

EFFECTS ON LOADING CALCULATION OF REINFORCED CONCRETE
STRUCTURAL DESIGN SUBJECTED TO FIRE: REVIEW ON BUILDING
CODES AND STANDARDS

WONG JING SIONG

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

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JANUARY 2019

DEDICATION

My dearest family, Dr Mariyana and friends”

ACKNOWLEDGEMENT

I would like to take this opportunity to express my deepest gratitude to my family for their continual support over the years. Not to forget the guidance from Dr. Mariyana and the opportunity given by University of Technology Malaysia for me to pursue the course of Master in Civil Engineering.

ABSTRACT

This study is to review the relevant building codes and standards for the design of reinforced concrete structural elements under fire condition. Detailed study of the relevant codes and standards for the reinforced concrete design under fire will be carried out. The design requirements will then be identified based on the respective codes requirement or recommendation to identify the differences between the codes in terms of prescriptive and performance design, load combination for fire condition and the design of reinforced concrete structural elements during fire condition. A simple numerical analysis of the reinforced concrete structural element will be carried out to demonstrate the difference in terms of loading calculation adopted for the element design and the reinforced concrete design. The calculation shows that the material strength reduction factor increased when the temperature rises which also affects the flexural strength of the concrete element. However, the reduced permanent and variable actions load factor for the fire condition load combination also reduced the designed moment required, corresponding to the reduction in flexural strength due to the reduced material strength exposed to fire.

ABSTRAK

Kajian ini dijalankan bagi tujuan pengulasan piawai reka bentuk struktur elemen konkrit bertetulang semasa waktu kebakaran. Pengajian bintan piawai reka bentuk struktur konkrit yang berlainann akan dilakukan. Perbezaan dalam segi piawai preskripsi atau prestasi, gabungan beban semasa waktu kebakaran dan reka bentuk struktur elemen konkrit bertetulang semasa kebakaran akan dikenal pasti. Pengiraan mudah bagi reka bentuk struktur akan ditunjukkan bagi menentu perbezaan dari segi gabungan beban dan reka bentuk struktur elemen konkrit bertetulang. Pengiraan tersebut menunjukkan bahawa faktor pengurangan kekuatan bahan meningkat apabila suhu kebakaran meningkat dan menjejaskan kapasiti beban beam. Walau sedemikian, gabungan beban yang dikurangkan semasa kebakaran juga mengurangkan kapasiti momen yang diperlukan dengan pengurangan kekuatan bahan semasa suhu kebakaran meningkat.

TABLE OF CONTENTS

	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xii
CHAPTER 1	INTRODUCTION	1
1.1	Reinforced Concrete Design Code of Practice	1
1.2	Fire Safety Engineering	2
1.3	Statement of the Problem	3
1.4	Objectives of the Study	5
1.5	Scope of the Study	6
1.6	Significance of the Study	6
1.7	Chapter Arrangement	6
CHAPTER 2	LITERATURE REVIEW	9
2.1	Introduction	9
2.1.1	Prescriptive Design	10
2.1.1.1	Eurocode 2, Part 1-2	10
2.1.1.2	New Zealand Building Code	11
2.1.1.3	Fire Resistance Rating	12
2.1.1.4	Australian Building Codes	13
2.1.1.5	British Standards	15
2.1.2	Performance Design	20

	2.1.2.1	Eurocode 2(2010): Actions on Structures Part 1-2: General Actions - Actions on Structures Exposed to Fire	20
	2.1.2.2	New Zealand Building Regulations	23
	2.1.2.3	The Building Code of Australia, Vol. 1, Part C, Fire Resistance	25
2.2		Load combinations for fire design	26
	2.2.1	Eurocode 2, Part 1-2	27
	2.2.2	Australia / New Zealand Standard AS/NZS 1170.0.2002	28
2.3		Fire Load	30
	2.3.1	Fire Scenario	31
	2.3.1.1	Eurocode Annex D – Advance fire models	31
	2.3.1.2	New Zealand Building Code (NZBC) 1992	32
	2.3.1.3	Eurocode Standard Temperature time curve	35
	2.3.1.4	Eurocode Parametric Temperature-time Curves	36
	2.3.1.5	Eurocode Localized Fire	38
	2.3.1.6	Eurocode Equivalent Time of Fire Exposure	40
	2.3.2	Heat Transfer	41
	2.3.2.1	Radiation	43
	2.3.2.2	Conduction	43
	2.3.2.3	Convection	43
2.4		Reinforced Concrete Structures	44
	2.4.1	Eurocode: Actions on Structure – Part 1-2:	47
	2.4.2	New Zealand Standards, Concrete Structure Standards, NZS 3101: Part 1: 2006, Chapter 4: Design for Fire Resistance	53
	2.4.3	Australian Standards AS 3600 – 2009 Concrete Structure, Chapter 5: Design for Fire Resistance	53
	2.4.4	British Standards, BS 8110: Part 1: Section 3 Design and Detailing: Reinforced Concrete, Part 2: Code of Practice for Special Circumstances	54

CHAPTER 3	RESEARCH METHODOLOGY	55
3.1	Research Design and Procedure	55
3.2	Operational Framework	55
3.3	Subjects or Data Sources	56
3.4	Assumptions and Limitations	57
3.5	Research Planning and Schedule (Gantt chart)	57
CHAPTER 4	RESULTS	59
4.1	Prescriptive Design Comparison	59
4.2	Reinforced Concrete Structure Design	62
4.3	Minimum Simply Supported Concrete Beam Cover and Dimensions	64
4.4	Minimum Simply Supported Concrete Slab Cover and Dimensions	65
4.5	Load Combination Comparison	66
4.6	Load Combination Simple Calculation	68
4.6.1	Eurocode: Actions on Structure – Part 1-2:	69
4.6.1.1	Direct Calculation:	69
4.6.1.2	Indirect calculation:	70
4.6.2	Australian and New Zealand code:	72
4.6.3	British Standards	73
4.7	Design checking for reinforced concrete structural member exposed to standard fire	73
4.7.1	Simply supported reinforced concrete slab	73
4.7.2	Simply supported reinforced concrete beam	89
4.7.3	Continuous Reinforced Concrete T-beam	104
4.8	Findings	110
CHAPTER 5	CONCLUSION AND RECOMMENDATIONS	119
5.1	Conclusions	119
5.2	Future Works	121
REFERENCES		123

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	Prescriptive reinforced concrete fire design building codes from various countries	10
Table 2.2	Acceptable solutions (AS) according to New Zealand Building Code	12
Table 2.3	Building classes according to Australian Building code	14
Table 2.4	Building types according to Australian Building code	14
Table 2.5	Variation of cover to main reinforcement with member width according to British Standards	15
Table 2.6	Reinforced concrete columns according to British Standards	15
Table 2.7	Concrete beams according to British Standards	16
Table 2.8	Plain soffit concrete floor according to British Standards	17
Table 2.9	Ribbed open soffit concrete floor according to British Standards	18
Table 2.10	Concrete walls with vertical reinforcement according to British Standards	19
Table 2.11	Performance Based Design for reinforced concrete structure	20
Table 2.12	Clause C3—Fire affecting areas beyond the fire source, functional requirement according to New Zealand Building Regulation	24
Table 2.13	Clause C6—Structural stability functional requirement according to New Zealand Building Regulation	24
Table 2.14	Building importance level according to New Zealand Building Regulation	25
Table 2.15	Heat flux between buildings according to Building Code of Australia	26
Table 2.16	Recommended values of ψ factors for building according to Eurocode 2	28
Table 2.17	Short-term, long-term and combination factors according to Australian / New Zealand Standard	29
Table 2.18	Ten Design Fire Scenarios according to New Zealand Building Code	32

Table 2.19	Pre-flashover design fire characteristic according to New Zealand Building Code	33
Table 2.20	Design Fire Load Energy Density (FLED) for use in modelling fires in C/VM2 according to New Zealand Building Code (Cont)	34
Table 2.21	Minimum column dimensions and axis distances for columns with rectangular or circular section according to Eurocode	46
Table 4.1	Prescriptive design comparison	60
Table 4.2	Performance design comparison	61
Table 4.3	Reinforced concrete design comparison	62
Table 4.4	Minimum concrete cover and dimensions for simply supported beam (Fire resistance = 60 minutes)	64
Table 4.5	Minimum concrete cover and dimensions for simply supported beam (Fire resistance = 90 minutes)	64
Table 4.6	Minimum concrete cover and dimensions for simply supported beam (Fire resistance = 120 minutes)	65
Table 4.7	Minimum concrete cover and dimensions for simply supported slab (Fire resistance = 60 minutes)	65
Table 4.8	Minimum concrete cover and dimensions for simply supported slab (Fire resistance = 90 minutes)	66
Table 4.9	Minimum concrete cover and dimensions for simply supported slab (Fire resistance = 120 minutes)	66
Table 4.10	Fire design load combination comparison	67
Table 4.11	Material strength reduction factor comparison under fire condition	67
Table 4.12	Comparison of variable load reduction factor during fire condition	68
Table 4.13	Direct calculation load and moment comparison	70
Table 4.14	Indirect calculation load and moment comparison	72
Table 4.15	Australian and New Zealand load and moment comparison	73
Table 4.16	Summary of design loading and moment	110

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 1.1	The EPF building on February 2018 (Photo: THE STAR / ASIA NEWS NETWORK)	3
Figure 1.2	Winsor Tower, Madrid	4
Figure 2.1	Design Procedure (Prescriptive method) according to Eurocode	11
Figure 2.2	Design Procedure for Eurocode Performance Based Codes (Eurocode 2, 2010)	23
Figure 2.3	Fin wall protecting a window (1m is just an example)	26
Figure 2.4	Fire temperature-time curves, Phan et al. 2010 NIST TN 1681 (Dat Duthinh, 2014)	30
Figure 2.5	Temperature time curve in the natural fire (Tudor Petrina, 2011)	31
Figure 2.6	Heat transfer mechanism (Dr Martin Gillie, 2008)	42
Figure 2.7	Simply supported slab exposed to fire (Andrew H. Buchanan, 2 nd Edition).	45
Figure 2.8	Reinforced concrete structure design method according to Eurocode	50
Figure 2.9	Tabulated data according to Eurocode	51
Figure 2.10	High strength concrete according to Eurocode	52
Figure 3.1	Research methodology flow chart	56
Figure 4.1	Simply supported beam	69
Figure 4.2	Simply supported beam bottom reinforcement numbering	89
Figure 4.3	Two span reinforced concrete T-beam	104
Figure 4.4	Concrete T-beam mid span fire design checking	104
Figure 4.5	Elevated temperature flexural strength against design moment for concrete cover of 25mm (simply supported slab)	112
Figure 4.6	Moment versus fire duration for concrete cover of 30mm (simply supported slab)	112
Figure 4.7	Moment versus fire duration for concrete cover of 35mm (simply supported slab)	113

Figure 4.8	Simply supported slab flexural moment comparison	113
Figure 4.9	Moment versus fire duration for concrete cover of 25mm (simply supported beam)	114
Figure 4.10	Moment versus fire durationfor concrete cover of 30mm (simply supported beam)	115
Figure 4.11	Moment versus fire duration for concrete cover of 35mm (simply supported beam)	115
Figure 4.12	Simply supported beam flexural moment comparison	116
Figure 5.1	Simply supported slab flexural moment comparison	120
Figure 5.2	Simply supported slab flexural moment comparison	120

CHAPTER 1

INTRODUCTION

1.1 Reinforced Concrete Design Code of Practice

British Standards Institution (BSI), which is the national standards body of United Kingdom, develops the British Standards (BS) under the authority of a Royal Charter. The principle of British Standards encompass the development, publication, maintenance and application of British Standards and related standardization documents, together with the UK's participation in European and international standardization.

Efforts to develop Eurocodes started in 1975. The Commission of the European Community (presently the European commission) decided to develop an action programme for the construction field. The purpose of the programme is to harmonise the technical specifications and to eliminate the technical obstacles. The established set of harmonised technical rules for the construction works would serves as an alternative to the national rule for the member states in the European Union, and ultimately replaced them. Ten sections of the Eurocodes are published as a separate European Standards. All the Eurocodes relating to material have a Part 1-1 which covers the design of building and other civil engineering structure and Part 1-2 for fire design.

Britain, which is part of the European Union, along with the rest of its member, is obligated to adopt the Eurocode with its respective national annex, which is consistent with the other European country, rather than national level. On April 2010, BSI withdraws 57 British Standards and replaced with the 10 new Eurocodes. The old British Standards may still be used; however, they will not be maintain or updated which means that one day it will be obsolete.

In Malaysia, Uniform building By Law governs the engineering practices. The latest amendment to the Uniform Building by Law includes the replacement of British Standards with Eurocodes and adopted as Malaysian Standards. Since April 2010, United Kingdom had withdrawn all British Standards and fully adopted the use of Eurocodes in United Kingdom consultancy practice. For the construction industries and the professional engineering practices to move forward, it is imperative that Eurocodes to be adopted as referenced designed standard and for submission purposes. However, the implementation of revised Building by Law has not yet to be adopted and implemented by all the local authorities' levels (Ir. Prof. Dr. Jeffrey Chiang, 2015).

1.2 Fire Safety Engineering

One of the biggest treats to be buildings around the world is fire. Fire in a building is a destructive force which can cause millions of dollars of damages and sometimes causes deaths to people. The outbreak of fire can occur at any time to any kind of building, and often least expected. Therefore, for the safety of the occupants, the building design largely focused on the escape routes for the occupant and the access for the fire fighter. The building layout must provide safe routes for the occupants to leave the building and access for fire fighter to enter or leave the building. Part of the structure must also be designed in such a way that it will not collapse during fire and does not allow the fire to spread, which is part of fire safety engineering for building. Fire safety engineering can be defined as the engineering application to the effects of fire in order to reduce the damages to the properties and loss of life by providing preventive or protective measures.

The loss of life and damages to the properties can be eliminated if fire outbreak can be prevented. Comprehensive strategies or preventive measures can be put in place to reduce the chances of fire, however, we can never be one hundred percent sure that it can prevent all major fires, hence the fire safety engineering design. In Malaysia, one of the most effective counter measures against the outbreak of fire is the provision of sprinkler system to control or extinguish the fire. Safe

routes for the occupants and fire fighters, barriers to control the spread of fire or smoke, and the structure will not collapse at the early stage of fire while the occupants are leaving the building is also being taken into consideration during design stage. Figure 1.1 shows the EPF building in Malaysia caught on fire caused by the flammable cladding of the building.



Figure 1.1 The EPF building on February 2018 (Photo: THE STAR / ASIA NEWS NETWORK)

1.3 Statement of the Problem

Among most of the widely adopted building material, concrete material provides the highest resistance to fire. Concrete material does not contribute to the fire load. Instead, it provides the necessary fire protection, thermal insulation and barrier between compartments which provides escape routes during fire. Concrete material also provides the most cost effective options for fire protective construction. Figure 1.2 shows the case of modern high-rise building exposed to fire. The building was destroyed by the fire outbreak at level 21 floor out of 29 floors in total. The used

of load bearing concrete elements such as shear wall, columns and corewalls helped to prevent the complete collapse of the building under fire which lasted for 25 hours. Based on the reinforced concrete fire resistance design, the provision of the respective concrete cover, fire resistance rating or fire resistance level helps to improve the fire resistance of the building.



Figure 1.2 Winsor Tower, Madrid

Before the publication and implementation of Eurocodes for reinforced concrete (RC) building design, British Standards is widely adopted for RC building design in Malaysia. Fire resistance of structure or structural element is given in the tabulated data under Section 4 of BS 8110 -2:1985, the fire resistance capacity of the structural element is specified in terms of concrete cover for the respective structural elements based on the respective fire resistance duration only.

Based on Eurocodes, an entire section of Eurocodes (Eurocode 2: Design of concrete structure – Part 1-2: General rules – Structural fire design) is dedicated for the design of structural element under fire. Different methods ranging from simplified method to complex finite element method are specified in the Eurocode. The reduction of material strength for the concrete and steel reinforcement is determined based on the estimated temperature, and the capacity of the structural

element is re-checked based on the reduced material strength and compared with the fire design load combination designed loadings.

With such contrast of the design requirement and recommendation for fire resistance, this study will focused on the review of the different for structural fire design codes not limited to Eurocode, but also British Standards, Australia standards and New Zealand Standards.

1.4 Objectives of the Study

The objectives of the study are as follows:

- a. To critically review the structural reinforced concrete design for fire based on Eurocode, but also British Standards, Australia Standards and New Zealand Standards.
- b. To identify the differences in terms of prescriptive and performance based standards, load combinations, material reduction factor during elevated temperature and the design of reinforced concrete structural fire design, based on Eurocode, British Standards, Australian Standards and New Zealand Standards.
- c. To carry out simple calculation for the respective load combinations, simply supported reinforced concrete beam and slab and minimum concrete cover and dimension required based on Eurocode, British Standards, Australian Standards and New Zealand Standards.
- d. To compare the design procedure and flexural strength of simply supported concrete beam and slab at ambient temperature and elevated temperature.

1.5 Scope of the Study

This research will review on both prescriptive and performance based standards, design procedure, load combinations, and design and analysis method for reinforced concrete structural fire design based on Eurocode, British Standards, Australia Standards and New Zealand Standards. Design of reinforced concrete structural element procedure comparison and simple analysis for the respective code of practice load combination for fire condition will be carried out. Simplified design method such as 500°C isotherm method for beam and slab design will be adopted to demonstrate the effect of different concrete cover on the flexural strength based on the respective load combination under fire condition for a simply supported rectangular beam, continuous T-beam and simply supported slab.

1.6 Significance of the Study

This study will identify the prescriptive and performance based standards, design procedure, load combinations, and design and analysis method for reinforced concrete structural fire design based on the respective codes of practices according to the different load combination and concrete cover for particular fire resistance duration. Perhaps this study can be used to compare the flexural strength of reinforced concrete structural element concrete at ambient and elevated temperature.

1.7 Chapter Arrangement

Chapter 1: In this chapter, introduction to the research study, statement of the problems objectives, scope of the study, and the significance of the study will be elaborated.

Chapter 2: This chapter will review on the prescriptive and performance based standards, design procedure, load combinations, and design and analysis

method for reinforced concrete structural fire design based on Eurocodes, British Standards, New Zealand Codes and Australian Codes.

Chapter 3: The outline and the research methodology of this study will be identified in this chapter.

Chapter 4: The respective prescriptive and performance based standards, design procedure, load combinations, and design and analysis method for reinforced concrete structural fire design based on Eurocodes, British Standards, New Zealand Codes and Australian Codes will be tabulated for comparison, and the findings of the comparison to be identified and elaborated.

Chapter 5: Summary of the research proposal above and the future works to be suggested.

REFERENCES

- Eurocode 2: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire
- British Standards, BS 8110: Part 1: Section 3 Design and Detailing: Reinforced Concrete
- British Standards, BS 8110: Part 2: Code of Practice for Special Circumstances
- New Zealand Standards, Concrete Structure Standards, NZS 3101: Part 1: 2006, Chapter 4: Design for Fire Resistance
- Australian Standards AS 3600 – 2009 Concrete Structure, Chapter 5: Design for Fire Resistance
- New Zealand Building Code 1992
- Australia / New Zealand Standard AS/NZS 1170.0.2002
- The Building Code of Australia, National Construction Code Series, Vol. 1, Part C, Fire Resistance
- Allan Jowsey, Peter Scott, and Jose Torero, “Overview of the benefits of Structural Fire Engineering”, International Journal of High Rise Buildings, Vol 2, No 2, 131-139, June 2013
- Dat Duthinh, “Structural Design for Fire: A Survey of Building Codes and standards”, NIST Technical Note 1842, Material and Structural System Division, Engineering Laboratory, September 2014
- KRZYSZTOF CHUDYBA, SZYMON SEREĞA, “Structural Fire Design Methods for Reinforced Concrete Members”, Technical Transactions, Civil Engineering, 1-B/2013
- Philip T Sanders, “Advances in Fire Design for Reinforced Concrete Structures – Moving to More Rational Design Methods”, National Engineer, Steel Reinforcement Institute of Australia
- Angela Liu. Peter Collier, “A framework to develop a cohesive structural and fire engineering design approach for buildings”, SR347 (2016)
- Andrew H. Buchanan & Anthony K. Abu, “Structural Design for Fire Safety, Second Edition”, University of Canterbury of New Zealand, 2017

Tudor Petrina, “Fire Structural Analysis According to European Codes”, Technical University of Cluj-Napoca, Faculty of Civil Engineering. 15 C Daicoviciu Str., 400020, Cluj- Napoca, Romania, 2011

Dr Martin Gillie, “Heat Transfer in Structures”, University of Edinburgh, 2008

Andrew H. Buchanan. Anthony K. Abu, “Structural Design for Fire Safety, 2nd Edition”, 2001

Ir. Prof. Dr.Jeffrey Chiang, “Structural Eurocodes to Replace British Standards in Malaysia”, The Institution of Engineers Malaysia (IEM) Honorary Treasurer Chairman, IEM Technical Committee on Earthquake Dean, Faculty of Engineering & the Built Environment, SEGi University, 2015