AN INVESTIGATION OF THE

LOAD CARRYING ABILITIES
OF
PRE-STRESSED CONCRETE COLUMNS

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Responsibility, for the shortcomings and possible errors in this thesis, is exclusively that of the author.

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ABSTRACT

Prestressed concrete columns are not able to sustain axial loads as large as those that can be carried by equivalent reinforced concrete columns. The equivalent reinforced concrete column is roughly ten per cent more efficient in this regard. If the column load becomes eccentric to the vertical axis the efficiency of the prestressed column will increase and eventually surpass that of the reinforced concrete column.

From the tests discussed herein a tentative formula has been suggested for predicting the ultimate load of prestressed concrete columns with $\frac{L}{d}$ of 25. The optimum steel percentage for prestressed columns was found to be approximately one percent and the use of column ties or spirals could increase the load carrying capacity of a prestressed column from five to ten percent.

The prestressed concrete column though giving up load carrying efficiency, for axial loads, to the reinforced concrete column, has better resiliency, is easier to handle and when precast can be cheaper to produce.

INTRODUCTION

The fundamental value of prestressing (pre-compressing) a concrete element is to improve its tensile resistance and ductility. The best advantage of prestressing would therefore obtain to structural concrete members where tensile stresses are predominant. The generally recognized conception is that there is nothing to be gained in applying this process to structural members carrying loads which induce compressive stresses.

The foregoing generalization though basically true, is subject to several positive exceptions from both a theoretical structural and economic point of view.

First of all it is relatively impossible to produce a concrete column without initial curvature or without heterogeneity of the materials from section to section. It is equally unlikely to achieve direct axial loading. Bending occurs at the first application of axial load and therefore pre-stress could be expected to be of some value in offsetting this condition. Certainly in the handling of pre-cast members there is need for resistance to tensile stresses.

There has been some discussion in the proceeding of the American Concrete Institute, that during long term loading of reinforced concrete columns much of the load is transferred to the steel as the concrete creeps. The ultimate failure of these columns may be, in part, due to buckling of the steel bars. In a prestressed column this is an unlikely phenomenon.

Pre-stressed columns are much more resilient than reinforced concrete columns and can recover from minor failures due to overloading without affecting their future ability to carry the working load. They are thus more reliable under impact loads.

Many compression members are from time to time subjected to transverse loads at which time they actually become flexural members. In this case the same advantages as in prestressing a beam would apply.

According to T. Y. Lin (1)[*] in his book entitled "Design of Prestressed Concrete Structures", prestressing a compression member actually reduces its deflection under transverse loads and that a prestressed pylon could be about 2.5 times as stiff as a reinforced one whose deflection is based on a cracked section. Reducing the deflection at the top of a column would minimize relative movements between building floors and thus effect a saving in the materials to strengthen other parts of the building.

Finally, there may be an advantage to prestressing from a production point of view. In plants that are set up for prestressing, the prestressed columns may be cheaper to produce than reinforced concrete columns and the difference in efficiency would thereby be compensated.

[*] Number in parenthesis refer to corresponding numbers in Bibliography

GENERALIZATION

The two major considerations for determining the load carrying ability of a column are the compressive strength of the material of which the column is made and the buckling behavior of the column. The part that these two factors play in the ultimate failure of a column is dependent upon its slenderness ratio.

The stresses ordinarily allowed in reinforced concrete column would not be applicable to pre-stressed concrete columns because the compressive stresses due to pre-compression do not contribute appreciable to buckling. The internal load of the prestressed column indirectly has some effect on buckling because it will alter the elastic modulus of the concrete.

To assess the value of prestressing a column and in part to justify this series of tests, it is imperative to examine the probable behavior of a prestressed column.

In short columns where the compressive strength of the material becomes the all important factor pre-stressing would appear to have no value for resisting pure axial load. Prestressing, in this instance, will probably be detrimental in that the internal load will have sapped some of the available compressive strength before the external load is applied (e.g. when the concrete reaches its ultimate strain value about 25% of the prestress will still remain).

Intermediate and long columns where buckling becomes a problem and initial curvature could produce bending stresses, may gain some real advantage from having any possible tension stresses relieved by prestressing.

R. A. Brechenridge at the University of Southern California (2) concluded, after several tests, that, the buckling strength of very slender columns is not reduced by prestressing.

Similar tests to those described in this text were undertaken at the University of Florida in 1956, by A. M. Ozell and A. M. Jernigan (3). This work at the University of Florida was unknown to the author prior to the inception of this research. The similarity between these tests and those at the University of Florida was purely coincidental but fortunate in that it provides some basis for comparison.

Certainly, in order for designers to obtain a basic understanding of prestressed column behavior numerous and varied testing should be undertaken.

OBJECTIVE

1. To determine the effect of L/d ratio with respect to the ultimate load carrying capacity of prestressed concrete columns.

2. To determine the effect of prestressing force on the ultimate load carrying capacity of a prestressed concrete column.

3. To determine the usefulness of lateral ties and in what locations they are most effective.

4. To draw a comparison between prestressed concrete columns, reinforced concrete columns and plain concrete columns.

DESCRIPTION

Twenty-five full sized columns were tested to failure; all of them loaded axially except one which was loaded with a 1½" eccentricity.

Because of the limits of the testing machine the column lengths were converted to a hinged-end condition. This was done to control the direction of buckling and was accomplished by the use of V-plates top and bottom (see fig.1)

Although the idealized end condition does not accurately represent connections found in practice, it was used in this investigation to obtain a member whose behavior under load might be more readily predictable from a theoretical approach. Any formulas that may be developed from these tests could be applied to any condition by incorporating a compatible multiplication factor.

There were two sets of tests. The first set was the pilot test consisting of 10 specimens which varied as to slenderness ratio and use of lateral ties.

There was a minor variation in the amount of prestress. (see fig. 2)

The second set of 15 specimens were all of equal cross-section and slenderness ratio. The amount of pre-stress was varied and these specimens also included some of reinforced concrete and some of plain concrete (see fig.3)

The following concrete mix design was used for both groups of specimens. The source of aggregate for the final tests was not the same as that for the pilot tests. However, they appeared to be basically similar.

1660#	3/4 stone (¾ to ¼ graded)
1340#	sand F. M. 2.80
700#	Portland cement type plain
300#	water

All concrete specimens were low pressure steam cured an average of 13 hours and had the following cylinder strength at destress:

Ap - 4750 psi

Bp - 5000 psi

At - 4200 psi

Bt - 4100 psi

Ct - 4300 psi

Specimens Ap and Bp were stored outdoors at sub-zero temperatures in order to arrest the curing process and thereby restrict the compressive strength of the concrete to a workable level. Strengths of 6000 psi and 7000 psi, which would have otherwise developed, would have resulted in ultimate loads, for the large columns, beyond the capacity of the testing frame. The specimens were placed in the laboratory at normal room temperatures for at least 24 hrs. prior to testing, to ensure testing was performed at normal room temperature.

The prestressing steel consisted of British Wire Rope seven wire strands with an ultimate tensile strength of 251,560 psi and an average modulus of elasticity of 29×10^6 psi. The reinforced concrete columns contained #4 deformed bars with an ultimate tensile strength of 60,000 psi. #2 column ties were used throughout. For data on the test specimens refer to figures 2 and 3.

TEST PROCEDURE

All specimens were tested in a 200, 000# column testing frame with all loads recorded in psi of ram head pressure on the hydraulic loading jack which itself was accurate to ½ of 1% of its load. The gauge was graduated to 200 psi and could be read to the nearest 100 psi. Prior to testing, this gauge was calibrated in a 200,000# Riehle testing machine. Deflections and lateral movements of the columns were recorded to 1/100th of an inch on steel scales fixed to the column at the top, bottom and mid-height, and read by means of a transit.

Several of the specimens were outfitted with SR4 type A3 and A9 strain gauges.

Two standard concrete cylinders were stored with each specimen and their average strength at the time the column was tested was taken as the f'c of the specimen concrete.

The ends of the columns were capped with 5/8" buffalo board and even bearing of the V- plates was provided for as shown in fig. 1. The loading heads on the columns were positioned by means of set screws in the loading heads so that concentricity of the load was achieved to the nearest 1/16 of an inch.

MATHEMATICAL SYMBOLS & ABBREVIATIONS

a - Initial accentricity

Ac - area of gross concrete cross-section

As - area of steel cross-section

E - modulus of elasticity

Eq - modulus of elasticity of concrete based on Portland Cement Association formula where Eq = 60,000 $\sqrt{f'c}$

Es - modulus of elasticity of concrete from Southwell plot

Et - modulus of elasticity of concrete based on average tangent modulus

d - least dimension of column cross-section

f'c - average ultimate concrete cylinder stress

f cu - average ultimate concrete stress due to axial load

f'cu - maximum ultimate concrete stress in extreme fibre due to axial load plus moment due to deflection plus prestress

h - measured lateral deflection due to load P

L - effective length of column

p - As/Ac

P - axial load

P_p - axial load due to prestress

Peq - ultimate load based on Euler formula using Eq

Pes - ultimate load based on Southwell plot

Pet - ultimate load based on Euler formula using Et

Pu - actual ultimate load

S - section modulus

σb - stress due to bending

σc - stress due to axial compression (external load)

σp - stress due to prestress

DISCUSSION OF TEST RESULTS

Table I and Table II contain a summary of the test results. This information is taken from and based upon the test data which is contained in the appendix to this text.

The ultimate strength of the columns varied and in most cases their variation was considerable. These variations were due to differences in concrete cylinder strength, differences in intial curvature and heterogeneity of the concrete. The largest contributing factor appears to be the variation in initial curvature. In any group the column with the greatest lateral deflection failed at the lowest ultimate load.

Fig. 4 shows the plot of ultimate load versus the concrete steel ratio. The variation, which is shown here highlights the difficulty in obtaining a mean curve for these points. An attempt was made to analyze these results by normal methods of experimental analysis. The result was that all differences were significant for any reasonable degree of freedom and similarly an analysis of variance drew an unsuccessful conclusion because a curve could not be accurately fitted. Unfortunately there is an insufficient number of tests to make a useful statistical analysis of the results. For a useful portrayal of the results we were therefore obliged to follow other methods as described below.

Using an average ultimate load value for the various groups a straight line is obtained and shown in Fig. 4. This in itself is unsatisfactory because it does not relate the steel-concrete ratio to the actual stresses in the column. We therefore have Fig.5, where the above condition is satisfied.

The three stresses involved while a column is being loaded are pre-stress, axial stress and bending stress due to lateral deflection.