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UNIVERSITI TEKNOLOGI MALAYSIA

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JUDUL: **FINITE ELEMENT ANALYSIS ON THE DEFECTED REINFORCED CONCRETE COLUMN**

SESI PENGAJIAN : **2006/2007**

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FINITE ELEMENT ANALYSIS ON THE DEFECTED REINFORCED CONCRETE COLUMN

CHONG KEAN YEE

A project report submitted in partial fulfilment
of the requirements for the award of the degree of
Master of Engineering (Civil-Structure)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JUNE, 2007

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

Signature : …………………………….....

Name : CHONG KEAN YEE

Date : 30 JUNE 2007

To my beloved family

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ABSTRACT

In construction industry, misinterpretation of detail drawings is likely to occur in a tight-scheduled project, leading to the non-conformance with the detail drawings. This study is conducted on a damaged column of a real construction project, where the as-built dimension of its stump does not comply with the detail drawings. The stump is protruded from the wall and is hacked for aesthetic reason, thus the strength of the column is reduced. The aim for this study is to conduct a finite element analysis on the reinforced concrete column whose stump is damaged, to study the behaviour of the column. The strength level and maximum hacking allowed are determined. Non-linear analyses are performed on the column model using LUSAS. The accuracy of the finite element model is verified against experimental data published. The theoretical results are also used to verify the finite element model. From the analysis results, the load capacity, deflection and stress contour of the column with the respected degrees of damage at stump due to hacking are known. Subsequently, the failure mode of the column and the maximum hacking allowed are determined. Besides that, an equation for the particular column is established to determine the column capacity based on the damage done to the stump due to hacking. At the end of the study, it is found that the column having its stump hacked is still able to sustain its design load and maintain its stability.

ABSTRAK

Dalam industri pembinaan, kesilapan membaca lukisan perincian sering berlaku disebabkan oleh kesuntukan masa pihak bertanggung-jawab. Hal menyebabkan kesilapan dalam pembinaan di mana pembinaan tidak sama dengan lukisan perincian. Kajian ini dilakukan ke atas tiang dengan merujuk kepada projek pembinaan sebenar, yakni ukuran 'as-built' untuk tunggul tiang tidak sama dengan lukisan perincian. Oleh yang demikian, sebahagian daripada tunggul tiang tersebut telah dipecahkan, dan menyebabkan kekuatan tiang tersebut telah berkurangan. Tujuan utama kajian ini adalah untuk menjalankan analisis unsur terhingga ke atas tiang konkrit bertetulang, bagi mengkaji kelakuan tiang tersebut dan seterusnya mencari tahap kekuatan serta menentukan tahap pecahan maksimum yang dibenarkan. Justeru, analisis tidak lelurus dijalankan ke atas model tiang dengan menggunakan LUSAS. Demi menentukan kejituan analisis unsur terhingga, data eksperimen makmal dari pihak lain telah dirujuk. Daripada keputusan analisis yang dijalankan ke atas tiang tersebut, kapasiti beban, pesongan and kontur tegasan telah diperolehi. Hasil analisis mod kegagalan dan tahap pecahan yang dibenarkan telah dikenalpasti. Selain itu, satu rumus yang dapat menentukan kapasiti tiang telah diperolehi. Akhirnya, tiang tersebut didapati masih berupaya untuk menahan beban rekabentuk.

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LIST OF SYMBOLS

A_e	-	Transformed sectional area
A_s	-	Area of reinforcement
A_s’	-	Area of compression reinforcement
b	-	Width of column
d	-	Effective depth
d’	-	Depth to the compression reinforcement
E	-	Elasticity
E_c	-	Secant or static modulus of concrete
E_s	-	Young’s modulus of steel
e	-	Eccentricity of load
F_{cc}	-	Concrete compression force
F_{sc}	-	Reinforcement compression force
F_s	-	Reinforcement tension force
f_b	-	Bond stress
f_{bu}	-	Ultimate bond stress
f_{cu}	-	Characteristic strength of concrete
f_y	-	Characteristic strength of reinforcement
h	-	Depth of column in the plane under consideration
I_e	-	Transformed section second moment of inertia
l_{anc}	-	Anchorage length
l_e	-	Effective column height
M_c	-	Moment before column buckle
M_{cap}	-	Moment capacity
M_o	-	Moment due to eccentric load
N	-	Column design load
N_{cap}	-	Column capacity
$N_{crushing}$	-	Crushing load of column

P	-	Vertical load to the column
P_c	-	Buckling load
r	-	Radius of gyration
x	-	Depth to the neutral axis
α	-	Modulus ratio
β	-	Coefficient dependant on the bar type
γ_m	-	Partial safety factor
δ	-	Second order lateral deflection
δ_o	-	Maximum deviation from the straightness at mid-height
δ_y	-	Vertical displacement of column
ε_{sc}	-	Reinforcement compression strain
ε_s	-	Reinforcement tension strain
σ	-	Stress
φ_e	-	Effective bar size

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CHAPTER 1

INTRODUCTION

1.1. Background

In construction industry, structural and architectural elements of a building are detailed in separate sets of drawings. When the time allocated for a project is short and the schedule is tight, misinterpretation of the drawings is likely to occur. As a result, non-conformance with either one of the drawings may happen during construction stage, leading to a conflict between aesthetic quality and structural stability.

This study is conducted in reference to a real construction project[1] where non-conformance of architectural and structural drawing has occurred. The site problem was initiated when a stump was cast higher than finished floor level, due to the misinterpretation of the drawings during levelling survey work. This resulted in the protrusion of the stump from acoustic wall surface. Hence, the stump was hacked to provide a flat surface for the installation of the acoustic wall (see Figure 1.1).

[1] The project name is not disclosed due to the request by the project owner.

Figure 1.1 : The damage to the column

The strength of the defected column is assumed to have reduced due to hacking. Because the column is an important structural member of the building, a study to determine its capacity is proposed.

1.2 Problem Statement

The type of structural defect due to hacking to the column as presented in this study is not common. Therefore, there is no comprehensive reference available with regards to the acquisition of the maximum capacity for the column. Also, the current code of practice (i.e. BS 8110) does not provide any provision on the design of structural members with openings, hence useful data and references are not available.

For the reasons stated above, analysis is required to understand the structural behaviour of the defected column and consequently know its load bearing capacity. The finite element method (FEM) is chosen as the analysis tool in this study, because it has the advantages in the ability of predicting localised and global behaviours of a structural member.

1.3 Objectives of the study

The objectives of the study are listed as below:

1. To conduct a study on a reinforced concrete (RC) column using finite element analysis, before and after the damage due to the over-hacking.
2. To comprehend the behaviour and to determine the strength level of the damaged RC column.
3. To determine the maximum hacking allowed to the RC column before failure.

1.4 Scopes of the Study

The scopes of the study are listed as below:

1. The finite element analysis is done by using LUSAS.
2. The linear and the non-linear analysis is done in 2-dimension.
3. Material and geometrical non-linearity are included in the analysis.
4. The study is based on the short-term behaviour of the concrete.
5. Analysis is conducted on a column according to the as-built details in the project

CHAPTER 2

LITERATURE REVIEW

2.1 Concrete

Concrete is a construction material consisting of fine aggregate, coarse aggregate, cementitous binder, and other chemical admixtures. It has a very wide variety of strength, and its mechanical behaviour is varying with respect to its strength, quality and materials.

2.1.1 Stress-strain Relation in Compression of Concrete

Concrete has an inconsistent stress-strain relation, depending on its respective strength. However, there is a typical patent of stress-strain relation for the concrete regardless the concrete strength, as shown in Figure 2.1.

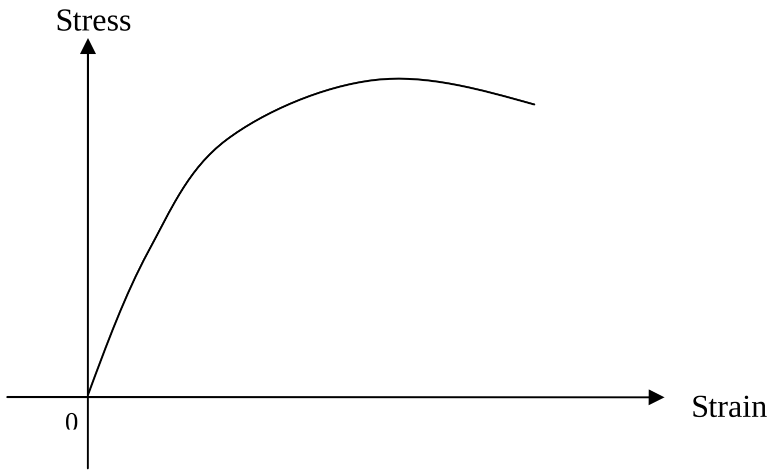

Figure 2.1 : Typical stress-strain curve for concrete in compression (Arya, 2001)

When the load is applied, the concrete will behave almost elastically, whereby the strain of the concrete is increasing approximately in a linear manner accordingly to the stress. Eventually, the relation will be no longer linear and the concrete tends to behave more and more as a plastic material, which in this state, recovery of displacement will be incomplete after the removal of the loadings, hence permanent deformation incurred.

Generally, the concrete is gaining its strength with age, but the rate is varied depending on the admixture added to the concrete, type of cement used, etc. Usually the increment of concrete strength is insignificant after the age of 28-day, and therefore assumption that the concrete strength taken as its strength at the age of 28-day is acceptable (Martin et al., 1989).

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 know as secant or static modulus (see Figure 2.2).

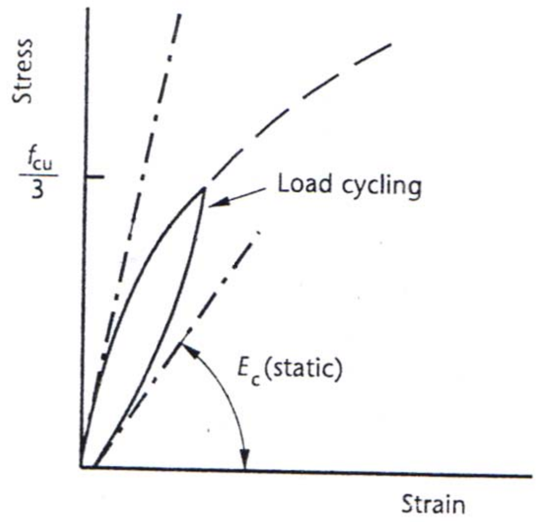

Figure 2.2 : Static modulus of concrete
(Mosley et al., 1999)

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 Reinforcing Steel

The reinforcing steel has a wide range of strength. It demonstrates more consistent properties compared to the concrete, because it is manufactured in a controlled environment.

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

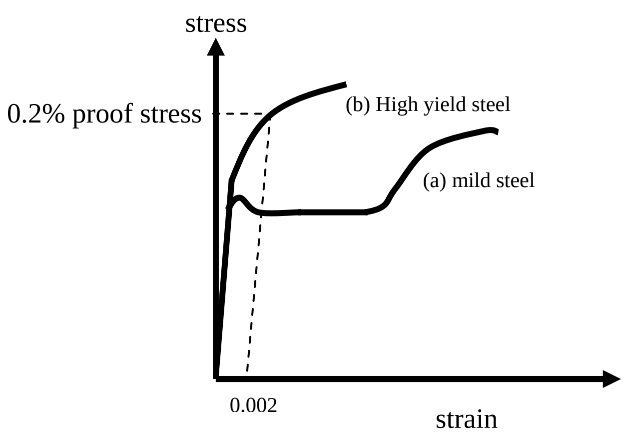

Figure 2.3 : Typical stress-strain curve for reinforcing steel
(Mosley et al., 1999)

Graph (a) and graph (b) in Figure 2.3 are indicating the stress-strain relation of high yield steel and the mild steel respectively. From the graph, it can be seen that the mild steel behaves as an elastic material until it reaches its yield point, eventually it will have a sudden increase in strain with minute changes in stress until it reaches the failure point. The high yield steel on the other hand, does not have a definite yield point but shows a more gradual change from elastic to plastic behaviour.

Despite of the various strength of the materials, reinforcing steels have a similar slope in the elastic region with E_s = 200 kN/mm^2. The specific strength taken for the mild steel is the yield stress. For the high yield steel, the specific strength is taken as the 0.2% proof stress (see Figure 2.3). BS8110 has recommended that the stress-strain curve may be simplified as per Figure 2.4. The suggested stress-strain relation is an elastic-plastic model, which the hardening effect is neglected.

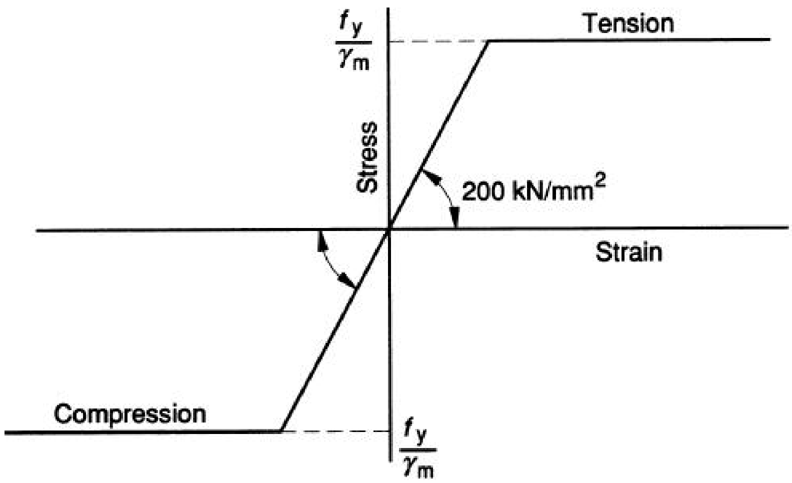

Figure 2.4 : Simplified stress-strain curve for reinforcing steel (BS8110, 1997)

2.3 Reinforced Concrete

Reinforced concrete is a strong and durable construction material that can be formed into many varied shapes and sizes ranging from a simple rectangular column (spanning in 1-dimensional) to a shell (spanning in 3-dimensional). Its utilities and versatilities are achieved by means of the composite action, with the best feature of concrete in compression and steel in tension.

The tensile strength of concrete is just about 10% of its compressive strength. In the design of reinforced concrete the tensile strength of concrete is neglected thus the tensile force is assumed to be resisted by the reinforcing steel entirely. The tensile stress is transferred to reinforcing steel from concrete through the bonding formed between the interface of the steel and concrete, therefore insufficient bond will cause the reinforcement to slip within the concrete.

Reinforcing steel can only develop its strength in concrete provided that it is anchored well to the concrete. BS 8110 has recommended formula in seeking the anchorage bonding stress, quoted.

$$f_b = \frac{F_s}{\pi \phi_e l_{anc}} \qquad \text{(eq. 2.1)}$$

The ultimate bond stress may be obtained by,

$$f_{bu} = \beta \sqrt{f_{cu}} \qquad \text{(eq. 2.2)}$$

When the thermal strain is considered, the differential movement between the reinforcing steel and the concrete will still be insignificant. This is because both the materials have a near value of thermal expansion co-efficient.

2.4 Reinforced Concrete Column

A column in a structure transfers loads from beams and slabs down to foundations. Therefore, columns are primarily compression members, although they may also have to resist bending forces due to the eccentricity. Design of the column is governed by the ultimate limit state, and the service limit state is seldom to be considered (Mosley et al., 1999).

2.4.1 Types of Column

There are two types of column, namely braced and unbraced. A braced column is the column that does not resist lateral load, because the load is resisted by the bracing members (i.e. shear wall). An unbraced column is the column that is subjected to lateral loads. The most critical arrangement of load is usually that causes the largest moment and axial load.

2.4.2 Column Classification and Failure Modes

A column can be classified as short or slender by a ratio of effective height, l_e, in the bending axis considered, to the column depth in the respective axis, h, (l_e/h). Based on the ratio, BS 8110 has recommended that a slender column can be determined by equation 2.3 (for braced structure) or equation 2.3 (for unbraced structure). By knowing the column is short or slender, the failure mode of the column can be predicted.

$$\text{Braced columns: } \frac{l_e}{h} \geq 15 \qquad \text{(eq. 2.3)}$$

$$\text{Unbraced columns: } \frac{l_e}{h} \geq 10 \qquad \text{(eq. 2.4)}$$

A short column is unlikely to buckle, hence it will fail when the axial load exceeded its material strength. This will cause the column to bulge and finally to crush.