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FINITE ELEMENT ANALYSIS OF REINFORCED CONCRETE COLUMN WITH LONGITUDINAL HOLE

AMIRHOSSEIN BASRAVI

A project report submitted in partial fulfillment of the
requirement for the award of the degree of
Master of Engineering (Civil – Structure)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

DECEMBER 2010

I declare that this project report entitled "*Finite Element Analysis of Reinforced Concrete Column with Longitudinal Hole*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any degree.

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Date : 3 DECEMBER 2010

To my beloved family

Love you forever

ACKNOWLEDGEMENT

I have a host of people to grace of their involvement in this major work. The order I mentioned below does not necessarily represent the amount of work they did.

I am sincerely grateful to my supervisor, Assoc. Prof. Ir. Dr. Mohd Hanim Osman, for his continuous support, suggestions and immeasurable contribution to my project. He always provides me guidance and feedback in this project. I am also very thankful to Prof. Dr. Jahangir Bakhteri for his advice, guidance and motivation. Without their help, I would not have completed my project.

I would also like to express my deepest gratitude to Universiti Teknologi Malaysia (UTM) for providing the necessary facilities and the staff in Faculty of Civil Engineering for their help in the completion of this project.

Deep appreciation goes to my dear parents and sisters; I would definitely not succeed in my life without their love and support. I would like to grab this opportunity to thank my friends who have always provided inspiring ideas on my work.

Lastly, thanks are due to the people that I did not mention their name for their assistance and encouragement.

ABSTRACT

A finite element study was carried out to investigate the effect of positioning hole along reinforced concrete short braced columns in multi-storey buildings. RC columns having different sizes and reinforcement, with holes positioned at the centers of their cross-sections were modeled by LUSAS using three-dimensional non-linear finite element analysis. The ultimate strengths of the columns obtained from the present study is compared with the results obtained from the laboratory testing of the same columns as well as with the design strengths recommended by the BS 8110 and ACI codes of practice. The reduction in the load carrying capacity of columns with holes was highlighted. In conclusion, the analysis results 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.

ABSTRAK

Satu kajian menggunakan kaedah unsur terhingga telah dilakukan untuk mengetahui kesan membuat kedudukan lubang di dalam tiang konkrit bertetulang pada bangunan bertingkat. Tiang konkrit tetulang yang memiliki ukuran dan tetulang yang berbeza, dengan lubang terletak di pusat keratan telah di modelkan dengan perisian LUSAS menggunakan analisis unsur terhingga tiga-dimensi secara non-linear. Kekuatan muktamad dari tiang yang diperolehi daripada kajian ini dibandingkan dengan keputusan yang diperolehi daripada ujian makmal keatas tiang yang sama saiz juga dengan kekuatan rekabentuk yang disyorkan oleh BS 8110 dan kod amalan ACI. Beban rintangan telah didapati berkurangan bagi tiang yang mempunyai lubang. Kesimpulannya, hasil analisis menunjukkan penurunan yang ketara pada beban keupayaan dan faktor keselamatan yang diperolehi jauh kurang dari nilai nominal yang biasanya disyorkan oleh pelbagai kod amalan.

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A_g	-	Gross area of the column section
A_{nc}	-	Net concrete area of the cross-section of the model
A_{sc}	-	Area of the longitudinal reinforcement
A_{st}	-	Total area of longitudinal reinforcement
b	-	Width of column
d	-	Effective depth
e	-	Eccentricity of load
E	-	Young's Modulus
f_{cu}	-	Characteristic compressive strength of concrete
f_y	-	Characteristic yield strength of steel
h	-	Gross area of the column section
l_e	-	Net concrete area of the cross-section of the model
M	-	Ultimate moment
N	-	Column design load
P	-	Vertical load to the column

α	-	Modulus ratio
β	-	Coefficient dependant on the bar type
$\varnothing$	-	Strength reduction factor
ε	-	Compressive strain
σ	-	Compressive stress

CHAPTER 1

INTRODUCTION

1.1 Background

A column is the vertical structural member supporting axial compressive loads, with or with-out moments. Columns support vertical loads from the floors and roof and transmit these loads to the foundations. The load carrying capacity of a column depends on the materials used in its construction, its length, the shape of its cross-section, and the restraints applied to its ends. 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.

For design purposes, columns are divided into two types namely, short columns and slender columns. Considering lateral load action, columns are divided into two groups which are braced columns and unbraced columns.

In the construction of modern multistory buildings, holes (pipes) are positioned vertically inside the reinforced concrete columns to accommodate the essential services such as drainage of roof top rain water, electric wiring from floor to floor etc. The holes (pipes) are placed inside the columns, based on pretext to maintain the aesthetic of the buildings. The practice of embedding rain water down pipes (holes) inside reinforced concrete columns is followed particularly in those multistory buildings which have flat roofs and glass front views. The diameters of holes (pipes) vary, depending on the amount of drained water.

Tropical countries such as Malaysia are having rainfall throughout the year, which require an effective and appropriate drainage system for rain water in the construction of any new building project. Therefore, the practice of positioning hole (Poly Vinyl Chloride (PVC) pipes) inside reinforced concrete (RC) columns to drain the rain water from the roof top of the multi-storey buildings and discharge it at the ground level has become a usual practice nowadays (Figure 1.1). The practice has been adopted under the impression that, exposing the pipes (holes) outside the columns will affect the appearance of the buildings.

Figure 1.1 Hole (rain water pipe) is positioned inside columns

However, this method of drainage could cause serious damage to the safety of the structure. Columns constructed with holes (embedded PVC drain pipes), not only have reduced load carrying capacities but also, could be very dangerous to the safety of the entire building structure and can reduce its useful life significantly.

Some of the problems caused by the practice of positioning hole (PVC rain water down pipe) inside the column are as follows:

i. Positioning the hole in the corner or edge of the column's section will reduce the effective cross-sectional area of the column significantly and also will affect to its shear capacity.

ii. Even in case the hole (rain water pipe) is positioned at the central part of the column's cross-section, the assessment of the effective depth of the column section might become inaccurate and hence, load carrying capacity of the columns is further reduced.

iii. There is a chance of formation of honeycombs around the hole (drain pipe).

iv. Leakage from the joint lapping part of the pipe (hole) can cause corrosion and rusting in the reinforcement of the column, and hence loss of bond and reduction in the strength of the structural element.

v. The huge reduction in the column's strength at ground level, where elbow part is used to discharge rainwater.

Therefore, the present study has been carried out to investigate the reduction in load carrying capacity of rectangular and square reinforced concrete short columns with hole (embedded PVC drain pipe).

The hysteric performance of the columns is evaluated using various cross sections with different amount of reinforcement. Figure 1.2 shows a typical column with hole positioned at the center of column cross-section. The cross section dimensions of the column are represented by *h* and *b*, where its height is *l*.

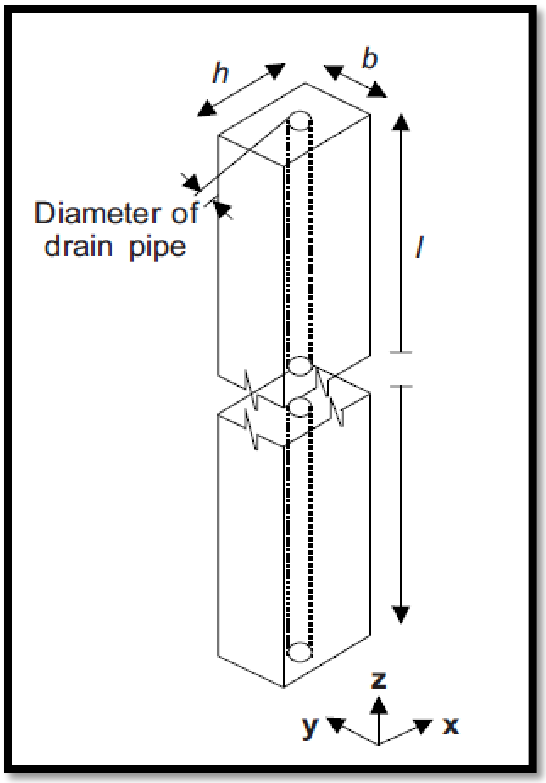

Figure 1.2 Typical column with hole (embedded drain pipe)

1.2 Problem Statement

The practice of positioning hole (PVC pipe) inside reinforced concrete (RC) columns to drain the rain water common nowadays, however this method of drainage could cause serious damage to the safety of the structure.

To the best of the knowledge of the author, 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 study of the effects of constant axial load and eccentric load on the behavior of rectangular and circular hollow reinforced concrete columns and also no information and guidelines in codes of practice (ACI 318-05, BS 8110-97) on this problem are available and no other significant investigations have been carried out.

1.3 Objective of the Study

The objectives of the study are listed below:

1. To investigate the reduction in load carrying capacity of the reinforced concrete short braced columns having rectangular and square cross-sections with hole (embedded drain pipe).

2. To model the RC columns using three-dimensional non-linear finite element analysis.

3. To study the compressive strength of the columns subjected to axial compressive loads only and to compare the research findings with the results of half scale laboratory tests and the design strengths recommended by the BS 8110 and ACI codes of practice.

1.4 Scope of the Study

The study includes 3-D finite element analyses of RC braced short columns with holes (embedded drain pipes) representing lower level (i.e. ground floor columns). The investigation concentrate on the modeling of axially loaded columns with hole (PVC drain pipes) positioned at the center of the columns' cross-sections. The LUSAS finite element program was used to model the columns. The analysis covers material non-linearity. The dimensions of the columns were the same as the dimensions of the model tested in the laboratory. The half scale laboratory test was carried out and the finite element analysis results were compared with them as part of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Concrete

Concrete materials have a sufficient compressive strength, so are widely used in civil engineering, reactor buildings, bridges, irrigation works and blast resistant structures, etc.

Concrete is a construction material consisting of coarse aggregate, fine aggregate, cement, water and other chemical and pozzolanic admixtures (superplasticizer, air entraining, retarder, fly ash and etc.) It has a very wide variety of strength, and its mechanical behavior is varying with respect to its strength, quality and materials. The strength and the durability are two important factors in concrete.

2.1.1 Stress-Strain Relation of Concrete

Concrete has an inconsistent stress-strain relation, depending on its respective strength. Compressive strength of concrete depends on the cement content, the cement-water ratio, the age of concrete and the type of aggregate. However, there is a typical patent of stress-strain relation for the concrete regardless the concrete strength, as shown in Figure 2.1.

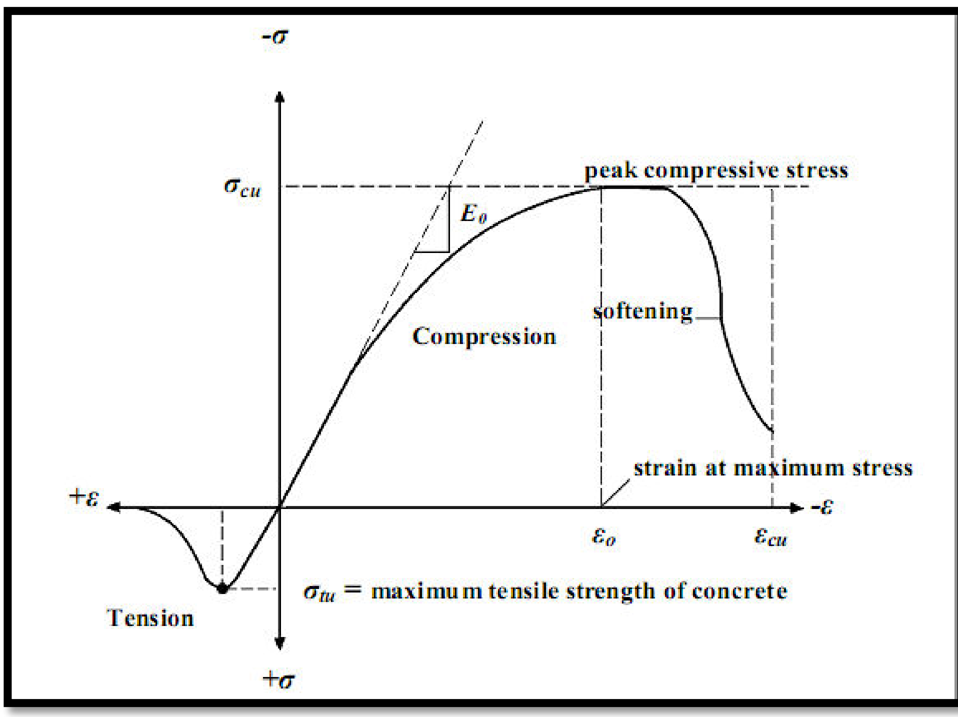

Figure 2.1 Stress-strain curve of concrete [1]

The behavior of concrete is almost elastically when the load is applied to the concrete. So according to the stress, the strain of the concrete is increasing approximately in a linear manner. Finally, the relation will be no longer linear and the concrete tends to behave more and more as a plastic material. So the displacement cannot complete after the removal of the loadings, therefore permanent deformation incurred.

Generally, the strength of concrete depends on the age, the cement-water ratio, type of cement and aggregate, and the admixture added to the concrete, an increment in any of these factors producing an increase in strength. Assumption the concrete can reach its strength at the age of 28-day because usually the increment of concrete strength is insignificant after the age of 28-day.

2.1.2 Elastic Modulus of Concrete

The stress-strain relationship for concrete is almost linear provided that the stress applied is not greater than one third of the ultimate compressive strength. A number of alternative definitions are able to describe the elasticity of the concrete, but the most commonly accepted is $E = E_c$, where E_c is known as secant or static modulus (see Figure 2.2).

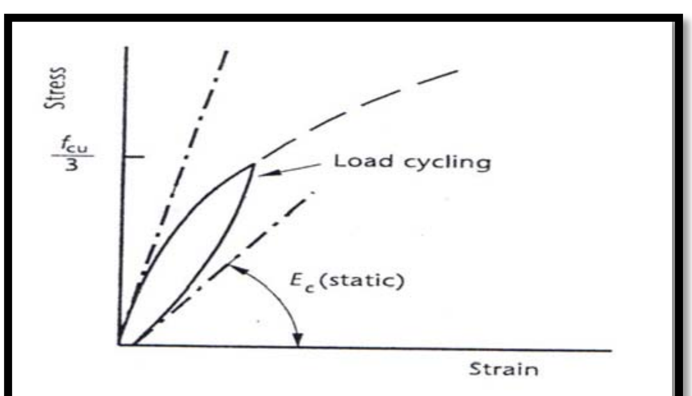

Figure 2.2 Static modulus of concrete [1]

The modulus of elasticity of concrete is not constant and highly depends on the compressive strength of concrete.

BS 1881 has recommended a series of procedure to acquire the static modulus. In brief, concrete samples in standard cylindrical shape will be loaded just above one third of its compressive strength, and then cycled back to zero stress in order to remove the effect of initial 'bedding-in' and minor redistribution of stress in the concrete under the load. Eventually the concrete strain will react almost linearly to the stress and the average slope of the graph will be the static modulus of elasticity [2].

2.2 Steel Reinforcement

Steel has great tensile strength and use in the concrete because concrete does not act in tension well alone; also there is good bond between concrete and reinforcement. The reinforcing steel has a wide range of strength. It has more consistent properties and quality compared to the concrete, because it is manufactured in a controlled environment. There are many types of steel reinforcement. The most common are plain round mild steel bars and high-yield stress deformed bars.

The typical stress-strain relations of the reinforcing steel can be described in the stress-strain curve as shown in Figure 2.3.