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Testing of ferro-cement

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**WOLLONGONG UNIVERSITY COLLEGE
THE UNIVERSITY OF NEW SOUTH WALES**



TESTING OF FERRO-CEMENT

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SCHOOL of CIVIL, MECHANICAL and MINING ENGINEERING.

May, 1972

THE TESTING OF FERRO-CEMENT
AS USED IN
THE BOAT BUILDING INDUSTRY

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THE TESTING OF FERRO-CEMENT AS USED IN THE BOAT

BUILDING INDUSTRY

ABSTRACT

At the present time there does not appear to be any standard methods of testing for ferro cement products used in the Boat Industry anywhere in the world.

Throughout the literature many tests are suggested, but, in general, are not definitive nor specified in detail.

This work considers testing procedures, equipment, and techniques with recommendations where possible for relevant tests on ferro cement products. Also included are results normally to be expected in practice.

1. INTRODUCTION

At present there appears to be an increased activity in the building of ferro cement boats in Australia. Although such boats have been built throughout the world since 1943, most activity has been in England, Canada and New Zealand where the boats built have been of the size for fishing.

In Australia many sailing vessels, including yachts, have been built, but these have generally not been licensed fishing boats. As fishing boats may be required to carry passengers they must pass appropriate tests as laid down by the pertinent Maritime Services Board, and, in many cases, insurance companies. At the present time, there is no Australian Standard covering the testing of such materials, although some A.S.T.M. Methods of Test for Honeycomb and Sandwich Materials could be applied.

At this stage, it may be worthwhile to note that currently most fishing boats are made of suitably ribbed sheets plastered in situ within, and around, a steel matrix as shown in Figure 1. The steel matrix generally is composed of $\frac{1}{4}$ " steel reinforcing rods running longitudinally at $2\frac{1}{4}$ " centres with $\frac{3}{16}$ " rods running transversely at $2\frac{3}{4}$ " centres, both being contained within up to 8 layers of wire netting - the steel framing being of the order of $\frac{1}{2}$ " thick. The entire skin is of the order of $\frac{3}{4}$ " to $\frac{7}{8}$ " thick, giving at least $\frac{1}{8}$ " cover. Most hulls are sanded smooth and then coated with epoxy-resin type materials to prevent the ingress of water. The type of wire mesh used is variable, some using 22 gauge, $\frac{1}{2}$ " mesh, galvanised bird wire subsequently treated with a 5% phosphoric acid solution, while others use black 22 gauge $\frac{1}{2}$ " square mesh fabric.

2. CEMENT, AGGREGATES - POZZALANIC MATERIALS USED

The type and quantity of cement, metal and aggregates should be specified by the design engineer.

A typical mortar mix is as follows :

180 lbs sand (sharp river),

100 lbs blast furnace pozzalana cement (15 lbs pozzalana
and 85 lbs Portland cement,

40 lbs water.

The water content given is sufficient to make a firm mix, with a water cement ratio of 0.40.

Rarely are chemical additives used. Since blended B.F.P. cements are now available commercially, their use is becoming more popular. When such cements are used, their use should be associated with A.S. No. A181-1971 or A.S. No's 1129 and 1130, 1971.

3. TEST ON MATERIALS USED

The normal strength tests for quality of cementing materials and aggregates and water are covered by relevant Australian Standards. Procedure for the manufacture of cylinders and equipment to be used should follow A.S. No. A103-1968. Curing should be carried out as per A.S. A103 for 28 days.

Of the six cylinders taken, three should be tested in compression, capping and testing to be conducted as per A.S. No. A104-1969, and three should be tested in tension as per the Splitting Tensile Test, A.S. No. A111-1967.

The appropriate strengths to be attained are design figures, but strengths to be expected are generally of the order of 6,000 lb/sq.in. for compression and 900 lb/sq.in for tension.

4. TYPE OF TESTS REQUIRED

The testing of materials used for ferro cement can be conveniently subdivided as follows :-

- (a) Material tests
- (b) Static strength tests on coupons from test panel
- (c) Dynamic (impact and fatigue) strength
- (d) Environmental tests

Standard tests on the mortar used are required and are given in A.S. No. A104.

Test panels made at the same time as the hull provide test coupons for all other tests.

The static strength tests normally carried out on the finished product are for tension, bending, shear, and compression. Such tests on steel reinforced composites are not covered by Australian Standards.

The dynamic strength test normally carried out is for impact strength. A constant strain fatigue life test is also required. Neither of these tests are covered by relevant Australian Standards.

5. TEST PANELS REQUIRED

The test panels should be made at the same time as the hull. Some statutory bodies require relatively large panels of test material to be made; for example, one authority requires a panel 6' x 4' made in a vertical plane. This size is most difficult to make (i.e. "floppy" during manufacture) and also is difficult to subsequently handle and "break" down to required sizes. Generally, panel sizes should be of the order of 24" x 24". The only exception to this size is a specially large panel for an impact test as described later.

Assuming that the entire hull of a 45 ft boat is to be made continuously, then eight 2 ft x 2 ft panels are made at equal intervals during the manufacture of the hull. Six are for testing and two as spares, as required. Finally, the special impact test panel of size 4' x 2' should be made. Both types of panels should be made in a vertical plane on rigidly supported steel frames with a clear inside width dimension of 26". On such frames should be attached steel reinforcing identical to that used in the hull. The steel reinforcing and mesh should be wired to or located within the steel frame in such a manner as to enable removal of the panels without causing any undue stressing. A sketch of a suitable frame is shown in Figure 2.

Curing of the hull is generally done by enclosing the entire hull in a large plastic envelope and spraying the hull with water. If this technique is specified by the design engineer, or for that matter, any other, then the panels should be cured in a similar manner in order that test results are directly comparable to the hull. Generally the curing

6.

procedure is continued for up to 28 days, the panels not being moved from their casting position due to possible damage resulting if moved. Both the test panels and the hull should be cured for the same period of time.

6. SIZE AND DISPOSITION OF TEST COUPONS

As stated previously, one size of steel reinforcement usually is placed longitudinally and another size, at a different pitch, is placed transversely. This leads to the finished material exhibiting orthotropic properties and requiring two separate series of tests. One series of test coupons (called longitudinal) will be cut from the test panels such that the longitudinal steel is parallel to the length of the coupon, while the other series of test coupons (called transverse) will be cut such that the transverse still is parallel to the length of the test coupon.

The size of the coupons is dictated to a large degree by the pitch of the reinforcement. The pitch is, however, of the order 2" to 3". For a 3" pitch, coupons should be $2\frac{1}{2}$ " wide with the single reinforcing rod disposed within a $\frac{1}{4}$ " of centre. The exceptions to this is the coupon for a fatigue test which is 5" wide.

The length of the coupons should vary from 12" to 22" for various tests as shown in Fig. 3. A clear test section of 6" length will include at least two pieces of cross reinforcement. The test coupons should be cut as shown in Figure 3.

The cutting of such panels frequently presents problems and unfortunately the coupon characteristics are often impaired by cutting off with a portable high speed abrasive type wheel. It has been found best to slice the specimen with a high speed diamond slitting wheel. Considerable care should be taken to produce a continuous edge on the coupon. When the coupon is made by cutting the edges progressively

deeper at each pass, discontinuities often result. Naturally, these discontinuities produce localised stress raisers and materially affect results, especially those from fatigue tests.

7. STATIC STRENGTH TESTS

For the various static strength tests described, some test results can be expected to yield low results due to possibility of poor manufacturing techniques. It should be acceptable to take the average of the best three of four tests. If, however, more than one test is markedly low in comparison to the others, then the whole set of coupons from that panel should be rejected and the spare panel used.

7.1 Tension Tests

The method of holding tensile coupons should be such as to produce no bending effects in the specimen under load. This can be achieved only by using two-directional swivel joints at each end. Such end attachments are defined in A.S.T.M. C273-61 "Shear Test in Flatwise Plane of Flat Sandwich Constructions". The attachment to the coupons can be achieved successfully using an epoxy resin adhesive. A U-shaped fixture as shown schematically in Figure 4 has been used successfully by the authors, Araldite Resin CY230 with Hardener HY951, being the adhesive used.

Most coupons tested exhibit cracking adjacent to a transversely disposed piece of reinforcing bar when loaded in tension.

Although tensile coupons frequently are capable of sustaining further loads, the load at first sign of cracking is used to calculate the tensile stress at failure.

The tensile stress recorded is calculated on the gross section and not on the nett area of concrete at the failed section. The final figure presented for the tensile strength should be the average of three such tests.

7.2 Bending Tests

Again, as for most subsequent tests noted, if there is differing reinforcing used in longitudinal and transverse sections, then two such series of tests are required.

Bending test coupons should be of the order of 5" wide by 20" long. Four point loading, as shown in Figure 5a should be used, this loading producing a constant bending moment in the mid 6" section. A further bend test is as shown in Figure 5b. On occasions both tests may be required as a check against the other.

Shown in Appendix 1 are sample calculations for the apparent stress (generally tensile) at failure of the bend specimens.

Considerable care should be exercised at the points of loading and light capping with neat Portland cement should be used. The loading jig used should conform generally to A.S. No. A106-1957 or A.S.T.M. C78-64, "Flexural Strength of Concrete". Such an arrangement allows for all possible distortions of the specimens used.

7.3 Shear Tests

Test specimens used for shear tests should be of the order of 12" long by 2" wide. Such a size allows two tests to be made on the one specimen, if required. With shear tests small voids or uneven properties at the section being sheared frequently cause the upper platen of Figure 6 to tilt slightly and give an erroneous result.

The upper platen is aligned by two rods, centrally disposed, attached to the lower platen and extending through the upper platen.

Results from three test specimens should be averaged for the final figure presented. Again, the gross area of the two sections being sheared should be used.

Any marked crumbling of the sheared edges should be noted, for under normal conditions with the mix noted earlier, relatively sharp edges are produced.

The disposition of the reinforcing for shear tests should be such that only one longitudinal piece of reinforcing is contained in the specimen. No transverse steel should be disposed within $\frac{1}{2}$ " of the vertical projection of the upper platen.

7.4 Compression Tests

Some statutory bodies require compression tests on panel specimens up to 6" x 6". This size of specimen would appear to be too large and not give a result of any significance.

The compression test on such larged sized specimens would only indicate large voids or faults made during placing of the mortar. This latter test for voids or poor workmanship is best made by a visual inspection of all sawn edges. An inspection of all such edges would give quite a representative view of the workmanship used, including both the placing of mortar and also the final positioning of all of the steel reinforcing (both steel rods and wire mesh).

8. DYNAMIC STRENGTH TESTS

8.1 Impact Tests

Nervi (1) reports impact tests conducted on 5 ft x 5 ft x 1.1" thick slabs by dropping 560 lbs on them from heights up to 10 ft. Apparently, greater heights caused the slabs to fail by cracking of concrete and yielding of the slab, although the slab did not disintegrate.

Usually the impact properties of concrete products is measured by the energy absorbtion from a pendulum.

Under impact, it has been shown (2) that the ability of concrete to absorb strain energy is increased considerably as the duration of the impact time is decreased. Tests reported indicate that, for high strength concrete, by reducing the impact time from 0.9 seconds to 0.00043 seconds -

- (a) the ratio of dynamic to static compressive strength increases from 1.13 to 1.85, and
- (b) the ratio of dynamic to static modulus of elasticity decreases from 1.47 to 1.33".

Very few results are reported for dynamic tensile stresses. Under impact, with a 5' x 5' sheet supported at its edges, the mechanism of failure would be initiated by a tensile failure on the face opposite to the impact. This is pre-supposing that the impact load is applied by means of a bag of lead shot or similar "variable shape" load. Quite obviously, if the load is applied by means of a hammer blow, there would be crushing, shear, or compression, apart from a tensile failure.

However, as impact strength is probably more closely associated with tensile strength (3), a more detailed examination of theoretical relationship is required.

Within the building industry, polyurethane filled building boards are commonly tested for impact by dropping a 50 lb sandbag from heights up to 15 ft on to sheets simply supported at their edges.

The test reported by Nervi whereby a 560 lb weight was dropped on to a 5' x 5' sheet from heights up to 10 ft would appear to be rather harsh as the impact velocity (from 10 ft) of the 560 lb weight would be nearly 20 m.p.h.

However, in view of the results reported by Nervi, an interim standard height and weight might be established, this figure to be clarified by further extensive experimental investigations. With such tests, the load should be made of lead shot contained in a heavy hessian container. As an interim however, a weighted bag dropped from a height of 15 ft on to a simply supported panel of span 36" and width 24", would be sufficient. The magnitude of the weight for 1" thick panels should be 220 lb. For other thickness panels, as a guide, the weight would be $220 d^2$ lbs where d is the overall thickness of the panel. Such a procedure would test the resilience and energy absorbing characteristics of ferro-cement skins.

It has been found by the Authors that a 220 lb bag dropped from 20 ft repeatedly fractures 1" panels made generally as described.

8.2 Fatigue Tests

For ferro-cement skins as used for general maritime work, fatigue tests are essential due to the low frequency vibrations so often met

with on trawlers and the like.

Unfortunately, the analysis of results from fatigue tests is clouded due to the unknown value of the modulus of elasticity, both static and dynamic.

Recent reports (4), (5) and (6) indicate that, in reversed bending, with a maximum stress of approximately 600 p.s.i. cracking occurred at 2×10^6 cycles. When the stress was raised to 1,100 p.s.i. there was cracking at 10^5 cycles. These figures are to be compared to those reported (7) for the fatigue testing of high strength concrete in tension where there was no cracking at 10^7 cycles at a 40% stress level, and no cracking at 5×10^3 cycles at an 80% stress level. The latter tests were conducted at 1,000 cycles/minute.

A relatively simple fatigue testing machine has been developed by the Authors whereby a specimen, 22" long by 5" wide, is simply supported at 20" centres as shown in Figure 7.

The centre of the beam is deflected up to 0.035" either side of centre to give reversed stresses on the extreme fibres. The machine tests at constant strain, as the modulus of elasticity changes with time and rate of loading.

Very little equipment exists that will determine stress absolutely at the fibres of the specimens. Previous results (5) indicate that an equivalent modulus of elasticity of 1.3×10^6 p.s.i. was used. On this basis, with a 20" span, to produce an initial, static stress level of 700 p.s.i., a deflection, from the unloaded position of some 0.03" is required. Sample calculations are shown in Appendix 2.

From initial studies it would appear that if a specimen will withstand a stress level of 700 p.s.i. (based on $E = 1.3 \times 10^6$ p.s.i.) for 2×10^6 cycles, without cracking, it will be satisfactory. Tests conducted to date by the Authors have been made at 2,850 cycles/min. At this speed, no heating of the specimen has been observed. Results to date are shown in Figure 8.

A further study is currently in progress on equivalent stress levels existing in the specimen, and the stress levels are being recorded as a function of number of cycles. For this study, pre-calibrated photoelastic material is attached to the specimen and studied with a reflective polariscope, the light source being stroboscopic. Tests to date indicate the equivalent static modulus of elasticity of the material used is initially 1.27×10^6 p.s.i.

Further results will be reported on effects due to speed of testing, stress level versus number of cycles to failure for varying sections, densities and geometrical arrangements of steel reinforcement.

As an interim however, it is recommended that a constant strain test be conducted on panels 5" wide simply supported at a span of 20". The central point is to be loaded and moved 0.035" away from the centre line in both directions at a rate of approximately 1500 cycles/minute. The panel should withstand 10^6 cycles without any indications of cracking.

The disposition of the reinforcing should be such that two longitudinal rods are contained in the 5" wide specimen, equispaced and that there is no transverse steel at the very centre, and such transverse steel is symmetrically disposed about the centre line.

9. ENVIRONMENTAL TESTS

As differing materials are used for this type of product a test should be instituted for attack by marine life. Similar tests are often applied to plain concrete and to wood products. Generally, if the boats are coated inside and out with epoxy resin type paints, then little marine attack should take place.

If boats are to be used in the unpainted state then tests for water absorption should be established. Such tests entail weighing of the specimens in air and subsequent weighing in water, due account being taken for the water displaced. The process is usually accelerated by boiling the specimens in water. If the sides of the specimens are sealed then the water absorbed through the exposed working surfaces can be calculated. Under some conditions, with poorly compacted mortar, the ingress of water would cause deterioration of the reinforcement.

Although ferro-cement boats and yachts in existence do not appear to have aged in that the physical attributes and characteristics of the concrete have decreased, under some conditions, an aging test may be desirable. Such accelerated aging tests are used for testing building materials, A.S.T.M. C481-62 "Laboratory Aging of Sandwich Constructions" being a good example of a reasonable test.

10. CONCLUSION

As it appears likely that there will be an increased activity in the use of ferro-cement for boat and ship building, statutory bodies will need to establish a standard of acceptance. The tests described broadly in this work should serve as a guide-line to types required.

Further work is necessary to establish acceptable stress levels for the various tests outlined.

As a guide, levels of stress generally found are shown in Appendix 3.

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APPENDIX 1Sample Calculations for Bend Specimens

The specimen was tested in a four point loading jig as shown in Figure 5a. This arrangement produced a constant bending moment in the central 6" section. The overall span of the lower supports was 18". The specimen size was 20" x 5" x 1.03" thick.

The average maximum total load recorded at first sign of cracking was 672 lbs.

This load produced a bending moment of 2016 lb.in.

For the composite steel/concrete section an equivalent moment of inertia I, can be calculated assuming it is uniformly concrete.

Hence $I = \frac{bd^3}{12} = 0.456 \text{ in}^4$ where b is the breadth and d is the depth of the section.

Using the equation, stress

$$f = \frac{My}{I}$$

where M is the bending moment and y is the distance from the extreme fibre to the neutral axis (which is presumed to be in the centre of the specimen), then

$$f = \frac{2016.051}{0.456} = 2420 \text{ lb/in}^2.$$

That is, the apparent stress to cause surface cracking was approximately 2,400 lb/in².

APPENDIX 2Sample Calculations of Forces Involved in Fatigue Tests

With a specimen of size 5" x 22", simply supported with four point loading, measurements of central deflection versus load were recorded. It was observed that the slope varied in three broad areas. Initially the ratio of load and deflection was 7850 lb/in, then 5040 lb/in, and finally 5600 lb/in. The final slope, when projected back, gave a single reasonable interpretation of the results, this being 5600 lb/in.

This figure of 5600 lb/in was for four point loading, the span being 18", and the upper load points separated 6".

For this configuration, the deflection

$$\delta = \frac{167P}{2EI}$$

where δ is in inches,

P is in lbs,

E is in lb/in², and

I is in in⁴.

Using the value of P/ δ obtained of 5600 lb/in and substitution in the above equation, a value of EI of 579,000 lb.in² is obtained.

From tests conducted as a three point loading system as shown in Figure 5b a similar result was obtained.

This experimental value of an equivalent EI can be applied to the fatigue test to find the deflection necessary to produce an equivalent stress level at the extreme fibre.

If I is assumed as 0.456 (Appendix 1) then a value of an equivalent E can be calculated as $1.27 \times 10^6 \text{ lb/in}^2$.

For a simply supported beam with three point loading the equation for deflection is

$$\delta = \frac{PL^3}{48 EI} .$$

For a 20" span as used in the fatigue tests, and a value of E of $1.27 \times 10^6 \text{ lb/in}^2$, then

$$\delta = \frac{P \cdot 20^3}{48 \cdot 1.1.27 \times 10^6}$$

from which $P = 7600 I \delta$.

$$\text{Since } f = \frac{My}{I} = \frac{PLy}{4I} ,$$

a value of P from the above can be substituted, yielding

$$f = \frac{7600 I \delta \cdot 20 \cdot 0.51}{4I}$$

$$= 19,400 \delta \text{ lb/in}^2.$$

That is, if a stress level of 700 lb/in^2 is required at the outer fibre, then a deflection of 0.035" is required (either side of a central position or stress free state).

The system for calculating a required deflection as above is reasonable only on a comparative basis, and does not yield a true level of stress, primarily due to a difference in the calculated moment of inertia, and also the difference between the static and dynamic modulus of elasticity.

To overcome some of the difficulties associated with the dynamic modulus of elasticity, an optically sensitive material (Araldite) was

attached to the specimen, adjacent to the centre, with reflective cement. The photoelastic properties of this material, during the static three point loading test, were calibrated versus load and deflection. The light used was from a mercury stroboscopic source through a simple reflective polariscope (polaroid plus $\frac{1}{4}$ wave plate). Colour changes in the Araldite were recorded for varying loads/deflection.

When the specimen was vibrated in the fatigue testing machine, the same Araldite specimen was viewed through the stroboscopic/reflective polariscope and colour changes noted for differing parts of the cycle. These colour changes were then compared with colour changes noted in the static calibration test.

This system was used as a check that the dynamic motion produced stresses of equal magnitude when the extreme fibres were alternatively in tension and compression.

The system also showed that under dynamic conditions, the static results could be applied to the dynamic case with a reasonable amount of faith in the results.

However, it must be noted that with constant deflection, that is constant strain on the surface, the equivalent stress level increased with time by an amount up to approximately 20% (after some 3 hours of testing). This was presumably due to an increase in the equivalent modulus of elasticity. After 3 hours of testing, little further change in the stress level was noted.

APPENDIX 3Stress Levels Generally Found. Mortar Test

As per A.S. No's A104-1969 and A111-1967.

Compressive Stress 8000 p.s.i. (some reports are up to 1200)

Tensile Test 12000 p.s.i.

Manufacture of Specimens to A.S. A103-1968

. Tension Test (on ferro cement)

Tensile Test 1500 p.s.i. (at first cracking)

. Bending Test (on ferro cement)

Tensile Stress 2400 p.s.i. (at first cracking)

. Shear Tests (on ferro cement)

Shear Stress 1900 p.s.i.

. Compression Test (on ferro cement, 6" x 6" x $\frac{3}{4}$ ")

No failure at 11,000 p.s.i. Test not recommended.

. Impact Test (on ferro cement)

Nervi reports 560 lb dropped from heights to 10 ft on to
f' x 5' x 1.1" panel. This appears to be marginal to the
onset of failure. Specimen was presumably simply supported
on all edges.

. Fatigue Tests (on ferro cement)

On the assumption that the equivalent dynamic modulus of
elasticity is approximately 1.3×10^6 p.s.i. a stress level
of ± 700 p.s.i. should be withstood for 2×10^6 cycles. The

24.

level of 700 p.s.i. is on the assumption that the design stress level is of the order of 500 p.s.i. However a deflection of 0.035" either side of centre for 1" thick specimens on a 20" span should be withstood for 2×10^6 cycles.

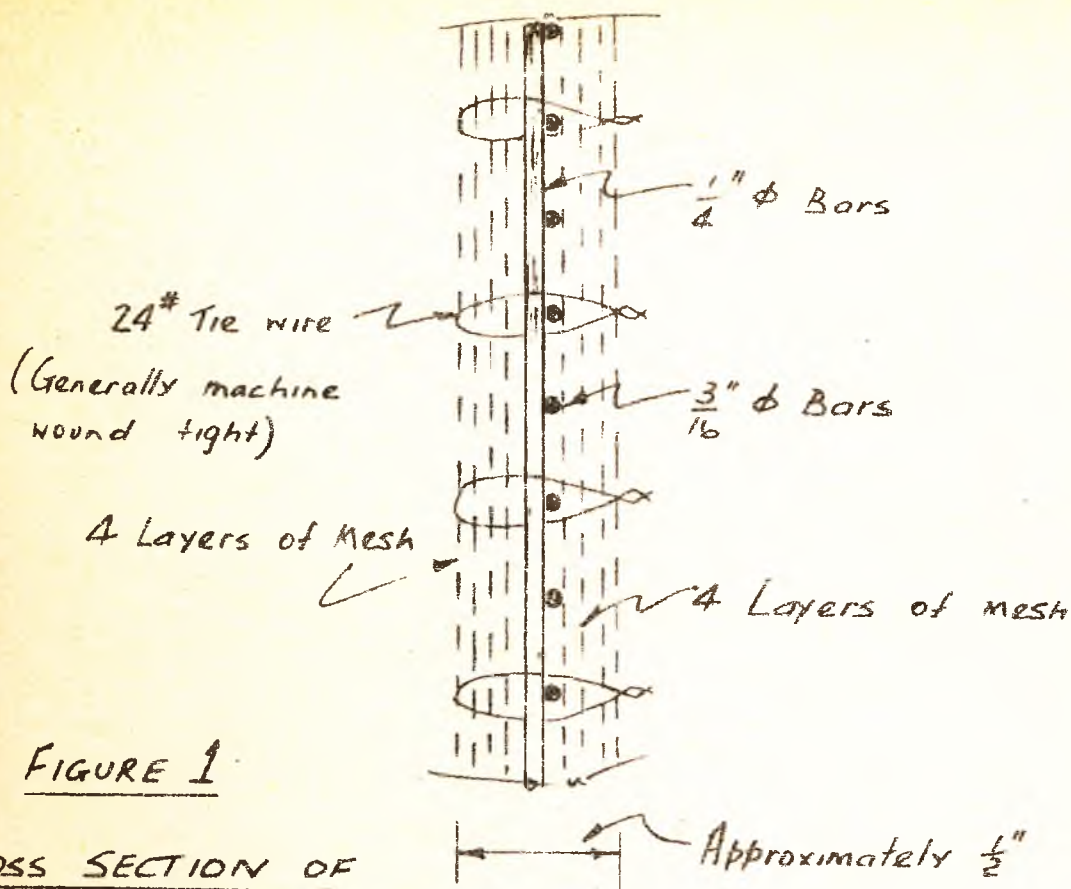


FIGURE 1

CROSS SECTION OF
STEEL MATRIX

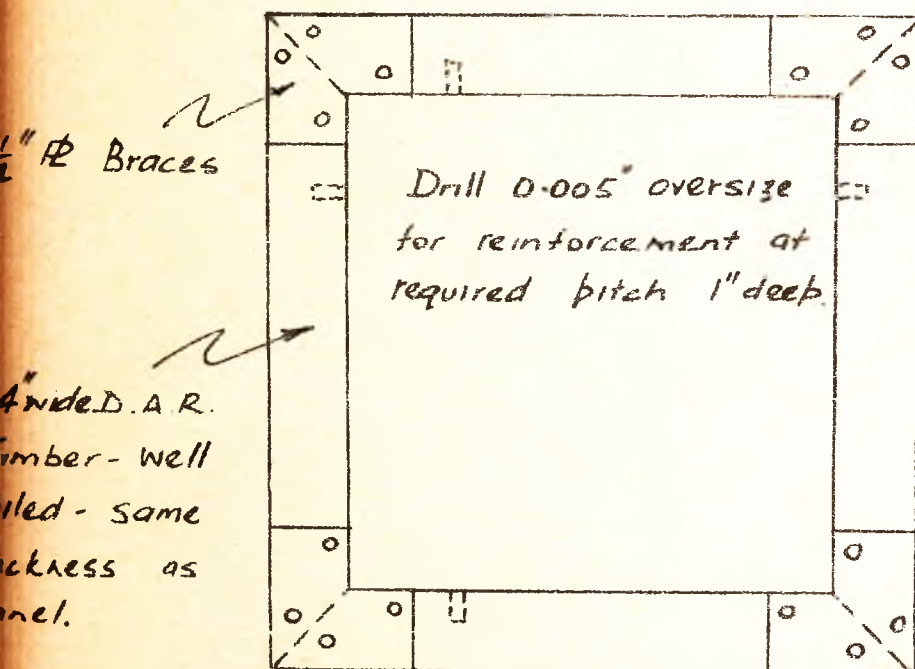
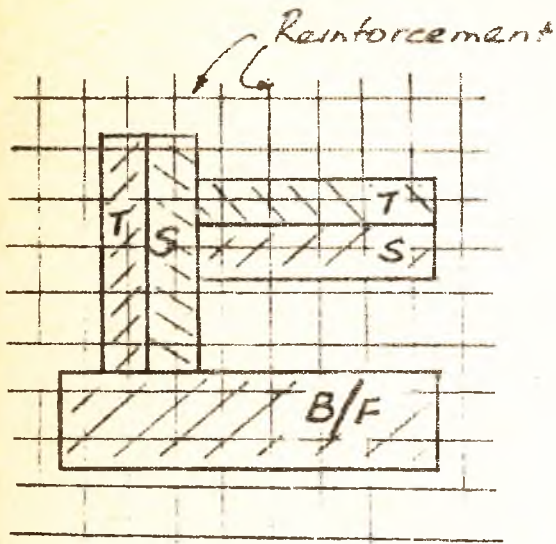


FIGURE 2 FRAME FOR TEST PANELS



- T - Tension Specimen
- S - Shear Specimen
- B - Bend Specimen
- F - Fatigue Specimen

Panels No's 1,3,5 - Bend Specimen to be cut

Panels No's 2,4,6 - Fatigue Specimen to be cut

FIGURE 3 - CUTTING OF PANELS

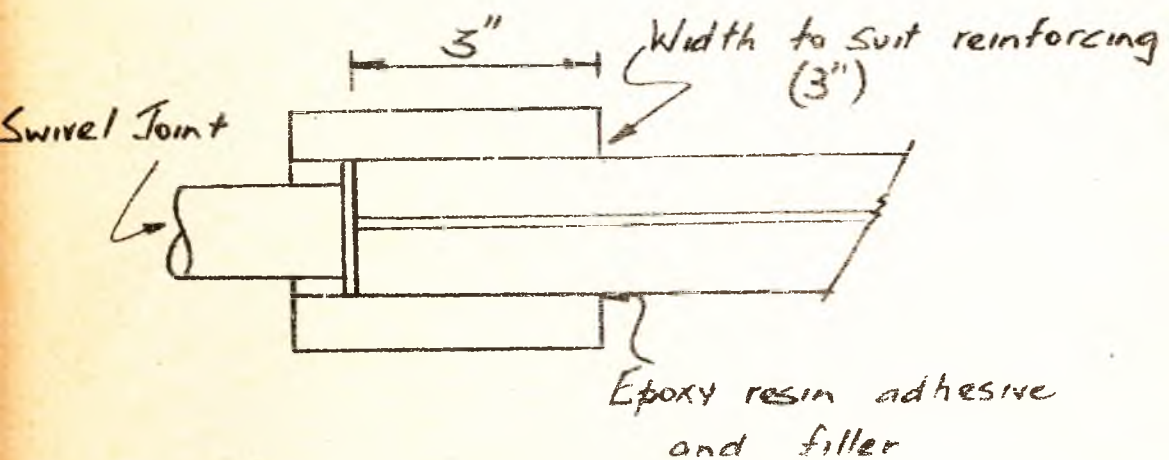


FIGURE 4 TENSION ATTACHMENT

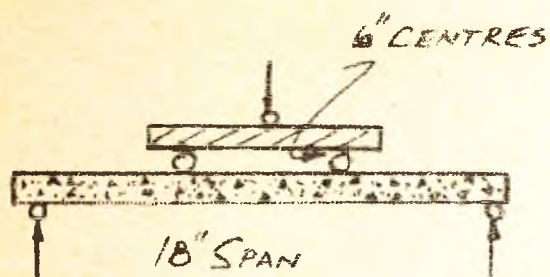


FIGURE 5A - FOUR POINT
LOADING

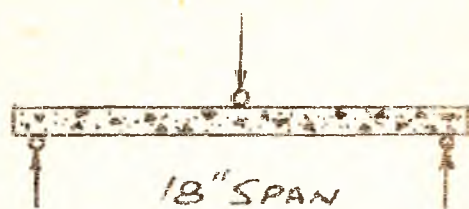


FIGURE 5B THREE
POINT LOADING

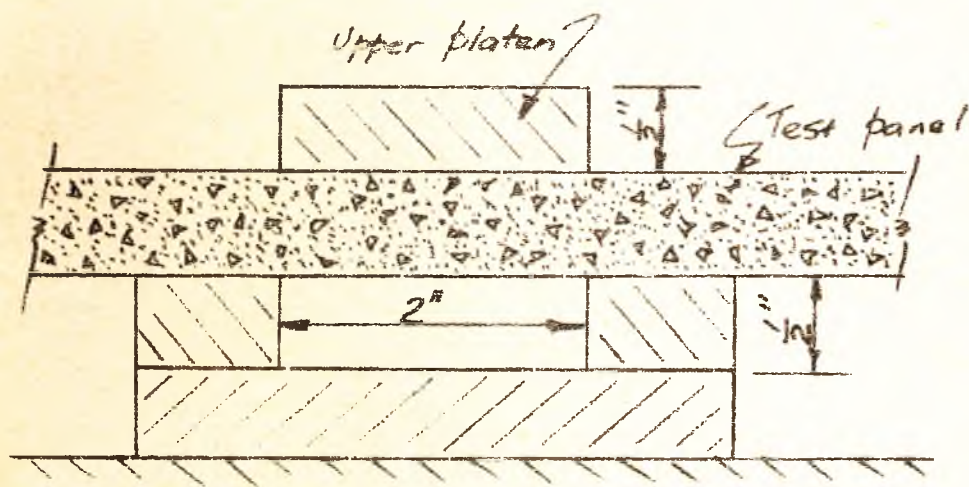


FIGURE 6 SHEAR TEST

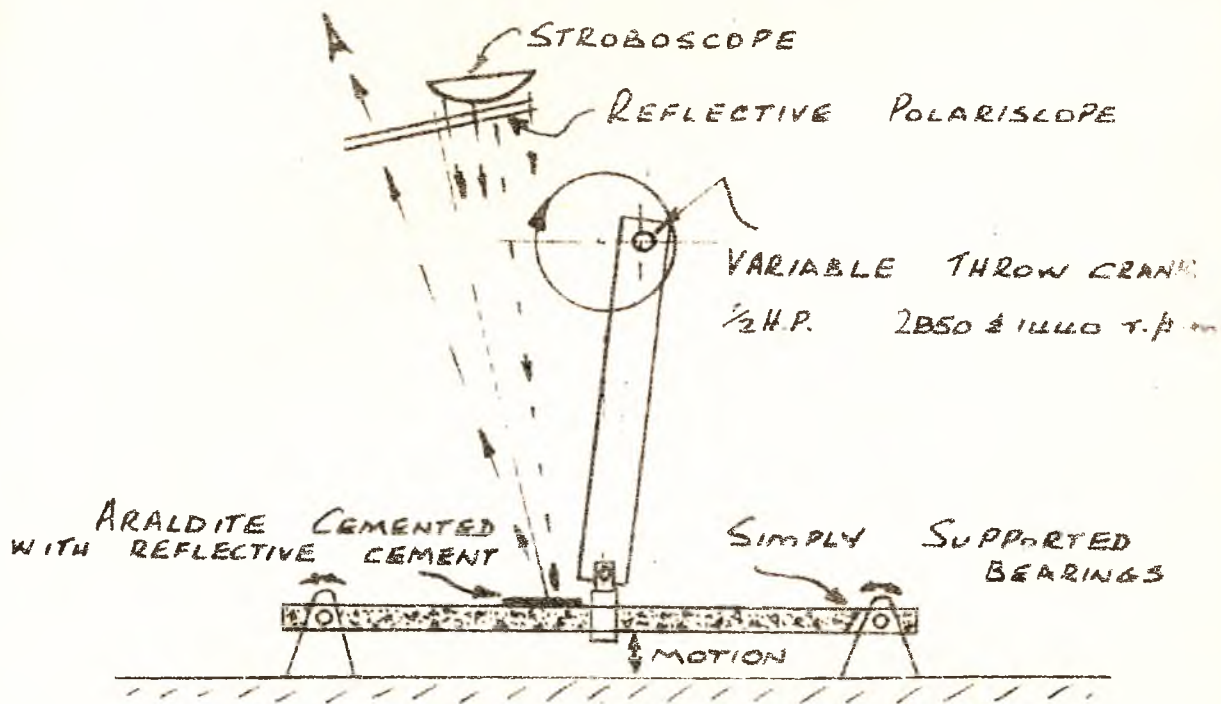


FIGURE 7 FATIGUE TEST

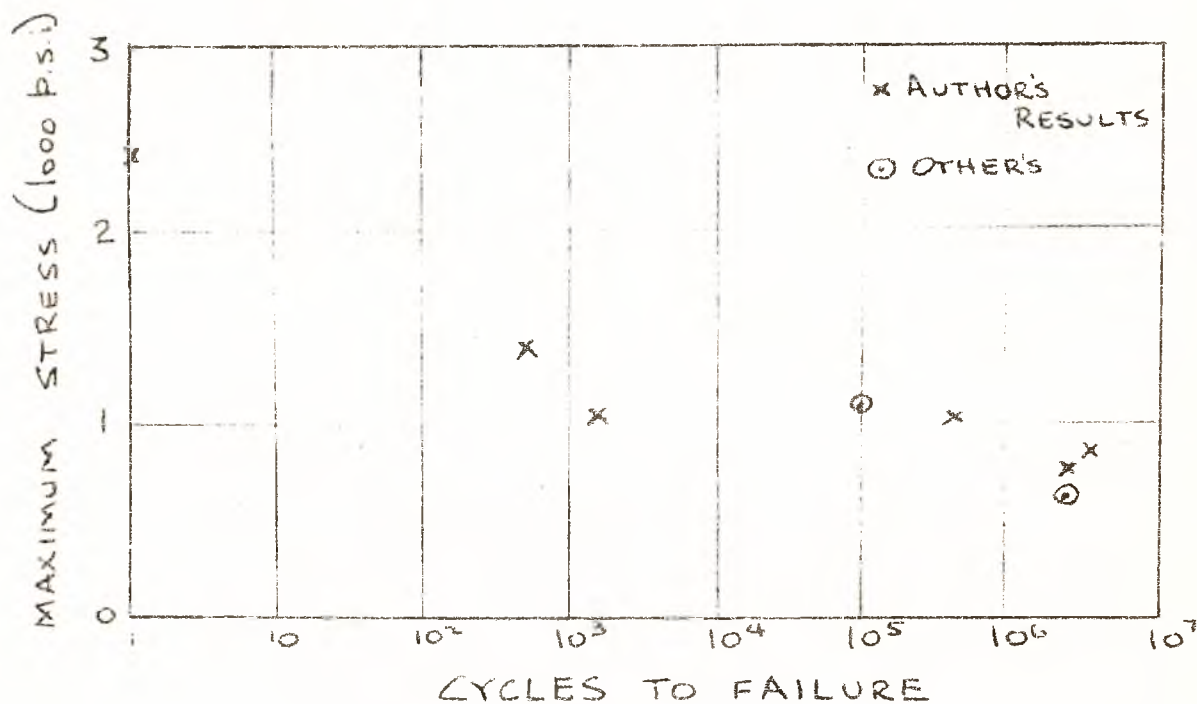


FIGURE 8 - FATIGUE TESTS ON
FERROCONCRETE FOR REVERSED
BENDING AT 2850 CYCLES/MINUTE