ISSN XXXX XXXX © 2017 IJESC

Research Article Volume 7 Issue No.6

Equivalent Axial Load of Water Filled Steel Hollow Columns under Fire Condition

Mina Daniel Talason[1], Mohamed M.Yahia[2], Sameh M. Gaawan[3]
Civil Engineer[1], Assistant Professor[2], Associate Professor[3]
Department of Civil Engineering
Helwan University, Egypt

Abstract:
Concrete Filled Steel Hollow Sections were primarily introduced to achieve fire resistance of the steel hollow sections. The concept of CFSHS relies much on the water content of the concrete to efficiently induce the so called Heat-Sink. As the concrete filling process could be difficult at large heights and also for small diameters, the concept of Water filled steel hollow section (WFSHS) was thus introduced. This research simulates the behavior of WFSHS under different elevated temperature cases and presents a finite element model to calculate their axial load capacities of WFSHS.

Keywords: Columns, Fire Resistance, Steel Tubes, Water filled

I. INTRODUCTION

Water filling using natural circulation provides a safe and reliable fire protection method for hollow section columns, provided that two conditions are satisfied (Hönig et al., 1985):

- The system is self activating in fire.
- The system is self-controlling.

In a properly designed system, the natural circulation will be activated when the columns are locally heated by a fire. The density of warm water is lower than that of cold water, which produces the pressure differentials that activate the natural circulation. The effect will be intensified when localised boiling commences and steam is formed. As the fire develops, the rate of steam production will also increase, thus forcing the cooling effect obtained by naturally activated circulation.
The following methods of permanent water filling are available:

1. *Un replenished columns*

Simply filling a column with water, with no provision for replacing any water lost through steam production, will lead to an increased, but limited fire resistance compared to that of the empty column. In multi-storey columns the water in the top-storey-columns will be first evaporated, but the fire resistance can be increased by externally protecting the top storey length and using it as a reservoir for the lower storeys. Heavy steam production may lead to an additional critical loss of water. Therefore, un replenished columns should be used only for lower fire resistance requirements, up to, say, 60 minutes.

2. *Columns with external pipe*

This system has a connecting down pipe between the bottom and top of the columns. The lighter, upward flowing water-steam mixture must be separated at the top, so that the water can return down through the pipe to the bottom. In this manner, an external naturally forced circulation will be activated. In addition, the pipe can be connected with a water storage tank at the top of the building to replace the water lost from steam production and possibly act as a common water/steam separating chamber. A group of individual columns can be connected at their bottom to a shared connecting pipe as well as with a connecting pipe at the top. For such a group of columns, only one down pipe is necessary, connecting top and bottom of the whole group

3. *Columns with internal pipe*

In this system, an internal down tube is used within each column to provide a supply of cool water to the bottom of each column. This promotes the internal, naturally activated circulation of the upward flowing water-steam mixture and the down flowing water after steam separation. Thus, each column acts as an individual member without any connection to the other columns. To minimise the number of water storage tanks, the tops of several columns can be connected by a common pipe leading to one storage tank for the whole group

4. *Mixed systems*

The above mentioned systems can be mixed within a building and they can be connected to act as a mixed integrated system. This can be advantageous for structures containing not only columns, but also water filled diagonals for bracing, etc. In the naturally circulating systems described above, a minimum declination of the diagonals of about 45 is recommended. It is not advisable to use any electro- mechanical installation, such as pumps, acting against the naturally produced circulation. This may lead to a failure of the cooling system and thus to a collapse of · the water filled structure. [3] [4]

II. LITERATURE REVIEW

According to G.V.L Bond [6] the earliest patent for fire proofing steel columns by water filling was taken out in the USA in 1884. Despite this early concept, the first building in which columns were fireproofed with water, the United States steel tower block in Pittsburgh, Pennsylvania, was not completed until 1970. This 64- story building is 841 ft. high. The external box columns being of welded cor-Ten steel, unpainted and filled with an aqueous solution to limit hydrostatic pressure, the columns are divided by means of horizontal diaphragms into four lengths from 14 to 18 stores. The Pittsburgh block is of course a unique prestige building, but it has encouraged other designers to use water filled columns in much more modest structures, not only in the USA but also in Europe.

In France:

A. The first building to use water filled columns is situated in the Champs Elysees. The purpose in this instance was to replace some bulky stone pillars in an existing building by the smallest possible columns.

B. A nine story building in Marseilles, uses water cooling in both external and internal columns made from rectangular hollow sections.

In Germany:

The first German building to have been protected in this manner is a new office block in Dusseldorf for the Verein deutsche eisenhuttenleute. This is a three-story building with exposed external square hollow columns of Cor-Ten steel. It is interesting to record that, on 28th August 1970, a full scale furnace test was carried out on a one-story height of one column, providing satisfactory confirmation of the theoretical calculations and within the limits of the test, proving the efficiency of the system. Other investigations on column systems have also been performed in Germany and Britain. These show that water cooling can provide excellent fireproofing properties and the results obtained have helped to provide the basis for theoretical calculations. Also Gorden Cooke [7] gave an example of a WFSHS Building which is the American insurance security co, Offices, Atlanta this four-story building employing twenty water-filled external columns of Cor-Ten steel from the first floor upwards , the 250*250*98 kg/m I-Section columns have a Cor-Ten closure plate welded to the inner flange tips to contain the water , and the closed loop system is fed by a roof tank with enough replenishment water to provide a 4-hour rating which is in excess of the building code requirement .

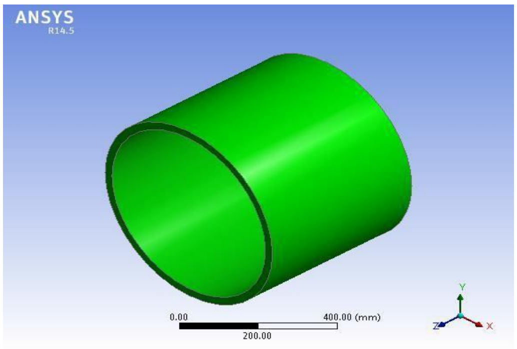
III. ANALYTICAL PROGRAM

Three Hollow columns steel samples are tested by ANSYS program. All of these samples are classified. The properties of these samples are defined next.

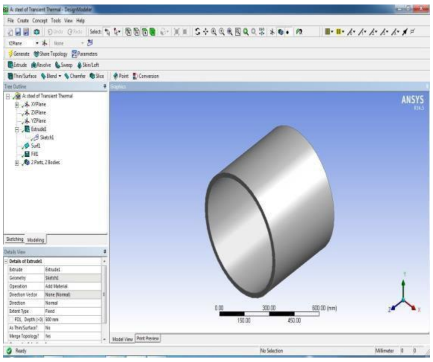
A. ***MEMBER PROFILES:*** Circular hollow section is used for all column members with 25 and 50 mm in thickness, and 50 and 60 in diameter. as shown in Table (1).

Table.1. Profile Properties

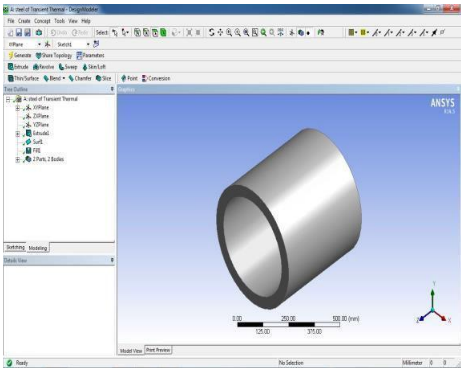
Profile	Th. (mm)	Rin (cm)	Rout (cm)
WFSHS 1	25	40	50
WFSHS 2	25	50	60
WFSHS 3	50	40	50



WFSHS 1



WFSHS 2



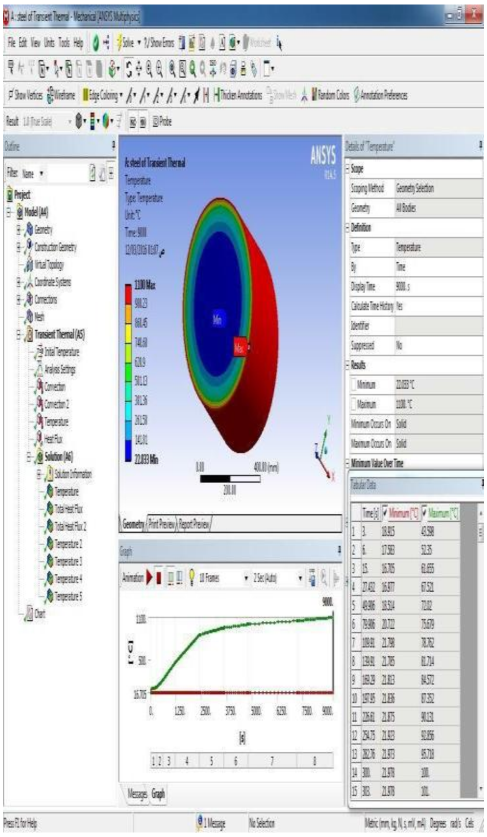
WFSHS 3

B. ***MEMBER MATERIAL***

The used material for all members is steel S355 with yield strength 3.55 T/cm2 and elastic modulus of 2100 T/cm2.

IV. ANALYSIS RESULTS

The next pages are monitoring the result of the analysis of the three samples which mentioned at table 1, and then this result analysis will be discussed.



Minimum 22.033 °C

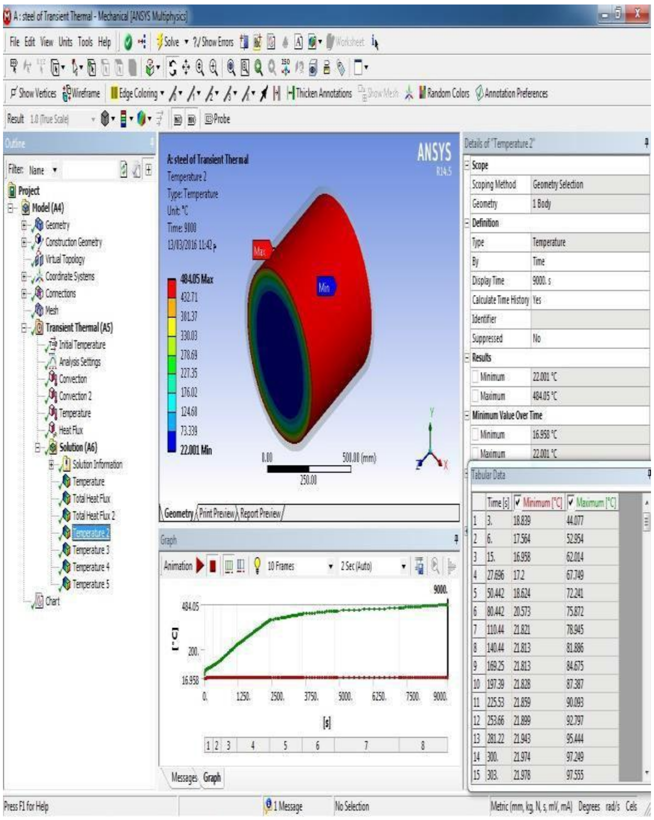
Maximum 1100. °C

Minimum Occurs On Solid

Maximum Occurs On Solid

	Time [s]	Minimum [°C]	Maximum [°C]
1	3.	18.915	43.598
2	6.	17.583	52.35
3	15.	16.705	61.655
4	27.432	16.977	67.521
5	49.986	18.514	72.02
6	79.986	20.722	75.679
7	109.91	21.798	78.762
8	139.91	21.765	81.714
9	169.29	21.813	84.572
10	197.95	21.836	87.352
11	226.61	21.875	90.131
12	254.75	21.923	92.856
13	282.76	21.973	95.718
14	300.	21.978	100.
15	303.	21.978	101.

WFSHS 1



A: steel of Transient Thermal
Temperature 2
Type: Temperature
Unit: °C
Time: 9000
12/03/2016 11:42

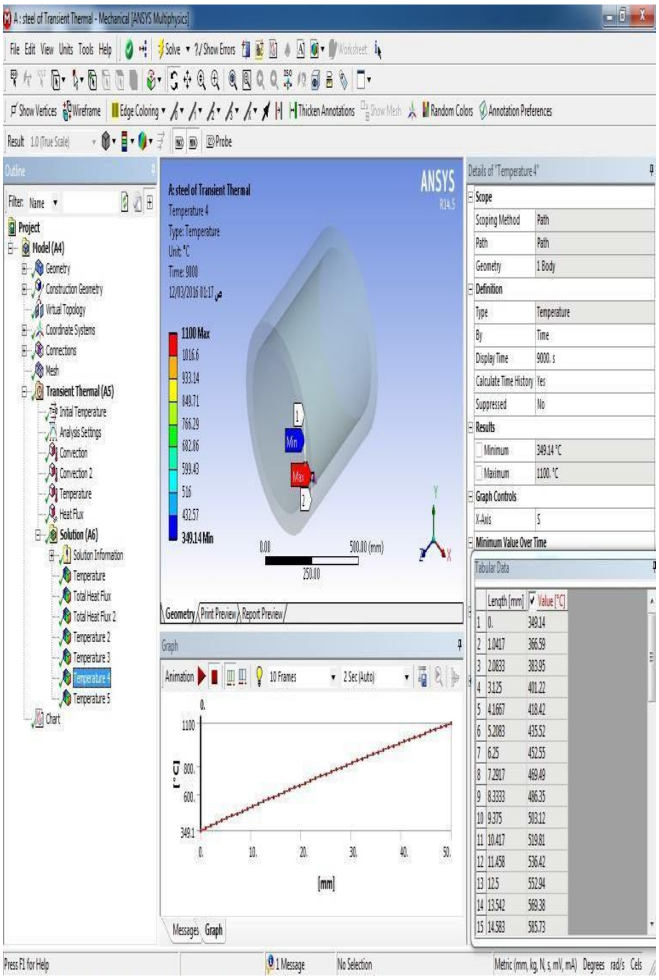
Details of "Temperature 2"

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Type	Temperature
By	Time
Display Time	9000. s
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	
☐ Minimum	22.001 °C
☐ Maximum	484.05 °C
Minimum Value Over Time	
☐ Minimum	16.958 °C
☐ Maximum	22.001 °C

Tabular Data

	Time [s]	☑ Minimum [°C]	☑ Maximum [°C]
1	3.	18.839	44.077
2	6.	17.564	52.954
3	15.	16.958	62.014
4	27.696	17.2	67.749
5	50.442	18.624	72.241
6	80.442	20.573	75.872
7	110.44	21.821	78.945
8	140.44	21.813	81.886
9	169.25	21.813	84.675
10	197.39	21.828	87.387
11	225.53	21.859	90.093
12	253.66	21.899	92.797
13	281.22	21.943	95.444
14	300.	21.974	97.249
15	303.	21.978	97.555

WFSHS 2



A: steel of Transient Thermal
Temperature 4
Type: Temperature
Unit: °C
Time: 9000
12/03/2016 01:17 م

Details of "Temperature 4"

Scope	
Scoping Method	Path
Path	Path
Geometry	1 Body
Definition	
Type	Temperature
By	Time
Display Time	9000. s
Calculate Time History	Yes
Suppressed	No
Results	
☐ Minimum	349.14 °C
☐ Maximum	1100. °C
Graph Controls	
X-Axis	S
Minimum Value Over Time	

Tabular Data

	Length [mm]	☑ Value [°C]
1	0.	349.14
2	1.0417	366.59
3	2.0833	383.95
4	3.125	401.22
5	4.1667	418.42
6	5.2083	435.52
7	6.25	452.55
8	7.2917	469.49
9	8.3333	486.35
10	9.375	503.12
11	10.417	519.81
12	11.458	536.42
13	12.5	552.94
14	13.542	569.38
15	14.583	585.73

WFSHS 3

V. ANALYSIS OF TESTING RESULTS

First of all figure (1) shows how temperatures develop in WFSHS exposed to standard fire conditions. [2]

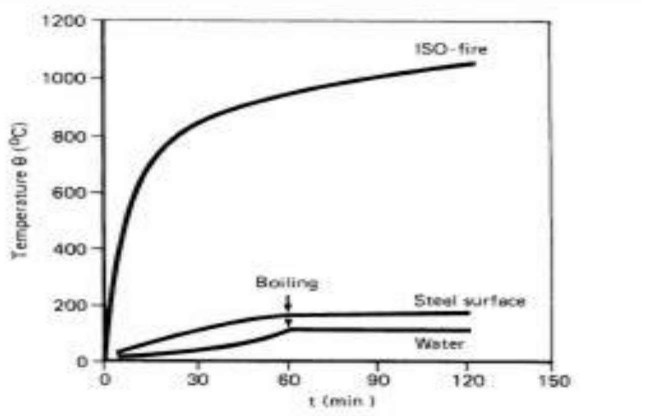


Figure.1. Typical temperature in a water filled SHS-column exposed to standard fire condition.

According to the result from ANSYS, temperature degrees of WFSHS of every sample will be used as an input to Figures (2,3,4,5) to get the yield strength , modulus of elasticity and the reduction factor for both of them for each layer (Thickness). [1] [5]

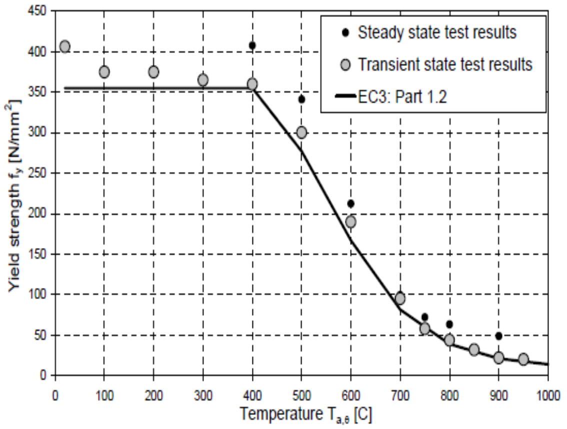


Figure.2. Yield strength of structural steel S355 at temperatures 20^{o} c – 950 ^{o} c

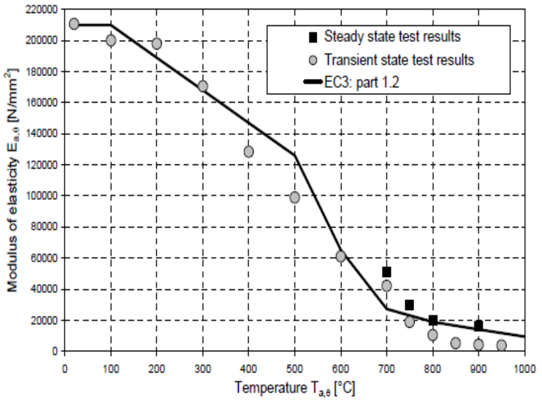


Figure .3. Modulus of elasticity of structural steel S355 at temperatures 20^{o} c – 950 ^{o} c

VI. EVALUATION IN ACCORDING TO THE CODES

The values of effective thickness and equivalent axial loads were measured using ANSYS software which applies the European Code. The obtained values with the experimental findings are presented next.

First: Effective thickness:

Table .2. Values calculated at critical stage.

Loading Pattern	Time/ Hour	Temperature Value / c	Effective Thickness / mm
WFSHS1	2,5	1100	6
WFSHS2	2,5	1100	9
WFSHS3	2,5	1100	18

Studying the previous table, you may find that the results are close to the EC code since that code concerns the second order effect in the analysis.

Second: Equivalent axial load:

A simplified design equation for evaluating the fire resistance of water-filled circular and square hollow structural steel (WFSHS) columns is presented. The equation is expressed in terms of various structural design parameters affecting the fire resistance, and hence can easily be integrated into conventional structural design. This equation can be used to evaluate the fire resistance of WFSHS columns filled with water. The use of the design equation greatly facilitates the calculation of the fire resistance of structural members on a performance basis. It also enables the designer to find cost- effective solutions in providing the required fire resistance performance for structural members, simply by varying the parameters of the members. The applicability of the proposed equation to a design situation is illustrated through a numerical example. Practical guidelines that can be implemented during the design and construction phase, and which have beneficial effects on the fire resistance behaviour water-filled of hollow steel columns, are also presented.

At service case (Normal condition): P = Area * Fy (Equ 1)

At fire case (for each layer of the column):

P' = A1*Fy1 + A2*Fy2 + A3*Fy3+…….. (Equ 2)

From Equation (2):

For WFSHS 1:

Table.3. Temperature and yield strength of finite layers of WFSHS1 after 2.5 hours of fire.

Thickness mm	Time /Hour	Temperature Value/c	Yields trength T/cm2	Axial loa dP
2	2.5	539.25	2.7	5.4
4		592.62	1.95	3.9
6		632.34	1.4	2.8
8		684.87	1.05	2.1
10		736.92	0.7	1.4
12		788.5	0.4	0.8
14		839.59	0.32	0.64
16		890.21	0.25	0.5
18		940.35	0.2	0.4
20		990.01	0.17	0.34
22		1039.2	0.15	0.3
25		1100	0.11	0.22
Sum				18.8

P' = 18.8/88.75 P = 21.2% P (Equ 3)

P': load in fire case

P: load in service case

Table.4. Temperature and yield strength of finite layers of WFSHS1 after 2 hours of fire.

Thickness mm	Time / Hour	Temperature Value/c	Yieldst rength T/ cm2	Axia lload P
2	2	517.19	2.8	5.6
4		567.91	2.1	4.2
6		618.18	1.8	3.6
8		667.98	1.1	2.2
10		705.04	0.9	1.8
12		754.05	0.6	1.2
14		802.6	0.45	0.9
16		850.69	0.4	0.8
18		898.33	0.3	0.6
20		945.51	0.25	0.5
22		992.24	0.2	0.4
25		1050	0.18	0.36
Y				22.2

P' = 22.2/88.75 P = 25% P

Table.5. Temperature and yield strength of finite layers of WFSHS1 after 1.5 hour of fire.

Thickness mm	Time / Hour	Temperature Value/c	Yieldst rength T/ cm2	Axial loadP
2	1.5	500.56	3	6
4		549.3	2.5	5
6		585.56	2.2	4.4
8		645.45	1.5	3
10		692.87	1.15	2.3
12		728.15	0.8	1.6
14		774.8	0.6	1.2
16		821.01	0.4	0.8
18		866.78	0.3	0.6
20		912.11	0.25	0.5
22		957	0.2	0.4
25		1012.5	0.15	0.3
Y				26.1

P' = 26.1/88.75 P = 29.5% P

Table.6. Temperature and yield strength of finite layers of WFSHS1 after 1 hour of fire.

Thickness mm	Time / Hour	Temperature Value/c	Yields trength T/ cm2	Axia lloa d P
2	1	472	3.2	6.4
4		517	2.8	5.6
6		551	2.5	5
8		607	1.9	3.8
10		651	1.5	3
12		684	1.25	2.5
14		727	0.8	1.6
16		771	0.5	1
18		813	0.4	0.8
20		856	0.3	0.6
22		898	0.25	0.5
25		950	0.23	0.46
Y				31.26

P' = 31.26/88.75 P = 35.2% P

From Equation (2):

For WFSHS 2:

Table .7. Temperature and yield strength of finite layers of WFSHS2 after 2.5 hours of fire.

Thickness mm	Time /Hour	Temperature Value/c	Yield strengthT/ cm2	Axial loadP
2	2.5	536	2.8	5.6
4		589	2.1	4.2
6		629	1.7	3.4
8		694	0.95	1.9
10		746	0.6	1.2
12		785	0.42	0.84
14		836	0.35	0.7
16		887	0.3	0.6
18		938	0.25	0.5
20		988	0.22	0.44
22		1038	0.2	0.4
25		1100	0.14	0.28
Y				20.1

P’avreage = 20.1 / 88.75 P = 23% P

Table.8. Temperature and yield strength of finite layers of WFSHS2 after 2 hours of fire.

Thickness mm	Time /Hour	Temperature Value/c	YieldstrengthT/ cm2	Axial loadP
2	2	514	2.9	5.8
4		565	2.5	5
6		602	1.9	3.8
8		665	1.4	2.8
10		714	0.9	1.8
12		751	0.6	1.2
14		799	0.5	1
16		848	0.3	0.6
18		896	0.28	0.56
20		943	0.25	0.5
22		991	0.2	0.4
25		1050	0.15	0.3
Y				23.76

P’avreage = 23.76/ 88.75 P = 26.8% P

Table.9. Temperature and yield strength of finite layers of WFSHS2 after 1.5 hour of fire.

Thickness mm	Time /Hour	Temperature Value/c	Yieldstrength T/ cm2	Axial loadP
2	1.5	498	3	6
4		546	2.5	5
6		582	2.1	4.2
8		642	1.6	3.2
10		690	1	2
12		725	0.85	1.7
14		772	0.5	1
16		818	0.48	0.96
18		864	0.3	0.6
20		910	0.25	0.5
22		956	0.2	0.4
25		1012	0.15	0.3
Y				25.86

P’avreage = 25.86 / 88.75 P = 29.1% P

Table.10. Temperature and yield strength of finite layers of WFSHS2 after 1 hour of fire.

Thickness mm	Time /Hour	Temperature Value/c	YieldstrengthT/ cm2	Axial loadP
2	1	472	3.2	6.4
4		517	2.8	5.6
6		551	2.5	5
8		607	1.9	3.8
10		651	1.5	3
12		684	1.25	2.5
14		727	0.8	1.6
16		771	0.5	1
18		813	0.4	0.8
20		856	0.3	0.6
22		898	0.25	0.5
25		950	0.23	0.46
Y				31.26

P’avreage = 31.26 / 88.75 P = 35.2% P

From Equation (2):

For WFSHS 3:

Table.11. Temperature and yield strength of finite layers of WFSHS3 after 2.5 hours of fire.

Thickness mm	Time /Hour	Temperature Value/c	Yields trengt h T/ cm2	Axi allo ad P
4	2.5	418	3.5	14
8		486	3.2	12.8
12		552	2.6	10.4
16		618	1.7	6.8
20		682	1.3	5.2
24		744	0.8	3.2
28		806	0.4	1.6
32		867	0.3	1.2
36		926	0.25	1
40		985	0.2	0.8
44		1043	0.15	0.6
50		1100	0.1	0.4
Y				58

P’avreage = 58 / 177.5 P = 32.6% P

Table.12. Temperature and yield strength of finite layers of WFSHS3 after 2 hours of fire.

Thickness mm	Time /Hour	Temperature Value/c	Yields trengt hT/ cm2	Axial loadP
4	2	402	3.5	14
8		467	3.3	13.2
12		530	2.7	10.8
16		592	2	8
20		653	1.5	6
24		712	0.9	3.6
28		756	0.6	2.4
32		828	0.4	1.6
36		885	0.3	1.2
40		941	0.25	1
44		996	0.2	0.8
50		1050	0.15	0.6
Y				63.2

P’avreage = 63.2 / 177.5 = 35.6 % P

Table.13. Temperature and yield strength of finite layers of WFSHS3 after 1.5 hour of fire.

Thickness mm	Time /Hour	Tempera ture Value/c	Yields trengt hT/	Axial loadP
4	1.5	390	3.6	14
8		452	3.3	13.2
12		513	2.8	11.2
16		573	2.2	8.8
20		631	1.6	6.4
24		688	1.2	4.8
28		744	0.7	2.8
32		800	0.5	2
36		854	0.3	1.2
40		908	0.25	1
44		960	0.2	0.8
50		1012	0.15	0.6
Y				66.8

P’avreage = 66.8 / 177.5 P = 37.6 % P

Table.14. Temperature and yield strength of finite layers of WFSHS3 after 1 hour of fire.

Thickness mm	Time /Hour	Temperature Value/c	Yields trengt hT/	Axial loadP
4	1	369	3.55	14.4
8		426	3.3	13.2
12		483	3.1	12.4
16		538	2.7	10.8
20		593	1.9	7.6
24		646	1.6	6.4
28		698	1	4
32		750	0.7	2.8
36		801	0.5	2
40		851	0.4	1.6
44		901	0.3	1.2
50		950	0.25	1
Y				77.4

P’avreage = 77.4 / 177.5 P = 43.6 % P

According to the previous tables (3:14) it can be concluded that **axial load capacities of WFSHS** under fire conditions are reduced with time which is clarified at Figure (4).

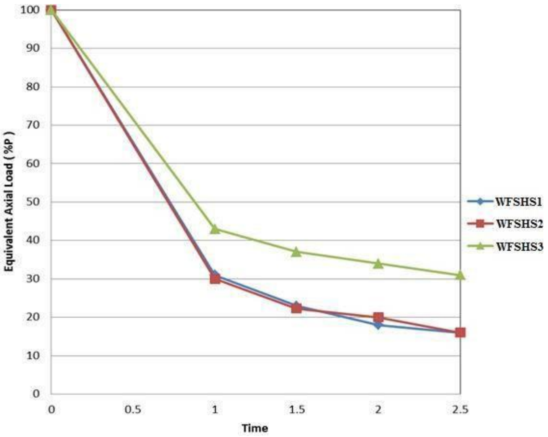


Figure.4. Equivalent axial load of samples analysed for different fire endurances.

VII. SUMMARY AND CONCLUSION

Investigation of the behavior of WFSHS under axial load through fire conditions is studied through testing of 3 samples. The yield strength reduction factor is varied from one thickness to another where the same load is applied on the columns. The measured values of the variations in loads are used to estimate the equivalent load for every case. The outcome of the research is itemized as:

1. Cases 1 and 2 are not so different and that means that changing the diameter of the hollow column is not so effective in resisting fire effect.
2. Although in case 3 when the sample thickness was different from 25 mm to 50 mm it was more efficiency.

VIII. REFERENCES

[1]. EN 1993-1-2 European Committee for Standardization, CEN, and Euro code 3: Design of steel structures Part 1-2: General rules. Structural fire design, 2005

[2].ASTM. _1997_. ―E21–92: Standard test methods for elevated temperature tension tests of metallic materials.‖ Annual book of ASTM standards, Vol. 03.01: Metals-mechanical testing; elevated and low-temperature tests; metallography, West Conshohocken, Pa.

[3].British Standards Institution _BSI_. _1998_. ―Structural use of steelwork in building—Part 8: Code of practice for fire resistant design.‖ BS 5950–8:1990, London.

[4]. Design guide for structural hollow section columns exposed to fire – L.TWILT, R.Hass, W,Klingsch, M.Edwards, D.Dutta – Verlag TUV Rheinland.

[5]. Outinen J., Mechanical properties of structural steels at elevated temperatures and after cooling down, Fire and Materials Conference, San Francisco, USA, Proceedings, Interscience Communications Limited, UK, 2006. (to be published in February 2006).

[6]. G.V.L Bond, Bsc, MICE, MI Struct E , Oscar Faber & Partners , Consulting Engineering , St Albans , Herts .(Paper Research).

[7]. Gorden Cooke, Bsc, C Eng, MI Mech E, MI Fire E, of Pell Frechmann & Partners. (Paper Research).