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TAJUK PROJEK : Analysis of reinforced concrete columns concealing rain water pipes in mult-storey buildings

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ANALYSIS OF THE REINFORCED CONCRETE COLUMNS CONCEALING RAIN WATER PIPE IN MULTI-STOREY BUILDINGS

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Abstrak

Tiang kinkrit bertetulang yang melitupi paip saliran air PVC digunakan dengan meluas dalam pembinaan bangunan bertingkat. Kajian ini dibuat bagi menyiasat kesan paip ini ke atas kekuatan tiang dan keupayaan membawa beban. Kajian dibuat secara ujikaji makmal dan analisis berangka. Sejumlah 28 tiang telah disediakan tetapi ujian mampatan paksi hanya dijalankan ke atas tiang-tiang yang sesuai (tanpa kecacatan). Satu kaedah meluruskan kedudukan tiang telah dibangunkan dan digunakan dalam ujikaji ini sebelum tiang dibebani. Hasil kajian menunjukkan tiang yang melitupi paip PVC mengalami pengurangan keupayaan membawa beban yang ketara. Kehadiran paip PVC memberi kesan yang nyata ke atas kekuatan tiang dan dan juga mod kegagalan tiang.

Selain dari ujikaji makmal, analisis menggunakan kaedah analisis unsur terhingga 3-dimensi juga telah dijalankan. Perbandingan yang dibuat menunjukkan analisis unsur terhingga memberikan faktor keselamatan yang lebih tinggi berbanding ujikaji makmal.

Sebagai kesimpulan dari kajian dibuat, prestasi tiang yang mengandungi paip PVC berada pada tahap yang kritikal dan boleh memberikan kesan terhadap keselamatan bangunan. Adalah dicadangkan agar satu kaedah yang lebih baik dicari untuk meletakkan paip PVC bagi tujuan saliran air. Antara kaedah yang boleh dikaji adalah meletakkan paip diluar tiang atau menggantikan paip PVC dengan paip keluli.

Abstract

Reinforced concrete columns concealing PVC drain water pipe have been used widely in the construction of multi storey buildings. The purpose of the investigation is to study the deficiencies caused in the strength and load carrying capacity of these columns through experimental and numerical analyses. A total number of 28 columns have been cast and only the appropriate ones which were without defects, have been tested under the axial compressive load. An approximate method of alignment for constructed columns has been developed and the alignment of the columns has been carried out before their testing. The study shows these columns have huge reduction in their load carrying capacities. The investigation showed that concealing drain pipes inside these columns had significant effects on their strength and mode of failure.

Three-dimensional finite element analysis of the above mentioned columns have also been carried out to investigate the effects of drain pipes on load carrying capacities of the columns. The numerical investigation predicts higher factors of safety than the experimental results.

In conclusions, the factors of safety obtained from experimental study shows that, the performance of the columns are in a critical level and could be hazardous to the safety of the building. Therefore an improved method of positioning the drain pipes outside the columns as well as the replacement of the PVC pipes by steel has been proposed.

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APPENDIX

Published research paper:

A critical review of the reinforced concrete columns and walls concealing rain water pipe in multistory buildings.

CHAPTER I

INTRODUCTION

1.0 Introduction

The drainage of rain water from the roof top of the building is always considered and properly handled in the Malaysian buildings construction. In many occasion rain water from the roofs are drained through PVC pipes concealed in the reinforced concrete walls and columns and taken out i.e. discharged at the ground level as shown in Fig.1. This common practice has been adopted on the basis that, projecting the pipes outside the columns can affect appearance of the buildings.

Columns are important vertical compression members of structural frames intended to support load carrying beams. Failure of columns in a critical location can cause the progressive collapse of the adjoining floors and the ultimate total collapse of the entire structure. Therefore, considering the useful life of the structures, the method of drainage can be hazardous to the safety of the buildings.

However, knowledge on the performance of this type of columns under different loading conditions are insufficient and limited.

Columns constructed with PVC pipes not only reduce the load carrying capacity of the columns but could be very dangerous to the safety of the building. The method may cause various difficulty in the construction of the columns. Positioning the drain pipes in the corner or at the edge of the column's section may significantly reduce the effective cross-sectional area of the column. The pipe may not be held at the central position inside the column, because during casting and vibration of the concrete there are chances that the pipe may get an inclined position that can further reduce the load carrying capacity of the columns. The fact that the PVC pipes may have leakage at their lapping / joints and in long terms the leakage can cause rusting of the reinforcement in the column hence, loss of bond and reduction in the strength of the structural elements. Due to the presence of the drain pipe in the beam-column joints, there will be heavy congestion and irregularities in the reinforcement of the structure.

1.1 Objective of the study

The main objectives of this investigation are:

a) To investigate the reduction in the load carrying capacity of RC columns which conceal PVC drain pipes.

b) To study the effect of drain pipes on the slenderness behaviour and buckling mode of columns.

1.2 Scope

The main scope of the investigation is to construct and test various reinforced concrete columns with different cross-sectional sizes representing vertical members of multi-storey buildings with PVC drain pipes within them. In order to verify the experimental results, the models are analyzed using finite element method.

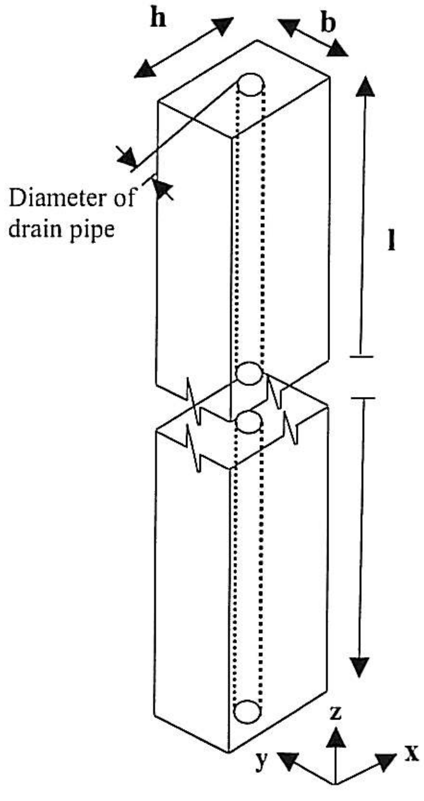

Figure 1: Typical column showing the position of drain pipe

1.3 Background of the problem

Tropical countries such as Malaysia are having heavy rainfall throughout the year, which requires an effective and proper drainage system in the construction of any new building project which has been taken care. Concealing the PVC drain pipes inside the reinforced concrete columns and walls in the building structures is a common practice in Malaysian construction industries. This condition has been imposed by the architects claiming the projecting them outside the columns will affect the appearance of the building. However, concealing the drain pipes inside the columns in buildings not only reduce the load carrying capacity of the columns but can be dangerous to the building safety as well.

The dangers arising from the concealment of the water pipes in the building's columns are as follows:

a) The pipes cannot be held at central position in the columns because, during concreting and vibrating the concrete there are chances that the pipes may be shifted to one side or may get an inclined position which will cause further decrease in load carrying capacity of the columns.

b) There are chances of honeycomb formation around the drain pipes.

c) The pipes may have leakage in their lapping parts or joints, which in long term can cause rusting in columns' reinforcement. Hence, loss of bond and reduction in the strength of columns.

d) Due to the presence of drain pipe in beam-column joints, the beam reinforcement have to be bent, which cause irregularity and non uniformity in the beams' reinforcement and hence a reduction in strength of the beams.

e) Elbow part of the pipe, which is used to drain the water at ground level is causing a huge reduction in the column's strength at base level(i.e. ground level).

Therefore, investigation is needed to estimate the reduction in load carrying capacity of columns containing PVC drain pipes. The research also propose a simple and efficient alternative solution to the problem (refer to the Appendix).

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Reinforced concrete columns concealing circular PVC drain pipe have been used in high-rise buildings in most of southeast Asian countries including Malaysia. However, no significant investigations on the performance of these types of columns under different loading conditions have been carried out. Most of the previous works in this regard have been limited to the effects of constant axial load and eccentric load on the behaviour of rectangular and circular hollow reinforced concrete columns [1,2,3,4,5,6,7].

Mander [2] has investigated the flexural strength and ductility of rectangular and circular hollow RC columns. Such columns, when properly detailed, were shown to perform an inelastic behavior in cyclic lateral loading. Inoue et al. [2] focused on the deterioration of concrete shear resistance for hollow column. They have concluded that the reduction in concrete shear resistance should be considered in the design of RC columns having hollow sections.

The purpose of this research is to investigate the compressive strength and performances of rectangular RC short braced columns (models) having rain water pipes inside them.The hysteretic performance of the columns are evaluated using various cross-sections with different amount of reinforcement as well as different sizes of drain pipes.

ACI code recommends a considerably higher strength reduction factor for the design of compression members than the reduction factors proposed for the members designed for flexure, shear or torsion.

Failure of columns occur as a result of material failure by initial yielding of the steel at the tension face or initial crushing of the concrete at the compression face or by loss of lateral structural stability (i.e. through buckling). If a column fails due to initial material failure, it is classified as a short column. As the length of the column increases, the probability that failure will occur by buckling also increases. Therefore, the transition from short column (material failure) to the long column (failure due to buckling) is defined by using the ratio of the effective length to the radius of gyration r.

2.2 American Concrete Institute ACI-318 recommendation

The maximum concentric load capacity of the columns can be obtained by adding the contribution of the concrete, which is $(A_g-A_{st})0.85f_c'$, and the contribution of the steel, which is $A_{st}f_y$, where A_g is the total gross area of the concrete section an A_{st} is the total steel area = $A_s + A'_s$. Thus the nominal concentric load capacity, P_o can be expressed as

$$Po = [0.85f_c(A_g - A_{st}) + f_yA_{st}] \qquad \text{... (1)}$$

it should be noted that concentric load causes uniform compression through out the cross section. Consequently, at failure the strain and stress will be uniform across the cross section.

It is highly improbable to attain zero eccentricity in actual structures. Eccentricities could easily develop because of factors such as slight inaccuracies in the layout of columns and unsymmetrical loading due to the difference in thickness of the slabs in adjacent spans or imperfection in the alignment, as indicated earlier. Hence a minimum eccentricity of 10% of the thickness of the column in the direction perpendicular to its axis of bending is considered as an acceptable assumption for columns with ties and 5% for spirally reinforced columns.

To reduce the calculation necessary for analysis and design for minimum eccentricity, the ACI code specifies a reduction factor in the axial load for tied columns and spiral columns. Using this factors, the maximum nominal axial load capacity of tied columns cannot be taken greater then

$$\phi P_{n(max)} = 0.85\phi[0.85f_c(A_g - A_{st}) + f_yA_{st}] \qquad \text{...(2)}$$

Normally, for the design purposes, A_s- A_{st} can be assumed to be equal to A_g without great loss in accuracy.

2.3 BS 8110 Recommendations for short braced and axially loaded columns

British Standards for structural use of concrete, BS 8110 : Part 1 : 1997 has recommended that the design ultimate axial load for a short braced column supporting an approximately symmetrical arrangement of beams can be calculated using the following equation(equation 39 of the code):

$$N = 0.35f_{cu}A_c + 0.7A_{sc}f_y \qquad \text{...(3)}$$

CHAPTER III

METHODOLOGY

3.0 Introduction

The research has been carried out using two methods of analysis, namely experimental Investigation and numerical analysis. In numerical analysis, the concrete and longitudinal reinforcement have been represented by brick element and bar element respectively.

3.1 Experimental study

The experimental work plan includes concrete mix design, casting of the reinforced concrete columns concealing PVC drain pipes, instrumentation and their testing. An approximate method of alignment for the constructed models has also been developed and used.

3.1.0 Construction of the models

3.1.1 Mix design

Using the procedures recommended by BS 8110 and BS 5328 codes of practice, a mix design for the grade 35 concrete was prepared. Few cube samples were cast and tested after 28 days which showed compressive strengths of 35 N/mm^2 to 40 N/mm^2. Therefore, the water/cement ratio, cement, sand and aggregate proportions for concrete of the models have been established.

3.1.2 Casting and curing of the models

Due to the space limitation in the testing hall, as well as ease in construction and handling of the models, half scale models having same slenderness ratio of the full scale columns were selected in this study. Therefore height in all models has been kept to 1.5m.

Deformed steel bars having yield strength of 460 N/mm^2 were used in the models. After completion of reinforcement details (i.e. bars cutting and bending) using water proof grade one plywood, appropriate formwork for the models were prepared. Extra care has been taken to maintain the verticality and designated size of the columns. Column dimensions, drain pipe size and reinforcement bars used in different models are shown in Table.1. The concreting of the models has been carried out inside the Structural Engineering laboratory, during which cube samples have been prepared in random order. This is needed in order to assess the actual strength of the concrete in the models.

The surface of the models have been kept moisten / wet for at least thee days. After removal of the formwork the models were kept undisturbed for 28 days. Then the alignment of the models were carried out.

Table 1: Column dimensions, drain pipe size and reinforcement bars used in the models

Column designation	Column size (mm)			Drain pipe dia. (mm)	Reinforcement bar
	h	b	l		
C1a	125	125	1500	33.5	4Y8
C1b	125	125	1500	33.5	4Y10
C2a	150	150	1500	48.0	4Y10
C2b	150	150	1500	48.0	4Y12
C3a	200	200	1500	60.5	4Y12
C4a	175	175	1500	48.0	4Y10
C5a	250	225	1500	60.5	4Y12
C5b	250	225	1500	60.5	4Y16
C5c	250	225	1500	60.5	4Y20
C6a	250	250	1500	89.0	4Y12
C6b	250	250	1500	89.0	4Y16
C6c	250	250	1500	89.0	4Y20
C7a	300	225	1500	60.5	4Y16
C7b	300	225	1500	60.5	4Y20

3.1.3 Columns alignment technique

Full attention has been paid to prepare the columns formworks such that to produce the exact dimensions of the models and to maintain the verticality in the models after removal of the formworks. However, there are always certain minor problems such as construction tolerances, changes caused to the formworks by concrete vibration and shrinkage effects which may cause some changes in the dimensions and verticality of the models. Therefore, an approximate method of alignment for the columns has been developed. Using this method, column's ends have been leveled with help of high-alumina cement mix. The steps followed in the alignment are:

(i) Positioned the column vertically on a leveled ground surface as shown in Fig. 2(a).
(ii) Insert thin plywood wedges under the column until the spirit level readings on opposite faces of the column become identical. Without any movement in the column, the top end of the column is leveled using high-alumina cement mix as shown in Fig. 2(b). The models have been kept undisturbed for a minimum time of 24 hours.
(iii) After hardening of the high-alumina cement mix, the column position has been reversed i.e. made up side down on the leveled ground surface as shown in Fig. 2(c). In this position the spirit level reading on opposite faces of the column will be almost identical. As shown in the figure, the top end of the column has been leveled using high-alumina cement mix.
(iv) Fig. 2(d) represents a column with completed alignment which is ready for the instrumentation and testing.

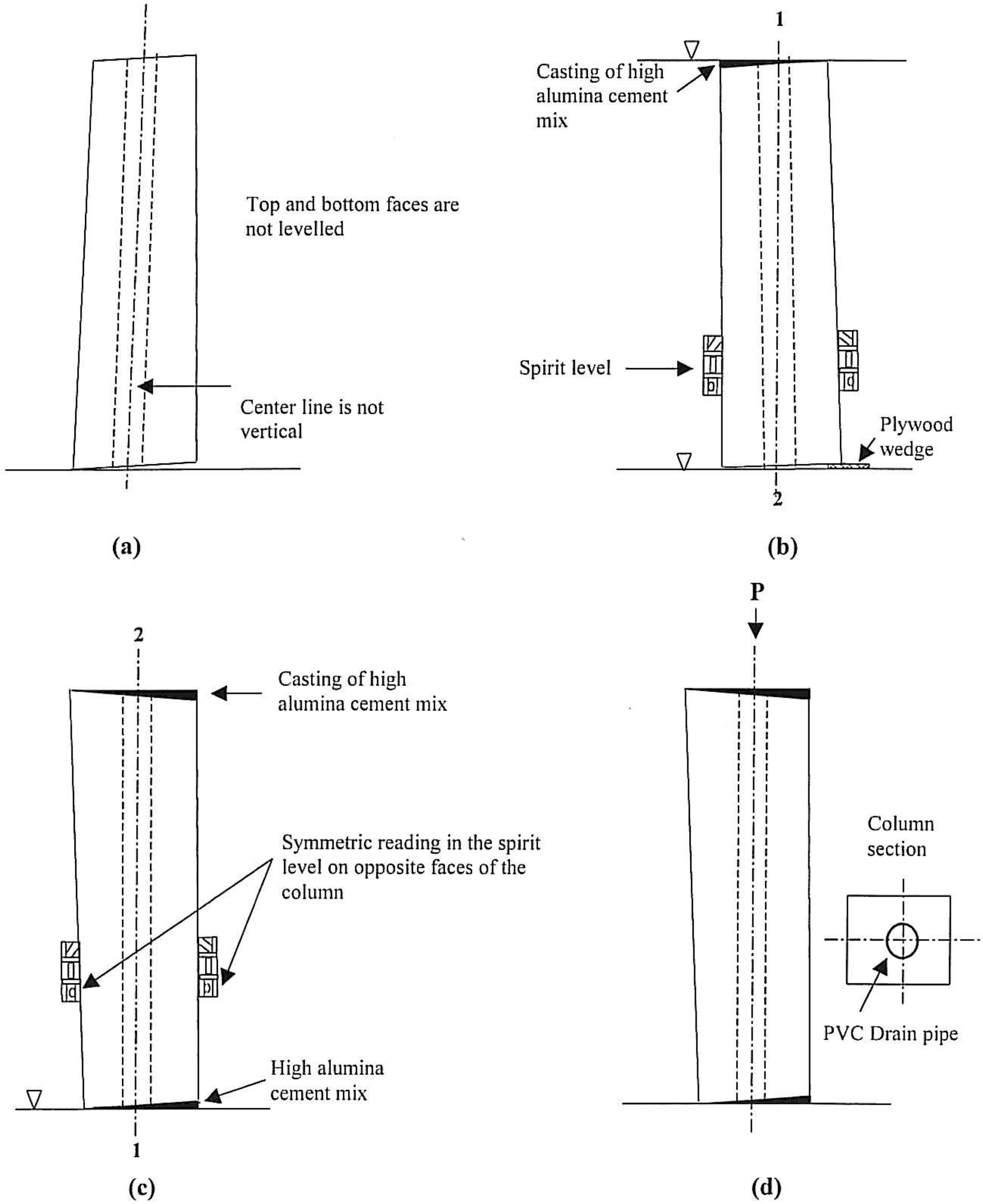

Figure 2: Steps in vertical alignments of the reinforced concrete columns

3.1.4 Testing of the models

Before the testing of the models instrumentation i.e. the installation of the strain gages on the models were carried out. In order to record the axial strains in the model two electric resistance strain gages on opposite vertical faces of the column at mid height level were installed. Two additional horizontal strain gages at the adjacent faces of the model near its top end were also fastened to monitor the lateral movement of the model.

In order to represent the restraint provided by the beams to the column in each floor level, in the test set up, at the ends of the model two set of rollers have been fastened to its opposite faces which are in turn fixed to a rigid steel frame to simulate the actual condition in the model.

The models have been tested using a 5000 kN capacity universal testing machine. The columns were loaded under monotonically increasing axial compressive loads. The axial strain readings were recorded after each increment of 20 kN. Fig.3 shows the collapse mode of a model which was typical in most of the columns.

Figure 3: Reinforced concrete columns showing the failure mode

3.2 Finite element modeling of the columns

Finite element method is a powerful numerical tool which can be used to analyze any complicated structure having complex loadings and boundary conditions. Using LUSAS computer software, three-dimensional nonlinear finite element analysis of various models has been carried out.

LUSAS is designed to be user friendly and interactive software. The input data consists of geometric data (rectangular column parameters in terms of cross-sectional dimensions), size and locations of longitudinal reinforcement, concrete and steel properties, as well as the applied loads, and the specific types of output to be generated from the analysis. Column's cross-sectional dimensions, reinforcement bars and drain pipe size assumed in the finite element analysis are shown in Table 2.

Using eight node, isoparametric brick elements for concrete and bar elements for steel, each model has been discretized into 280 elements. Perfect bond between steel and concrete is assumed.

Each model is assumed to be subjected to axial compressive load as shown in Fig. 4. The boundary condition adopted is that all nodes at the base of the models are assumed to be fixed. The assumed material properties for concrete and steel in the models considered in FEM are presented in Table 3. The generated mesh, applied load and boundary condition of the model are shown in Fig.4. In finite element modeling, the 25mm concrete cover to the reinforcement has also been considered.

Fig. 5 represents the deformed shape of column C1a and Table 6 shows the maximum vertical compressive stress and strain in each of the model analyzed using finite element method.

Table 2: Column dimensions, drain pipe sizes and reinforcement bars used in the models

Column designation	Column size (mm)			Drain pipe diameter (mm)	Reinforcement bar
	h	b	l		
C1a	125	125	1500	33.5	4Y10
C2a	150	150	1500	48.0	4Y10
C3a	200	200	1500	60.5	4Y10
C4a	175	175	1500	48.0	4Y10
C5c	250	225	1500	60.5	4Y16
C6a	250	250	1500	89.0	4Y12
C7a	300	225	1500	60.5	4Y16
C7b	300	225	1500	60.5	4Y20

Table 3: Material properties of the constituents of the model

Material types	Properties		
	Young modulus (N/mm^2)	Poisson's ratio	Characteristic strength (N/mm^2)
Concrete	27000	0.15	$f_{cu} = 35$
Steel	210000	0.3	$f_y = 460$

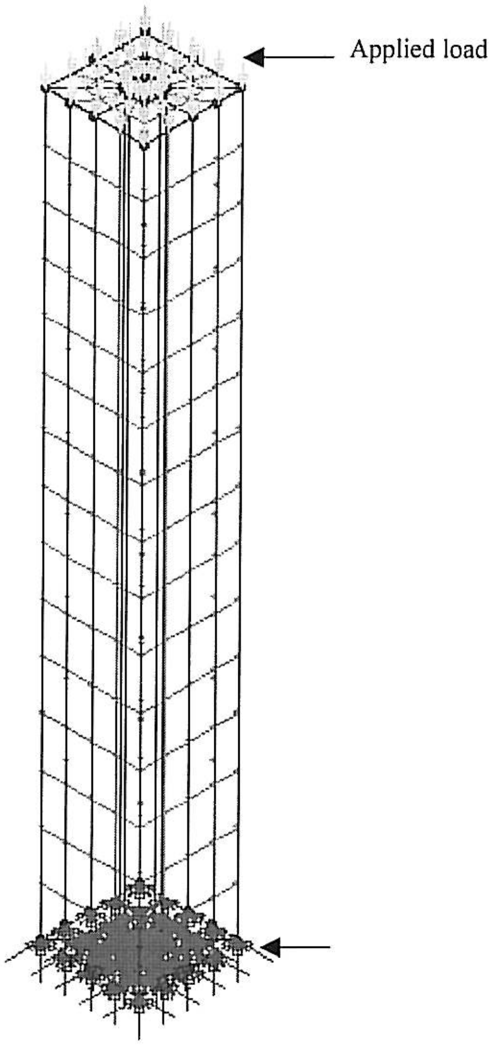

Figure 4: Typical model showing the generated mesh, applied load and boundary conditions

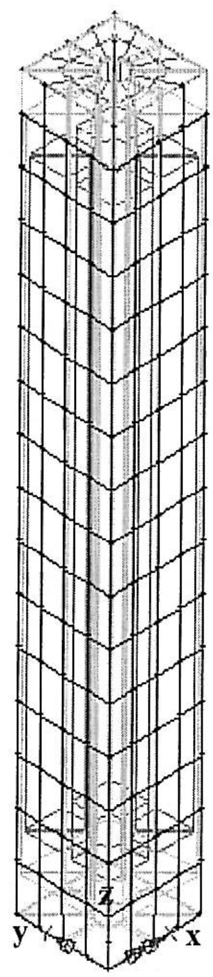

Figure 5: Deformed shape of model C1a (Deformation magnified 20 times)

CHAPTER IV

RESULTS AND DISCUSSION

4.0 EXPERIMENTAL RESULTS

The maximum vertical compressive stress and strain in each model recorded from experimental study are shown in Table.4

Table 4: Results from experimental study showing maximum vertical stresses and strains in the models

Model No.	Max. stress (N/mm^2) σ_z	Max. strain(mm/mm) ε_z
C1a	23.06	0.0008890
C1b	22.65	0.0007610
C2a	22.71	0.0009485
C2b	25.62	0.0007710
C3a	28.69	0.0017950
C4a	27.76	0.0014380
C5a	21.25	0.0014430
C5b	24.36	0.0017110
C5c	27.17	0.0021820
C6a	23.28	0.0011050
C6b	24.43	0.0010730
C6c	25.77	0.0011160
C7a	22.90	0.0003100
C7b	31.56	0.0011010

The results from experimental study in the form of vertical stress-strain curves for various tested models are shown in Fig.6 to Fig.12.

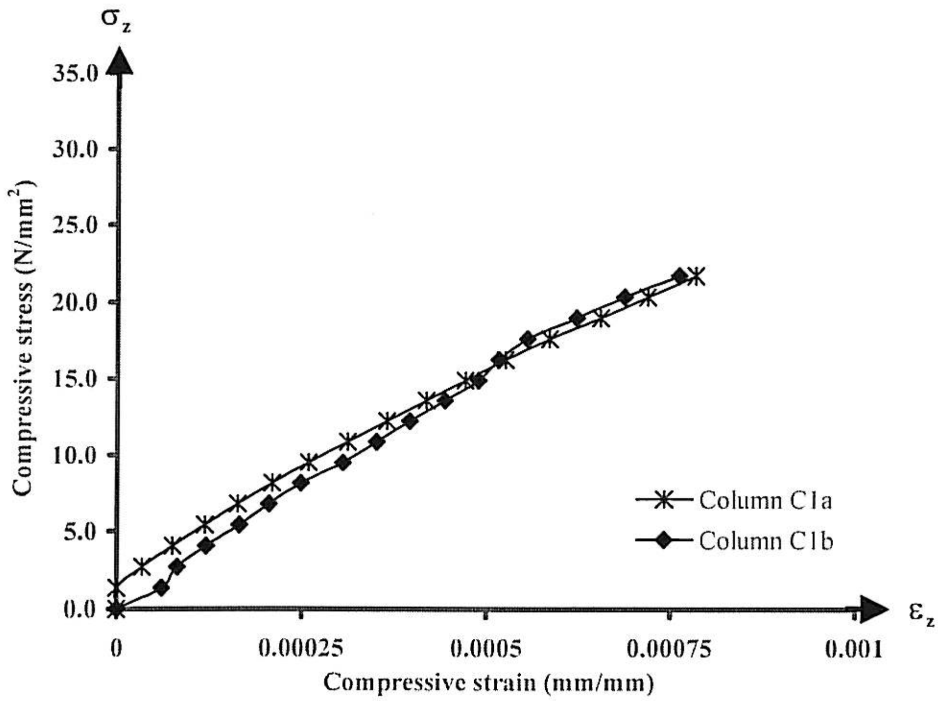

Figure 6 Stress-strain curve for column with cross section: 125x 125mm

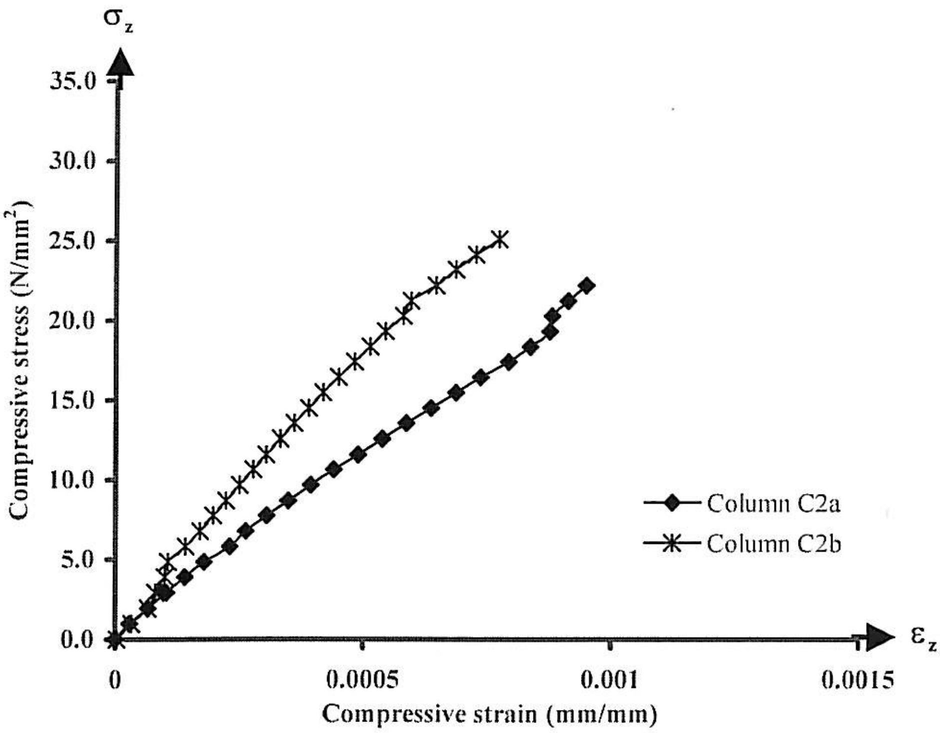

Figure 7.rain curve for column with cross section : 150 x 150mm

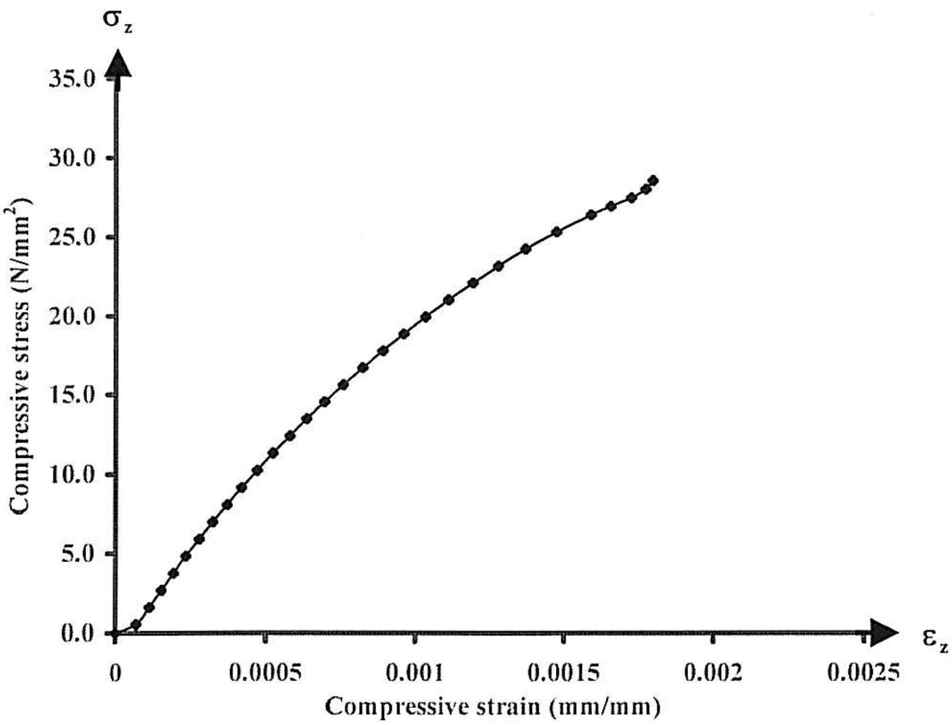

Figure 8 Stress-strain curve for column C3a with cross section : 200 x 200mm

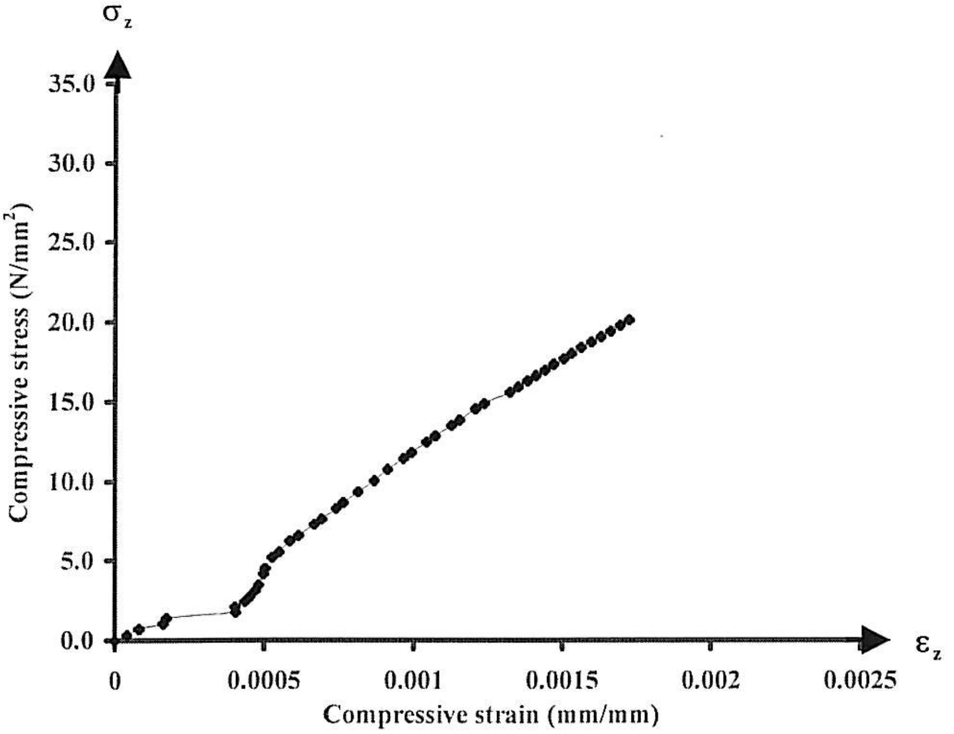

Figure 9 Stress-strain curve for column C4a with cross section : 175 x 175mm

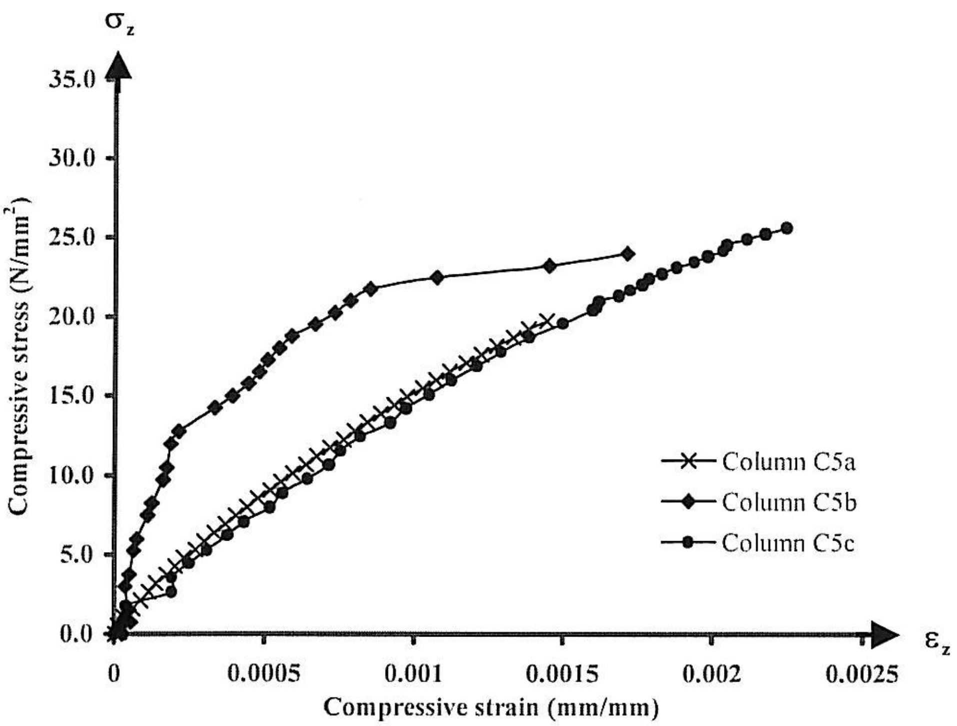

Figure 10 Stress-strain curve for column with cross section : 250 x 225mm

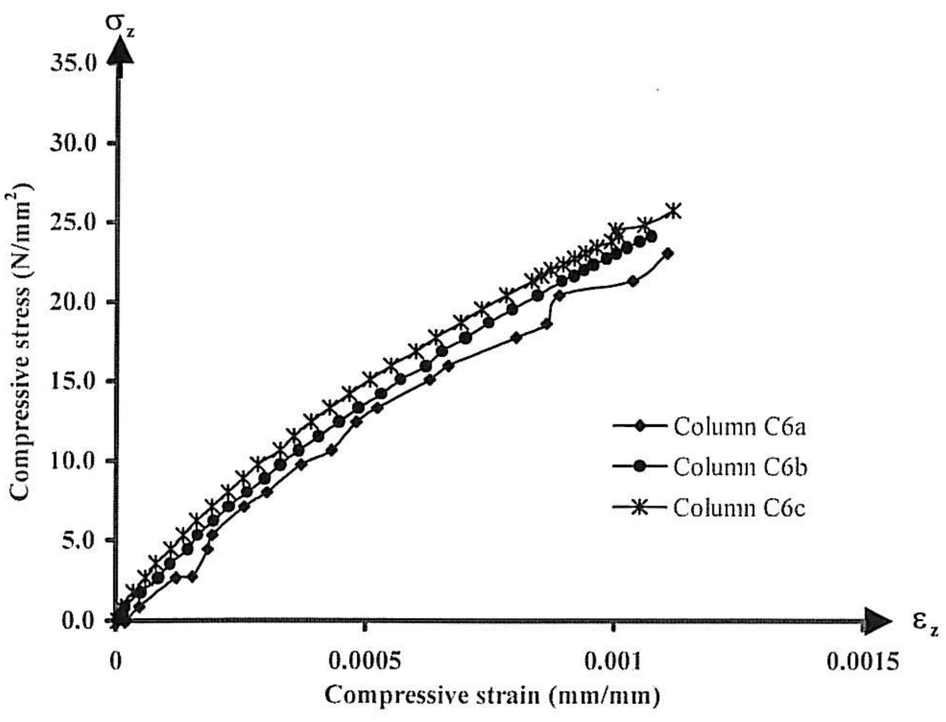

Figure 11 Stress-strain curve for column with cross section : 250 x 250mm

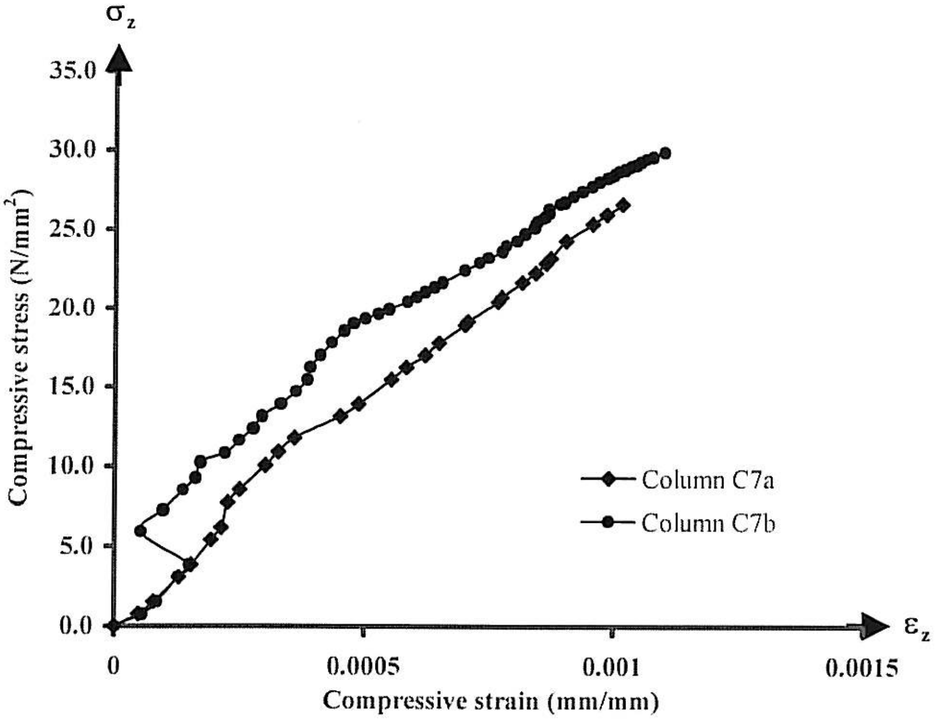

Figure 12: Stress-strain curve for column with cross section : 300 x 225mm

4.1 Calculation of ultimate strength

The maximum design axial load capacity of each column can be calculated using eqn. (2) recommended by the American Concrete Institute (ACI 318) and eqn. (3) recommended by the British code BS 8110 (equation 39 , BS 8110: part 1).

$$\phi P_{n(max)} = 0.85\phi[0.85f_c(A_g - A_{st}) + f_y A_{st}] \qquad ...(2)$$

$$N = 0.35f_{cu}A_{nc} + 0.7A_{sc}f_y \qquad ...(3)$$

where,.
A_g = gross area of the column section (mm^2)
A_{st} or A_{sc}= total area of longitudinal reinforcement (mm^2)
A_{nc}= net concrete area (mm^2)
f_{cu} or f_c = specified compressive strength of concrete (Mpa)

f_y = specified yield strength of reinforcement (Mpa)
ϕ = Strength reduction factor

The experimental collapse load and design strength calculated using eqns. (2) and (3) for each column are shown in Table.5. The factors of safety shown in Table 5 are obtained as experimental collapse load divided by design strength recommended by the ACI and BS codes of practices

Table 5: Results of experimental study showing the experimental collapse loads, design strength and factor of safety of the columns

Model	Failure load (kN)	Design load (kN) Using eq.(3)	Factor of safety using. BS code	Design load (kN) using eq.(2)	Factor of safety using ACI code
C1a	340	242.80	1.20	294.07	1.16
C1b	334	277.92	1.18	321.32	1.04
C2a	470	350.70	1.34	420.40	1.12
C2b	530	393.59	1.35	453.70	1.17
C3a	1065	594.90	1.79	727.51	1.46
C4a	800	450.30	1.78	555.76	1.44
C5a	1134	793.97	1.43	998.23	1.14
C5b	1300	902.95	1.44	1083.01	1.20
C5c	1450	1043.04	1.39	1192.01	1.22
C6a	1310	829.54	1.58	1046.60	1.25
C6b	1375	938.50	1.47	1131.38	1.22
C6c	1450	1078.66	1.34	1240.38	1.17
C7a	1480	1040.81	1.77	1270.43	1.45
C7b	2040	1181.03	1.73	1379.43	1.48

However the present study shows the factors of safety obtained for the models from experimental studies varies from 1.18 to 1.79 considering BS 8110 recommendation. The corresponding values obtained using ACI recommendation varies between 1.04 to 1.48. Theses are much lower than the recommended value of 2 to 3 by various codes of practice. This shows a huge reduction in the load bearing capacity of the columns containing drain pipes.

4.2 Numerical results

The maximum vertical compressive stress and strain in the models (both in concrete and steel) using finite element analysis are shown in Table 6. Figure 13 shows the contours for vertical stresses in model C7b.

Table 6: Finite element analysis results for different columns

Model No.	Normal stress* in concrete (N/mm^2)	Normal strain ** in concrete	Normal stress* in steel (N/mm^2)	Normal strain ** in steel
C1a	36.31	0.00275	251.45	0.00215
C2a	36.3	0.00272	256.46	0.00218
C3a	36.22	0.00251	260.95	0.00236
C4a	36.3	0.00241	256.44	0.00216
C5a	36.33	0.00324	258.47	0.00265
C6a	35.32	0.00236	258.61	0.00214
C7a	35.13	0.00302	257.63	0.00214
C7b	36.96	0.00305	256.31	0.00215

* Max. vertical compressive stress σ_z

** Max. vertical compressive strain ε_z

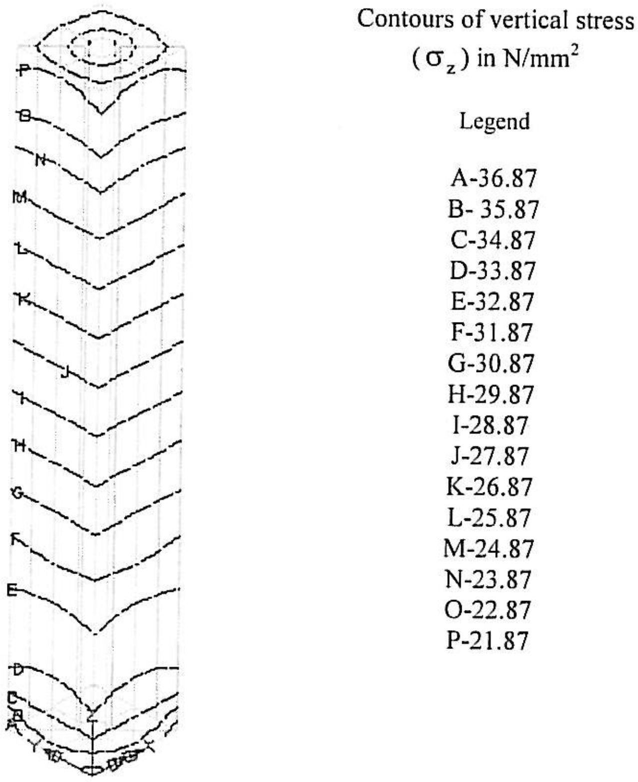

Figure 13: Vertical stress contour of model C7b

4.3 Comparison of the results

Maximum vertical compressive stresses and strains from experimental investigation and finite element study of the models are compared in Table.7.

Safety factors in the models obtained from experimental study, numerical analysis and eqn.(3) i.e. BS 8110 recommendation are shown in Table.8.

Similarly, safety factors in the models obtained from experimental study, numerical analysis and eqn. (2) i.e. ACI recommendation are shown in Table.9.

Table 7: Comparison of maximum vertical compressive stress and strain in the models from experimental study and finite element analysis.

Model No.	Max. compressive stress (N/mm^2) experimental	Max. compressive strain experimental	Max. compressive stress (N/mm^2) using FEM	Max. compressive strain using FEM
C1a	22.66	0.00167	36.31	0.00275
C2a	22.72	0.00184	36.34	0.00272
C3a	28.69	0.00196	36.22	0.00251
C4a	27.76	0.00174	36.3	0.00241
C5a	24.35	0.00254	36.33	0.00324
C6a	23.28	0.00175	35.32	0.00236
C7a	28.47	0.00113	35.13	0.00302
C7b	31.57	0.00121	36.96	0.00305

Table 8: Comparison of factors of safety from experimental study, finite element analysis and using eqn.1 (BS 8110)

Model No.	Design Load (kN) Using Eq.1	Max. Load (kN) (Experimental)	Factor of safety (Experimental)	Max. Load (kN) (FEM)	Factor of safety (FEM)
C1a	277.92	334	**1.20**	535.21	1.93
C2a	350.70	470	**1.34**	745.00	2.12
C3a	594.00	1065	**1.79**	1345.00	2.26
C4a	450.30	800	**1.78**	1045.86	2.32
C5a	902.95	1300	**1.44**	1939.29	2.15
C6a	829.54	1310	**1.58**	1987.73	2.40
C7a	1040.81	1840	**1.77**	2269.97	2.18
C7b	1181.03	2040	**1.73**	2389.00	2.02

Table 9: Comparison of factor of safety from experimental study, finite element analysis and e.q 2 (ACI 318)

Model	Design Load (kN) Using Eq.2	Max. Load (kN) (Experimental)	Factor of safety (Experimental)	Max. Load (kN) (FEM)	Factor of safety (FEM)
C1a	321.32	334	**1.04**	535.21	1.67
C2a	420.40	470	**1.12**	745.00	1.77
C3a	727.51	1065	**1.46**	1345.00	1.85
C4a	555.76	800	**1.44**	1045.86	1.88
C5a	1083.01	1300	**1.20**	1939.29	1.79
C6a	1046.60	1310	**1.25**	1987.73	1.90
C7a	1270.43	1840	**1.45**	2269.97	1.79
C7b	1379.43	2040	**1.48**	2389.00	1.73

The vertical stress-strain curves for few models both from experimental and finite element analysis are shown in Fig.14 to Fig.17.

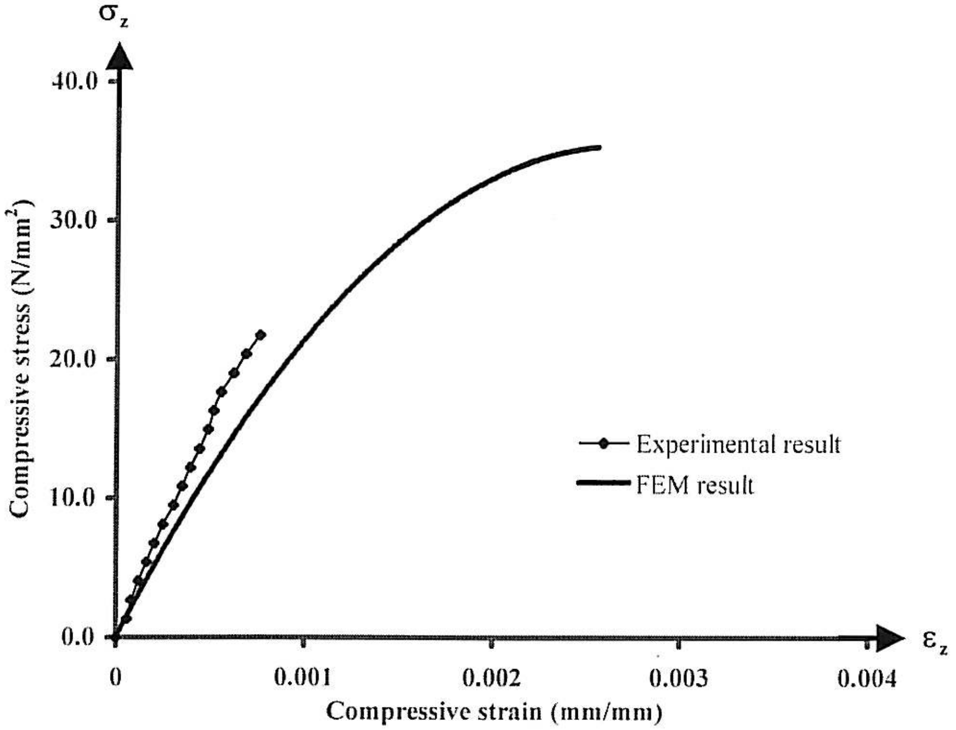

Figure 14: Vertical stress-strain curve for column C1a

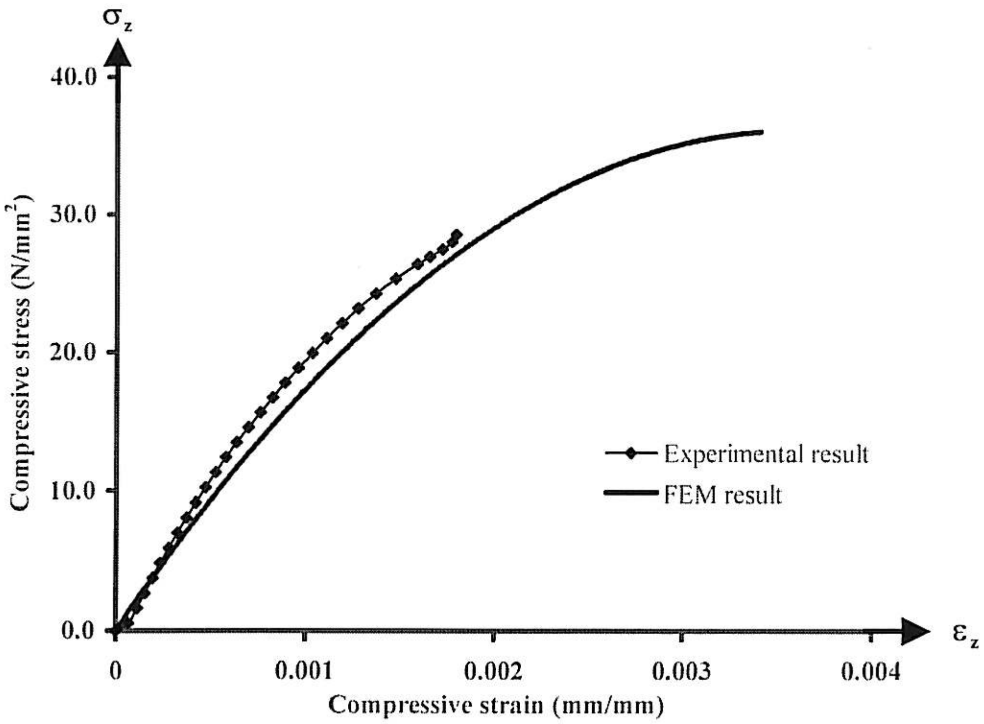

Figure 15: Vertical stress-strain curve C3a

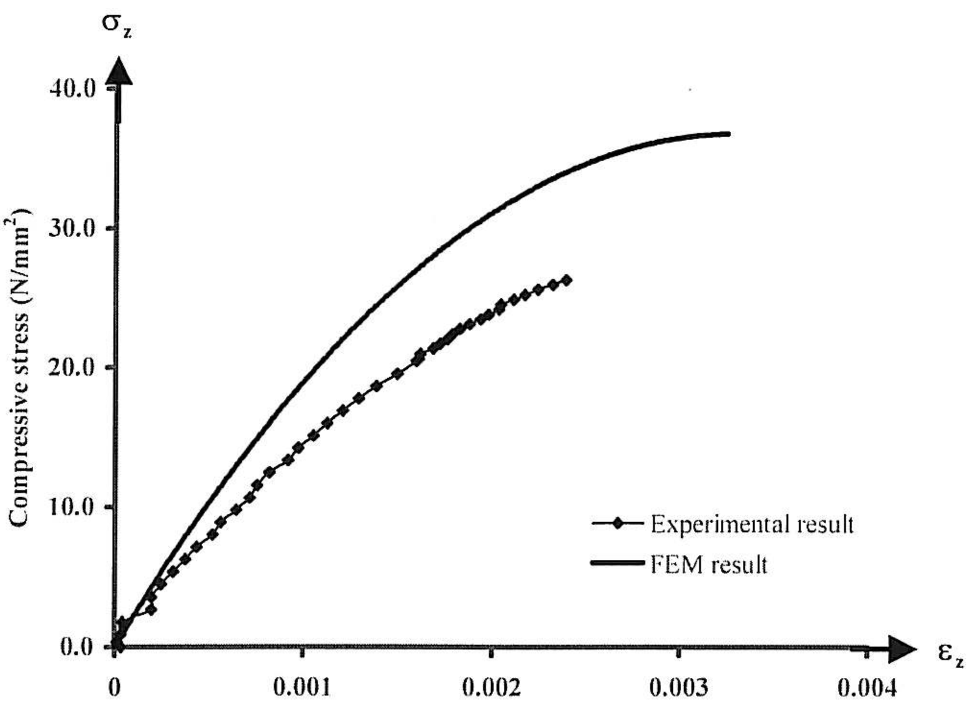

Figure 16: Vertical stress-strain curve for column C5a

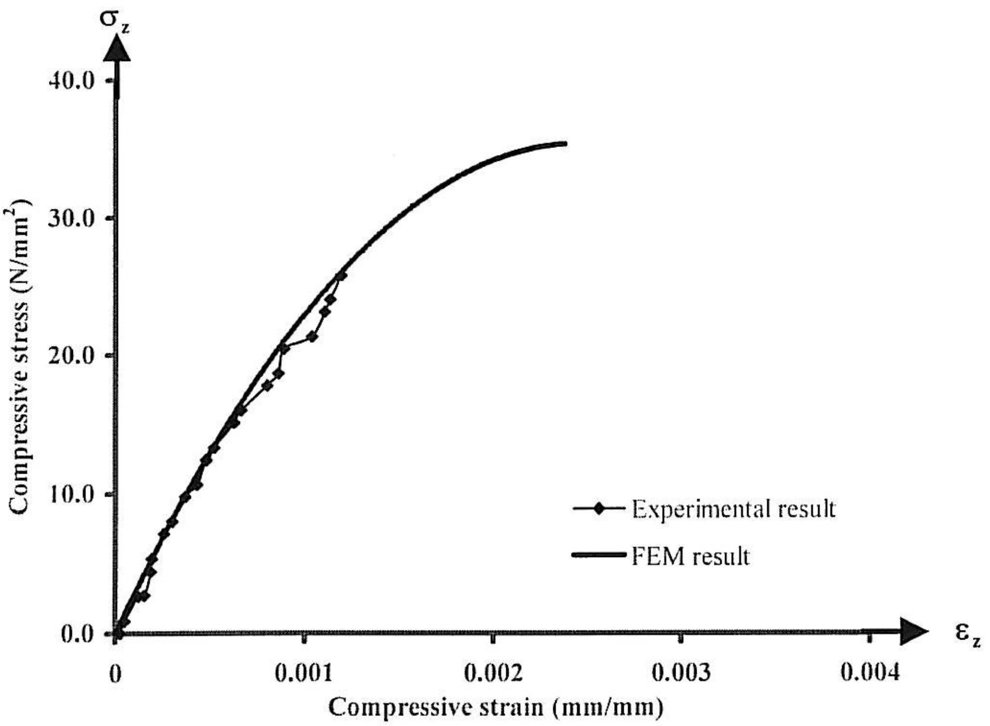

Figure 17: Vertical stress-strain curve for column C6a

Comparison of the results show that finite element modelling of the models predict much higher vertical compressive strength in the models.

Column is a key element in a structure therefore, it is important that these elements should be designed and constructed such that they should have full strength with factors of safety of 2 to 3 as recommended by various codes of practice.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The research has been carried out to investigate the deficiencies and reduction in load carrying capacity of the RC columns caused by concealing drain pipes within them. An approximate method of alignment for the testing of such columns has been developed and used. The following conclusions are drawn based on this study.

1) The load carrying capacity of the RC columns concealing PVC drain pipes inside them reduces significantly than the expected strength.

2) The present study shows the factors of safety of the models from experimental studies are between 1.18 to 1.79 based on the recommendation of BS code of practice i.e. BS : 8110-I : 1997. Based on the AC I recommendation, the safety factors in models varied between 1.04 to 1.48, which were much lower than BS code recommendation.

3) The finite element modelling of the columns predict much higher strength for the columns than experimental results, which might be due to the assumptions of consistent and uniform material in the models, the assumption of perfect verticality, perfect fixity assumption at the base of columns etc..

4) Considering the finding of huge reduction in the load carrying capacity of these types of columns, it is recommended that the design strength of the columns should be taken as half of the design strength calculated using eqn. (39) of the BS:8110.

5) As an alternative solution, PVC drain pipes can be replaced by steel pipes, positioned at the centre of the column section and should have proper coating in order to avoid rusting which may increase the strength of the column significantly.

6) As another alternative, it is proposed that the drain pipes can be placed outside the column's section passing through the corner of the slab adjacent to the column as shown in the appendix.

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The research carried out is financed by the research management centre of the Universiti Teknologi Malaysia. Their support is gratefully acknowledged.

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A CRITICAL REVIEW OF THE REINFORCED CONCRETE COLUMNS AND WALLS CONCEALING RAIN WATER PIPE IN MULTISTOREY BUILDINGS

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ABSTRACT

Various problems and deficiencies in the strength and load carrying capacity of the reinforced concrete (RC) walls and columns caused by concealing PVC drain pipes within them have been identified. Alternative methods of positioning the drain pipes outside the columns are proposed. An improved method of the present practice has also been suggested. Finally, the research methodology and investigation of this problem which is presently in progress at the Universiti Teknologi Malaysia, Skudai, has been outlined.

INTRODUCTION

Tropical countries such as Malaysia are having heavy rainfall throughout the year, which requires an effective and proper drainage system in the construction of any new building project.

The drainage of rain water from the roof top of the buildings is always considered and properly handled in the Malaysian buildings construction. In many occasions rain water from roofs are drained through PVC pipes concealed in the RC walls and columns and taken out i.e. discharged at the ground level. However, considering the useful life of the structures, this method of drainage can be hazardous to the safety of the buildings.

Through the intensive experience of the first author in the Malaysian buildings industry, it has been observed sometimes that even in two storey bungalows which are usually supported by 125x125mm or 150x150mm RC columns, the drain pipes are positioned inside the columns. Though in these cases the loads might not be very high, but considering the size of the columns it might cause serious danger to the safety of the structures in the long-term.

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PRESENT PRACTICE AND ITS SHORTCOMING

Concealing the PVC drain pipes inside the columns and walls in building structures is a common practice in Malaysian buildings. This condition has been imposed by the architects on the basis that projecting them outside the columns and walls will affect the appearance of the buildings.

However, concealing the drain pipes inside the columns and walls in buildings not only reduces the load carrying capacity of the columns and walls but could be very dangerous to the buildings safety as well. The dangers arising from the concealment of the rain water pipes in the building's columns and walls are as follows :

1. Positioning the drain pipe in the corner or at the edge of the column's section will virtually reduce the effective cross-sectional area of the column as indicated in Fig.1(a), (b), and (c). The pipe may not be held at central position in the column/wall, because during casting and vibrating of the concrete there are chances that the pipe may get an inclined position as shown in Fig.1(d), which will cause further decrease in load carrying capacity of the column / wall.

2. There are chances of honeycomb formation around the drain pipe in the column as shown Fig. 2.

3. The pipes may have leakage at their lapping parts or joints as indicated in Fig. 3, which in long-term can cause rusting of reinforcement in the structure hence, loss of bond and reduction in the strength of the structural elements .

4. Due to the presence of drain pipe in beam-column joints, the beam's reinforcement has to be bent as shown in Fig. 4, which causes irregularity and non-uniformity in the beam's reinforcement and hence a reduction in strength and functioning of the beam. The problem will be much critical in beams with higher percentage of reinforcement.

5. Elbow part of the pipe, which is used to drain the rain water at ground level may cause a huge reduction in the column's strength at base level. In the construction of building projects, occasionally it has occurred that the drain pipe has not been taken out at ground level i.e. the positioning of the elbow part of the pipe has been forgotten. To rectify this mistake, the concrete of the column's section at ground level has been hacked severely and then the elbow part of the pipe has been installed followed by grouting of fresh concrete as shown in Fig.5. However, the above mentioned method of rectification is very damaging to the robustness and safety of the structure.

6. In the case of RC walls, if the drain pipe is positioned at either end of the wall's section as shown in Fig. 6, it will be dangerous to the safety of the structure. This is because, the RC walls are mostly designed to resist lateral loads and are key elements in the building structures. Therefore, any deficiency at the end of the wall section which is usually a highly stressed zone in the wall, may cause a partial or full collapse to the structure.

PROPOSED SOLUTIONS

(a) Exterior Columns:

In the case of exterior columns in a building, the drain pipe can be placed outside the column's section and covered either in a concrete box section attached to the column or in a brickwork box section with concrete stiffeners as shown in Fig. 7. This method will be very helpful in case the drain pipe needs service at later stages.

(b) Interior Columns:

In the case of interior columns in a building, the drain pipes can be placed outside the column's section passing through the corner of the floor slab. Again they can be covered either in a concrete box or in a brickwork box section as shown in Fig. 8.

(c) Usage of steel pipe instead of PVC as an improvement of the present practice: The usage of steel pipes instead of PVC pipes is another alternative, provided that the steel pipes must have a proper coating in order to avoid rusting. In this method the steel pipes can be positioned at the center of the columns' section, which will act not only as drain pipes but also as a replacement for the concrete removed from the section.

(d) In concrete walls, the pipe can be placed at the middle third of the wall section preferably at the centroid of the section as shown in Fig. 9. This is because of the fact that mostly the extreme edges of the wall will have higher stresses than the middle part of its section. In case of any deficiency / failure in the wall around the drain pipe, the wall will virtually be converted to two walls with smaller sections rather than partial or total collapse of the wall. However, in this case as a precautionary measure additional reinforcement around the pipe should be provided.

EXISTING DESIGN PRACTICE

The columns concealing drain pipes are usually designed by the Malaysian practicing engineers on the basis of their reduced cross-sectional areas A_r which is calculated as follows:

$$A_r = A_g - A_p \qquad (1)$$

where, A_r is reduced area of the section of the column, A_g is gross area of the column's section, and A_p is cross-sectional area of the drain pipe.

In case of the column with higher flexural stresses (i.e. moment), the assumption made in the effective depths of the column which contains drain pipe is usually inappropriate.

This is because, for the design purposes, the practicing engineers assume an approximate effective depth for the column's section and a rational formula for the calculation of the effective depth of such type of columns is lacking.

ASSESMENT OF LOAD CARRYING CAPACITY OF THE COLUMNS CONCEALING DRAIN PIPES

Assume the column sections shown in Fig.1(a), (b) and (c) are having 350x350mm, 400x400mm and 450x600mm cross-sections respectively and their respective drain pipes to be $\phi 50$, $\phi 75$ and $\phi 100$ (diameters in mm). If 6Y16 bars are used as vertical reinforcement in the column shown in Fig.1(a), 4Y25 bars in column shown in Fig.1(b) and 6Y25 bars in column shown in Fig.1(c), then the probable effective cross-sectional areas of the columns will be:

(a) $350 \times (350 - 35 - 16 - 50) = 87150 \text{ mm}^2$
(b) $400 \times 400 - (35 + 25 + 75)^2 = 141775 \text{ mm}^2$
(c) $450 \times (600 - 35 - 25 - 100) = 198000 \text{ mm}^2$

Using equation (1) the effective areas for the above three columns used by practicing engineers in the industry are 120536 mm^2, 155582 mm^2 and 262146 mm^2 respectively.

Assuming these columns as short braced columns with minimum moment, the maximum axial load capacity of each column can be calculated using equation 39 of the BS 8110: Part 1 (clause 3.8.4.4), reproduced below as equation (2)

$$N = 0.35 f_{cu} A_c + 0.7 A_{sc} f_y \qquad (2)$$

Where, A_c is the net concrete area, A_{sc} is steel area, f_{cu} and f_y are characteristic strengths of concrete and steel respectively. In the present study the strengths are assumed as $f_{cu} = 35$ N/mm^2 and $f_y = 460$ N/mm^2 and 25 mm nominal concrete cover to the links of all columns which are assumed to be 10mm bars.

The maximum load carrying capacity of the above mentioned columns considering the two different effective cross-sectional areas are calculated and presented in Table 1. The values in the table are obtained by using Equation (2) and their differences in percentage have also been indicated.

Table 1 Maximum axial load capacity of columns using equation (2)

Column shown in Fig.	Column's exterior dimension (mm)	(A) Column's axial load capacity on the basis of industry's effective area (kN)	(B) Column's axial load capacity using effective area by present study (kN)	Differences in percentage between the two axial load capacities (A)&(B)
1 (a)	350 x 350	1850	1441	28.38%
1 (b)	400 x 400	2514	2345	7.21%
1 (c)	450 x 600	4124	3338	23.55%

Table 1 indicates that the industry engineers assume the axial load capacity of columns as high as 28% in comparison to the present case which can be a threat to the safety of the structure.

RESEARCH METHODOLOGY

(a) Investigation is undertaken to estimate the reduction in load carrying capacity of column containing drain pipe including elbow part

(b) Research is going on to study the effects of drain pipes on the slenderness of the columns.

(c) The investigation will also determine the effects of drain pipes on the buckling mode of columns.

(d) Methods of Research :

(i) Experimental method : Testing of various scaled models with different sizes of drain pipes including elbow part.

(ii) Numerical method : Finite Element Modeling and Analysis of the tested models to validate the experimental results.

CONCLUDING REMARKS

In this paper a critical review of the ongoing practice of concealing drain pipes inside the RC column and wall sections in the Malaysian buildings' industry has been provided. Since presently a rational and reliable design formula for the calculation of load carrying capacity of the affected columns is not available, it is therefore recommended that the proposed alternative solutions may be adopted.

The probable effective areas such as those shown in Fig.1(a), (b) and (c) can also be adopted for design purposes as a second alternative tentatively. This will reduce the threat to the safety of structure.

The research initiated at UTM will assess the actual load carrying capacities of columns concealing drain pipes including their elbow parts. On the basis of outcome of this research it will be possible to provide an approximate but realistic formula for the design of such columns.

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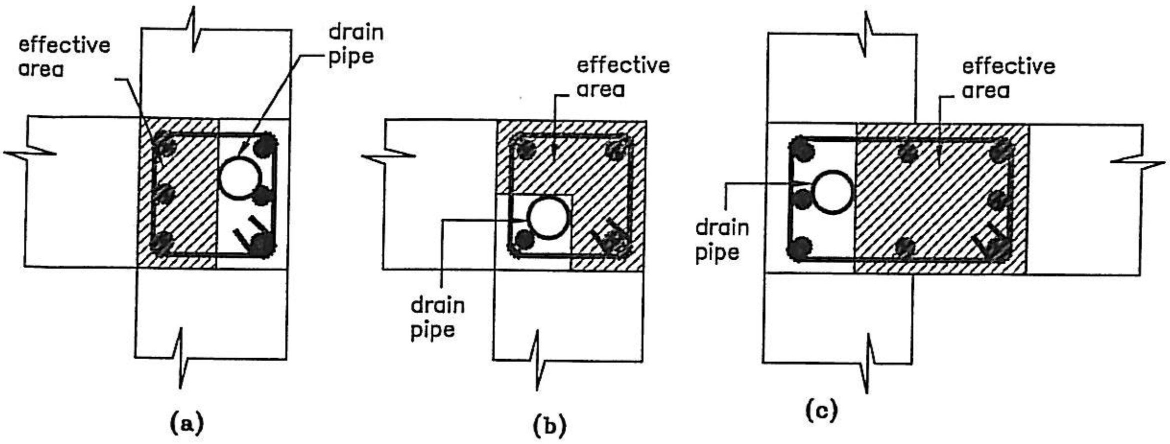
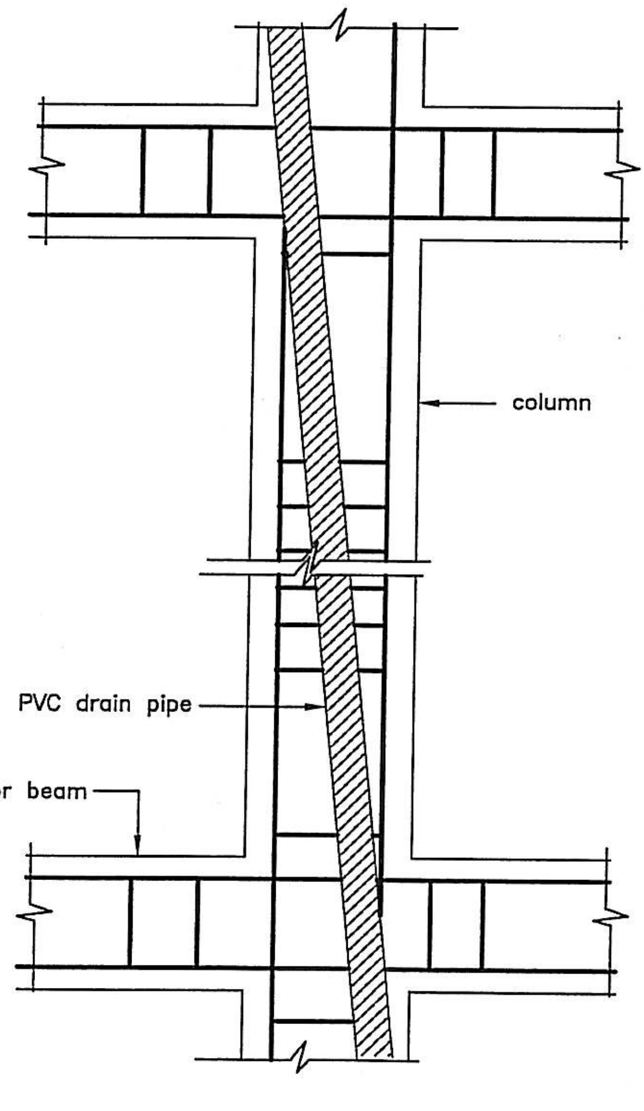


Column sections in plan showing the probable effective areas



d) Vertical section of column showing the inclined positioning of the drain pipe

Fig. 1 Inappropriate positioning of rain water pipe in column's section

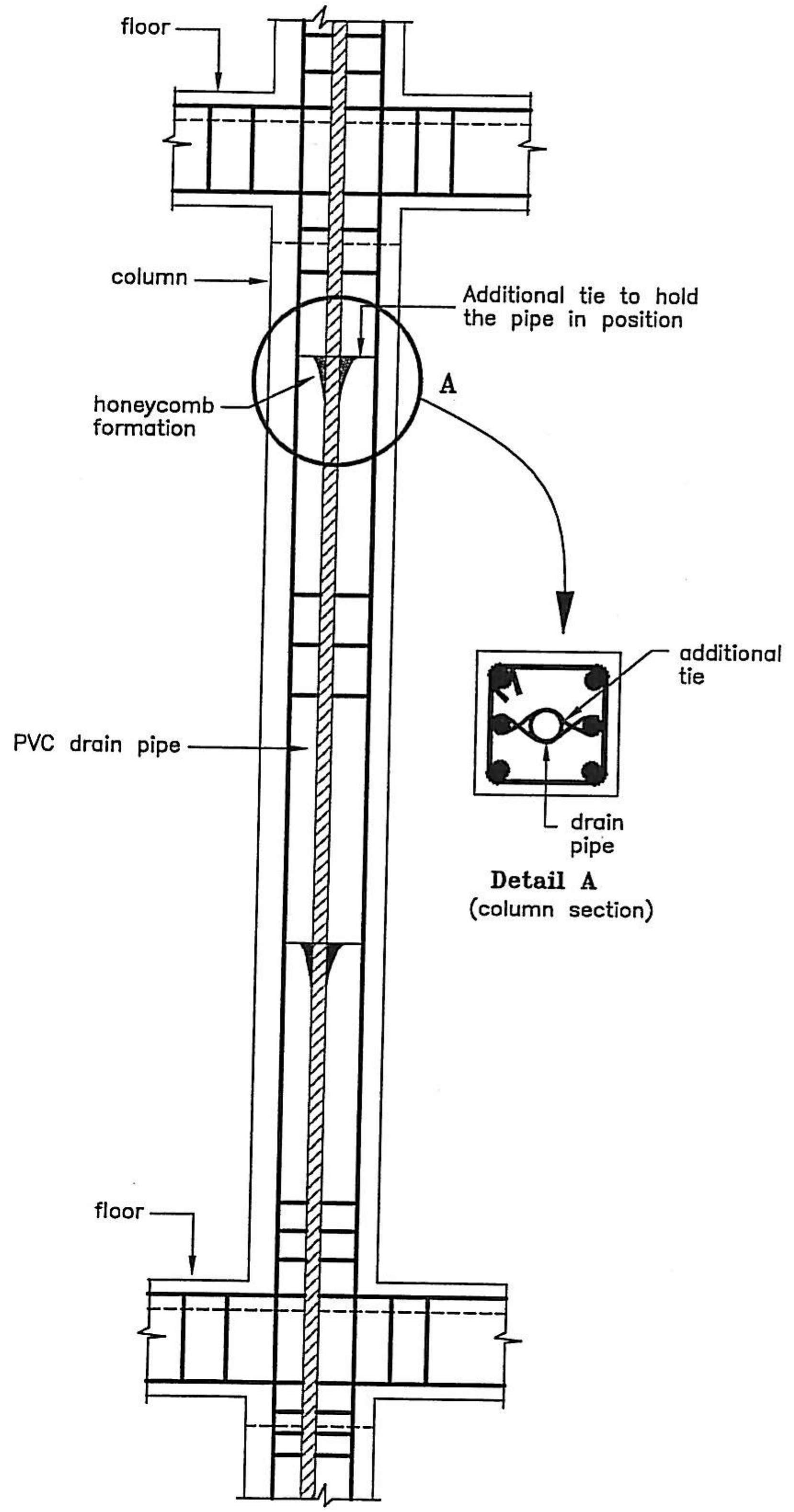


Fig. 2 Formation of honeycombs around the drain pipe

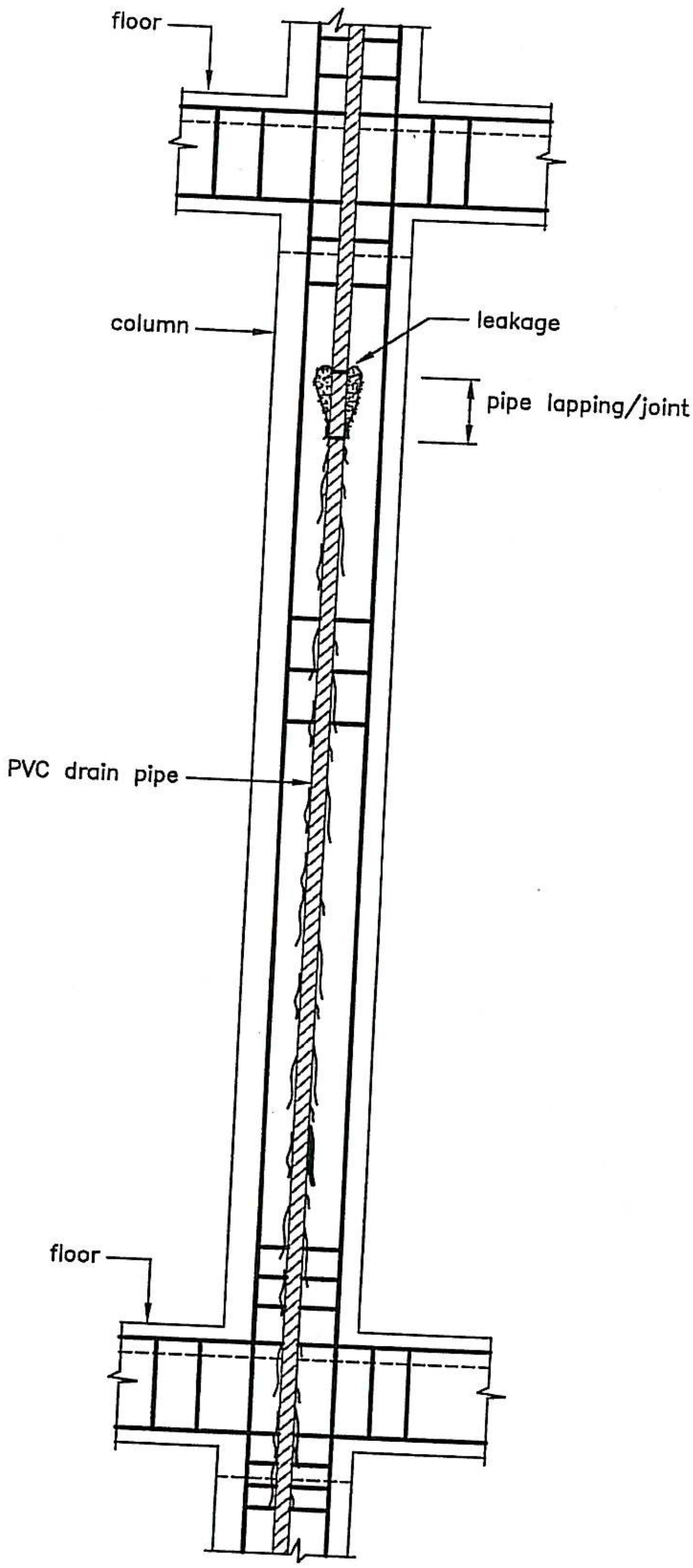
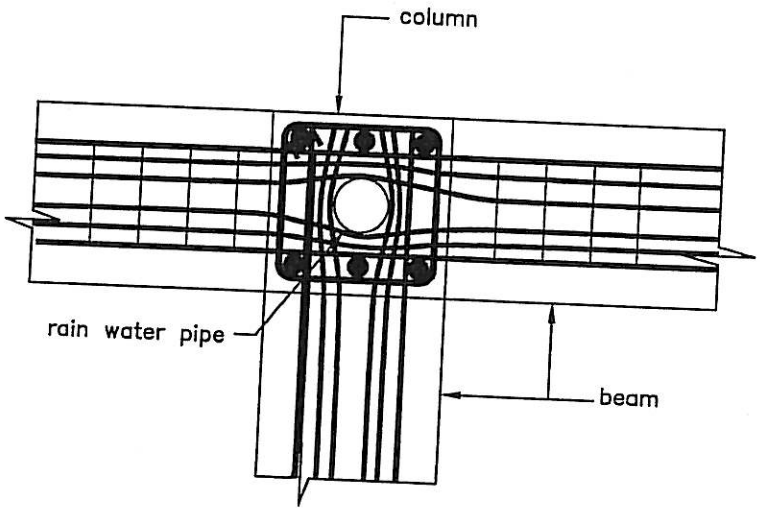
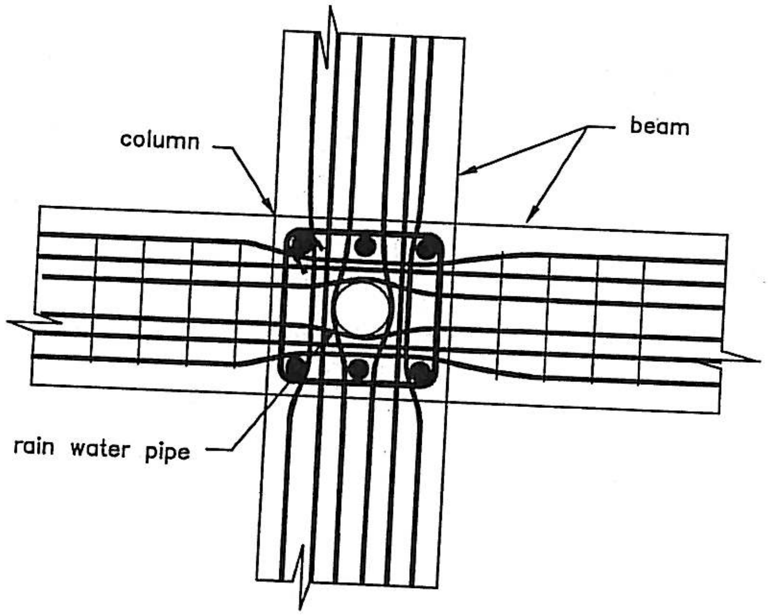


Fig. 3 Leakage in the lapping parts of the PVC drain pipes



(a) Column's section at the outer edge of building



(b) Central column section

Fig. 4 Congestion and nonuniformity in beams reinforcements at column's section caused by the presence of drain pipe

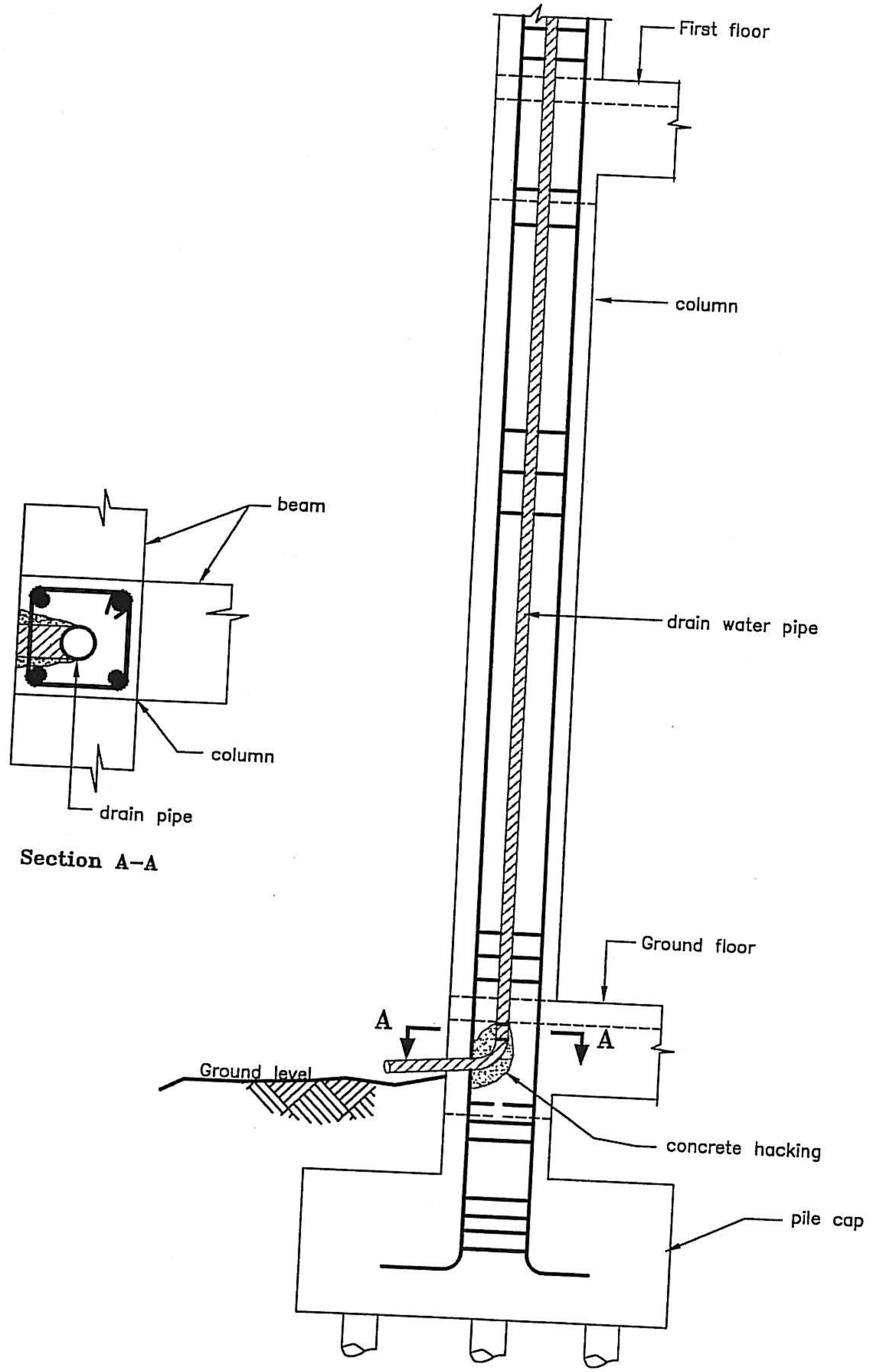


Fig. 5 Elbow part of the drain pipe at the ground level

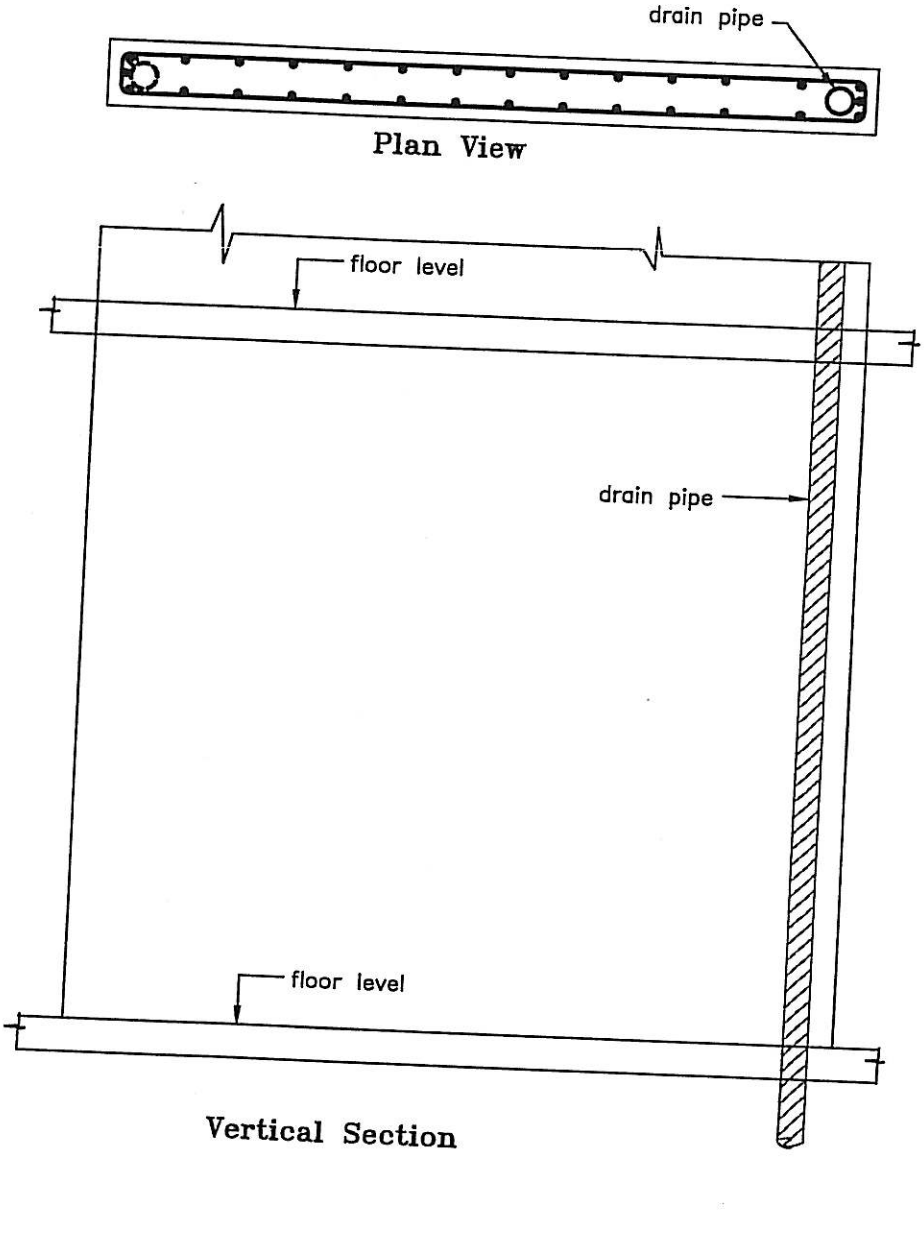


Fig. 6 Drain pipe positioned at the edge of RC wall

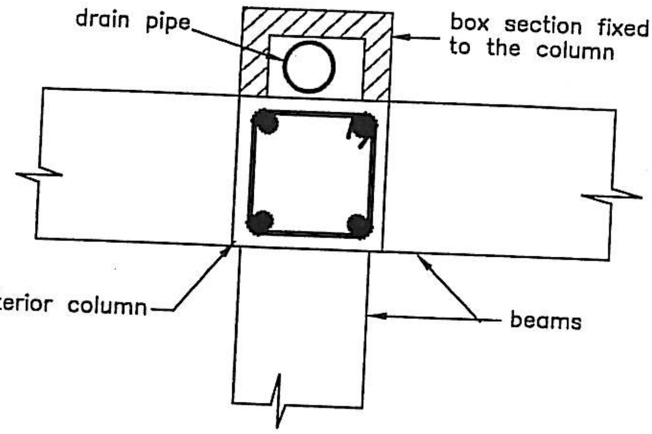


Fig. 7 Rain water pipe hidden in a hollow box section outside column's section (attached to column)

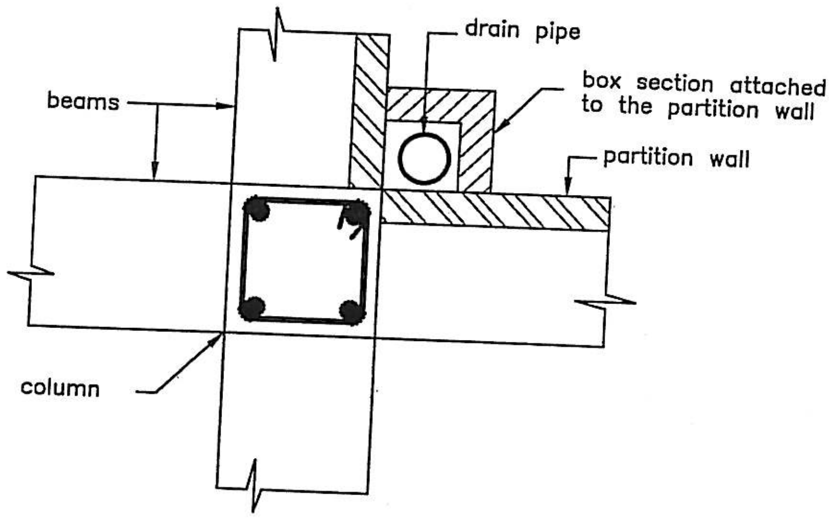


Fig. 8 Rain water pipe outside column's section passing through corner of the slab covered in hollow box section

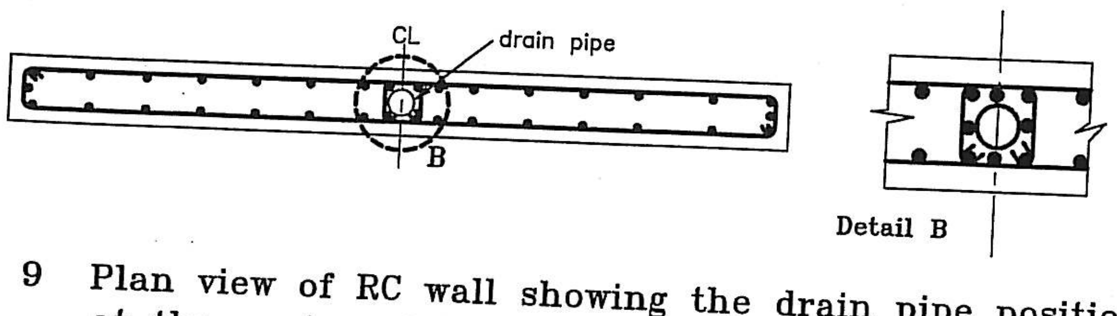


Fig. 9 Plan view of RC wall showing the drain pipe positioned at the centre of the section of wall