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INFLUENCE OF CONCRETE STRENGTH ON THE BEHAVIOR OF EXTERNAL REINFORCED CONCRETE BEAM-COLUMN JOINT

HII HOW NGUONG

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Civil engineering

Faculty of Civil Engineering
Universiti Teknologi Malaysia

NOVEMBER 2007

"I declare that this thesis entitled "Influence of Concrete Strength on the Behavior of External 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 sister.

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ABSTRAK

Pengkonkritan rasuk and 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 ujikaji ke atas 4 spesimen sambungan rausk-tiang luaran, di mana pengaruh kekuatan konkrit yang lebih rendah serta pengaruh perangkai dan tetulang condong dalam zon sambungan ke atas keupayaan ricih tiang diselidiki. Secara umumnya tiang terdiri dari konkrit Gred C35, dan rasuk dari Gred C30. Semua spesimen rasuk-tiang mempunyai zon sambungan dari Gred C25. Keputusan ujikaji menunjukkan kekuatan ricih zon sambungan rasuk-tiang luaran tidak banyak dipengaruhi jika perbezaan kekuatan konkrit antara tiang dengan rasuk adalah kecil. Penggunaan perangkai atau tetulang condong meningkatan keupayaan zon sambungan ke tahap melebihi keupayaan zon dengan konkrit Gred C25. Keputusan juga menunjukkan purata beban muktamad atau tegasan ricih yang dicapai dalam kajian adalah 25-30% lebih rendah dari nilai teori. Dengan itu, dapat disimpulkan bahawa bagi tiang dengan kekuatan konkrit sehingga 10 N/mm^2 lebih tinggi dari kekuatan konkrit dalam zon sambungan, kiraan reka bentuknya masih boleh dilakukan berdasarkan kekuatan konkrit tiang, tetapi had tegasan rich maksimum di dalam zon sambungan rasuk-tiang perlu disemak semula.

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 4 external beam-column specimens, in which the influence of the lower concrete strength, the horizontal links and the inclined bars in the connection zone, on the shear capacities of the columns were investigated. In general the columns and beams were of Grade C35 and Grade C25 concretes respectively. The connection zone in all the beam-column specimens was cast with Grade C25 concrete. The test results show that the shear strength of the connection zone of the external beam-column joints did not much affected by concrete strength if the difference of concrete strength between column and joint was small. The use of links or inclined bars improves the capacity of the connection zone to a level beyond the capacity of the zone cast with Grade C25 concrete. The results also show that the average ultimate loads or shear stresses achieved in the investigation are 25-30% lower than the theoretical values. It may therefore be concluded that the design calculations for the columns with the concrete strength of the order of $10N/mm^2$ higher than that in the connection zone, may safely be done based on the column concrete strength, but the current allowable value of the shear stresses in the connection zone should be revised.

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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
$M_{u(col)}$	-	Moment must able to be resist by column
M_{bL}	-	Moment produced by left side beam
M_{bR}	-	Moment produced by right side beam
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
V	-	Joint ultimate shear strength
f_{cu}	-	Characteristic strength of concrete
A_{so}	-	Area of the outside layer of the column reinforcement furthest away from the column maximum compression face.
b_c	-	Width of the column
d_c	-	Effective depth of the column
d_b	-	Effective depth of the beam
N_u	-	Axial loading on column
A_g	-	Area of column at connection joint
A_{js}	-	Total area of horizontal link reinforcement crossing the diagonal plane from corner to corner of the joint between the beam compression and tension reinforcement.
f_{yv}	-	Characteristic strength of the link reinforcement

$V1$	-	Strength of the joint with links
A_{sv}	-	Area of links
a_v	-	Shear span
s_v	-	Spacing of the links
$V2$	-	Maximum shear strength for joint
A_s	-	The area of inclined bars
θ	-	The inclination of reinforcing bars to the column axis
V_{sx}	-	Shear carried by the inclined bar after first yielding
v_c	-	Design concrete shear stress
v_c'	-	Design concrete shear stress corrected to allow for axial forces
h_c	-	Thickness of column
N	-	Applied axial load on column
M	-	Moment at connection zone
A_c	-	Gross area of the column

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CHAPTER 1

INTRODUCTION

1.0 Introduction

In the analysis of reinforced concrete moment resisting frames, the joint was generally assumed as rigid. In normal design practice for gravity loads, the joint was usually neglected for specific design with attention being restricted to provision of sufficient anchorage for beam longitudinal reinforcement (S.R. Uma, A. Meher Prasad, 2000). Hence, the design check for joints was not critical and not warranted. This may be acceptable when the joint has the same concrete grade with the column. In construction practice, the construction stage of beam-column always being divided into three stages and as a result, the concrete grade at the joint was always different from the concrete grade of column.

It is very common in reinforced concrete structures that columns being designed and constructed with the concrete of a higher strength than that of the surround beam/slab system (Wen Bin Siao, 1994). This is because the columns always need to support larger load. In the earlier stage of concreting, the bottom column poured until the soffit of beam. The beam or floor system, including the portion of column intersecting with the beam/slab system was then cast at one time using concrete strength of beam/slab. The top column was only being poured after beam had reached the certain strength. In this case, the whole column actually did not have the uniform concrete strength as in design stages. As result, the structures might have failure at connection zone due to weak connection because of low concrete strength.

For connection which mainly concerning with the exterior column, the force from the beams could actually let the connection zone always sustains the huge shear force. In this case, failure of the connection zone was thus always cause by the diagonal shear cracking which could easily occurred with the forces value far lower than the actual capacity of column. This condition becomes more serious with non existence of shear link in connection zone with accordance to construction practice nowadays. Furthermore, the failure most probably may occur earlier with the low concrete strength in connection zone.

1.2 Problem Statement

As mentioned earlier, it was very common that columns always being designed and constructed using higher strength concrete than the surrounded beams or slab. This leads to the situation where column always did not have the uniform value of concrete strength especially in the connection zone. This was because the connection zone is always cast in one time with beam system using same concrete strength. This condition becomes worst when no horizontal link or reinforcing bar was provided in the connection zone as to avoid congestion in the connection zone. This type of column sometimes may able work well in serviceability stage, but it might fail at ultimate limit stage. This happened especially for exterior beam-column connection, where high shear force could lead to earlier failure at connection zone.

To have a similar concrete strength for the whole column, some contractor even applied unique technique during concreting. First, they poured the bottom column until the soffit of the beam. Then, they cast the connection zone by using column's concrete strength before concreting the beam by using lower concrete strength. Lastly, they poured the upper column. These steps could ensure that the whole column have the uniform concrete strength including the connection zone. But somehow, this type of construction practice might produce construction joint in the beam near the face of the support. Besides, since there was no blockage provided at the beam section, the concrete poured to the connection zone would continuously free flow out to the beam section during compaction. Therefore, the concrete near the construction joint cannot have the perfect compaction before the casting of beam. Moreover, with congested reinforcing steel bar at connection zone, the task of compacting became tougher.

Although there was a number of studies being conducted by Parker and Scott on behavior of beam-column joint, but all their specimens were fully in accordance to the design practice rather than construction practice. In other word, connection zone at specimen always have the same concrete strength as column. So, this study aimed to gain more understanding on the behavior of exterior joint with respect to different concrete strength.

1.3 Objectives of Study

Generally, this study was aimed to have a better understanding on behavior of beam-column joint when subjected to large shear force. There are two objectives needed to be achieved in this study:

i. To study the behavior of beam-column joint with different concrete strength in connection zone.

ii. To study the influence of shear link or inclined reinforcing bar in beam-column joint to the shear capacity of connection zone.

1.4 Scope of Study

In this study, there were four specimens being formed. The limitations of each specimen were as below:

a) All specimens consisted of three main structural elements. They were the exterior bottom column, top column and a beam connected to the columns.

b) Two type of concrete strength being used in this study, which were Grade C25 and Grade C35. In general, the beam was constructed with Grade C25 while the column was constructed with Grade C35.

c) Monotonic loading was used for testing. A fixed value of compression force acted upon the top of column and at the same time, the increasing vertical load applied on the edge beam until the specimen fails.

d) Steel bar with Grade 460 was used as main reinforcing bar while steel bar with grade 250 was used as link for all specimens. The quantity and detail of reinforcement were the same for all specimens.

e) Two specimens were provided with additional reinforcement at the connection zone. One was provided with additional horizontal shear link while the other was provided with a pair of inclined reinforcing bar at the connection zone.