The Structural Behavior
of Higher Strength Concrete

by

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

PAGE

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

Chapter 1

INTRODUCTION:

The term high strength concrete is relative to any assemblage of concrete technologists. Most concrete technologists classify concrete as follows:

2500 - 6000 Psi -------> Normal strength concrete;
(13.8 to 41.5 MPa)

6000 - 12000 Psi -------> Higher strength concrete;
(41.5 MPa - 83 MPa)

> 12000 Psi -------> High strength concrete.
(> 83 MPa)

In this report higher strength concrete implies concrete of strength 6000 Psi (41.5 MPa) and above.

A few years ago concrete of 5000 Psi (34.5 MPa) and above was considered high strength concrete. But, today with the development of new materials, admixtures and processers, even concrete of 6000 Psi (41.5 MPa) is considered normal strength concrete.

PRESENT USAGE:

There are many advantages in using higher strength concrete over normal strength concrete.

a) Higher strength concrete has greater load carrying capacity than normal strength concrete. This helps in reduction of member dimensions and hence dead weight is greatly reduced.

b) Higher strength concrete is very advantageous in compression members. In columns, if the section is decreased the self weight decreases, and the stress due to self weight is much lower, hence greater external load can be taken.

c) The precast and prestress industry is the largest user of higher strength concrete. In prestressed concrete members, the moment due to self weight is decreased, higher external moment can be taken, and the efficiency of the structure is increased. In prestressed concrete, concrete strengths of up to 10000 Psi (68.9 MPa) have been used.

d) It is not particularly advantageous to use higher strength concrete in slabs, as thin sections have more deflections.

Higher strength concrete is being used extensively in New York and Chicago. In the Chicago area concrete of 10,000 Psi (18.9 MPa) was used in at least six different buildings (21). Nuclear power plants require concrete in the 8000 Psi (55 MPa) range.

OBJECTIVES

a) To study the compressive and flexural behavior of higher strength concrete [11,000 Psi or 75.8 MPa] made with Kansas aggregate, in order to verify proposed stress-strain relationships and to study the shape of the stress block.

b) To compare the cylinder and flexural stress-strain curves.

c) To find Poisson's ratio.

d) To determine strain at f'_c and at rupture.

e) To determine modulus of elasticity.

CHAPTER 2

SELECTION OF MATERIALS

INTRODUCTION

Material selection is an important factor in the production of higher strength concrete as it has to meet requirements for workability and strength development. Locally available materials should be used to fullest advantage, subject to suitability, to make the production of higher strength concrete economical. Once the materials are selected, the remaining variables should be studied to develop an optimum mix on the basis of strength, cost and field performance.

CEMENT

The strength of a mix is proportional to the strength of the cement. As reported in the state-of-the-art report of high-strength concrete [24] published in the ACI Journal "The choice of Portland cement for high strength concrete is extremely important. Unless high initial strength is the objective, such as in prestressed concrete, there is no need to use a Type III cement. Furthermore, within a given cement type, different brands will have different strength development characteristics because of the variations in compound composition and fineness that are permitted by ASTM C 150".

Walker and Bloom (see Ref. 5) presented values of compressive strength for concrete from different cement suppliers and offered the following conclusions:

a) Average strength for different cements varied substantially.

b) At least one-half of the individual cement differs from shipment to shipment sufficiently to have an effect on uniformity of concrete strength.

c) There is a need for better control of uniformity of the cement within individual sources.

Figure 2.1 (20) shows the effect of various cement types on concrete compressive strengths based on mixes having the same workability (5). Type I (standard) or Type II (low heat) cement should be recommended for high strength concrete mixes and the same brand of cement is to be used throughout the job (5). Type III cement is too finely ground and results in rapid setting, accelarated heat of hydration, and high early strength development with relatively moderate strength gains at 91-day or one year intervals (5).

In the present investigation, a mix developed by Nikaeen (11) was used. Type I cement was used. Figure 2.2 shows that Type I cement gives the highest compressive strength at all ages.

COARSE AGGREGATE

As coarse aggregate comprises a major portion of the volume, it is very important to use proper coarse aggregate in developing higher strength concrete. Kaplan (8) has reported that the use of different coarse aggregates has a marked effect on the strength of concrete with the same mix proportions. Depending on the aggregates, a difference of 40% in flexural strength and 29% in compressive strength were obtained in Kaplan's experiments.

The strength, up to 5000 Psi (34.5 MPa) depends essentially on the quality of the hardened cement paste that holds the aggregate particles together. The aggregate at this strength level and above always has a much greater strength than the cement paste. The following factors should be considered in selecting a coarse aggregate for higher strength concrete.

a) Strength
b) Maximum size and gradation
c) Particle shape and surface texture
d) Cleanliness
e) Mineralogy and formation
f) Aggregate-cement bond

STRENGTH

The aggregates chosen for higher strength concrete should have a crushing strength at least equal to the hardened cement paste. Most good quality aggregates have crushing strength in excess of 12000 Psi (83 MPa) and, hence, strength is not a major problem in the production of higher strength concrete.

MAXIMUM SIZE AND GRADATION

Several researchers (3, 4, 10) have shown that in higher strength concrete the compressive strength increases when the maximum size of aggregate decreases. However, it is obvious that there should be some limitation in order to keep drying shrinkage and creep to a reasonable and practical value. A maximum size of 0.4 in. (10 mm) is recommended for most cases (10). Figures 2.3 and 2.4 show the size effect of coarse aggregate on compressive strength. In Figure 2.4, it is indicated that the smaller size aggregate provides the most efficient use of cement in higher strength concrete. This higher strength efficiency which is obtained when using smaller aggregate is due to greater bond between the cement and coarse aggregate because of the increase in surface area. However, there is a different optimum size for each aggregate and for each level of strength desired, depending on the economics of the situation. Therefore final batching for each job is highly recommended.

PARTICLE SHAPE AND SURFACE TEXTURE

In the research done by Carrasquillo, Ramon and Nilson (5), it is indicated that the ideal coarse aggregate for high-strength concrete appears to be clean, cubical, angular, 100% crushed stone with minimum flat size and elongated particles. It is also stated that if all other factors are equal, crushed stone coarse aggregate produces higher strength concrete than does a rounded aggregate. In Figures 2.5 and 2.6, the compressive strength of concrete using different types of coarse aggregate is shown.

CLEANLINESS

Coarse aggregate used in higher strength concrete should be free of dust coating, because the dust content causes an increase in the fines, and consequently an increase in the water requirement of the resulting concrete mixture. Hence, the water-cement ratio increases and the strength decreases. Washing the crushed stone coarse aggregate may not always be necessary, but is always recommended (22).

MINERALOGY AND FORMATION

As discussed above, the compressive strength of concrete increases when using crushed stone as the coarse aggregate. This is not only because of the shape of the aggregate but also due to its mineralogy. The Waterways Experiment Station has done some work on the effect of mineralogy on concrete strength. They achieved 17000 Psi (117 MPa) using granite rock (14).

AGGREGATE-PASTE BOND

When high-strength concrete is desired, the aggregate paste-bond should be strong, a good quality aggregate with a suitable surface texture should be used.

The aggregate-paste bond is known to decrease with increasing water-cement ratio and increasing the size of aggregate. Alexander (1) found that the cement-aggregate bond to a 3 inch particle was almost 1/10 of that to a corresponding 1/2 inch particle.

FINE AGGREGATE:

The gradation and particle shape of fine aggregate are very important factors in the production of higher strength concrete. Fine aggregate has a great effect on the water requirement and consequently the strength of the concrete mix. In sand of the same grading, a 1% increase in fine aggregate voids may cause a 1 gallon per cubic yard increase in water demand (6).

One of the important functions of fine aggregate in conventional concrete is its role in providing workability and good surface finishing. Since higher-strength concrete contains a large amount of cement paste, the role of fine aggregate in providing workability and good finishing is not so crucial. Fine aggregates with a fineness modulus between 2.7 and 3.2 have been most satisfactory (9). Blick (2) reported that fine aggregates with fineness modulus below this range might produce low strength and "sticky mixes". A reduction of the amount passing the No. 50 and No. 100 sieve on the lower side of the specification limit from ASTMEC-33 is suggested. Such reductions have shown an increase in compressive strength of 500 to 1000 Psi (3.5 to 7.0 MPa) (15).

In this investigation, Kaw River Sand with a maximum sieve size of No. 4 was used.

WATER

Studies (6,20) have shown that water meeting specification ASTM C-94(19) has no harmful effect on high-strength concrete. Therefore, water meeting ASTM C-94 is adequate.

ADMIXTURES

Due to the low water-cement ratio, high-strength concrete has low slump and workability is not adequate. A chemical admixture called superplasticizer or "super water reducer" can be used to improve workability and slump. This admixture actually reduces the friction angle between the water and surface of contact and causes the mix to be more workable. It is important to note that this effect is for a limited time and the mix changes to its original property after a short time. Therefore superplasticizer increases the slump within a limited time without altering the compressive strength, because the slump will go back to its original position as if no admixture was used in the mix. Figure 2.7 shows the effect of superplacticizer on the slump versus the time on a mix with water cement ratio of 0.35 (11). It is believed to have a similar effect on all other mixes. In this investigation, the brand of superplacticizer used was Sikament. The quantity of superplacticizer used was in accordance with the mix proportion developed by Nikaeen (11). As slump decreases rapidly with time, it is important to consider this effect on the job site.

CHAPTER 3

LITERATURE SURVEY FOR COMPRESSIVE STRESS BLOCK

The ultimate strength of reinforced concrete members subjected to flexure and axial loading can be predicted using the equivalent rectangular stress distribution in the concrete compressive zone. In designing, β_1 the ratio of the depth of the equivalent compressive stress block to the depth of the actual one, and ε_{cu}, the extreme fibre compressive strain, are to be known. Based on beam tests, using concretes with compressive strength less than 6000 psi, (41.3 MPa) the American Concrete Institute (ACI) (17) suggested values for β_1, depending on the concrete strength. In 1975, a minimum value of β_1 , equal to 0.65, was suggested by the ACI. The validity of this stress block, has always been in question with regard to higher-strength concrete. Hence, there is a need to study the shape of the stress block in higher strength concretes.

Many views have been expressed concerning high strength concrete, but the views are not consistent and they contradict each other.

In the work done by Leslie, Rajagopalan and Everard [9], they concluded:

a) The ACI building code rectangular stress block does not predict the behavior of beams with f'_c above 8000 psi (55 MPa).

b) Further research is warranted with respect to maximum strain in concrete for f'_c exceeding 8000 psi (55 MPa).

c) Pending further tests, a triangular stress block with an extreme fibre stresses of f'_c and zero stress at the neutral axis is recommended as a conservative model for predicting the behavior of beams with f'c above 8000 psi (55 MPa).

In the work done by Wang, Shah, and Naaman [16], the following conclusions were made:

a) The rectangular stress distribution gives a sufficiently accurate prediction of ultimate loads and moments for reinforced concrete beams and columns made with high strength concrete.

b) The value of maximum concrete compressive strain at ultimate was always higher than 0.003 in/in.

In the work done by Nikaeen [11], he concludes:

a) The shape of the stress block at ultimate changes from rectangular to parabolic type as the strength increases, because he found that the position of the concrete internal reaction force is $k_2 = 0.37$ at ultimate condition for higher strength mix (i.e., f'_c = 9500 psi, 65 Mpa). This value is very close to 0.375 which is the center of gravity of a parabolic stress block rather than 0.5 which is the center of gravity of a rectangular stress block.

b) The strain behavior of high strength concrete is different from normal strength concrete, because strain at the ultimate condition is less than 0.003 in/in. proposed by ACI code (17) or it might be greater than that proposed by ACI, but it decreases with time drastically. Therefore, a more conservative value of 0.002 in/in. was recommended.

CHAPTER 4

TEST SPECIMEN AND METHOD OF TESTING

In 1955, Hognestad, McHenry and Hanson [7] formulated the ultimate strength design criterion for concrete. In their work, they used a special C-shaped structural element. Tensile stresses were completely eliminated in the test region of the specimen, by applying loads at two points and varying them such that the neutral axis remained at the face of the test specimen throughout the test.

The test specimen had a central unreinforced test region, and reinforced brackets at the end of the test specimen which accomodated the two thrusts.

The test reported here was done on a similar specimen and the dimensions were as used by Nikaeen [11] (Fig 4.1).

In this test, the method and analogy adopted by Nikaeen are very closely followed in order to investigate the behavior and shape of the stress block in the higher strength concrete beam section.

METHOD OF TESTING

Suitable tension, compression, and shear reinforcement were placed in the end bracket to assure that failure would occur in the central, unreinforced test region. A major thrust P_1 was applied and the neutral axis was maintained at the face of the test specimen throughout the test. Strains were measured over the test region.

In investigating the behavior and shape of the stress block, the method and equations developed by Hognestad, McHenry, and Hanson [7] were used. To formulate the ultimate strength design criterion, they derived some equations and used a C-shaped structural element. The present ACI code for ultimate strength theory is based on their work. They formulated stress in concrete fibres as a function of strain in those fibres. They also showed that stress-strain relationships for concrete in concentric compression are indeed applicable to flexure (Figure 4.2 shows this fact). The following equations which permit stress to be expressed in terms of measured strain and other known parameters were developed by them [see 7].

$$f_c = \varepsilon_c \frac{df_o}{d\varepsilon_c} + f_o \tag{4.1}$$

$$f_c = \varepsilon_c \frac{dm_o}{d\varepsilon_c} + 2m_o \tag{4.2}$$

$$f_o = \frac{P_1 + P_2}{bc} \tag{4.3}$$

$$m_o = \frac{P_1 a_1 + P_2 a_2}{bc^2} \tag{4.4}$$

where

f_c = Concrete compressive stress in outer fiber of the beam;

ε_c = Concrete strain in outer fiber of the beam;

P_1 = major thrust;

P_2 = minor thrust;

a_1 and a_2 are lever arms;

b is the width and c is the depth of the testing region.

The details are shown in Figure 4.1.

Figure 4.3 gives the reinforcement layout of the test specimen. Figures 4.4 and 4.5 give the sections at A-A and B-B respectively (see Figure 4.1).

STRAIN GAGES

Strain gages were used to measure strains. The strains were monitered by an automated data acquisition system controlled by a model 2E Apple Computer.

Ten of Micro Measurement EA-06-750DT-120 electrical resistance strain gages were used on the test beam of the locations shown in Fig. (4.1).

CHAPTER 5

EXPERIMENTAL WORK AND RESULTS

CASTING

The specimens were cast horizontally on a level surface. Vibration was used to consolidate the concrete. There was a minimum cover of 3/8 in. The mix proportions used for all the 4 specimens are shown in Appendix IIa. Some 3x6 in. cylinders were cast at the same time with each mix.

CURING

Twenty-four hours after casting, the specimen was taken out of the mold and then placed in a 100% humidity curing room. All the specimens were in the curing room for 52 days. The specimens were then taken from the curing room and were kept in a 50% humidity environment for 7 days in order to prepare them for the test. Table 5.0 shows details of the test specimens. Cylinders corresponding to each specimen were taken out at the same time as the specimen.

INSTRUMENTATION AND APPARATUS

The location of the strain gages used to measure the strain can be seen in Fig. 4.1. The major load P_1, Figure 4.1, is applied by a 300,000 lb, load-controlled testing machine through a system of bearing plates and rollers. The minor load P_2 is applied by a hydraulic jack through a steel frame shown in Appendix II-c. A pressure gage system, calibrated prior to the test, was used to control the load.

TEST PROCEDURE

Tables 5.1, 5.2, 5.3, and 5.4 give the average compressive stress for the 3x6in cylinders corresponding to the 4 test specimens. Two strain gages were mounted on some cylinders and strain was recorded as a function of load up to failure. Cylinders were tested on the same day that the corresponding structural element was tested in order to determine the strength of the mix. The data are in the tables 5.5 and 5.6 corresponding to beam I, 5.7 and 5.8 corresponding to beam II, 5.9 and 5.10 corresponding to beam III, and 5.11 corresponding to beam IV. Cylinders corresponding to structural elements I and II and some of the cylinders of structural element III were tested on a machine which was not functioning properly. Hence, the strength of the mix corresponding to specimen IV (f'_c = 11100 psi or 76.49 MPa) was used in all the 4 specimens in computing the stress factors.

The test specimen was loaded in such a manner that the neutral axis always coincided with the outside face of the specimen. The location of the neutral axis is shown in Figure 4.1. After each increment of major thrust P_1, the corresponding increment was such that the average strain across the neutral surface was approximately zero. This was monitored by connecting the strain gages on the neutral face to a wheatstone bridge and maintaining zero potential. The load and strain at each level were recorded and the procedure repeated up to failure. The zero strain surface represents the neutral axis of the specimen and the opposite side of the cross section represents the extreme compressive surface. The recorded data for specimens I, II, III, and IV are shown in 5.12, 5.13, 5.14, and 5.15 respectively. The average strain at each level is given as a function of load and is in Tables 5.16, 5.17, 5.18, and 5.19 corresponding to the 4 specimens.

RESULTS AND DISCUSSION OF THE RESULTS

The average values of cylinder stress-strain data of Tables 5.6, 5.7, 5.10, and 5.11 corresponding to Specimens I, II, III, and IV are plotted in Figures 5.1, 5.2, 5.3, and 5.4 respectively. Using the corresponding cylinder stress-strain curve and the strain values for the flexure test (indicated in Tables 5.16, 5.17, 5.18, and 5.19) the stress values at each loading level could be directly determined. The variation of strain along the depth is shown for beams I, II, III, and IV in Figures 5.5, 5.6, 5.7, and 5.8 respectively. The shape of the stress block for beams I, II, III, and IV are shown in Figures 5.9, 5.10, 5.11, and 5.12 respectively. The average values of flexural strain at the inner face (maximum compression) are plotted against load in Figures 5.13, 5.14, 5.15, and 5.16 for beams I, II, III, and IV respectively.

To determine the ultimate strength factors, k_1k_3 and k_2 the equilibrium concept is used. The details are shown in Appendix II-b. By equilibrium of forces and moment from Figure 5.21, k_1k_3, and k_2 can be determined.

$$k_1k_3 = \frac{C}{bcf'_c} = \frac{P_1 + P_2}{bcf'_c} \tag{5.1}$$

$$k_2 = 1 - \frac{P_1a_1 + P_2a_2}{(P_1 + P_2)c} \tag{5.2}$$

The values of k_1k_3, k_2 and $\frac{k_2}{k_1k_3}$ can be measured directly from zero up to failure. The individual value of the coefficient k_3 is the ratio of maximum compressive stress in the beam (i.e., $f_c$max flexural test) to the corresponding average cylinder strength f'_c. To calculate k_1, which is the shape factor, k_1k_3 and k_2 are to be evaluated. The values of ultimate strength factors are given in Tables 5.20, 5.21, 5.22, and 5.23 for beams I, II, III, and IV. The ultimate strength factor k_2 indicates the position of the resultant reaction force which is produced by concrete.

Figures 5.17, 5.18, 5.19, and 5.20 show the values of k_1k_3 and k_2 computed by equations (5.1) and (5.2) as a function of strain ε_c at the compression face for Beams I, II, III, and IV. The term k_2 indicates the position of the resultant force in the concrete from the outer fiber of the beam. Figure 5.18 shows that the position of the resultant force is 0.32 at lower loads and 0.36 at ultimate condition. In beam II, k_2 changes from 0.32 at lower loads to 0.36 at ultimate (Figure 5.19). From Figure 5.19, 5.20, and 5.21, one can see that k_2 changes from 0.31 to 0.35. This indicates that the stress block is more triangular than rectangular or parabolic, but it tends to become closer to parabolic towards the ultimate. Beam I unlike the other three beams had k_2 changing from 0.37 to 0.43 which indicates the stress block appears to be close to a rectangular shape. The curve pattern for beam I looks exactly like the curves for the other three specimens but it seems to be shifted. This may be due to some error in conducting the experiment.

The f'_c value corresponding to the beam IV cylinder was used in calculating k_3 for all the four specimens as the cylinders corresponding to the other beams were tested in a defective machine. The outer fiber stress is calculated using equations 4.1 and 4.2 for all the specimens. The results are given in the Tables 5.24, 5.25, 5.26, 5.27, 5.28, 5.29, 5.30, and 5.31 corresponding to beams I, II, III, and IV. A computer program was used to find the differential parts. Tables 5.28, 5.29, 5.30, and 5.31 give flexural stresses using both the methods i.e., Equations 4.1, 4.2, and the cylinder stress-strain curve, for comparison purpose for beams I, II, III, and IV.

Figures 5.22, 5.23, 5.24, and 5.25 show the values of f_o (Equation 4.3) as a function of strain ε_c at the compression face for the four beams respectively. Figures 5.26, 5.27, 5.28, and 5.29 show the values of m_o (Equation 4.4) as a function of strain ε_c at the compression for the four beams respectively. Figures 5.30 and 5.32 give average f_c from Equation (4.1) and Equation (4.2) vs. strain for beam II and beam IV respectively.

Comparing the area of the ACI stress block (17), with the area of the parabolic, stress block, we have

$$0.85\, f'_c (\beta_1 c) b = k_1 k_3 f'_c bc \qquad \text{or}$$

$$\beta_1 = \frac{k_1 k_3}{0.85}$$

The values of β_1, so calculated are 0.88, 0.8, 0.8, and 0.72 for beams I, II, III and IV respectively. This is higher than the ACI recommended value of 0.65.

The modulus of elasticity corresponding to cylinders of Beam III and Beam IV were 6.71×10^6 psi (0.462 GPa) and 6.67×10^6 psi (0.459 GPa) respectively. This was found to be nearly equal to the modulus of elasticity calculated from

American Concrete Institute formula (17), which was 6.36 x 10^6 psi (0.438 GPa). The Poisson's ratio corresponding to a cylinder from Beam II was found to be 0.23.

STRAIN BEHAVIOR

The maximum recorded strains corresponding to Specimens I, II, III, and IV are 0.00330 in/in., 0.00303 in/in, 0.00280 in/in. 00021 in/in. respectively. Maximum recorded cylinder strains at stress near ultimate corresponding to Specimens I, II, III, and IV are 0.0021 in/in., 0.00243 in/in., 0.002116 in/in. and 0.00203 in/in. respectively. The cylinders had maximum recorded strain values less than 0.003 in/in. Two of the beams had maximum recorded strain values greater than 0.003 and two of them had maximum recorded strain values less than 0.003 in/in. Therefore, a more conservative value of 0.0025 in/in. is recommended. Reference (12) has also suggested a similar value. Nikaeen [11] has suggested a very conservative value of 0.002 in/in.

CHAPTER 6

SUMMARY AND CONCLUSIONS

SUMMARY

Four "dogbone" shaped [7] beams of higher strength concrete were tested to investigate their structural bending properties. The beams were loaded such that zero strain was maintained at the outer face. The beams were made out of concrete of 11000 psi (76 Mpa). A number of 3"x 6" cylinders corresponding to each beam were tested in concentric compression. The main objective of this experiment was to study the shape of the stress block of failure for higher-strength concrete. The following conclusions were made from the test results.

CONCLUSIONS

1. Higher-strength concrete has a brittle mode of failure and failure is sudden without any formation of cracks before failure. The failure line passes through the stone and not through the interface of mortar as in normal strength concrete. [This was also observed by other investigators (12, 11)].
2. The values of k_2 near the ultimate condition for beams II, III, and IV were 0.36, 0.36 and 0.35. These values

are very close to 0.375 the value for a parabolic stress distribution. Thus higher strength mixes appear to have a parabolic stress distribution of failure in bending.

3. Strain-behavior in higher strength concrete is different from normal strength concrete and is observed to be less than the ACI proposed value of 0.003 in/in. A more conservative value of 0.0025 in/in. is recommended.
4. The modulus of elasticity may be estimated by the ACI formula (17) (Eq. 10).
5. The value of β_1 in higher strength concrete is greater than the ACI recommended value of 0.65.

RECOMMENDATIONS FOR FUTURE WORK

For higher-strength concrete to be effectively used in the future, intensive research should be conducted. Higher-strength concretes of ranges 11,000 psi to 15000 psi (75.8 MPa to 103.4 MPa) should be tested to determine the structural behavior in bending. Also, experiments should be done on a larger scale i.e., more beams should be tested to get consistent results and some definite code requirements should be developed.

APPENDIX I

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APPENDIX II

a. MIX PROPORTIONS (Based on trial mix done by Nikaeen (11))

Proportions used for 1 cu ft.

Materials	Quantity
Cement, Type I	31.93 lb
Quartzite	49.65 lb
Sand	60.88 lb
Water	8.28 lb
Superplasticizers	340 ml.

1 lb. = .45 kg

b. Derivation of ultimate strength factors k_1k_3, k_2

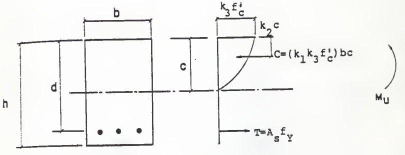


Figure a: Force Couple System

Without any assumptions we obtain the equilibrium equation of force and moment:

$$F_x = 0, \quad T = C \dashrightarrow T = k_1k_3\ f'_c\ bc$$

$$k_1k_3 = \frac{T}{f'_c\ bc} \qquad \text{———————} \quad (I.1)$$

$$M = 0 \quad T(d - k_2c) = C(d - k_2c) = M_u$$

$$k_2 = \frac{d}{c} = \frac{M_u}{Tc} = \frac{d}{c} = \frac{M_u}{Cc} \qquad \text{———————} \quad (I.2)$$

Applying the same concept to the test specimen shown in figure 5.21, we have $C= P_1 + P_2$.

Substituting in Equation (I.1) we obtain

$$k_1k_3 = \frac{P_1 + P_2}{bcf'_c} \qquad \text{———————} \quad (I-3)$$

where f'_c is the cylinder compressive strength.

$$M_u = P_1a_1 + P_2a_2$$

Substituting in Equation (I.2)

$$k_2 = \frac{d}{c} - \frac{P_1a_1 + P_2a_2}{(P_1 + P_2)c}$$

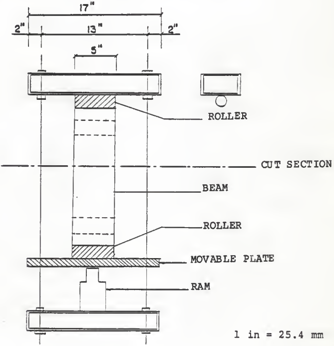
$d = c$ for the test specimen

Therefore:

$$k_2 = 1 - \frac{P_1a_1 + P_2a_2}{(P_1 + P_2)c}$$

c. STEEL FRAME

The minor load P_2 is applied by a hydraulic Jack through a steel frame shown below (Adapted from Ref. 11).



1 in = 25.4 mm

d. Computer Program For Calculating $\frac{dmo}{dfc}$, $\frac{dfo}{d\ c}$, f_o, m_o and f_c

```
10  INPUT "NO. OF DATA POINTS N=?";N
20 DIM X(N),Y(N),A(3),DY(N),Z(N)
30 N2 = N - 2
40 DIM B(5,3),BB(3,3),BF(3)
50 FOR I = 1 TO N
60      PRINT"DATA POINT NO.";I
70      INPUT"X(I)=?";X(I)
80      INPUT"Y(I)=?";Y(I)
90      INPUT"Z(I)=?";Z(I)
100 NEXT I
110 FOR T=1 TO 2
120 FOR I = 3 TO N2
130 FOR J = 1 TO 5
140      B(J,1)= 1
150      IJ = I - 3 + J
160      B(J,2) = X(IJ) - X(I)
170      B(J,3) = B(J,2)^2
180 NEXT J
190 FOR J = 1 TO 3
200 FOR K = 1 TO 3
210      BB(J,K) = 0
220 FOR L = 1 TO 5
230      BB(J,K) = BB(J,K) + B(L,J)* B(L,K)
240 NEXT L,K,J
250 FOR J = 1 TO 3
260     BF(J) = 0
270 FOR K = 1 TO 5
280      IK = I - 3 + K
290 IF T=2 THEN Y(I)=Z(I)
300 IF T=2 THEN Y(IK)=Z(IK)
310      BF(J) = BF(J) + B(K,J) * Y(IK)
320 NEXT K,J
330 D = BB(1,1) * (BB(2,2) * BB(3,3) - BB(2,3) * BB(3,2)) - BB(1,2) * BB(2,1) *
    BB(3,3)
340 D = D + BB(1,2) * BB(2,3) * BB(3,1) + BB(1,3) * (BB(3,2) * BB(2,1) - BB(2,2)
    * BB(3,1))
350 E = BB(1,1) * (BF(2)*BB(3,3) - BB(2,3)*BF(3)) - BF(1)*(BB(2,1)*BB(3,3) -
    BB(2,3) * BB(3,1))
360 E = E + BB(1,3) * (BB(2,1) * BF(3) - BF(2) * BB(3,1))
370 C(2) = E/D
380 E = BB(1,1) * (BB(2,2) * BF(3) - BF(2) * BB(3,2)) - BB(1,2) * (BB(2,1)
    * BF(3) - BF(2) * BB(3,1))
390 E = E + BF(1) * (BB(2,1) * BB(3,2) - BB(2,2) * BB(3,1))
400 C(3) = E/D
410 IF I = 3 THEN 450
420 IF I = N2 THEN 510
430 DY(I) = C(2)
440 GOTO 560
450 DY(I - 2) = C(2) + 2 * C(3) * (X(1) - X(3))
460 LPRINT"DY/DX(1)=";DY(1)
470 DY(2) = C(2) + 2 * C(3) * (X(2) - X(3))
480 LPRINT "DY/DX(2)=";DY(2)
490 DY(I) = C(2)
500 GOTO 560
```

```
510 DY(I) = C(2)
520 DY(I + 1) = C(2) + 2 * C(3) * (X(I + 1) - X(I))
530 LPRINT "DY/DX(";I + 1;")=";DY(I + 1)
540 DY(I + 2) = C(2) + 2 * C(3) * (X(I + 2) - X(I))
550 LPRINT "DY/DX(";I + 2;")=";DY(I + 2)
560 LPRINT "DY/DX(";I;")=";DY(I)
570 NEXT I
580 IF T<>1 THEN 610
590 LPRINT "STRAIN AT COMP FACE         F0                  DF/DE           FC"
600 GOTO 620
610 LPRINT "STRAIN AT COMP FACE         M0                  DM/DE           FC"
620 FOR M=1 TO N
630 IF T=2 THEN Y(M)=2*Z(M)
640 F=X(M)*DY(M)+Y(M)
650 IF T=2 THEN Y(M)=Z(M)
660 LPRINT TAB(5) X(M) TAB(25) Y(M) TAB(40) DY(M) TAB(60) F
670 NEXT M
680 NEXT T
690 END
```

e. Calibration of the minor load P_2

Pressure (Psi)	Load (lb)
75	500
150	1000
235	1500
315	2000
395	2500
475	3000
550	3500
625	4000
700	4500
750	4850
800	5200

1 psi = 6.89 kPa
1 lb = 4.45 N

APPENDIX III

TABLES
AND
FIGURES

Table 5-0: Information About the Test Specimens

Specimen Subscript	Water Cement Ratio	Casting Date	No. of Days in Curing Room	No. of Days in 50% Humidity	Age at test (Days)
Beam I	0.30	6/ 7/84	6/8/84 to 7/31/84	8/1/84 to 8/6/84	60
Beam II	0.30	6/14/84	6/15/84 to 8/7/84	8/8/84 to 8/13/84	60
Beam III	0.30	6/21/84	6/22/84 to 8/14/84	8/15/84 to 8/20/84	60
Beam IV	0.30	6/28/84	6/29/84 to 8/21/84	8/22/84 to 8/29/84	60

Table 5.1

Cylinder Data Corresponding to Beam I*

No. of Cylinders	3 x 6 in. Area in^2	Load lb.	Stress psi
1	7.07	55,000	7779
2	7.07	56,500	7991
3	7.07	55,000	7779
4	7.07	53,500	7567
5	7.07	50,000	7072
6	7.07	53,500	7567

f'_c average $= \frac{\sum f'_c}{6} = \frac{45755}{6} = 7626$ psi

1 in = 25.4 mm

1 lb = 4.45 N

1 psi = 6.89 KPa

* while testing these cylinders, the machine was not functioning properly and hence the strength indicated is not the true strength of the mix.

Table 5.2

Cylinder Data Corresponding to Beam II*

No. of Cylinders	3 x 6 in. Area in^2	Load lb.	Stress psi
1	7.07	63,000	8911
2	7.07	69,000	9760
3	7.07	65,000	9194
4	7.07	64,000	9052
5	7.07	66,000	9335
6	7.07	64,000	9052

f'_c Average = $\frac{\sum f'_c}{6} = \frac{55305}{6} = 9220$ psi

1 in = 25.4 mm

1 lb = 4.45 N

1 psi = 6.89 kPa

* while testing these cylinders, the machine was not functioning properly and hence the strength indicated is not the true strength of the mix.

Table 5.3

Cylinder Data Corresponding to Beam III*

No. of Cylinders	3 x 6 in Area in^2	Load lb.	Stress psi
1	7.07	76,000	10,750
2	7.07	68,500	9,689
3	7.07	68,500	9,689
4	7.07	68,000	9,618
5	7.07	67,000	9,477
6	7.07	75,000	10,622
7	7.07	67,500	9,547

$$f'_c \text{ Average} = \frac{\sum f'_c}{7} = \frac{69592}{7} = 9920 \text{ psi}$$

1 in = 25.4 mm

1 lb = 4.45 N

1 psi = 6.89 kPa

* while testing these cylinders, the machine was not functioning properly and hence the strength indicated is not the true strength of the mix.

Table 5.4

Cylinder Data Corresponding to Beam IV

No. of Cylinders	3 x 6 in Area in^2	Load lb.	Stress psi
1	7.07	78,000	11,033
2	7.07	72,000	10,184
3	7.07	80,000	11,315
4	7.07	82,000	11,598
5	7.07	80,000	11,315
6	7.07	78,600	10,750
7	7.07	81,800	11,570

f'_c Average $= \frac{\sum f'_c}{7} = 77765 = 11110$ psi

1 in = 25.4 mm

1 lb = 4.45 N

1 psi = 6.89 kPa

Table 5.5

Stress-Strain Relationship for Cylinder #1

Corresponding to Beam I

Load (Lb)	Stress (psi)	Strain Reading in Gage #1 (με)	Strain Reading in Gage #2 (με)	Average (με)
0		0	0	0
5,000	707	− 32	− 216	− 124
10,000	1420	− 57	− 420	− 239
15,000	2120	− 117	− 615	− 366
20,000	2830	− 220	− 793	− 506
25,000	3540	− 360	− 965	− 662
30,000	4240	− 524	−1140	− 831
35,000	4950	− 707	−1330	−1019
40,000	5660	− 937	−1560	−1248
45,000	6370	−1190	−1820	−1500
50,000	7070	− 240	− 276	− 258

1 lb = 4.45N

1 psi = 6.89 kPa

Table 5.6

Stresa-Strain Relationship for Cylinder #2

Corresponding to Besm I

Load (Lb)	Stress (psi)	Strain Reading in Long Gage #1 (με)	Strain Reading in Long Gage #2 (με)	Average of Longitudinal Strain Readings (μs)	Strain Reading in Transverse Gage #1 (μs)	Strain Reading in Transverse Gage #2 (μs)	Aversge of Transverae Strain Readings (με)	Poisson's Ratio
5,000	707	− 91	− 132	− 111	−19	−95	−57	.514
10,000	1420	− 215	− 273	− 254	33	−75	−21	.083
15,000	2120	− 328	− 402	− 365	47	−44	2	.005
20,000	2830	− 454	− 541	− 498	66	−66	−24	.048
25,000	3540	− 600	− 705	− 653	90	10	50	.077
30,000	4240	− 752	− 878	− 815	113	42	78	.096
35,000	4950	− 909	−1070	− 986	140	70	105	.106
40,000	5660	−1094	−1280	−1188	173	115	144	.121
45,000	6370	−1300	−1540	−1420	217	167	192	.135
50,000	7070	−1570	−1900	−1740	279	234	256	.147
53,500	7570	−1880	−2340	−2110	472	326	399	.189

1 lb = 4.45N

1 psi = 6.89 kPa

Table 5.7

Stress-Strain Relationship For Cylinder #2

Corresponding to Beam II

Load (Lb)	Stress (psi)	Strain Reading in Long Gage #1 (µs)	Strain Reading in Long Gage #2 (µs)	Average of Longitudinal Strain Readings (µs)	Strain Reading in Transverse Gage #1 (µs)	Strain Reading in Transverse Gage #2 (µs)	Poisson's Ratio
0		0	4		2	2	
5,000	707	37	- 280	- 158	30	19	.155
10,000	1420	- 56	- 290	- 173	18	28	.133
15,000	2120	- 102	- 368	- 234	48	43	.194
20,000	2830	140	- 570	- 355	82	55	.193
25,000	3540	- 184	- 785	- 485	125	70	.201
30,000	4240	- 255	- 938	- 596	161	81	.203
36,200	5120	- 344	-1080	- 713	200	97	.208
40,000	5660	- 474	-1258	- 866	250	117	.212
43,000	6080	- 570	-1370	- 972	288	134	.217
46,000	6510	- 645	-1460	-1050	317	145	.220
49,000	6930	- 717	-1540	-1130	346	158	.223
52,000	7360	- 805	-1640	-1220	381	177	.229
55,000	7780	- 901	-1750	-1330	415	196	.230
58,000	8210	- 996	-1860	-1430	449	218	.233
61,000	8630	-1110	-2000	-1560	496	244	.237
63,000	8910	-1240	-2160	-1700	559	271	.244
64,000	9050	-1422	-2440	-1930	627	284	.236

1 lb = 4.45N

1 psi = 6.89 kPa

Table 5.8

Stress-Strain Relationship For Cylinder #1

Corresponding to Beam II

Load (Lb)	Stress (psi)	Strain Reading in Gage #1 (με)	Strain Reading in Gage #2 (με)	Average (με)
0		− 508	− 13	
5,000	707	− 110	− 253	− 121
10,000	1420	− 219	− 253	− 236
15,000	2120	− 315	− 402	− 358
20,000	2830	− 403	− 546	− 474
25,000	3540	− 516	− 689	− 602
30,000	4240	− 627	− 816	− 721
33,000	4670	− 707	− 904	− 806
36,000	5090	− 784	− 988	− 886
39,000	5520	− 865	−1080	− 970
42,000	5940	− 945	−1160	−1054
45,000	6370	−1020	−1240	−1130
48,000	6790	−1110	−1347	−1230
51,000	7210	−1200	−1450	−1325
54,000	7640	−1290	−1550	−1424
57,000	8060	−1390	−1670	−1530
60,000	8630	−1490	−1797	−1645
62,000	8770	−1576	−1930	−1750
64,000	9050	−1670	−2060	−1870
66,000	9340	−1770	−2080	−1930

1 lb = 4.45 N
1 psi = 6.89 kPa

Table 5.9

Stress-Strain Relationship For Cylinder #1 Corresponding To Beam III

Load (Lb)	Stress (psi)	Strain Reading in Gage #1 (με)	Strain Reading in Gage #2 (με)	Average (με)
0		6	3	4
2,000	280	− 54	− 45	− 50
5,000	707	− 115	− 116	− 115
10,000	1420	− 239	− 224	− 231
15,000	2120	− 359	− 356	− 357
20,000	2830	− 463	− 484	− 474
25,000	3540	− 570	− 623	− 597
30,000	4240	− 673	− 753	− 713
33,000	4670	− 738	− 830	− 784
36,000	5090	− 810	− 916	− 863
39,000	5520	− 879	− 999	− 939
42,000	5940	− 950	−1080	−1020
45,000	6370	−1023	−1165	−1090
48,000	6790	−1110	−1260	−1180
51,000	7210	−1200	−1360	−1280
54,000	7640	−1290	−1460	−1380
57,000	8060	−1390	−1571	−1480
60,000	8490	−1510	−1700	−1600
63,000	8910	−1650	−1830	−1740
66,000	9340	−1840	−2010	−1930
67,500	9550	−2090	−2150	−2120

1 lb = 4.45 N
1 psi = 6.89 kPa

Table 5.10

Stress-Strain Relationship for Cylinder #2 Corresponding to Beam III

Load (Lb)	Stress (psi)	Strain Reading in Longitudinal Gage #1 (µs)	Strain Reading in Longitudinal Gage #2 (µs)	Average of Longitudinal Strain Readings (µs)	Strain Reading in Gage #1 (µs)	Strain Reading in Gage #2 (µe)	Average of Transverse Strain Readings (µs)	Poisson's Ratio
2,000	280	- 39	- 40	- 40	12	11	11	0.28
5,000	707	- 73	- 134	- 104	20	27	24	0.23
10,000	1420	- 88	- 344	- 216	30	69	50	0.23
15,000	2120	- 118	- 517	- 317	40	108	74	0.23
20,000	2830	- 170	- 663	- 417	54	141	98	0.24
25,000	3540	- 234	- 810	- 552	68	176	122	0.22
30,000	4240	- 300	- 944	- 622	82	208	145	0.22
35,000	4950	- 374	-1090	- 730	94	247	171	0.23
39,000	5520	- 434	-1198	- 816	105	281	193	0.24
43,000	6080	- 495	-1310	- 904	120	317	218	0.24
46,000	6510	- 547	-1410	- 976	127	352	240	0.25
49,000	6930	- 601	-1510	-1050	136	396	266	0.25
52,000	7360	- 655	-1610	-1130	145	455	300	0.27

Table 5.10: Continned

Load (Lb)	Stress (psi)	Strain Reading in Longitndinal Gage #1 (µε)	Strain Reading in Longitndinal Gage #2 (µε)	Average of Longitndinal Strain Readings (µε)	Strain Reading in Gage #1 (µε)	Strain Reading in Gage #2 (µε)	Average of Transverse Strain Readings (µε)	Poisson's Ratio
55,000	7780	- 713	-1710	-1209	154	524	339	0.33
58,000	8210	- 772	-1820	-1300	161	594	378	0.29
61,000	8630	- 836	-1930	-1390	170	679	424	0.31
64,000	9050	- 902	-2060	-1480	177	823	500	0.34
67,000	9480	- 974	-2190	-1580	183	1030	606	0.38
71,000	10000	-1100	-2450	-1770	191	1490	841	0.48
75,000	10600	-1250	-2950	-2100	179	2860	1520	0.72
75,100	10600	FAILURE LOAD						

1 lb = 4.45 N
1 psi = 6.89 kPa

Table 5.11
Stress-Strain Relation for Cylinder #1
Corresponding to Beam IV

Load (lb)	Stress (psi)	Strain Reading in Gage #1 (με)	Strain Reading in Gage #2 (με)	Average (με)
0	0			0
5,000	707	− 36	− 161	− 99
10,000	1410	− 161	− 238	− 200
15,000	2120	− 284	− 313	− 298
20,000	2830	− 401	− 432	− 417
27,000	3820	− 517	− 603	− 560
30,000	4240	− 655	− 609	− 632
35,000	4950	− 740	− 698	− 719
39,000	5520	− 811	− 881	− 846
43,000	6080	− 868	− 960	− 914
46,000	6510	− 941	−1051	− 969
49,000	6932	−1010	−1120	−1050
52,000	7360	−1140	−1120	−1130
55,000	7780	−1290	−1190	−1240
58,000	8210	−1350	−1260	−1310
61,000	8630	−1430	−1340	−1390
64,000	9050	−1500	−1460	−1480
67,000	9480	−1600	−1570	−1580
71,000	10000	−1620	−1720	−1670
75,000	10600	−1880	−1880	−1880
78,200	11100	−1960	−2010	−1990
81,000	11500	−2010	−2190	−2100

1 psi = 6.89 kPa

Table 5.12 : Load-Strain Data for Flexural Test of Beam I

P_1 Axial Load (M/C Load) (lb)	Ram Pressure (psi)	P_2 Eccentric Load Ram Load (lb)	Strain Readings in Gage #1 to #8 (μs)							
			Gage #1	Gage #2	Gage #3	Gage #4	Gage #5	Gage #6	Gage #7	Gage #8
10,000	0	0	− 67	− 67	− 74	− 70	− 58	− 47	− 43	− 51
10,500	28	183	− 45	− 86	− 125	− 131	− 106	− 62	− 34	− 1
20,500	83	550	− 86	− 167	− 256	− 268	− 227	− 227	− 76	− 15
30,000	128	850	−130	− 247	− 374	− 392	− 335	− 206	− 110	− 21
40,400	180	1180	−173	− 338	− 500	− 527	− 450	− 279	− 146	− 27
50,400	220	1410	−222	− 426	− 618	− 649	− 550	− 342	− 173	− 29
60,400	270	1720	−281	− 529	− 755	− 794	− 660	− 409	− 206	− 26
70,000	318	2020	−315	− 613	− 867	− 915	− 776	− 487	− 246	− 37
80,000	363	2300	−357	− 699	− 983	−1030	− 895	− 568	− 296	− 55
90,000	410	2590	−390	− 779	−1100	−1150	−1020	− 652	− 344	− 71
100,000	450	2840	−424	− 871	−1220	−1300	−1160	− 754	− 463	− 91
110,000	503	3180	−465	− 965	−1340	−1460	−1290	− 849	− 463	−114
120,000	540	3430	−499	−1050	−1460	−1590	−1420	− 943	− 518	−130
125,000	555	3530	−521	−1100	−1530	−1650	−1490	− 994	− 552	−145
130,000	570	3630	−542	−1160	−1600	−1710	−1580	−1060	− 594	−158

Table 5.12: Continued

P_1 Axial Load (M/C Load) (lb)	Ram Pressure (psi)	P_2 Eccentric Load Ram Load (lb)	Strain Readings in Gage #1 to #8 (με) Gage #1	Gage #2	Gage #3	Gage #4	Gage #5	Gage #6	Gage #7	Gage #8
135,000	589	3750	− 560	−1210	−1650	−1760	−1650	−1110	− 626	−166
140,000	598	3820	− 575	−1250	−1700	−1770	−1720	−1160	− 659	−181
145,000	618	3950	− 598	−1310	−1780	−1580	−1820	−1230	− 707	−199
150,000	635	4070	− 617	−1370	−1860	−1150	−1910	−1300	− 751	−215
155,000	645	4130	− 637	−1430	−1940	− 928	−2000	−1370	− 796	−236
160,000	660	4230	− 655	−1480	−2010	− 836	−2100	−1440	− 840	−253
162,000	658	4220	− 678	−1530	−2060	− 751	−2160	−1480	− 875	−272
162,700	658	4220	− 682	−1550	−2090	− 675	−2200	−1500	− 887	−273
165,000	660	4230	− 691	−1580	−2140	− 597	−2260	−1550	− 912	−280
170,000	668	4280	− 714	−1650	−2230	− 476	−2370	−1620	− 964	−306
175,100	668	4350	− 737	−1720	−2320	− 270	−1700	−1700	−1020	−329
179,600	668	4350	− 760	−1780	−2420	54	−2610	−1790	−1070	−350
185,000	668	4350	− 788	−1860	−2520	313	−2730	−1870	−1120	−372
190,000	676	4330	− 832	−1990	−2870	1770	−2880	−1950	−1160	−359
205,000	500	3170	−1180	−2910	−1450	2050	−3340	−2110	−1160	−119

1 lb = 4.45 N
1 psi = 6.89 kPa

Table 5.13: Load and Strain Data for Flexural Test of Structural Specimen II

P1 Axial Load (M/C Load) (lb)	Ram Pressure (psi)	P2 Eccentric Load Ram Load (lb)	Strain Readings in Gage #1 to #8 (µs) Gage #1	Gage #2	Gage #3	Gage #4	Gage #5	Gage #6	Gage #7	Gage #8
9,500	0	0	-9	-42	-77	-132	-125	-92	-40	-8
19,800	90	600	-40	-102	-166	-248	-232	-167	-86	-32
30,000	100	670	-91	-164	-234	-320	-281	-208	-121	-66
40,500	215	1380	-99	-233	-362	-521	-469	-322	-167	-48
50,000	303	1900	-125	-293	-465	-669	-599	-409	-211	-60
60,100	373	2359	-152	-359	-568	-803	-724	-494	-260	-74
70,000	423	2670	-182	-423	-659	-929	-840	-578	-309	-92
80,000	470	2970	-209	-484	-752	-1060	-956	-661	-359	-117
90,100	525	3330	-236	-550	-854	-1200	-1090	-760	-420	-141
100,000	575	6670	-263	-613	-949	-1330	-1220	-856	-482	-171
110,000	623	3980	-290	-678	-1050	-1470	-1350	-958	-546	-202
119,800	673	4320	-314	-746	-1150	-1620	-1490	-1070	-620	-236
129,500	710	4570	-336	-813	-1260	-1790	-1650	-1200	-702	-275
139,500	750	4830	-365	-883	-1360	-1940	-1790	-1320	-780	-315

Table 5.13: Continued

P1 Axial Load (M/C Load) (1b)	Ram Pressure (psi)	P2 Eccentric Load Ram Load (1b)	Strain Readings in Gage #1 to #8 (με)							
			Gage #1	Gage #2	Gage #3	Gage #4	Gage #5	Gage #6	Gage #7	Gage #8
149,400	783	5050	- 400	- 970	-1490	-2130	-1960	-1470	- 876	- 367
154,500	798	5150	- 423	-1030	-1570	-2250	-2060	-1550	- 934	- 394
159,500	800	5170	- 442	-1080	-1640	-2340	-2150	-1630	- 987	- 419
164,500	808	5220	- 460	-1120	-1700	-2450	-2240	-1710	-1040	- 445
169,400	810	5230	- 484	-1190	-1790	-2600	-2350	-1820	-1110	- 479
175,200	823	5320	- 510	-1250	-1880	-2750	-2460	-1920	-1180	- 511
180,000	823	5320	- 534	-1310	-1970	-2920	-2570	-2020	-1230	- 537
185,000	823	5320	- 605	-1480	-2180	-3310	-2830	-2350	-1460	- 665
190,000	810	5230								
195,000		FAILURE								

1 1b = 4.45 N

1 psi = 6.89 kPa

Table 5.14: Load-Strain Data for Flexural Test of Beam III

P_1 Axial Load (M/C Load) (lb)	Ramp Pressure (psi)	P_2 Eccentric Load Ramp Load (lb)	Strain Readings in Gage #1 to #8 (μs)							
			Gage #1	Gage #2	Gage #3	Gage #4	Gage #5	Gage #6	Gage #7	Gage #8
10,000	0	0	-46	-51	-51	-54	-59	-47	-49	-48
10,000	60	400	-26	-76	-113	-149	-149	-75	-39	-3
20,000	120	800	-50	-133	-191	-263	-283	-167	-108	-45
30,000	175	1150	-66	-180	-261	-369	-408	-255	-169	-79
39,000	235	1500	-82	-231	-336	-487	-539	-348	-232	-114
50,000	295	1875	-100	-287	-421	-615	-685	-458	-306	-159
60,000	350	2220	-115	-335	-492	-730	-822	-562	-381	-209
70,000	395	2500	-131	-382	-563	-842	-948	-661	-449	-252
80,400	455	2875	-151	-440	-651	-973	-1090	-769	-523	-296
90,000	505	3200	-172	-495	-733	-1100	-1230	-869	-592	-335
100,000	563	3580	-193	-560	-528	-1240	-1380	-981	-666	-378
110,000	612	3920	-219	-626	-927	-1390	-1530	-1100	-744	-419
120,000	650	4170	-248	-691	-1020	-1530	-1670	-1200	-815	-465
130,000	695	4470	-273	-762	-1120	-1680	-1820	-1320	-896	-508
140,000	735	4730	-302	-840	-1240	-1860	-2000	-1450	-982	-555

Table 5.14: Continued

P_1 Axial Load (M/C Load) (lb)	Ram Pressure (psi)	P_2 Eccentric Load Ram Load (lb)	Gage #1	Gage #2	Gage #3	Gage #4	Gage #5	Gage #6	Gage #7	Gage #8
150,500	775	5000	-334	- 929	-1370	-2060	-2190	-1590	-1080	-611
160,000	815	5270	-364	-1010	-1500	-2260	-2380	-1740	-1180	-665
165,000	818	5280	-384	-1060	-1570	-2370	-2490	-1820	-1240	-705
170,000	825	5330	-400	-1120	-1660	-2500	-2630	-1920	-1310	-747
175,000	828	5350	-419	-1180	-1730	-2630	-2750	-2010	-1380	-790
185,000	815	5270	-441	-1240	-1840	-2760	-2860	-2080	-1450	-830
195,000	820			FAILURE						

1 lb = 4.45 N

1 psi = 6.89 kPa

Table 5.15: Load and Strain Data for Flexural Test of Structural Specimen IV

P_1 Axial Load (M/C Load) (lb)	Ram Pressure (psi)	P_2 Eccentric Load Ram Load (lb)	Strain Readings in Gage #1 to #8 ($\mu\varepsilon$)							
			Gage #1	Gage #2	Gage #3	Gage #4	Gage #5	Gage #6	Gage #7	Gage #8
7,000	0	0	- 12	- 9	- 11	- 17	- 30	- 36	- 35	- 29
10,000	0	0	- 20	- 17	- 21	- 31	- 48	- 62	- 58	- 50
11,500	30	200	- 1	- 18	- 60	- 100	- 135	- 157	- 113	- 76
20,000	98	650	0	- 44	- 119	- 183	- 223	- 226	- 152	- 86
30,000	153	1020	- 10	- 87	- 211	- 307	- 352	- 336	- 220	-114
40,000	238	1520	- 20	- 138	- 321	- 456	- 509	- 458	- 292	-152
50,500	293	1860	- 45	- 191	- 419	- 583	- 642	- 563	- 358	-175
60,100	363	2300	- 70	- 254	- 528	- 724	- 785	- 671	- 421	-200
70,300	458	2890	- 74	- 315	- 653	- 899	- 969	- 803	- 490	-210
80,000	498	3150	-103	- 373	- 744	-1013	-1086	- 893	- 547	-240
90,000	530	3370	-143	- 440	- 838	-1126	-1198	- 986	- 611	-277
100,000	605	3870	-166	- 516	- 965	-1294	-1375	-1117	- 683	-298
110,100	643	4120	-208	- 591	-1077	-1430	-1510	-1230	- 754	-333
120,000	713	4580	-231	- 672	-1220	-1620	-1670	-1370	- 830	-351
130,000	748	4820	-268	- 754	-1330	-1770	-1850	-1490	- 901	-378

Table 5.15: Continued

P_1 Axial Load (M/C Load) (lb)	Ramp Pressure (psi)	P_2 Eccentric Load Ramp (lb)	Strain Readings in Gage #1 to #8 (µs)							
			Gage #1	Gage #2	Gage #3	Gage #4	Gage #5	Gage #6	Gage #7	Gage #8
140,000	775	5000	-316	-836	-1440	-1910	-1990	-1600	- 971	-413
149,500	808	5220	-363	-930	-1570	-2080	-2160	-1740	-1050	-446
159,000	840	5630	-415	-1040	-1720	-2280	-2350	-1910	-1150	-486
164,400	824	5330	-452	-1110	-1800	-2390	-2460	-2010	-1210	-515
170,000					FAILURE					

1 lb = 4.45 N

1 psi = 6.89 kPa

Table 5.16: Load And Average Strain At Each Level, For Flexural Test of Beam I

P_1 Axial Load (Machine Load) (lb)	Ram Pressure Reading (psi)	P_2 Eccentric Load Ram Load (lb)	AVERAGE STRAIN READING ($\mu\varepsilon$)			
			Average Gage #1, #8	Average Gage #2, #7	Average Gage #3, #6	Average Gage #4, #5
10,000	0	0	-58	-55	-60	-64
10,500	28	183	-23	-59	-93	-118
20,500	83	550	-50	-121	-197	-247
30,000	128	850	-75	-178	-289	-363
40,400	180	1180	-100	-239	-389	-488
50,400	220	1410	-125	-299	-479	-599
60,400	270	1720	-153	-367	-582	-726
70,000	318	2020	-176	-429	-676	-845
80,000	363	2300	-206	-497	-775	-963
90,000	410	2590	-230	-561	-873	-1080
100,000	450	2840	-257	-637	-987	-1230
110,000	503	3180	-289	-714	-1100	-1370
120,000	540	3430	-314	-785	-1200	-1500
125,000	555	3530	-332	-827	-1260	-1570
130,000	570	3630	-350	-876	-1330	-1650

Table 5.16: Continued

P_1 Axial Load (Machine Load) (lb)	Ram Pressure Reading (psi)	P_2 Eccentric Load Ram Load (lb)	AVERAGE STRAIN READING (μs) Average Gage #1, #8	Average Gage #2, #7	Average Gage #3, #6	Average Gage #4, #5
135,000	589	3750	-338	- 916	-1380	-1710
140,000	598	3820	-378	- 955	-1430	-1750
145,000	618	3950	-398	-1010	-1510	-1820 *
150,000	635	4070	-416	-1060	-1580	-1910
155,000	645	4130	-436	-1110	-1650	-2010
160,000	660	4230	-454	-1160	-1720	-2100
162,000	658	4220	-475	-1200	-1770	-2160
162,700	658	4220	-478	-1220	-1800	-2200
165,000	660	4230	-486	-1250	-1840	-2260
170,000	668	4280	-510	-1310	-1920	-2370
175,100	668	4350	-530	-1370	-2010	-2490
179,600	668	4350	-555	-1430	-2100	-2610
185,000	668	4350	-580	-1490	-2200	-2730
190,000	676	4330	-596	-1570	-2410	-2878
205,000	500	3170	-649	-2030	-1780	-3340

1 lb = 4.45 N
1 psi = 6.89 kPa

*From this point onwards Gage #4 was not working and hence the reading of gage #5 was taken and not the average.

Table 5.17: Load and Average Strain At Each Level, For Flexural Test of Beam II

P_1 Axial Load (Machine Load) (lb)	Ram Pressure Reading (psi)	P_2 Eccentric Load Ram Load (lb)	AVERAGE STRAIN READING ($\mu\varepsilon$) Average Gage #1, #8	Average Gage #2, #7	Average Gage #3, #6	Average Gage #4, #5
9,500	0	0	− 9	− 41	− 85	− 129
19,800	90	600	− 36	− 94	− 166	− 240
30,000	100	670	− 79	− 143	− 221	− 300
40,500	215	1380	− 73	− 200	− 342	− 495
50,000	303	1900	− 93	− 252	− 437	− 631
60,100	373	2359	−113	− 310	− 531	− 764
70,000	423	2670	−137	− 366	− 619	− 884
80,000	470	2970	−163	− 422	− 707	−1000
90,100	525	3330	−188	− 485	− 807	−1150
100,000	575	3670	−217	− 548	− 902	−1270
110,000	623	3980	−246	− 612	−1000	−1410
119,800	673	4320	−275	− 683	−1110	−1560
129,500	710	4570	−306	− 758	−1230	−1720
139,500	750	4830	−340	− 832	−1340	−1860
149,400	783	5050	−384	− 923	−1480	−2040

Table 5.17: Continued

P_1 Axial Load (Machine Load) (lb)	Ram Pressure Reading (psi)	P_2 Eccentric Load Ram Load (lb)		AVERAGE STRAIN READING (με)		
			Average Gage #1, #8	Average Gage #2, #7	Average Gage #3, #6	Average Gage #4, #5
154,500	798	5150	-409	- 980	-1560	-2150
159,500	800	5170	-431	-1030	-1630	-2250
164,500	808	5230	-452	-1080	-1700	-2350
169,400	810	5320	-482	-1150	-1810	-2470
175,200	823	5320	-511	-1210	-1900	-2610
180,000	823	5320	-535	-1270	-2000	-2740
185,000	823	5320	-635	-1470	-2270	-3070
190,000	810	5230				
195,000		FAILURE				

1lb = 4.45 N

1 psi = 6.89 kPa

Table 5.18: Load And Average Strain At Each Level, For Flexural Test of Beam III

P_1 Axial Load (Machine Load) (lb)	Ram Pressure Reading (psi)	P_2 Eccentric Load Ram Load (lb)	AVERAGE STRAIN READING ($\mu\varepsilon$) Average Gage #1, #8	Average Gage #2, #7	Average Gage #3, #6	Average Gage #4, #5
10,000	0	0	-47	-50	-49	-57
10,000	60	400	-29	-58	-94	-149
20,000	120	800	-47	-120	-179	-273
30,000	175	1150	-73	-175	-258	-388
39,000	235	1500	-98	-231	-342	-513
50,000	295	1875	-130	-297	-440	-650
60,000	350	2220	-162	-358	-527	-776
70,000	395	2500	-192	-415	-612	-895
80,000	455	2875	-225	-481	-710	-1030
90,000	505	3200	-254	-543	-801	-1160
100,000	563	3580	-285	-613	-904	-1310
110,000	612	3920	-319	-685	-1010	-1460
120,000	650	4170	-357	-753	-1110	-1600
130,000	695	4470	-390	-829	-1220	-1750
140,000	735	4730	-429	-911	-1340	-1930

Table 5.18: Continued

P_1 Axial Load (Machine Load) (lb)	Ram Pressure Reading (psi)	P_2 Eccentric Load Ram Load (lb)	AVERAGE STRAIN READING (με)			
			Average Gage #1, #8	Average Gage #2, #7	Average Gage #3, #6	Average Gage #4, #5
150,500	775	5000	−473	−1000	−1480	−2130
160,000	815	5270	−515	−1100	−1620	−2320
165,000	818	5280	−544	−1150	−1700	−2430
170,000	825	5330	−573	−1220	−1790	−2570
175,000	828	5350	−605	−1280	−1870	−2690
185,000	815	5270	−635	−1350	−1960	−2810
195,000	820	5300	FAILURE			

1 lb = 4.45 N

1 psi = 6.89 kPa

Table 5.19: Load And Average Strain At Each Level, For Flexural Tests of Beam IV

P_1 Axial Load (Machine Load) (lb)	Ram Pressure Reading (psi)	P_2 Eccentric Load Ram Load (lb)	AVERAGE STRAIN READING (μs)			
			Average Gage #1, #8	Average Gage #2, #7	Average Gage #3, #6	Average Gage #4, #5
7,000	0	0	- 20	- 22	- 24	- 23
10,000	0	0	- 35	- 37	- 41	- 39
11,500	30	200	- 39	- 66	- 108	- 117
20,000	98	650	- 43	- 98	- 173	- 203
30,000	153	1020	- 62	- 154	- 274	- 329
40,000	238	1520	- 81	- 215	- 390	- 482
50,500	293	1860	-110	- 275	- 491	- 613
60,100	363	2300	-135	- 337	- 599	- 755
70,300	458	2890	-142	- 402	- 728	- 934
80,000	498	3150	-171	- 460	- 819	-1050
90,000	530	3370	-210	- 526	- 912	-1160
100,000	605	3870	-232	- 599	-1040	-1330
110,100	643	4120	-270	- 672	-1150	-1470
120,000	713	4580	-291	- 751	-1420	-1660
130,000	748	4820	-323	- 828	-1410	-1800
140,000	775	5000	-364	- 903	-1520	-1950

Table 5.19: Continued

P_1 Axial Load (Machine Load) (lb)	Ram Pressure Reading (psi)	P_2 Eccentric Load Ram Load (lb)	AVERAGE STRAIN READING (με)			
			Average Gage #1, #8	Average Gage #2, #7	Average Gage #3, #6	Average Gage #4, #5
149,500	808	5220	−404	− 991	−1660	−2120
159,000	840	5630	−450	−1100	−1810	−2320
164,400	824	5530	−483	−1160	−1900	−2420
170,000		FAILURE				

1 lb = 4.45 N

1 psi = 6.89 kPa

Table 5.20: Load and Ultimate Strength Factors For Specimen I

P_1 Major Thrust (lb)	P_2 Minor Thrust (lb)	s_c at Comp Face µs	f_c* psi	k_1	k_2	$k_3 f_c/f'_c$	k_1k_3	$\frac{k_2}{k_1k_3}$	f_o** psi	m_o*** psi
10,000	0	− 64	− 528	0.851	0.50	0.047	0.040	12.50	400	200
10,000	183	− 118	− 683	0.655	0.41	0.061	0.040	10.25	407	240
20,500	550	− 247	− 1580	0.567	0.37	0.141	0.080	4.63	842	529
30,000	850	− 363	− 2430	0.504	0.36	0.218	0.110	3.27	1230	784
40,400	1180	− 488	− 3280	0.512	0.36	0.293	0.150	2.40	1660	1060
50,400	1410	− 599	− 4030	0.528	0.37	0.360	0.190	1.95	2070	1310
60,400	1720	− 726	− 4840	0.508	0.36	0.433	0.220	1.64	2490	1580
70,000	2020	− 845	− 5620	0.516	0.36	0.503	0.260	1.38	2880	1840
80,000	2300	− 963	− 6350	0.510	0.36	0.568	0.290	1.24	3290	2100
90,000	2590	−1080	− 7010	0.526	0.36	0.627	0.330	1.09	5700	2360
100,000	2840	−1230	− 7680	0.538	0.36	0.687	0.370	0.97	4110	2610
110,000	3180	−1370	− 8480	0.540	0.36	0.759	0.410	0.88	4530	2890
120,000	3430	−1500	− 9220	0.533	0.36	0.825	0.440	0.82	4940	3140
125,000	3530	−1570	− 9660	0.532	0.37	0.864	0.460	0.80	5140	3260
130,000	3630	−1650	−10600	0.508	0.37	0.944	0.480	0.77	5350	3390
135,000	3750	−1710	−11000	0.507	0.37	0.986	0.500	0.74	5550	3510

Table 5.20: Continued

P_1 Major Thrust (lb)	P_2 Minor Thrust (lb)	s_o at Comp Face μs	f_c* psi	k_1	k_2	k_3 f_o/f'_c	k_1k_3	$\frac{k_2}{k_1k_3}$	f_o** psi	m_o*** psi
140,000	3820	-1750	-11300	0.512	0.37	1.014	0.520	0.71	5750	3620
145,000	3950	-1820	-11000	0.538	0.37	0.985	0.530	0.70	5960	3750
150,000	4070	-1910	-10500	0.585	0.37	0.939	0.550	0.67	6160	3880
155,000	4130	-2000	-10400	0.613	0.37	0.930	0.570	0.65	6370	3990
160,000	4230	-2100	- 9960	0.662	0.37	0.891	0.590	0.63	6570	4110
162,000	4220	-2160	- 9750	0.688	0.38	0.872	0.600	0.63	6650	4160
162,700	4220	-2200	- 9660	0.707	0.38	0.863	0.60	0.63	6680	4170
165,000	4230	-2260	-10200	0.68	0.38	0.910	0.61	0.62	6770	4210
170,000	4280	-2370	-10900	0.635	0.38	0.976	0.62	0.61	6970	4330
175,100	4350	-2490	-11300	0.632	0.38	1.012	0.64	0.59	7180	4440
179,600	4350	-2610	-11400	0.646	0.38	1.021	0.660	0.58	7360	4530
185,000	4350	-2730	-11500	0.660	0.39	1.030	0.68	0.57	7570	4640
190,000	4330	-2880	-11300	0.692	0.39	1.011	0.70	0.56	7770	4740
205,000	3170	-3340	-10200	0.824	0.43	0.913	0.750	0.57	8330	4780

f'_c = 11180 psi (77 MPa)

* f_c - obtained from equations (4.1) and (4.2) (average)

** $f_o = \dfrac{P_1 + P_2}{bc}$ *** $m_o = \dfrac{P_1a_1 + P_2a_2}{bc^2}$

1 lb = 4.45 N

1 psi = 6.89 kPa

Table 5.21: Load and Ultimate Strength Factors for Beam II

P_1 Major Thrust (lb)	P_2 Minor Thrust (lb)	ε_c at Comp Face $\mu\varepsilon$	f_c* psi	k_1	k_2	$k_3 f_c/f'_c$	k_1k_3	$\frac{k_2}{k_1k_3}$	f_o** psi	m_o*** psi
9,500	0	− 129	− 894	0.375	0.50	0.080	0.03	16.67	380	190
19,800	600	− 240	− 1770	0.440	0.36	0.159	0.07	5.14	816	526
30,000	670	− 301	− 2320	0.529	0.39	0.208	0.11	3.55	1230	744
40,500	1380	− 495	− 3240	0.517	0.34	0.290	0.15	2.27	1680	1110
50,000	1900	− 631	− 4080	0.520	0.32	0.365	0.19	1.68	2080	1410
60,100	2360	− 764	− 5060	0.486	0.31	0.453	0.22	1.41	2500	1710
70,000	2670	− 885	− 5850	0.496	0.32	0.524	0.26	1.23	2900	1980
80,000	2970	−1000	− 6600	0.507	0.32	0.591	0.30	1.07	3320	2240
90,100	3330	−1140	− 7350	0.502	0.33	0.658	0.33	1.00	3740	2520
100,000	3670	−1270	− 8010	0.516	0.33	0.717	0.37	0.89	4150	2790
119,800	3980	−1560	− 9310	0.528	0.33	0.834	0.44	0.75	4970	3330
129,500	4320	−1720	− 9880	0.542	0.33	0.885	0.48	0.69	5360	3580
139,500	4570	−1860	−10300	0.564	0.34	0.922	0.52	0.65	5770	3830
149,400	5050	−2040	−10700	0.574	0.34	0.958	0.55	0.62	6180	4080
154,500	5150	−2150	−10900	0.584	0.34	0.976	0.57	0.60	6390	4200

Table 5.21: Continued

P_1 Major Thrust (lb)	P_2 Minor Thrust (lb)	ε_c at Comp Face $\mu\varepsilon$	f_c* psi	k_1	k_2	k_3 f_c/f'_c	k_1k_3	$\frac{k_2}{k_1k_3}$	f_o** psi	m_o*** psi
159,500	5170	−2250	−10900	0.604	0.35	0.976	0.59	0.59	6590	4310
164,500	5230	−2350	−11200	0.608	0.35	1.003	0.61	0.57	6790	4420
169,400	5320	−2480	−11200	0.628	0.35	1.003	0.63	0.56	6990	4520
175,200	5320	−2610	−11100	0.653	0.36	0.994	0.65	0.55	7220	4650
180,000	5320	−2740	−10800	0.682	0.36	0.967	0.66	0.55	7420	4740
185,000	5320	−3070	− 9580	0.790	0.36	0.857	0.68	0.53	7610	4850

1lb = 4.45 N   1 psi = 6.89 kPa   Failure at 195,000 lb

*, **, ***, see Table 5.20

Table 5.22: Load And Ultimate Strength Factors For Specimen III

P_1 Major Thrust (lb)	P_2 Minor Thrust (lb)	s_c at Comp Face µs	f_c* psi	k_1	k_2	k_3 f_c/f'_c	k_1k_3	$\frac{k_2}{k_1k_3}$	f_o** psi	m_o*** psi
10,000	0	- 57	- 490	0.930	0.50	0.043	0.04	12.5	400	200
10,000	400	- 149	- 785	0.571	0.31	0.070	0.04	7.75	416	286
20,000	800	- 273	- 1650	0.472	0.31	0.148	0.07	4.43	832	573
30,000	1150	- 389	- 2550	0.482	0.32	0.228	0.11	2.91	1250	848
39,000	1500	- 513	- 3320	0.505	0.32	0.297	0.15	2.13	1620	1100
50,000	1880	- 650	- 4210	0.504	0.32	0.377	0.19	1.68	2080	1410
60,000	2220	- 776	- 5050	0.487	0.33	0.452	0.22	1.50	2490	1680
70,000	2500	- 895	- 5800	0.501	0.33	0.519	0.26	1.27	2900	1940
80,400	2880	-1030	- 6560	0.511	0.33	0.587	0.30	1.10	3330	2230
90,000	3200	-1160	- 7210	0.511	0.33	0.645	0.33	1.00	3730	2490
100,000	3580	-1310	- 7970	0.519	0.33	0.713	0.37	0.89	4140	2770
110,000	3920	-1460	- 8620	0.532	0.33	0.771	0.41	0.80	4560	3050
120,000	4170	-1600	- 9290	0.530	0.34	0.831	0.44	0.77	4970	3300
130,000	4470	-1750	- 9800	0.547	0.35	0.877	0.48	0.73	5370	3500

Table 5.22: Continued

P_1 Major Thrust (lb)	P_2 Minor Thrust (lb)	ε_c at Comp Face	f_c* psi	k_1	k_2	k_3 f_c/f'_c	k_1k_3	$\frac{k_2}{k_1k_3}$	f_o** psi	m_o*** psi
140,000	4730	-1930	-10400	0.561	0.34	0.927	0.52	0.65	5790	3820
150,500	5000	-2130	-10800	0.578	0.34	0.969	0.56	0.61	6220	4090
160,000	5270	-2320	-11000	0.600	0.34	0.983	0.59	0.58	6110	4340
165,000	5280	-2430	-11500	0.595	0.35	1.026	0.61	0.57	6810	4440
170,000	5330	-2570	-11600	0.610	0.35	1.033	0.63	0.56	7010	4550
175,000	5350	-2690	-11600	0.626	0.35	1.038	0.65	0.54	7210	4660
185,000	5270	-2810	-11800	0.644	0.36	1.056	0.68	0.53	7610	4840
195,000	FAILURE LOAD									

1lb = 4.45 N   1 psi = 6.89 kPa

*, **, ***, See Table 5.20

Table 5.23: Load And Ultimate Strength Factors For Beam IV

P_1 Major Thrust (1b)	P_2 Minor Thrust (1b)	ε_c at Comp Face $\mu\varepsilon$	f_c* psi	k_1	k_2	k_3 f_c/f'_c	k_1k_3	$\frac{k_2}{k_1k_3}$	f_o** psi	m_o*** psi
7,000	0	− 23	− 324	1.034	0.50	0.029	0.03	16.67	280	140
10,000	0	− 39	− 477	0.930	0.50	0.043	0.04	12.50	400	200
11,500	200	− 117	− 782	0.571	0.42	0.070	0.04	10.50	468	273
20,000	650	− 203	− 1480	0.530	0.35	0.132	0.07	5.00	826	540
30,000	1020	− 329	− 2360	0.521	0.34	0.211	0.11	3.09	1240	819
40,000	1520	− 482	− 3190	0.526	0.32	0.285	0.15	2.13	1660	1130
50,500	1860	− 613	− 3960	0.537	0.33	0.354	0.19	1.74	2090	1410
60,100	2300	− 755	− 4790	0.536	0.32	0.551	0.22	1.45	2500	1700
70,300	2890	− 934	− 5880	0.494	0.32	0.551	0.22	1.45	2930	2030
80,000	3150	−1090	−6580	0.510	0.31	0.588	0.30	1.03	3330	2280
90,000	3370	−1162	−7400	0.499	0.31	0.661	0.33	0.97	3740	2530
100,000	3870	−1330	−7960	0.520	0.32	0.712	0.37	0.86	4260	2840
110,100	4120	−1470	− 8560	0.536	0.32	0.765	0.41	0.78	4570	3090
120,000	4580	−1660	− 9450	0.532	0.32	0.845	0.45	0.71	4980	3390
130,000	4820	−1800	−10100	0.533	0.32	0.901	0.48	0.67	5400	3640

Table 5.23: Continued

P_1 Major Thrust (lb)	P_2 Minor Thrust (lb)	s_c at Comp Face $\mu\varepsilon$	f_c* psi	k_1	k_2	k_3 f_c/f'_c	k_1k_3	$\frac{k_2}{k_1k_3}$	f_o** psi	m_o*** psi
140,000	5000	−1950	−10700	0.544	0.33	0.956	0.52	0.63	5800	3880
149,500	5220	−2120	−10900	0.565	0.33	0.973	0.55	0.60	6190	4120
159,000	5630	−2320	−11000	0.602	0.34	0.980	0.59	0.58	6580	4350
164,000	5530	−2420	−10900	0.625	0.35	0.976	0.61	0.57	6790	4440

1lb = 4.45 N   1 psi = 6.89 kPa

*, **, *** See Table 5.20

Table 5.24: Load And Stress Data For Flexural Test Of Beam I Using Eqnations (4.1, 4.2)

Msjor Thrnst P_1 (1b)	Minor Thrnst P_2 (1b)	Average Strain At Comp Face s_c (μs)	f_o psi	m_o psi	$\frac{df_o}{ds_c}$	$\frac{dm_o}{ds_c}$	$f_c = s_c \frac{df_o}{ds_c} + f_o$ Eq. (4.1) (psi)	$f_c = s_c \frac{dm_o}{ds_c} + 2m_o$ Eq. (4.1) (psi)	f_c Average of Eq. (4.1), Eq. (4.2) (psi)
10,000	0	− 64	400	200	2.244	1.730	− 544	− 511	− 528
10,000	183	− 118	407	240	2.469	1.824	− 670	− 696	− 683
20,500	550	− 247	842	529	3.005	2.049	−1590	−1560	−1580
30,000	850	− 363	1230	784	3.456	2.229	−2490	−2380	−2430
40,400	1180	− 488	1660	1060	3.453	2.201	−3350	−3200	−3280
50,400	1410	− 599	2070	1310	3.427	2.180	−4130	−3930	−4030
60,400	1720	− 726	2490	1580	3.398	2.165	−4660	−4730	−4830
70,000	2020	− 850	2880	1840	3.383	2.170	−5740	−5500	−5620
80,000	2300	− 963	3290	2100	3.302	2.101	−6480	−6220	−6350
90,000	2590	−1080	3700	2360	3.158	2.011	−7120	−6900	−7010
100,000	2840	−1230	4110	2610	2.990	1.905	−7790	−7570	−7680
110,000	3180	−1380	4530	2890	2.974	1.872	−8610	−8350	−8480
120,000	3430	−1500	4940	3140	2.980	1.815	−9420	−9020	−9220

Table 5.24: Continued

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strain At Comp Face s_c (µs)	f_o psi	m_o psi	$\frac{df_o}{ds_c}$	$\frac{dm_o}{ds_c}$	$f_c = s_c \frac{df_o}{ds_c} + f_o$ Eq. (4.1) (psi)	$f_c = s_c \frac{dm_o}{ds_c} + 2m_o$ Eq. (4.1) (psi)	f_c Average of Eq. (4.1), Eq. (4.2) (psi)
125,000	3530	−1570	5140	3260	3.028	1.829	− 9900	− 9400	− 9660
130,000	3630	−1650	5350	3390	3.433	2.033	−11000	−10100	−10600
135,000	3750	−1700	5550	3510	3.469	2.075	−11400	−10600	−11000
140,000	3820	−1750	5750	3620	3.464	2.073	−11800	−10900	−11300
145,000	3950	−1820	5960	3750	2.940	1.767	−11300	−10700	−11000
150,000	4070	−1910	6160	3880	2.313	1.387	−10600	−10400	−10500
155,000	4130	−2000	6370	3990	2.042	1.173	−10500	−10300	−10400
160,000	4230	−2100	6570	4110	1.583	0.860	− 9890	−10000	− 9960
162,000	4220	−2160	6650	4150	1.381	0.727	− 9630	− 9870	− 9750
162,700	4220	−2200	6680	4170	1.298	0.661	− 9530	− 9780	− 9660
165,000	4230	−2260	6770	4210	1.482	0.799	−10120	−10200	−10200
170,000	4280	−2370	6970	4330	1.696	0.924	−11000	−10900	−10900
175,100	4350	−2490	7180	4440	1.706	0.904	−11400	−11100	−11300

Table 5.24: Continued

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strain At Comp Face ε_c ($\mu\varepsilon$)	f_o psi	m_o psi	$\frac{df_o}{d\varepsilon_c}$	$\frac{dm_o}{d\varepsilon_c}$	$f_c = \varepsilon_c \frac{df_o}{d\varepsilon_c} + f_o$ Eq. (4.1) (psi)	$f_c = \varepsilon_c \frac{dm_o}{d\varepsilon_c} + 2m_o$ Eq. (4.1) (psi)	f_c Average of Eq. (4.1), Eq. (4.2) (psi)
179,600	4350	-2610	7360	4530	1.616	0.829	-11600	-11200	-11400
185,000	4350	-2730	7570	4640	1.529	0.704	-11700	-11200	-11500
190,000	4330	-2880	7770	4740	1.396	0.473	-11800	-10800	-11300
205,000	3170	-3340	8330	4780	0.994	0.227	-11600	- 8810	-10200

1lb = 4.45 N   1 psi = 6.89 kPa

Table 5.25: Load and Stress Data for Flexural Test of Beam II Using Equations (4.1, 4.2)

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strain At Comp Face ε_c ($\mu\varepsilon$)	f_o psi	m_o psi	$\frac{df_o}{d\varepsilon_c}$	$\frac{dm_o}{d\varepsilon_c}$	$f_c = \varepsilon_c \frac{df_o}{d\varepsilon_c} + f_o$ Eq. (4.1) (psi)	$f_c = \varepsilon_c \frac{dm_o}{d\varepsilon_c} + 2m_o$ Eq. (4.1) (psi)	f_c Average of Eq. (4.1), Eq. (4.2) (psi)
9,500	0	− 129	380	190	4.768	3.182	− 996	− 791	− 894
19,800	600	− 240	816	526	4.123	2.823	− 1810	− 1730	− 1770
30,000	667	− 301	1230	744	3.773	2.627	− 2360	− 2280	− 2320
40,500	1382	− 495	1680	1110	3.007	2.186	− 3170	− 3300	− 3240
50,000	1900	− 631	2080	1410	2.995	2.165	− 3970	− 4190	− 4080
60,100	2360	− 764	2500	1710	3.262	2.230	− 4990	− 5130	− 5060
70,000	2670	− 885	2910	1980	3.282	2.183	− 5810	− 5890	− 5850
80,000	2970	−1000	3320	2240	3.255	2.130	− 6590	− 6620	− 6600
90,100	3330	−1140	3740	2520	3.127	2.057	− 7310	− 7390	− 7350
100,000	3670	−1270	4150	2790	2.978	1.965	− 7940	− 8080	− 8010
119,800	4320	−1560	4970	3330	2.748	1.760	− 9250	− 9400	− 9310
129,500	4570	−1720	5360	3580	2.590	1.627	− 9810	− 9950	− 9880
139,500	4830	−1860	5770	3830	2.402	1.478	−10254	−10430	−10340

Table 5.25: Continued

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strain At Comp Face ε_c (με)	f_o psi	m_o psi	$\frac{df_o}{d\varepsilon_c}$	$\frac{dm_o}{d\varepsilon_c}$	$f_c = \varepsilon_c \frac{df_o}{d\varepsilon_c} + f_o$ Eq. (4.1) (psi)	$f_c = \varepsilon_c \frac{dm_o}{d\varepsilon_c} + 2m_o$ Eq. (4.1) (psi)	f_c Average of Eq. (4.1), Eq. (4.2) (psi)
149,400	5050	−2040	6180	4080	2.161	1.262	−10600	−10700	−10700
154,400	5150	−2150	6390	4200	2.073	1.162	−10850	−10980	−10880
159,500	5170	−2250	6590	4310	1.922	1.045	−10900	−11000	−10900
164,500	5220	−2350	6790	4420	1.876	0.998	−11200	−11200	−11200
169,400	5230	−2480	6990	4520	2.386	0.863	−12900	−11200	−12100
175,200	5320	−2610	7220	4650	2.164	0.717	−12900	−11200	−12100
180,000	5320	−2740	7410	4740	1.929	0.559	−12700	−11000	−11900
185,000	5320	−3070	7610	4850	1.269	0.126	−11500	−10100	−10800

1lb = 4.45 N   1 psi = 6.89 kPa   Failure at 195,000 lbs.

Table 5.26: Load and Stress Data for Flexural Test of Beam III Using Eq (4.1, 4.2)

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strain At Comp Face ε_c ($\mu\varepsilon$)	f_o psi	m_o psi	$\frac{df_o}{d\varepsilon_c}$	$\frac{dm_o}{d\varepsilon_c}$	$f_c = \varepsilon_c \frac{df_o}{d\varepsilon_c} + f_o$ Eq. (4.1) (psi)	$f_c = \varepsilon_c \frac{dm_o}{d\varepsilon_c} + 2m_o$ Eq. (4.1) (psi)	f_c Average of Eq. (4.1), Eq. (4.2) (psi)
10,000	0	- 57	400	200	1.584	1.584	- 490	- 490	- 490
10,000	400	- 149	416	286	2.103	1.780	- 731	- 838	- 785
20,000	800	- 273	832	573	2.800	2.043	- 1600	- 1710	- 1650
30,000	1150	- 389	1250	848	3.313	2.236	- 2540	- 2570	- 2550
39,000	1500	- 510	1620	1100	3.270	2.186	- 3300	- 3330	- 3320
50,000	1880	- 650	2080	1410	3.279	2.163	- 4210	- 4220	- 4210
60,000	2220	- 780	2490	679	3.304	2.167	- 5060	- 5040	- 5050
70,000	2500	- 900	2900	1940	3.248	2.130	- 5810	- 5790	- 5800
80,400	2880	-1030	3330	2230	3.107	2.057	- 6540	- 6580	- 6560
90,000	3200	-1160	3730	2490	2.942	1.966	- 7150	- 7270	- 7210
100,000	3580	-1310	4140	2770	2.875	1.892	- 7910	- 8030	- 7970
110,000	3920	-1460	4560	3050	2.788	1.725	- 8630	- 8610	- 8620
120,000	4166	-1600	4970	3300	2.710	1.679	- 9290	- 9280	- 9290

Table 5.26: Continued

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strain At Comp Face ε_c ($\mu\varepsilon$)	f_o psi	m_o psi	$\frac{df_o}{d\varepsilon_c}$	$\frac{dm_o}{d\varepsilon_c}$	$f_c = \varepsilon_c \frac{df_o}{d\varepsilon_c} + f_o$ Eq. (4.1) (psi)	$f_c = \varepsilon_c \frac{dm_o}{d\varepsilon_c} + 2m_o$ Eq. (4.1) (psi)	f_c Average of Eq. (4.1), Eq. (4.2) (psi)
130,000	4170	−1750	5370	3500	2.547	1.584	− 9840	− 9780	− 9810
140,000	4730	−1930	5790	3820	2.305	1.480	−10200	−10500	−10400
150,500	5000	−2130	6220	4090	2.090	1.332	−10700	−11000	−10800
160,000	5270	−2320	6610	4340	1.825	1.062	−10800	−11100	−11000
165,000	5280	−2430	6810	4440	1.904	1.077	−11400	−11500	−11500
170,000	5330	−2570	7010	4550	1.766	0.954	−11500	−11600	−11600
175,000	5350	−2690	7210	4660	1.645	0.844	−11600	−11600	−11600
185,000	5270	−2810	7610	4840	1.520	0.731	−11900	−11700	−11800

1lb = 4.45 N   1 psi = 6.89 kPa

Table 5.27: Load and Stress Data for Flexural Test of Beam IV Using Eq. (4.1, 4.2)

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strain At Comp Face ε_c ($\mu\varepsilon$)	f_o psi	m_o psi	$\frac{df_o}{d\varepsilon_c}$	$\frac{dm_o}{d\varepsilon_c}$	$f_c = \varepsilon_c \frac{df_o}{d\varepsilon_c} + f_o$ Eq. (4.1) (psi)	$f_c = \varepsilon_c \frac{dm_o}{d\varepsilon_c} + 2m_o$ Eq. (4.1) (psi)	f_c Average of Eq. (4.1), Eq. (4.2) (psi)
7,000	0	- 23	280	140	2.017	1.657	- 328	- 319	- 324
10,000	0	- 39	400	200	2.128	1.716	- 485	- 468	- 477
11,500	200	- 117	468	273	2.666	2.004	- 782	- 782	- 782
20,000	650	- 203	826	540	2.946	2.178	- 1430	- 1520	- 1480
30,000	1010	- 329	1240	819	3.266	2.302	- 2320	- 2400	- 2360
40,000	1520	- 482	1660	1130	3.021	2.096	- 3120	- 3270	- 3190
50,500	1860	- 613	2090	1410	2.854	2.025	- 3840	- 4070	- 3960
60,100	2300	- 755	2500	1700	2.858	2.009	- 4650	- 4910	- 4780
70,300	2890	- 930	2930	2030	3.064	2.048	- 5790	- 5980	- 5880
80,000	3150	-1050	3330	2280	3.001	2.020	- 6480	- 6680	- 6580
90,000	3370	-1160	3740	2530	3.134	2.030	- 7380	- 7410	- 7400
100,000	3870	-1330	4160	2840	2.754	1.844	- 7810	- 8120	- 7960
110,100	4120	-1470	4570	3090	2.582	1.738	- 8370	- 8740	- 8560

Table 5.27: Continued

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strain At Comp Face ε_c ($\mu\varepsilon$)	f_o psi	m_o psi	$\frac{df_o}{d\varepsilon_c}$	$\frac{dm_o}{d\varepsilon_c}$	$f_c = \varepsilon_c \frac{df_o}{d\varepsilon_c} + f_o$ Eq. (4.1)	$f_c = \varepsilon_c \frac{dm_o}{d\varepsilon_c} + 2m_o$ Eq. (4.1)	f_c Average of Eq. (4.1), Eq. (4.2) (psi)
120,000	4580	-1660	4980	3390	2.626	1.676	- 9340	- 9560	- 9450
130,000	4820	-1800	5390	3640	2.560	1.605	- 9990	-10200	-10100
140,000	5000	-1950	5800	3880	2.504	1.509	-10700	-10700	-10700
149,500	5220	-2120	6190	4120	2.193	1.275	-10800	-10900	-10900
159,000	5430	-2320	6580	4350	1.876	0.999	-10900	-11000	-11000
164,400	5330	-2430	6790	4440	1.693	0.851	-10900	-10900	-10900

1lb = 4.45 N   1 psi = 6.89 kPa   Failure at 170,000 lb

Table 5.28: Load and Stress Data for Flexural Test of

Beam I Using Eq. 4.1 and Eq. 4.2 and

Cylinder Stress-Strain Curve

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strain at Compression (με)	f_c Average of Eq. (4.1) and (4.2) (psi)	f_c Using Cylinder Stress Strain Curve (psi)
10,000	0	− 64	− 528	− 458
10,000	183	− 118	− 683	− 840
20,500	550	− 247	− 1580	− 1740
30,000	850	− 363	− 2430	− 2530
40,400	1180	− 488	− 3280	− 3370
50,400	1410	− 599	− 4030	− 4090
60,400	1720	− 726	− 4840	− 4900
70,000	2020	− 845	− 5620	− 5630
80,000	2300	− 963	− 6350	− 6330
90,000	2590	−1080	− 7010	− 7010
100,000	2840	−1230	− 7680	− 7810
110,000	3180	−1370	− 8480	− 8560
120,000	3430	−1500	− 9220	− 9180
125,000	3530	−1570	− 9660	− 9490
130,000	3630	−1650	−10600	− 9870
135,000	3750	−1710	−11000	−10000
140,000	3820	−1750	−11300	−10200
145,000	3950	−1820	−11000	−10500
150,000	4070	−1910	−10500	−10800
155,000	4130	−2000	−10400	−11100
160,000	4230	−2100	− 9660	−11400

Table 5.28 Continued

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strain at Compression (με)	f_c Average of Eq. (4.1) and (4.2) (psi)	f_c Using Cylinder Stress Strain Curve (psi)
162,000	4220	−2160	− 9750	−11500 *
162,700	4220	−2200	− 9660	−11700
165,000	4230	−2260	−10200	−11800
170,000	4280	−2370	−10900	−12000
175,100	4350	−2490	−11300	−12300
179,600	4350	−2610	−11400	−12400
185,000	4350	−2730	−11500	−12500
190,000	4330	−2880	−11300	−12500
205,000	3170	−3340	−10200	

1lb = 4.45 N

1 psi = 6.89 kPa

* values of stress from this point on obtained from extrapolated curve.

Table 5.29: Load and Stress Data for Flexural Test of Beam II

Using Eq. (4.1) and Eq. (4.2) and Cylinder Stress-Strain Curve

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strainat Compression ($\mu\varepsilon$)	f_c Average of Eq. (4.1) and (4.2) (psi)	f_c Using Cylinder Stress Strain Curve (psi)
9,500	0	− 129	− 894	− 915
19,800	600	− 240	− 1770	− 1690
30,000	670	− 301	− 2320	− 2100
40,500	1380	− 495	− 3240	− 3410
50,000	1900	− 631	− 4080	− 4300
60,100	2360	− 764	− 5060	− 5130
70,000	2670	− 885	− 5850	− 5870
80,000	2970	−1000	− 6600	− 6570
90,100	3330	−1140	− 7350	− 7350
100,000	3670	−1270	− 8010	− 8040
119,800	4320	−1560	− 9310	− 9410
129,500	4570	−1720	− 9880	−10100
139,500	4830	−1860	−10300	−10700
149,400	5050	−2040	−10700	−11300
154,500	5150	−2150	−10900	−11600 *
159,500	5170	−2250	−10900	−11800
164,500	5220	−2350	−11200	−12000
169,400	5230	−2480	−11200	−12200
175,000	5320	−2610	−11100	−12400
180,000	5320	−2740	−10800	−12500
185,000	5320	−3070	− 9580	−12500

1lb = 4.45 N   1 psi = 6.89 kPa   Failure at 195,000 lb

* values of stress from this point on obtained from extrapolated curve.

Table 5.30: Load and Stress Data for Flexural Test of Beam III

Using Eq. (4.1) and Eq. (4.2) and Cylinder Stress-Strain Curve

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strain at Compression (με)	f_c Average of Eq. (4.1) and (4.2) (psi)	f_c Using Cylinder Stress Strain Curve (psi)
10,000	0	− 57	− 490	− 408
10,000	400	− 149	− 785	− 1060
20,000	800	− 273	− 1650	− 1920
30,000	1150	− 389	− 2550	− 2700
39,000	1500	− 513	− 3320	− 3530
50,000	1875	− 650	− 4210	− 4420
60,000	2220	− 776	− 5050	− 1680
70,000	2500	− 895	− 5800	− 1940
80,400	2875	−1030	− 6560	− 6740
90,000	3200	−1160	− 7210	− 7450
100,000	3580	−1310	− 7970	− 8240
110,000	3920	−1460	− 8620	− 8980
120,000	4166	−1600	− 9290	− 9590
130,000	4170	−1750	− 9800	−10200
140,000	4733	−1930	−10400	−10900
150,500	5000	−2130	−10800	−11500 *
160,000	5270	−2320	−11000	−12000
165,000	5280	−2430	−11500	−12200
170,000	5330	−2570	−11600	−12300
175,000	5350	−2690	−11600	−12500
185,000	5270	−2810	−11800	−12500

1lb = 4.45 N 1 psi = 6.89 kPa Failure at 195,000 lb

* values of stress from this point on obtained from extrapolated curve.

Table 5.31: Load and Stress Data for Flexure Test of Beam IV

Using Eq. (4.1) and Eq. (4.2) and Cylinder Stress Strain Curve

Major Thrust P_1 (lb)	Minor Thrust P_2 (lb)	Average Strain at Compression (μa)	f_c Average of Eq. (4.1) and (4.2) (psi)	f_c Using Cylinder Stress Strain Curve (psi)
7,000	0	- 23	- 324	- 173
10,000	0	- 39	- 477	- 286
11,500	200	- 117	- 782	- 834
20,000	650	- 203	- 1480	- 1430
30,000	1010	- 329	- 2360	- 2290
40,000	1520	- 482	- 3193	- 3330
50,500	1860	- 613	- 3960	- 4180
60,100	2300	- 755	- 4790	- 5080
70,300	2890	- 934	- 5880	- 6160
80,000	3150	-1050	- 6580	- 6830
90,000	3370	-1160	- 7400	- 7450
100,00	3870	-1330	- 7960	- 8310
110,100	4120	-1470	- 8560	- 9030
120,000	4580	-1660	- 9450	- 9860
130,000	4820	-1800	-10100	-10400
140,000	5000	-1950	-10700	-11000
149,500	5220	-2120	-10900	-11500
159,000	5430	-2320	-11000	-12000
164,400	5330	-2420	-10900	-12100

1lb = 4.45 N 1 psi = 6.89 kPa Failure at 170,000 lb

* values of stress from this point on obtained from extrapolated curve.

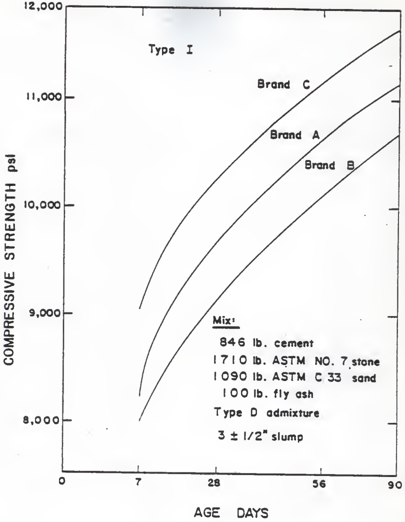


Figure 2.1: Effect of Various Brands of Type I Cement on Concrete Compressive Strength (20)

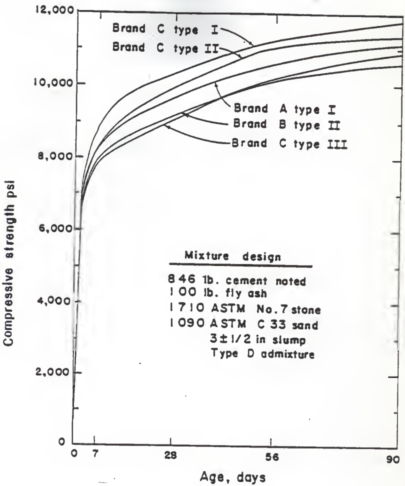


Figure 2.2: Effect of Various Cements on Concrete Compressive Strength (2)

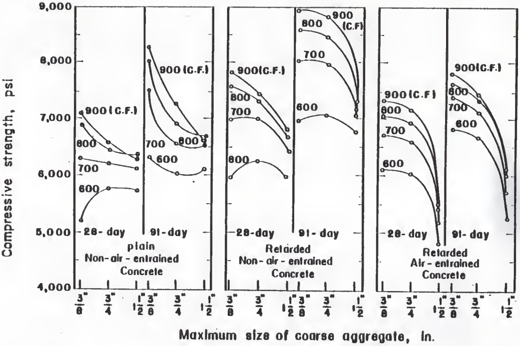


Figure 2.3: Effect of Size of Coarse Aggregate on Compressive Strength in Different Types of Concrete (adapted from Ref. 5)

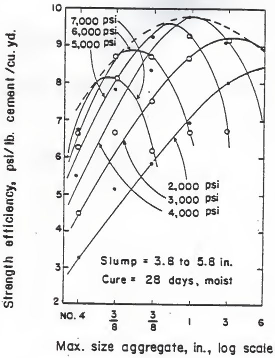


Figure 2.4: Maximum Size Aggregate for Strength Efficiency Envelope (15)

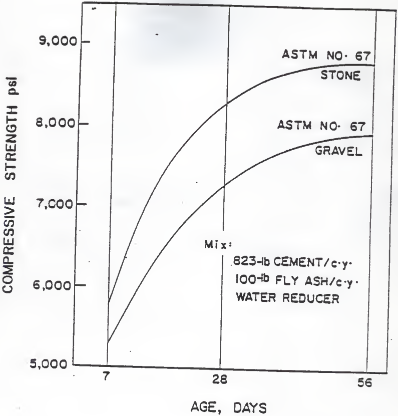


Figure 2.5: Compressive Strength of Concrete Using Two Sizes and Types of Coarse Aggregate for 7,500 psi Concrete (1)

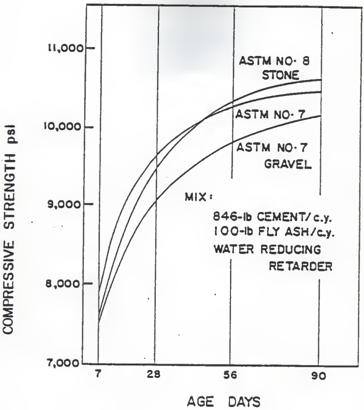


Figure 2.6: Compressive Strength of High-Strength Concrete Using Three Sizes and Types of Coarse Aggregate

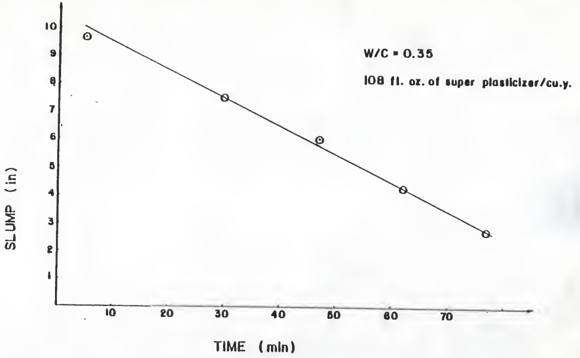


Figure 2.7 : Slump vs. Time When Using Superplasticizer

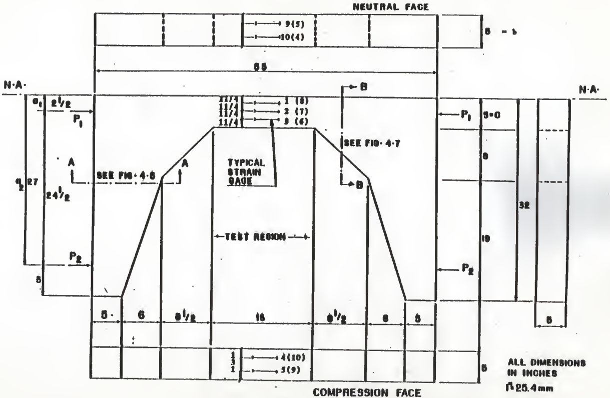


Figure 4.1: C-Shape Structural Element for Flexural Test II

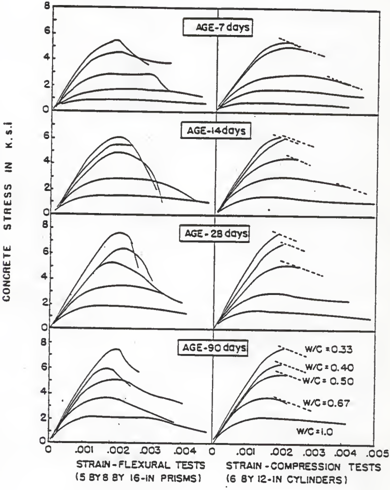


Figure 4.2: Concrete Stress-Strain Relations (7)

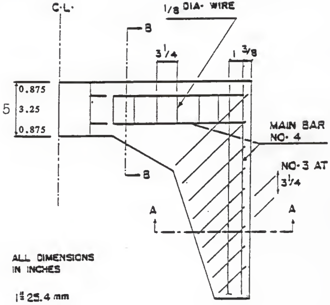
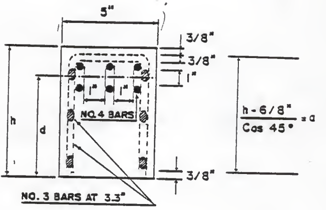


Figure 4.3: Reinforcement Layout (11)



SECTION A-A (SEE FIG. 4.2, 4.3)
1" = 25.4 mm

a = the leg size of stirrup

Figure 4.4: An Arbitrary Section A-A With Rebar Arrangement at Each Leg (11)

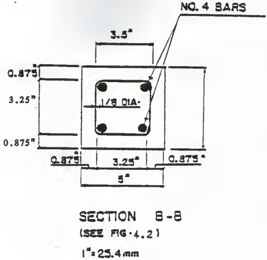
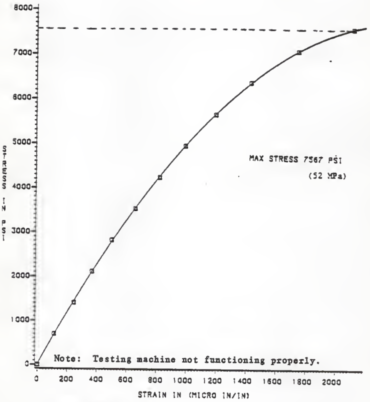


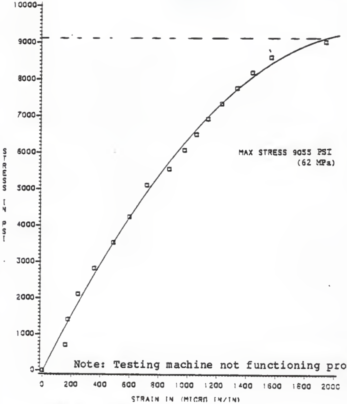
Figure 4.5: An Arbitrary Section of Column Part With Rebar Arrangement (11)



Note: Testing machine not functioning properly.

1 Psi = 6.89 kPa

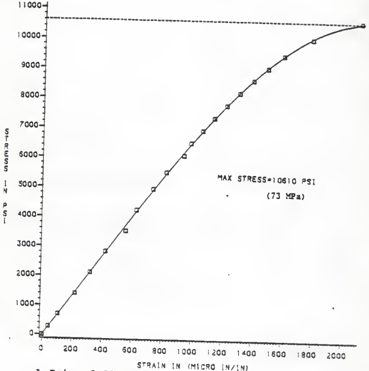
Figure 5.1: Cylinder Compressive Stress-Strain Curve for Beam I, Data from Table 5.6



Note: Testing machine not functioning properly.

1 Psi = 6.89 kPa

Figure 5.2: Cylinder Compressive Stress-Strain Curve for Beam II, Data from Table 5.7



1 Psi = 6.89 kPa

Figure 5.3: Cylinder Compressive Stress-Strain Curve for Beam III, Data from Table 5.10

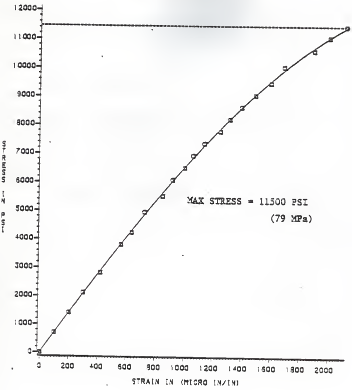
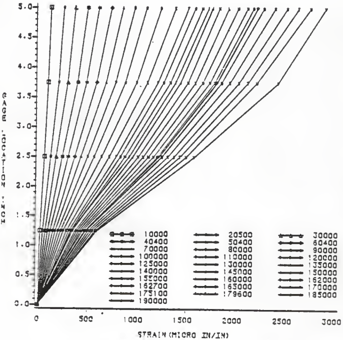


Figure 5.4: Cylinder Compressive Stress-Strain Curve for Beam IV, Data from Table 5.11

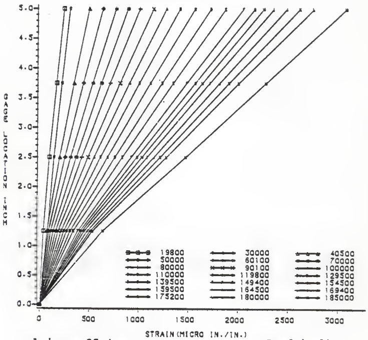


1 in. = 25.4 mm

Load in lb

1 lb = 4.45 N

Figure 5.5: LOcation of Strain Gages vs. Strain for Beam I

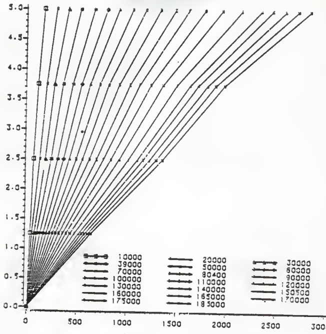


1 in. = 25.4 mm

Load in lb

1 lb = 4.45 N

Figure 5.6: Location of Strain Gages vs. Strain for Beam II

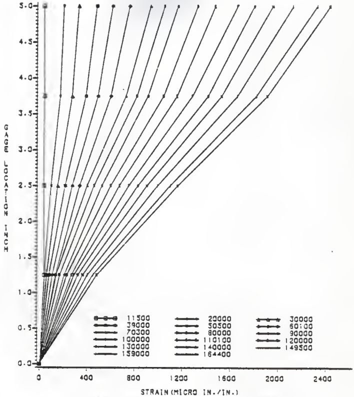


1 in. - 25.4 mm

Load in lb

1 lb = 4.45 N

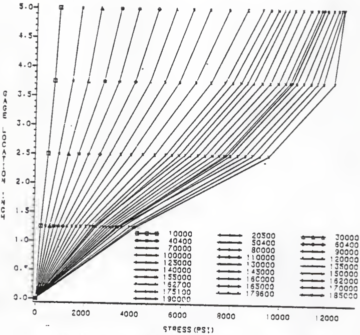
Figure 5.7: Location of Strain Gages vs. Strain for Beam III



1 in. = 25.4 mm Load in lb

1 lb = 4.45 N

Figure 5.8: Location of Strain Gages vs. Strain for Beam IV

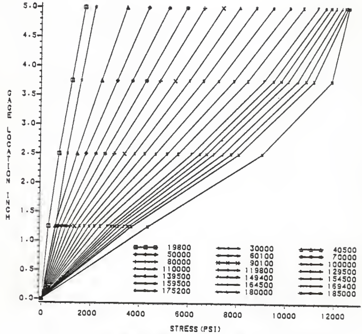


1 in = 25.4 mm, 1 psi = 6.89 kpa

Load in lb

1 lb = 4.45 N

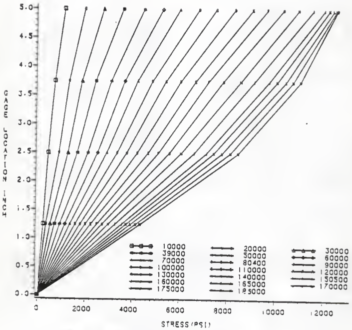
Figure 5.9: Stress Block of Beam I



1 in = 25.4 mm, 1 psi = 6.89 kpa Load in lb

1 lb = 4.45

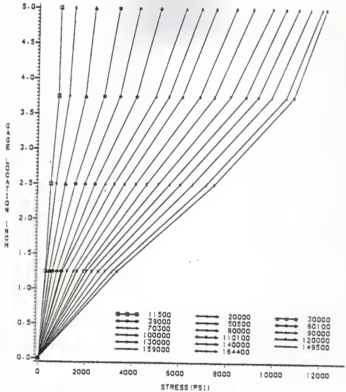
Figure 5.10: Stress Block of Beam II



1 in = 25.4 mm, 1 psi = 6.89 kpa   Load in lb

1 lb = 4.45 N

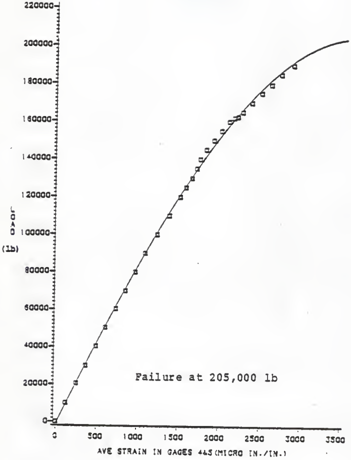
Figure 5.11: Stress Block of Beam III



1 in = 25.4 mm, 1 si = 6.89 kpa   Load in lb

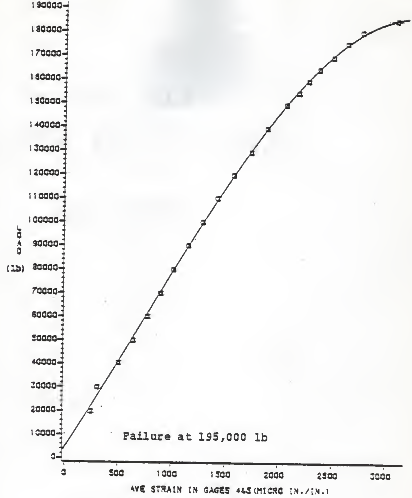
1 lb = 4.45 N

Figure 5.12: Stress Block of Beam IV



1 lb = 4.45 N

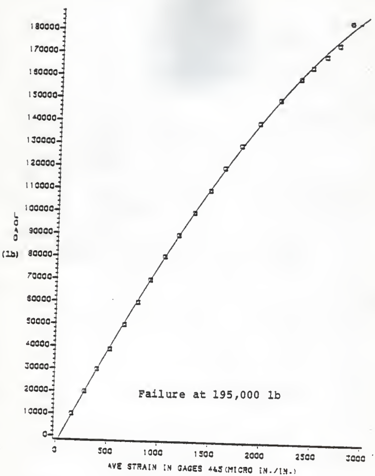
Figure 5.13: Axial Load vs. strain for gages 4 and 5 for Beam I



Failure at 195,000 lb

1 lb = 4.45 N

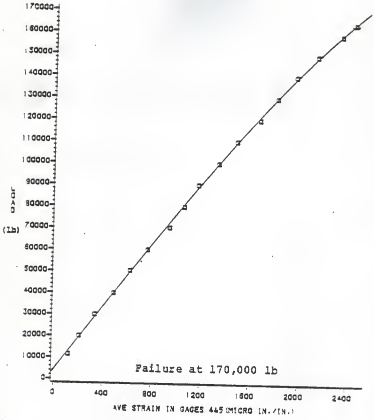
Figure 5.14: Axial Load vs. strain for gages 4 and 5 for Beam II



Failure at 195,000 lb

1 lb = 4.45 N

Figure 5.15: Axial load vs. strain for gages 4 and 5 for Beam III



1 lb = 4.45 N

Figure 5.16: Axial load vs. strain for gages 4 and 5 for Beam IV

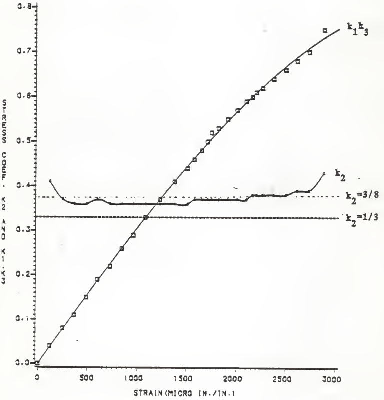


Figure 5.17: Stress Factors k_2, k_1k_3 Vs. Concrete Strain For Beam I

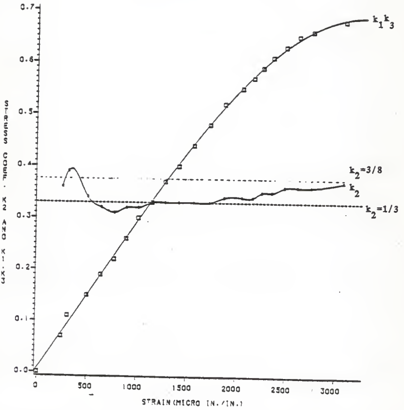


Figure 5.18: Stress Factors k_2, k_1k_3 Vs. Concrete Strain For Beam II

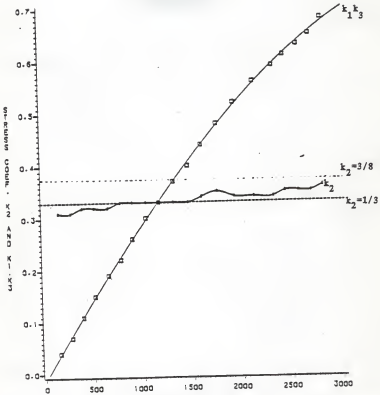


Figure 5.19: Stress Factors k_2, k_1k_3 Vs. Concrete Strain For Beam III

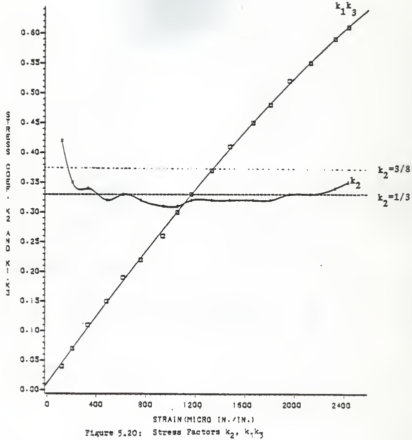


Figure 5.20: Stress Factors k_2, k_1k_3 Vs. Concrete Strain For Beam IV

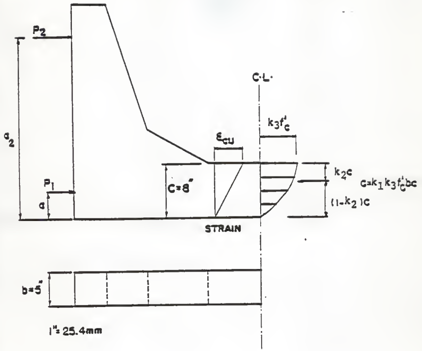
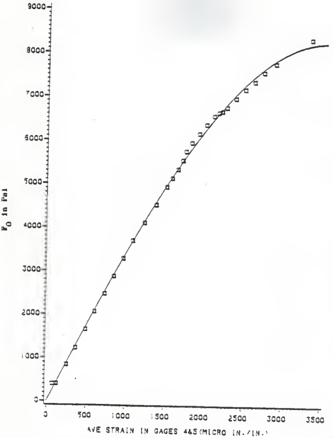
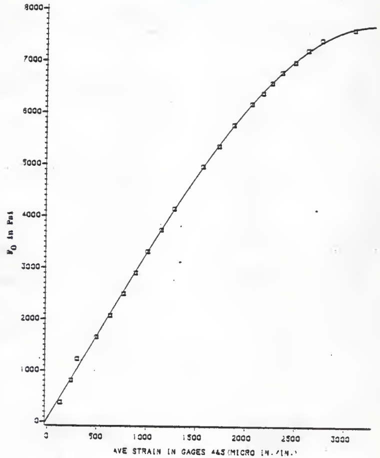


Figure 5.21: Condition at Ultimate Load in Test Specimen



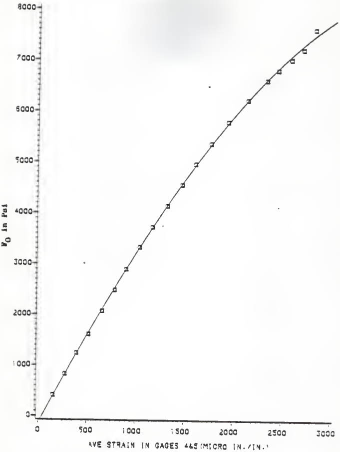
1 psi = 6.89 kPa

Figure 5.22: f_o vs concrete strain for Beam I



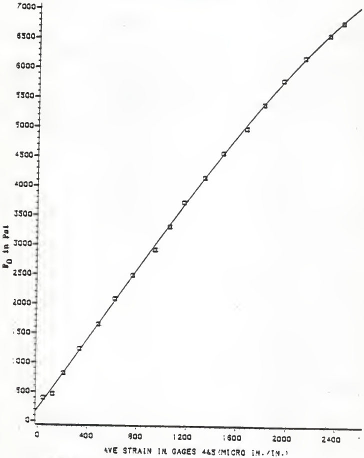
1 psi = 6.89 kPa

Figure 5.23: f_o vs concrete strain for Beam II



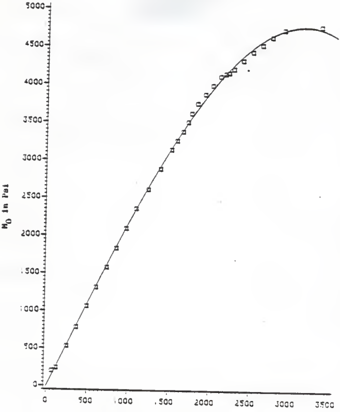
1 psi = 6.89 kPa

Figure 5.24: f_o vs concrete strain for Beam III



1 psi = 6.89 kPa

Figure 5.25: f_o vs concrete strain for Beam IV



1 psi = 6.89 kPa

Figure 5.26: m_o vs concrete strain for Beam I

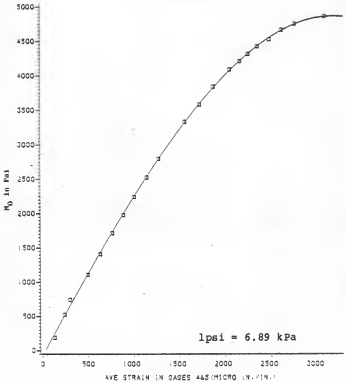
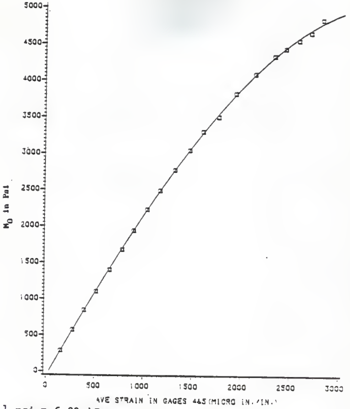
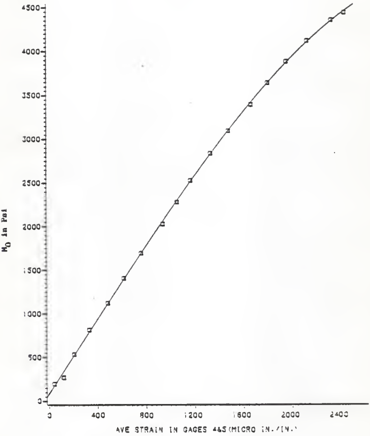


Figure 5.27: m_O vs concrete strain for Beam II



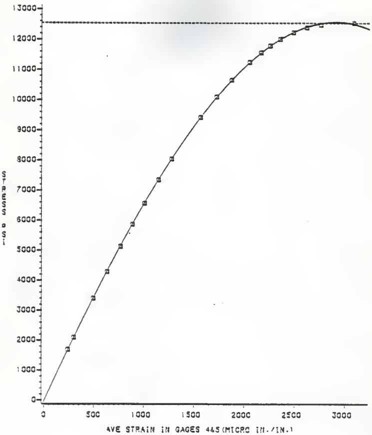
1 psi = 6.89 kPa

Figure 5.28: m_b vs concrete strain for Beam III



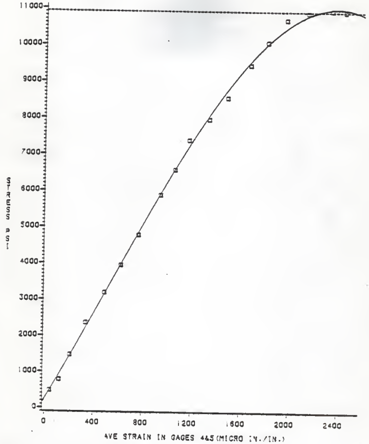
1 psi = 6.89 kPa

Figure 5.29: m_o vs concrete strain for Beam IV



1 psi = 6.89 kPa

Figure 5.30: Average f_c from Eq (4.1) and (4.2) vs strain for Beam II



1 psi = 6.89 kPa

Figure 5.31: Average f_c from Eq (4.1) and (4.2) vs strain for Beam IV

APPENDIX IV

NOTATION

ε = strain.

ε_c = strain at compression face.

a = level arm.

b = width of beam.

c = depth of beam.

d= distance for outermost fiber to center of gravity of steel.

f_c = stress in concrete at different levels of loading.

f'_c = concrete cylinder strength.

f_o, m_o = cross-section stress parameters.

f_y = estimated allowable strength in reinforcement.

h = height of beam.

k_1, k_2, k_3 = ultimate strength factors (k_1, k_2 are shape factors and k_2 is the position of concrete internal force from outermost compresion fiber.

C = concrete internal force.

A_s = area of reinforcement.

M = moment.

M_u = ultimate moment.

P_1 = axial load applied by testing machine (i.e., major thrust).

P_2 = eccentric load applied by hydraulic ram system (i.e., minor thrust).

T = force carried by reinforcement.

y = depth of stress block.

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The Structural Behavior
of Higher Strength Concrete

by

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ABSTRACT

An experimental investigation into the structural bending properties of plain beams of higher strength concrete was performed.

The objective of this study was to obtain further information on the shape of the compressive stress block at failure for higher strength concrete beams.

Four "dogbone" shaped beams were cast with an unreinforced test region. Loads were applied so that bending was produced in the unreinforced test region and the neutral axis maintained at the outer surface of the test region.

Experimental data were obtained up to the failure of the test specimen and the k_2 values of beams II, III, and IV were 0.36, 0.36, and 0.35. These were very close to 0.375, the k_2 value for a parabolic stress distribution.