflections an 8 inches concrete slab bonded to a 5 inches cement treated base was able to support twice as much load as carried by the 8 inches slab on a 5 inches gravel base.

1.2 NEED OF STUDY

Though the importance of soil-cement as a highway base material is a settled fact, the design concepts for soil-cement base courses need be rationalised. A pavement is normally subjected to a series of stress applications and releases in the form of pressure pulses[9]. Shen and Mitchell[10] concluded in their study that the repeated loading test may provide a realistic means of assessing soil-cement proportion in the laboratory for predicting field behaviour under repetitive traffic loads. In as much as the results indicate that values for moduli may be considerably different when evaluated under static loading rather than repeated loading conditions, it is particularly important that consideration be given to the type of test for selection of property values. An attempt was really made by Hveem to develop a thickness design method on the basis of the results of study conducted by Hveem and Carmany[11] in which it was showed that the thickness of cement treated base required to carry 10,000 repetitions of a 6000 lbs. load was 8 to 10 inches, whereas the thickness of a flexible pavement with CBR 100 was at least 13 inches.

1.3 SCOPE OF THIS STUDY

The present investigation aimed to study the effects of repeated applications of stress on the strength and deformation characteristics of soil-cement specimens. Compressive and flexural strength being the main considerations in the study of behaviour of soil-cement, experiments were carried out to study the influence of repeated load application on cylinderical and beam specimens, for which the tests were performed at varying stress-levels and number of stress applications.

CHAPTER II

REVIEW OF PREVIOUS WORK

2.1 Prior studies of fatigue characteristics of soil-cement are limited in number. H.E. Boefinger[12] investigated the fatigue behaviour of a heavy black clay stabilized with 8, 12 and 16 percent cement. He observed that in flexural fatigue the stress ratio at 5,00,000 load repetitions was independent of cement content for the range tested. Assuming plane strain distribution, he showed that the stress diagram must be curved (variable E-value) to give extreme fibre stress equal to the maximum measured tensile stress.

2.2 Shen and Mitchell investigated the effect of repeated compression and flexure on the behaviour of soil-cement beams and cylinders. They worked on two typical soils - one silty clay of A-6 group which was a representative subgrade material and another a sand mixture of A-2-4 group a type which may be preferred as a cement treated base-course material. The cement percentages used were 13% and 7% for silty clay and sand respectively. These cement percentages were based on durability criterion.

Triaxial compression tests on cylinderical specimens and flexural tests on beam specimens were conducted by them. Ranges of repeated loading stress intensities were selected on the basis of computations using three layer elastic theory for highway and airfield loading conditions assuming the silty clay as stabilised subgrade material and sand mixture to be a stabilised base course. In tests where applied stress-intensity was not considered as a variable, stress - intensities of 50 and

100 psi were used for sand mixture in compression and 50 psi in flexure. Similarly for silty clay stress-intensities used were 20 and 40 psi in compression and 20 psi in flexure.

The samples were subjected to 24000 repetitions and were tested in conventional strength tests for compression and flexure. Also a dummy sample of the same age as the corresponding repeated loading sample was also tested to determine the effect of repeated load application on its' mechanical properties.

The repeated loading equipment used by Shen and Mitchell in this study was the same as that used in the soil mechanics lab at the University of California[13]. The frequency of load application was 20 repetitions per minute and average duration of a load application was 0.1 second. In this successful piece of equipment, a loading system was designed for testing specimens in triaxial compression under repeated loading, the stress being rapidly applied and removed with negligible impact effects and with suitable controls to regulate magnitude of load, duration of load application and interval between load application. It could safely work for long periods of operation (1 month) and was portable.

Repeated loading compression tests were carried out inside triaxial compression cells without different confining pressures and samples were tested undrained without accounting for any pore-pressure.

Shen and Mitchell studied-

1. Effect of density on the behaviour under repeated compression as well as flexure and found that modulus of resilient deformation at a given number of load applications is directly related to dry density for sand-cement samples investigated.

2. Effect of moisture content on the behaviour under repeated flexure, and it was found in case of silty - clay - cement samples that the modulus of resilient deformation decreases as the moulding water content increases. The influence of dry density and water content was more pronounced on the resilient modulus in compression in case of cylinderical samples. In both the materials the ranges of modulus variation are greater in compression than in flexure.

3. Effect of stress-intensity on the properties of soil-cement and found that the modulus of resilient deformation was greatly affected by magnitude of stress intensity in case of compression test. It rapidly decreased with increase in the applied stress-intensity at low stress-levels. But at stress-levels higher than 30 to 40% of initial strength of samples the effect of stress-intensity on the resilient modulus was very little. However, this effect of stress-intensity on resilient modulus in case of repeated flexure tests was different and in this case both the resilient modulus and the strength were virtually un-affected by the stress - intensity.

4. The effect of number of load repetitions in case of repeated flexure tests and found that the resilient deformation remains unchanged with respect to number of load applications even at very high stress levels, very close to the limiting value which causes fatigue failure. Results from repeated compression tests did show that only at applied stress - levels of less than about 30 to 40 percent of initial strength, is the magnitude of resilient deformation not affected by the number of load applications. At higher applied stress - intensities, resilient deformations vary with the number of load applications with the maximum values occurring between about 1 and 500 load repetitions. The resilient deformation at one lakh repetitions may be only about 1/5th to 1/4th of the maximum value.

5. Influence of time of curing and the results obtained showed that larger the curing period before the start of repeated compression the greater the minimum resilient modulus at a given stress-level applied repeatedly.

In effect, their flexural tests revealed that neither the resilient modulus (ratio of applied stress to resulting deformation) nor the strength were influenced significantly by the magnitude of applied repeated stress - intensity (in the absence of fatigue failure). For soil-cement made with sand, these properties were influenced primarily by density, and for soil-cement made with clay the properties were also sensitive to moisture content. For flexural tests, the minimum stress ratio to cause failure at less than 25000 repetitions was 75 percent for the sand soil-cement and 90 percent for the clay soil-cement.

2.3 FATIGUE OF SOIL-CEMENT

Larsen and Nussbaum conducted the tests to examine the effects on fatigue life of (1) soil type and consequent physical properties (2) Thickness of the layer and (3) Reaction modulus of the supporting subgrade. They worked on three typical soils representative of the dominant soil-types of North America. Cement content was restricted to the optimum required to produce soil-cement for each soil as determined by PCA methods. Specimens were compacted at standard conditions of moisture and density.

They carried out their tests on beams of 3 x 3 x 11½ inches size which were cut from larger beams of 28 inches length, 6 inches width and depths of 4, 6, 8 and 10 inches. These larger beams were kept in steel moulds under moist conditions for 24 hours to develop sufficient strength to permit handling after which they were kept in a fog room for curing for 28 days at 73°F temperature and 100 percent relative humidity. Before testing these were air-dried for one day, coated with a sealer and stored in the laboratory. They tested 286 beam specimens, on end supports, with a neoprene subgrade between supports. The criterion for failure was first visible crack because on full size soil-cement pavements, the failure was observed to begin with radial cracking in the bottom surface.

The fatigue test programme included studies on the effect of (a) three soil types for 6 inches deep beams (b) four thicknesses for one soil type and (c) four subgrade strengths using one soil type and 6 inches deep beams. Thus not all combinations of the variables were included in the test programme. They reported the following conclusions.

In a static test the radius of curvature decreased with increasing load and developed a minimum value at the location where the specimen eventually failed. The minimum radius of curvature at failure when loaded statically was defined as the critical radius of curvature. Specimens made from a given soil type had a characteristic value of critical radius of curvature.

The ratio of the critical radius of curvature R_c and the radius of curvature produced at the beginning of a fatigue test R, together with the number of load repetitions to produce failure, N, were used to define fatigue. Curves for values of N from 10 to 1 million were described in the form of an equation.

The soil type and specimen thickness influenced the fatigue characteristics. However, subgrade strength had no significant influence on the fatigue characteristics. They developed equations that defined the fatigue behaviour of soil-cement produced from three soil types and for four slab thicknesses.

General equation for allowable radius of curvature R as derived by them is as follows :-

$$R = \frac{R_c \; N^b}{1.05 - 0.042\,h} \qquad \ldots (1)$$

The exponent 'b' in above equation depends upon soil type used in producing the three soil-cement. For the soil types tested by them the equations reported by them are as follows :-

for Soil A-1-b: $$R = \frac{R_c . \; N^{0.032}}{1.05 - 0.042\,h} \qquad \ldots (2)$$

for Soil A-2-4: $$R = \frac{R_c . \; N.^{0.025}}{1.05 - 0.042\,h} \qquad \ldots (3)$$

for Soil A-4(3): $$R = \frac{R_c . \; N^{0.054}}{1.05 - 0.042\,h} \qquad \ldots (4)$$

Where,

b = dimensionless exponent in fatigue equation.

N = Number of load repetitions.

R = Radius of curvature, in., developed for given load and number of load repetitions.

R_c = Critical radius of curvature, in., defined as the radius of curvature at failure.

h = Thickness of specimen (depth of beam) in.,

CHAPTER III

INSTRUMENTATION

3.1 DESIGN CRITERIA

In the present study testing of 5 cm. dia x 10 cm. height cylinderical soil-cement specimens in repeated compression and 7.5 x 7.5 x 28.1 cms. soil-cement beam specimens in repeated flexure was contemplated. For this work a repeated load equipment was required which could satisfy the following conditions :-

1. It could apply a stress upto about 28 Kg./cm^2 which could normally be the strength of soil-cement specimens at rich cement contents. For this, it should be stout enough to apply such a stress repeatedly without excessive vibrations. Motor should be powerful enough to operate the loading device continuously for long durations. The wear of moving parts should not be excessive under the effect of repeated heavy loads.

2. There should be enough space to accomodate cylinderical as well as beam specimens mounted on the test platform for the purpose of testing under repeated load.

3. The amount of load required to be applied on the lever arm was to be kept within reasonable limit and so the ratio of the distances on the lever arm

$$= \frac{\text{Distance between the fulcrum and weight hanger}}{\text{Distance between the fulcrum and loading frame}}$$

should be as large as practically possible.

4. It was aimed that tests would be carried out at successively reducing stress - level until the specimen takes unlimited number of repeated load applications without excessive deformation. Unlimited number of repetitions being an impractical proposition to realise in practice, it was aimed that 50,000 number of repetitions will be applied and if the specimen does not fail, it would be tested under static load to study the effect of repeated loading on its strength. Thus the instrument was required to fulfil the need of 50,000 number of repetitions for which it was to run non-stop for about 50 hours. The belt and pully arrangement transmitting the power of motor to the equipment had to be adequate for the purpose.

5. To be representative of the actual loading conditions of the pavement, the minimum period of load application was set at about 0.1 second, which corresponds to wheel loads moving at about 48 Kmph.

6. It was thought to be desirable to apply the load with minimum impact. A spring loaded telescopic loading head was fabricated to meet this requirement. The details are described in the following article.

3.2 DESCRIPTION OF THE EQUIPMENT FABRICATED

The repeated load-equipment, fabricated for these investigations, consists of following principal organs -

1. Automatic compactor
2. Lever arm

3. Loading frame
4. Loading head
5. Plat-form
6. Belt and pulley drive
7. Motor

3.2.1 Automatic Compactor

For lifting the lever arm end, on which the weights are to be hung, modified automatic compactor was used. The connection between the edge of sliding rod and top end of lever arm was made by a G.I. chain strong enough to safely lift a load of about 40 Kg. The length of the chain was kept adequate to permit the lever arm to take full swing. A revolution counter was also available to show upto only 100 repetitions. The number of repetitions were counted personally in the cases when it could be possible i.e. in cases of testing at higher stress levels where specimens failed at fewer number of stress applications. However, this could not be possible in cases of the study of specimens' behaviour at low stress levels because the number of load repetitions was very large and it took hours of equipments' operation. To count number of load repetitions, in such cases, the time of working of the equipment upto the failure of specimen was correctly noted and by multiplying this with the frequency of load repetition, the number of repetitions was determined.

During the upstroke of the sliding rod, the lever arm is lifted up and when the sliding rod takes a down-stroke, the lever arm is released, chain becomes loose, and thus the lever arm comes down under the action of gravity due to the weights put on the hanger.

3.2.2 Lever Arm

Lever arm consisted of two mild steel flats of 5 cm x 0.6 cm size 170.0 cm long, both joined together by a number of stiffeners as shown in figure 4. The stiffeners were in the form of M.S. flats 3.75 cm x 0.6 cm and 10 cm. length. The aim was to make it strong enough to carry up and down a weight of 40 Kg. hanging at 136 cms distance from the fulcrum repeatedly, without bending or buckling. The lever arm was supported on the fulcrum at a distance of 136 cm from one end and 34.0 cm from the other.

Suitable weight hangers to carry the required load were also designed. These were in the form of M.S. rods 1.9 cms dia. and 25 cms long, threaded on both ends. These could be screwed in the end stiffeners of the lever arm and held in position by the nuts. Weights in the form of annular rings could slide on this M.S. rod and tightened in position by means of both and plates. Self weight of the lever arm and other accessories is counterbalanced by putting weights on the lighter end of the lever arm. This was called for in cases when specimens were to be tested at low stress levels.

During the downward motion of the slider of the compactor the lever arm and the loading yoke also are lowered and the chain gets loose, causing the stress application on the specimen kept beneath the loading head in proper position.

3.2.3 Loading Frame

Loading frame as shown in figures 1 and 3 consisted of two stirrups each made of two M.S. rods of 1.9 cms. dia, joined by 10 cms pieces of M.S. flats at both ends, on each side of the plateform. The clear distance between the both sides of the loading frame was kept as 80 cms. The height of the frame was made adjustable by providing threads on the upper ends of the M.S. rods on which the loading yoke could slide and be bolted at a desired height.

The loading frame was originally supported on the lever arm by means of a 1.9 cm dia m.s. rod which could not take the full load and was to be replaced by 3.75 cm dia M.S. rod at a later stage. Bearings were also provided in the lever arm flats where 3.75 cm M.S. rod of the loading frame met the lever arm flats. This was thought to be essential to check the enlarging of the holes in the flats due to excessive loads coming on the loading frame. In order to permit the lever arm to swing freely, slots were provided in the flats joining the two rods in the both stirrups of the loading frame.

As mentioned in Art. 3.2.2 the distance of the fulcrum from the load end of the lever arm was 136 cms. The distance of the point at which loading frame would be attached to the lever-arm was kept minimum possible (equal to 8.5 cms) so as to obtain maximum possible mechanical advantage (of 16).

Thus for a load of 40 Kg at the lever arm end (maximum capacity of the machine) the maximum load that could be applied on the specimen was 40 Kg. This load corresponds to a stress equal to about 28 Kg/cm^2 on cylinderical specimen of 5 cm dia.

To keep the stirrups of the loading frame in correct vertical position, supports by means of 3.75 cms x 0.6 cm flats were provided on both sides as shown in Figure 3.

3.2.4 Loading Head

The type of loading desired for testing is such a repeated load which could rapidly be applied and removed with negligible impact effects. Therefore, in this equipment, a spring loaded telescopic loading plunger was used in the loading head to minimise the impact. A compression spring properly guided is enclosed in a two piece brass head, one piece of which is tightly screwed to the loading yoke (see Figure 3).

3.2.5 Platform

The platform is made of a rectangular frame of 2.5 cms x 2.5 cms angle irons and salwood planks of equal thickness. Extra pieces of 7.5 cms x 7.5 cms angle-irons were used under the seat of the specimens in order to prevent the platform from deflecting at the time of testing.

The size of the platform is 100 cms x 80 cms with a view to enhance its utility for testing model slabs of soil-cement.

3.2.6 Belt and Pulley Drive

To transmit the power of the electric motor to the automatic compactor wooden pulleys with grooves are used along with V-shaped rubber belt. The pulleys are made of 7.5 cms and 20 cms dia and these are keyed with the shafts of motor and the automatic compactor to check their sliding under heavy load. Continuous operation of the equipment for long hours causes loosening of the belt and arrangement to keep it tight was made.

3.2.7 An electric motor of two horse-power capacity was used as source of power to drive the compactor.

CHAPTER IV

TEST PROGRAMME

4.1 FACILITIES FOR EXPERIMENTAL WORK

The laboratory tests for unconfined compressive strength and flexure under static load conditions were carried out in the compression testing machine of 5 Tons capacity available in the Highway Engineering laboratory, University of Roorkee, Roorkee. For testing the beam specimens for flexural strength the special mount was used. For transmission of load from the head of the testing machine a steel ball was used which was placed in a groove centrally located in the upper face of a steel plate on the lower face of which two parallel steel rods were welded at a distance of 7.6 cms from axis to axis. The whole arrangement confirmed to the requirements recommended by ASTM specification[14] No. D1635 - 63.

For repeated load tests an equipment was got fabricated in the Workshop of the Highway Engineering Laboratory, the details of which have already been described in Chapter III.

Constant volume split moulds were used for moulding cylindrical specimens 5 cms x 10 cms for compressive strength tests.

The beam specimens were moulded in the moulds of size 7.5 cms x 7.5 cms x 28.1 cms and were compressed in the compression machine, to get constant volume specimens.

An oven controlled at a constant temperature of $40^{\circ} \pm 2^{\circ}C$ was used for curing of some of the specimens.

4.2 MATERIALS

Local sandy soil available in the Roorkee University campus was used for the present study. The physical properties of this soil are given in table 4.1.

The optimum moisture content and maximum dry density were adopted as 12 percent and 1.86 gm/c.c.

Ordinary portland cement from fresh stocks was used.

4.3 CEMENT TREATMENT LEVEL

To decide the amount of cement to be used, unconfined compressive strength and flexural tests were conducted on the specimens prepared with three different cement contents (6, 8 and 10 percent). From these tests 8 percent cement was selected for further study as it gave 7 days compressive strength to be more than 17.5 Kg/cm^2 (250 psi).

4.4 PREPARATION OF SPECIMENS

Soil brought from the nearby site was dried, pulverised and sieved through 2 mm. sieve.

Appropriate amounts of soil, cement and water required for compression as well as flexure specimens were calculated. Then, appropriate amounts so calculated were weighed. Soil and cement was first mixed in an air-dry condition, then the necessary amount of water was added and was thoroughly mixed for about 3 minutes. In as much as delaying compaction after mixing reduces the dry density and strength of a compacted specimen, the time lapse between mixing and compaction was tried, as far as it could be practicable, to be kept same for all samples. The amount of water-cement-soil mixture mixed each time was enough for two cylinderical specimens or for one beam specimen.

Compaction in case of cylinderical as well as beam specimens was performed by hand tamping. Tamping was done uniformly on the total area of cross-section of the mould, was done in three layers. Mix thus filled in the moulds remained uniformly projected beyond the required heights of specimens which were pressed to constant volume in the compression machines. The specimens were kept compressed for a few minutes before reverting the compression machine to take the specimens out.

All samples, except those used for the study of the effects of curing time, were cured for 7 days. Freshly prepared specimens were left for 24 hours in the atmosphere for hardening to permit handling, then these were enclosed in polythene bags, properly tied and kept in moist sand for next six days. Some specimens were cured at a constant temperature of 40°C in the oven also just for a trial to decide proper mode of curing.

4.5 TEST METHODS USED

4.5.1 Static Tests

Both, unconfined compression tests on cylinderical specimens and flexural tests on beam specimens were conducted to find out ultimate strength.

51 cylinderical specimens of size 5 x 10 cms were prepared for static tests in the manner described in Art.4.4. These specimens were tested to determine compressive strength at zero lateral pressure (unconfined) in strain controlled compression machine at a constant rate of 1.25 cm/minute. Of the total 51 compression specimens, first 18 specimens were prepared and tested at three different cement contents (6, 8 and 10 percent). These were cured under moist sand. Again 12 specimens - four at each cement content, were prepared and cured in an oven at 40°C. Specimens were enclosed in polythene bags and a tray full of water was kept on the floor of the oven to maintain humidity within the oven. Further, 4 specimens were prepared at only 8 percent cement content. These were also kept in the oven as done in earlier case but with the difference that these specimens were coated with grease before putting them in the oven. Then again four specimens were prepared at 8 percent cement content and cured under moist sand. As some variation or the other was noticed in the strength values each time, two specimens were prepared in each case before starting repeated load tests which were performed at six different stress levels. In the end one specimen was prepared and cured for ten days before testing. In addition to compressive strength, model deformation readings were also taken in typical cases.

32 beam specimens were prepared for static testing, in the manner described in Art.4.4. First 18 specimens were prepared with three different cement contents (6, 8 and 10 percent). Two specimens were tested each time before commencing repeated load tests at six different stress levels. Two specimens were tested in the end to study effect of time of curing and for that one specimen was tested after 7 days and another after 10 days of curing. All these specimens were tested for flexural strength in the same strain controlled compression machine at a rate of 1.25 m.m./min. but the load application was by means of the equipment described in Art.3.1 para 1. In addition to determining the flexural strength, model deformation readings were also taken in typical cases.

4.5.2 REPEATED LOAD TESTING

20 cylindrical specimens were prepared and cured in the manner described in Art.4.4 and these were tested under repeated load at six different stress levels viz. 90, 80, 70, 60, 50 and 40 percent of their ultimate strengths. The ultimate strengths of the test specimens were determined separately each time before commencing repeated load testing. Load to be applied was decided by multiplying this ultimate strength with the appropriate percentage. The equipment was then set to apply the required load by adjusting the weights on either side of the lever arm. Amount of load was checked by proving-ring kept under the loading head and starting the equipment to work at its normal frequency. The frequency

of the equipment was noted to be 3.85 secs/cycle i.e. the load was applied 936 times in an hour.

Four or more, until consistent results were obtained, were tested at 90, 80, 70 and 60 percent of ultimate load whereas at 50 and 40 percent stress level only two specimens each were tested. Reason being very large number of repetitions needed at lower stress-levels and also that the results obtained were consistent. The tests were continued till destruction except in case of specimens tested at 40 percent of ultimate strength where failure did not take place. The number of repetitions causing first crack and complete destruction of the specimen respectively were noted. In case of specimens tested at 40 percent of ultimate strength, tests were stopped after applying 50,000 repetitions. The specimens still secured to be unaffected and these unbroken specimens were tested by the standard method to find ultimate strength and deformation characteristics. In case of tests at low stress- levels number of load repetitions was so large that the equipment used could not work non stop. In such cases some rest was given to the motor and power transmission system at suitable intervals, to avoid overheating. Interruptions including those due to power failure were duly accounted for in working out number of load repetitions coming over the specimens.

Similarly, 20 beam specimens were prepared and cured in the manner described in Art.4.4. These were also tested under repeated loads at six different stress-levels in the exactly similar manner as described above in case of cylindorical specimens. The load transmission was through the mount as for the standard flexural strength test.

4.6 TESTS TO ACCOUNT FOR ADDITIONAL CURING PERIOD

Repeated load tests at 40 percent of ultimate strength took more than two days because of low frequency of the equipment. Thus at the time when repeated loading was stopped the specimen remained exposed to the atmosphere for about 3 days after normal 7 days curing period. To determine the effect of this three days' additional air-drying two dummy specimens of parallel curing conditions - one in case of compression and other in flexure - were tested for ultimate strength and deformation characteristics, along with the unbroken samples tested at 40% (percent) stress levels.

CHAPTER V

ANALYSIS OF RESULTS AND DISCUSSION

In the following paragraphs the results of various tests carried out have been presented and analysed and their inferences discussed.

5.1 STATIC LOAD TESTS FOR ULTIMATE STRENGTH

As reported in Art.4.5.1, tests to determine the ultimate strength of specimens had to be repeated a number of times under different curing conditions in search for correct and consistent results.

First of all, in the first half of February, compressive as well as flexural strength tests were carried out with the specimens cured under moist sand. Results are given in tables 5.1 and 5.2.

These results though fairly consistent were much on lower side. Compressive strength in 6 percent cement specimen never was more than 4.366 Kg./cm^2 (62.37 psi) and in those with 8 percent cement it did not exceed 5.926 Kg./cm^2 (84.65 psi) Even 10 percent cement which was considered to be rather a high cement content for this sandy soil did not give strength more than 7.453 Kg/cm^2 (106.9 psi). These were much below even the ordinarily expected strength of 17.5 Kg/cm^2 (250 psi). The flexural strength tests also showed similar trends. All possibilities were considered and it was found that the reason for low strength was due to low temperature of curing due to severe winter.

Then the unconfined compressive strength test specimens were again prepared and cured in the oven set at a constant temperature of 40°C. The results of these specimens are reported in Table 5.3

These results show marked increase in the strength as compared to the results contained in Table 5.1, strength going as high as 20.43 Kg/cm^2(291.80 psi) in case of 8 percent cement specimens and going upto 28.07 Kg/cm^2 (401 psi) in case of 10 percent specimens. However, the results were very much inconsistent. In case of 6 percent specimens strength varied from 6.24 Kg/cm^2 (89.10 psi) to 12.17 Kg/cm^2(173.80 psi). Similarly, other specimens showed wide variation in strength results. The reason seemed to be moisture loss from different specimens, in a varying measure, from the sealed polythene bags at this temperature. In some cases droplets of moisture condensed on the inside of polythene bag paper were clearly visible. Another cause of variation in evaporation was the differing amount of space available within the envelope. Some specimens were tightly enclosed with the paper just wrapping them, others were not. The specimens which lost moisture due to evaporation could not develop full strength due to fall in water-cement ratio.

Then, an alternative was tried by coating the specimens with grease before wrapping them in polythene paper. Only four specimens were tested under these curing conditions, the results of which are given in Table 5.4.

These results though not so inconsistent as those reported in Table 5.3 but still are not consistent. The difficulty of moisture less though rectified to a large extent but was still present. However, the strength recorded was fairly high, in no case going below 21.00 Kg/cm^2 (300 psi). Another difficulty with the oven was that though it precisely maintained a fairly constant temperature of 40^{o}C but in case of power break-down this temperature would not be maintained. April had reached by this time and atmospheric temperature was also increasing and so another attempt was made to examine the success of curing in atmospheric temperature. Results are given in the Table 5.5.

Those results showed that at this temperature of atmosphere specimens were developing reasonable strength consistently and it was decided that specimens for further testing will be cured under moist sand. However, as the further testing was to be carried out from April to June during which the atmospheric temperature was likely to vary and so it was felt necessary that at the time of beginning the repeated load testing for a particular set of specimens, two specimens will be tested for ultimate strength each time again and again. This whole exercise reveals the strong influence of curing temperature on the strength of soil-cement.

5.3 STUDY OF REPEATED LOAD APPLICATIONS ON COMPRESSIVE STRENGTH SPECIMENS

The repeated stress applications were made with different stress levels of 50, 60, 70, 80 and 90 percent of their ultimate strengths. Frequency of load application was the same in all cases i.e. 3.85 secs/cycle or 15.6 rpm. The number of repetitions required for destruction of the specimen in each case was noted. The results obtained are plotted in figure 5. However, the specimen did not fail under 50 percent stress level. Even after 50,000 stress applications after which its ultimate strength was determined.

5.3.1 Effect of Number of Stress - Applications on Compressive Strength

In figure 5, a graph has been plotted in which the number of stress applications have been plotted on Y-axis in log scale and on the X-axis the different stress-levels on which the various tests were carried out have been plotted.

Evidently, the number of repetitions causing failure is more in case of lower stress levels as compared to higher stress levels. The early trend of the curve upto 70 percent stress level does not indicate any specific relationship between number of load applications and the level of stress application. However, there is steep rise in the number of stress applications taken by the specimens below 70 percent stress-level and below 40 percent stress level the specimen can take indefinite number of load applications. This means that whatever be the amount of traffic, the soil cement base designed for about double the strength required in an unconfined compressive strength test will have no chance of failure due to fatigue. This result is in conformity with the similar experiences on cement concrete. However, this study is incomplete because many variables e.g. frequency of load application, curing period, type of loading, specimen type and shape etc. have not been considered.

5.3.2 Study of Stress/ Strain Relationship in case of cylindrical specimens

Stress-strain relationships have been considered in cases of i a specimen cured for 7 days. ii an unbroken specimen which took 50,000 repetitions at 40 percent stress-level and iii another specimen of the same age. Strains are plotted on X-axis and stresses on Y-axis. (See fig.7).

In case i the strain noted is much higher than the following two cases which means that the strength has increased with age in the specimens of cases ii and iii. An interesting thing to be noted is that the strain in case of the specimen which had taken 50,000 repetitions of 40 percent stress was lesser than the dummy specimen of the same age. This means that repeated load application has increased the strength of the specimen at this stress level viz. 40 percent. This is a curious phenomenon which need to be studied further. One of the possible explanation is that rearrangement of particles takes place during repetitions of stresses as is the case in simple soil specimens. However, similar conclusion was drawn by Chen and Mitchell also in their studies.

All the three curves are steeper in the beginning, then they become flatter. In the end there is sudden spurt in the strain due to incipient failure of the bonded material. This can be explained because the rate of strain will progressively decrease as the load increases.

5.3.3 Effect of Stress Applications on Flexural Strength

In Figure 6, a graph is plotted showing the relationship between number of stress applications causing failure and stress levels to bring out the effect of stress application on the flexural strength. Number of stress-applications are plotted on Y-axis (log - scale) and stress levels are plotted on X-axis.

As in case of compressive strength tests number of repetitions causing failure is more in case of lower stress-levels as compared to higher stress-levels. However, the trend of the curve in this case is definite. It is flat at low stresses and becomes progressively steep as the stress-level reduces. Very much more number of stress-applications can be taken at lower stress-levels as compared to higher stress-levels. In this case even at 50 percent stress-level the specimen does not fail as against 40 percent in case of compressive strength specimen. It means that the specimens at flexture can stand the low stress levels in a slightly better way.

5.3.4 Study of Deflection V/s Modulus of Rupture Relationship in case of Beam Specimens

In case of flexural strength tests also deflection V/s flexural strength relations were considered. Three parallel cases as reported in Art.5.3.2 were considered in this case also. The only difference being that in case unbroken specimens took 50,000 repetitions at 50 percent stress level. These relationships are plotted in Figure 8.

In case i the strain noted is much higher than the following two cases which confirms the earlier result that the strength (flexural in this case) increases with age. As in case of compressive strength specimens, the increase in strength of specimen is noted due to repeated stress applications. This increase is rather more pronounced in this case due to considerable difference in the ultimate strengths of the specimens in cases ii and iii . Also this increase in strength has taken place even at 60 percent of stress-level. This curious phenomenon though is in line. With the results obtained in an earlier study, needs further investigation.

CHAPTER VI

CONCLUSIONS

1. Temperature of curing has a vital effect on the strength-development in soil-cement both in compressive as well as flexural strength.

2. Moisture losses during curing drastically affects the strength of soil-cement specimens.

3. Soil-cement specimen gain in strength considerably with age of curing. In case of compressive strength specimens, ten days strength was 39 percent higher than seven days strength whereas in case of flexural strength, the gain in strength was 43 percent in case of specimens cured for ten days as comprod to those cured for seven days (under specific curing conditions).

4. Both flexural and compressive stresses applied repeatedly adversely affect the strength of soil-cement specimens at higher stress levels.

5. At low values of repetitive stresses the strength values of soil-cement specimens shows a definite increase after 50,000 applications of stresses. In case of compressive strength, failure did not occur at repeated stresses equal to 40 percent of ultimate strength, whereas in case of flexural test, the specimen did not fail even with 50 percent of ultimate strength applied 50,000 times.

6. The effect of repetitive loading on compressive strength is not consistent whereas in case of flexural strength it consistently increases at low stress levels.

7. The relation between applied stress (flexural) and number of load repetitions (log-scale) is not linear as in the case of concrete. However, the general belief that concrete can take unlimited number of load applications if stress is not exceeding 50 percent of ultimate strength may be considered applicable in the case of soil-cement also in the light of this study.

TABLE 4.1

PHYSICAL PROPERTIES OF THE SOIL

Percentage passing 200 ASTM	Liquid Limit	Plastic Limit	Plasticity Index	Group Index	Classification U.S.P.R.A.	Unified
5	NP	NP	NP	0	A-3(0)	SU-SP

TABLE 5.1

UNCONFINED COMPRESSIVE STRENGTH TEST RESULTS

MODE OF CURING - Under moist sand

TIME OF TEST - First week of February

Cement Content	Specimen Number	Reading on proving ring dial (divisions) 1 division = 7 lbs	STRESS psi	STRESS Kgm/cm²
6%	1	26	57.92	4.05
	2	23	51.23	3.59
	3	27	60.15	4.21
	4	28	62.37	4.37
	5	26	57.92	4.05
	6	22	49.00	3.43
8%	1	38	84.65	5.93
	2	36	80.19	5.61
	3	32	71.27	4.99
	4	33	73.50	5.15
	5	38	84.65	5.93
	6	35	77.96	5.64
10%	1	48	106.9	7.48
	2	46	102.4	7.17
	3	46	102.4	7.17
	4	42	93.33	6.53
	5	45	100.2	7.00
	6	47	104.7	7.34

TABLE 5.2

FLEXURAL STRENGTH TEST RESULTS

MODE OF CURING - Under moist sand

TIME OF TEST - Second week of February

Cement Content	Specimen Number	Reading on proving ring dial (Division) 1 Division = 7 lbs.	Modulus of Rupture= $\frac{Pl}{bd}$	
			psi	Kgm/cm^2
6 percent	1	18	42.00	2.94
	2	16	37.33	2.61
	3	15	35.00	2.45
	4.	17	39.67	2.78
	5	18	42.00	2.94
	6	17	39.67	2.78
8 percent	1	26	60.67	4.25
	2	27	63.00	4.41
	3	28	65.33	4.57
	4	28	65.33	4.57
	5	27	63.00	4.41
	6	26	60.67	4.25
10 percent	1	29	67.67	4.74
	2	31	72.33	5.06
	3	32	74.67	5.23
	4	33	77.00	5.39
	5	31	72.33	5.06
	6	30	70.00	4.90

TABLE 5.3

UNCONFINED COMPRESSIVE STRENGTH TEST RESULTS

MODE OF CURING - In the oven set at 40°C

TIME OF TEST - First week of March

Cement content	Specimen Number	Proving ring dial gauge reading 1 Division = 7 lbs	Compressive strength psi	Compressive strength Kgm/cm^2
6 percent	1	78	173.80	12.17
	2	40	89.10	6.24
	3	70	155.90	10.91
	4	48	106.90	7.48
8 percent	1	125	278.40	19.49
	2	85	189.30	13.75
	3	102	227.20	15.90
	4	131	291.80	20.43
10 percent	1	93	207.10	14.50
	2	180	401.0	28.07
	3	120	267.30	18.71
	4	130	289.30	20.25

TABLE 5.4

UNCONFINED COMPRESSIVE STRENGTH TEST RESULTS

MODE OF CURING - In the oven at 40°C. Specimens coated with grease.

TIME OF CURING - Third week of March

Cement Content	Specimen Number	Proving ring dial gauge reading 1 Division= 7 lbs.	Compressive strength psi	Compressive strength Kgm/cm^2
8 percent	1	142	316.30	22.14
	2	165	367.30	22.77
	3	135	300.70	21.20
	4.	148	329.70	21.52

TABLE 5.5

UNCONFINED COMPRESSIVE STRENGTH TEST RESULTS

MODE OF CURING - Under moist sand

TIME OF TESTING - Second week of April

Cement Content	Specimen Number	Proving ring dial gauge reading 1 Div.=7 lbs.	Compressive strength psi	Compressive strength Kg/cm^2
8 percent	1	142	316.3	22.14
	2	146	325.3	22.77
	3	136	302.9	21.20
	4	138	307.4	21.52

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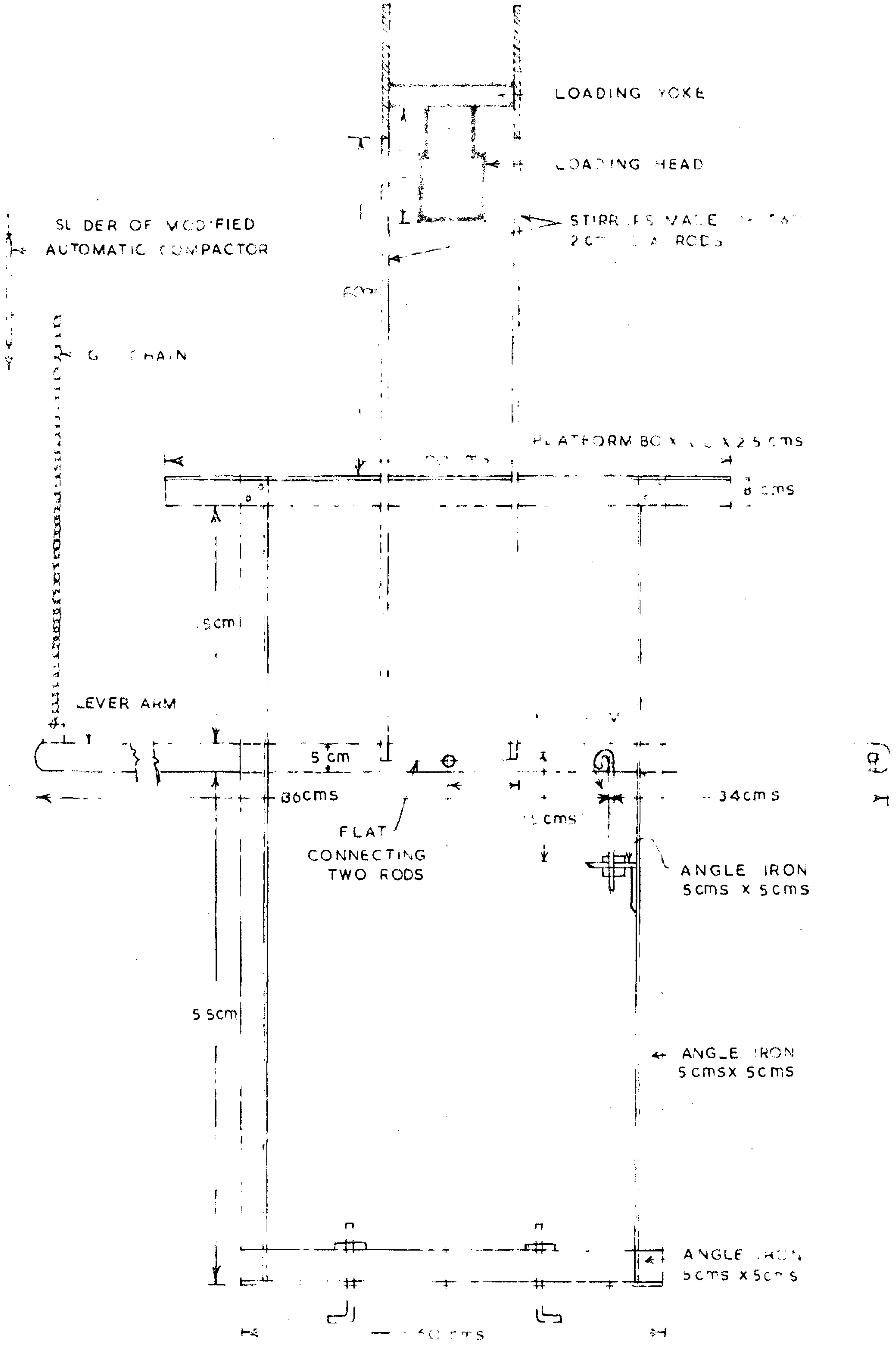
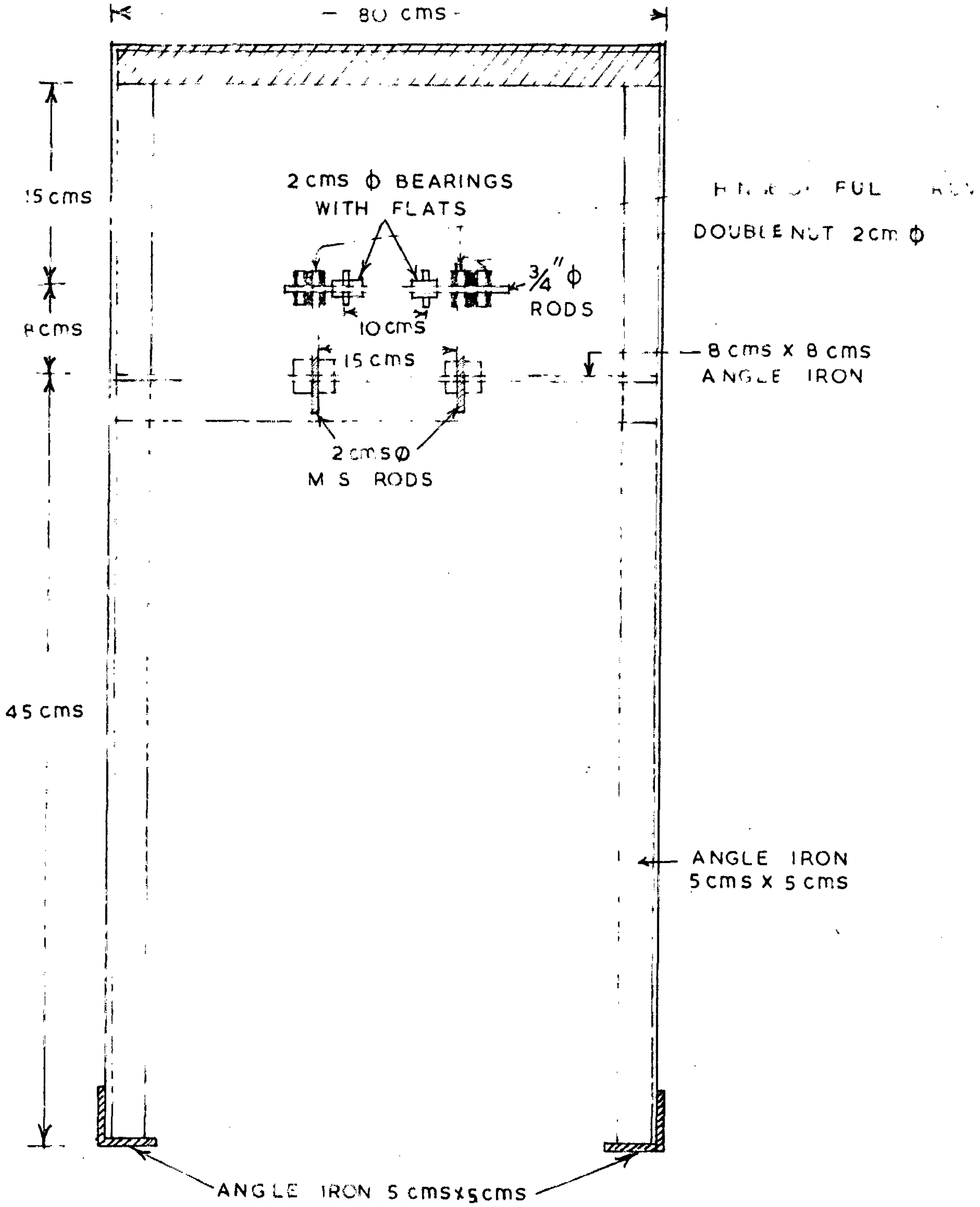


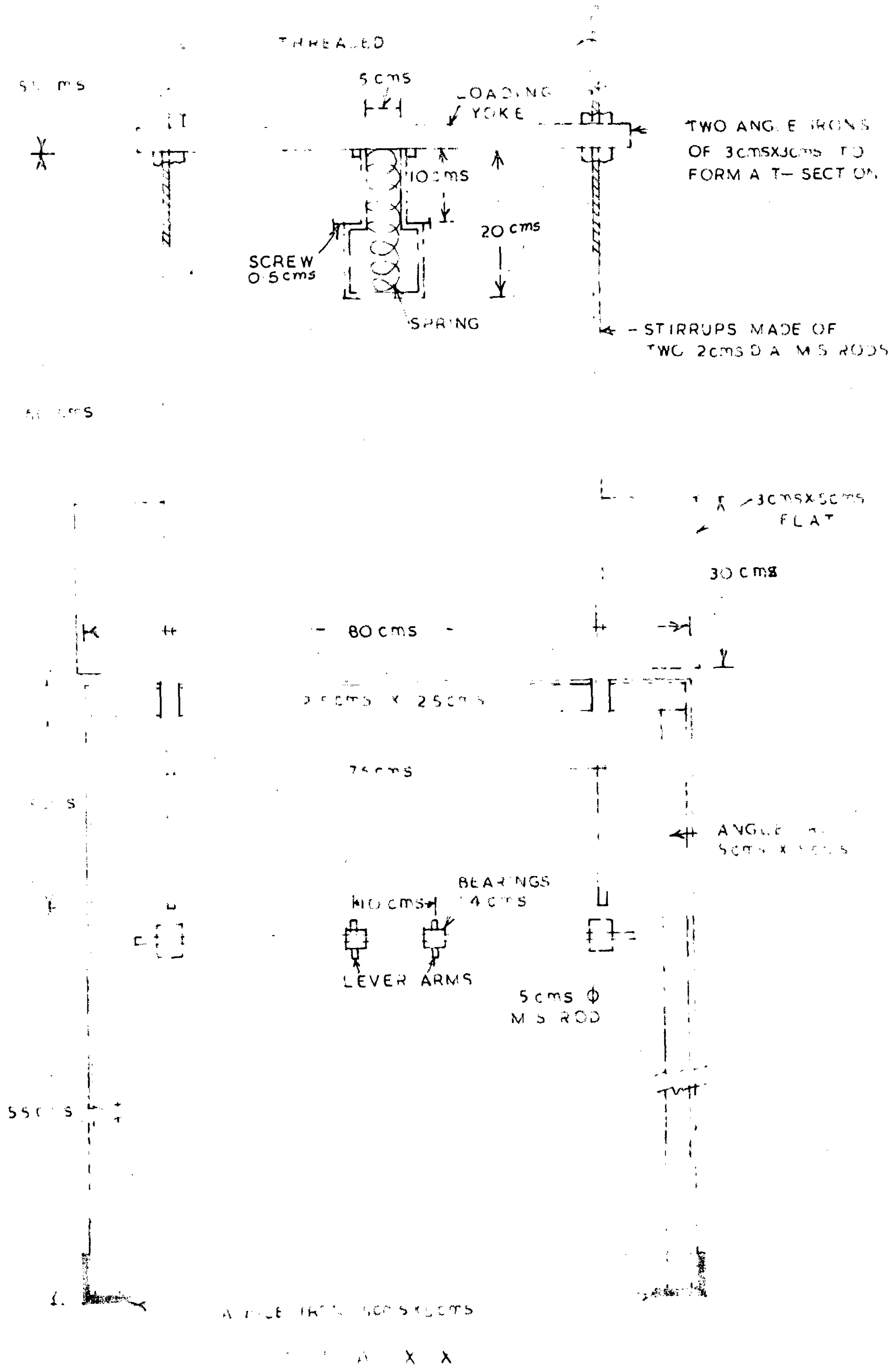
LOADING YOKE
LOADING HEAD
STIRRUPS MADE
2 CM RODS
SLIDER OF MODIFIED
AUTOMATIC COMPACTOR
CHAIN
PLATFORM BOX
8 cms
5cm
LEVER ARM
5 cm
36cms
34cms
FLAT
CONNECTING
TWO RODS
cms
ANGLE IRON
5cms x 5cms
55cm
ANGLE IRON
5cmsx 5cms
ANGLE IRON
5cms x5cms



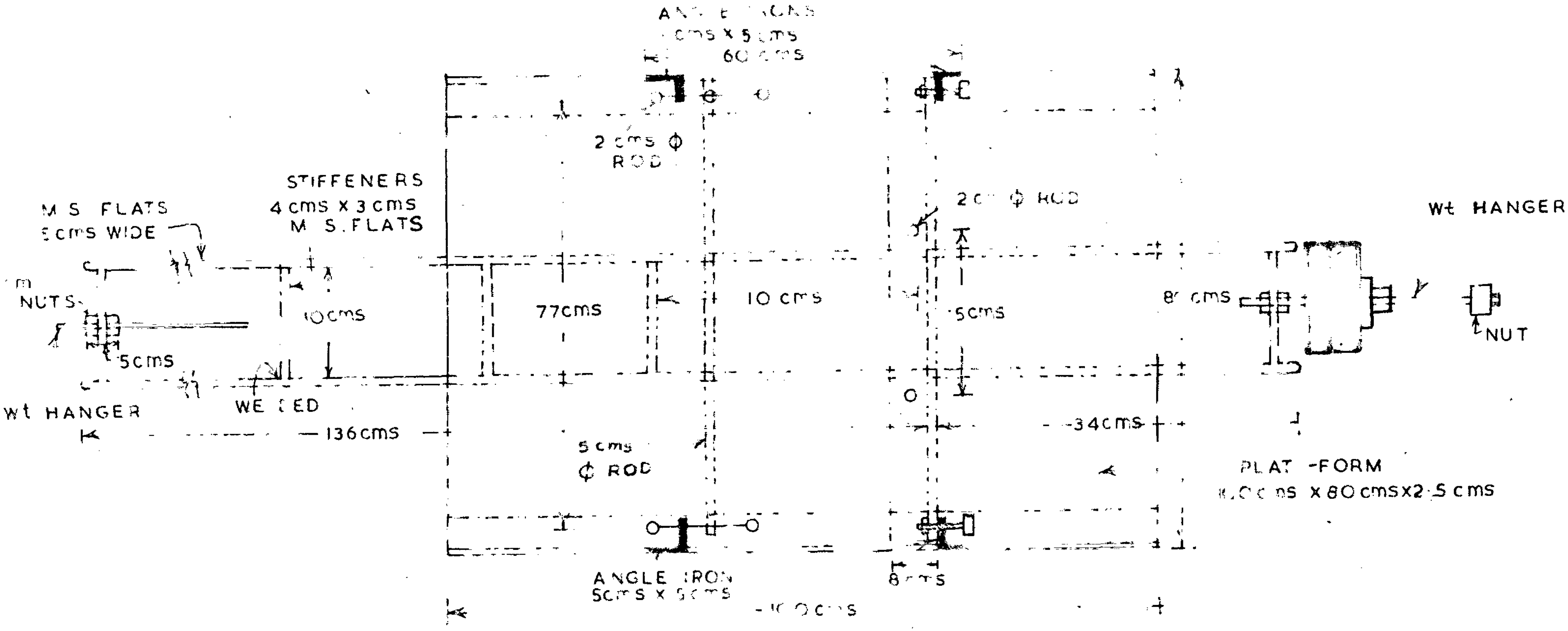
SECTION AT Y-Y

DETAILS OF FULCRUM

FIG. 2



DETAILS OF LOADING ARRANGEMENT


STIFFENERS
4 cms x 3 cms
M S. FLATS
M S FLATS
NUTS
5cms
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136cms
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77cms
2 cms Φ
ROD
5 cms
Φ ROD
10 cms
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NUT
PLAT -FORM
X 80 cmsx2 5 cms

PLAN

4

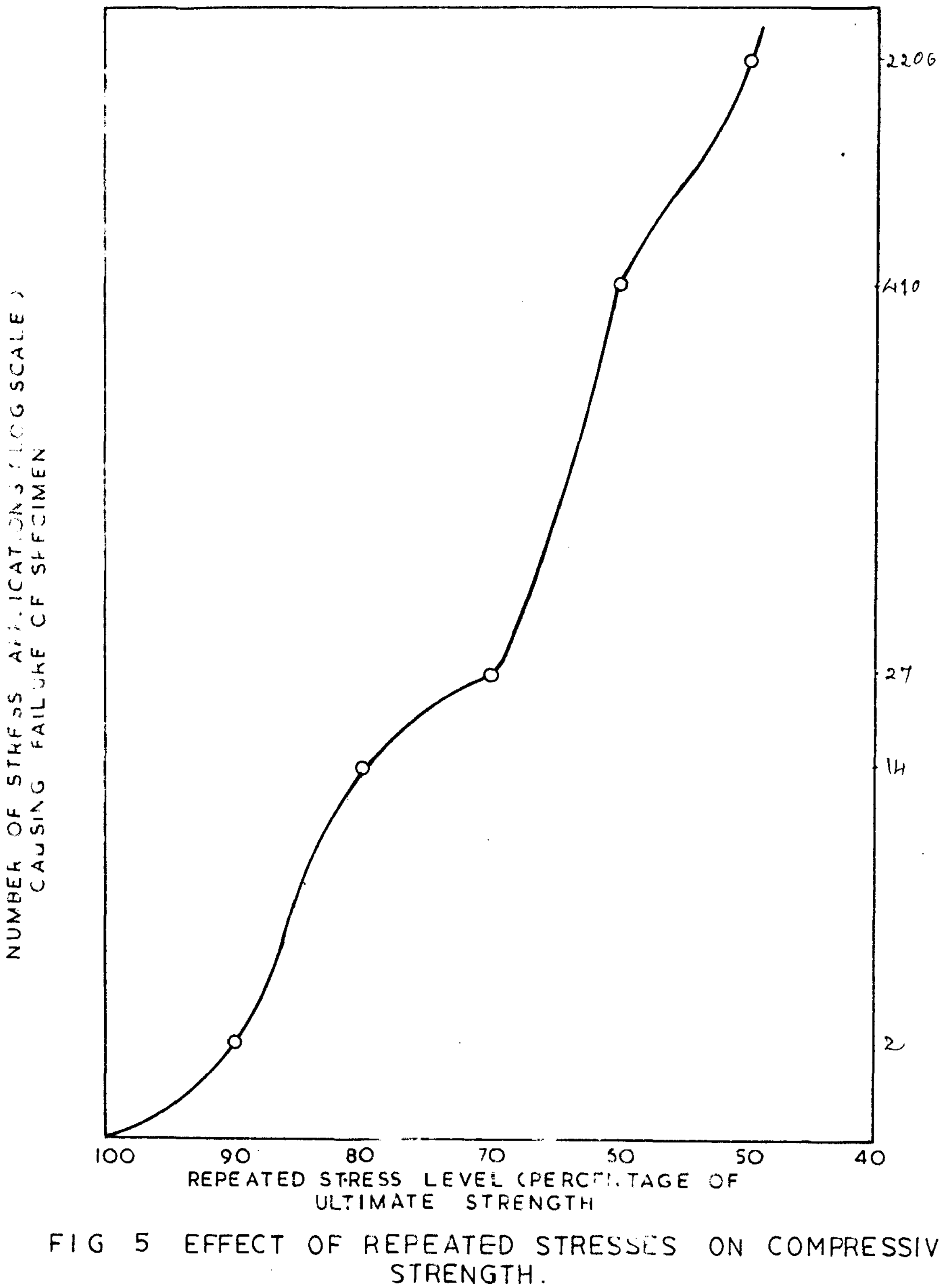

FIG 5 EFFECT OF REPEATED STRESSES ON COMPRESSIVE STRENGTH.

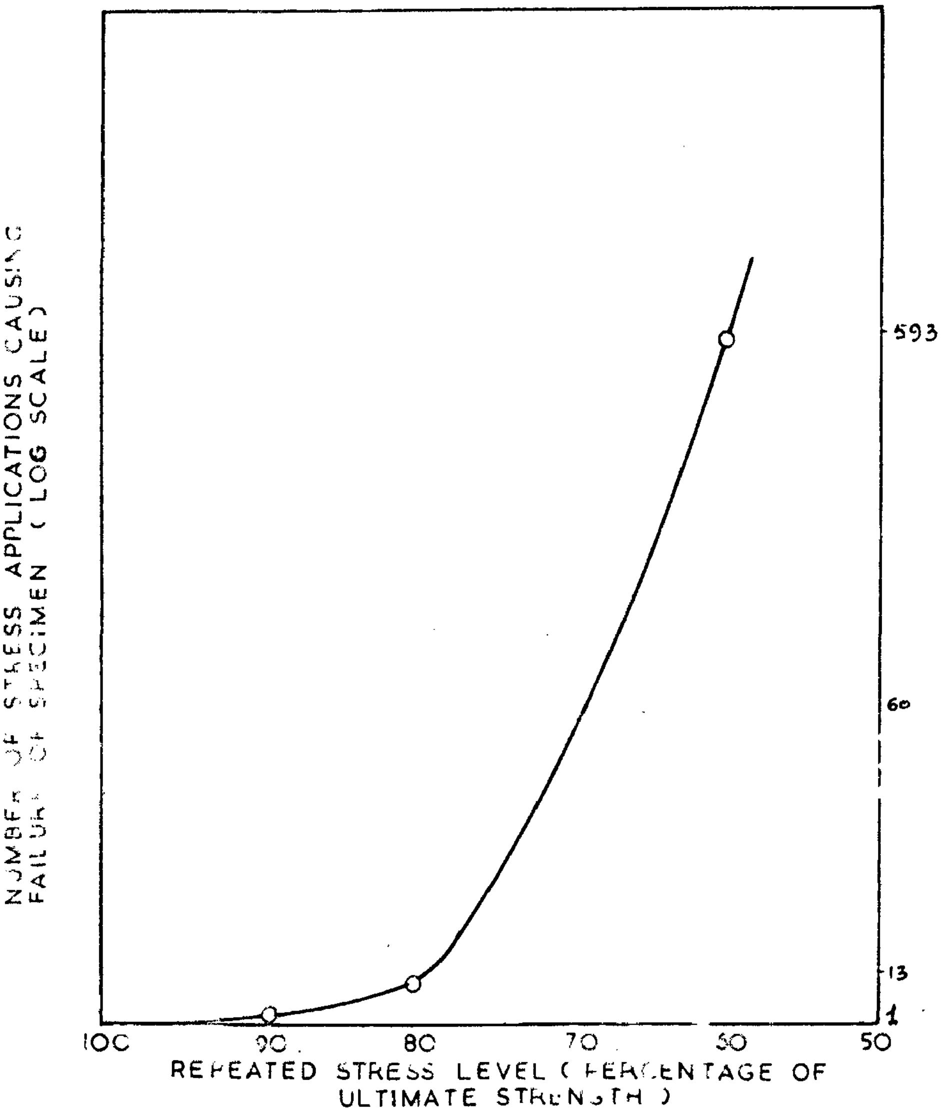

FIG. 6 EFFECT OF REPEATED STRESS ON FLEXURAL STRENGTH.

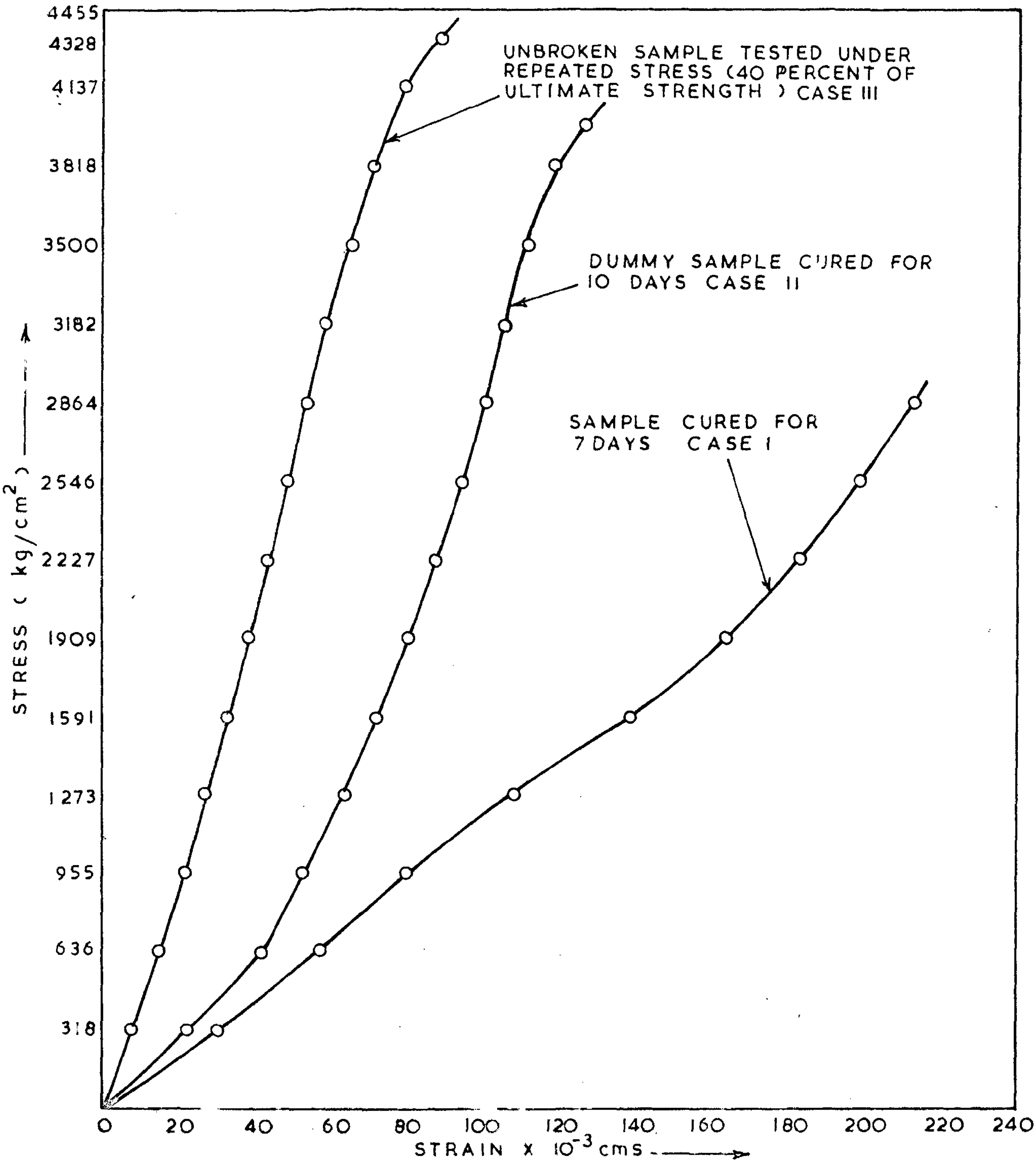

FIG. 7 COMPARISON OF STRESS STRAIN RELATIONSHIP IN CASE OF CYLINDERICAL SPECIMENS CURED FOR 7 DAYS, FOR 10 DAYS AND SPECIMEN ON WHICH REPEATED STRESS HAD BEEN APPLIED (50,000 REPITITION OF 40 PERCENT OF ULTIMATE STRENGTH)

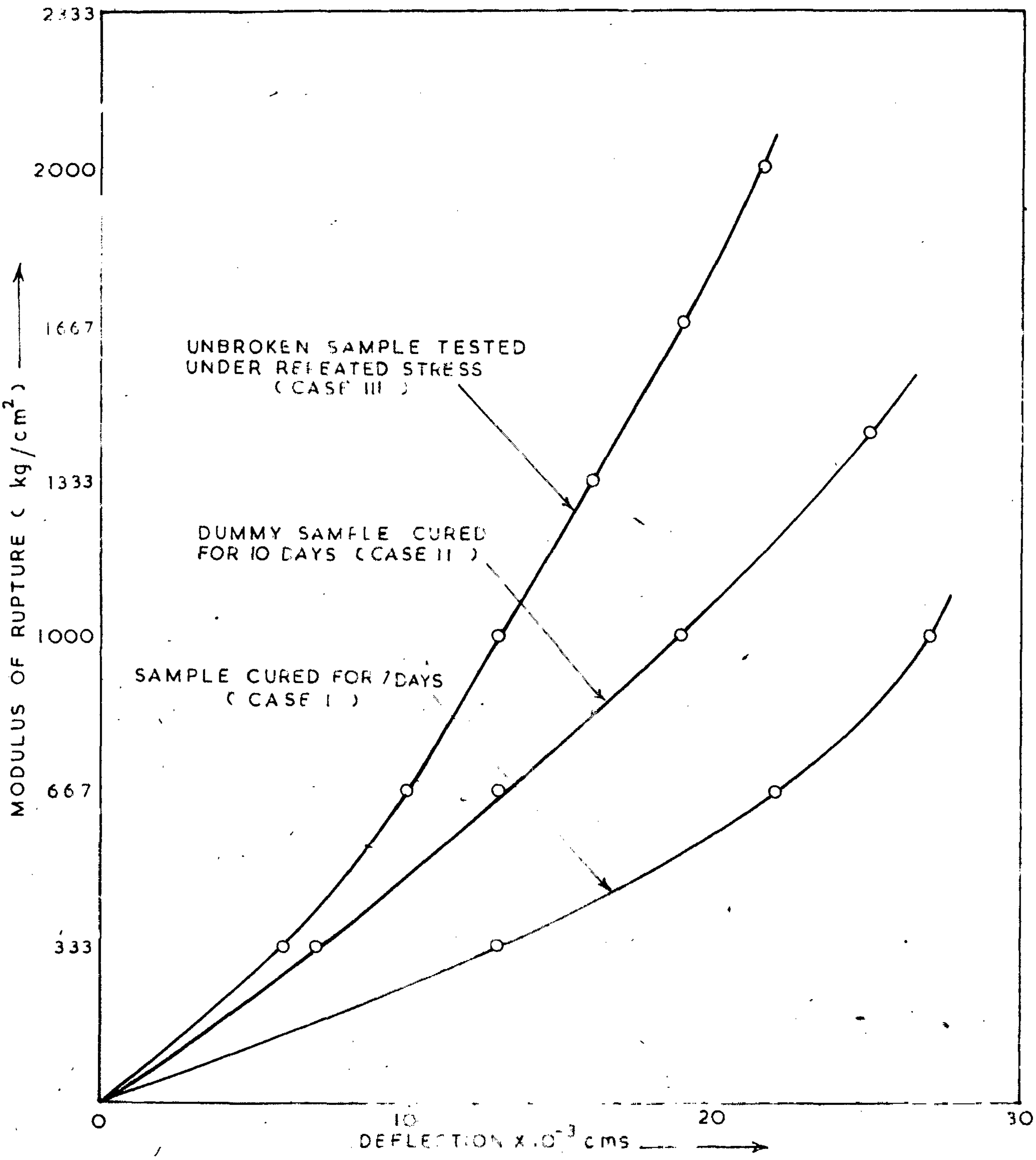

FIG 8 COMPARISON OF MODULUS OF RUPTURE Vs DEFLECTION RELATIONSHIP IN CASES OF BEAM SPECIMENS CURED FOR 7 DAYS, FOR 10 DAYS AND SPECIMEN ON WHICH REPEATED STRESS HAD BEEN APPLIED (50,000 REPITITION OF 50% OF ULTIMATE STRENGT