INVESTIGATING THE EFFECTS OF HIGH TEMPERATURE ON THE PERFORMANCE OF STRUCTURAL STEEL CONNECTIONS USING FE ANALYSIS

KAMAL AHMED MOHAMMED AL-FAKIH

DOCTOR OF PHILOSOPHY

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR’S DECLARATION

We hereby declare that we have checked this thesis and, in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

____

(Supervisor’s Signature)

Full Name : IR.DR. CHIN SIEW CHOO
Position : SENIOR LECTURER
Date :

____

(Co-supervisor’s Signature)

Full Name : DR. DOH SHU ING
Position : SENIOR LECTURER
Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

(Student's Signature)

Full Name : KAMAL AHMED AL-FAKIH
ID Number : PAC16001
Date :

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

Faculty of Civil Engineering & Earth Resources

UNIVERSITI MALAYSIA PAHANG

SEPTEMBER 2019

ACKNOWLEDGEMENTS

No words could adequately indicate the acknowledgment I have for my supervisor, Dr. Chin Siew Choo, who have been a constant source of knowledge, unconditional support, and strength in difficult times. Grateful for her willingness in providing me informative ideas and recommendations that had helped me in completing this research.

I certainly would like to thank my family, especially my father for his support. I thank all the other staffs of the Civil Engineering faculty. My deepest appreciation goes to my brother Ramzi Al-Fakih for guidance through the dark period.

I also gratefully acknowledge the financial support by UMP Postgraduate Research Grants Scheme (PGRS 180313).

I would like to express my very great appreciation to all friends and teammates who gave me all the support needed throughout the research process. This research would not be completed without their help.

Finally, I greatly express my sincere appreciation to my wife, Yasmeen, for handling all family problems and taking care of our children throughout the time of my study.

ABSTRAK

Salah satu faktor yang menyebabkan kegagalan dan kemudian keruntuhan struktur keluli adalah suhu tinggi yang sangat merosakkan ketegaran pembinaan. Oleh itu, perlu diambil kira mempertimbangkan pengenalan langkah-langkah keselamatan kebakaran dalam reka bentuk bangunan apabila mereka bentuk. Program simulasi dan analisis telah membantu meningkatkan kajian mengenai sambungan kebakaran. Untuk menilai rintangan struktur keluli kepada api, adalah penting untuk memahami kesan haba kepada tindak balas sambungan untuk memastikan keselamatan struktur keluli selepas terdedah kepada kebakaran. Dalam kajian ini, tingkah laku hubungan sudut antara rasuk dan lajur dibincangkan pada suhu yang sangat tinggi. Analisis tidak linear adalah sains yang kompleks dan tidak ada penyelesaian segera dan pantas untuk masalah ini. Semua pengiraan reka bentuk untuk pautan boleh disahkan hanya melalui ujian makmal. Ini membawa kepada kehilangan masa, usaha dan wang. Pada masa ini, dengan adanya perisian simulasi kejuruteraan dapat mengatasi masalah ini. Untuk menyediakan ciri-ciri momen- putaran semi-tegar antara rasuk dan lajur yang terdedah kepada suhu ambien dan suhu tinggi. Di samping itu, untuk mengkaji kemerosotan dalam sifat sambungan rasuk-ke-kolum keluli di bawah beban ricih dan / atau momen. Untuk mencapai matlamat ini, simulasi dilakukan untuk mengkaji kesan suhu tinggi pada sambungan sudut antara balok dan lajur menggunakan unsur terhingga (FEA) yang dikenali sebagai "ABAQUS". Empat jenis sambungan; sambungan sudut web (DWA), sambungan sudut atas dan tempat duduk (TSA), dan sambungan sudut atas dan tempat duduk dengan sambungan sudut ganda web (TSA-DWA) telah dipertimbangkan dalam kajian ini, dan sambungan plat akhir (EP). Lapan model yang berlainan dari pelbagai bahagian silang di bawah kesan pemuatan dan syarat sempadan yang berbeza telah diperiksa. 64 model telah disimulasikan dan dikaji. Bahan non-linear diperkenalkan dengan sifat definisi plastik elastik termasuk hubungan geseran antara permukaan untuk mensimulasikan keadaan sebenar. Kajian ini telah disediakan untuk mencari tingkah laku hubungan komunikasi antara jambatan dan lajur pada suhu tinggi 25 °C hingga 700 °C. Keputusan ujian menunjukkan ciri-ciri momen-putaran lengkung semi-tegar dari rasuk-ke-kolum. Hasil analisis dibandingkan dengan data empirikal yang disediakan oleh literatur. Hasil analisis dibandingkan dengan data eksperimen yang tersedia dari kesusasteraan. Selepas suhu tinggi digunakan pada jenis sambungan, ini dan lengkung momen-putaran (M-Ø) sebelum dan selepas keadaan ini dibandingkan untuk mencari momen maksimum menurun. Hasil pengesahan model menunjukkan bahawa mereka berada dalam persetujuan yang baik dengan eksperimen standard, dengan perbezaan kurang dari 5.1% untuk semua sampel. Di samping itu, hasilnya menunjukkan bahawa momen-putaran lengkung untuk semua sambungan, moment ini berkurangan dengan peningkatan suhu dan sebaliknya, yang putaran meningkat. Selain itu, sambungan pada 200 °C kehilangan daya tahannya kepada 18% dan menurun kepada 58% pada 400 °C dan sehingga 85% pada 600 °C daripada kapasiti keseluruhan dan runtuh sepenuhnya pada suhu melebihi 700 °C. Sebaliknya, kenaikan suhu menyebabkan beban paksi tensional, yang membawa kepada ubah bentuk yang lebih tinggi. Kaedah kegagalan dan corak ubah bentuk disiasat, dan lengkung rotation-moment dibentangkan dan dibincangkan.

ABSTRACT

This thesis presents a numerical investigation on the effects of elevated temperature on the performance of structural steel connections using FE analysis. One of the factors that lead to the failure, and then to the collapse of the steel structure, is the high extreme temperature that undermines the integrity of the building. Consequently, it is necessary to take into consideration the introduction of fire safety measures in the design of buildings during the designing process. To evaluate the resistance of the steel structure to the fire, it is important to understand the effects and response of the elevated temperatures, to ensure the safety of steel structure at exposure to fire. Analysis of nonlinear connections is a complex science and there is no immediate and rapid solution to the problem. All the results of the accounts of the design connections cannot be verified only through the lab tests on a large scale. This leads to the loss of a great deal of time, effort and money. At present, with the availability of engineering simulation software. It is possible to overcome these problems. The aim of this study is to provide moment-rotation characteristics and corresponding parameters of the steel beam-to-column connection exposed to the elevated temperature. To achieve the objective, a simulation was carried out to study the effect of the elevated temperature on the angles connection between beam and column using the finite element analysis (FEA). Four types of connections; double-web angles (DWA), top and seat angles (TSA), end-plate (EP), and top and seat with double-web angles connections (TSA-DWA) were considered in this study. Eight different models of various cross sections under the effect of different loading and boundary conditions were examined. Materials non-linearity was modelled with the elastic-plastic definition properties including frictional contact between surfaces to simulate actual conditions. This research investigates the behaviour of steel at an elevated temperature from 25 °C to 700 °C. The analysis of results was compared with the experimental data available from the literature. The model behaviour validation shows that the model is in good agreement with the existing experimental results. The validated FE model was used to conduct further studies with new three-dimensional (3D) loading conditions in order to produce moment-rotation curve and enhance the understanding of steel joints behaviour on fire. In addition, the results showed for that the moment-rotation curve for all connections, the moment is decreased with increasing temperatures and in contrast, the rotation increased. Moreover, the loss of total capacity of connections is 18 % at 200 °C and increased to 58 % at 400 °C. For 600 °C, it reached 85 % and completely collapsed at temperatures higher than 700 °C. In addition, it is found that the deformation capacity is controlled by the possibility of fracture in the angle connection, in the failure of the bolts and thickness of angles. Therefore, factors such as bolts diameter, type of bolts, angles thickness and properties of materials can improve the connections behaviour.

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LIST OF SYMBOLS

A	Cross-Section Area of Beam Section
b_f	Width Flange of beam
d	Depth of the Beam Element
E	Young’s Modulus of Elasticity
F_y	yield Strain of steel
g_1	gage distance
G	Shear modulus of the steel
h	Beam depth
L	Length of the Beam
l_p	Length of angle
M	Bending Moment
M_u	Ultimate Moment Capacity of the Connection
n	Shape factor
K_ϕ	Initial connection stiffness
t	Thickness of angle leg
t_f	Thickness of Flange
t_w	Thickness of Web
V	Shear force
Ø	Rotation
$\emptyset_0$	Reference plastic rotation
$\emptyset_b$	Beam rotation
$\emptyset_c$	Column rotation
$\emptyset_j$	Connection rotates
Є	Strain
Σ	Stress
A	The Stiffness Factor
Δx	Change of horizontal displacement
I	The length at 20 °C
ΔI	The temperature induced elongation
θ_a	the steel temperature [°C].

LIST OF ABBREVIATIONS

AISC	American Institute of Steel Construction
TSA	Top and Seat Angles Construction
TSA-DWA	Top and Seat Angles with Double-Web Angles Construction
DWA	Double-Web Angles Construction
EP	End-Plate Construction
FE	Finite Element
FR	Fully Restrained
LRFD	Load and Resistance Factor Design
PR	Partially Restrained
PRC’s	Partially restrained connections
3-D	Three Dimensional
HEA-220	Column Section H220 × 213 × 7 × 10
IPE-330	Column Section I360 × 170 × 8 × 12

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