STRENGTH OF CONCRETE COLUMN CONFINED BY PLASTIC (PVC) PIPE

[1]AKPAN, A. J. [2]LETCHA, S. S. AND [3]FAROUK. M

Transport School Nigerian Institute of Transport Technology, Zaria
Civil Engineering Department, Ahmadu Bello University, Zaria
Sokoto Urban Development Authority, Sokoto, Nigeria.

ABSTRACT

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

Pipes of 75.0mm and 100.0mm diameters and of varied lengths were used. Two different concrete mixes were tested. The first had a 1.5 sand cement ratio and 3.0 coarse aggregate - cement ratio, while the second ,a 1.0 sand - cement ratio and 7.0 course aggregate - cement ratio was used.

The samples were made into three groups and one of these groups was reinforced with 6.0mm diameter bars. All tests were carried out in uniaxial compression under monotonic loading.

The results showed appreciable increase in concrete strength when confined by plastic pipe. Increase in strength of about two 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. The ultimate strength of the confined columns decreased with increasing slenderness ratio.

LIST OF SYMBOLS

D = Average pipe diameter.
t = Average pipe wall thickness.
P_o = Effective radial pressure between concrete core and pipe
P_b = Pipe burst pressure.
F_p = Ultimate strength of plastic material.
F_{max} = Ultimate strength of confined concrete core.
f'_c = Ultimate strength of unconfined concrete core.
α = Ratio of increase in core strength to pipe burst pressure.
$\Sigma_z, \Sigma_r, \Sigma_\theta$ = Normal, radial and tangential strains respectively.
$\sigma_z, \sigma_r, \sigma_\theta$ = Normal, radial and tangential stresses respectively.
μ_c, μ_p = Poisson's ratio for concrete and plast' pipe respectively.
E_c, E_p = Modulus of elasticity for concrete and plastic pipe respectively.

1.0 INTRODUCTION

The output of polymer based structural materials is growing at an increasing rate and their range is expanding rapidly. There are many areas of application in which the reflection of a metal or alloy in the only feasible solution to a design requirement, but there are also situations in which plastic materials have replaced the use of metals, and in many instances, a plastic material provides a better solution than a metallic material although metals may have been used in the particular situation for many years. The increase in the use of plastics is attributed to their many useful properties coupled with their comparatively low cost, which more than offset their disadvantages. Engineering and economical grounds therefore, for using plastics in construction, is of particular significance in this respect.

The use of confining reinforcement in reinforced concrete building elements is based on the conditions that confinement increases compressive strength and the capacity of concrete to sustain large deformations without substantial strength loss. The mechanism of confinement by ties and spirals has been well investigated. The deficiencies of these two forms of confinement are the non-uniform and ineffective confinement of the concrete core due to arching effect between wires. At higher strains, the concrete cover begins to spall and this reduces the area of concrete, consequently failure. Plastic encasement however, seems to be able to overcome these deficiencies as has bear observed from work done on this structural concept, where it was shown that there is an increase in strength of a short concrete core surrounded by acrylonitrile butadiene styrene (ABS) and polyvinyl chloride (PVC) pipes; and the slenderness ratio influences the ultimate strength of the composite column.

This work therefore, aimed at the experimental investigation of the structural behaviour of commercially available PVC pipes filled with concrete. The strength of concrete confined by plastic pipe was investigated by testing several columns, both confined 1 unconfined, under an axial compressive loading ...m. The influence of two concrete design strengths ...e effects of longitudinal reinforcement was also ...stigated. both slender and short columns were considered in the investigations. it is hoped that the results from this investigation will provide the basis for further research on this structural concept.

1.1 EFFECTS OF CONFINEMENT ON STRENGTH AND DEFORMATION OF CONCRETE

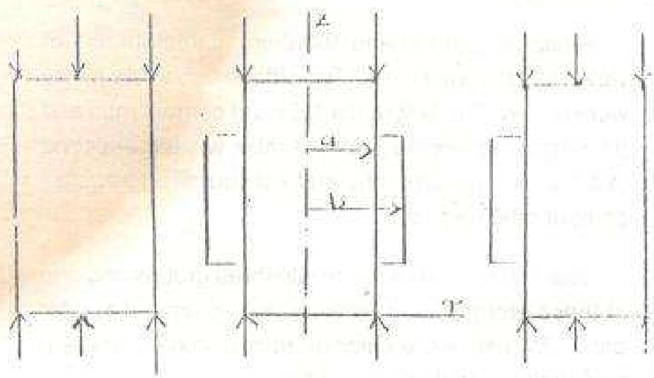
For the purpose of design, it has been found satisfactory to express the axial strength of confined concrete as the unconfined strength plus a constant times the uniform lateral pressure. Lateral confinement of concrete may lead to strength increase due to the fact that it delays the development of microcracks and thus the formation of discontinuities, and even after some cracking has occurred, further microcracking may be delayed and the strength of an individual element is increased by lateral confinement.

Lateral confinements has no measurable effect on loads less than 80% of the unconfined strength of concrete. At this stage of loading, the lateral strains begin to increase indicating the occurrence of significant vertical microcracking.

The lateral restraint, which develops as a result of microcracking inhibits to some ententes, further microcracking and local failures in the concrete. studies have 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.

1.3 CONCRETE FILLED PLASTIC COLUMNS

The elastic behaviour of this structural concept is derived from the theory of plane stress and plane strain elasticity. A thick cylinder analysis is presented (since plastic pipes are available in many diameter to thickness ratios, and some of these are quite low) from which the results for relatively their pipes can be deduced. The structural models are as shown in fig 1.



Unconfined specimen	Pipe not axially loaded	Pipe axially loaded
(TYPE A)	(TYPE B)	(TYPE C)

FIGURE 1 MODEL TYPES

For type B model, the strain - stress relationships are as follows:

For concrete,

$$\Sigma_z = 1/E_c [\sigma_z - \mu_c(\sigma_r + \sigma_\theta)]$$
$$\Sigma_r = 1/E_c [\sigma_z - \mu_c(\sigma_\theta + \sigma_z)] \quad \text{.............................(1)}$$
$$\Sigma_\theta = 1/E_c [\sigma_\theta - \mu_c(\sigma_r + \sigma_z)]$$

and for plastic pipes

$$\Sigma_z = 1/E_p (\sigma_r - \mu_z\sigma_\theta)$$
$$\Sigma_\theta = 1/E_p (\sigma_\theta - \mu_p\sigma_r) \quad \text{.....................................(2)}$$

As the concrete is loaded axially an effective compressive pressure is generated on the boundary between the cover nd pipe due to the poison effect. Thus, the boundary conditions are:

1. For the concrete cover, the radial and tangential stresses are finite at the core centre and equal to the effective pressure P_0, at the outer edge.
2. for the plastic pipe, the radial stress is equal to the effective pressure P_0, at the inner surface and zero at the outer edge.
3. That is, for concrete,

$$\sigma_r = \sigma_\theta = -P_0 \quad \text{.................................(3)}$$

and for plastic pipe,

$$\sigma_r = -\frac{a^2b^2}{b^2-a^2}\left(\frac{Po}{r^2}\right) + \frac{Poa^2}{b^2-a^2}$$

and

$$\sigma_\theta = -\frac{a^2b^2}{b^2-a^2}\left(\frac{Po}{r^2}\right) + \frac{Poa^2}{b^2-a^2} \quad \text{...........(4)}$$

where a = inner radius of plastic pipe
b = outer radius of plastic pipe
r = is a value between a and b

When the above stresses are substituted into the corresponding strain-stress relationships nd the resulting strains integrated into the strain-displacements equations, the radial displacements of the concrete are 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 radial pressure becomes:

$$P_0 = -\frac{\mu\sigma_{cz}}{1-\mu_c + \frac{E_c}{E_p}\left(\frac{b^2+a^2}{b^2-a^2}\right) + \mu_p} \quad \text{............(5)}$$

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

$$P_0 = -\frac{\mu_c\sigma_z}{1-\mu_c + \frac{E_c}{E_p}\left(\frac{D}{2t}\right)} \quad \text{.........(6)}$$

The corresponding tangential stress equation then becomes:

$$\sigma_\theta = \frac{P_0 D}{2t} \quad \text{..................(7)}$$

The above analysis shows that, as the axial stress of the concrete core is increased, the effective radial pressure will also increase. It is this effective radial pressure that increases the 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, P_b is obtained from the relationship:

$$\alpha = \frac{f_{max} - f_c}{P_b}$$

Where

$$P_b = \frac{2F_{pt}}{D}$$

It should be noted that the average value for a is relatively insensitive to pipe material.

2.0 MATERIALS

2.1 POLYVINYL CHLORIDE (PVC) PIPES

The PVC pipes used had a material tensile strength of 45.0MN/m² as determined from a textile test. Two pipe diameters of 100.0mm and 75.0mm with 3.0mm and 2.0mm thicknesses respectively were used. The pipes were cut into lengths varying from 20.9mm to 1210.0mm, so as to obtain short and slender columns.

2.2 CONCRETE

Two types of concrete mixes were prepared. The first mix 1:1.5:3 had a water/cement(w/c) ratio of 0.55 while the other mix, 1:1:2 had a 0.65 w/c ratio. For both mixes, the maximum size of coarse aggregate used was 9.4mm.

3.0 EXPERIMENTAL PROCEDURE

Tests were performed on column samples prepared from the two concrete mixes and grouped into three series. The first group comprised of samples prepared from the 1:1:5:3 mix. Samples prepared from the 1:1:2 formed the second group. The third group comprised of samples prepared from the 1:1.5:3, but reinforced with 6.0mm diameter mild steel bars. Except for the third group, all groups include unconfined samples. Each group of samples were prepared at a week's interval and marked for identification.

The samples were air-dried in a humid environment, except for the unconfined samples which were tested after 28 days of curing. All columns were tested under and compressive loading using a Universal Testing Machine. In testing, the load was progressively increased until failure occurred. The mode of failure and failure load of the columns were observed and recorded. Concrete cube strengths were also determined for each group of samples.

4.0 RESULTS AND DISCUSSIONS

All column samples were observed to have failed from the upper end, while the colour of the pipes changed to white at the locations of failure. The unconfined columns failed by shearing (diagonal failure), while the confined columns underwent compression failure. Whereas the short columns bulged at the upper ends, the slender columns buckled in addition to bulging at the upper ends. The test results are as shown in tables 1, 2, and 3. Samples A_1 A_2 A_3 A_4 A_5 A_6 A_7 and B_1 B_2 B_3 B_4 B_5 B_6 B_7 are unconfined samples. All other sample" were clearly confined.

The effect of confinement plastic pipe on the compressive strength of the concrete core is evaluated by calculating the non-dimensional constant, , which relates the increase in concrete core compressive strength, ($f_{max} - f_{c1}$), to the lowest pressure of the pipe, P_b.

That is

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

and

$$P_b = \frac{2F_p t}{D} \qquad (9)$$

For example,

for α - Value for sample A_{11},

$$P_b = \frac{2 \times 45 \times 3}{101.2} = 2.66\text{N/mm}^2$$

$$f_{max} = 25.73\text{N/mm}^2 \text{ ; } f'_c = 16.69\text{Nmm}^2$$

$$\alpha = \frac{25.73 - 16.69}{2.66} = 3.40$$

for α - Value for sample A_{51},

$$P_b = \frac{2 \times 45 \times 2}{76.2} = 2.36\text{N/mm}^2$$

$$f_{max} = 18.43\text{N/mm}^2 \text{ ; } f'_c = 11.85\text{Nmm}^2$$

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

for α - Value for sample B_{51},

$$P_b = \frac{2 \times 45 \times 2}{76.2} = 2.36\text{N/mm}^2$$

$$f_{max} = 23.69\text{N/mm}^2 \text{ ; } f'_c = 16.45\text{Nmm}^2$$

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

α - values are similarly calculated for all samples tested, excluding those reinforced, and the results are summarized in table 4.

As can be observed from table 4, the compressive strength of the concrete core of 1:1.5:3 mix increased by an average value of 3.41 x pipe burst pressure for the 775.0mm diameter pipe and 2.75 x pipe burst pressure for the 75.0mm diameter pipe and 4.12 x pipe burst pressure for the 100.0mm diameter pipe. The concrete strength affects the ultimate column strength as can be seen from tables 1 and 2. The columns of average concrete strength 35N/mm² had higher ultimate strengths than those of average concrete strength 32.22Nmm².

The effect of the slenderness ratio on the column load-carrying capacity can be obtained from figure 2. It can be seen that shorter columns sustained from figure 2. It can be seen that shorter columns sustained higher loads than slender columns.

The longitudinal reinforcement had negligible contribution to the ultimate strength of the columns, with slight increase occurring at slenderness ratios of 25 and above. The reinforcement however, contributed significantly to the buckling of columns under compressive loading.

5.0 CONCLUSIONS

From the results of the experimental investigation carried out, the following conclusions are made:

1. The PVC pipe provided sufficient lateral support for the concrete core and increased the ultimate strength of the concrete core, the magnitude of which can be predicted by a linear relationship between the pipe burst pressure and the unconfined strength of the concrete core.
2. The ultimate strengths of the confined columns are influenced by the concrete design strengths. [Tables 1 and 2]
3. The ultimate strengths of the confined columns decreases as the slenderness increases. [Tables 1 and 2]
4. The longitudinal reinforcement does not have any appreciable influence on the strength of the confined concrete core.
5. The structural concept investigated has beneficial safety features, in that large and noticeable deformations of the PVC pipe is observed before total failure occurs.

5. REFERENCES

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LIST OF TABLES

TABLE 1a

COLUMN LABEL	COLUMN LENGTH [mm]	SLENDERNESS RATIO	MEAN ULTIMATE COLUMN LOAD [KN]
$A_{11}, A_{12}, A_{13}, A_1$	1210.0	47.63	200.0
$A_{21}, A_{22}, A_{23}, A_2$	810.0	31.89	216.0
$A_{13}, A_{32}, A_{33}, A_2$	410.0	16.14	236.0
$A_{41}, A_{42}, A_{43}, A_2$	210.0	8.27	248.0

MIX RATIO 1:1.5:3 PIPE DIAMETER = 101.6mm THICKNESS = 3.0mm

TABLE 1b

COLUMN LABEL	COLUMN LENGTH [mm]	SLENDERNESS RATIO	MEAN ULTIMATE COLUMN LOAD [KN]
$A_{51}, A_{52}, A_{53}, A_5$	1000.0	52.49	84.00
$A_{61}, A_{62}, A_{63}, A_6$	810.0	42.52	103.0
$A_{71}, A_{72}, A_{73}, A_7$	410.0	20.99	128.0

MIX RATIO 1:1.5:3 PIPE DIAMETER = 76.2mm THICKNESS = 2.0mm

1(b)

TABLE 1 RESULTS OF COMPRESSIVE STRENGTH TEST FOR GROUP 1 COLUMN SAMPLES

TABLE 2a

COLUMN LABEL	COLUMN LENGTH [mm]	SLENDERNESS RATIO	MEAN ULTIMATE COLUMN LOAD [KN]
$B_{1b}, B_{12}, B_{13}, B_1$	1210.0	47.63	236.0
$B_{2b}, B_{22}, B_{23}, B_2$	810.0	31.89	246.0
$B_{3b}, B_{32}, B_{33}, B_2$	410.0	14.4	259.0
$B_{4b}, B_{42}, B_{43}, B_4$	210.0	8.27	268.0

MIX RATIO 1:1.0:2 PIPE DIAMETER = 101.6mm THICKNESS = 3.0mm (2a)

TABLE 2b

COLUMN LABEL	COLUMN LENGTH [mm]	SLENDERNESS RATIO	MEAN ULTIMATE COLUMN LOAD [KN]
$B_{51}, B_{52}, B_{53}, B_5$	1000.0	52.49	108.00
$B_{61}, B_{62}, B_{63}, B_6$	810.0	42.52	124.00
$B_{71}, B_{72}, B_{73}, B_7$	410.0	20.99	140.00

MIX RATIO 1:1.0:2 PIPE DIAMETER = 76.2mm THICKNESS = 2.0mm (2b)

TABLE 2 RESULTS OF COMPRESSIVE STRENGTH TEST FOR GROUP 2 COLUMN SAMPLES

TABLE 3a

COLUMN LABEL	COLUMN LENGTH [mm]	SLENDERNESS RATIO	MEAN ULTIMATE COLUMN LOAD [KN]
$B_{1b}, B_{12}, B_{13}, B_1$	1210.0	47.63	236.0
$B_{2b}, B_{22}, B_{23}, B_2$	810.0	31.89	246.0
$B_{3b}, B_{32}, B_{33}, B_2$	410.0	14.4	259.0
$B_{4b}, B_{42}, B_{43}, B_4$	210.0	8.27	268.0

MIX RATIO 1:1.0:2 PIPE DIAMETER = 101.6mm THICKNESS = 3.0mm (2a)

TABLE 3b

COLUMN LABEL	COLUMN LENGTH [mm]	SLENDERNESS RATIO	MEAN ULTIMATE COLUMN LOAD [KN]
$C_{1b}, C_{12}, C_{13}, C_1$	1210.0	47.63	216.0
$C_{2b}, C_{22}, C_{23}, C_2$	810.0	31.89	220.0
$C_{3b}, C_{32}, C_{33}, C_2$	410.0	14.4	233.0
$C_{4b}, C_{42}, C_{43}, C_4$	210.0	8.27	264.0

MIX RATIO 1:1.5:3 PIPE DIAMETER = 101.6mm THICKNESS = 3.0mm Concrete reinforced with 6mm diameter mild steel.

TABLE 3: RESULTS OF COMPRESSIVE = STRENGTH TEST FOR GROUP 3 (REINFORCED) COLUMN SAMPLES

MIX RATIO	PIPE DIAMETER (mm)	PIPE BURST PRESSURE (N/mm^2)	RANGE OF - VALUES	AVERAGE OF - VALUES
1:1.5:3	75.0	2.36	2.69-4.28	3.41
	100.0	2.66	2.01-3.40	2.75
1:1.0:3	75.0	2.36	3.06-4.09	3.62
	100.0	2.66	3.99-4.27	4.12

TAB 4 SUMMARY OF CALCULATED α Values.