BEARING CAPACITY OF STEEL FIBROUS CONCRETE

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ABSTRACT

This study was carried out to determine the influence of the randomly oriented discrete steel fibres on the bearing capacity of plain concrete through testing concentrically loaded 150mm square prisms. The concrete strength, ratio of total area to loaded area, height of prisms, dimensions and fibre percentage were varied throughout the investigation.

It was found that the bearing capacity increases with the concrete strength and the ratio of the total to loaded area both for the plain and for the fibrous concrete.

It was also found that the bearing capacity of steel fibrous concrete was significantly higher than that of unreinforced concrete, and showed ductile mode of failure and retained their integrity also at failure. It was also found that the bearing capacity of fibrous concrete increases with the aspect ratio of the used fibres.

Prediction of the bearing capacity both for the plain and fibrous concrete using the limit theorems of perfect plasticity showed fair agreement with the experimental results.

KEYWORDS: Bearing capacity, concrete, limit theorem, plasticity, steel fibres.

مقاومة الإرتكاز للخرسانة الليفية الفولاذية

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الخلاصة

أعدت هذه الدراسة لمعرفة تأثير الألياف الفولاذية القصيرة المتقطعة الموزعة عشوائيا على مقاومة الارتكاز للخرسانة العادية وذلك من خلال فحص نماذج موشورية (150×150 ملم) محملة مركزيا. مقاومة الخرسانة، نسبة المساحة الكلية إلى المساحة المحملة، ارتفاع الموشور، وأبعاد ونسبة الألياف الحجمية تغيرت ضمن البرنامج العملي.

أثبتت الدراسة أن مقاومة الارتكاز تزداد بزيادة مقاومة الخرسانة ونسبة المساحة الكلية إلى المساحة المحملة للخرسانة العادية والخرسانة الفولاذية. كما أثبتت الدراسة أن مقاومة الارتكاز للخرسانة الليفية الفولاذية أكثر من الخرسانة العادية كما أظهرت نمط من الفشل المطيلي وحافظت على تكاملها عند الفشل. كما وجد أن مقاومة الارتكاز للخرسانة الليفية تزداد بزيادة النسبة الباعية للألياف.

التنبؤ بمقاومة الارتكاز للخرسانة العادية والليفية باستعمال النظرية الحدية لللدونة التامة أظهرت توافقا جيدا مع النتائج العملية.

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NOTATION

B	width of specimen
D	diameter (width) of specimen
fcf	cylinder compressive strength of fibrous concrete
ftf	tensile strength of fibrous concrete
H	height of specimen
K	constant depending on concrete characteristics
q	bearing capacity
R	total area / loadedc area (effective unloaded area / loaded area; Eq.(2))
W	diameter of specimen
φ	angle of internal friction

INTRODUCTION

The problem of load concentration on limited area usually facing designers, e.g. in footings supporting columns, end anchorages of prestressed concrete members, deep beams supporting columns, etc. Such zones are subjected to complicated stresses due to the stress concentration and the boundary conditions. Failure in such cases is controlled by many parameters such as the tensile strength of concrete, geometry of the specimen and the ratio of the total area to the loaded area.

Kriz and Raths [1] conducted an extensive study on the bearing capacity of plain and reinforced concrete column heads. The variables studied included the concrete strength, size of the specimen and width of the loaded plate. The following equation was suggested for estimating the bearing capacity:

$$q = 18.3\ \sqrt{fc'}(D/W)^{1/3} \qquad ..(1)$$

where D and W (in mm) are the diameter of the plate and specimen respectively, and f'c is the cylinder compressive strength of concrete (MPa)

Test results were also reported by Hawkins [2, 3] on concrete blocks loaded through rigid and flexible plates. For specimens loaded through, the following expression was developed for the bearing strength:

$$q = fc' + K\sqrt{fc'}(\sqrt{R} - 1) \qquad ..(2)$$

Where R= effective unloaded area / loaded area and K= is a constant depending upon the characteristics of the concrete.

Test results were reported by Hawkins [4] on 39 concrete blocks loaded through rigid plates extending across the full width of the block. Expressions were developed for the bearing capacity and for the length at which the crack on the axis propagates spontaneously.

Hyland and Chen [5] examined the applicability of perfect plasticity to punch loaded cylindrical concrete blocks and the test results were compared with the results of limit analysis solution by Chen and Drucker [6] and showed fair agreement.

Niyogi [7, 8] conducted extensive investigation on the bearing strength of concrete. The variables investigated were the geometry of specimens, the bearing area, mix proportions, strength of concrete, amount and form of reinforcement and nature of the bed. A general expression for the bearing strength of concrete was proposed.

Kotsovos and Newman [9] presented a nonlinear finite-element technique to analyze plain concrete structural forms under concentration of load induced by a wide range of boundary conditions. The predicted behaviour was found to be in close agreement with the experimental values.

Carson and Chen [10] studied the influence of adding steel fibres on the bearing capacity and ductility of concrete through testing 150 mm concrete cylinders. It was found that the bearing capacity was significantly higher than that of unreinforced materials.

Al-Feel [11] reported test results for standard 150 mm diameter concrete cylinders loaded through various diameters (30, 55, 75, and 95 mm) of rigid plates. Two mix proportions (1:1.5:2.5/0.5 and 1:1.8:2.8/0.4), 10 mm maximum aggregate size, and three steel fibre percentages (0.5, 1.0, and 1.5) were used. It has been found that the bearing capacity increases with the fibres volume and with decreasing the diameter of the loaded plate.

This investigation was designed to determine the influence of randomly oriented discrete steel fibres on the bearing capacity of plain concrete through testing 150 mm square prisms and varying the ratio of the total to loaded area. The limit theorem of perfect plasticity was used to predict the bearing capacity of both plain and fibrous concrete.

EXPERIMENTAL PROGRAMME Three mix proportions by weight were used as shown in Table (1). Maximum coarse aggregate was 12.7 mm. River sand and ordinary Portland cement were used. Three fibre percentages by volume (0.4, 0.8, and 1.2) for each mix and two lengths of shelled fibres were used. The fibres lengths were 16 mm and 32 mm with an equivalent aspect ratio of 21.8 and 32 respectively. The cast specimens were 150 mm square prisms with heights of 150 mm, 120 mm, and 90 mm. Water was added after the dry concrete constituents were mixed first. The steel fibres were then added gradually to the mixer. The cast specimens were compacted by table vibration. The specimens were stripped 24 hours after casting and cured in water for 14 days in room temperature which varied from 17-20 °C. After that the specimens were left in the laboratory till their testing at the age of 28 days.

Table (1) Mix Proportions

Mix No.	Cement	Sand	Gravel	W/C Ratio
A	1	1.2	2	0.38
B	1	1.35	2.7	0.43
C	1	1.7	3.5	0.45

The load was applied through 25 mm thick square plate, Fig. (1). Four plate sizes were used; 30, 50, 75 and 100 mm to give a ratio of total area to loaded area (R) of 25, 9, 4 and 2.25 respectively.

RESULTS AND DISCUSSION

Test results for the first group; i.e., specimens with 150 mm height are shown here for brevity.

Figure (2) shows the bearing capacity versus the concrete strength of plain concrete. The fibres in this figure have a length of 16 mm and an equivalent aspect ratio of 21.8. The figure shows that the bearing capacity increases with the concrete strength as demonstrated previously by many researchers experimentally.

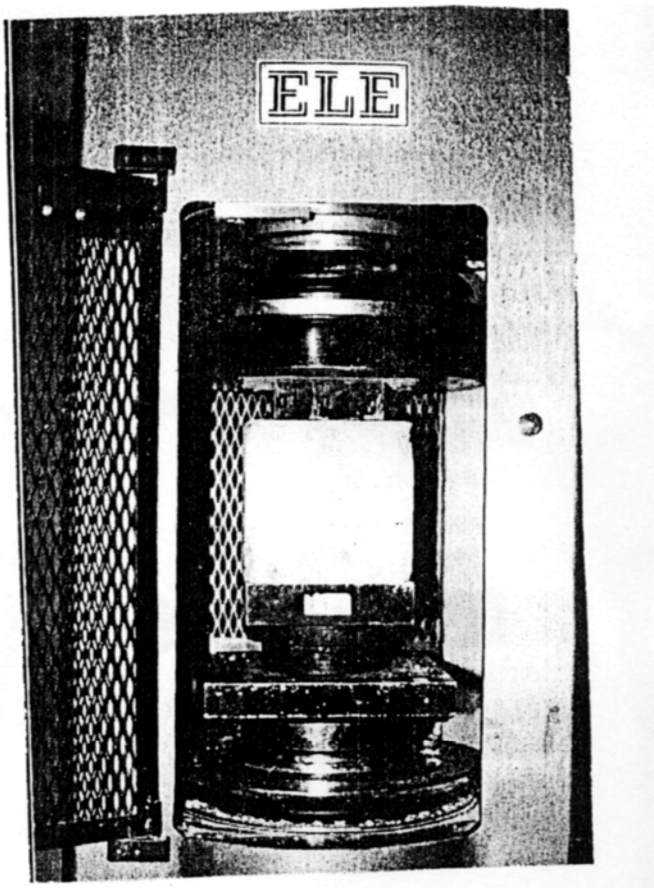
The bearing capacity increases also with the ratio R due to confinement of concrete and the triaxial behaviour exhibited by the concrete under the bearing plate as demonstrated by previous investigators [2-7, 11].

The figure shows also that the bearing capacity increase up to about 40 percent with the fibres percentage due to the increase in the tensile strength and the marginal increase in the compressive strength. The presence of the steel fibres changed the mode of failure of the specimens from a brittle to a ductile one and at failure the fibrous concrete specimens retained their integrity since the steel fibres bridging the failure surfaces act as cracks arrestors or retarders and transfer the stresses from one side of the cracks to the other.

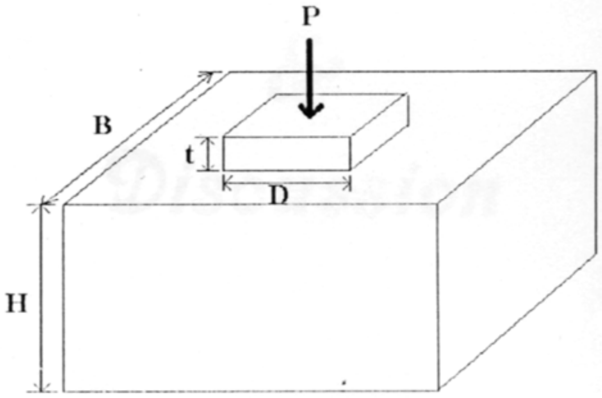
Figure (3) show the same relationships as given figure (2) for fibres 32 mm long and an equivalent aspect ratio of 32. The figure shows that the bearing capacity increases with the aspect ratio and the length of the steel fibres. This is due to the increase in the tensile strength of the concrete and to the higher pinching forces exerted by the fibres on both faces of the cracks when using relatively long fibres. The enhancement in the bearing capacity reaches 55 percent for values of R = 25.

Figure (4) shows some of the failed specimens. The splitting mode of failure is evident for these specimens. The failure is initiated by the inverted square pyramid pushing out the four parts of the specimens outside.

Although concrete is a material of limited deformability, there are indications that the load carrying capacity of blocks subjected to load over part of their surface can be computed on the basis of limit theorem [6, 10] of perfect plasticity. The solution reported by Chen and Drucker [6] for the bearing capacity of square blocks is used to predict the bearing capacity. A Mohr-Coulomb failure surface in compression and small tension is utilized. An upper bound of the average bearing capacity was suggested as follow:

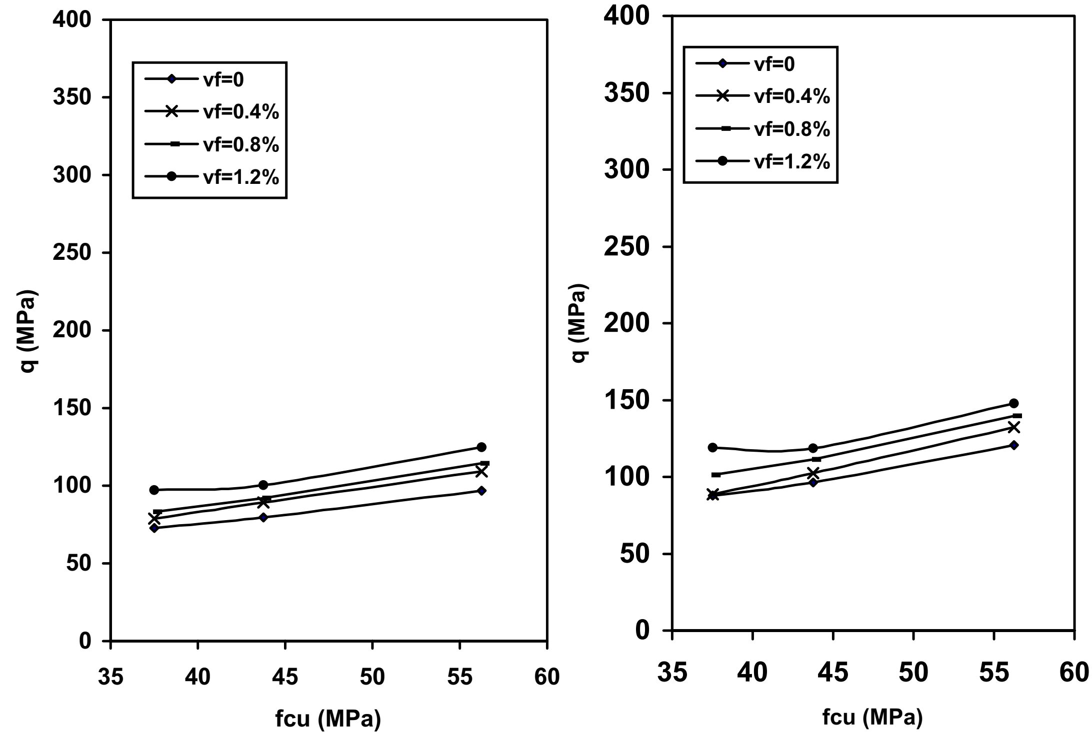


(a) Testing Machine

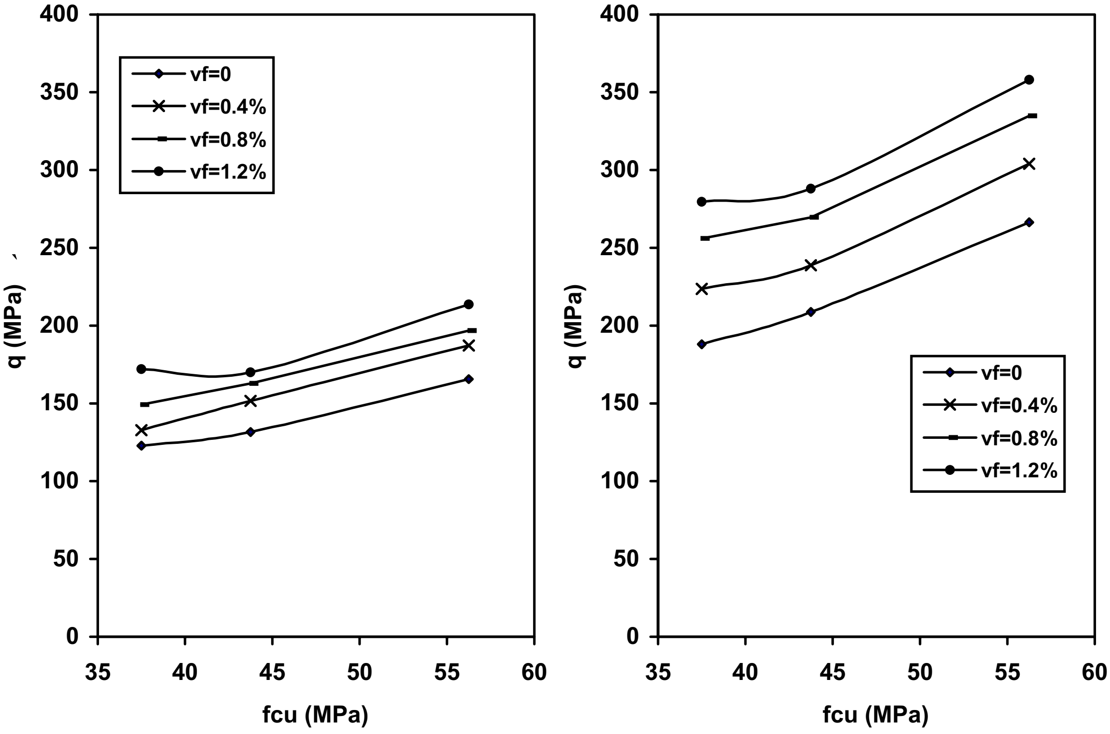


(b) Method of Loading the Specimens.

Figure (1) Method of Testing Specimens, a) Testing Machine, b)Procedure of Loading Specimens.

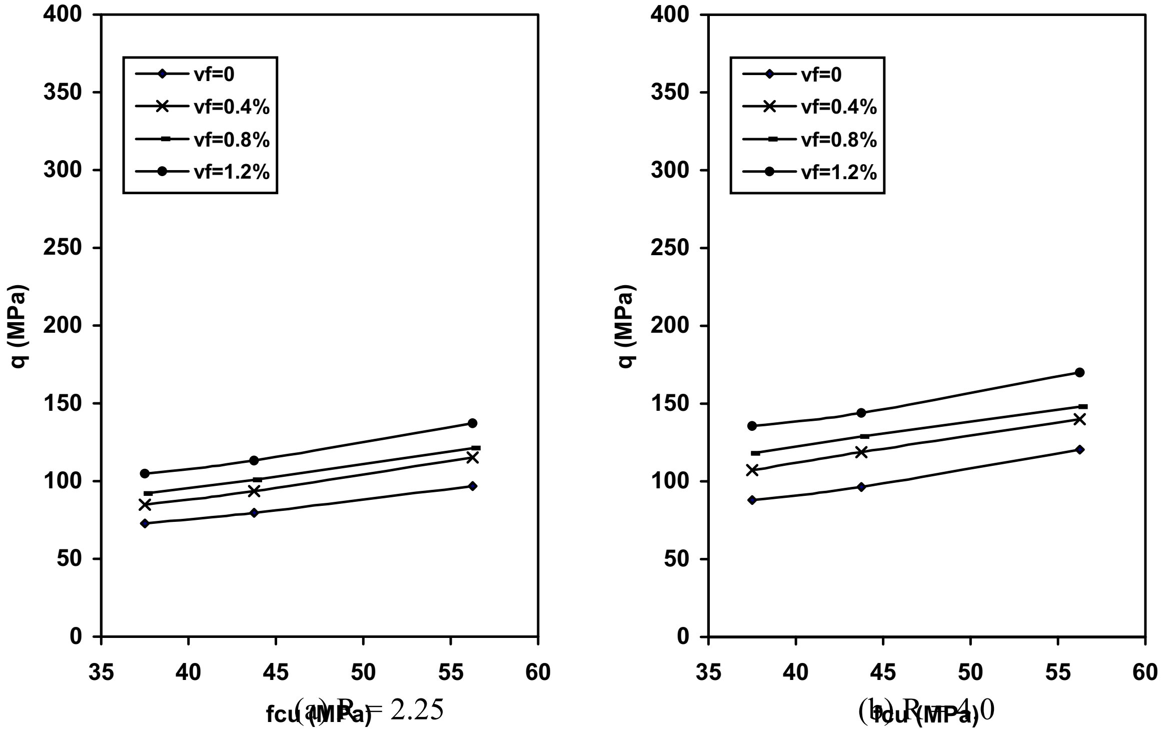


(a) R = 2.25 (b) R = 4.0



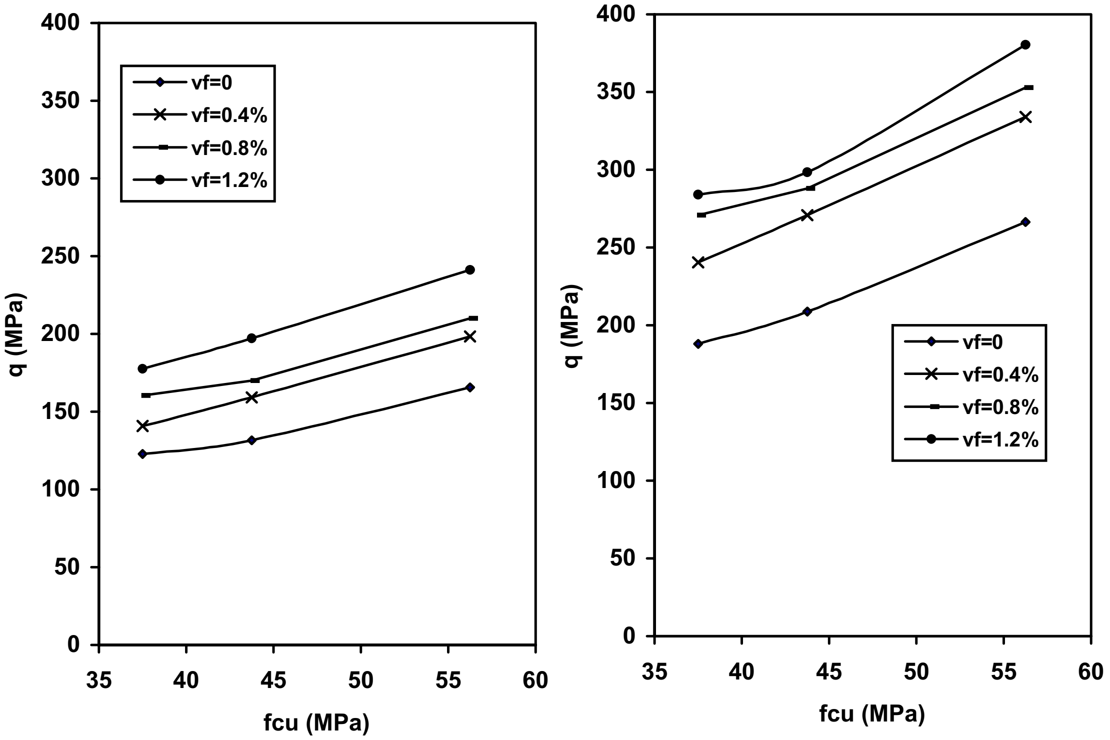
(c) R = 9.0 (d) R = 25.0

Figure (2) Variation of the bearing capacity with compressive strength and fibre volume percentage ($l_f/d_f = 21.8$).



(a) R = 2.25

(b) R = 4.0



(c) R = 9.0

(d) R = 25.0

Figure (3) Variation of the bearing capacity with compressive strength and fibre volume percentage ($l_f/d_f = 32$).

$$q = \frac{1-\sin\phi}{\sin\alpha\cos(\alpha+\phi)}\frac{f_{cf}}{2} + \tan(\alpha+\phi)\left(\frac{4B.H}{D^2} - \cot\alpha\right) f_{tf} \qquad \ldots.(3)$$

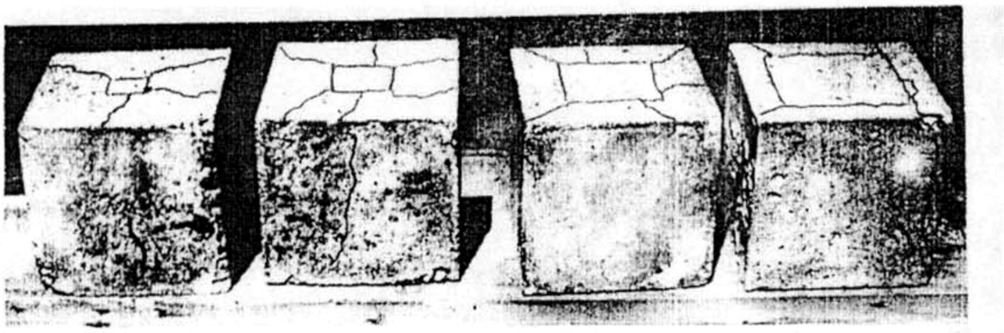
where $$\alpha = \cot^{-1}\left\{\tan\phi + \sec\phi\left[1 + \frac{4BH\cos\phi/D^2}{\frac{f_{cf}}{f_{tf}}\left(\frac{1-\sin\phi}{2}\right) - \sin\phi}\right]\right\} \qquad \ldots.(4)$$

ϕ is the angle of internal friction and assumed equal to 20 ° as used by many researchers [6, 10], B is the width of specimen, H = is the height of specimen, D is the width of the loaded square area, and ftf and fcf is the tensile and compressive strength of fibrous concrete respectively.

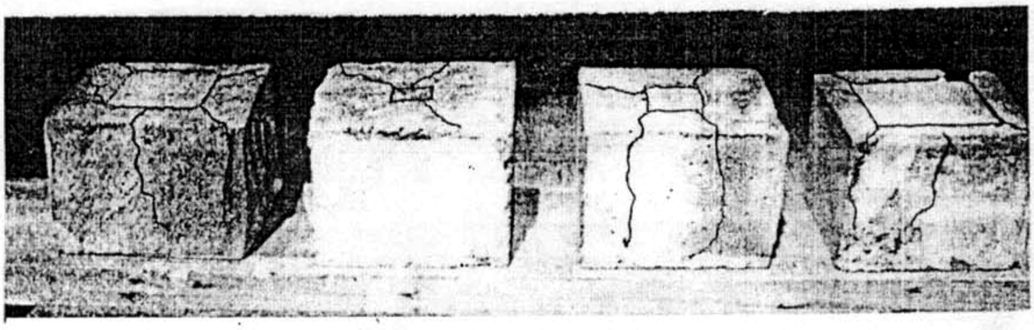
The results using the limit theorem are shown in Figures (5, 6) for fibres with aspect ratio of 21.8 and 32 respectively. A fair agreement can be noticed from these figures (for R values less than or equal to 10) except those with R = 25. The same difference in results was reported by Chen and Carson [10] for higher values of R.

CONCLUSIONS

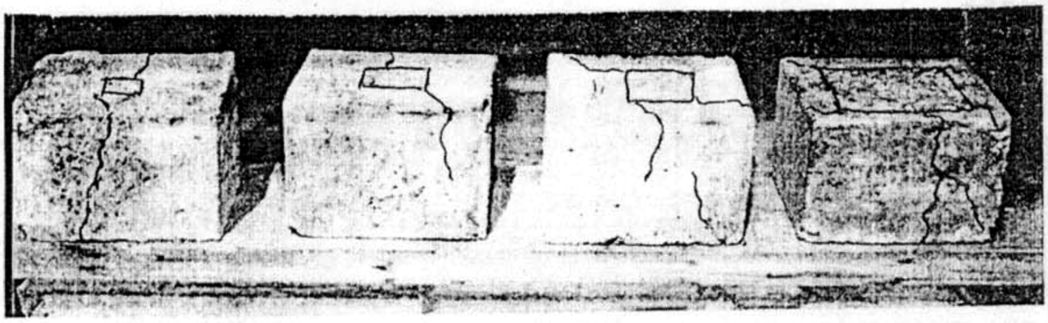
The bearing capacity of concrete increases with the concrete strength, volume percentage, and aspect ratio of the fibres. For the types of fibres used in this investigation, the bearing capacity increases 10-20 percent for specimens with aspect ratio = 32 over those with aspect ratio = 21.8. The bearing capacity increased also with the ratio of the total area to the loaded area. The mode of failure changed due to the presence of fibres from brittle one to a ductile one and the specimens retained their integrity at failure. The limit theorem of perfect plasticity can be used to predict the bearing capacity of both plain and fibrous concrete for moderate values of R (less than or equal to 10).



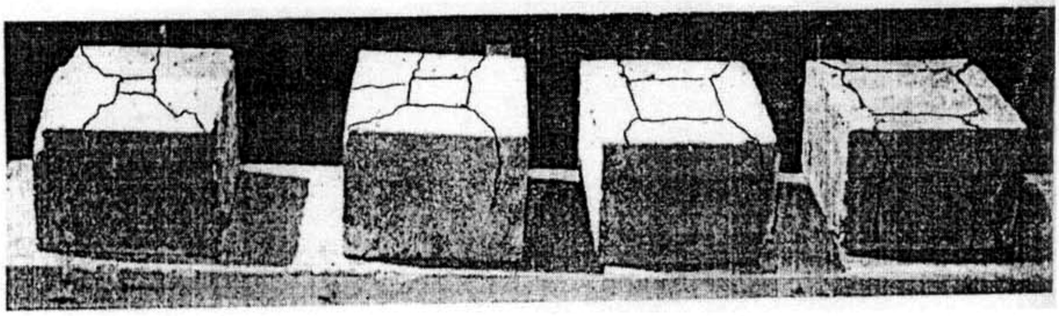
(a) Specimens 150 mm high, mix A, $v_f = 0.4\%$ and $l_f/d_f = 32$



(b) Specimens 120 mm high, mix B, $v_f = 0\%$



(c) Specimens 120 mm high, mix B, $v_f = 0.8\%$ and $l_f/d_f = 21.8$



(d) Specimens 90 mm high, mix C, $v_f = 1.2\%$ and $l_f/d_f = 21.8$

Figure (4) Typical examples of failed specimens.

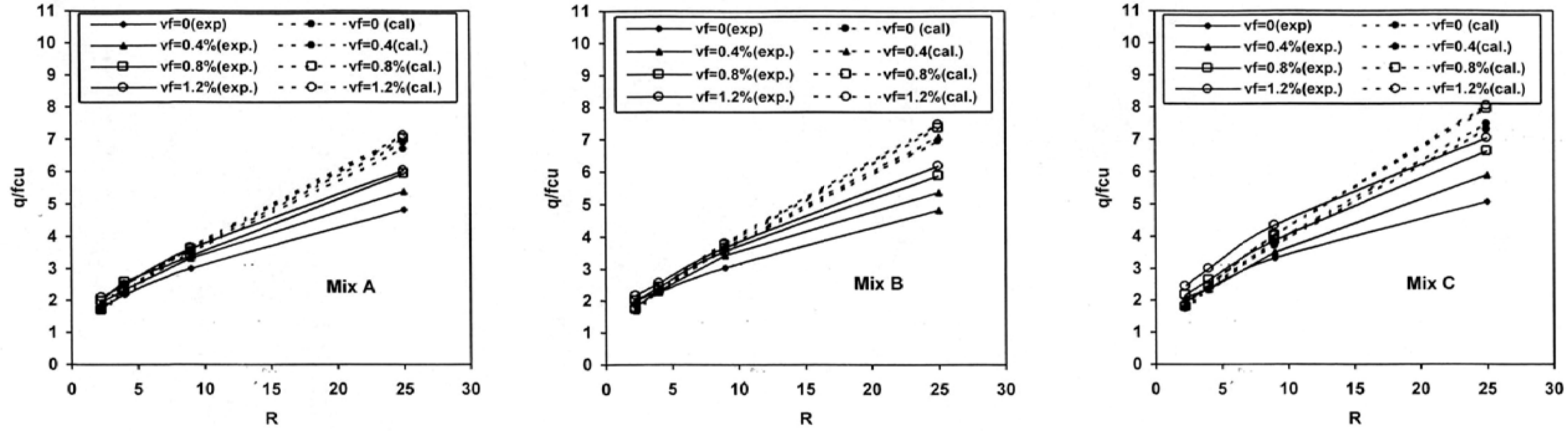


Figure (5) Comparison between the calculated and the experimental results ($l_f/d_f = 21.8$).

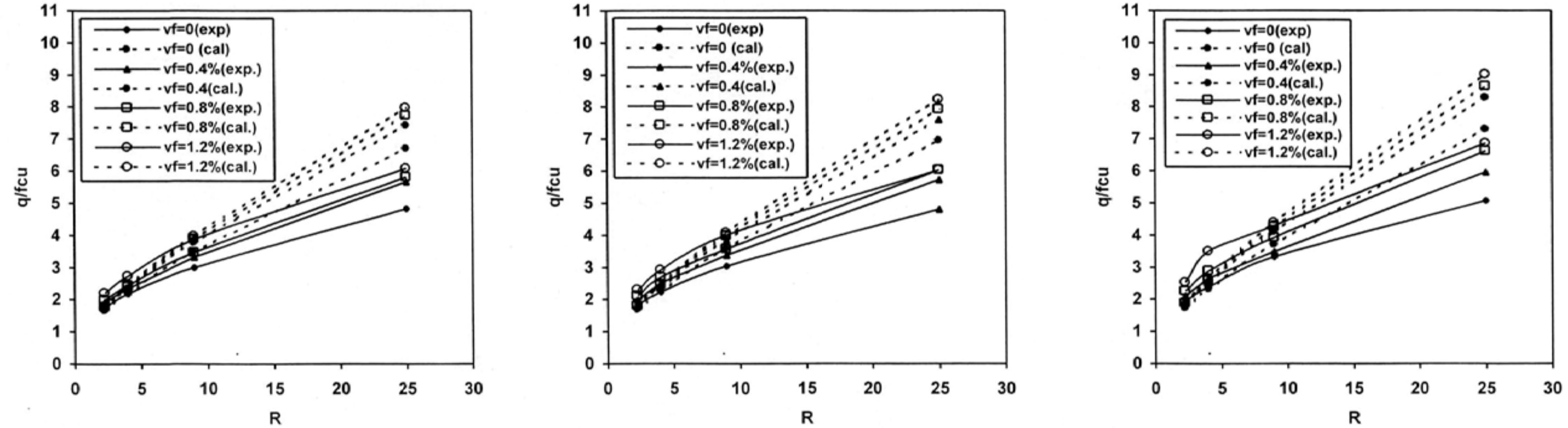


Figure (6) Comparison between the calculated and the experimental results ($l_f/d_f = 32$).

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