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# INFLUENCE OF DIFFERENT CONCRETE STRENGTH ON THE BEHAVIOR OF INTERIOR REINFORCED CONCRETE BEAM-COLUMN JOINT

FELICIA THIEN YING CHIK

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Civil Engineering

Faculty of Civil Engineering
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NOVEMBER 2007

"I declare that this thesis entitled "Influence of Different Concrete Strength on the Behaviour of Interior Reinforced Concrete Beam-Column Joint" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree."

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Dedicated to

*To my beloved parents and brothers.*

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# ABSTRACT

The concreting of the beams and slabs at a particular floor level is carried out together with the beam-column connection zone using the same grade of concrete. In the case of the columns constructed from concrete of higher strengths than that of the beams, such concreting sequence forms beam-column connection zones with concrete of lower strengths than that in the columns. This thesis presents the comparisons of the test results on 6 internal column specimens, in which the influence of the lower concrete strength and the horizontal links in the connection zone, on the compression capacities of the columns was investigated. In general the columns and connection zones were of Grade C70, Grade C40 and Grade C25 concretes. The connection zone in five of the column specimens were cast with Grade C25 concrete, while that in the other one was with Grade C40. The test results show that although the ultimate load of the column with the connection zone from Grade C25 concrete is 25 % lower, it is still higher than the design load of the column calculated using Grade C70 concrete. The use of links also improves the capacity of the connection zone to a level beyond the capacity of the zone cast with Grade C25 concrete. It may therefore be concluded that the design calculations for the columns with the concrete strength of the order of 30 $N/mm^2$ higher than that in the connection zone, may safely be done based on the column concrete strength.

# ABSTRAK

Pengkonkritan rasuk dan papak pada sesuatu aras dilakukan sekali dengan zon sambungan rasuk-tiang menggunakan konkrit dari gred yang sama. Dalam kes tiang dengan konkrit berkekuatan lebih tinggi dari rasuk, langkah pengkonkritan tersebut menghasilkan zon sambungan rasuk-tiang dengan kekuatan konkrit yang rendah berbanding kekuatan konkrit tiang. Tesis ini memaparkan perbandingan keputusan ke atas 6 spesimen tiang dalaman, di mana pengaruh kekuatan konkrit yang lebih rendah serta pengaruh perangkai dalam zon sambungan ke atas keupayaan mampatan tiang diselidiki. Secara umumnya tiang terdiri daripada konkrit Gred C70, Gred C40 dan Gred C25. Lima daripada specimen tiang mempunyai zon sambungan dari Gred C25, manakala satu lagi dari Gred C40. Keputusan ujikaji menunjukkan walaupun beban muktamad tiang dengan zon sambungan dari konkrit Gred C25 adalah 25 % lebih rendah, ianya masih lebih besar dari beban reka bentuk keseluruhan tiang yang dikira berdasarkan konkrit Gred C70. Penggunaan perangkai dalam zon sambungan juga dapat meningkatkan keupayaan zon sambungan ke tahap melebihi keupayaan zon dengan konkrit Gred C25. Dengan itu, dapat disimpulkan bahawa bagi tiang dengan kekuatan konkrit sehingga 30 N/mm$^2$ lebih tinggi dari kekuatan konkrit dalam zon sambungan, kiraan reka bentuknya masih boleh dilakukan berdasarkan kekuatan konkrit tiang.

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| | | |
|---|---|---|
| $T$ | - | Tension force |
| $C$ | - | Compression force |
| $V_j$ | - | Shear load joint has to resist |
| $A_s$ | - | Reinforcemnt steel area |
| $f_y$ | - | Steel yield Strength |
| $V_{col}$ | - | Column shear force |
| $c$ | - | Column side for normal-strength concrete column |
| $C_{eqv}$ | - | Equivalent column side for high-strength concrete |
| $(E_{cc})_H$ | - | Modulus of elasticity for high-strength column |
| $(E_{cc})_N$ | - | Modulus of elasticity for normal – strength column |
| $P_o$ | - | Cross section capacity of a column under concentric load |
| $\alpha_1$ | - | Constant |
| $f'_c$ | - | Concrete cylinder strength |
| $A_g$ | - | Gross area of the column |
| $f'_{ce}$ | - | Effective column strength |
| $P_{test}$ | - | Maximum load carried by the test specimen |
| $f'_{cc}$ | - | Cylinder compressive strength of column concrete |
| $f'_{cs}$ | - | Cylinder compressive strength of slab concrete |
| $f'_{cp}$ | - | Apparent compressive strength of floor concrete in column test |
| $f'_{cf}$ | - | Cylinder compressive strength of slab concrete |
| $N$ | - | Axial loading on column |
| $A_c$ | - | Area of column at connection joint |
| $f_{yv}$ | - | Characteristic strength of the link reinforcement |
| $A_{sv}$ | - | Area of links |
| $h_c$ | - | Thickness of column |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

For reasons of economy, concrete columns are often made with higher strength concrete than that in the beams and slabs they support. In the preferred method of construction, the slab is cast continuous through the beam-column joint. As a result, that part of the column forming the joint between the beam and the column is made with a lower grade of concrete than that in the rest of the column. Consequently, the behavior of reinforced concrete beam-to-column joints has become a topic of particular challenge to researchers for the last 30 years or so. While much progress has been made in this time on the fronts of experimental research and design, many new unanswered questions have also appeared.

In present day construction practice, it is very common that the columns being designed and constructed within concrete of higher strength than that of the surrounding beam or slab system. High strength concrete is a relatively new construction material. Technology for producing high strength concrete has sufficiently advanced that concretes with compressive strength up to 100 $N/mm^2$ are commercially available and strengths much higher than that can be produced in laboratories. High strength concrete offers significantly better structural engineering properties, such as higher compressive strengths, higher stiffness, and better durability, when compared to conventional normal strength concrete. Thus, high strength concrete is an obvious choice in protecting building against the extreme loading conditions.

Besides, according to the investigation carried out by Marzouk et. al. (1996), it has been found that the use of high-strength columns increased connection shear strength compared to normal-strength concrete by about 5 percent in the case of no moment and 17 percent in the case of high moment. Not only was shear strength increased but the connection performance was greatly enhanced by the use of high-strength concrete columns.

For ease of construction, the floor system including the portion of column intersecting with the beam or slab system is cast using concrete of lower strength than the rest of the column. Thus, there is a problem of determining what concrete strength to use in assessing the compressive strength of the column when it is traversing through the floor system (Siao, 1994). To develop the full flexural capacity of beams, which are usually of weaker design than columns, the beam-to-column connection (also referred to as joint) must maintain its strength as well as stiffness during the loading cycles.

This paper reported experimental results of tests with properly modeled confinement conditions. There were six reinforced concrete sandwich column specimens, consisting of high-strength concrete column with a lower strength concrete central section which acted as the interior beam-column connection. The results show that the higher compressive strength at upper and lower part of the column enhanced the performance of the lower strength central portion of the column.

## 1.2 Problem Statement

Production of high strength concretes with compressive strengths exceeding 80 N/mm$^2$ is now technically and economically feasible in commercial ready mix concrete plants. It is not envisioned that the whole complete frame system will be constructed in the future using concrete with 80 N/mm$^2$ concrete strength (Marzouk et. al., 1996). Hence, further investigations are needed to develop and evaluate more research data to determine whether it is realistic and adequate for high-strength concrete to be constructed at the beam-column connections.

Current code provisions for the design of beam-column connections are based on the test results of connections constructed with relatively low compressive strengths not exceeding 40 N/mm$^2$. Nowadays, the floor or beam concrete commonly has a compressive strength of 25 N/mm$^2$, while that for the column maybe 40 N/mm$^2$ or greater. Thus, one design issue becomes whether the column strength should be based on the 25 N/mm$^2$ floor strength, the 40 N/mm$^2$ column strength, or some value in between due to the restraint conditions. Therefore, results of tests conducted on six combination of concrete strength on interior columns were evaluated.

## 1.3 Objectives

The main objective of this research investigation is to study and evaluate the behavior for beam-column connections constructed with combinations of high strength concrete columns and normal strength concrete beams. As a whole, the objectives for this study are:

a) To study the failure characteristics of reinforced concrete column under ultimate compressive strength.

b) To study the effect of normal concrete strength at beam-column connection to the ultimate compressive strength of column.

c) To study the effect of shear link and restraint beam at connection zone to the ultimate compressive strength of column.

## 1.4 Scope of Study

This paper carried out test on six specimens with the concrete strength as the variable. The specimens were axially loaded sandwich columns with the size of 150 x 150 mm and 1200mm in length. The scope of the research includes:

(a) The specimens were interior reinforced concrete columns tested for the compressive strength. The compression load was subjected to the end of the column until it failed.

(b) The specimens had the combinations of three different concrete strengths which were Grade 25, Grade 40 and Grade 70. Generally, the beam or the joint had the concrete strength of Grade 25, while the upper and lower column had the concrete strength of Grade 40 and Grade 70.

(c) One specimen was provided with additional reinforcement in form of shear links at the connection zone. The other five specimens had no additional reinforcement at the connection.

(d) One specimen was provided with beam restraint at the connection zone to study the difference between the restraint and unrestraint specimens.

(e) Three steps of concreting the column were employed, that is the concreting of lower column until the beam's soffit, followed by the concreting of beam including column at the particular level, and finally the concreting of the upper column.

(f) The main reinforcement in all specimens was from the Grade 460 steel bars while the shear link applied was Grade 250. The quantity and the detailing of main reinforcement were the same for all specimens.