AN EXPERIMENTAL INVESTIGATION OF "END-BLOCK" REINFORCING in PRESTRESSED CONCRETE BEAMS

by
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ABSTRACT

High concentrations of stresses occur around the anchorage of the cables of a prestressed concrete beam and transverse tension may cause failure of the end-block unless reinforcement is placed parallel to the end face. The allowable bearing on the anchorage theoretically depends on the design of the reinforcement. Concrete specimens with three different schemes of reinforcing were constructed and loaded to failure. Results showed no substantial difference for capacity of ultimate load. A light reinforcement is required to counteract the transverse tension and minimize the brittle nature of concrete. Overreinforcement introduces adverse effects on the ultimate load capacity of the blocks.
ACKNOWLEDGEMENTS

The author would like to thank the many helping hands that have been offered throughout the course of the preparation of this thesis. In particular, my thanks go to Prof. M. J. Holley, of M.I.T., whose supervision is deeply appreciated, and also Mr. B. Velelmo, Mr. A.J. O'Neill, and Mr. J. White, also of M.I.T., for their helpful suggestions concerning testing procedures. Also, my thanks go to those who have helped in many ways during the preparation of this manuscript.
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INTRODUCTION

In the case under study the prestressing forces are applied parallel to the axis of the beam, and act solely on the end faces. The stresses developed at the end faces are completely discontinuous. Compressive stresses reach high values on the limited areas where the prestressing forces are applied, while the remainder of the end surface is totally unstressed.

From the principle of St. Venant, which has been verified experimentally by photoelasticity, the transverse stresses become negligible at a distance approximately equal to the depth of the beam from the end face and the entire stress system is almost longitudinal. These longitudinal stresses act along the entire cross section of the beam in accordance to the classic linear distribution. They are influenced by the magnitude and location of the applied forces but not by the manner in which the forces are spread over the end surface.

The zone lying between the end face of the beam and the section where a linear distribution of stress is first attained is called the "lead-in zone." Inside this zone the longitudinal stresses must pass progressively from the discontinuous to a continuous distribution. In the process of this transformation, transverse and shear stresses are generated along both horizontal and vertical longitudinal planes. As a result of the generation of these stresses, certain areas of the "lead-in zone" are subjected to transverse tension and if
the stresses are high relative to the strength of the concrete in tension, reinforcement parallel to the bearing surface must be provided.

The diagram below represents a vertical section of the end of a prestressed beam along its longitudinal axis.

The "lead-in zone" lies between the plane defined by CD and the bearing surface defined by AB. The portion of the beam defined by ABCD is in equilibrium under the action of the prestressing forces on AB, which are concentrated on small areas with $P_1$ and $P_2$ on their resultants, and the forces on CD represented by the linear stress diagram. The existence of the normal forces $f_y$ and the tangential stresses $t$ can be realized if in theory the segment ABCD is subdivided by the horizontal plane EF.
These stresses are needed for the equilibrium of segment BEFC, and they vary according to the position of the point considered in EF.

In the case shown above the prestressing forces are normal to AB. The following equilibrium conditions are to be maintained:

(a) The resultant of the $f_y$ forces have to be equal to zero. Therefore zones of tension and compression exist along EF.

(b) The sum of the moments of the forces acting on EB and FC about a point in EF must be equal to the moments of the $f_y$ stresses.

(c) The resultant of the $t$ stresses must be equal to the resultant of the forces applied on planes BE and CF.

These conditions are not sufficient to determine the distribution of stresses since the usual laws of strength of materials cannot be applied correctly on a beam of proportions such as ABCD. It is evident that the $f_y$ stresses do not obey the ordinary linear distribution since the stress must be approximately equal to zero at F. Instead, the $f_x$ stresses follow a distribution such as that shown below:
This type of distribution is extremely complex and varies a great deal according to the manner the forces are distributed along AB and EF. The number of the points of zero stress vary and so does the position of the maximum stress. To simplify the problem the load is assumed to be spread across the width of the beam which reduces the problem to one of two dimensions. The stresses are independent of the position of the point considered in the breadth of the beam and stresses in the direction of the breadth of the beam are zero.

On the basis of elastic theory values of $f_y$ have been obtained and are presented in the literature by curves joining points of equal stress value. A case of two symmetrical distributed forces acting on a rectangular beam is shown below:

From the diagram it can be seen that there are two general areas of tension. The one in the center of the section is called the "bursting zone." This zone has the maximum tension along the line of the load and at some distance from it. The other area of tension close to the end surface is called
the "spalling zone" which is subject to high tensile stresses but only over a small area.

The available tension graphs like the one presented above are theoretically correct and some of them have been verified experimentally by photoelasticity. Their application, however, is not straightforward. Concrete is not a perfectly elastic material and, it will act plastically particularly when overstressed. Present theory is not strong enough to answer such questions as: What should be the allowable tension in the concrete? If the allowable tension is exceeded, what should be the design of the reinforcing steel? Theory is undoubtedly necessary in analysis, but judgement must be exercised in design.
PROCEDURE

In the design of post-tensioned concrete units the distribution of stress in the end blocks must be known. High concentrations of stresses occur around the anchorage of the cables and the concrete may fail if adequate steel reinforcement is not supplied at the overstressed regions. Although the "spalling zone" is characterized by the highest tensile stresses, it is not of particular interest because of its very small area of action. Transverse reinforcement placed parallel to the end face counteracts the tensile stresses of the "bursting zone." The allowable bearing stress depends on such factors as the amount of reinforcement at the anchorage, the ratio of bearing to total area, and the method of stress computation. If the last two factors remain constant and the first one is varied, it is possible to study the influence of the amount and placement of the reinforcing on the strength of the end block.

For the purpose of this study four sets of three identical concrete blocks were built to represent end blocks. Each of these rectangular specimens had a cross section of five (5) inches by twelve (12) inches and a length of seventeen (17) inches. The length of the specimen was made longer than its depth in order to guarantee the existence of the "lead-in zone" inside the block. Concrete of the same strength designed for 4,000 psi was used for all specimens so that a valid comparison of results could be made. The reason for using three specimens of each type was to obtain a measure
of the reliability of the results by the degree of their consistency.

In the first set of blocks named "AC", the specimens were without any reinforcement. The measurement made on these blocks provided a basic standard against which all tests on reinforced structures could be compared.

The specimens which made up the second set named "SA" were reinforced by four stirrups placed at intervals of two inches. From the diagram of Transverse Tensile Stress shown on page 4 it appears that the area of highest Tensile Stress coincides with the area which was reinforced.

The blocks of the third set named "BS" had the same area reinforced, but the amount of reinforcing was increased. Seven stirrups were used spaced one inch from center to center. The results obtained from these specimens as compared to those of the "BS" set will enable an evaluation of the increase in the amount of reinforcement.

The specimens of the last set called "CS" were reinforced with seven stirrups spaced two inches from center to center. This scheme of reinforcement extends beyond the theoretical "lead-in zone" of the specimen, and it was selected to be compared with that of set "SA". A comparison of the results of these two sets should be of assistance in studying the validity of the assumed tensile stress distribution shown on page 4.

The specimens were loaded to failure. Because the end block of a prestressed concrete beam has the characteristics
of a cracked section, since it is under the high forces of prestressing, the capacity of ultimate load was chosen as an appropriate means of comparison of the strength of the blocks. The bearing load was uniformly distributed as shown on pages 4 and 16. The bearing plates were made of steel with a minimum thickness of one inch to assure rigidity and avoid variation of pressure on the contact area. The steel cover plate was made rigid enough (one-inch thick) to prevent the introduction of horizontal force components on the bearing plates. A thin coat of plaster of Paris was applied on the top surface of every concrete block to provide a smooth contact surface. A steel plate one-quarter inch thick was also placed beneath the block for the same reason. The two-inch steel rods welded to the base plate (see page 4) for the purpose of fastening the plate to the block are assumed not to have affected the strength characteristics of the specimens since they lie beyond the critical "lead-in zone."

Testing was done on a Hydraulic-type Southwark-Emery resting machine of 300,000 lb. capacity. In order to avoid any dynamic effect, the load was applied at a rate of about 1,000 lb. per second. The spherical head of the compression machine was used to give a bearing as uniform as possible. All testing was to be performed under as nearly the same conditions as possible and therefore an effort was made to place all specimens at the same position relative to the base of the machine.
RESULTS OF TESTING

A. Cylinders

<table>
<thead>
<tr>
<th>Description</th>
<th>Ultimate load</th>
<th>Cross-Area</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. M6-2</td>
<td>128,000 lb.</td>
<td>28.27 sq. in.</td>
<td>4,525 psi</td>
</tr>
<tr>
<td>2. M6-3</td>
<td>137,000 lb.</td>
<td>28.27 sq. in.</td>
<td>4,840 psi</td>
</tr>
<tr>
<td>3. M6-4</td>
<td>162,500 lb.</td>
<td>28.27 sq. in.</td>
<td>5,750 psi</td>
</tr>
<tr>
<td>4. M10-1</td>
<td>129,500 lb.</td>
<td>28.27 sq. in.</td>
<td>4,580 psi</td>
</tr>
<tr>
<td>5. M10-2</td>
<td>139,000 lb.</td>
<td>28.27 sq. in.</td>
<td>4,910 psi</td>
</tr>
<tr>
<td>6. M10-3</td>
<td>139,400 lb.</td>
<td>28.27 sq. in.</td>
<td>4,925 psi</td>
</tr>
<tr>
<td>7. M10-a</td>
<td>34,500 lb.</td>
<td>7.70 sq. in.</td>
<td>4,480 psi</td>
</tr>
<tr>
<td>8. M10-b</td>
<td>30,000 lb.</td>
<td>7.70 sq. in.</td>
<td>3,900 psi</td>
</tr>
<tr>
<td>9. M10-c</td>
<td>30,500 lb.</td>
<td>7.70 sq. in.</td>
<td>3,962 psi</td>
</tr>
</tbody>
</table>

B. Concrete Blocks

<table>
<thead>
<tr>
<th>Description</th>
<th>Ultimate load</th>
<th>Load-bearing area</th>
<th>Load Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set &quot;AC&quot; (Plain concrete)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. AC-1</td>
<td>150,000 lb.</td>
<td>30.0 sq. in.</td>
<td>5,000 psi</td>
</tr>
<tr>
<td>2. AC-2</td>
<td>193,300 lb.</td>
<td>30.0 sq. in.</td>
<td>6,475 psi</td>
</tr>
<tr>
<td>3. AC-3</td>
<td>196,500 lb.</td>
<td>30.0 sq. in.</td>
<td>6,550 psi</td>
</tr>
<tr>
<td>Set &quot;AS&quot; (Reinforced, 4 @ 2&quot;)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. AS-1</td>
<td>178,500 lb.</td>
<td>30.0 sq. in.</td>
<td>5,950 psi</td>
</tr>
<tr>
<td>5. AS-2</td>
<td>205,100 lb.</td>
<td>30.0 sq. in.</td>
<td>6,840 psi</td>
</tr>
<tr>
<td>6. AS-3</td>
<td>228,400 lb.</td>
<td>30.0 sq. in.</td>
<td>7,610 psi</td>
</tr>
<tr>
<td>Set &quot;BS&quot; (Reinforced, 7 @ 1&quot;)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. BS-1</td>
<td>177,500 lb.</td>
<td>30.0 sq. in.</td>
<td>5,910 psi</td>
</tr>
<tr>
<td>8. BS-2</td>
<td>143,000 lb.</td>
<td>30.0 sq. in.</td>
<td>4,765 psi</td>
</tr>
<tr>
<td>9. BS-3</td>
<td>193,000 lb.</td>
<td>30.0 sq. in.</td>
<td>6,440 psi</td>
</tr>
<tr>
<td>Description, Ultimate Load, Bearing Area, Load Intensity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Set &quot;CS&quot;, 7 @ 1&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. CS-1 195,000 lb. 30.00 sq. in. 6,500 psi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. CS-2 171,600 lb. 30.00 sq. in. 5,710 psi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. CS-3 200,200 lb. 30.00 sq. in. 6,675 psi</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Although the concrete was designed for a strength of 4,000 psi, the testing of the cylinders indicated a higher value. The specimens of sets "AC" and "AS" were made from the first batch of concrete. A second batch was mixed for the other two sets, and the strength of both mixes came out remarkably close.

Average strength of first batch ("AC", "AS"): 5,040 psi
Average strength of second batch ("BS", "CS"): 4,815 psi
Difference between the two average strengths: 4.7%

Even though the strength of the concrete came out higher than that which was designed, there will be no adverse effects on the results of the tests because of the consistency between the two batches.

The ultimate load capacity of the blocks varied by a small percentage contrary to the expected results. It is apparent that the amount or the method of placing of the reinforcement did not have any significant effect on the strength of the concrete.

An interesting comparison is that of the maximum, minimum and average values of ultimate capacity for the four sets of concrete blocks.
<table>
<thead>
<tr>
<th></th>
<th>&quot;AC&quot; Concrete</th>
<th>&quot;AS&quot; 4 @ 2&quot;</th>
<th>&quot;BS&quot; 7 @ 2&quot;</th>
<th>&quot;CS&quot; 7 @ 1&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Ultimate Load Intensity</td>
<td>6,550 psi</td>
<td>7,610 psi</td>
<td>6,440 psi</td>
<td>6,675 psi</td>
</tr>
<tr>
<td>Max. diff.</td>
<td>: 18.2%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min. diff.</td>
<td>: 1.7%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum Ultimate Load Intensity</td>
<td>5,000 psi</td>
<td>5,950 psi</td>
<td>4,765 psi</td>
<td>5,710 psi</td>
</tr>
<tr>
<td>Max. diff.</td>
<td>: 19.0%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min. diff.</td>
<td>: 4.2%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Ultimate Load Intensity</td>
<td>6,008 psi</td>
<td>6,700 psi</td>
<td>5,710 psi</td>
<td>6,300 psi</td>
</tr>
<tr>
<td>Max. diff.</td>
<td>: 17.3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min. diff.</td>
<td>: 5.2%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference of Max. and Min. Load Intensity</td>
<td>23.0%</td>
<td>27.9%</td>
<td>35.0%</td>
<td>16.9%</td>
</tr>
</tbody>
</table>

The specimens of the lightly reinforced set "AS" showed the highest maximum, minimum, and average Ultimate load capacity. Their strength was consistently higher than those of plain concrete by approximately 18%. Set "BS" which was reinforced with the same spacing but with reinforcement reaching beyond the "lead-in-zone", was found to be the weakest set. This is contrary to the theoretical expectations. These results suggest that overreinforcing has adverse effects on the strength of the blocks.

The specimens of set "CS" were reinforced twice as heavily relative to those of set "BS" in the critical "lead-in-zone" yet the values of the Ultimate capacity of the
former were consistently higher than those of the latter. The location, rather than the amount of reinforcement is apparently more critical in determining the ultimate strength.

The results of set "CS" compared to those of "AS" and those of the plain concrete indicate that some reinforcement placed inside the "lead-in-zone" will improve the ultimate capacity of the block. If the amount of this reinforcing exceeds a certain maximum, the ultimate capacity will decrease rather than increase with additional steel.

Theoretical stress distributions have led to the belief that reinforcement would substantially increase the ultimate load capacity of the concrete blocks. The experimental results do not support this theory and this leads to the possible hypothesis that the failure of the blocks was not due to tensile stress but rather to some other factor which was not influenced to any great extent by the reinforcement. On pages 17 to 22 pictures of the blocks after failure are shown. The breaks of the "AS" specimens are very similar to those of the "BS" and the "CS" sets. One can deduce from these pictures that the failure was caused by transverse tension. This was clearly demonstrated by the dynamic nature of the break during the moment of failure. The break was very violent and noisy which is a characteristic of tension failure.

It is interesting to observe from the pictures that the break was more severe along the "lead-in-zone". It is possible
that the friction of the base plate and the steel rods welded to it might have influenced the shape of the break at the lower end of the block, but this effect is assumed to have been negligible.

CONCLUSIONS

The ultimate load capacity of the unreinforced concrete specimens was found to be practically the same. The three reinforcing schemes tested do not alter the ultimate capacity as the theory of transverse tension suggests.

Some reinforcement in the end block is necessary to counteract the transverse tension. This will not only increase the ultimate load capacity, but simultaneously transforms the failure from a very sudden, violent, and brittle one to one with more ductile characteristics. Over-reinforcement is unfavorable. It is best to use light reinforcement starting near the bearing area and extending not beyond the "lead-in-zone".

The failure of the end blocks is caused by transverse tensile stresses. The shape of the broken specimens support the suggested tensile distribution on page 4.

It is necessary that many more specimens which encompass a greater variety of reinforcing schemes be tested before a clear picture of the influence of reinforcing on the allowable load bearing intensity can be drawn.
TYPICAL CONCRETE BLOCK

- Thin coat of Plaster of Paris
- Stirrups
- Concrete
- Base Steel Plate
- Steel rods welded to the Base Plate
REINFORCING SCHEMES

Set "AS", 4 @ 2"

Set "BS", 7 @ 1"

Typical Stirrup

Set "CS", 7 @ 2"
TYPICAL LOADING

Base of Compression Machine.
CONCRETE BLOCKS AFTER LOADING TO FAILURE

A. Set "AC", Plain Concrete.
CONCRETE BLOCKS AFTER LOADING TO FAILURE (cont.)

A. Set "AC", Plain Concrete.
CONCRETE BLOCKS AFTER LOADING TO FAILURE (cont.)

A. Set "AC", Plain Concrete.
CONCRETE BLOCKS AFTER LOADING TO FAILURE (cont.)

B. Set "AS", Reinforced 4 @ 2"
CONCRETE BLOCKS AFTER LOADING TO FAILURE (cont.)

B. Set "AS", Reinforced 4 @ 2"
CONCRETE BLOCKS AFTER LOADING TO FAILURE (cont.)
Form Used For Pouring Concrete Specimens
APPENDIX I

Design of Concrete Mix

Designed compressive strength .................. 4,000 psi
Designed slump ..................................... 5 in.
Course aggregate used ............................. 3/4 in.
Course aggregate bulk dry specific gravity .. 2.68
Unit weight of C. A. (dry rodded) ............. 100 lb.
Sound - bulk dry specific gravity ............... 264
Fineness modulus .................................. 2.80
Total water content ............................... 42 gal/cu. yard
Air entrapped ...................................... 2%
Water cement ratio ................................. 6 gal/sack
Cement .............................................. 7 sacks/yard
Ratio of volume of C.A. to total volume ..... 0.62

Quantities used for five cubic yards of concrete

Cement (Type III) ................................ 122 lb.
Water .............................................. 56.1 lb.
Sand (moisture equal to 4.8%) ................. 238 lb.
Course aggregate ................................. 310 lb.
BIBLIOGRAPHY


9. Proceedings - Western Conference on Prestressed Concrete, Los Angeles, California, November 1952