Jurnal Teknologi, 43(B) Dis. 2005: 13-26

EXPERIMENTAL STUDY OF REINFORCED CONCRETE COLUMNS CONCEALING RAIN WATER PIPE

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Abstract. An experimental study has been carried out to investigate the effect of concealing rain water pipes inside reinforced concrete columns in multistorey buildings. Fourteen columns in seven sets, having different sizes and reinforcement, with a PVC drain pipe positioned at the centre of cross-section of each one of them have been tested. An approximate method of columns' alignment has also been developed and the alignment of the constructed columns has been carried out before their testing. The ultimate strength of the columns obtained from the present investigation have been compared with the design strengths recommended by the British code of practice (BS 8110) and the American code of practice (ACI). The columns showed significant reduction in their load carrying capacities and the safety factors obtained were much less than the nominal value usually recommended by various codes of practice.

Keywords: Reinforced concrete column, load carrying capacity, drain pipe, stress, strain, factor of safety

Abstrak. Suatu kajian bereksperimen telah dijalankan untuk menentukan kesan paip air hujan tersembunyi di dalam tiang konkrit bertetulang dalam bangunan bertingkat. Sebanyak empat belas tiang telah diuji dalam tujuh set dengan saiz dan tetulang yang berbeza dengan satu paip saliran PVC yang terletak di tengah keratan rentas setiap satunya. Satu kaedah penghampiran penjajaran tiang juga telah dibangunkan dan jajaran tiang yang dibina telah dijalankan sebelum memulakan uji kaji. Kekuatan muktamad yang diperoleh dari uji kaji ini telah dibandingkan dengan kekuatan reka bentuk yang disarankan oleh kod amalan British (BS 8110) dan kod amalan Amerika (ACI). Tiang menunjukkan kemerosotan ketara dalam kapasiti menampung beban dan faktor keselamatan yang didapati adalah jauh lebih kurang daripada nilai nominal yang disarankan oleh kebanyakan kod amalan.

Kata kunci: Tiang konkrit bertetulang, kapasiti menampung beban, paip saliran, tegasan, keterikan, faktor keselamatan

1.0 INTRODUCTION

Columns are important vertical compression members of structural frames in buildings intended to support load carrying slabs and beams. Failure of a column in a critical location can cause the progressive collapse of the adjoining floors and the ultimate total collapse of the entire structure.

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Tropical countries such as Malaysia are having rainfall throughout the year, which require an effective and appropriate drainage system in the construction of any new building project. The practice of positioning Poly Vinyl Chloride (PVC) pipes inside reinforced concrete (RC) columns to drain the rain water from the roof top of the high-rise building and discharge it at the ground level has become quite common nowadays.

However, this method of drainage could cause serious damage to the safety of the structure [1]. Therefore, the present study was undertaken to investigate the load carrying capacity of these type of columns.

To the best of the knowledge of the authors, no significant investigations have been carried out to study the load carrying capacity of these types of columns. Most of the previous works in this regard have been limited to the studies of the effects of constant axial load and eccentric load on the behaviour of rectangular and circular hollow reinforced concrete columns [2 - 6].

Mander [7] 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.* [8] focused on the deterioration of concrete shear resistance for hollow column. They concluded that the reduction in concrete shear resistance should be considered in the design of RC columns having hollow sections.

The paper discusses some results of a research carried out to investigate the compressive strength and load carrying capacity of rectangular reinforced concrete short columns (models) having rain water pipes inside them.The hysteric performance of the columns is evaluated using various cross-sections with different amount of reinforcement. Figure 1 shows a typical column with drain pipe positioned at the

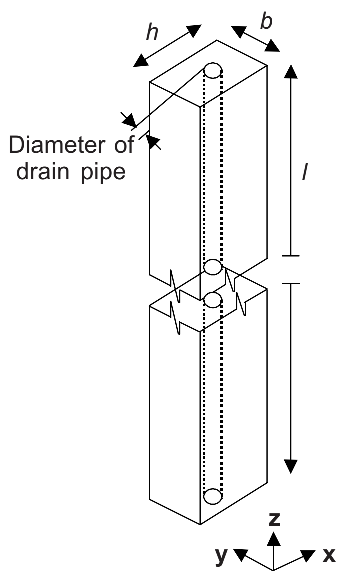

Figure 1 Typical column showing the position of drain pipe

center of its cross-section. The cross-sectional dimensions of the column are represented by ***h*** and ***b***, where its height is represented by ***l***.

2.0 EXPERIMENTAL PROGRAM

The experimental parts of the study include 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.

2.1 Construction of the Models

2.1.1 Mix Design

Using the procedures recommended by BS 8110 and BS 5328 codes of practice, a 35 grade mix design for the concrete of the models has been prepared. Several cube samples have been prepared and tested after 28 days, which showed compressive strengths of 35 to 40 N/mm^2. Therefore, the water-cement ratio, cement, sand and aggregate proportions for concrete of the models have been established [9 - 11,13].

2.1.2 Casting and Curing of the Models

Due to the space limitation problems in the testing hall, as well as the ease in the construction, handling, and testing of the models, half scale models having the same slenderness ratios of that of the full scale columns were adopted in this study. Therefore, height (***l***) in all models has been kept to 1.5 m.

High strength 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.

Using 4 mm steel bar, the drain pipes inside the column (i.e. in the central part of the column's cross-section) have been fastened firmly to the vertical steel and formwork at three points along the height of the column. Column's 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 at UTM, 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 has been kept wet for at least three days. After removal of the formworks, the models were kept undisturbed for 28 days.

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

Column designation	Column size (mm) *h*	*b*	*l*	Drain pipe diameter (mm)	Reinforcement bar
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

2.2 Columns Alignment Technique

Extra care has been taken to prepare the columns' formworks such that to produce the exact dimensions of the models and to maintain the verticality in the models. However, there are always certain problems such as the construction tolerances, changes caused to the formworks by concrete and its vibration, and shrinkage effects, which may cause some changes in the dimensions and verticality of the models. Therefore, a simple and approximate method of alignment for the columns has been developed. Using this method, column's ends have been leveled with the help of high-alumina cement mix.

The steps followed in the alignment procedure are as follows:

(i) Column was positioned vertically on a leveled ground surface as shown in Figure 2(a).

(ii) Thin plywood wedges were inserted under the column until the spirit level readings on opposite faces of the column became identical. Without any movement in the column, the top end of the column was leveled using high-alumina cement mix as shown in Figure 2(b). The models were kept undisturbed for a minimum period of 24 hours.

(iii) After hardening of the high-alumina cement mix, the column position was reversed, i.e. made up side down on a leveled ground surface as shown in Figure 2(c). In this position, the spirit level reading on opposite faces of the column will be almost identical. The top end of the column was leveled using the same mix.

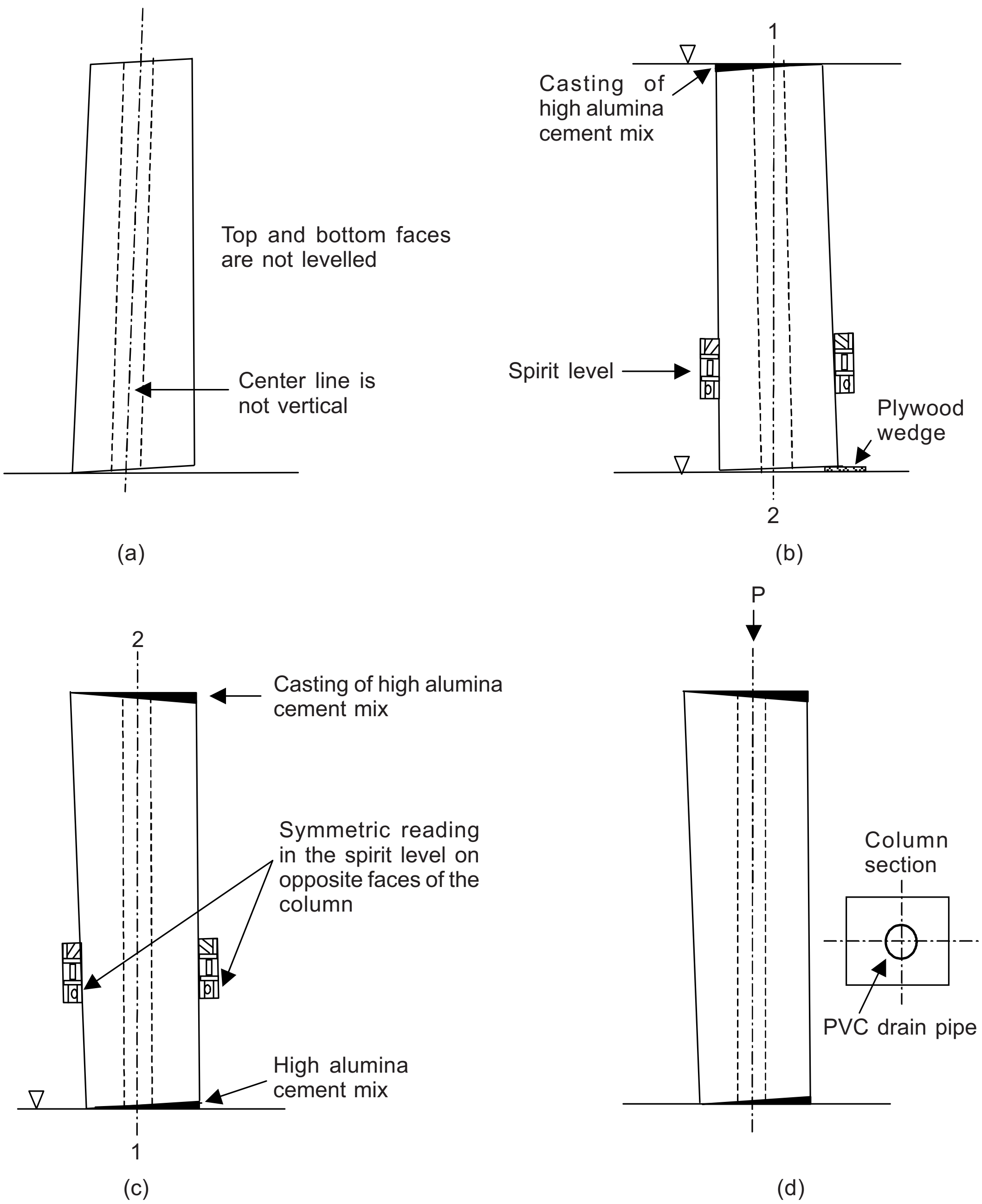

Figure 2 Steps followed in the vertical alignment of the models

(iv) Figure 2(d) represents a column with completed alignment which is ready for the instrumentation and testing.

2.3 Instrumentation and Testing of the Models

Before the testing of the models, instrumentation i.e. the installation of the strain gauges on the models was carried out. In order to record the vertical axial strains in each model, two electric resistance strain gauges on opposite vertical faces of the column at its mid height have been installed. Two additional horizontal movement monitoring strain gauges at the adjacent faces of the model near its top end were also fastened to observe and record the horizontal movement of the model.

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

The models have been tested using a 5000 kN capacity universal testing machine. The columns were loaded under a monotonically increasing axial compressive load until their collapse. The vertical axial strain readings were recorded after every increment of 20 kN load.

Figure 3 shows the collapse mode of a model which was typical in most of the columns.

Figure 3 Reinforced concrete column after collapse

3.0 COMPARISON OF RESULTS AND DISCUSSIONS

3.1 Results of the Investigation

The models have been loaded axially until their failure and the collapse load and maximum axial strain for each one of them have been recorded. Using the average cross-sectional area and its corresponding collapse load, the ultimate strength of each column has been calculated. The maximum axial compressive strain and stress for each column is shown in Table 2. The vertical stress- strain curves for various models are plotted and shown in Figures 4 to 10.

Table 2 Tests results showing maximum vertical stress and strain in the columns

Model	Maximum vertical stress (N/mm2)	Maximum vertical strain (mm/mm) × 10^{-6}
C1a	23.06	889
C1b	22.65	761
C2a	22.71	948
C2b	25.62	771
C3a	28.69	1795
C4a	27.76	1438
C5a	21.25	1443
C5b	24.36	1711
C5c	27.17	2182
C6a	23.28	1105
C6b	24.43	1073
C6c	25.77	1116
C7a	22.90	310
C7b	31.56	1101

3.2 Design Strength Requirement of the Columns

Most of the columns are key elements in structures, therefore, it is important to design and construct columns such that they should have the required strength and to attain a factor of safety of 2 to 3, as recommended by various codes of practice [9, 12].

3.2.1 Design Strength of the Models Based on BS 8110: Part 1 Recommendation

Using Equation (39), clause 3.8.4.4 of the BS 8110: Part 1 [9], reproduced here as Equation (1), the design load N_d for each model has been calculated.

$$N_d = 0.35 f_{cu} A_{nc} + 0.7 A_{sc} f_y \tag{1}$$

where,

f_{cu} = characteristic compressive strength of concrete in N/mm^2
A_{nc} = net concrete area of the cross-section of the model in mm^2
A_{sc} = the area of the longitudinal reinforcement in mm^2
f_y = characteristic yield strength of steel in N/mm^2

Considering axial concentric load with minimum eccentricity, the design strength of each model based on Equation (1) has been calculated and shown in Table 3.

3.2.2 Design Strength of the Models Based on ACI Recommendation

Using Equation 10-2 of ACI 318, i.e. American Building Code Requirements for Reinforced Concrete [12] reproduced as Equation (2), the design axial load strength of the models has been calculated and shown in Table 3.

$$\varphi P_{n,max} = 0.80\varphi[0.85 f_c (A_g - A_{st}) + f_y A_{st}] \tag{2}$$

where,

A_g = gross area of the column section (in^2)
A_{st} = total area of longitudinal reinforcement (in^2)
f_c = specified compressive strength of concrete assumed to be 5067.08 psi i.e. 35 N/mm^2
f_y = specified yield strength of reinforcement assumed to be 66595.99 psi i.e. 460 N/mm^2
φ = strength reduction factor which is 0.65 for tied columns

3.2.3 Load Carrying Capacity and Safety Factors Assessment of the Models

Based on the ultimate strength / collapse load of the models, the safety factor for each model has been calculated with the help of Equation (1) i.e. BS 8110 and Equation (2) i.e. ACI codes. The safety factor for each tested model is obtained by dividing the collapse load (experimental) by the design strength of the model using Equation (1) and Equation (2). The factors of safety obtained from both cases of BS 8110 and ACI codes are shown in Table 3.

However, the present study shows that the factors of safety of the models obtained by using BS 8110 design strength, vary from 1.20 to 1.79, which is much lower than its recommended value.

Similarly, the safety factors obtained by using ACI recommended design strength vary from 1.12 to 1.59, which is very much smaller than the recommended value.

Table 3 Collapse/failure loads, design loads based on BS and ACI codes of practice and the corresponding factors of safety for the models

Model	Models' failure load (kN)	Design load (kN) using Equation. (1)	Factor of safety based on BS code	Design load (kN) using Equation. (2)	Factor of safety based on ACI code
C1a	340	242.80	1.40	273.07	1.25
C1b	334	277.92	1.20	298.37	1.12
C2a	470	350.70	1.34	390.33	1.20
C2b	530	393.59	1.35	421.29	1.26
C3a	1065	594.90	1.79	675.54	1.58
C4a	800	450.30	1.78	516.06	1.55
C5a	1134	793.97	1.43	926.48	1.22
C5b	1300	902.95	1.44	1005.64	1.29
C5c	1450	1043.04	1.39	1106.86	1.31
C6a	1310	829.54	1.58	971.85	1.35
C6b	1375	938.50	1.47	1050.57	1.31
C6c	1450	1078.66	1.34	1151.78	1.26
C7a	1480	1040.81	1.42	1179.69	1.26
C7b	2040	1181.03	1.73	1280.90	1.59

4.0 PROBLEMS CAUSED BY THE PRESENT PRACTICE

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. Many problems may arise in the construction of these columns due to the existence of PVC pipes. Some of these problems are listed below:

(i) Positioning the drain pipes in the corner or at the edge of the column's section as often practiced will significantly reduce the effective cross-sectional area of the column.

(ii) In case where the drain pipe is positioned at the central part of the column's cross-section, the pipe may not be held at the centre position in the column, because during casting and vibration of the concrete there are chances that the pipe may get an inclined position, which can further reduce the load carrying capacity of the column significantly.

(iii) The PVC pipes may have leakage at their joints or lapping parts, which in the long term can cause rusting of the reinforcement in the column, hence losing the bond which can cause huge reduction in the strength of the structural elements.

(iv) Due to the presence of drain pipe in beam-column joints, the beam's reinforcement has to be bent which causes irregularity and non-uniformity in the reinforcement, hence reduction in strength and functioning of the structure [1].

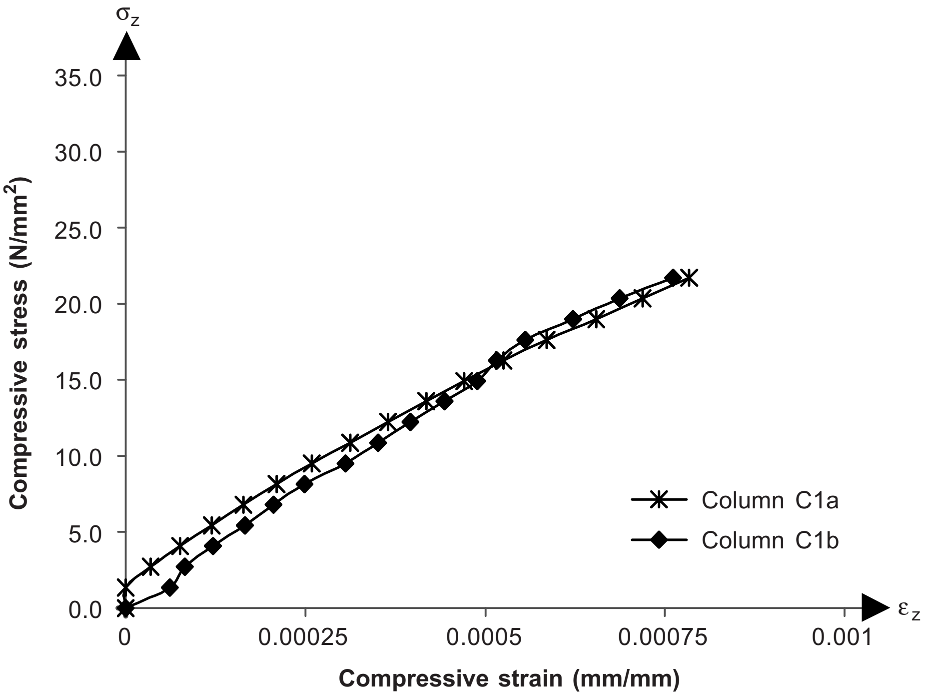

Figure 4 Stress-strain curves for columns with cross section of 125 × 125 mm

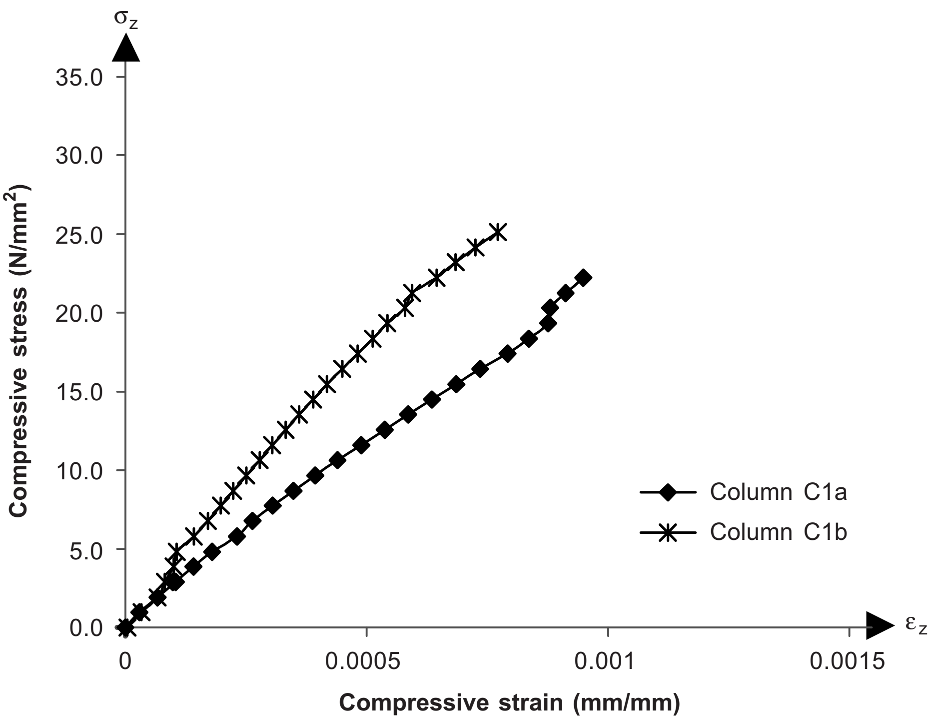

Figure 5 Stress-strain curves for columns with cross section of 150 × 150 mm

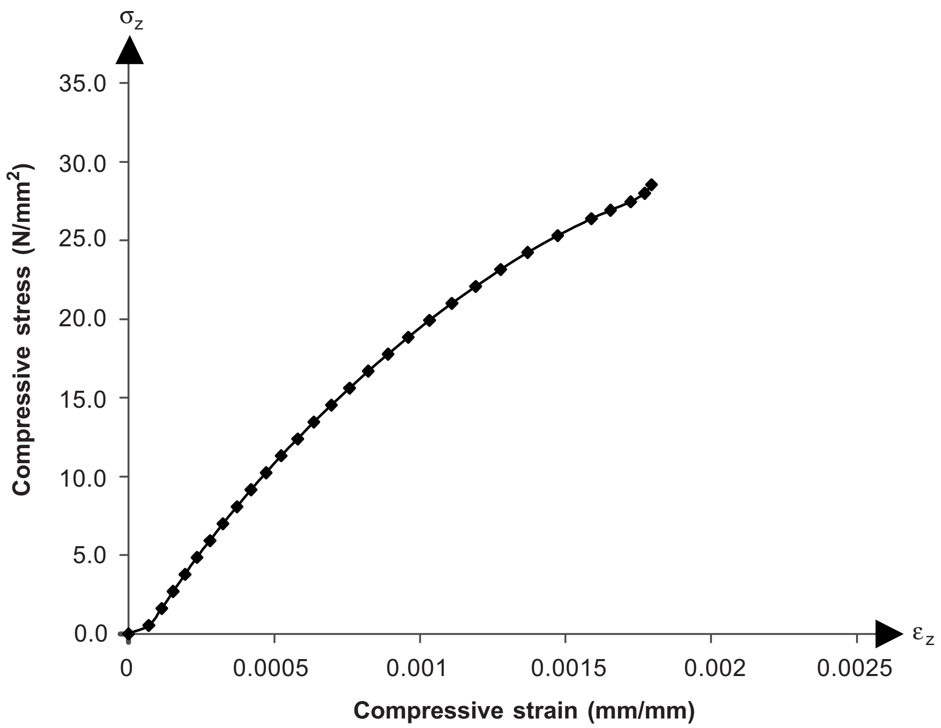

Figure 6 Stress-strain curve for column with cross section of 200 × 200 mm

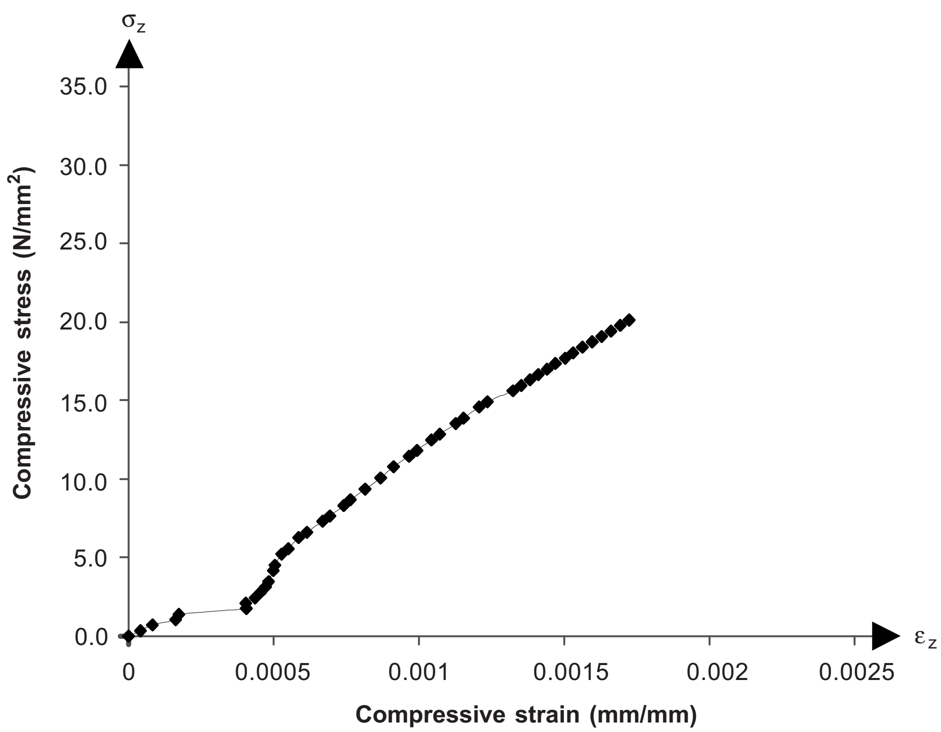

Figure 7 Stress-strain curve for column with cross section of 175 × 175 mm

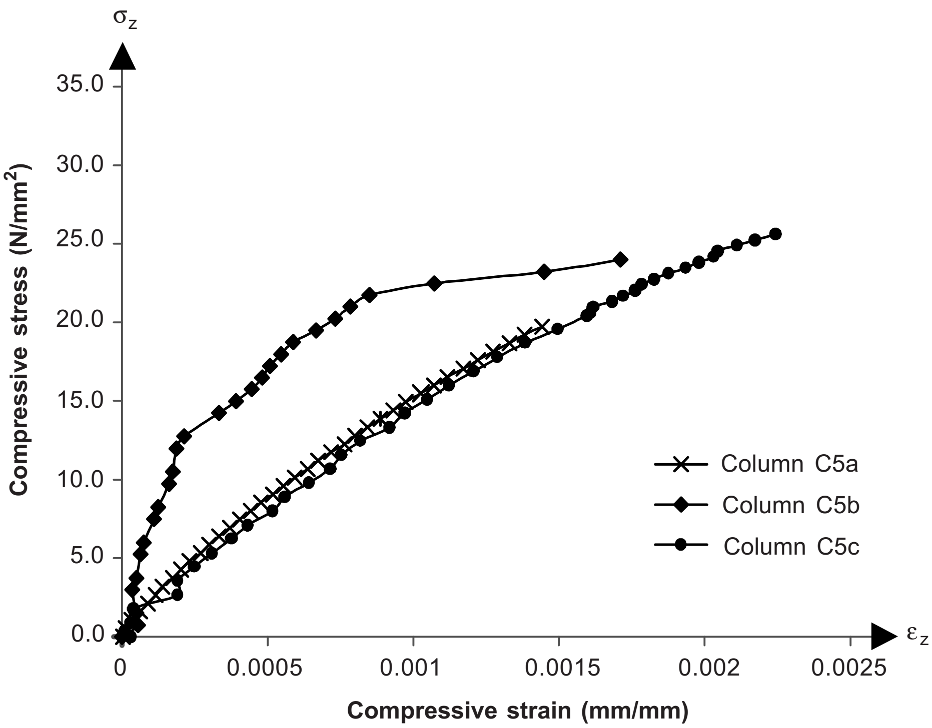

Figure 8 Stress-strain curves for columns with cross section of 250 × 225 mm

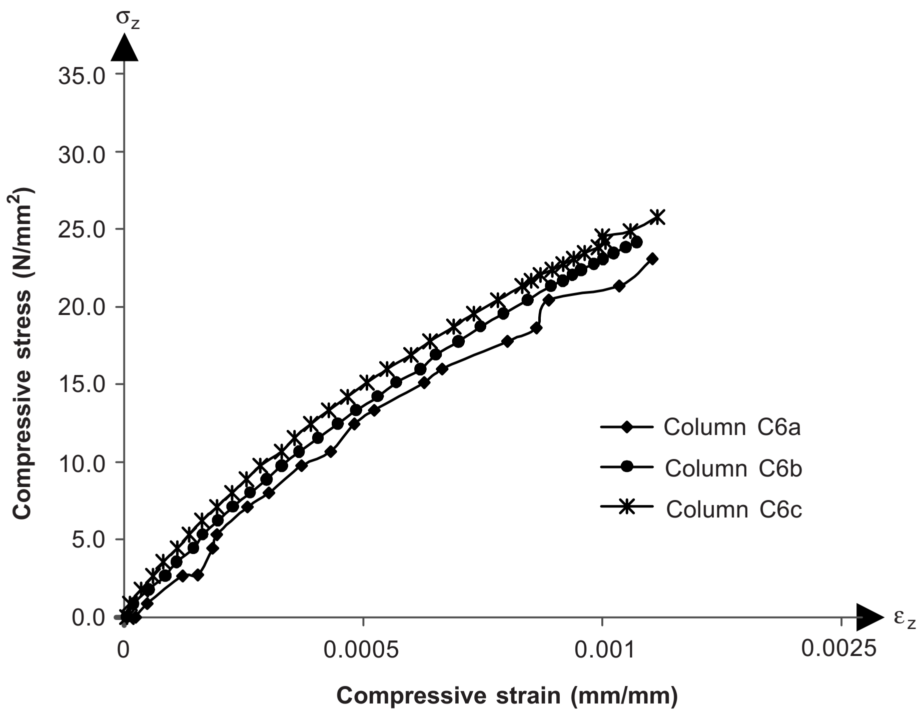

Figure 9 Stress-strain curves for columns with cross section of 250 × 250 mm

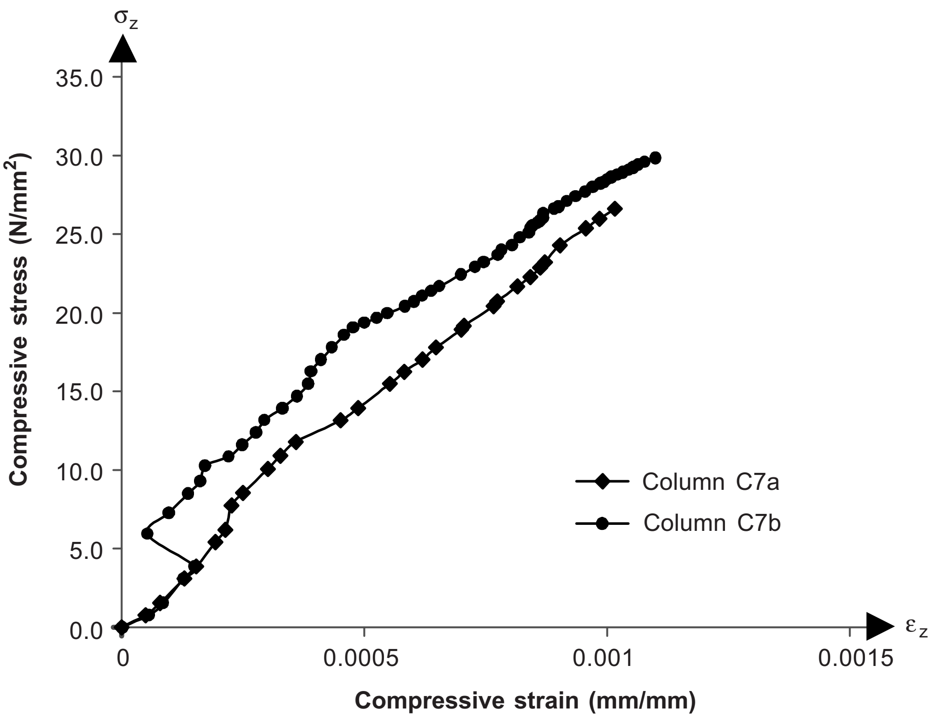

Figure 10 Stress-strain curves for columns with cross section of 300 × 225 mm

5.0 CONCLUSIONS

The investigation shows that by positioning a drain pipe inside the column reduces the load carrying capacity of the column significantly.

The study indicates that the factors of safety of the models obtained from the experimental investigation, vary from 1.20 to 1.79 using BS 8110 code. Based on ACI code evaluation, the corresponding factors vary from 1.12 to 1.59. In both cases, the obtained values are less than the nominal value of 2 as recommended by the codes.

Considering huge reduction in the load carrying capacity of these types of columns, it is recommended that, for the design purposes, the strength of the columns should be taken as half of the values obtained using Equations (1) or (2).

As an alternative solution, PVC drain pipes can be replaced by steel pipes, positioned at the centre of the column's cross-section. However, proper coating of the pipes should be done to avoid their rusting. By using steel pipes instead of PVC drain pipes, the load carrying capacity of the columns can be enhanced as well.

Since the appropriate determination of the effective depth of the column concealing rain water pipe is difficult, therefore, in the cases of structures subjected to lateral loads, this practice should not be used at all.

An approximate method of alignment for the columns has been developed which can be used in the testing of columns.

ACKNOWLEDGEMENTS

The research reported in this study was financially supported by Research Management Centre (RMC), Universiti Teknologi Malaysia. Their support is gratefully acknowledged.

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