SIMULATION BEHAVIOUR OF FIRE RESPONSE TO FIRE RESISTANCE STEEL BEAMS

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ABSTRACT

High temperature is one of the factor that caused the structure to be severe and would undermine the soundness of the building. Therefore, it is very important to introduce fire safety measures appropriate to the building designer design a building before. Recent introduction of computer-based code has been helping and improving the fire resistance rating on the model. To evaluate fire resistance to the structure of steel, this is expected to alter the properties of steel used as input data. To ensure safety of the steel structure after exposure to fire, it is important to understand the effects and response to high temperature. At high temperatures, stainless steel and shape retention were stronger than conventional steel structures. In addition, the relationship between strength and stiffness at high temperatures influenced by buckling of retaliation against the structural components. Several sets of numerical experiment using the computer software LUSAS was conducted to investigate the effect of reaction to fire steel beams and columns based on a real fire as well as the burdens. Finite element model is valid based on experimental data, and the effect of high temperature on steel beams and columns can be described. A valid model is used to carry out some parametric research. This research emphasizes to find the strength of stainless steel in high temperature, 25°C, 100°C, 200°C, 300°C, 400°C, 500°C, 600°C, 700°C and 800°C. The test results show the method to fire appropriate to extend the fire exposure time, reducing the change of structure, and increase the critical temperature of the column to beam type connection.

ABSTRAK

Suhu yang tinggi merupakan salah satu faktor yang menyebabkan struktur menjadi teruk dan akan melemahkan kekukuhan bangunan. Oleh itu, amat lah penting untuk memperkenalkan langkah-langkah keselamatan kebakaran yang sesuai kepada para pereka bangunan sebelum mereka membina bangunan. Pengenalan kod yang terkini berasaskan komputer telah membantu dan meningkatkan penilaian ketahanan api terhadap model. Untuk menilai ringtangan api bagi struktur jenis keluli, nilai yang dijangka dapat mengubah sifat keluli dijadikan sebagai data input. Demi memastikan struktur keluli akan selamat selepas terdedah terhadap api, adalah penting untuk mengetahui kesan dan tindak balas terhadap suhu tinggi. Pada suhu tinggi, keluli tahan karat menunjukkan pengekalan bentuk dan lebih kuat jika dibandingkan dengan struktur keluli biasa. Selain itu, hubungan antara kekuatan dan kekakuan pada suhu yang tinggi dipengaruhi oleh tindakan balas lengkokan terhadap komponen struktur. Beberapa set kajian berangka menggunakan perisian computer iaitu LUSAS telah dijalankan untuk menyelidik kesan tindakbalas api untuk rasuk dan tiang besi berasaskan kebakaran sebenar dan juga beban-beban. Model elemen terhingga adalah sah berdasarkan data eksperimen, dan kesan suhu tinggi terhadap rasuk dan tiang besi boleh digambarkan. Model yang sah digunakan untuk menjalankan beberapa penyelidikan parametrik. Penyelidikan ini menekankan untuk mencari kekuatan besi tahan karat pada suhu yang tinggi iaitu, 25°C, 100°C, 200°C, 300°C, 400°C, 500°C, 600°C, 700°C dan 800°C. Keputusan ujian terhadap api menunjukkan kaedah yang sesuai untuk memanjangkan masa dedahan api, mengurangkan perubahan bentuk struktur, dan meningkatkan suhu kritikal terhadap jenis sambungan rasuk kepada tiang .

TABLE OF CONTENT

CHAPTER	TITLE	PAGE
	TITLE PAGE	i
	STUDENT'S DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENT	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF SYMBOLS	xiii
	LIST OF ABBREVIATIONS	xiv
CHAPTER 1	**INTRODUCTION**	1
	1.1 Introduction	1
	1.2 Problem Statement	3
	1.3 Objective	4
	1.4 Scope of Work	4
	1.5 Significant of Study	4
CHAPTER 2	**LITERATURE REVIEW**	5
	2.1 Introduction	5
	2.2 Fire Resistance Steel (Stainless Steel)	6

2.3 Structural Steel 7

2.4 Advantages of Stainless Steel 10

CHAPTER 3 METHODOLOGY 11

3.1 Introduction 11

3.2 Project Flow 12

3.3 Experiment Setup 13

3.4 Finite Element Analysis Method: LUSAS Modeller 14.0.3 15

3.4.1 Introduction of LUSAS Finite Element Analysis Software 15

3.4.2 Concepts and Procedure 16

3.4.3 Attributes of Modelling 19

3.4.3.1 Thin Shell Surface Element (QSL8) 20

3.4.3.2 Geometric Surface 23

3.4.3.3 Material 24

3.4.3.4 Support condition 26

3.4.3.5 Loading 28

3.4.3.6 Temperature load (TEMP, TMPE) 29

3.5 Finite Element Analysis 31

3.5.1 Linear Analysis 33

3.5.2 Linear Buckling Analysis 33

CHAPTER 4 RESULTS AND ANALYSIS 35

4.1 Introduction 35

4.2 Finite Element Analysis 35

4.3 Result of Linear Analysis 36

4.3.1 Finite Element Model 36

4.3.2 Deformed Mesh 37

4.3.3 Linear Analysis 38

4.3.3.1 Maximum Stress 38

4.3.3.2 Maximum Strain 40

4.3.4 Linear Buckling Analysis 41

4.3.4.1 Linear Buckling Analysis of Restrain Steel Beam 42

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS 48

5.1 Introduction 48

5.2 Conclusion 48

5.3 Recommendations 49

REFERENCES 50

APPENDICES A 52

APPENDICES B 54

LIST OF TABLES

TABLE NO.	TITLE	PAGE
3.1	Application and Function of LUSAS at Industry	15
3.2	Available Loading in QSL8	22
3.3	Material Properties	25
3.4	Support Condition and its Explanation	26
4.1	Buckling Load Factors at Temperature 25°C	43
4.2	Buckling Load Factors at Temperature 400°C	45
4.3	Buckling Load Factors at Temperature 800°C	47

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Relative stiffness retention at elevated temperature	6
2.2	Dimension of the column to beam type connection	8
2.3	Location need to burn	9
2.4	The FE simulated failure mode with the test result for specimen	9
3.1	Flow Chart of the Research Progress	12
3.2	Photo of test setup in the furnace	13
3.3	Schematic test setup	14
3.4	Photos of the two specimens after fire test	14
3.5	Attributes in LUSAS Analyst 14.0.3	18
3.6	Thin Shell Element (QSL8)	20
3.7	Stress Resultant of a Thin Shell Element	21
3.8	Continuum Stress in a Thin Shell Element	21
3.9	Local axes for Thin Shell Elements	21
3.10	Surface mesh dataset	22
3.11	Geometric Surface dataset	23
3.12	Location, Thickness and Eccentricity of Element	24
3.13	Material Properties dataset	25
3.14	Support condition of column to fire resistance steel beam	27
3.15	Structural support dataset	27
3.16	Loading condition of column to fire resistance steel	28
3.17	Structural loading dataset	29
3.18	Loading condition of column to fire resistance steel	30
3.19	Temperature loading dataset	31
3.20	Flow Chart of Analysis by Using LUSAS Software	32
4.1	Finite Element Model of column fire resistance steel beam	36
4.2	Deformed mesh of column to fire resistance steel beam	37

4.3	Maximum stress, N_{max} at temperature 25°C	38
4.4	Maximum stress, N_{max} at temperature 400°C	39
4.5	Maximum stress, N_{max} at temperature 800°C	39
4.6	Maximum strain, E_{max} at temperature 25°C	40
4.7	Maximum strain, E_{max} at temperature 400°C	40
4.8	Maximum strain, E_{max} at temperature 800°C	41
4.9	Eigen value at temperature 25°C	42
4.10	Eigen value at temperature 400°C	44
4.11	Eigen value at temperature 800°C	46

LIST OF SYMBOLS

SYMBOL	MEANING
et al.	And Others
m	Meter (Length Unit)
mm	Millimeter (Length Unit)
N	Newton (Load Unit)
kN	Kilo Newton (Load Unit)
W	Weight (Load Unit)
M	Moment (Nm)
E	Young's Modulus
v	Poisson Ratio
σ	Stress (N/mm^2)
ε	Strain
γ	Strain
ψ	Flexural Strain
σ_{max}	Maximum Stress (N/mm^2)
ε_{max}	Maximum Strain
3D	Three Dimensions
PDE	Partial Differential Equations

LIST OF ABBREVIATIONS

ABBREVIATION	MEANING
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
LUSAS	London University Structural Analysis Software
ANSYS	Acronym to Analysis System
ABAQUS	Other Program of Finite Element Analysis Software
QSL8	Quadrilateral Thin Shell Elements with 8 Nodes Clockwise
TEMP	Temperature

CHAPTER 1

INTRODUCTION

1.1 Introduction

In steel structures, the beam is a horizontal structural element that is capable of withstanding load primarily by resisting bending force. Generally, beams are not only can carry horizontal loads like the loads due to earthquake and wind but also can be used to carry a vertical gravitational force which is the load of the structures. The loads carried by a beam are transferred to columns, walls, or girders, which then transfer the force to adjacent structural compression members. In light frame construction the joists rest on the beam.

Bending moment is the bending force induced into the material of the beam as a result of the external loads, own weight, span and external reactions to these loads. Beams are characterized by their profile (the shape of their cross-section), their length, and their materials. For nowadays construction, beams are normally made by steel or reinforced concrete. One of the most common types of steel beam is the I-beam or wide-flange beam (universal beam). This is commonly used in steel-frame buildings and bridges. Other common beam profiles are the C-channel, the hollow structural section beam, the pipe, and the angle.

In order to satisfy stability conditions as well as to limit the deformations to a certain allowance, the supports are restricting to lateral and rotational movements. A simple beam is supported by a pin support at one end and a roller support at the other end. A beam with a laterally and rotationally fixed support at one end with no support at the other end (cantilever beam). A beam simply supported at two points and having one end or both ends extended beyond the supports (overhanging beam).

Steel structural systems are quite frequently used in high-rise buildings due to high structural performance such as ductility and strength that steel can provide, compared to other materials. Fire represents one of the most severe environmental conditions to which structures may be subjected, and hence, the provision of appropriate fire resistance is an important consideration in the design of buildings. There are many drawbacks in the current approaches of evaluating fire resistance of structural members since these methods are based on "standard" conditions and do not account for 'realistic' fire, loading and restraint scenarios. Thus, there is dearth of experimental data, mathematical models and design specifications for predicting the response of restrained steel beams under design fire scenarios. (Mahmud and Venkatesh, 2008)

At present, the fire resistant design for a steel beam is based on the bending resistance of the beam. Since it is limited to the plastic bending moment capacity of the beam at small deflection. So, based on this design concept, the steel beam not only have a relatively low survival temperature in fire but also would require expensive fire protection. There are alternative design method had been available to eliminate fire protection. For example by using tensile membrane action in floor slabs or by integrating the functions of load bearing and thermal insulation of concrete.

However, the applications these alternative methods will still leave the majority of steel beams requiring fire protection. Under fire conditions, the design requirement can be different and large deflection may be tolerated provided a structure still maintains its stability. At large deflection, the behaviour of a beam will change from bending to catenaries action. Since the amount of catenaries action is principally a function of the beam's deflection, this can give the beam a very high load carrying capacity without a structural collapse. (Li et al. 2007)

There is possible of using catenaries action in the fire resistant design of beams because thought it would be possible to eliminate fire protection to all steel beams in a building. Therefore, any design method that makes use of catenaries action in beams should also consider the effect of catenaries forces on the adjacent structure, including the connections. In addition, it is important that the beam deflections are accurately estimated because excessively large deflections become a concern of possible integrity failure of a building.

Due to the effects of restraints, a steel beam in fire condition can undergo very large deflections and the runaway damage may be avoided. In addition, axial forces will be induced with temperature increasing and play an important role on the behaviour of the restrained beam. The factors influencing the behaviour of a restrained beam subjected to fire include the stiffness of axial and rotational restraints, the load type on the beam and the distribution of temperature in the cross-section of the beam. (Guoand, 2009)

1.2 Problem Statement

Usually the strength of the steel beam will decrease under high temperature. This situation mostly happen during fire hazard. Unstable connection between column and beam can cause the failure of a structure. During fire hazard the behaviour of the steel beam will become weak when burning. So, in order to investigate the performance of steel beam under high temperature, there are necessary fire resistance tests for different types of steel connections are conducted.

1.3 Objective

a) To investigates the performance of fire resistance steel beam under high temperature.
b) To investigate the effects of a fire under a steel beam.

1.4 Scope of work

The scope of study of this project is to investigate the effect of the high temperature to the types of fire resistance steel beams by using finite element computer package which is LUSAS Modeling version 14.0. This specimen support condition is column to beam type connection. In this study, there are nine temperature parameter had been use to analyze the performance of fire resistance steel beams.

1.5 Significance of Study

It is necessary to have knowledge about properties of steel beams to prevent the risks that might be happen. The purpose of the study is to show that the critical temperature to failure the fire resistance steel beam structure.

This study is to identify the fire-induced forces and deflections of fire resistance steel beams. Through the fire test can effectively extend the fire endurance time, reduce structural deformation, and raise the critical temperature to failure for the steel beams. Then, the damage and the failure of the structure can be avoided. This study also can be used as a reference for further studies and further improvement for related research in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section aims to discuss the theoretical, computational and experimental research relevant to fire engineering and designing leading up to the present day. It is also to show the requirement for further investigation of structures with a fire.

Within the past ten to fifteen years the importance of understanding and predicting the response of buildings subject to thermal loading from fires has driven a huge growth in research into this phenomenon. Perhaps the most well-known event in recent history of fire being a building's root cause of collapse is 'World Trade Centre Seven' on September 11th 2001. The collapse of this building solely from fire proved that the mechanisms of fire were not fully understood in terms of structural response. Since such events the prominence and requirements of fire safety engineering has developed considerably. To date, the majority of the researches are undertaken in the field of Fire Engineering has dealt with the growth period of a fire including flashover with respect to structural response. (Bailey et al. 1996). So, these reasons are the greatest focus on understanding the behaviour of structures while in the burning stages.

2.2 Fire Resistant Steel (Stainless Steel)

In fire conditions, beam-to-column connections play an important role in the structural behaviour of steel structures. Due to the degradation of the strength and stiffness of steel at elevated temperatures, whether the connections can sustain large forces and rotations in fire directly affects the ability of the connections to redistribute forces from the beams to other structural members and influences the survival time of steel structures in fire. The figure 2.1 shows relative stiffness retention at elevated temperature. Many fire scene investigations of steel buildings and the results of the Cardington full-scale eight story steel building fire tests in the UK have also shown how the connections help the structural system survive extreme fires without progressive collapse. Therefore, preventing beam-to-column connections from failing is important for steel structures subjected to fires.

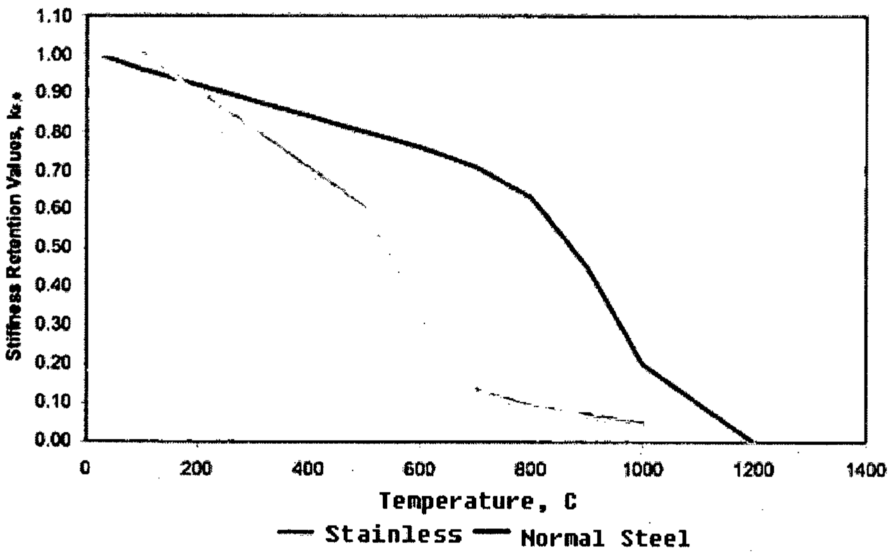

Figure 2.1: Relative stiffness retention at elevated temperature

Traditionally, to protect steel structures from fire damage, fire-protection materials such as thermal insulation components are required by the prescriptive-based fire protection design method. By applying the prescribed thicknesses of fire-protection material on steel members as surface coatings, the temperatures of steel members can be kept below the specified high temperatures for the given fire durations, and steel members can achieve the fire ratings required by code. However, this traditional method can add 30% to the construction cost of bare steel-work and increase the construction time for steel structures. (Chen.H.L et al. 2011).

In addition to the traditional method, the use of fire-resistant steel, which can retain 2/3 or more of its specified ambient temperature yield strength at 600 °C, provides an alternative way to improve the fire-resistant ability for components of steel structures. (Sakumoto et al. 2009). Using structural members made of fire resistant steel can effectively reduce the usage of fire-protection coatings.

Moreover, in some special fire conditions in which the temperature will not reach 600 °C, structural members made of fire-resistant steel may be exposed to fire without any protection. However, experimental investigations of beam-to-column connections made of fire-resistant steel are rarely reported in literature. This may be due to the difficulty of conducting beam-to-column connection tests and the variety of the connection types.

In addition, the cost of fire-resistant steel is still higher than that of conventional steel, so it is important to determine how to use fire-resistant steel economically. Instead of applying fire-resistant steel to all of the structural members, fire-resistant steel could be used only in the parts that are most important or susceptible to fire.

2.3 Structural Steel

Structural steel is steel construction material, a profile, formed with a specific shape or cross section and certain standards of chemical composition and mechanical properties. Structural steel shape, size, composition, strength, storage and else. It possesses high strength, high ductility and high stiffness. It is regulated in most industrialized countries.

Structural steel also has high fire resistance compared to other material. The cost of construction using steel is usually lower than traditional building methods and they are lighter weight, thus, they are easier to maintain. Structural steels have good weld ability, they do not contain additional elements and they are not submitted to any further heat treatments. Structural steel comprises from components such as beams, girders, column, trusses, floor plates, purlins and girt.

Steel loses strength when heated sufficiently. The critical temperature of a steel member is the temperature at which it cannot safely support its load. Building codes and structural engineering standard practice defines different critical temperatures depending on the structural element type, configuration, orientation, and loading characteristics. The critical temperature is often considered the temperature at which its yield stress has been reduced to 60% of the room temperature yield stress. The Figure 2.2 – Figure 2.4 show the dimension, burning location and their model result by these researches.

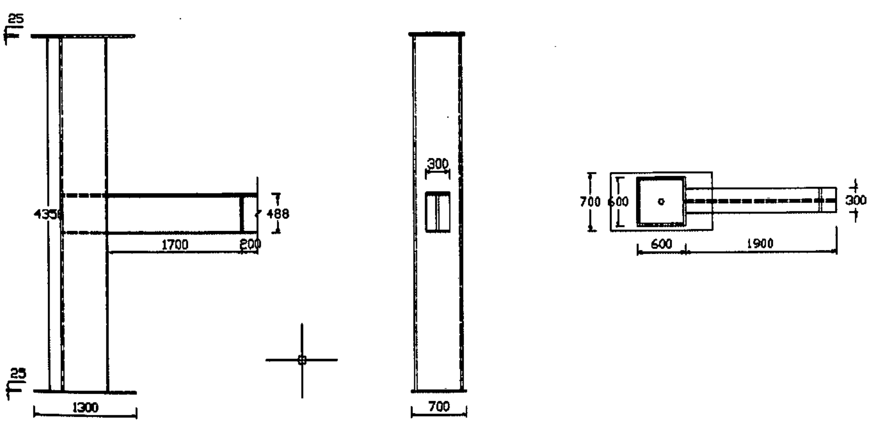

Figure 2.2: Dimension of the column to beam type connection

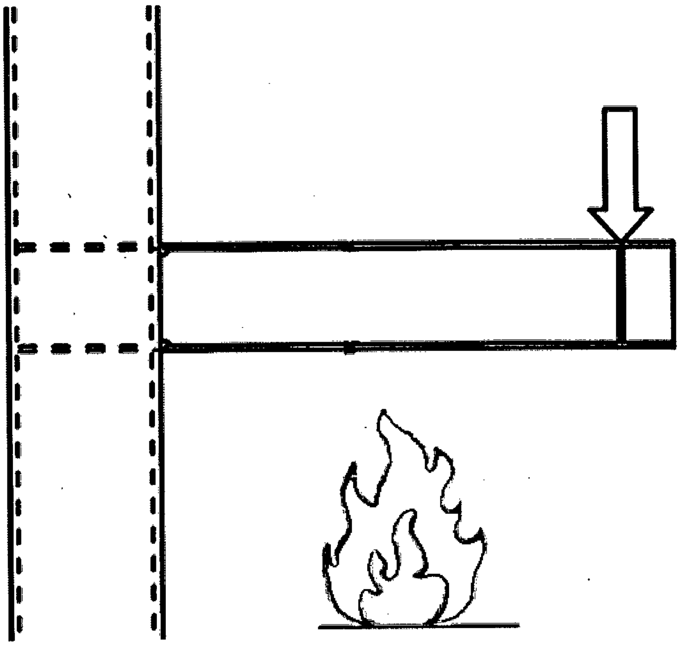

Figure 2.3: Location need to burn

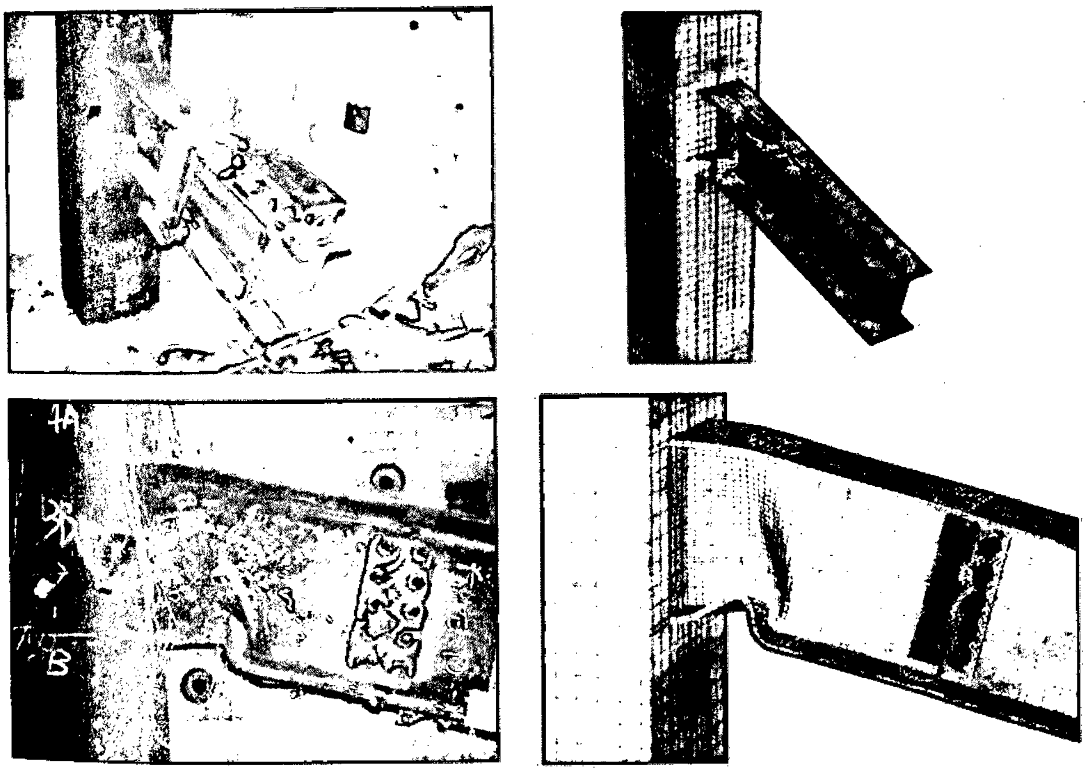

Figure 2.4: The FE simulated failure mode with the test result for specimen

2.4 Advantages of Stainless Steel

a) High corrosion resistance allowing it to be used in rigorous environments.

b) Does not burn and will not contribute fuel to the spread of fire.

c) It will not rot, split, crack or creep.

d) Slower aging process with less maintenance.

e) Fire parapets can be eliminated.

f) Its strength to weight advantage that allows it to be used with a reduced material thickness over conventional grades

g) Resistance to fire and heat allowing it to resist scaling and retain strength at high temperatures.

h) A long term value created by its long useful life cycle often yields the least expensive material option.

i) Rust resistance.

j) The price of a stainless steel appliance is comparable to or cheaper than appliances made of other materials.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The finite element method is a numerical analysis technique for approximate solutions to a wide variety of engineering problems. In the field of design, finite element method is uses as numerical analysis technique in this research. That is because finite element method can evaluate a complex engineering design in much more easier and economic way by saving the time and cost for the experiment testing. There is plenty of software available in the market, including LUSAS, MSC. Patran/Nastran, and SAMCEF. LUSAS 14.0.3 software was used in this study to obtain the performance and behaviour of fire response to fire resistance steel beam.

3.2 Project Flow

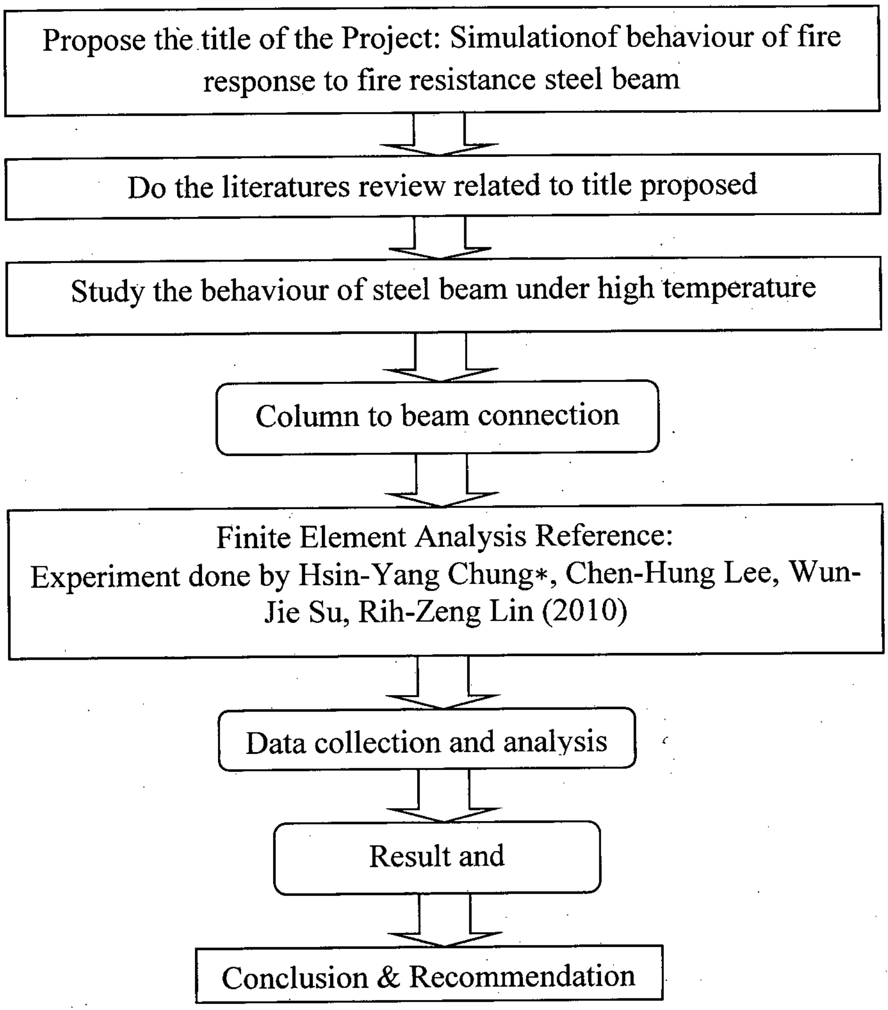

Figure 3.1: Flow Chart of the Research Progress

3.3 Experiment Setup

This project is based on the experimental laboratory by Hsin-Yang Chung et al. (2010). This project presents by using fire-resistant steel to improve the fire-resistance of beam-to-column moment connections in steel structures. In order to verify the feasibility of the proposed method, there are two full-scale beam-to-column moment connection specimens were tested at elevated temperatures according to the standard ISO-834 fire. Moreover, a detailed 3-D finite element model was developed to simulate the structural behaviour of the beam-to-column moment connection specimens in fire. After the fire test, the results show that the proposed method can effectively extend the fire resistance time, reduce structural deformation, and raise the critical temperature to failure for the beam-to-column moment connections. The results that obtained from the 3-D finite element analyses for specimens are successfully simulated the fire test results. The Figure 3.2 – Figure 3.4 show the experiment setup by these researches.

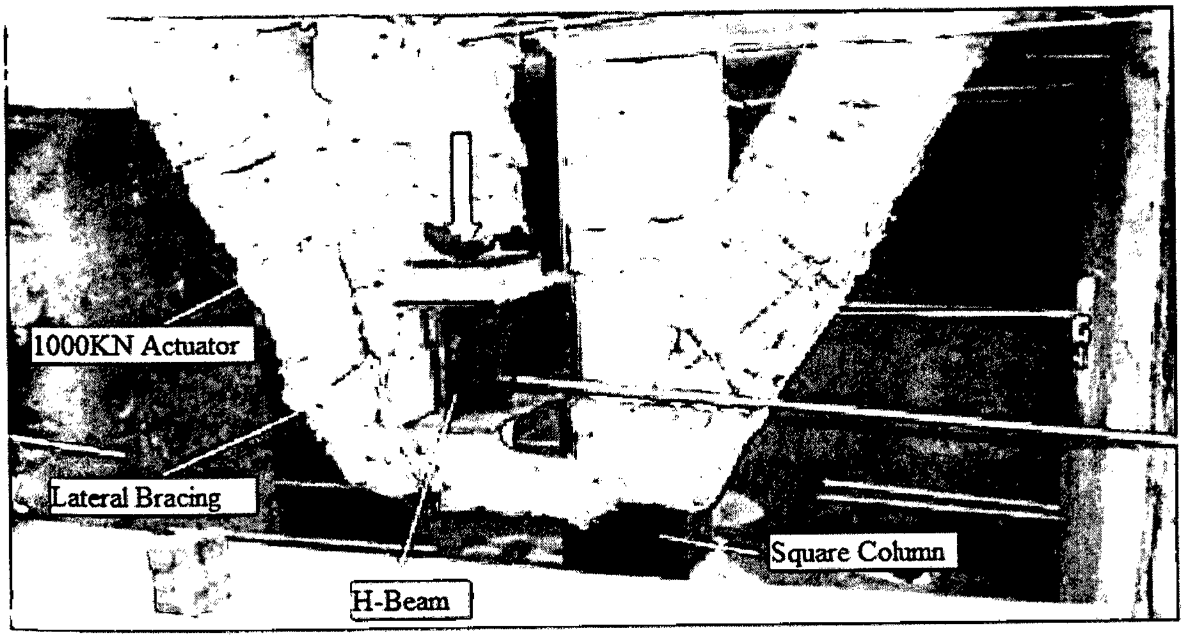

Figure 3.2: Photo of test setup in the furnace.