Eng. & Tech. Journal , Vol.27, No.6 ,2009

Behavior of Short Reinforced Porcelinite Concrete Columns Under Concentric Loads

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Received on : 17/3/2008

Accepted on : 9/10/2008

Abstract:

This study presents on experimental method to investigate the behavior of reinforced porcelinite concrete columns subjected to concentric load. The experimental work includes investigation of ten lightweight concrete columns with square cross section 190×190mm and 1000mm in length subjected to concentric load to assess the effect of the amount of longitudinal steel reinforcement, lateral tie reinforcement and grade of concrete. From the experimental observation it was found that the porcelinite aggregate is a good structural material to produce lightweight concrete columns. It is noted from tested columns that keeping the amount of the longitudinal steel ratio constant, the increase in the amount of transverse steel to about four times (by decreasing the spacing to about a quarter according to the ACI-Code (318M-05)) gave a significant influence on column post-cracking behavior. The improvements in the column due to higher value of confinement include: (i) less brittle behavior; (ii) significantly less damage to the concrete core; (iii) 12% increase in column load carrying capacity. Also, A modified formula for column capacity is proposed to take into account the influence of spacing of ties (effect of confinement).

Keywords: Porcelinite, R.C., Columns

تصرف الأعمدة الخرسانية المسلحة القصيرة المصنوعة من ركام البورسلينايت تحت الاحمال المركزية

الخلاصة:

تقدم هذه الدراسة بحثا عمليا لدراسة سلوك الاعمدة الخرسانية خفيفة الوزن التي تحوي علـــى ركام البورسلنايت تحت تاثير الاحمال المحورية. يتضمن الجزء المختبري فحص عشرة أعمدة خفيفـــة الوزن مربعة المقطع بابعاد (190×190ملم) وبطول (1000ملم) والمعرضة الى احمـــال محوريـــة لتقدير تاثير كمية الحديد الطولي وكمية الحديد العرضي (lateral) ومقاومة الخرســـانة للانـــضغاط. يمكن الملاحظة من خلال التجارب المختبرية (العملية) بان مادة ركام البورسلنايت جيدة انشائيا وملائمة لتنتج خرسانة خفيفة الوزن وكذلك يمكن الملاحظة عند الحفاظ على كمية الحديد الطـــولي ثابتـــة فـــان الزيادة في الحديد العرضي اربعة أضعاف حسب ماتحدده متطلبات الكود الامريكي لسنة 2005 يـــؤثر تاثيرا كبيرا على تصرف العمود في مرحلة ما بعد التشقق. ان تحسين اداء وكفاءة العمود مـــن خـــلال استخدام نسبة حديد عرضي اكبر يؤدي الى: أ-زيادة في المطيلية . ب-اقل تـــضررا لقلـــب العمـــود الخرساني (الجزء الخرساني من العمود والمحصور داخل الحديد العرضي). ج-زيادة 12% للتحمـــل الاقصى للعمود.

كذلك تم تطوير معادلة تجريبية لحساب الحمل تاخذ بنظر الاعتبار تاثير الحديد العرضي.

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https://doi.org/10.30684/etj.27.6.19

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Introduction

Compression members are key elements of all skeletal structures, and the study of their behavior is usually based on testing of concentrically loaded columns. Compression members, or columns, may be defined as members that carry axial compressive loads, and whose length is considerably greater than the cross-sectional dimensions. Lightweight concrete has successfully been used for many years for structural members and systems in buildings and bridges. In addition to its lighter weight, which permits saving in dead loads, and thus reducing the costs of both superstructure and foundation, it is more resistant to fire and provides better heat and sound insulation than concrete of normal density(1,2). Lightweight concrete is considered as having a density not exceeding 1920 kg/m3, while normal density concrete is considered to have a usual density ranging between 2240 and 2480 kg/m^3 (3). Also lightweight concrete with compressive strength ranging between 17 and 27 MPa is defined as low-strength concrete. For compressive strength ranging from 27 to 41 MPa it is defined as medium-strength concrete. However, for compressive strength greater than 41 MPa, it is defined as high-strength concrete (1). In Iraq, little work has been done on the use of lightweight concrete in structural members, such as slabs; beams, columns, foundations, etc.

Recent research (4, 5, 6, 7) has shown that there is an abundant supply of lightweight rock that may be used to produce concrete of lower density than the density of normal concrete in the present practice in this country. The lightweight aggregate, which is used, is quarried from rocks discovered in the Iraqi Western Desert. It is called porcelinite (8) and Fig. (1) shows the location. Since the production of manufactured lightweight aggregate (from clay, shale, etc) is more costly, successful use of natural lightweight aggregate will be much more economic. The well-known advantages of using lightweight concrete worldwide are even more important in Iraq, since much of this country has low soil bearing capacity (9, 10).

Experimental Work

The tests were made on ten reinforced concrete columns, with a cross section of 190mm × 190mm, and a total length of 1000mm. The columns were loaded at the ends with concentric loads. The reinforcing bars were cut to the desired length. For all tested columns, 90-degree hook was formed at the ends of each longitudinal bar. Lateral ties were made from 9.5mm diameter deformed bars. Additional ties were placed close to the ends of the specimens to prevent failure at these regions. Two mixes were used in the experimental work. Mix C1 was prepared without superplasticizer and used for groups G1 and G2. While mix C2 was prepared with superplasticizer and used for groups G3 and G4. Twelve 150 × 300 mm cylindrical control specimens were used for groups G1 and G2 and twelve specimens for groups G3 and G4 (three specimens to calculate the modulus of elasticity, three specimens to calculate splitting tensile strength and six specimens for calculating the compressive strength of concrete at age 7 days and at 28 days). An internal vibrator machine was used to compact the fresh concrete. After 24 hours the column and the control specimen molds were stripped and the specimens were kept moist cured in a water bath for a curing period of 28 days. The columns were divided into four groups (G1, G2, G3 and G4). For groups G1 and G3, three columns were tested for each group. The columns were designated as A1B1C1, A1B2C1, A1B3C1, A1B1C2, A1B2C2 and A1B3C2. For groups G2 and G4, two columns were tested for each group. The columns were designated as A2B1C1, A3B2C1, A2B1C2 and A3B1C2. The letter A refers to longitudinal steel ratio and the subscript number 1 refers to 4-Ø15.9mm, 2 refers to 4-Ø12.7mm and 3 refers to 8-Ø15.9mm. The letter B refers to transverse steel ratio, the subscript number 1 refers Ø9.5 @190mm, 2 refers to Ø9.5 @125mm and 3 refers to Ø9.5 @50mm. The letter C refers to compressive strength of concrete and the subscript number 1 refers to concrete without superplasticizer and the subscript number 2 refers to concrete with superplasticizer. Figs. (2) and (3) refer to the classification chart of column groups and column reinforcement before casting respectively.

Concrete Mixes

Concrete mixes containing porcelinite aggregate as lightweight aggregate should have an oven - dry density less than 2000 kg/m^3, and a compressive strength greater than 15.0 MPa[11]. Mix C1 has (1:1.13:1.8) by volume with Ordinary Portland Cement of 550 kg/m^3 content, fine aggregate of 522 kg/m^3 content and LWA content of 518 kg/m^3 were used in this work. The w/c ratios were 0.43 for mix C1 and 0.35 for mix C2 to give a slump of 100±25 mm. The concrete contained 4% superplasticizer (SP1) by weight of cement. Table (1) shows the details of the mixes used throughout this investigation.

Materials

1- Cement

The type of cement used in this study was ordinary Portland cement (Type I). It was manufactured at Lebanon factories (cement Siblin). It was kept in a dried place to avoid atmospheric damage. The chemical and physical analyses of the used cement conformed to the Iraqi Standard Specification No.5/1984 [12].

2- Fine Aggregate

Normal-weight natural sand obtained from Al- Akhaider region was used as fine aggregate. The sand was sieved on 4.75-mm sieve. The grading of the sand conformed to the requirements of BS 882- 1992[13]

3- Porcelinite Aggregate

Local naturally occurring lightweight aggregate of porcelinite stone was used as coarse aggregate. It was received in large lumps from the State Company of Geological Survey, Western Desert at Al-Anbar Governorate. The lumps were manually crushed into smaller sizes by means of a hammer in order to facilitate the insertion of lumps through the feeding openings of the crusher machine. The jam crusher was set up to give a finished product of about 12.5mm maximum aggregate size. The aggregate taken from the crusher was screened on a standard sieve series complying with ASTM C330 [14]. The individual size fraction for each batch was recombined in proper proportions to produce the desired grading. The required quantity of coarse lightweight aggregate for each batch was washed by water in order to remove the dust associated with crushing process of the coarse aggregate. A high proportion of dust leads to segregation and causes crazing of exposed concrete [15].

The coarse aggregate was dripped off and spread inside the laboratory in order to bring the aggregate particles to saturated surface dry (SSD) condition. Due to the rapid water absorption of this aggregate type, the surface drying has been done by spreading the aggregate in the laboratory air for a suitable time.

Several physical and chemical properties were determined for coarse porcelinite aggregate. Some of these properties would be used as basis for mix proportioning purposes, such as dry rodded unit weight and absorption. Table (2) lists these properties and their corresponding proper specifications.

4- Admixture

The superplasticizer used in this work was RHEOBUILD(16) SP1 which is a liquid admixture for concrete, based on sulphonated naphthalene.

5- Water

Tap water of Baghdad was used for mixing concrete. The ideal water should be clean and clear. However, no test was carried out on the water to be used.

6- Reinforcing Steel

Reinforcing steel used as longitudinal bars and lateral ties in reinforced concrete columns met the ASTM A615(17) requirements. All the longitudinal bars used were of the same type and had the same mechanical properties and rib geometry. Longitudinal reinforcing steel bars, which were of Ukrainian origin, were purchased from a local market in Najaf. The bars have been tested at the Laboratory of Mechanical Engineering Department at Kufa University in Najaf. The longitudinal steel bars for all tested columns had diameter of 12.7 and 15.9 while 9.5mm bars were used as lateral ties. The main data obtained for testing bars are shown in Table (3).

Demec points were used to measure the surface strains in concrete. They were mounted along the concrete surface (or faces) within the effective span (measuring zone) of the tested samples.

Two demec gage points were mounted at spacing of 150mm at the column mid-height along the column vertical axis to measure the longitudinal compressive strains at two perpendicular faces of the column. Also additional two demecs were mounted horizontally to measure lateral strains at two perpendicular faces of the column.

Details of demec gage distribution are shown in Figs. (4).

Results:

1- Compressive Strength

The strength values were obtained as the average of three cylinders for each test. It is noted that the use of superplasticizer (SP1) increases the cylinder compressive strength from 22MPa to 32MPa (+45%) and decreases the w/c ratio from 0.43 to 0.35 (-18.6%).

2- Spliting Tensile Strength

The values are obtained as the average of three cylinders at age of 28 days. It is noted that the splitting tensile strength increases by about (19.2%) when the compressive strength rises from 22MPa to 32MPa.

3- Test Observation

Photographs of the tested concentrically loaded short columns are shown through Figs. (5) to (10). It is noticed from the tests that the appearance of vertical cracks in the concrete cover was always the first sign of failure of the tested columns. These cracks spread rapidly after spalling of concrete cover. At this stage the core of concrete carried the applied axial load because it is confined by the confining effect between the ties and the longitudinal bars. At the end of this stage the ties will slip (open) as the expansion of concrete core occurs. This was particularly evident for columns $A_1B_3C_1$ and $A_1B_3C_2$. In columns $A_1B_1C_1$ and $A_1B_1C_2$, columns $A_1B_2C_1$ and $A_1B_2C_2$ and columns $A_2B_1C_1$ and $A_2B_1C_2$, when a vertical crack appeared a sudden cover spalling took place and buckling of longitudinal bars occurred. This was invariably associated with opening of the ties. As the ties snapped, the core concrete in the near vicinity was reduced because of crushed concrete being ejected from the core. Columns $A_3B_1C_1$ and $A_3B_1C_2$ have shown much more ductility of behavior after cover spalling, as compared with columns $A_1B_1C_1$ and $A_1B_1C_2$.

4- Load versus Mid-Height Longitudinal Strain Results

Ten short reinforced lightweight concrete columns were cast and tested under concentric loads up to failure. Experimental behavior of load versus mid-height longitudinal compressive strain curves of all tested columns are presented in Figs. (11) and (12).

It may be noticed that the response by the load versus mid-height longitudinal and lateral strains can be divided into two distinct stages of behavior. The first stage is characterized by an approximately linear relationship between the load and the longitudinal and lateral strains. This stage represents the response of columns before cracking of concrete cover.

The second stage represents the behavior beyond the initial cracking of concrete cover. At this stage the stiffness of the column is decreased as indicated by the reduced slope of the load versus longitudinal and lateral strain curves. During this stage, the cover starts to spall out. The end of this stage is distinguished when the longitudinal reinforcement starts to be dented and the core of concrete carries all the axial loading while the concrete cover is completely spalled out. Table (4) shows the ultimate experimental load capacities for all tested columns[18].

5- Effect of Transverse Reinforcement Ratio

In order to examine the effect of using different amounts of transverse reinforcement in the lightweight concrete column on its axial behavior, Group G1 without superplasticizer and with transverse steel ratios of 0.48%, 0.73% and 1.83% respectively is considered. In this group the longitudinal steel ratio and concrete compressive strength were 2.19% and 22MPa respectively.

Group G3 with superplasticizer (SP1) was selected and it consisted of columns $A_1B_1C_2$, $A_1B_2C_2$ and $A_1B_3C_2$ with transverse steel ratios of 0.48%, 0.73% and 1.83% respectively. In this group the longitudinal steel ratio and concrete compressive strength were kept at 2.19% and 32MPa respectively.

It is noted that the variation of the transverse steel ratio slightly affects the post-cracking response (second stage) and the ultimate load. Also when the transverse steel ratio was increased from 0.48 to 0.73 percent (spacing between ties changed from 190mm to 125mm respectively) there was negligible effect on the post-cracking behavior and the ultimate load. Fig. (13) shows the effect of transverse reinforcement on the load versus lateral strain. When the transverse steel ratio was increased from 0.48 to 0.73 percent the figure reveals that a slightly stiffer post cracking response is obtained. In contrast it is noted that when the transverse steel ratio was increased from 0.73 to 1.83 percent (spacing between ties was changed from 125mm and 50mm respectively) there was a significant effect on the post-cracking behavior because of the better confinement of concrete core and less damage in the concrete core and longitudinal steel bars at failure.

6- Effect of Percentage of Longitudinal Steel Ratio

The longitudinal steel ratios, r_l, which have been used were 1.40%, 2.19% and 4.38%. The transverse steel reinforcement and concrete compressive strength were 0.48% and 22MPa for group G2 respectively. While for group G4, the transverse steel reinforcement and concrete compressive strength were 0.48% and 32MPa respectively.

7- Effect of Concrete Compressive Strength

The selected values of concrete compressive strength were 22 and 32MPa for columns $A_1B_1C_1$ and $A_1B_1C_2$ respectively. A relatively stiffer response in precracking stage was noted for the column with concrete compressive strength equal to 32MPa. The collapse load increased from 942 to 1220kN (+29.5%) when the compressive strength was increased from 22 to 32MPa (+45%). Therefore, it can be concluded that the concrete compressive strength significantly influences the post-cracking stiffness and the collapse loads.

8- Nominal Axial Load Capacity

Based on the limited amount of experimental tests, the following expression of nominal load capacity for porcelinite lightweight concrete columns subjected to concentric load is proposed for concrete compressive strength ranging between 22MPa to 32MPa.

$$P_{n2} = \left[0.85 f'c + x \times f'_2 \times \left(1 - \frac{s}{d_c}\right)\right]\left(A_{con} - A_{st.}\right) + \left[\frac{y \times s}{s_{min}}\right]^z A_{st.} f_y \quad ..(1)$$

where:

x, y and z = constants obtained from a statistical regression analysis

x = 0.171

y = 0.98

z = 8.08

$s_{min.}$ = minimum required spacing between ties according to ACI-Code (318M-05).

s = actual spacing between ties.

d_c = outside to outside dimension of tie dimension.

$f'_2 = \dfrac{2A_{st.} f_y}{d_c s}$, confinement stress with lateral reinforcement

$f'_2 \times \left(1 - \dfrac{s}{d_c}\right)$, effective confinement stress

$$R^2 = \frac{\sum_{i=1}^{n} \left(y_i - y_{av.}\right)^2_{predicted}}{\sum_{i=1}^{n} \left(y_i - y_{av.}\right)^2_{observed}} = 98.389\%$$

C.O.V. = 0.1923

Conclusions

1- It is noted from the tested columns that the porcelinite aggregate is a suitable structural material to produce lightweight concrete columns.

2- It was observed that the use of superplasticizer in concrete mix at 4% (of cement weight) would increase the compressive strength of lightweight concrete from 22 to 32MPa and reduce concrete spalling at the outside cover.

3- It is noted from tested columns that keeping the amount of the longitudinal steel ratio constant, the increase in the amount of transverse steel by about 50% (by decreasing spacing by 50%) from the ACI-Code (318M-05) minimum requirement has a negligible for effect on collapse load but it slightly improves post-cracking behavior.

4- It is noted from tested columns that keeping the amount of the longitudinal steel ratio constant, the increase in the amount of transverse steel to about four times (by decreasing the spacing to about a quarter) according to minimum requirement of the ACI-Code (318M-05) has a significant influence on column post-cracking behavior. The improvements in the column with higher value of confinement include: (i) greater ductility; (ii) significantly less damage to the concrete core; (iii) 12% increase in column load carrying capacity.

5- It is noted from tested columns that keeping the amount of the transverse steel ratio constant, the increase in percentage of longitudinal reinforcement substantially affects the post-cracking behavior. It is noted that with the increase in longitudinal steel ratio from 1.4% to 4.38%, the collapse loads increased by about 41%.

6- The experimental results show that the increase of the concrete compressive strength from 22MPa to 32MPa results in a slightly stiffer response in pre-cracking region. Also, The ultimate load increases by about 29.5% when the concrete compressive strength increases from 22MPa to 32MPa.

References:

[1] Slate, F. O., Nilson, A. H., and Martinez, **"Mechanical Properties of High-strength Lightweight Concrete"**, ACI Journal, Proceedings V. 83, No. 4, July-August 1986, pp. 606-613.

[2] Mays, G. C., and Barner, R. A., **"The Performance of Lightweight Aggregate Concrete Structures in Service"**, The Structural Engineer, Vol. 69, No 20, 15 October 1991, pp. 351-360.

[3] ACI 213R-03, **"Guide for Structural Lightweight-Aggregate Concrete"** American Concrete Institute, 2003, pp.1-37.

[4] Al-Dhaher, B. A. A., **"The Use of Local Porcelinite for the Production of Lightweight Concrete Units"**, M.Sc. Thesis, University of Technology, Baghdad, 2001, pp. 113.

[5] Al-Ani, M. K. M., **"Corrosion of Steel Reinforcement in Structural High Performance Lightweight Concrete"**, M.Sc. Thesis, University of Technology, 2002, pp. 104.

[6] Al-Kadhi, A. G. T., **"Engineering Properties of High Performance Fiber Reinforced Porcelinite Lightweight Aggregate Concrete for Structural Purposes"**, M.Sc. Thesis, University of Technology, Baghdad, 2002, pp. 139.

[7] Hadhrati, H, F., **"Mechanical Properties of Self-Compacting High Performance Structural Lightweight Aggregate Concrete"** M.Sc. Thesis, University of Technology, Baghdad, 2006, pp. 119.

[8] Al-Jabboory, W. M., **"Mining Geology of the Porcelinite Deposits in Wadi AL_Jandali-Western Desert, Iraq",** M.Sc. Thesis, University of Baghdad, 1999, pp. 100.

[9] Al-Barsom, M. M., **"Observed and Predicted Geotechnical Features of the Soil at Garmat Ali",** MSc. Thesis, University of Baghdad, 1979, pp. 170.

[10] Hatab, T. N., Kachachy, G**.A.,** Taiseer, S., **"A Study of the Engineering Soil Characteristics of Baghdad Area",** National Center for Construction Laboratories., Report , No.39, Baghdad, Iraq, 1986, pp 82.

[11] CEB / FIP Manual of Lightweight Aggregate Concrete, 2nd Edition, Surrey University Press, London, 1983, pp. 259. (Cited by Al-Musawi, J. M. S., **"Flexural Behavior of Porcelinite Reinforced Concrete Beams",** Ph.D. Thesis, University of Technology, Baghdad, 2004, pp. 181.

[12] المواصفة القياسية العراقية رقم 45 لسنة 1984 "ركام المصادر الطبيعية المستعمل في الخرسـانة والبنـاء" الجهـاز المركـزي للتقيـيس والسيطرة النوعية، بغداد ، 4 صفحات .

[13] BS 882, 1992**, "Specification for Aggregate from Natural Sources for Concrete",** British Standards Institution, London, pp. 98.

[14] ASTM C330-03, **"Standard Specification for Lightweight Aggregates for Structural Concrete"** Annual Book of ASTM Standards, Vol.04-02, 2003, pp.1-4.

[15] Taylor. W. H., **"Concrete Technology and Practice"**, McGraw-Hill Book Company, 4th Edition, 1977.

[16] Degussa Construction Chemical, **"Handbook Technical Data Sheets"**, 2004, pp. 74-75.

[17] ASTM A615/615M-05a, **"Standard Specification for Deformed and Plain Carbon**

Structural Steel Bars for Concrete Reinforcement", Anual Book of ASTM Standards, Vol.01.02, 2005.

[18] Shuber, M, S,. **"Behavior of porcelinite Concrete Short Columns Under Concentric Loads",** Ph.D. Thesis, University of Technology, Baghdad, 2007, pp. 160.

[19] ASTM C127-01, **"Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate",** Manual Book of ASTM Standards, Vol. 04.02, 2001, pp.1-6.

[20] ASTM C29/C29M-97 (Reapproved 2003), **"Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate",** Anual Book of ASTM Standards, Vol. 04.02, 2003, pp.1-4.

[21] BS 812, Part 110, 1990, **"Method for Determination of Aggregate Crushing Value (ACV)",** British Standards Institution, London, pp 8.

[22] BS 3797, Part 2, 1981, **"Specification for Lightweight Aggregate for Concrete",** British Standards Institution, London, pp 2.

[23] ASTM C 641-98, **"Standard Test Method for Iron Staining Materials in Lightweight Concrete Aggregates",** Anual Book of ASTM Standards, Vol.04.02, 1998, pp. 1-4.

Table (1) Details of Concrete Mixes

Mix symbol	Cement content kg/m^3	SP1 (%) by wt. of cement	w/c (to give slump 100±25)	Water reduction (%)
C_1 (without SP1)	550	0	0.43	0
C_2 (with SP1)	550	4	0.35	18.6

Table (2) Chemical And Physical Properties of Porcelinite Lightweight Aggregate+

Property	Specification	Result
Specific gravity	AS TM C 127-01 (19)	1.65
Absorption, %	ASTM C 127-01 (19)	35
Dry loose unit weight, kg/m^3	ASTM C 29- 97 (20)	772*
Dry rodded unit weight, kg/m^3	ASTM C 29-97(20)	830
Aggregate crushing value, %	BS 812- part 110- 1990 (21)	16
Sulphate content (as SO_3), %	BS 3797-part 2 – 1981(22)	0.34**
Staining materials *** :		
Stain intensity	ASTM C 641-98(23)	No stain
Stain index		0

* Within the limit of ASTM C330 (880kg/m3) and BS 3797:part 2(960 kg/m3).

** Within the limit of BS 3797part 2(1.0%).

*** Staining material test was done in the Building and Glass Research Center.

+ Tests were carried out by the SCGSM.

Table (3) Longitudinal And Lateral Reinforcement Properties

Bar size (mm)	Area (mm^2)	Yield stress (MPa)	Tensile strength (MPa)	Grade of Steel	Elongation (%)
9.5	71.25	423	586	60	18.18
12.7	126.67	452	573	60	21.14
15.9	197.93	492	660	60	16.98

Table (4) Experimental Ultimate Load For All Tested Columns

Specimens	P_u (kN)
Column $A_1B_1C_1$	942
Column $A_1B_2C_1$	942
Column $A_1B_3C_1$	1065
Column $A_2B_1C_1$	845
Column $A_3B_1C_1$	1280
Column $A_1B_1C_2$	1220
Column $A_1B_2C_2$	1220
Column $A_1B_3C_2$	1370
Column $A_2B_1C_2$	1120
Column $A_3B_1C_2$	1580

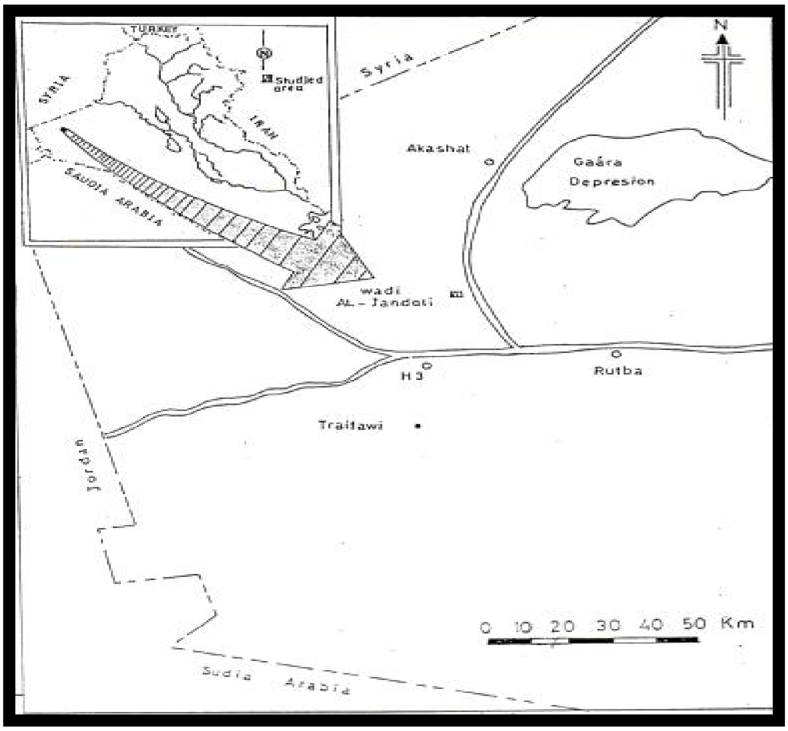

Figure (1) Map of Porcelinite Stone Location(8)

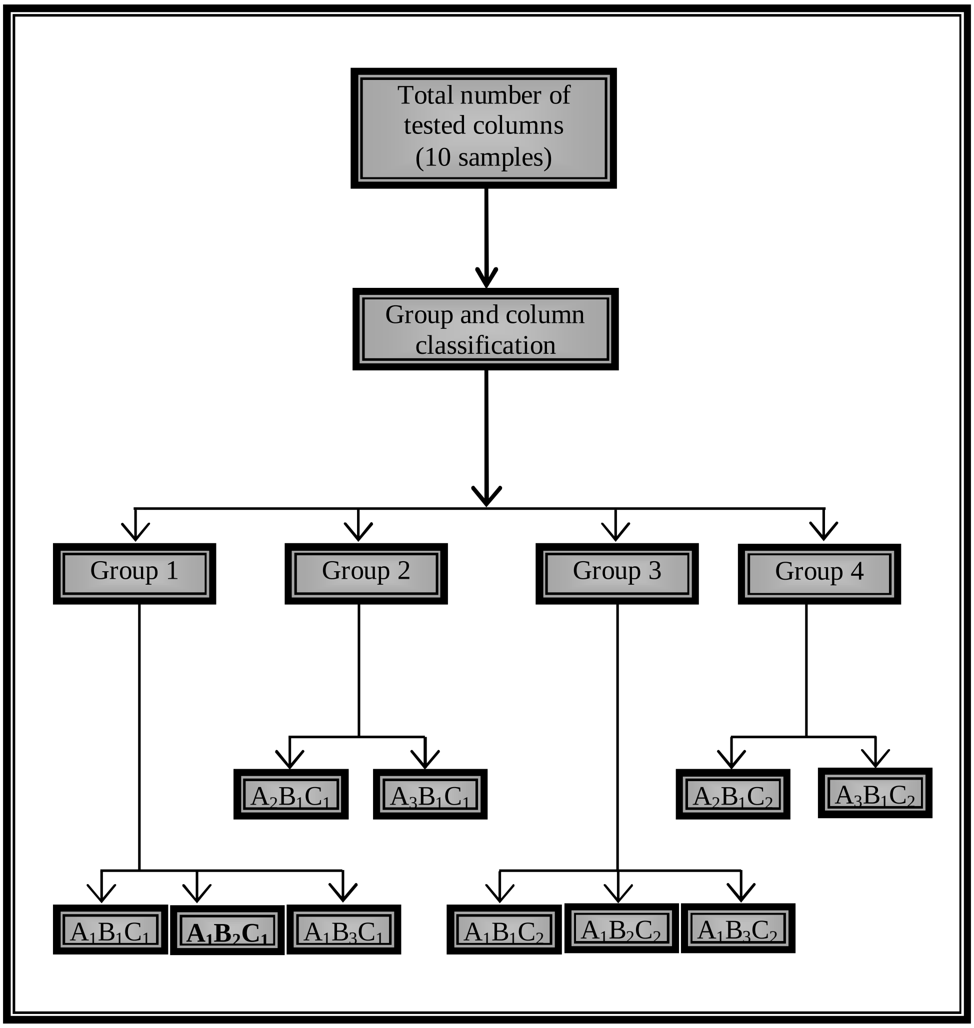

Figure (2) Classification Chart of Column Groups

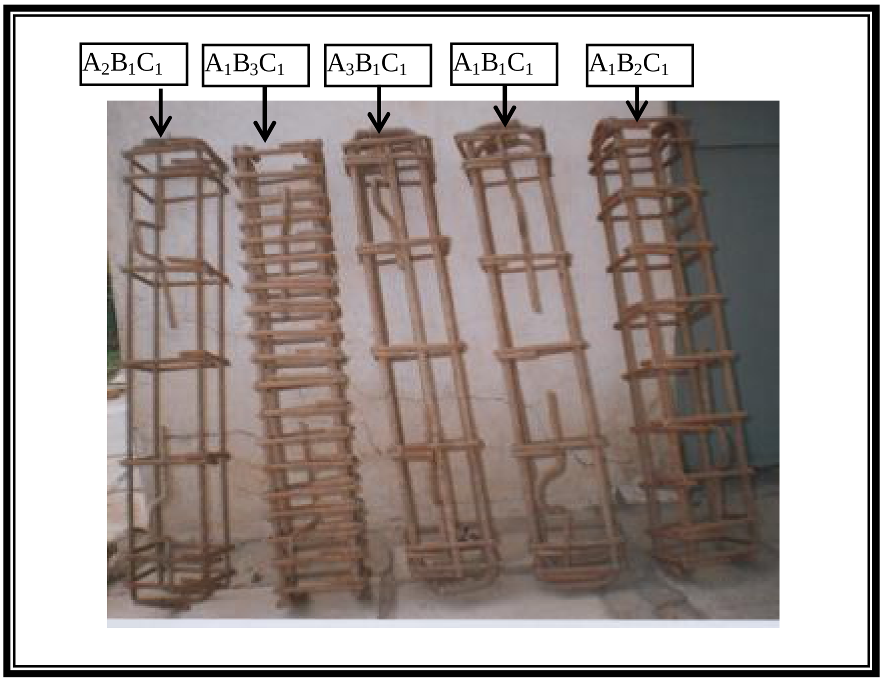

Figure (3) Column Reinforcement Cages

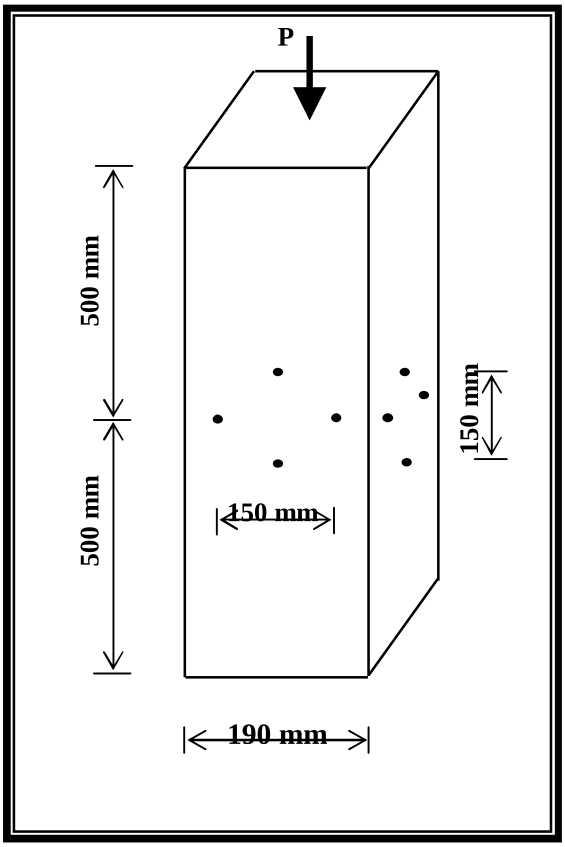

Figure (4) Distribution of Demec Points on Column Specimens

Figure (5) Failure Mode of Column $A_1B_1C_1$

Figure (6) Failure Mode of Column $A_1B_1C_2$

Figure (7) Failure Mode of Column $A_1B_2C_1$

Figure (8) Failure Mode of Column $A_1B_2C_2$

Figure (9) Failure Mode of Column $A_3B_1C_1$

Figure (10) Failure Mode of Column $A_3B_1C_2$

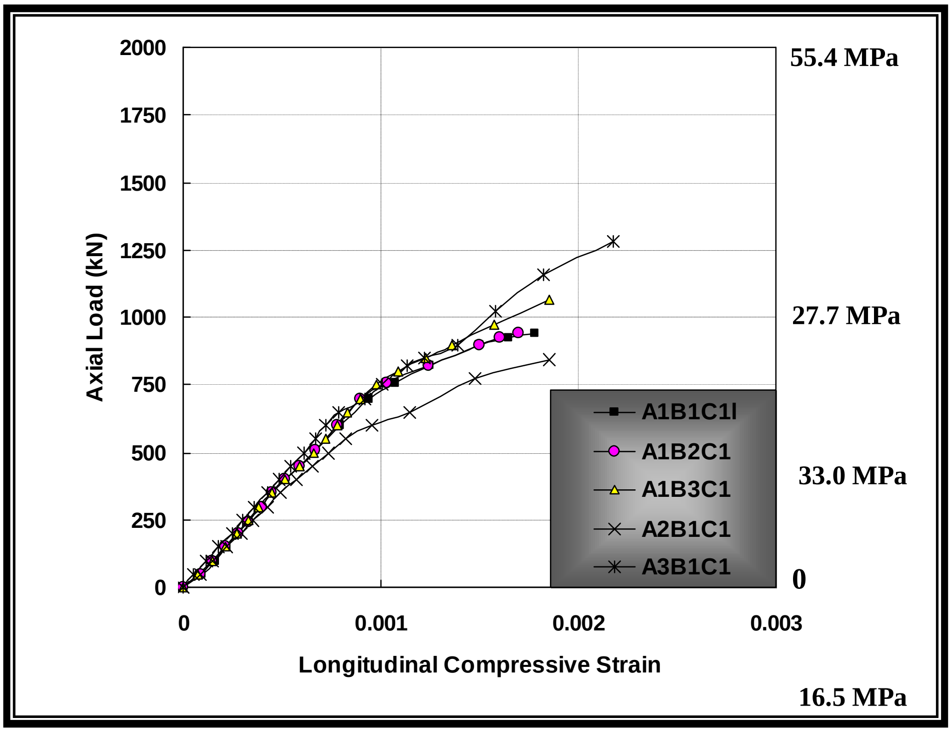

Figure (11) Load – Longitudinal Compressive Strain Curves for Column Without Superplasticizer

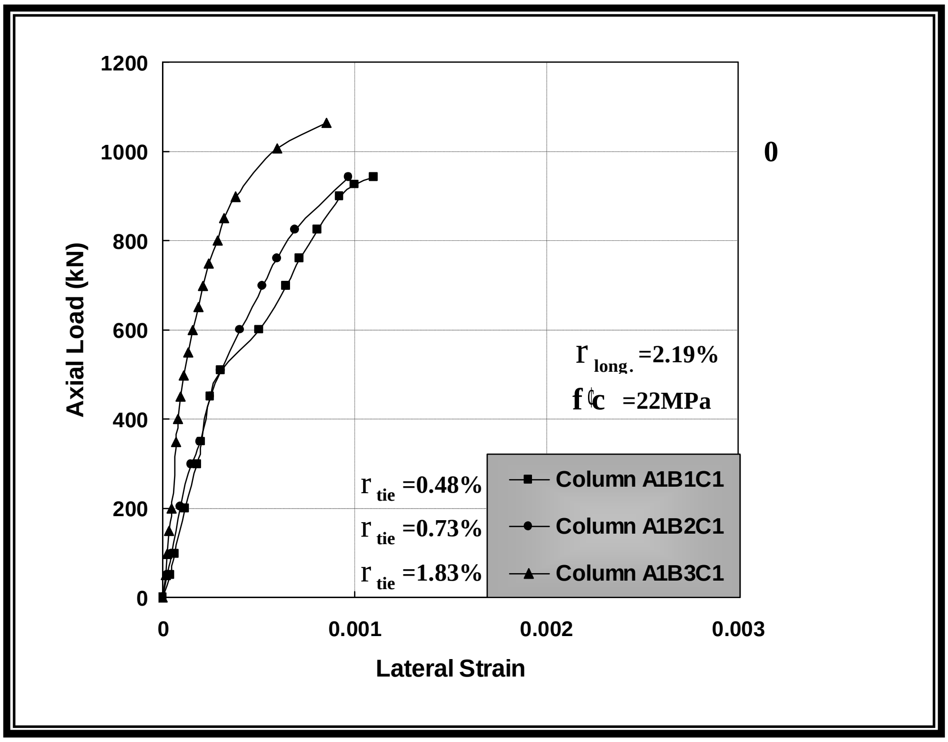

Figure (13) Effect of Transverse Steel Ratio on Load–Lateral Strain Curves of Columns $A_1B_1C_1$, $A_1B_2C_1$ and $A_1B_3C_1$