Behavior of R.C Columns with Poor Concrete Strength at Upper Part

M. Rabie

Structure Engineering Department. Faculty of Engineering, Cairo University, Egypt.
rabie_eng@yahoo.com

Abstract: Reinforced concrete columns are the main load bearing elements of any structure. It support the beams and slabs and transfer the loads to the foundations. Hence they have to be designed and detailed adequately to resist both gravity and lateral loads. In some buildings, especially when quality control is poor; the upper part of column contains few amount of mortar cement and large amount of aggregates, this mean that compressive strength of concrete is weak in this part. Low compressive strength for upper part of the column will lead to a reduction in bearing capacity of column. Moreover; upper part does not behave in the same manner as is the rest of the column body. This study is carried out to investigate the behavior of 12 types of reinforced concrete columns subjected to a concentric compressive load. The experimental specimens were made of concretes with compressive strengths ranging from 12.5MPa to 40MPa. Grade 400 was used for steel ties reinforcement in order to investigate the ability of higher yield strength steel to confine the concrete core of column. The behavior of the tested specimens is compared to predict the effect of studied parameters on the ultimate load, vertical and horizontal strains of the columns. This research presents a proposed equation for calculating the ultimate load of column taking into considerations the effect of poor concrete strength at upper part.

[M. Rabie. **Behavior of R.C Columns with Poor Concrete Strength at Upper Part.** Life Sci J 2012; 9(2):1159-1165]. (ISSN: 1097-8135). http://www.lifesciencesite.com. 173

Key Words: R.C columns, poor concrete, upper part, concentric.

1. Introduction

. Structural column failure is one of major significant concern in terms of economic as well as human loss. Thus, extreme care needs to be taken in column design, with higher conservative precautions than in the case of beams and other horizontal structural elements, since compression failure provides little visual warning.

This study is carried out to investigate the general deformational behavior of R.C Columns with Poor Concrete Strength at Upper Part of column body. These columns are subjected to axial compression loads acting at their top level. The cross section of columns and their reinforcing steel are kept constant, while the spacing between stirrups at the upper part is changed in some tested specimens. Also, the height of concerned upper part of column is changed in some tested specimens.

A lot of previous researches focused on the behavior of column with constant strength along its full height, even if there is a local defect in the column. In the present study the construction deficiencies such as bad quality concrete at upper part of column are precisely considered as shown in figure (1).

Soliman(1) Carried out a study to investigate the behavior of concrete columns strengthened by using circular concrete jackets. This study indicated that the use of spiral stirrups as a transversal reinforcement of the jacket improves the strength and the ductility of the strengthened or repaired column than using of rectangular separate stirrups.

Usama(2) carried out an experimental investigation on strengthening of the defected part in the column. The construction deficiencies such as bad quality of concrete and bad arrangement of horizontal reinforcement (stirrups) are only investigated. This study concluded that ultimate load of defected part of a column is increased by wrapping its cross section by a concrete jack, the presence of a defected part along the column height significantly changes its behavior (deformations of upper zones are more than the deformation of middle zone), and the compressive strength of the column has a great effect on the load capacity of the column compared with the bad arrangement of the stirrups.

Shamim *et al.,*(3) Fifteen 12-in. (305 mm) square cross section and 9-ft (2.74 m) long reinforced concrete columns were tested under flexure to large inelastic deformations while simultaneously subjected to constant axial load to investigate the behavior of column sections confined by rectangular ties. Major variables considered in this program included distribution of longitudinal and lateral steel. It was found that a larger number of laterally supported longitudinal bars results in higher flexural strength and ductility.

Unsupported longitudinal bars tend to buckle and push the ties outward at large deformations, resulting in a brittle behavior caused by a loss of confinement.

Němeček *et al.,* (4) The behavior of six series of reinforced concrete columns with a square cross section was investigated experimentally and numerically. Two different grades of concrete (normal and high strength) and three different densities of stirrups were chosen. The columns were loaded in eccentric compression with small eccentricity. The major experimental and numerical results are as follows:

- Compression failure (crushing) accompanied by concrete softening and steel buckling developed in the columns.
- Failure of columns localized into the middle part, where a wedge-shape failure pattern developed in the concrete, together with buckling of the reinforcement between the stirrups. The damage zone had approximately the same dimensions for all tested series.
- The influence of the density of the stirrups on the column strength was negligible in the investigated cases (i.e. square cross section, stirrup density 50 mm–150 mm).

Kim *et al.,* [(5)] The effects of concrete strength and longitudinal steel ratio on the ultimate load and axial force, bending moment relation of a column were investigated.

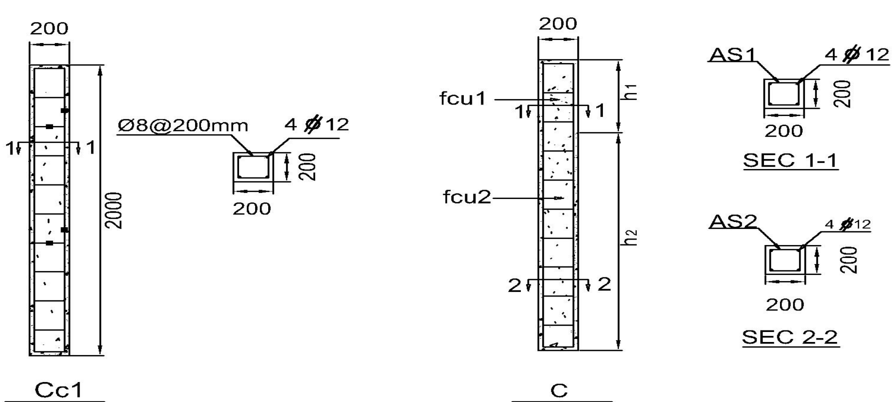
A series of tests was carried out for 30 tied reinforced concrete columns with 80 mm square cross section and three slenderness ratio of 10.60 and 100 three different concrete strengths of 25.5 , 63.5 and 86.2 Mpa, and two different longitudinal steel ratios of 1.98 and 3.95% were used. Experimental results revealed that the ultimate load for a short high-strength concrete column was significantly increased .The possibility of stability failure for a slender column was increased with the increase of concrete strength. The increment of ultimate load due to increase in longitudinal reinforcement for the short column was less than for the slender one, and the heavier reinforcement for the slender column led to a more stable column

Fig. (1) Bad quality concrete at upper part of column

2. Experimental Work

Test Specimens

Twelve 200 × 200 × 2000 mm rectangular columns of concrete strength (f_{cu}) 40 MPa were cast and tested. The main variables of the studied parameters were the upper poor concrete strength (12.5 – 20) MPa, the spacing of stirrups (200 -100 mm), and the stirrups diameter (8-10 mm). (36/52) steel grade was used for longitudinal reinforcement (diameter of 12 mm). The details of the specimens are as given in Figure (2).The columns were cast vertically to simulate the columns in actual practice of construction and compacted with a needle vibrator., Instrumentation, casting, and curing are shown in figures (3 , 4 , 5).Also the tested specimens properties are given in table (1).



h1 = height of poor concrete part of column

h2 = height of column part with normal constant strength

Fig (2) test specimens details

Fig. (3) Fixing electrical strain gages

Fig. (4) Specimens casting

Fig. (5) Specimens curing

Table (1) test specimens

Test specimen	h1(mm)	h2(mm)	Ast1	Ast2	fcu1	fcu2
Cc1	0	2000	Ø8@200 mm	Ø8@200 mm	40	40
Cc2	500	1500	Ø8@150 mm	Ø8@200 mm	40	40
Cc3	500	1500	Ø8@100 mm	Ø8@200 mm	40	40
Cc4	500	1500	Ø10@200 mm	Ø8@200 mm	40	40
C1	500	1500	Ø8@200 mm	Ø8@200 mm	14	40
C2	500	1500	Ø8@200 mm	Ø8@200 mm	18	40
C3	500	1500	Ø8@200 mm	Ø8@200 mm	20	40
C4	500	1500	Ø8@150 mm	Ø8@200 mm	14	40
C5	500	1500	Ø8@100 mm	Ø8@200 mm	14	40
C6	500	1500	Ø10@200 mm	Ø8@200 mm	14	40
C7	350	1650	Ø8@200 mm	Ø8@200 mm	14	40
C8	650	1350	Ø8@200 mm	Ø8@200 mm	14	40

f cu1 = concrete characteristic strength of upper part of column.
f cu2 = concrete characteristic strength of column.

Equipment and Instrumentation:

All columns were loaded with 500 ton hydraulic machine in Cairo university concrete research lab. The applied load was read out on the load cell scale. The set up of loading of the tested columns is shown in figure (6). To ensure concentric loading; displacement dial gauges of 0.01 mm accuracy and LVDT were placed at upper and middle position along column two perpendicular sides to monitor its deflected shape at different increments of loading as shown in fig. (7).

Concrete strains were measured by mechanical strain gauges of 100 mm gauge length, using demic points mounted on the upper and lower columns' sides at the same positions in all columns. Also, electric srain gauges are fixed on longitudinal steel bars and transversal stirrups.

Fig. (6) Set up of loading of the tested columns

=

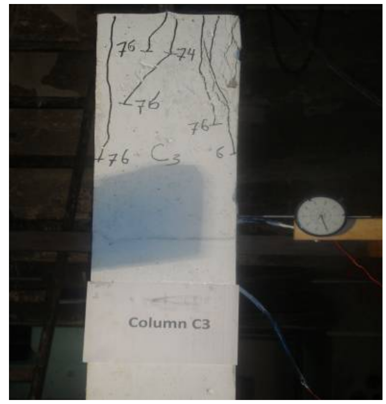


Fig. (7) Location of dial gauges and LVDT at upper and middle position along column

3. Analysis and Discussion of the Experimental Results

Mode of failure and failure load

The applied load was increased gradually from zero to the ultimate load with a constant increment of 10 tons. The load remained constant at each increment of load to record the concrete strain, the longitudinal reinforcement strains, the transversal reinforcement strain and crack patterns till collapse

For the twelve tested columns, the first crack appeared at a load level about 70% to 80 % of the ultimate (the failure) load for upper poor concrete strength specimens. While it was appeared at a load level about 80% to 90 % of the ultimate (the failure) load for control specimen of normal concrete strength, table (2) shows the value of loads at which the first crack appeared at upper part for each column. In addition; figures (8) to (10) show the crack pattern and the shape of failure of the tested columns.

Fig. (8) crack pattern and the shape of failure of cc1, c1,c2,c3

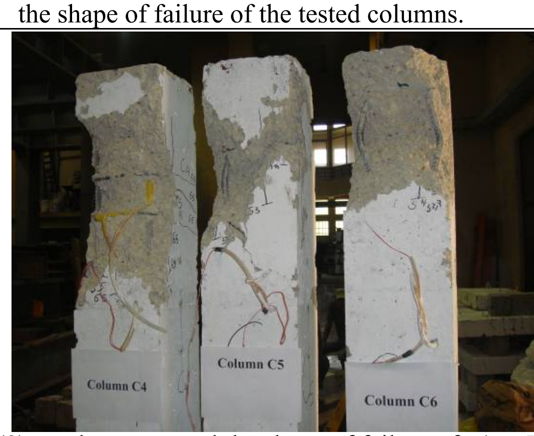


Fig. (9) crack pattern and the shape of failure of c4 , c5 , c6

Fig. (10) crack pattern and the shape of failure of c7 , c8

Table (2) Cracking and Failure Loads

Column No.	Cracking load (ton)	Failure load (ton)	Cracking load % of Failure load	Mode of failure
Cc1	100	113	88	Crushing
Cc2	130	143	91	Crushing
Cc3	121	134	90	Crushing
Cc4	127	143	89	Crushing
C1	45	63	71	Crushing
C2	55	78	70	Crushing
C3	57	79	72	Crushing
C4	51	65	78	Crushing
C5	50	66	76	Crushing
C6	47	67	70	Crushing
C7	52	72	72	Crushing
C8	43	61	70	Crushing

Figures (11, 12) illustrate that the ultimate load decreased by about 45,31 and 30% in specimens C1, C2, and C3 as the concrete strengths in the upper part of the column were 14, 18, and 20 MPa respectively compared with the control specimen of constant concrete strength of 40 MPa. While the column longitudinal strain at the same ultimate load decreased in lower portion of column with normal strength concrete compared with upper poor strength concrete part.

Figures (13 , 14 , 15) showed that the effect of decreasing the spacing between stirrups or increasing its diameter in the upper poor concrete strength part of the specimens C4 , C5 ,and C6 had little effect on measured ultimate load. While, this effect was increased in control specimens Cc2, Cc3, and Cc4.

Figure (16) showed that the height decreasing of upper poor concrete strength (h1) of specimens C7 by about 30% increased the ultimate load by about 14% compared with tested specimen C1. While the height increasing of upper poor concrete strength (h1) of specimens C8 by about 30% decreased the ultimate load by about 4% compared with tested specimen C1.

Figures (17, 18) illustrate that longitudinal steel – strains in upper poor concrete part of specimens C1 and C2 was more than that of lower normal concrete part. Also longitudinal steel – strain increased in upper part compared with control specimen Cc1.

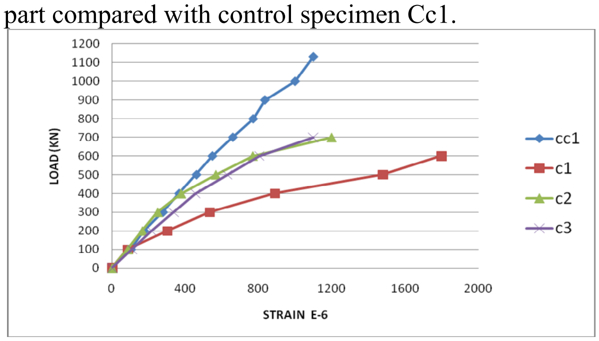


Fig. (11) Load - Vertical Concrete Compressive Strain of Upper Part

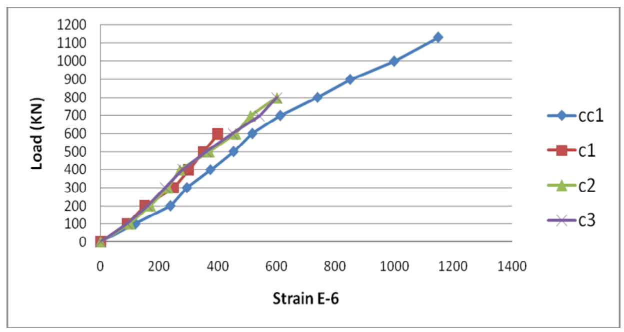


Fig. (12) Load - Vertical Concrete Compressive Strain of Lower Part

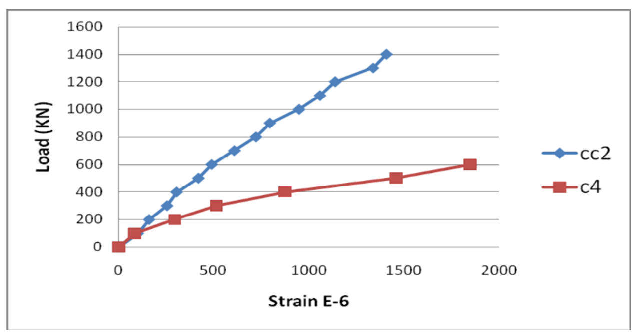


Fig. (13) Load - Vertical Concrete Compressive Strain of Upper Part

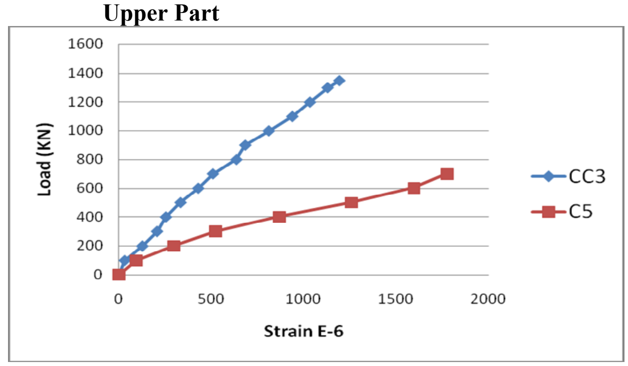


Fig. (14) Load - Vertical Concrete Compressive Strain of Upper Part

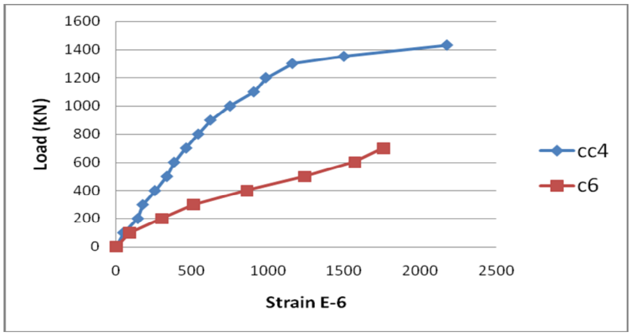


Fig. (15) Load - Vertical Concrete Compressive Strain of Upper Part

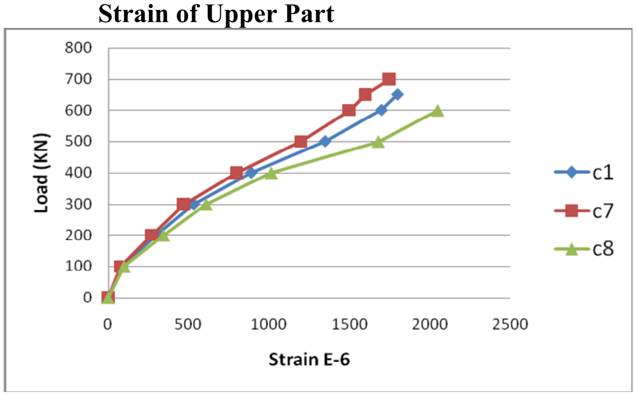


Fig. (16) Load - Vertical Concrete Compressive Strain of Upper Part

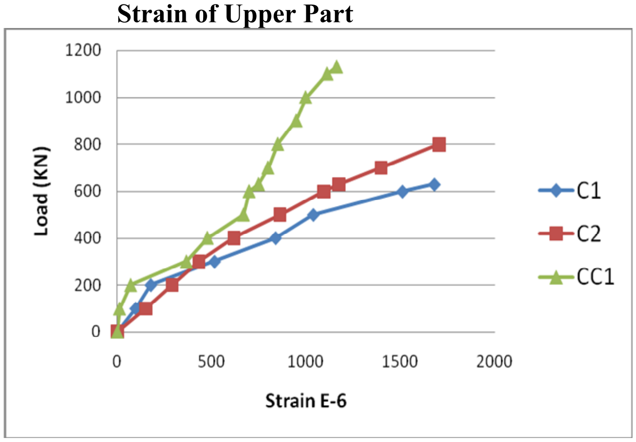


Fig. (17) Load - Vertical Steel Compressive Strain of Upper Part

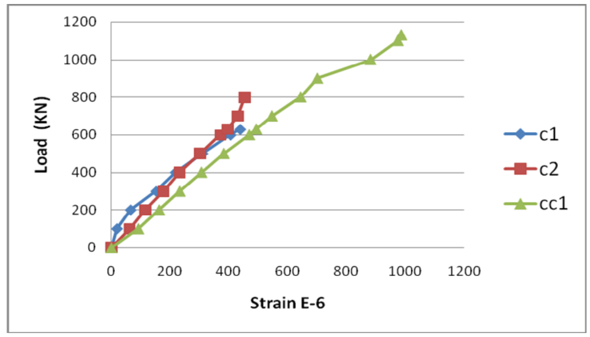


Fig. (18) Load - Vertical Steel Compressive Strain of Bottom Part

Calculating the load carrying capacity of columns using code equation with suggested modified factors.

A relation between the load carrying capacity and the concrete strength at upper and lower parts of tested specimens can be obtained by regression analysis which used best fit of the test results. Accordingly; a usable formula was obtained as follows.

Assuming that columns considered in the present study is part of a braced structure; the ultimate load carrying capacity of the column according to ECP 203 code [(6)] can be calculated as follows:

$$Pu = 0.35 * f_{cur} * AC + 0.67 * f_y * A_{SC}$$

Where:

Pu = Design load of tied columns, (ton).

$$f_{cur} = 0.92 \sqrt{f_{cu1} * f_{cu2}} * \sqrt{h_2 / h_1}$$

f_{cu1} = Concrete characteristic strength of upper part of column.

f_{cu2} = Concrete characteristic strength of column.

Ac = Area of column's cross section.

Fy = Yield strength of steel.

Asc = Area of longitudinal reinforcement.

h_1 = height of poor concrete part of column.

h_1 = height of column part with normal constant strength.

Table (3) and figure (19) showed good agreement between experimental measured ultimate load and the calculated one using the proposed equation.

Table (3) Cracking and Failure Loads

specimens	b1 (mm)	b2 (mm)	F_{cu1} (Mpa)	F_{cu2} (Mpa)	h_1 (mm)	h_2 (mm)	P_u (exp) (kN)	P_u(pe)* (kN)	P_u (exp) / P_u(pe)
c1	200	200	14	40	500	1500	630	636	0.99
c2	200	200	18	40	500	1500	780	714	1.09
c3	200	200	20	40	500	1500	790	746	1.05
c4	200	200	14	40	500	1500	650	642	1.01
c5	200	200	14	40	500	1500	660	642	1.02
c6	200	200	14	40	500	1500	670	642	1.04
c7	200	200	14	40	350	1650	720	777	0.93
c8	200	200	14	40	350	1350	610	553	1.10

***P_u(pe) = P_u using proposed equation**

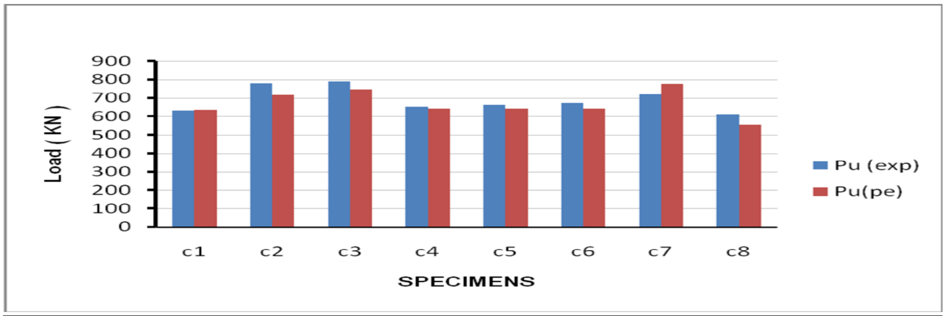


Fig. (19) comparison between P_u (exp) and P_u(pe)

Conclusions

1. Mode of failure of all poor concrete upper part tested specimens was the initiation of vertical crack at upper part followed by crushing of concrete at top of column. While horizontal and vertical cracks appear at middle of normal concrete strength control specimen.
2. Ultimate column load decreased as the concrete strength of upper part decreased.
3. Decreasing of stirrups spacing or increasing its diameter at upper poor concrete part had no significant effect on the ultimate column load. While, stirrups concentration in the upper part increased the ultimate column load by about 20% in case of normal concrete strength along the whole height of columns.
4. Ultimate column load increased as the height of poor concrete part decrease and visa versa.
5. Longitudinal steel – strains in upper poor concrete part of column was more than that of lower part of normal concrete strength.
6. A proposed equation for calculating the ultimate load for short braced columns which takes into consideration the effect of height and strength of upper poor concrete and lower normal concrete parts was presented as follows:

$$P_u = 0.35 * f_{cur} * AC + 0.67 * f_y * A_{SC}$$

Where:

$$f_{cur} = 0.92 \sqrt{f_{cu1} * f_{cu2}} * \sqrt{h_2 / h_1}$$

Correspondence author
M. Rabie
Struct. Eng. Dept., Faculty of Eng., Cairo Univ.
rabie_eng@yahoo.com

References

1. Soliman M . I . (1998): "Repair of Distressed Reinforced Concrete Columns" Bulletin of Faculty of Engineering , Ain Shams University ,.
2. Usama M. Abdel Hameed(1999): "Behavior of Partially Strengthened Reinforced Concrete Columns under Axial Loads" Master of Science in Structural Engineering , faculty of Engineering, Cairo University,.
3. Shamim A. Sheikh and and Ching-Chung Yeh (1990):"Tied Concrete Columns under Axial Load and Flexure" Journal of Structural Engineering, Vol., 116, No.(10), October.
4. Němeček J., P. Padevět, Z. Bittnar(2004):" Effect of Stirrups on Behavior of Normal and High Strength Concrete Columns" . Acta Polytechnica Vol., 44 No.(5–6).
5. Kim, J.K., Yang, J.K., (1993): "Buckling Behavior of Slender High –Strength Concrete Columns" . Engineering Structures vol., 17, No.(1):1995.
6. The Egyptian Code for Design and Construction of Reinforced Concrete Structures , ECP 203-2007.

5/2/2012