UNIVERSITI TEKNOLOGI MALAYSIA

# BORANG PENGESAHAN STATUS TESIS ♦

JUDUL : **TORSION IN REINFORCED CONCRETE STRUCTURES: DESIGN REQUIREMENTS AND PROCEDURES IN BS 8110 AND EUROCODE 2**

**SESI PENGAJIAN: 2006/2007**

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# TORSION IN REINFORCED CONCRETE STRUCTURES: DESIGN REQUIREMENTS AND PROCEDURES IN BS 8110 AND EUROCODE 2

LEE DERK CHYUAN

A report submitted in partial fulfilment of the
requirements for the award of the degree of
Bachelor of Civil Engineering

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APRIL, 2007

I declare that this report entitled "*Torsion in Reinforced Concrete Structures: Design Requirements and Procedures in BS 8110 and Eurocode 2*" 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 other degree.

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*To my parents, brother and friends*

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# ABSTRACT

Torsion has been an integral part in the design of reinforced concrete since its inception. A lot of researches were done to determine torsional effects on reinforced concrete beams. Although it is normally assumed to have only secondary effects and thus the shear and longitudinal reinforcements are adequate in resisting torsional cracking, the effects of torsion on reinforced concrete beams in certain cases should not be overlooked. In some designs, a small percentage of reinforcement is added to cater for torsion while a few others neglect torsional effect based on the assumption that torsion gives only secondary effects. This project reviews the requirements and design procedure of reinforced concrete beams subjected to torsional moment. Comparisons of torsional design in BS 8110 and Eurocode 2 were made as BS 8110 will soon be replaced by Eurocode 2 in the coming few years. Applications of torsional design were obtained from a range of references including consulting current practicing engineers regarding their opinions on torsion. The results indicate that Eurocode 2 provides a more economical design than BS 8110 in the requirements of reinforcement's area for torsional resistance. Discussions were also made with local design engineers of various consulting firms regarding their experience in design that involved torsion or their opinion on the matter. From the discussions, it was found that most engineers only added an extra percentage of links ranging from 10% to 15% for torsional resistance.

# ABSTRAK

Puntiran merupakan satu bahagian yang penting dalam rekabentuk konkrit bertetulang. Banyak kajian dan eksperimen telah dijalankan untuk menentukan kesan-kesan puntiran terhadap konkrit bertetulang. Walau pada kebiasaannya puntiran dianggap hanya mempunyai kesan sampingan dan tetulang memanjang serta tetulang pengikat cukup untuk menangani kesan puntiran, namum kesan-kesan ini tidak patut diabaikan dalam sesetengah rekabentuk. Sebilangan rekabentuk hanya akan menambahkan beberapa peratus tetulang tambahan untuk puntiran dan ada juga yang terus mengabaikan kesan puntiran. Projek ini mengkaji keperluan dan prosedur rekabentuk konkrit bertetulang yang mengalami kesan puntiran. Selain itu, perbandingan rekabentuk puntiran di dalam BS 8110 dan Eurocode 2 juga akan dijalankan. Ini adalah kerana Eurocode 2 bakal menggantikan BS 8110 dalam beberapa tahun yang akan datang. Keputusannya menunjukkan Eurocode 2 menghasilkan rekabentuk yang lebih ekonomi daripada BS 8110 dari segi keluasan tetulang puntiran yang diperlukan. Beberapa sesi soal jawab juga telah dijalankan dengan jurutera perunding tempatan untuk memahami tentang puntiran di dalam rekabentuk struktur-struktur bangunan. Daripada sesi soal jawab, adalah didapati kebanyakan jurutera hanya menambah sebilangan tetulang pengikat iaitu di antara 10% dan 15% untuk menangani kesan puntiran.

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## Latin upper case letters

| | |
|---|---|
| $A$ | Cross sectional area |
| $A$ | Total area of cross-section within the outer circumference |
| $A_c$ | Cross sectional area of concrete |
| $A_s$ | Cross sectional area of reinforcement |
| $A_k$ | Area enclosed by the centre-lines of connecting walls |
| $A_{sl}$ | Area of longitudinal torsion reinforcements |
| $A_{sv}$ | Area of shear reinforcement |
| $A_{sw}$ | Area of shear reinforcement |
| BS | British Standard |
| CP | Code of Practice |
| EC | Eurocode |
| $F$ | Force |
| $G$ | Modulus of rigidity |
| $H$ | Height of the 'sand-heap' |
| $J$ | Torsional constant |
| $M$ | Bending moment |
| $M$ | Applied torque at the section |
| $M_z$ | Resulting torque about the shear centre |
| MS | Microsoft |
| RC | Reinforced concrete |
| $S$ | Shearing stress |
| $S$ | Shear Force |
| $T$ | Torsional moment due to ultimate loads |
| $T_{Ed}$ | Applied design torsion |
| $T_{sd}$ | Design ultimate torsion |
| $T_{lim}$ | Maximum torsional moment allowed |
| $T'$ | Ultimate torsional strength or RC beams in pure torsion |
| $T_{ca}$ | Allowable torque carried by the concrete |
| $T_s$ | Strength due to the torsional reinforcement |
| UTM | Universiti Teknologi Malaysia |
| $V_{Ed}$ | Design value of the applied shear force |
| $V_{lim}$ | Maximum shear force allowed |

**Latin lower case letters**

| | |
|---|---|
| $b$ | Breadth |
| $b_f$ | Breadth of bottom flange |
| $b_t$ | Breadth of top flange |
| $b_w$ | Breadth of web |
| $c$ | Compression stress |
| $d$ | Effective depth of a cross section |
| $e$ | Eccentricity |
| $f_c$ | Compressive strength of concrete |
| $f_{cu}$ | Characteristic compressive cube strength of concrete at 28 days |
| $f_{cd}$ | Design value of concrete compressive strength |
| $f_{ck}$ | Characteristic compressive cylinder strength of concrete at 28 days |
| $f_{cm}$ | Mean value of concrete cylinder compressive strength |
| $f_{ctk}$ | Characteristic axial tensile strength of concrete |
| $f_{ctm}$ | Mean value of axial tensile strength of concrete |
| $f_y$ | Yield strength of reinforcement |
| $f_{yd}$ | Design yield strength of reinforcement |
| $f_{yk}$ | Characteristic yield strength of reinforcement |
| $f_{yl}$ | Yield strength of longitudinal reinforcement |
| $f_{yv}$ | Yield strength of shear reinforcement |
| $f_{yld}$ | Design yield strength of longitudinal reinforcement |
| $f_{ywd}$ | Design yield strength of shear reinforcement |
| $h$ | Height |
| $h$ | Overall depth of cross section |
| $h_f$ | Height of top flange |
| $h_b$ | Height of bottom flange |
| $h_{min}$ | The smaller dimension of a rectangular section |
| $h_{max}$ | The larger dimension of a rectangular section |
| $q$ | Shear flow |
| $s$ | Spacing of shear reinforcements |
| $t$ | Thickness |
| $t$ | Tension stress |
| $t_{ef}$ | Effective wall thickness. May be taken as $A/u$ |
| $u,v,w$ | Components of the displacement of a point |
| $u$ | Outer circumference of the cross-section |
| $u_k$ | Perimeter of centre line of thin-walled section |
| $v$ | Shear stress |
| $v_t$ | Torsional shear stress |
| $x,y,z$ | Coordinates |
| $x_1$ | Smaller centre-to-centre dimension of rectangular link |
| $y_1$ | Larger centre-to-centre dimension of rectangular link |

**Greek lower case letters**

| | |
|---|---|
| $\gamma$ | Coefficient depending on the ratio *h/b* |
| $\gamma$ | Shearing strain |
| $\gamma$ | Partial factor |
| $\gamma_m$ | Partial factors for a material property |
| $\tau$ | Shear stress due to applied torque |
| $\tau_t$ | Torsional shear stress in wall |
| $\phi$ | Cross sectional rotation |
| $\alpha$ | Angle to neutral axis |
| $\psi$ | Airy's Stress function |
| $\theta$ | Angle |
| $\rho$ | Oven-dry density of concrete in $kg/m^3$ |
| $\rho_l$ | Reinforcement ratio for longitudinal reinforcement |
| $\rho_w$ | Reinforcement ration for shear reinforcement |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Most beam designs nowadays do not take much consideration of the torsional effects. Although it is normally assumed to have only secondary effects and thus the shear and longitudinal reinforcements are adequate in resisting torsional cracking, the effects of torsion on reinforced concrete beams in certain cases should not be overlooked. Structural elements such as at balcony beams, bow girders, beams supporting a secondary beam and beams with unsymmetrical loading should be designed or at least be checked for torsion.

Research works on structural members under the effect of torsion dated back to as far as 1903 where it was mentioned. The code of practice CP110:1972 dealt with the design of sections to resist torsion for the first time as a structural code while torsion is then shifted to Part 2: Code of practice for special circumstances of BS 8110.[1] In Eurocode 2[2], which is scheduled to replace BS 8110[1] by the year 2010, torsion is given more attention than before.

Torsion arising from statically indeterminate structures may be ignored as the lack of torsional resistance will only result in minor cracking whereas in a statically determinate structure, lack of torsional resistance will result in the collapse of the structure. But when does a structure really needs torsional reinforcements? Some engineers are still confused on the application of torsion in reinforced concrete design.

## 1.2 Problem Statement

Torsion is an important element to be considered in the design of reinforced concrete beams. It does not only produce cracks but also will result in total failure for beams directly affected by torsion. Therefore, it is important to understand the behaviour of torsion. Eurocode 2[2] will be replacing BS 8110[1] in the coming few years and with different approaches in the code of practices towards torsion, a review and comparison is necessary. Local engineers have been making their own assumptions on torsional design. Thus, it is essential to look into the application of torsional design in practice.

## 1.3 Objective

a. To study the effects of torsion on reinforced concrete beams.
b. To examine and compare the torsional designs in BS 8110[1] and Eurocode 2.[2]
c. To determine the practical application of torsional reinforcements in practice.

## 1.4 Scope of Study

a. Formulas for torsional design were obtained directly from the codes of practices.
b. Structures affected by torsion were photograph and shown.
c. Comparison was done for torsional design in BS 8110[1] and Eurocode 2[2]
d. Questionnaire and discussions with local engineers on torsion in reinforced concrete design.