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R. E. Walther

R. F. Warner

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Prestressed Concrete Bridge Members

Progress Report 18

ULTIMATE STRENGTH TESTS OF
PRESTRESSED AND CONVENTIONALLY
REINFORCED CONCRETE BEAMS IN
COMBINED BENDING AND SHEAR

by

✓ Rene E. Walther

and

✓ Robert F. Warner

Fritz Engineering Laboratory
LEHIGH UNIVERSITY
Bethlehem, Pennsylvania

September, 1958
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LOAD-DEFLECTION CURVES

Load-deflection curves for the test beams appear on pages 32 through 52.

PHOTOGRAPHS OF TEST BEAMS AFTER FAILURE

Photographs of all the test beams, taken after failure, are contained on pages 52 through 58.

PULL OUT TEST RESULTS

The results of the pull out tests are presented on pages 62 through 69.
INTRODUCTION

In an earlier report* an analytic study was made of the strength of prestressed concrete beams failing under the combined actions of bending and shear. On the basis of that study, two series of beam tests were carried out to determine, experimentally, the effects on ultimate shearing strength of

(a) the magnitude of the prestressing force, and
(b) the condition of the bond between the steel and the concrete. A total of twenty beams of conventionally reinforced concrete and pretensioned prestressed concrete were tested to failure. The resulting data is contained in this report.

The work to date comprises the initial phase of a theoretical and experimental investigation of the ultimate strength of prestressed concrete members which is being carried out at Lehigh University. A study of the experimental data, reported herein, is presently in progress, together with a re-examination and extension of the theoretical work. Further experimental work is planned in which the effects of other factors influencing ultimate strength will be examined.

The two series of tests were carried out on specimens 8 inches wide and 18 inches deep which were loaded at the third-points of a 9 foot span. Sixteen of the twenty beams were prestressed and had high tensile steel strand as reinforcement, the

other four were conventionally reinforced with hard grade steel bars. Because of the scatter which exists among the results of previous shear tests, it was decided, in this first phase of the experimental work, to make and test the prestressed beams in like pairs and to observe the variation that might occur in the results of identical tests. Thus, the twenty specimens tested represented eight different types of prestressed beams and four different reinforced concrete beams.

The major variable in the five pairs of prestressed beams comprising series A was the effective prestressing force. Each beam contained six 7/16 inch diameter high tensile steel strands as reinforcement. A different level of prestress was used in each pair of beams, the values varying from zero up to a maximum, after all losses had taken place, of 145,000 psi.

Series B consisted of three pairs of beams prestressed with 1/4, 3/8 and 1/2 inch diameter high tensile steel strand respectively, and four beams each conventionally reinforced with different kinds of hard grade steel bars. This series of tests was designed to show whether or not the constitution of the steel-concrete surface and the resulting bond would effect the shearing strength.

Full details of the test specimens and of their manufacture and testing are given in the following pages, together with the results of the tests. Because one of the main interests in this experimental work was with the effect of bond, a number
of pull out tests were made for each type of strand and steel bar used as reinforcement. The pull out tests are reported separately in Appendix III.

Acknowledgments

The work described in this report was carried out in Fritz Laboratory, under the auspices of the Institute of Research of Lehigh University. It was sponsored by the Lehigh Prestressed Concrete Committee whose membership is composed of representatives from the following organizations: The Reinforced Concrete Research Council; Pennsylvania Department of Highways; U. S. Bureau of Public Roads; Concrete Products of America, Division of the American Marietta Company; American Steel and Wire, Division of U. S. Steel Corporation; John A. Roebling's Sons Corporation; Lehigh University.

The high tensile strand reinforcement was provided without charge by John A. Roebling's Sons Corporation.

Valuable assistance in both the manufacture and the testing of the specimens was given by Kenneth R. Harpel, laboratory foreman, and the Fritz Laboratory technicians.

Special appreciation is due to Bryce H. Baldwin who took an important part in all stages of the laboratory work and the reduction of data.
The research program on prestressed concrete bridge members is under the general direction of Dr. Carl E. Ekberg, Jr. Professor W. J. Eney is director of Fritz Laboratory and head of the Department of Civil Engineering.

**Notation**

In presenting the test data variables are denoted by symbols. The following notation is used:

- \( b \) = width of beam
- \( d \) = depth of the center of gravity of the reinforcement
- \( e_{cu} \) = concrete strain at the top fiber in the pure moment region of the beam at failure.
- \( f'c \) = concrete compressive strength as obtained from six by twelve inch cylinder tests.
- \( F_i \) = total force in prestressed reinforcement just prior to the transfer of the force from the prestressing bed to the beam.
- \( F_o \) = total force in the reinforcement at the beam mid span just after transfer.
- \( F \) = total force in the reinforcement at the beam mid span just prior to testing.
- \( h \) = total depth of beam
- \( P_d \) = force applied to the test beam at each load point at the time of diagonal cracking.
- \( P_f \) = force applied at each load point when the first crack appears in the pure moment region of the test beam.
- \( P_i \) = force applied at each load point when the first crack appears at the bottom fiber in the shear span.
- \( P_u \) = the force applied at each load point to cause failure of the beam.
DETAILS OF TEST SPECIMENS

Concrete

The concrete was made from 3/4 inch maximum size crushed limestone, fine Lehigh River sand and high early strength Portland cement. Sieve analyses of the sand and coarse aggregate gave the grading curves shown in Figure 1 and an average fineness modulus value for the sand of 1.72. The specific gravities of sand and coarse aggregate were 2.65 and 2.69 respectively. All batching was done by weight, the mix proportions used being as follows:

MIX PROPORTIONS

(Weight per unit weight of cement)

<table>
<thead>
<tr>
<th>No.</th>
<th>Cement</th>
<th>Water</th>
<th>Sand</th>
<th>Coarse Aggregate</th>
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<tbody>
<tr>
<td>I</td>
<td>1</td>
<td>0.458</td>
<td>1.32</td>
<td>2.56</td>
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<tr>
<td>II</td>
<td>1</td>
<td>0.573</td>
<td>1.32</td>
<td>2.56</td>
</tr>
<tr>
<td>III</td>
<td>1</td>
<td>0.496</td>
<td>1.38</td>
<td>2.56</td>
</tr>
</tbody>
</table>

In beam A1, the first to be cast, considerable difficulty was experienced in compacting the concrete, which had the proportions shown as mix I. The water content of the following batches of concrete, for use in A2, was thus increased to the figure shown for mix II. The slump values of the concrete in A1 and A2 were one inch and six inches. Mix III was used in all subsequent beams. With an average slump of three inches, it had good workability as well as the required compressive strength.
GRADING CURVES FOR SAND AND COARSE AGGREGATE

Figure 1
Steel

The reinforcement for the different prestressed concrete beams consisted of 1/4, 3/8, 7/16 and 1/2 inch nominal diameter high tensile steel strand. The stress strain curves for each strand size, shown in Figs. 2 through 5, were obtained from load-deflection relations given by the manufacturer. The conversion from load to strain was made using the nominal cross sectional area of the strand, the value of which is quoted in the appropriate stress strain figure.

Smooth, deformed and threaded 3/4 inch diameter bars and deformed 5/8 inch diameter hard grade steel bars constituted the four different types of reinforcement used in the four conventionally reinforced concrete beams. The modulus of elasticity and yield point of all bars as given by the manufacturer, were $30 \times 10^6$ psi, and 55,000 psi, respectively.

Test Beams

Series A beams had an overall cross section 8 inches wide and 18 inches deep and were 15 feet long. Six 7/16 inch diameter strands were used as reinforcement at an effective depth from the top surface of 13 inches. The position and spacing of the strand in the cross section are shown in Fig. 6, other relevant details of the specimens, including age at transfer, age at test and effective prestress, are given in Table II. No web reinforcement was included in any of the beams in series A.

The series B specimens were also 8 inches wide, 18 inches deep and in all cases the center of gravity of the reinforcing steel
Stress-Strain Curve for 1/4" diameter High Tensile Steel Strand
Nom. Area = 0.0356 sq in.

Stress-Strain Curve for 3/8" diameter High Tensile Steel Strand
Nom. Area = 0.0799 sq in.

Figure 2

Figure 3
Nom. Area = 0.1089 sq in.

Stress-Strain Curve for 7/16" diameter High Tensile Steel Strand
Nom. Area = 0.1438 sq in.

Figure 4

Figure 5
Six 7/16" dia. Strands

Sixteen 1/4" dia. Strands

Six 3/8" dia. One 7/16" dia. Strands

Four 1/2" dia. Strands

All Beams in Series A

Beams B1, B2

Beams B3, B4

Beams B5, B6

DETAILS OF CROSS SECTIONS OF TEST BEAMS

Figure 6A
 DETAILS OF CROSS SECTIONS OF TEST BEAMS

Figure 6B
was placed at an effective depth of 13 inches. The prestressed beams were 15 feet long, but the overall lengths of the reinforced beams, listed in Table II, were between fourteen and fourteen and a half feet. Details of the different kinds of reinforcements and the beams in which they were used are contained in Table I and Fig. ...

To retard horizontal splitting along the reinforcement in the four conventionally reinforced beams, a stirrup, consisting of two legs of 5/8 inch diameter deformed reinforcing bar, was cast in each side of the beam at the section where the support was to be placed. As these were the only stirrups used, none of the beams had web reinforcement within the test span.

Manufacture of Test Beams

A frame for pretensioning the strand reinforcement was set up on the dynamic test bed as shown in the schematic diagram in Fig. 7. Anchors for the prestressing forces were provided at each end using a cross-head, 2, supported against a pair of stub columns, 3, which were bolted to the test bed floor with two, four inch diameter, pretensioned high tensile steel bolts. The two cross-heads were identical, consisting of two 18 inch deep channels back to back, bolted together with a space of two and a half inches between them provided by packing pieces. At one end the cross-head rested directly against the stub columns, at the other end a 50 ton capacity jack, 1, was placed in front of each stub column between column and cross-head. The strands were threaded through the cross-head and into an appropriate grid of holes in a one inch
1. Mechanical Jacks
2. Crosshead
3. Stub Columns
4. Dynamometers
5. Strand Vises
6. Steel Guide for Moving Crosshead

SCHEMATIC DIAGRAM OF PRESTRESSING BED

Figure 7
PHOTOGRAPH OF JACKING END OF PRESTRESSING BED
Figure 8
steel plate which was bolted to the outer side of the cross-head. The strands were pulled tight manually and dynamometers and strand vises were placed on the ends. The cross-head at the jacking end was jacked away from the stub columns until the required tension was obtained in the strands. Steel guides and timber chocks were placed above the moving cross-head to prevent any possible overturning of jack and cross-head. A photograph of the jacking end is shown in Fig. 8. By adopting a repeated routine of tensioning, untensioning, packing shims of suitable thickness behind the strand vise and retensioning, the variation in stress among individual strands, as measured by the dynamometers, was limited to five percent of the mean prestress.

It was intended to use an initial steel stress of 200,000 psi for beams A9 and A10, however before this stress was reached in the jacking operation, two of the wires of one strand fractured in the strand vise at the jacking end. The forces in each strand immediately changed, but as the resulting values were accurately measured by the dynamometers the manufacture of these beams was continued without any further jacking of the strands. The prestress in beams A9 and A10 is therefore less than the original design value.

The prestressing bed was sufficiently long to allow two beams to be cast end to end on each set of tensioned strands, thus the sixteen pretensioned beams, A1 through A10 and B1 through B6, were made as identical pairs; A1 with A2, B1 with B2, etc.

After the tensioning had taken place, the formwork consisting of two 15 foot lengths of 18 inches deep channel bolted with
flat faces inwards to a plywood timber base, was set up at the correct height around the tensioned reinforcement. Spacing bars at five different positions held the tops of the channels to the correct width while end plates, threaded on to the strands prior to the tensioning operation, were bolted to the side forms to keep the section rectangular. In the beams without any prestress, that is, A1, A2 and B7 through B10, the reinforcement was held in the desired position by thin tie wires.

The concrete was mixed in six cubic foot batches in the mixer in the concrete laboratory and transported in buggies, by means of a crane, to the prestressing area. Six batches of concrete were required for each pair of beams.

Beams A1 through A8 and B1 and B2 were each cast with three consecutive batches of concrete, however in the other beams each of the six batches of concrete was poured in equal layers into the two beams being cast. At least twelve control cylinders were made for each pair of beams.

When the concrete had set, the side forms were removed and wet burlap and plastic sheeting were placed over the beams which were left to gain strength for the period of time (usually five days) indicated in Table II. The jacks were then gradually released, the strands were cut with an acetylene torch and the beams were removed to another part of the laboratory where they were wrapped in wet burlap and placed under moisture proof plastic. Water was regularly sprinkled on the burlap and the curing was continued until several days before testing.
Measurement of Prestressing Force and Losses

The forces in the strands were measured during the prestressing operation with dynamometers placed between the strand vise and the cross-head. The dynamometers consisted of eight inch lengths of pipe, one and a half inches outside diameter and one half inch inside diameter. Readings from strain gages attached to the outside surface were calibrated to give a measurement of the force in the strand.

For the beams in series A and for B5 and B6, dynamometers were placed on all strands at the jacking end. However, in the case of beams B1 through B4, because of the close strand spacing, it was possible to use dynamometers only on the strands at the outside corners and the two strands at the center of the grid. The average force in these six was taken as the average force in all strands. Two dynamometers were always placed at the other end of the strands to indicate the magnitude of friction losses but in no cases were these significant.

The prestressing operation was carried out a day before casting. The forces were checked and, if necessary, adjusted just before the concrete was placed. Dynamometer readings were taken at regular intervals of time with final readings just before and after stress transfer.

Elastic losses and losses due to creep and shrinkage were estimated from strain measurements made on both sides of the concrete at mid span. These were obtained with a 10 inch gage.
length Whittemore extensometer on six pairs of small aluminum targets cemented at various levels to each side of the beam. A target consisted of a 3/8 inch square piece of aluminum, 1/16 inch thick, with a fine "target" hole drilled in it to take the extensometer point. The changes in the distance apart of each pair of targets was measured just prior to and just after transfer and again just prior to testing. From the readings the concrete strain distribution, the strain at the steel level and hence the change in the steel stress were calculated. The values of the total force in the steel at different stages are given in Table II.
DESCRIPTION OF TESTS

Several days before testing the beams were removed from the curing area and allowed to dry out. A coat of whitewash was applied to the concrete surface and the aluminum targets, for strain measurements, were inspected to determine whether they had been damaged in transport or loosened by moisture. In most cases the targets were in quite satisfactory condition; those which were not were replaced. Just before the beam was hoisted into position for testing, Whittemore readings were taken on the original targets to determine the final value of the creep and shrinkage losses.

All beams were tested in a similar manner, on a nine foot span with two equal loads at the one third points. Details of the loading set up are shown in Fig. 9. Each end support consisted of a two inch wide and one inch thick steel distributor plate sitting on a one inch diameter roller on a steel pier. At the load points a four inch wide and half inch thick piece of "Horosote" fibrous hard board rested on the top surface of the beam beneath a four inch by one inch steel distributor plate. The loads were applied with two fifty five kips capacity Amsler jacks, through spherical heads, onto the distributor plates. The jacks were bolted, in the correct position above the test beam, to a steel frame, which transmitted the reactive forces through cross beams and columns to the test bed.

A light frame running the length of the beam was set on simple supports on the top surface of the concrete directly above
1. 4" x 8" x 1/2" thick "Horosote" fibrous hard board, beneath 4" x 8" x 1" thick steel distributor plate

2. 2" x 8" x 1" thick distributor plate

3. 1" diameter roller

4. 1/2" x 1/2" steel bars welded to pedestal to provide horizontal restraint

5. Supporting frame for dial gages

6. Dial gages

**TESTING SET-UP**

*Figure 9*
the beam supports. Deflections at mid span and at the overhanging edges were measured with dial gages attached to this frame. A vertical scale, also to measure deflection at mid span, was clamped to the frame close to the side of the beam. Strains were measured on both sides of the beam at mid span between the load points using the Attemore extensometer and aluminum targets previously described.

Loads were applied in increments of 5000 lb. per jack at a rate of 1250 lb. per minute. After each increment of load had been added, the cracking pattern was inspected and its development noted in detail. Strain and deflection readings were taken when a period of time had been allowed to elapse for the readings to settle down to steady values. In the higher loading ranges the tendency of the specimen to creep was far more noticeable and the load had to be maintained for a longer period of time to obtain reasonably steady strain and deflection readings. Load increments were added until failure took place. The time required to load the beam to failure was usually between two and three hours. Control cylinders were tested on the same day in a 300,000 lb. capacity universal testing machine.
PHOTOGRAPH OF TEST SETUP

Figure 10
BEAM TEST RESULTS

Behavior of Test Beams Under Load

The loads at which cracks first appeared and the subsequent development with increased load were stenciled on the side of each beam. Thus, the progress of the crack patterns may be observed in the photographs, on pages 56 through 62, which were taken of the beams after failure had occurred. In A1 for example, it can be seen that the first cracks appeared in the pure moment region, when the load in each jack was 8 kips, and rose almost immediately to mid depth. The cracks in the left and right shear span appeared at 11 and 14 kips respectively. The crack in the right shear span, having inclined towards the load point and risen at a faster rate than the vertical cracks and having, between 21 and 24 kips, extended outwards and down to the bottom fibre in a line from the load point, brought about failure. A study of the other photographs will indicate the crack development in the test beams.

The first cracks to form were always situated in the central pure moment region. When several additional increments of load were added cracks appeared in the shear spans at the lower fibers near the load point. In this initial stage of loading the behavior of both prestressed and reinforced beams were similar, however the later development of the cracks differed somewhat for the two types of beams.

The failure of the prestressed concrete beams in series A occurred by development of the existing cracks until the concrete
at the upper fibers crushed. The cracks in the shear span, once formed, usually developed at a faster rate than those in the pure moment region, inclining in a curve towards the load. The relative development of the vertical and inclined cracks was observed to be in proportion to the amount of prestress. Thus in beams A1 and A2, which had zero prestress, an inclined crack rose in each shear span until it was one or two inches beneath the load pad, it then took an almost horizontal path to extend into the pure moment region. Crushing of the concrete took place directly under, and on the inside of, the load. In beams with increased prestress the flexural cracks had developed to a greater extent at failure. In beam A8 a vertical crack had reached high enough for the concrete to crush directly above it. Also in A9 and A10, which had the highest level of prestress, the crushing of the concrete took place in a region above both an inclined and a vertical crack. Here it would have been difficult, if not meaningless, to choose one crack rather than the other as being responsible for failure.

For purposes of classification of the test results in this report, failure by crushing of the concrete above the developed inclined crack is called "shear compression" and failure by crushing of concrete above a crack which has developed in the pure flexural region of the beam is called "flexure". It is important to note that these definitions are introduced only to allow classification of the phenomena of the tests being reported. They become inadequate when other systems of loading are adopted.
An interesting variation among the crack patterns was observed in the prestressed beams in series B. A far greater number of cracks, more closely spaced, appeared in the beams with 1/4 inch diameter strand as compared with the beams reinforced with larger diameter strand. It should be noted that there is no significant difference either in total steel area or in prestress in these beams. In beams B5 and B6 for example, which had 1/2 inch strand reinforcement, a total of only five or six cracks formed along the length of the beam whereas B1 and B2, reinforced with 1/4 inch diameter strands, had three times as many cracks in the same region. The cracks in B1 and B2, being considerably more numerous, did not widen to the extent of those in the beams with larger diameter strands. A comparison of the photographs taken after failure of beams B1 through B6 indicates clearly this variation in crack formation. However no significant variation was observed either in total beam deflection at any stage of loading or in ultimate beam strength.

The behavior of the reinforced concrete beams, B7 through B10, was somewhat different. The vertical and inclined cracks appeared and developed as in the prestressed beams, but at a higher stage of loading, diagonal cracks occurred, usually near mid shear span and a little below mid depth, and extended down almost to the support and above the existing inclined crack to within one or two inches from the load. Although a major diagonal crack quickly opened, almost to its final extent, the beam was able to accept considerably more load. Final failure of B7 and B8 took place when
the concrete above the diagonal crack, on the support side of the load, suddenly sheared through. In beams B9 and B10 the diagonal crack extended horizontally beneath the load and the compressive concrete in the pure moment region crushed in a similar manner to that in the shear compression failure of the prestressed beams.

The restraining influence of the load pads, at the top surface of the concrete, on crack development and on completion of the failure mechanism was very evident in the reinforced concrete beams in which final collapse was greatly retarded by the compressive stresses and the physical restraint in the loading region. The increase in load above diagonal cracking, which in some cases amounted to 30 per cent, could be attributed to this phenomenon.

In the tabulation of test data in Table III, the last column lists the type of failure. The letters S, C, and F stand for shear compression and flexure. Those failures which were composed of crushing of the concrete above a diagonal crack, are denoted by DT-SC.

Load Deflection Relations

Deflections were measured at the mid span and at each overhanging end. The distance from the support to the overhanging end of the beam where the reading was taken was three feet for the sixteen prestressed beams but for the reinforced beams the value was between two feet six inches and two feet nine inches. The purpose of these readings was to provide a measure of the end
rotation of the beam at the supports. To allow more uniformity in the presentation of the results, the measured end rotations of the reinforced beams were used to calculate the equivalent deflection on a three foot overhang. Thus, all end rotation measurements are presented as the deflection of a three foot overhanging end, the value in radians can be obtained simply by dividing the given deflections by 36 inches.

Very close agreement was obtained in the deflection readings at the two ends of each beam, even when failure was imminent, and so only the average value of the two ends is given in the results.

For each specimen the central deflection and the average value of the end deflections, based on a three foot overhang, are plotted against load in Appendix I.

**Beam Test Results**

The results of the beam tests are contained in Table III. The notation used at the head of each column has been explained on page 4 in the introduction. Column 2 gives the value of the effective prestress at time of test. The negative values for B7 and B8 indicate initial compression in the reinforcing steel, resulting from concrete shrinkage in the beams with zero prestress. No shrinkage measurements were made on the other beams, A1, A2, B9 and B10, without prestress.

Values of f'c listed in column 4 represent the strength in the upper third portion of the beam as obtained from cylinder
tests. The variation occurring in the strength of concrete at different levels in any one beam was not significant.

Column 5 contains the values of the extreme fiber concrete strain in the pure moment region at failure which were extrapolated from the extensometer readings taken on both sides of the beam during testing. The values are important in that they give some indication of the proximity of flexural failure in this region of the beam. No value is given for beam B10 because the Whittemore readings were found to be faulty.

Columns 6, 7 and 8 list the various cracking loads. \( P_i \) is the load at which a crack first appeared at the lower fiber in the shear span. Diagonal cracks formed only in some of the specimens, a dash placed in column 8 indicates that no diagonal cracks were observed.

The force in each loading jack at failure, corresponding to the maximum loading on the beam, is listed in column 9. Column 10 gives the corresponding maximum moment.
<table>
<thead>
<tr>
<th>BEAMS</th>
<th>TOTAL STEEL AREA (sq. inches)</th>
<th>DESCRIPTION</th>
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</thead>
<tbody>
<tr>
<td>A1 through A10</td>
<td>0.653</td>
<td>6 - 7/16&quot; dia. high tensile steel strands</td>
</tr>
<tr>
<td>B1, B2</td>
<td>0.573</td>
<td>16 - 1/4&quot; dia. high tensile steel strands</td>
</tr>
<tr>
<td>B3, B4</td>
<td>0.587</td>
<td>6 - 3/8&quot; dia. and 1 - 7/16&quot; dia. high tensile steel strands</td>
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<tr>
<td>B5, B6</td>
<td>0.575</td>
<td>4 - 1/2&quot; dia. high tensile steel strands</td>
</tr>
<tr>
<td>B7</td>
<td>3.240</td>
<td>8 - 3/4&quot; dia. hard grade steel deformed bars; 23/32&quot; average measured diameter</td>
</tr>
<tr>
<td>B8</td>
<td>3.040</td>
<td>11 - 5/8&quot; dia. hard grade steel deformed bars; 19/32&quot; average measured diameter</td>
</tr>
<tr>
<td>B9</td>
<td>3.537</td>
<td>8 - 3/4&quot; dia. hard grade steel round bars</td>
</tr>
<tr>
<td>B10</td>
<td>2.520</td>
<td>8 - 3/4&quot; dia. hard grade steel round bars with U.S. standard thread; 40/64&quot; internal dia., 10 threads per inch</td>
</tr>
<tr>
<td>SERIES</td>
<td>BEAM</td>
<td>AGE IN DAYS AT STRESS TRANSFER</td>
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<td>A</td>
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Appendix I: Load Deflection Curves
LOAD-DEFLECTION DIAGRAM FOR BEAM AI
LOAD - DEFLECTION DIAGRAM FOR BEAM A2
LOAD - DEFLECTION DIAGRAM FOR BEAM A3

- CENTER DEFLECTION
- END DEFLECTION
LOAD-DEFLECTION DIAGRAM FOR BEAM A4
LOAD-DEFLECTION DIAGRAM FOR BEAM A5
LOAD - DEFLECTION DIAGRAM FOR BEAM A6
LOAD-DEFLECTION DIAGRAM FOR BEAM A7
LOAD - DEFLECTION DIAGRAM FOR BEAM A8

- CENTER DEFLECTION
- END DEFLECTION

LOAD (KIPS)

DEFLECTION (INCHES)
LOAD-DEFLECTION DIAGRAM FOR BEAM A9
LOAD-DEFLECTION DIAGRAM FOR BEAM A10
LOAD - DEFLECTION DIAGRAM FOR BEAM B1

CENTER DEFLECTION

END DEFLECTION
LOAD-DEFLECTION DIAGRAM FOR BEAM B2
LOAD - DEFLECTION DIAGRAM FOR BEAM B3
LOAD - DEFLECTION DIAGRAM FOR BEAM B4
LOAD-DEFLECTION DIAGRAM FOR BEAM B5
LOAD - DEFLECTION DIAGRAM FOR BEAM B6

- CENTER DEFLECTION
- END DEFLECTION
LOAD - DEFLECTION DIAGRAM FOR BEAM B7
LOAD-DEFLECTION DIAGRAM FOR BEAM B8
LOAD-DEFLECTION DIAGRAM FOR BEAM B9
LOAD-DEFLECTION DIAGRAM FOR BEAM B10
Appendix II: Photographs of Test Beams after Failure
Appendix III: Pull Out Tests

Pull out tests were carried out on samples of each kind of strand and steel bar used as reinforcement in the beams. The pull out specimens consisted of a standard six inch diameter by twelve inch long concrete cylinder with a five foot length of the steel reinforcement passing through the longitudinal axis. At least three specimens were tested for each type of reinforcement.

The specimens were made, three at a time, in a vertical frame, the purpose of which was to provide a small initial tension in the steel to keep it straight and vertical. The bar or strand passed through the longitudinal axis of a cardboard cylinder mold which was itself held in the correct position, relative to the piece of reinforcement, by wooden templates. Mix III concrete (details given on page ) was used in all specimens. The concrete was taken from the batches being used for the manufacture of those test beams which had the same kind of reinforcement as was being used in the pull out specimen. Thus the type, age and strength of concrete in the pull out specimens is the same as for the corresponding beams.

A loading rig was designed for use with a tension testing machine to apply tension to the protruding strand or bar and a reactive compressive force to the end of the concrete cylinder. A sketch of the apparatus is shown in Fig. 11. The face of the cylinder to which the compressive force was applied was capped with carbo-vitrobond capping mixture. Loads were added in increments of
1000 lbs. and relative deflections between concrete and steel, at the top and bottom surfaces of the cylinder, were measured with dial gages clamped to the steel and bearing against the concrete. The specimens were loaded until the steel was about to yield.

The deflection readings from the tests on each type of reinforcement were averaged, corrections were applied for the elastic strain occurring in the steel between the concrete lower surface and the point of clamping of the bottom gages and the results are presented in graphical form on the following pages.
---Dial Gages

---Steel bar or strand

---6" dia. x 12" long concrete cylinder

Layer of Capping Material

---Dial Gages

---Spherical Head

Machine Crosshead

FULL OUT SPECIMEN TESTING APPARATUS

Figure 11
Pullout Tests of 5/8" Dia. Deformed Bars

Bottom Deflection

(No top deflection observed)

Deflection in inches x 10^-4

Load in kips

20.0
16.0
12.0
8.0
4.0

20 40 60 80 100
PULLOUT TESTS OF 3/4" DIA. DEFORMED BARS
PULLOUT TESTS OF 3/4"DIA. THREADED BARS
Pullout tests for 3/4" dia. smooth bars

Bottom Deflection
(No top deflection observed)

Deflection in inches x 10^-4
PULLOUT TESTS ON 1/4" DIA. STRAND

Bottom Deflection

(No top deflection observed)
Deflection in inches x 10^{-4}

PULLOUT TESTS ON 3/8" DIA. STRAND
Deflection in inches x 10^{-4}

FULLOUT TESTS ON 7/16" DIA. STRAND
Pullout Tests on 1/2” Dia. Strands