STRENGTH OF CONCRETE COLUMN CONFINED BY PLASTIC PIPE (FYC).

BY

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A thesis submitted to the postgraduate School, Ahmadu Bello University, Zaria in partial fulfilment of requirements for the degree of Master of Science in Civil Engineering (Structures).

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THESIS DECLARATION

I hereby declare that this thesis has been entirely composed by me and that it is a record of my research work. It has not been accepted in any previous publication for the award of higher degree.

Where quotations are made from previous publications, they are distinguished by quotation marks and the sources of information are specifically acknowledged by means of reference.

Maiturare

Maiturare, Faruk Doda

August, 1990

CERTIFICATION

We hereby recommend that this thesis, prepared under our supervision by Maiturare, Faruk Doda entitled "The strength of Concrete Column confined by plastic pipe, (PVC). be accepted as partial fulfilment of the requirements for the award of Master of Science degree in Civil Engineering (Structures) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to late Alhaji Labbo Dogon Daji and my family.

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ABSTRACT

This experimental investigation was carried out to determine the strength of concrete confined by plastic pipe and the effect of slenderness ratio on the strength.

Pipes of 75mm and 100mm diameters of varied lengths: 410mm to 1210mm were used. Two different concrete mixes were tested: a 1.5 sand-cement ratio and 3 coase aggregate cement ratio. The second had a 1.0 sand - cement ratio , and 2.0 coarse aggregate cement ratio. The samples were made into three series and one group was reinforced with 6mm diameter bars. All tests were carried out in uniaxial compression under monotonic loading.

Results showed appreciable increase in concrete strength when confined by the plastic pipe. Increase in strength of about 2 times the strength of unconfined concrete was recorded. The reinforcement bars were of no significance in terms of strength increase particularly in the case of short columns. By slender columns slight increases were recorded.

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SYMBOLS AND NOTATIONS.

a = radius of concrete core and inner radius of plastic pipe;

b = Outer radius of plastic pipe;

D = average pipe diameter;

E = Modulus of Elasticity;

F = Ultimate Strength;

f'_c = Ultimate Strength of unconfined concrete core;

f_{max} = Ultimate strength of confined concrete core;

P_o = effective radial pressure between concrete core and plastic pipe;

P_b = Pipe burst pressure;

t = Pipe wall thickness;

α = ratio of increase in core strength to pipe burst pressure;

ϵ = normal strains;

μ = Poisson's ratio;

σ_z = applied stress on concrete core;

σ = normal stresses.

A_{cc}; Ab = Gross Area of confined concrete core.

A_s; A_{sb} = Area of cross-section of Binders.(Ties)

A_{sp} = Area of cross section of spiral steel.

d_s = diameter of spiral.

f_y = Yield stress of steel

d_s = diameter of spiral.

F_1 = Lateral pressure on Concrete.

f_{sh} = Stress in the hoop

S = Spacing of Binders.

P_{plain} = Untimate load on plain concrete specimens.

P_{max} = Ultimate load on specimens

Bs = British standard

PVC = Polyvinyl chloride

ABS = acry lonitrile butadiene styrene

ACI = American concrete Institute

ASCE = American Society of Civil Engineers.

in = Inch

^{o}C = degree celsius

Hcl = Hydrogen chloride

kgf/cm^2 = kilogramme force per square centimeter.

Kgf/cm^2

CHAPTER ONE

1.1 INTRODUCTION

The output of polymer based structural materials is growing at an increasing rate and their range is expanding rapidly. In 1970 the volume of plastic materials produced amounted to about thirty percent of the total volume of world metal consumption, and was about six times greater than the total volume production of all non-ferrous metals.

There are many areas of application in which the selection of a metal or alloy is the only feasible solution to a design requirement, but then there are also many instances where plastic materials have replaced the use of metals, and in many instances a plastic material can provide a better solution than a metallic material even though metals may have been used in the particular situation for many years.

The great increase in the use of plastics is due to their many useful properties coupled with comparatively low cost, which more than offset their disadvantages. Engineering and economical grounds for using plastics in construction is of particular significance in this respect.

This work sought to examine the structural behaviour of commercially available polyvinyl chloride (PVC) pipes filled with a concrete core. Work on this structural concept was undertaken by Carl E. Kurt (1978). In his paper it was shown that there is:

1. An increase in strength of a short concrete core surrounded by acrylonitrile butadiene styrene (ABS) and PVC pipes.

2. Influence of the slenderness ratio on the ultimate strength of the composite column.

1.1 Objectives

The use of confining reinforcement in reinforced concrete building elements particularly in earthquake resistance structures is based on the conditions that confinement increases compressive strength and the capacity of concrete to sustain large deformations without substantial strength loss as observed by Roy and Sozen (1964), Iyengar et. al (1970), Sheikh and Uzumeri (1980). The mechanism of confinement by ties and spirals is well understood. The deficiences of these two forms are the non uniform and ineffective confinement of the core due to arching effect between wires Iyengar et. al. (1970). At higher strains, the concrete cover begins to spall and this reduces the area of the concrete thus leading to failure.

Plastic encasement seems to be able to overcome these deficiencies. Since informations on this promising form of confinment appears to be scanty, it is considered necessary to carry out investigations into this structural concept. It is hoped that these investigations would provide a basis for further research.

1.2 Scope and Limitations

The strength of concrete confined by plastic pipe was investigated. Several columns were tested under an axial compressive loading. Unconfined concrete columns were also tested along with the confined ones.

Influence of two concrete design strengths and the effects of longitudinal reinforcement was investigated. Both slender and short columns were considered in the investigations.

Long term environmental and loading effects on the plastic materials are not considered. Fire protection is another area that need evaluation but it is not considered here. Only that the columns could be painted with any intumescent paints.

CHAPTER TWO

LITERATURE REVIEW

As early as 1928, Richart et. al. demonstrated that the presence of a uniform lateral pressure increased the uniaxial strength of a short concrete specimen. This strength increase was found to be approximately 4.1 times the least lateral pressure. Similar findings have been reported by others and interaction diagrams for biaxial and triaxial states of stress have been developed on the basis of laboratory experimentation.

The spiral steel reinforcement in a circular column exerts a lateral pressure in the inner concrete core under axial compression. In fact, the concrete code ACI 31 (2) requirements for spiral steel assume that when the concrete cover spalls, the spiral steel yields and exerts a radial pressure on the concrete core. This phenomenon increases the compressive strength of the core by approximately the value reported by Richart et. al.

2.1 Concrete filled Structural Plastic Columns

In the work published by Carl E. Kurt (1978), interaction between the concrete core and plastic pipe (ABS, PVC) was suggested and it sought to find how the plastic pipe with its relatively low modulus of elasticity provided sufficient radial support to increase the uniaxial strength of the concrete core. In the above write up an increase in strength of a short concrete core surrounded by an ABS or PVC plastic pipe; and the influence of the slenderness ratio on the ultimate strength of the composite column were evaluated.

The elastic behaviour of this structural concept was derived from the theory of plane stress and plane strain elasticity. The structural models are shown in Fig. 1. Since plastic pipe is available in many diameter to thickness ratios and some of these are quite low, a thick cylinder analysis is presented. The results are reduced for the case of relatively thin plastic pipes.

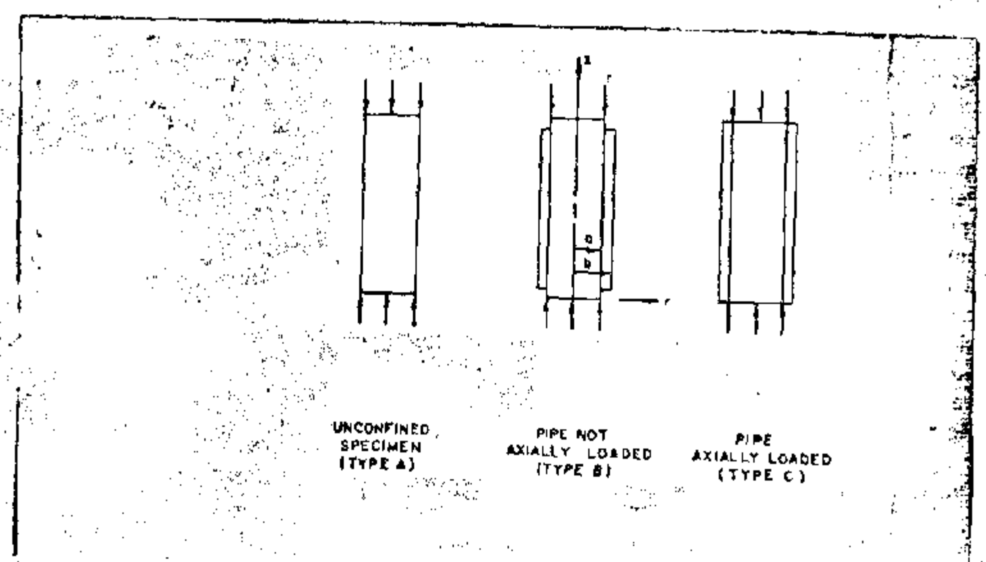


FIG. 2.1 Specimen Types

Source: Journal of the Structural Division. January 1978 (Carl E. Kurt)

For the Type B specimen, the strain-stress relationships for the concrete and plastic pipe are as follows. For concrete:

$$\left.\begin{aligned} \epsilon_z &= \frac{1}{E_c}\left[\sigma_z - \mu_c(\sigma_r + \sigma_\theta)\right]; \\ \epsilon_r &= \frac{1}{E_c}\left(\sigma_r - \mu_c(\sigma_\theta + \sigma_z)\right) \\ \epsilon_\theta &= \frac{1}{E_c}\left(\sigma_\theta - \mu_c(\sigma_r + \sigma_z)\right) \end{aligned}\right\} \quad \ldots \quad (1)$$

and for plastic pipe:

$$\begin{aligned} \epsilon_r &= \frac{1}{E_p}(\sigma_r - \mu_p\sigma_\theta); \\ \epsilon_\theta &= \frac{1}{E_p}(\sigma_\theta - \mu_p\sigma_r) \end{aligned} \quad \ldots \quad \ldots \quad (2)$$

in which σ_z = applied axial stress on concrete core (tension positive);

E_c, E_p = modulus of elasticity for concrete and pipe,

and μ_c, μ_p - Poisson's ratio for concrete and pipe

ϵ_z = axial strain on concrete core

ϵ_r = radial strain and ϵ_θ = tangential strain

As the concrete is loaded axially, an effective compressive pressure is generated on the boundary between the core and pipe due to the Poisson effect. Thus, the boundary conditions for the concrete core becomes:

(1) At the core centre the radial and tangential stresses are finite;

(2) at the outer edge, they are equal to the effective pressure, P_o. For the plastic pipe, the radial stress is equal to the effective pressure, P_o, on the inner surface and zero on the outer edge. From these boundary conditions, it can be shown that the stresses in the concrete core and pipe are, for concrete:

$$\sigma_r = \sigma_\theta = -P_o; \ \sigma_z = \text{applied axial stress on concrete core.} \quad \ldots \ldots \quad (3)$$

and for plastic pipe:

$$\sigma_r = -\frac{a^2 b^2}{b^2 - a^2} \frac{P_o}{r^2} + \frac{P_o a^2}{b^2 - a^2};$$

$$\sigma_\theta = \frac{a^2 b^2}{b^2 - a^2} \frac{P_o}{r^2} + \frac{P_o a^2}{b^2 - a^2} \quad \ldots \ldots \quad (4)$$

in which a, b are inner and outer radii of plastic pipe respectively and r is a value between a and b.

When these stresses are substituted into the corresponding strain-stress relationships and the resulting strains integrated into the strain-displacement equations, the radial displacements of the concrete core and plastic pipe are found.

Since the radial displacements at the interface (r =a) of the concrete and pipe are equal, the relationship between the applied core stress and effective pressure becomes:

$$P_o = - \frac{\mu_c \sigma_z}{1 - \mu_c + \frac{E_c}{E_p} \frac{b^2 + a^2}{b^2 - a^2} + \mu_p} \quad \ldots \quad (5)$$

This expression can be substituted into the stress equations (Eqs 3 and 4) to determine the actual stresses in the concrete core or plastic pipe for any applied stress, σ_z. If the diameter - to - thickness ratio for the plastic pipe is sufficiently large, the pipe will act as a thin ring and Eq. 5 will reduce to:

$$P_o = - \frac{\mu_c \sigma_z}{1 - \mu_c + \frac{E_c}{E_p} \frac{D}{2t}} \quad .. \quad .. \quad (6)$$

in which D = average pipe diameter; and t = pipe thickness.

The corresponding tangential stress equation for the pipe then reduces to

$$\sigma_\theta = \frac{P_o D}{2t} \quad .. \quad .. \quad (7)$$

This analysis indicates that the effective pressure is proportional to the Poisson's ratio of concrete and approximately inversely proportional to the ratio of the modulus of elasticity of concrete and plastic. In the plastic regions, a more complicated analysis would be required. The significance of this analysis is that it demonstrates the interaction between the two materials. That is, as the axial stress of the concrete core is increased the beneficial effective radial pressure will also increase. It is this effective radial pressure that increases the strength of the concrete core.

To determine the effect of the radial pressure on the axial strength of the concrete core, the burst pressure of the pipe was calculated (since the pipe D/t ratio was large in this analysis) for each pipe from:

$$P_b = \frac{2F_p t}{D} \quad \cdots \qquad (8)$$

where P_b = Pipe burst pressure,

F_p = Ultimate strength of plastic,

t = pipe wall thickness,

D = average pipe diameter,

Once the burst pressure, ultimate strength of the unconfined specimen, and the ultimate strength of the confined specimen were known, a constant, α, relating the increase in compressive strength of the concrete core strength to ultimate burst pressure was calculated from:

$$\alpha = \frac{f_{max} - f_c'}{P_b} \quad .. \quad ... \quad (9)$$

in which f_{max} = ultimate strength of confined concrete core; and f_c' = ultimate strength of unconfined concrete core.

For type C specimens, the ultimate load on the concrete core was reduced by the load carried by the pipe at a 0.003-in/in (0.076mm/mm) strain level.

To determine if the plastic pipe improved the compressive strength of the concrete core, a non-dimensional constant, α, which relates the increase in concrete core compressive strength to the burst pressure of the plastic pipe was calculated. This constant was calculated for all short specimens where L/r was less than 11. Values of α ranged from 3.10 to 3.68 for the PVC pipe and for ABS pipes, α values ranged from 2.93 to 3.67, the average of which are 3.29 and 3.25 respectively.

It should be noted that the average value for α is relatively insensitive to pipe material. Based on the theoritical analysis, the effective lateral pressure

P_o, is approximately inversely proportional to ratio of concrete to pipe modulii of elasticity. For these plastic materials, this ratio is approximately the same order of magnitude.

When safety is considered, it is important for any structural system to be capable of carrying a high percentage of its ultimate load when deforming over a high deflection range. To determine the column toughness, a load deflection curve was automatically plotted for each column tested. This curve was nondimensionalized into a load ratio (actual/ultimate load) versus strain curve. Typical load ratio-strain curves for each material and for a high and low slenderness ratio are shown in Fig. 2. For comparism purposes, the load ratio strain curve for the concrete core is also presented.

2.2 Effects of Confinement on Strength and Deformation

2.2.1 Ultimate Compressive Strength

For design it has been found satisfactory to express the axial strength of confined concrete as the unconfined strength plus a constant times the

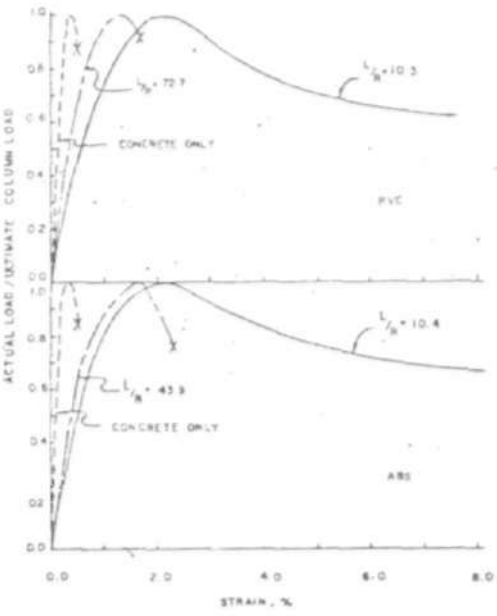


FIG. 2.2 Influence of Slenderness Ratio on Column Strain

Source: Journal of the Structural Division. January 1978 (Carl E. Kurt).

uniform lateral pressure. Tests show that a column reinforced with longitudinal bars alone often fails at a lower load than a column of similar section without reinforcement. This is because, in the average column, the L/K ratio of the reinforcing bars is about 200, consequently they will tend to buckle easily under load.

Also on hardening, the shrinkage sets up tensile stresses in the concrete surrounding the bar, buckling increases the tension followed by spalling off of the concrete. When this happens nothing is left to confine the bar. Area of concrete is reduced due to area of bar and spalled concrete.

Many proposals have been made for the strength of concrete confined by lateral steel. For instance, Norman extended the Blume, Newmark and Coming (BNC) equation to arrive at the capacity of concrete given by

$$P_{max} = f_c \cdot A_b$$

where:
f_c = concrete stress

A_b = confined cross sectional area based on outside dimensions of hoop. Blume et. al. had applied the basic empirical results of Richart et. al. to the case of a passive lateral pressure applied on the concrete by action of hoops $f_c = f'_c + 4.1\sigma_1$

In doing this they idealised as uniform the distribution of lateral pressure due to hoops. For rectangular hoops they proposed:

$$\sigma_1 = 0.5 \left(2 \frac{A_s b}{a.s} f_s b \right)$$

a = longer side of the rectangular hoop

f_{sb} = stress in the hoop

A_{sb} = area of cross-section of binders.

S = pitch of the spiral

The term in the parenthesis is the lateral confining stress while 0.5 was introduced somewhat arbitrarily to take into account the reduced effect of rectangular hoops in confining a concrete core, thus:

$$f_c = 0.85 f'_c + 4.1 \frac{A_{sb} f_{sb}}{a.s} \quad \text{(for closely spaced ties)}$$

now $P_{max} = f_c A_b$

$$P_{max} = 0.85 f'_c A_b + 4.1 \frac{A_b A_{sb} f_{sb}}{a.s}$$

$P_{plain} = 0.85 f'_c A_b$ (according to Richart and Brown, and Hopnestad)

f'_c = cylinder compressive strength.

For circular spirals, assuming that the spirals are sufficiently close to apply a near uniform pressure, the confining pressure may be calculated from the hoop tension developed by the spiral steel.

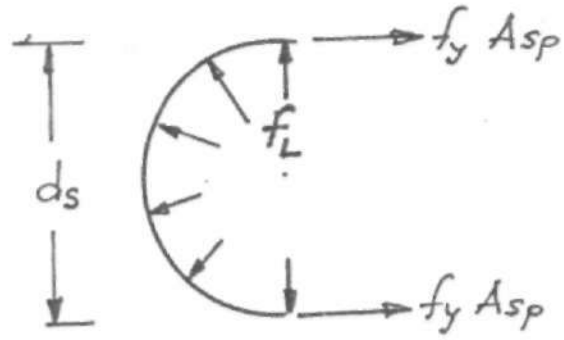


FIG. 2.3 Hoop tension developing by spiral steel

f_L = lateral pressure on concrete and reaches a maximum when the spiral reinforcement reaches yield strength f_y.

d_s = diameter of spiral

A_{sp} = area of spiral bars

S = pitch of the spiral

f_y = yield strength of spiral reinforcement

Considering equilibrium of forces from FIG. 2.3

$$2f_y\ A_{sp} = ds.\ S.\ f_L$$

$$f_L = \frac{2f_y\ A_{sp}}{d_s . S}$$

substituting into the basic equation

$$f_c = f'_c + 4.1 f_L$$

$$f_c = f'_c + \frac{8.2\ f_y\ A_{sp}}{d_s .\ S.}$$

Thus the ultimate load of a spiral column may be written as

$$P_{max} = (0.85\ f'_c + \frac{8.2\ f_y\ A_{sp})}{d_s \cdot S}\ Acc$$

It can be shown that the steel in the spiral is approximately twice as effective as same volume of longitudinal steel in contributing to the strength of column. However the high load carrying capacity of column having heavy spirals is available only at large deformations and after the shell concrete has spalled.

Test by Chan suggested that when considering strength, the efficiency of ties may be 50% of that of the same volume of spiral. Tests by many others have indicated an enhancement of strength due to lateral confinement by closely spaced rectangular ties.

2.2.2 Cracking

Lateral confinement of concrete may lead to strength increase for two reasons:

(i) It delays the development of microcracks and thus the formation of discontinuities, and

(ii) Even after some cracking has occurred, further micro-cracking may be delayed and the strength of an individual element is increased by lateral confinement.

Lateral confinement has no measurable effect on loads less than about 80 - 90% of the unconfined strength of concrete. At this stage of loading the lateral strains begin to increase indicating the occurrance of significant vertical microcracking. The lateral restraint, which develops as a result of microcracking inhibits to some extent further microcracking and local failures in the concrete. As a consequence the stress strain curves for the plain and reinforced concrete no longer coincides.

Research work by Bertero and Felipa, Base and Read; and Warwaruk and Ward has shown that lateral confinement by way of ties or circular spirals effectively improves the flexural modulus, moment rotation and energy absorption capacity of the confined concrete.

2.2.3 Concrete confined by spirals

Iyengar, Desayi and Reddy carried out tests on steel binders including circular and square spirals. As the load on the specimens increased the peeling of concrete in between the spirals was seen to start at about 60-90% of the maximum load while spalling of concrete took place at about maximum load. Stress strain curves were plotted from strain measurements by dial guages fitted at four diametrically opposite points.

A confinement index was employed to measure the degree of confinement by concrete binders. Confinement factor was taken as:

$$P_b - \bar{P}_b = \frac{f_y}{f_c}$$

where

$\bar{P}_b$ is particular volumetric ratio, that is value of P_b when the pitch of binder is equal to least lateral dimension of specimen.

P_b is volumetric ratio:- ratio of volume of binder to volume of confined concrete.

f_y - yield stress of steel binder

f'_c - ultimate stress of unconfined specimen.

This is so defined that, for a spacing of binder equal to the least lateral dimension of the specimen its value is zero. Iyengar et. al noticed that the strength and ductility were considerably increased on introduction of spiral binders but that confinement improves the deformation capacity to a much greater degree than its strength. Circular spiral were found to be more effective than square spirals.

They found a relation for strength of concrete with circular spiral confinement as:

$$f_c = f_c' + 9.2 \frac{A_s f_y}{D} \left(\frac{1}{S} - \frac{1}{S'} \right)$$

noting that the influence of confining is felt only for spacing S S' where S' is least lateral dimension.

It was found more effective to decrease the spacing of spirals than to increase the diameter of the spiral wire.

2.2.4 Concrete confined by rectilinear ties

Several researchers have published results of tests carried out on rectilinear steel binders. Although almost all agree on the increase in ductility, at least quantitatively, no agreement seems to exist on the strength of concrete so confined. Researchers don't even seem to agree on the variables to be considered.

Almost all the analytical models for confinement are based on experimented results, mostly on small scale tests on simple tie configurations. In most of the tests the ratio of the area of core bounded by the centre line of the perimeter tie to the gross area of the specimen was small compared with the values commonly used in practice.

Shamim A. Sheikh found that in addition to the commonly acknowledged variables such as amount of lateral reinforcement and steel strength, two other variables play important roles in determining the behaviour of confined concrete. These are the distribution of longitudinal steel around the core perimeter and the resulting tie configuration, and the spacing of ties. Better distribution of steel and closer spacing of ties along the column longitudinal axis (for the same amount of reinforcement) results in higher concrete strength and ductility.

It has been demonstrated that with the specimens having only four corner bars, the effectively confined concrete area at the critical section between the ties would be very small compared to the core area bounded by the centre line of the tie. This will result in poor confinement of the concrete core. Small specimen sizes, simple steel arrangement low volumetric ratios of lateral steel to concrete core and low ratios of core area to gorss area of columns would result in only small increases in confined concrete strength and ductility. Therefore the total capacity of the concrete after the cover has spalled off would not exceed the unconfined specimens capacity. This seems to be the main reason for the disagreement amonst researchers about increase in strength of concrete confined by rectilinear ties.

2.2.5 Concrete confined by wire mesh

Another possible form of lateral reinforcement is the use of wire mesh. It could be predicted to perform better than the conventional forms for the following reasons:

- The confining wire is available in both directions, a property which will reduce the arching effect offered by ties.
- The confining wires are more closely spaced.
- In severe climates their presence near the cover will help to arrest the effects of temperature variations.
- Aggregate interlock with reinforcement is better achieved and it is likely to give a more homogeneous action between cover and core.

As in spiral reinforcement it is likely to perform better if circular. Unlike in spirals, the continuous hoop tension effect and thus the uniform confining pressure effect is not available, however, extra confinement is offered by the longitudinals in the mesh. The aggregate mesh interlock will help to develop hoop tension in the lateral direction. Because of the relative slenderness of the wires, they may not be regarded as a carrying any longitudinally applied loads.

2.2.6 Ductility

A significant consideration to be added to strength is ductility. It is important that in the extreme event of a structure being loaded to failure it will behave in a ductile manner. This means ensuring that the structure will be capable of large deformations at near maximum load which gives ample warning of failure, and by maintaining load carrying capacity, total cellapse may be prevented. In the case of severe earthquake for instance, reliance is placed on the availability of sufficient ductility after yielding to enable the structure to collapse.

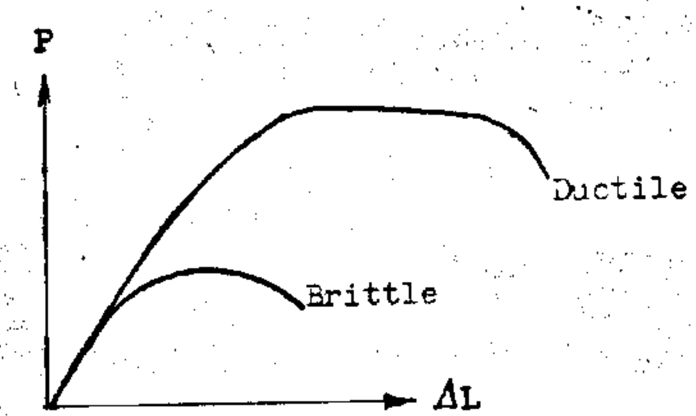


FIG. 2.4 Behaviour of Ductile and Brittle materials under loading

It is necessary to consider the load-deflection characteristics of members since the possible distributions of shear force, bending moment and axial load that could be used in design of statically indeterminate structures depend on the ductility of members at critical sections.

Large differences exist between various codes on the amount of confining steel for members subjected to axial load and flexure.

ACI 318 provisions are based on the philosophy that the axial load strength of column after the concrete cover has spalled off should at least be equal to the axial load strength of the colum before spalling, and they assume that the efficiency of rectangular hoops as confining reinforcement is 50% of that of spirals. The Seismology committee "Structural Engineers Association of California" provisions are somewhat similar to the ACI provisions when a number of hoop legs or supplementary cross ties exist across the section and reduce the unsupported length of the peripheral hoop.

There is a general agreement among investigators that the presence of closely spaced spirals or rectangular ties greatly enhances the ductility of concrete members.

CHAPTER THREE

DISCUSSIONS ON MATERIALS

3.1 Polyvinyl chloride (PVC) pipe material

More than one type of pipe materials are obtainable in the market depending on the manufacturers specifications and composition, some are more ductile than others. Tensile Test of two types of PVCs was done, the one that was brittle gave 26.7mN/m^2 while the other that was more ductile gave 45MN/m^2. The one that exhibited high ductility was used for this research.

The initial problem of cutting the pipes into the required sizes was overcome by cutting the pipes with a saw blade.

In order to find out how the slenderness ratio affects the ultimate strength of the composite column, the pipes were cut in such a way as to obtain short and slender columns.

3.1.1 Properties of Plastics

Plastics have a number of very valuable physcial physical and mechanical properties. Thus, plastics with powder and fibrous fillers have a compressive strength of 1200-2000 kgf/cm^2 and a bending strength up to 200 kgf/cm^2. Tensile strength of plastics with sheet form fillers may be as high as

1500 kgf/cm^2, and that of fiberglass anisotropic material 4800-9500kgf/cm^2.

Plastics are not susceptible to corrosion, they resist attack by solution of weak acids and alkalis and some plastics e.g. polytethylene, polyisobutylene, polystyrene, Polyvinyl chloride, withstand the action even of concentrated solutions of acids, salts and alkalis; they are used for building chemical installations, sewage systems and for insulating storage tanks.

Plastics are poor conductors of heat, their coefficient of heat conductivity is 0.2 - 0.7 kcal/m.h^{o}C, and of foam plastics, 0.06-0.026 kcal/m.h.^{o}C, and because of this they are widely used as heat insulating materials.

Plastics can be manufactured in any colour when dyes are fast, plastics retain their colour for a longtime thus avoiding the need for repeated painting and so reducing the running costs. They have a good workability, they can be given various shapes, however complicated. A large group of plastics can be welded to one another which allow the manufacture of complicated piping. The welding can be done by mere heating to a temperature between 150^{o}C and 250^{o}C with the aid of hot gas.

However, plastics have a number of shortcomings. Most plastics have a low heat resistance (70-200^{o}C) and some can withstand temperatures up to 250^{o}C. Plastics are not very hard. They have a high coefficient of thermal expansion, varying from 25×10^{-6} per ^{o}C to 120×10^{-6} per ^{o}C, that of steel is 11×10^{-6} per ^{o}C. They exhibit high creep, with time plastics begin to flow much easier than other materials (steel, concrete). They are susceptible to ageing i.e. they disintegrate gradually, lose strength and hardness, soften and get dull. Ageing of plastic is due to the action of light, air temperature.

3.2 Concrete

The concrete was made from one brand of cement, Portland cement made by Ashaka Cement Company, No special effort was made to achieve any predetermined strength, however attempts were made to produce as near uniform strength as possible. Thus both the sand and gravel were obtained from single supplies.

Adequate compaction was achieved as was demonistrated by the smoothness of the surfaces of the unconfined samples. The strength of concrete produced from two batches of same mix are on the average the same.

Design of concrete mix.

Volume of pipe $= \frac{\pi d^2 h}{4}$

$= \frac{3.14 \times 0.1 \times 1.2}{4}$

$= 0.00944 m^3$.

density of concrete = $\frac{2400}{22.608kg}$

Add 50% for waste = $\frac{11.304 \text{ kg}}{33.912 \text{ kg.}}$

For 12 pipes,

weight of mix = 33.912 x 12

= 406.944 kg

For 6 cubes,

150 x 150 x 150 = $3375 \times 10^{-6} m^3 \times 2400$

= 8.1 kg.

8.1kg x 6 = 48.6kg

Add 50% for waste 24.3kg

72.9kg

Total weight of mix $\quad 406.944$

$$\begin{array}{r} 406.944 \\ +\ 72.900 \\ \hline 479.844\text{kg} \end{array}$$

For mix ratio 1: 1.5 : 3,

$$1 + 1.5 + 3 = 5.5$$

Cement $= \frac{1}{5.5} \times 479.844 = 87.24$kg.

Sand $= \frac{1.5}{5.5} \times 479.844 = 130.87$kg

Aggregates $= \frac{3}{5.5} \times 479.844 = 261.73$kg.

Water $= 0.55 \times 87.24 = 47.98$kg.

For mix ratio 1: 1 : 2

$$1 + 1 + 2 = 4$$

Cement $= \frac{1}{4} \times 479.844 = 119.96$ kg.

Sand $= \frac{1}{4} \times 479.844 = 119.96$kg.

Aggregates $= \frac{2}{4} \times 479.844 = 239.92$ kg.

Water $= 0.65 \times 119.96 = 77.97$kg

3.3. Experimental Programme

The pipe material (PVC pipes) were of 75mm and 100mm diameter. The thicknesses of which were 2mm and 3mm respectively. This was measured with the help of a vernier caliper. The pipes were cut into various lengths (200-1210mm) so as to obtain short and slender columns. Three samples were made for each length to allow repeatability of test results. The cutting was done with the help of saw blade to achieve a smooth and even edge. The pipes were washed and dried before use.

Two types of concrete design strengths were chosen for this experiment. The first mix had a Point fifity five water-cement ratio, a one point five sand-cement ratio and a three coarse aggregate (9.4mm maximum size) - cement ratio and the second mix had a point sixty-five water cement ratio, a one sand-cement ratio and a two coarse aggregate (9.4mm maximum size)- cement ratio.

The tests were carried out in three series, so the samples were prepared into three groups from the two concrete mixes.

In the first group, the concrete mix ratio of the first mix a was 1:1.5:3 (i.e. cement,: sand: coarse aggregates). The samples consist of plastic pipes of thicknesses 3mm and 2mm with diameter of 100mm and 75mm respectively. Short and slender columns were prepared from the two types of pipes. A total of twenty eight samples were prepared for this group, these include the unconfined samples. The results obtained are on table 3.1 and table 3.2.

The second group consist of a concrete mix ratio of 1:1:2 (cement: a sand: coarse aggregates). As in the first group the samples were prepared from pipes of 3mm and 2mm thicknesses with 100mm and 75mm diameters respectively. Also short and slender columns were prepared for the two different diameters. A total of twenty eighty samples were made for this group, including the unconfined samples. Details of results obtained for this group are on table 3.3 and table 3.4.

In the third group, the sample concrete mix ratio was used as in the first group, but reinforced with 6mm diameter bars. The aim here is to evaluate the influence of longitudinal reinforcement. Only pipe material of 3mm thickness with 100mm diameter was used. Bar arrangement was as specified by BS 8110. Here also both short and slender columns were prepared, but no unconfined samples. A total of twelve columns were produced for this group. See table 3.5 for details.

Each group was produced at a week's interval and marked for identification. The specimens were air dried in a humid environment and tested after 28 days of curing, except the unconfined specimens which were immersed in a curing tank and tested after 28 days.

The unconfined samples were made by oiling the PVC pipes and later torn open after a day. Binding wire was welded to the reinforcement bars in a circular form at the top and bottom ends of the bars to keep them in position.

3.4 Casting of Columns

The plastic pipes were washed and dried to remove dust. They were positioned vertically on polythene leather spread on the ground. Each of the pipes was parked tightly in position in a hollow block with cement paper bags and small wooden parts.

As the pipes were positioned, the mixing of concrete with a mixing machine started. Sand and cement were weighed and mixed first before the coarse aggregate was added, water was gradually added while mixing continued. Each of the materials was weighed according to proportion with an avery weighing machine.

The pipes were filled in layers and compacted manually with a tamping rod. The columns were plumbed as they were compacted to produce a straight column. Within three hours after casting the samples were smoothen to give a flat and uniform surface for crushing.

The unconfined columns were cast in the pipes which serves as the formwork. The pipes were oiled before the concrete was cast and after a day they were torn open with a sawing machine in the departmental workshop.

All the columns were tested under axial compressive load using Universal Testing Machine in the departmental laboratory. In testing, the load was increased progressively until failure occurred. While each sample was aligned, it was being plumbed to reduce accentricity. The experimental set-up is shown on plate I. It was not possible to measure the strain as the strain guages were faulty and the automatic graph plotter of the machine which was to plot the load-strain curves was also faulty. The mode of failure, load at failure and structural behaviour of the columns were observed and noted.

3.5 Observations and Results

When testing the composite columns, all were observed to be failing from the upper end but one which failed at the bottom.

At the locations of failure, the colour of the pipes was observed to change to white. Failure usually occurred quietly, but for some specimens a soft cracking was heard when the ultimate load was attained.

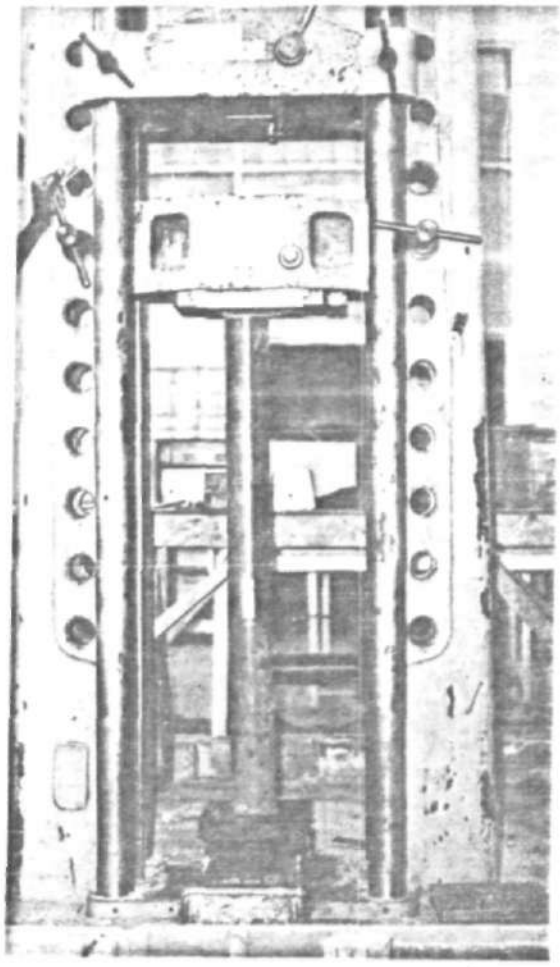


PLATE I Column Under Test
ready to be loaded

Mode of Failure

The columns tested in this investigations mostly showed the following modes of failure: diagonal and compression.

Diagonal failure

This type of failure occurred in plain columns. Some of the plain concrete columns failed by shearing.

Compression failure

This type of failure occurred in confined columns. The short columns bulged at the upperside, and slender columns failed in the same manner but accompanied by buckling. The longitudinally reinforced columns showed signs of failure at mid span as well and accompanied by severe buckling. Angle of failure is approximately 45°. Typical failure modes are shown on plates II and III.

Test results are shown on the following tables:

Specimen Type	A_{11}	A_{12}	B_{13}	A_1	A_{21}	A_{22}	A_{23}	A_2	A_{31}	A_{32}	A_{33}	A_3	A_{41}	A_{42}	A_{43}
Thickness mm	3	3	3	N/A	3	3	3	N/A	3	3	3	N/A	3	3	3
Diameter mm	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6
Length(mm)	1210	1210	1210	1210	810	810	810	810	410	410	410	210	210	210	210
Slenderness Ratio	47.63	47.63	47.63	47.63	31.89	31.89	31.89	31.89	16.14	16.14	16.14	16.14	8.27	8.27	8.27
Ultimate Column Load (KN)	201	200	198	131	215	218	215	152	236	239	233	181	248	248	248
Average Ultimate Column Load (KN)		200				216				236				248	

Mix Ratio 1: 1½: : 3

Table 3.1

Specimen Type	A_{51}	A_{52}	A_{53}	A_5	A_{61}	A_{62}	A_{63}	A_6	A_{71}	A_{72}	A_{73}	A_7
Thickness (mm)	2	2	2	N/A	2	2	2	N/A	2	2	2	N/A
Diameter (mm)	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2
Length (mm)	1000	1000	1000	1000	810	810	810	810	410	410	410	410
Selenderness Ratio	52.49	52.49	52.49	52.49	42.52	42.52	42.52	42.52	20.99	20.99	20.99	20.99
Ultimate Column Load (KN)	84	83	85	54	105	103	101	67	127	130	127	84
Average ultimate Column load(KN)		84				103				128		

Mix Ratio 1:1½:3

Table 3.2

Specimen Type	B_{11}	B_{12}	B_{13}	B_1	B_{21}	B_{22}	B_{23}	B_2	B_{31}	B_{22}	B_{33}	B_3	B_{41}	B_{42}	B_{43}	B.
Thickness (mm)	3	3	3	N/A	3	3	3	N/A	3	3	3	N/A	3	3	3	N/
Diameter (mm)	100.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6
Length (mm)	1210	1210	1210	1210	810	810	810	810	410	410	410	410	210	210	210	210
Slenderness ratio	47.63	47.63	47.63	47.63	31.89	31.89	31.89	31.89	16.14	16.14	16.14	16.14	8.27	8.27	8.27	8.27
Ultimate column load (KN)	236	235	237	149	248	246	244	156	258	259	260	169	268	268	268	268
Average Ultimate column load (KN)		236				246				259				268		

Mix Ratio 1: 1:2.

Table 3.3

Specimen Type	B_{51}	B_{52}	B_{53}	B_5	B_{61}	B_{62}	B_{63}	B_6	B_{71}	B_{72}	B_{73}	B_7
Thickness (mm)	2	2	2	N/A	2	2	2	N/A	2	2	2	N/A
Diameter (in)	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2
Length (mm)	1000	1000	1000	1000	810	810	810	810	400	400	400	400
Slender-ness Ratio	52.49	52.49	52.49	52.49	42.52	42.52	42.52	42.52	20.99	20.99	20.99	20.99
Ultimate column load(KN)	108	108	108	75	124	122	126	84	140	140	140	96
Average ultimate column load (KN)		108				124				140		

Mix Ratio 1:1:2

Table 3.4

Specimen Tpe	C_{11}	3_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}
Thickness (mm)	3	3	3	3	3	3	3	3	3	3	3	3
Diameter (mm)	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6
Length (mm)	1210	1210	1210	810	810	810	410	410	410	210	210	210
Slenderness Ratio	47.63	47.63	47.63	31.89	31.89	31.89	16.14	16.14	16.14	8.27	8.27	8.27
Ultimate Column load(KN)	218	216	217	220	220	221	234	233	233	246	247	246
Average ultimate Column load(kN)		216			220			233			246	

Concrete mix. 1: 1½: 3

Pipe material PVC.

Steel dia. 6mm.

Table 3.5

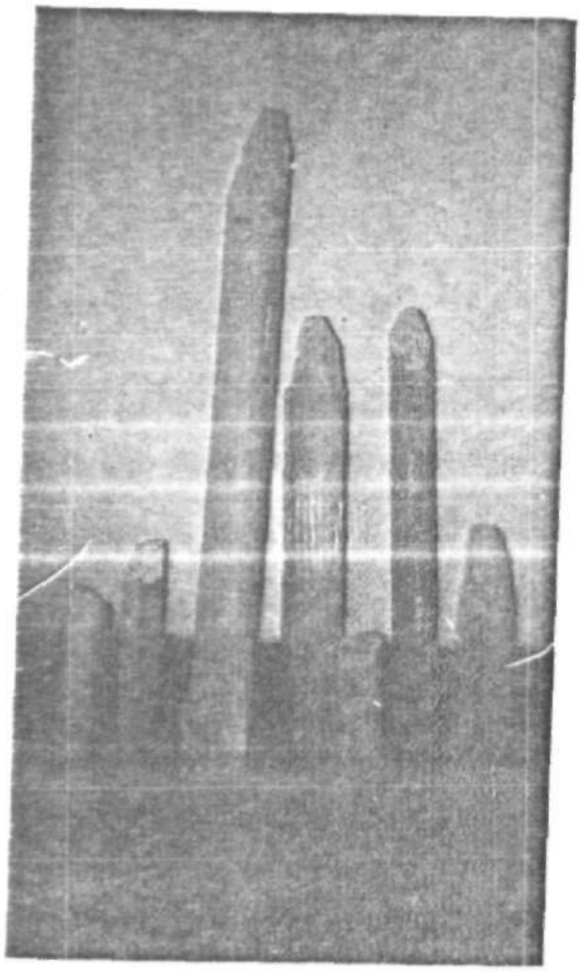


PLATE II Typical Diagonal Failure of Plain Concrete Columns

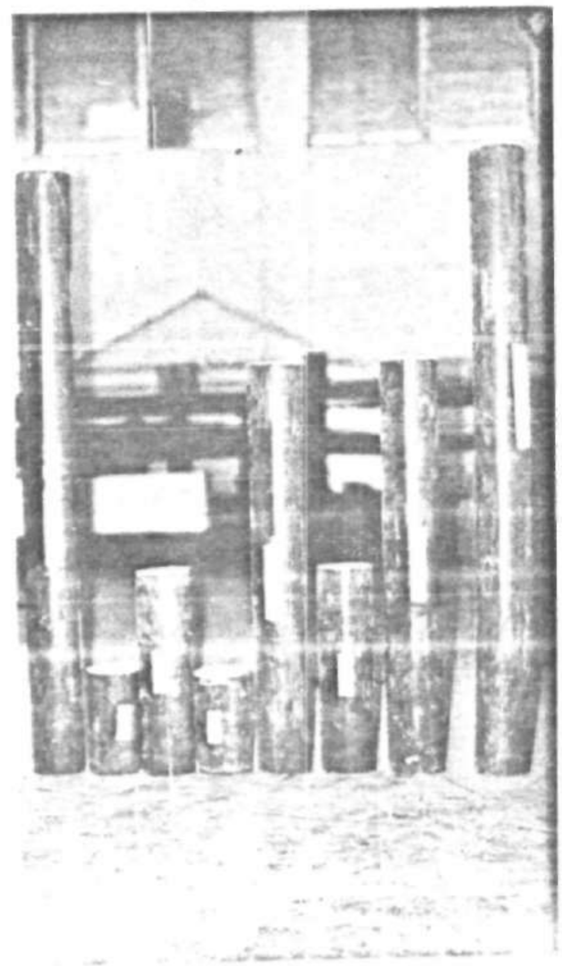


PLATE III Compression Failure of
Confined Concrete Columns

CHAPTER FOUR

ANALYSIS OF TEST RESULTS AND DISCUSSIONS

It is important to determine if the plastic pipe improved the compressive strength of the concrete core. This improvement in strength is quantified by calculating the nondimensional constant, which relates the increase in concrete core compressive strength to the burst pressure of the plastic pipe i.e.

$$\alpha = \frac{f_{max} - f'_c}{P_b}$$

where f_{max} - ultimate strength of confined concrete core.

f'_c - ultimate strength of unconfined concrete core

P_b - pipe burst pressure

and

$$P_b = \frac{2\ F_p\ t}{D}$$

where

F_p - ultimate strength of plastic

t - pipe wall thickness and

D - average pipe diameter.

α- value for specimen A_{11}.

Pipe burst pressure, P_b, $= \frac{2 \times 45 \times 3}{101.2}$

$= 2.66\ N/mm^2$

$f_{max} = 25.73 N/mm^2$ for specimen A_{11}

$f'_c = 16.69 N/mm^2$ for specimen A_1

$$\alpha = \frac{f_{max} - f'_c}{P_b} = \frac{25.73 - 16.69}{2.66}$$

$$= \underline{3.40}$$

α- value for specimen A_{51}

Pipe burst pressure, $P_b = \frac{2 \times 45 \times 2}{76.2}$

$= 2.36 N/mm^2$

f_{max} for specimen $A_{51} = 18.45 N/mm^2$

f'_c for specimen $A_5 = 11.85 N/mm^2$

$$\alpha = \frac{18.43 - 11.85}{2.36} = \underline{2.78}$$

α - value for specimen B_{11}

Pipe burst pressure, $P_b = \frac{2 \times 45 \times 3}{101.2}$

$= 2.66 N/mm^2$

f_{max} for specimen $B_{11} = 29.12 N/mm^2$

f'_c for specimen $B_1 = 18.39 N/mm^2$

$$\alpha = \frac{29.12 - 18.39}{2.66} = \underline{4.03}$$

α - value for specimen B_{51}

Pipe burst pressure $P_b = \frac{2 \times 45 \times 2}{76.2}$

$= 2.36 \ N/mm^2$

f_{max} for specimen $B_{51} = 23.69 \ N/mm^2$

f'_c for specimen $B_5 = 16.45 N/mm^2$

$$\alpha = \frac{23.69 - 16.45}{2.36} = 3.07.$$

This constant was calculated for all specimens tested excluding those reinforced with bars.

Values of α, for each specimen are shown on tables 4.1, 4.2, 4.3 and 4.4.

Specimen type	f_{max} (N/mm^2)	f_c' (N/mm^2)	α- values
A1	Unconfined	16.69	
A11	25.73		3.40
A12	25.48		3.31
A13	25.22		3.21
A2	Unconfined	19.36	
A21	27.39		3.02
A22	27.77		3.16
A23	27.39		3.02
A3	Unconfined	23.06	
A31	30.06		2.63
A32	30.45		2.78
A33	29.68		2.49
A4	Unconfined	26.24	
A41	31.59		2.01
A42	31.59		2.01
A43	31.59		2.01

Pipe burst pressure P_b = 2.66 N/mm^2

TABLE 4.1: α - Values for specimen A_{11} - A_{43}

Specimen type	f_{max} (N/mm^2)	f_c' (N/mm^2)	α- values
A5	Unconfined	11.85	
A51	18.43		2.78
A52	18.21		2.69
A53	18.65		2.80
A6	Unconfined	14.70	
A61	23.04		3.53
A62	22.60		3.35
A62	22.16		3.16
A7	Unconfined	18.43	
A71	27.86		3.99
A72	28.52		4.28
A73	27.86		3.99

Pipe burst pressure

$P_b = 2.36$ N/mm^2.

TABLE 4.2: α-Values for Specimend A_{51}- A_{73}

Specimen Type	f_{max} (N/mm^2)	f'_c (N/mm^2)	α - values
B1	Unconfined	18.39	
B11	29.12		4.03
B12	29.00		3.99
B13	29.25		4.08
B2	Unconfined	19.25	
B21	30.61		4.27
B22	30.36		4.18
B23	30.11		4.08
B3	Unconfined	20.86	
B31	31.84		4.13
B32	31.96		4.17
B33	32.09		4.22
B4	Unconfined	22.21	
B41	33.07		4.08
B42	33.07		4.08
B43	33.07		4.08

Pipe burst pressure

$P_b = 2.66 N/mm^2$

TABLE 4.3: α- Values for Specimen B.11 - B.43

Specimen Type	f_{max} (N/mm^2)	f_c' (N/mm^2)	α- values
B5	Unconfined	16.45	
B51	23.69		3.06
B52	23.69		3.06
B53	23.69		3.06
B6	Unconfined	18.43	
B61	27.20		3.71
B62	26.77		3.53
B63	27.64		3.90
B7	Unconfined	21.06	
B71	30.71		4.09
B72	30.71		4.09
B73	30.71		4.09

Pipe burst pressure

$P_b = 2.36$

TABLE 4.4: α-Values for specimens B51 - B75

LOAD CARRYING CAPACITY OF COLUMNS

The maximum load carried by columns tested under axial compression are given in **Tables 3.1-3.5.** Graphs plotted from these results are as shown on figures 4.1. - 4.5.

It can be seen how slenderness affects the loading capacity of columns. Short columns carry more loads than slender columns.

Concrete strength also influences the strength of the composite columns. In this case columns of average concrete strength of $35 MN/m^2$ have higher ultimate strength than those of average concrete strength of $32.22 MN/m^2$.

It is important to add here that the longitudinal reinforcement contributed very little to the strength of columns. Infact the increase is only at a slenderness ratio of 25 and above. See graph in figure 4.1. The reinforcement contributed alot to the buckling of columns under the compressive loading.

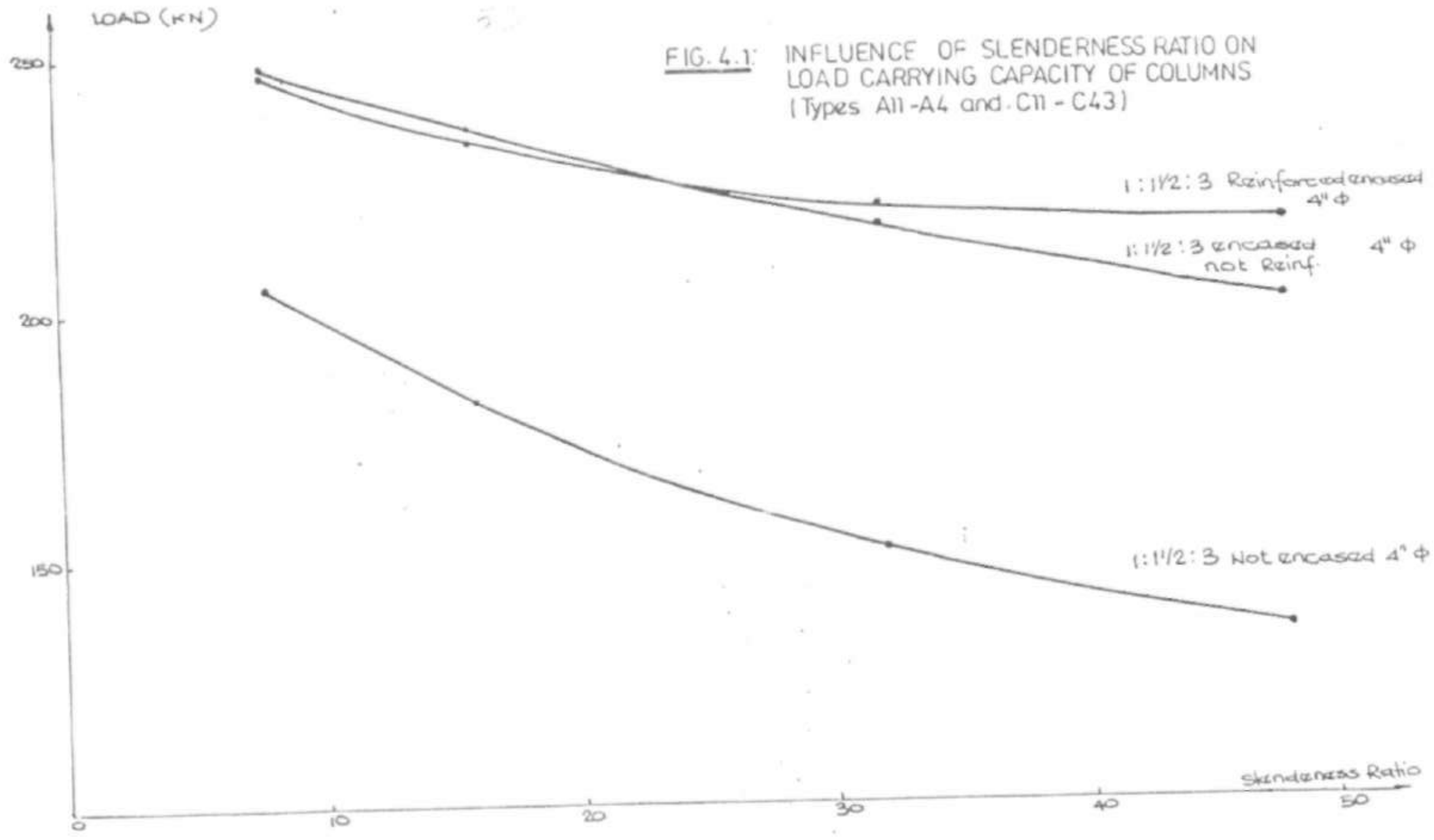


FIG. 4.1: INFLUENCE OF SLENDERNESS RATIO ON LOAD CARRYING CAPACITY OF COLUMNS (Types A11-A4 and C11 - C43)

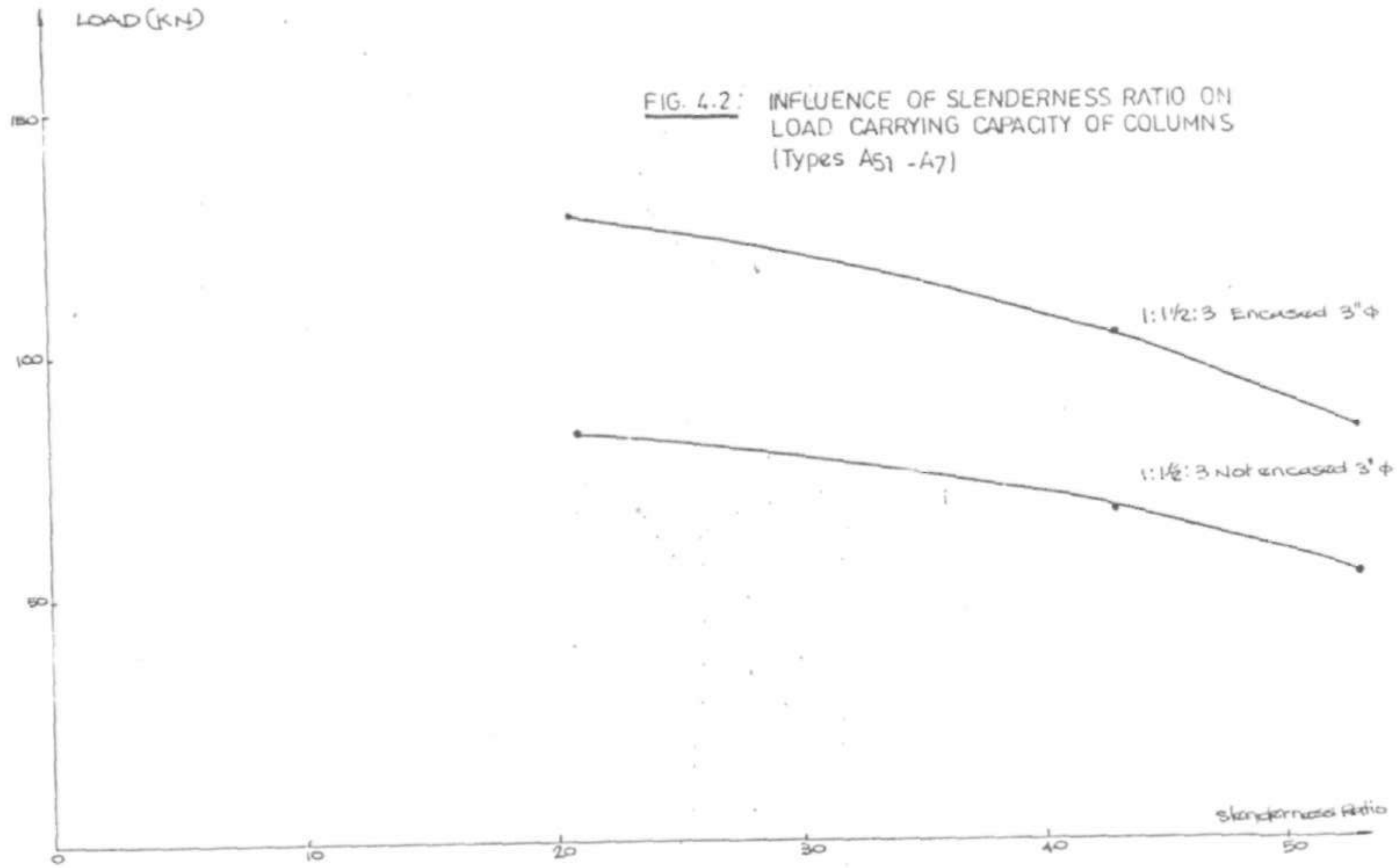


FIG. 4.2: INFLUENCE OF SLENDERNESS RATIO ON LOAD CARRYING CAPACITY OF COLUMNS (Types A51 - A7)

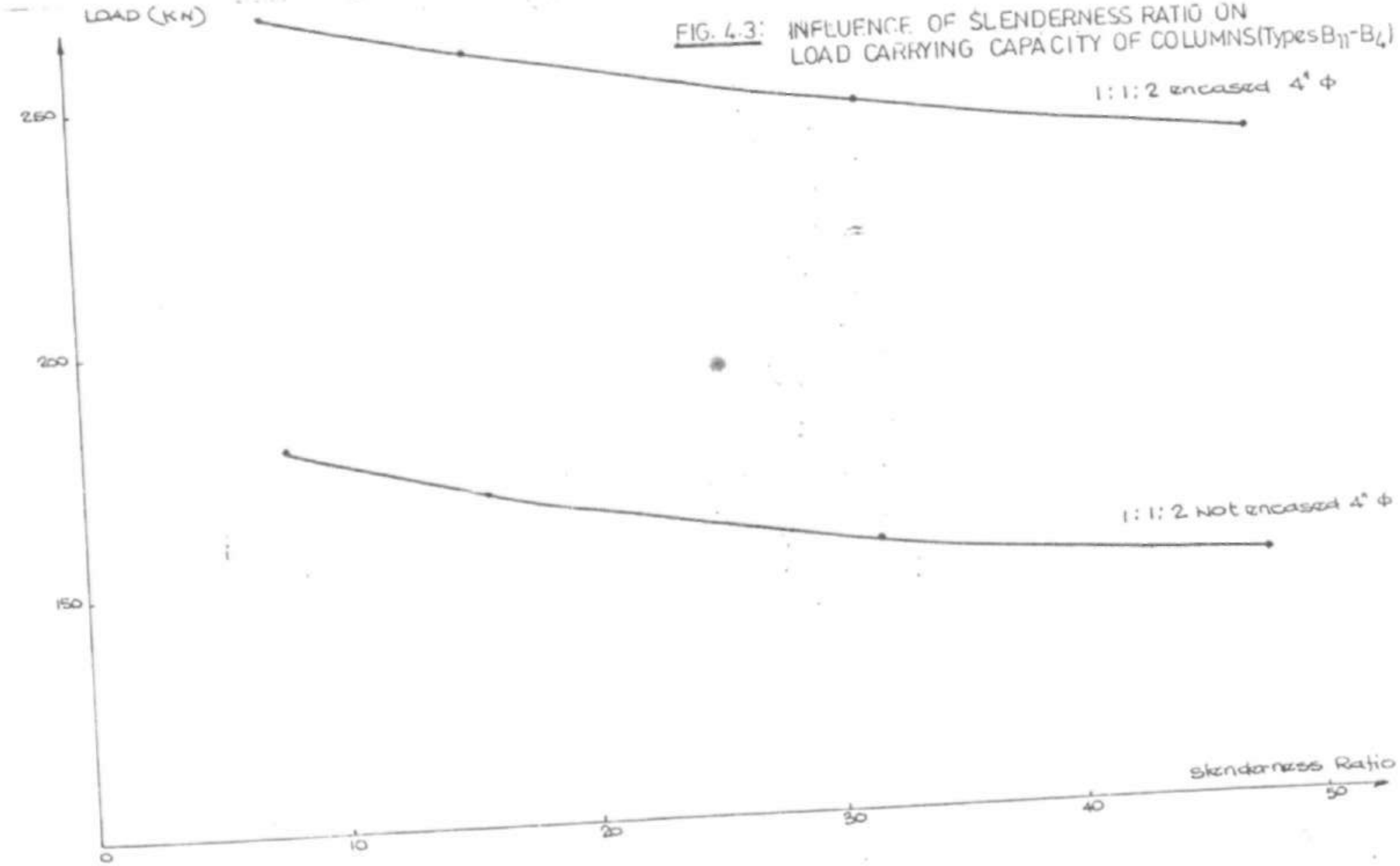
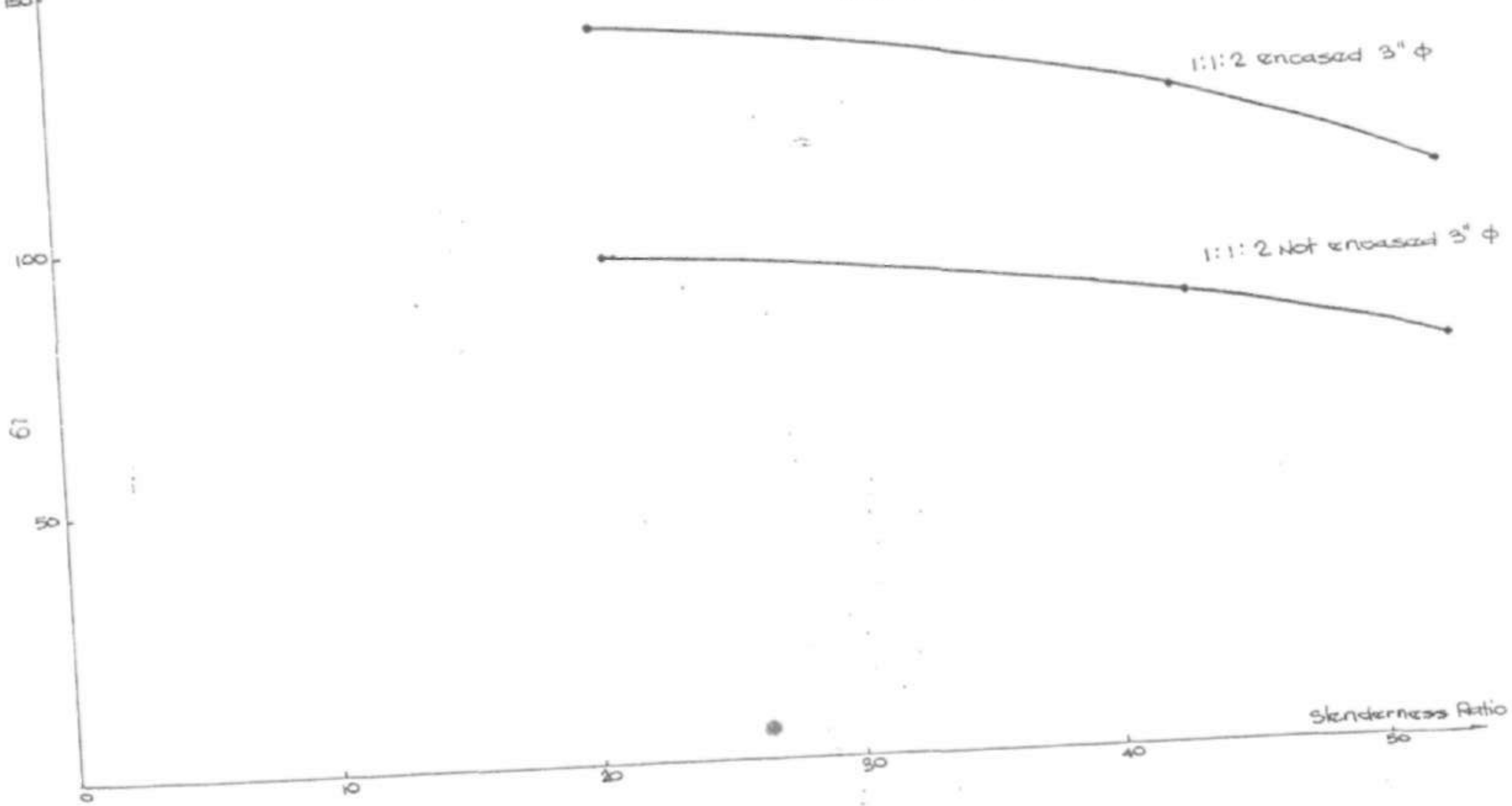


FIG. 4.3: INFLUENCE OF SLENDERNESS RATIO ON LOAD CARRYING CAPACITY OF COLUMNS (Types B_{11}-B_4)

FIG. 4.4: INFLUENCE OF SLENDERNESS RATIO ON LOAD CARRYING CAPACITY OF COLUMNS (Types B_5 - B_7)



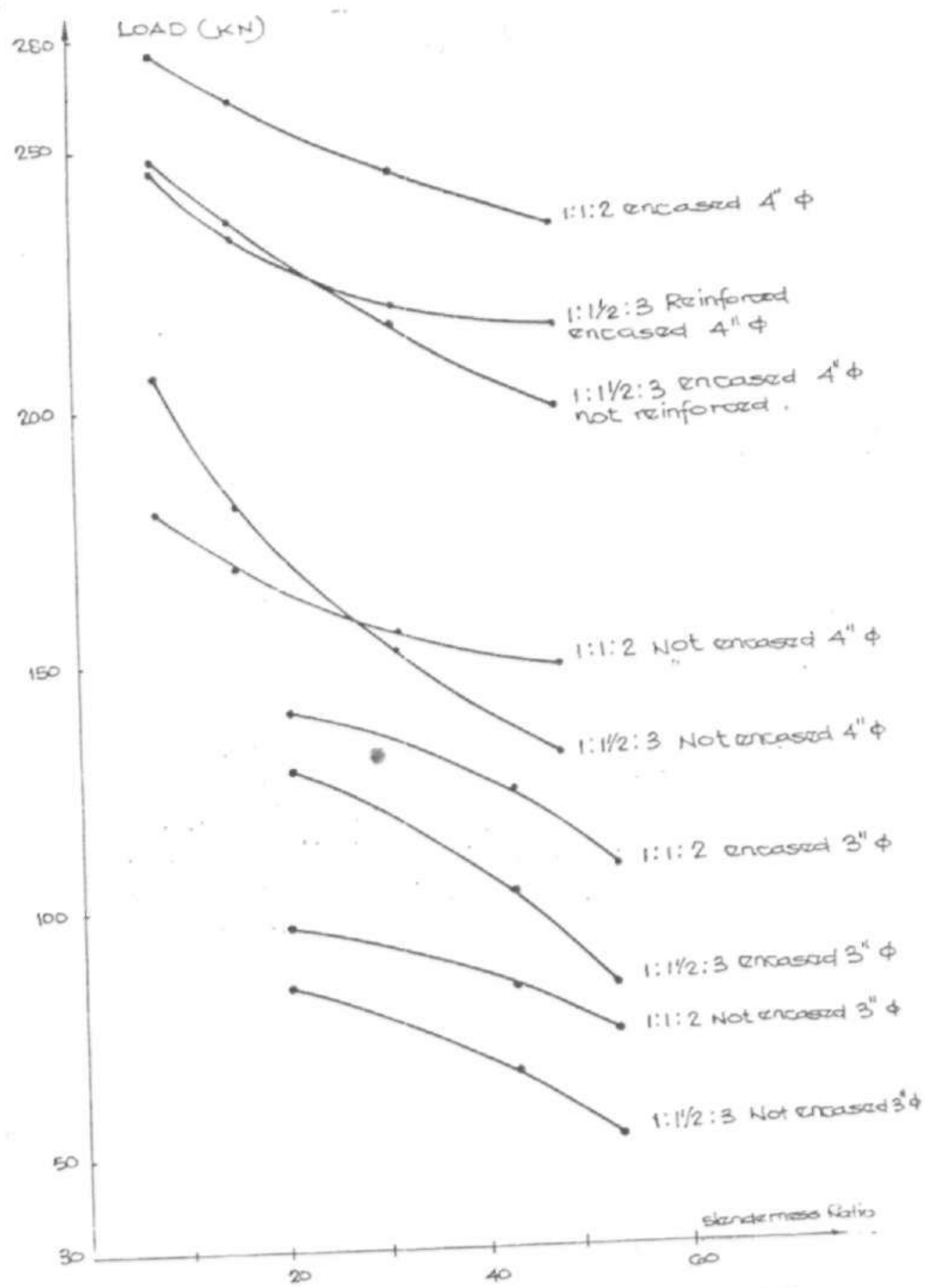


FIG. 4.5: COMPARISM OF THE LOAD CARRYING CAPACITY OF ALL THE COLUMNS TESTED

Sources of Errors

1. Straightening of pipes.

The PVC pipes were not perfectly straight from the market. Efforts to straightened them was made by placing blocks on them for days before work started.

2. Cutting of Pipe.

This was done by hand using saw blade, the ends may not be perfect even.

3. Casting of Columns

Although care was taken to ensure quality control, some lapses did occur during casting. Some of these include the shifting of the reinforcement cage while compacting the concrete, and though the pipes were tightly kept in position in a hollow block it can not be perfectly tightened as to prevent the pipes from tilting. Pipes were plumbed during casting in order to ensure perfection.

4. Positioning of columns on the testing machine

The plate on which the columns were positioned have to be set after each test so that the columns can be vertically upright. The plate was readjusted while the column was being plumbed. Error might have occurred before loading started.

5. Instrumental Error

The universal testing machine is prone to malfunction.

6. Human Error

This might have occurred during measurements or in workmanship.

CHAPTER FIVE

5.0 CONCLUSIONS

The aim of this research is to evaluate the influence of other concrete design strengths different from the one used by Carl E. Kurt (1978) and longitudinal reinforcement confined by plastic pipe (PVC), the effect of the slenderness ratio on both short and slender columns and the resulting column strength. The following conclusions can be made based on the results of the axial compressive tests conducted during this investigation.

1. The plastic pipe (PVC) provided sufficient lateral support of the concrete core and increased the ultimate strength of the concrete core and column. As proposed by Kurt (1978), this increase in strength can be predicted with a linear relationship between the pipe burst pressure and unconfined strength of the concrete core.

2. When acting as confinement reinforcement, the plastic pipe behaves in a manner similar to spiral reinforcement of a standard reinforced concrete column.

3. The confined strength of the concrete core of diameter 100mm and mix ratio $1:1\frac{1}{2}:3$, was increased an average of 2.75 times the burst pressure of the pipe. Actual α- value ranged from 2.01 to 3.40. The average α- value of same mix but of 75mm diameter is 3.41 and the range is from 2.69 to 4.28.

   The confined strength of the concrete core of diameter 100mm with a mix ratio of 1:1:2 was increased an average of 4.12 times the burst pressure of the pipe. Actual value ranged from 3.99 to 4.27. The average of same mix but of 75mm diameter is 3.620 and the range is from 3.06 to 4.09.

4. The longitudinal reinforcement does not influence the strength of the confined concrete core appreciably, a maximum increase of 9 percent of the strength of the confined concrete core (without reinforcement) was recorded.

5. The ultimate strength of the composite columns decreases as the slenderness increases.

6. This structural concept has certain inherent safety features. Large and noticeable deformations of the plastic pipe are observed before total collapse-occurs. A small amount of audible noise is present during loading.

5.1 RECOMMENDATION

Further testing is recommended to evaluate other parameters such as long term environmental and loading effects on the plastic materials. Fire protection for this concept also needs evaluation.

Investigations in the method by which beams or slabs would be connected to the columns of this concept is also recommended.

The composite action of this structural concept was investigated at the ultimate load stage, it is recommended that further investigations on this concept be carried out at the service load stage.

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Appendix

Results of concrete cube strength tests first

FIRST BATCH

Cube No	Weight, kg	Crushing load kN	Strength MN/m^2
A1	7.90	700	32.11
A2	8.00	700	32.11
A3	8.00	750	33.33
A4	8.20	750	33.33

Average = 32.22 MN/m^3

SECOND BATCH

Cube No	Weight kg	Crushing load kN	Strength MN/m^2
B1	7.80	670	29.78
B2	8.10	950	42.22
B3	7.90	820	36.44
B4	7.98	710	31.56

Average = 35.00MN/m^2

THIRD BATCH

Cube No	Weight kg	Crushing load kN	Strength MN/m^2
C1	7.45	600	26.67
C2	7.80	600	26.67
C3	7.80	630	28.00
C4	7.80	620	27.56

Average = 27.23MN/m^2