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SENSITIVITY ANALYSIS OF COLUMNS AT EXTREME TEMPERATURE

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ABSTRACT

This paper carried out a sensitivity analysis in order to know the effect of each parameters towards the mechanical strength of the protected column so that the results of this sensitivity analysis can be used to assist in the further research to increase the fire resistance. Among the parameters investigated are temperature, insulation thickness, load carrying capacity.

1.0 INTRODUCTION

Theoretical studies have been carried out to predict the fire resistance of protected I-shaped steel insulated with ceramic fibre. A mathematical model to calculate the temperatures, deformations and fire resistance of the columns have been developed for this purpose [1]. Calculated results are compared with those measured in several tests. The results indicate that the model is capable of predicting the fire resistance of ceramic protected I-shaped steel with an accuracy that is adequate for practical purposes.

The model enables the expansion of data on the protected steel columns involving ceramics which at present, consists predominantly with data for columns with concrete. Using the model, the fire resistance of ceramic protected I-shaped steel columns can be evaluated for any value of the significant parameters such as load, column-section dimensions, column length and the percentage of reinforced steel, without the necessity of experiment.

This research paper carried out sensitivity analysis in order to know the effect of each parameters towards the mechanical strength of the protected column so that the results of this sensitivity analysis can be used to assist in the further research in increasing the fire resistance.

2. 0 DISCUSSION ON CERAMIC THICKNESS

2.1 The Effect on Temperature

Figure 2 shows that temperature-time curves at different thickness at point A and B (see Fig. 1). of the column. This graph clearly indicate that the temperature at the boundary of ceramic-steel will decrease with the rise of the ceramic thickness. This is because with the increase of the thickness of ceramic, the cross-sectional area of column will also increase. The heat transfer at smaller cross-section is small compared to column with larger cross section hence smaller cross-section will be heated up faster than a column with bigger cross-section area. For smaller section column, the rise in temperature is higher since the temperature have rose to 740°C after only 90 minutes.

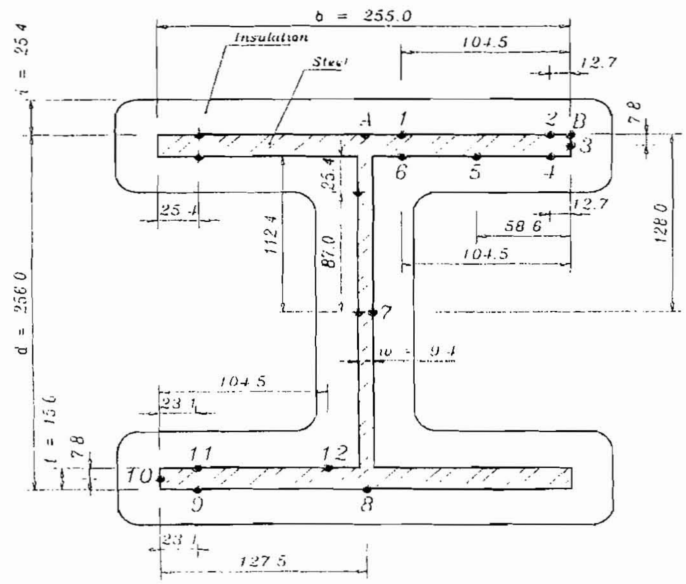

Fig. 1 Cross Section of Column

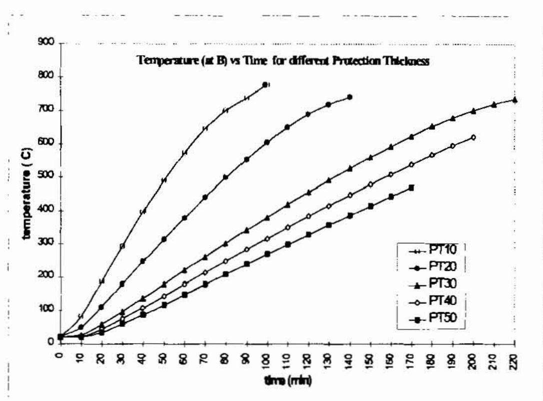

Fig. 2 Temperature at Point A for Different Insulation Thickness

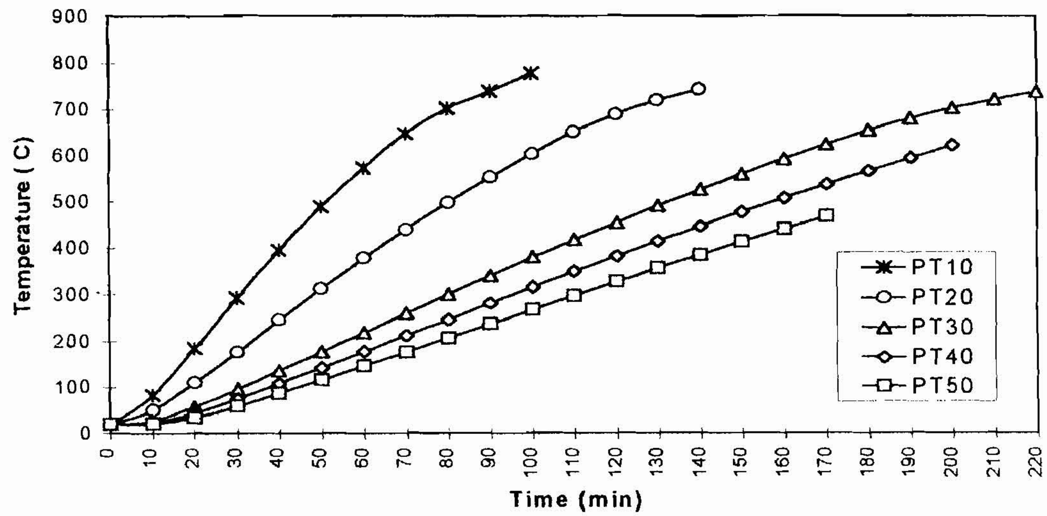

Fig. 3 Temperature at Point B for Different Insulation Thickness

2.2 The Effect on Column Strength

As mentioned before the column with smaller cross sectional area will be heated faster. Figure 4 demonstrate the graph of load carrying capacity (strength) against time for various thickness. However since the ceramic in this case does not support loading, the strength for the column is the same for all at time = 0.

Strength for all columns (different thickness) will decrease with the rise of heating time or with the increase of temperature. This occur because when the column is heated, the atom in the steel will vibrate at higher rate and forcing greater distance between atoms thus decreasing the ionic molecular bond. This cause the strength of the material to deteriorate and hence reducing the load capacity of the column. This mean the strength of column will decrease as time increases.

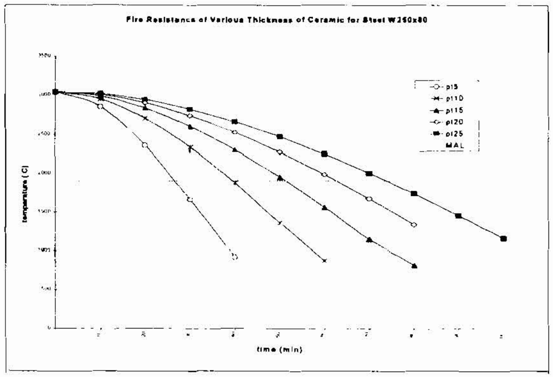

Fig. 4 Fire Resistance of Column for Different Insulation Thickness

2.3 Effect on the Fire Resistance

Fire resistance for the column W250x80 for various thickness of ceramic is shown in Fig. 4 and the conclusion seen in Table 1.

Table 1 Fire Resistance for Various Ceramic Thickness for Column

Thickness (mm)	5	10	15	20	25
Fire Resistance (min)	27	40	51	63	74

The effect on the increase in ceramic thickness can be seen from Table 1. The increase of 300mm in ceramic thickness will cause a 100% increase in the column strength (from 60 min for 10mm to 160 minute for 40 mm thickness of ceramic.

3.0 DISCUSSION ON YIELD STRENGTH

3.1 The Effect on Load Carrying Capacity.

The effect on the strength of column with respect to yield strength is shown in Fig 5. The yield strength value used in this study is for hot-rolled steel 210, 260, 310, 340 and 420 MPa. All column with different yield strength will have different maximum allowable load capacity. In this graph, it is shown as yield strength increase, the loading capacity will increase.

3.2 The Effect on Fire Resistance

In Fig 5, maximum allowable load is used and not applied load. This is because to obtain fire resistance for column with the different yield strength i.e. better by using maximum allowable load otherwise the result will be inaccurate and questionable since the column with larger yield strength can last longer with equal applied load. The fire resistance for column with different yield strength is shown in Table 2.

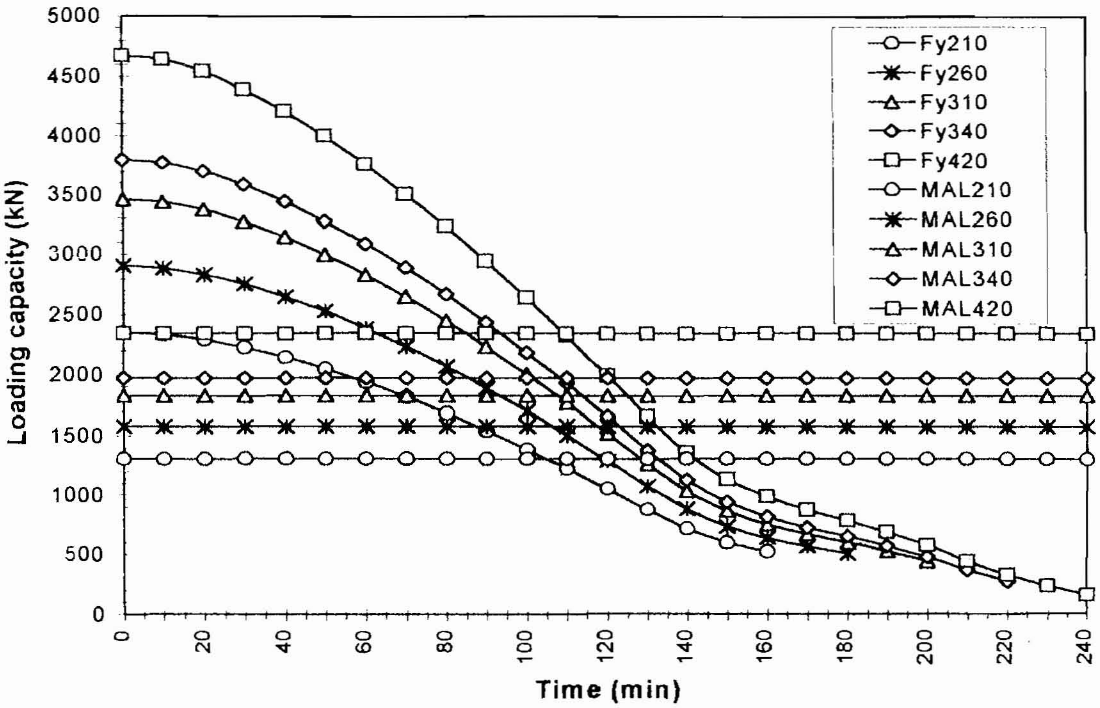

Fig. 5 Fire resistance for Various Yield Strength of Steel (20 mm Ceramic Thickness)

Table 2 Fire Resistance for Various Yield Strength

Yield Strength (MPa)	210	260	310	340	420
Fire Resistance (min)	104	106	107	108	109

The increase of yield strength to fire resistance is seen in Fig 6. The increase in yield strength will result in higher fire resistance but not linearly. The expression for this relationship is :

$$y = 4.1667x^3 - 34.643x^2 + 131.19x + 108$$

where,

y = loading capacity

x= yield strength

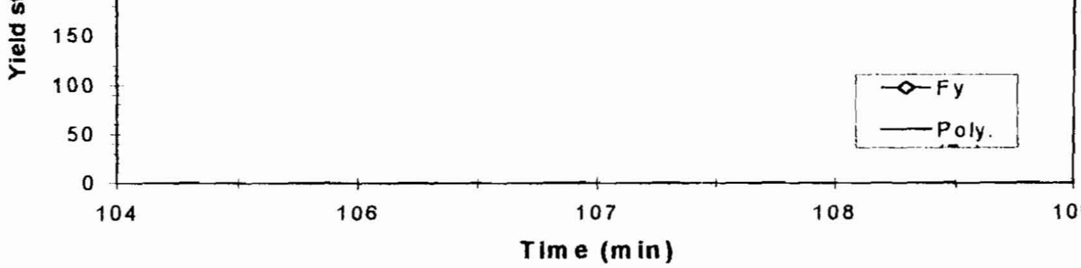

Fig. 6 Relationship of Fire Resistance and the Yield Strength of Steel

4.0 DISCUSSION ON EMISSIVITY OF COLUMN PROTECTED WITH CERAMIC

From Figs. 7 and 8 shown that the increasing in emissivity will increase the temperature in steel. This is because as the value of emissivity of ceramic reached 1.0, it can absorb heat at faster rate since the ceramic approach the properties of black body (emissivity 1.0).

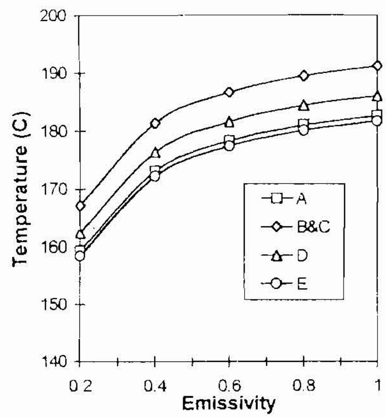

Fig. 7 Temperature at Several Points at Steel Boundary Against Increasing Emissivities of Ceramic at Time 40 min

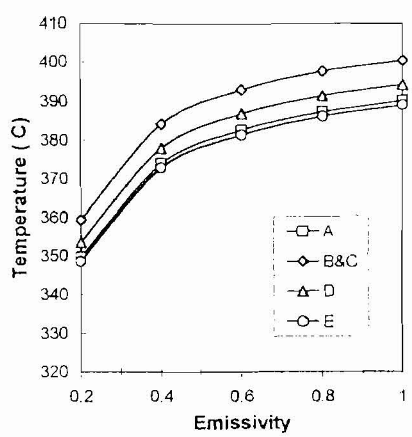

Fig. 8 Temperature at Several Points at Steel Boundary Against Increasing Emissivities of Ceramic at Time 80 min

The rise in temperature for emissivity 0.4 from 0.2 is very obvious after burning time of 80 min. As an example, for point B, the difference of temperature for both emissivity is about 24.7%. From Figs 5 and 6, also shown the difference in temperature decrease as emissivity exceed 0.4.

According to Lie, an emissivity of 0.6 is in general, sufficient to bring the surface to exposed material to temperature that are close to the fire temperature. A further increase in emissivity will only then slightly increase the surface temperature and along the path to the steel boundary. This theory coincides with the result obtained in Figs 9 , 10 and 11.

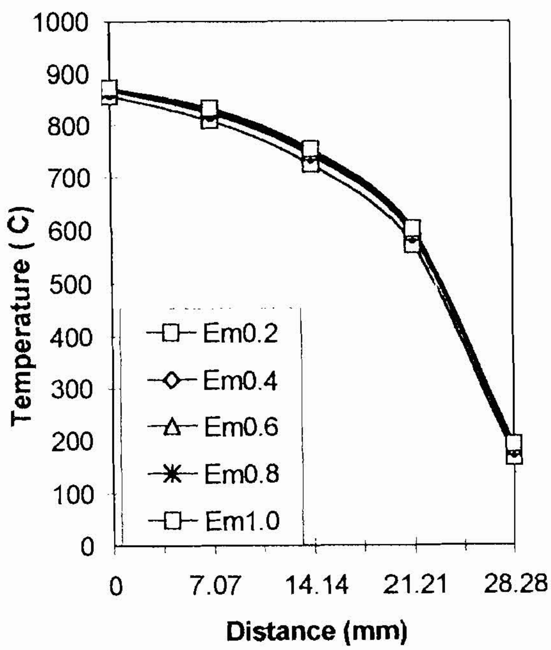

Fig. 9 Temperature Distribution Along Path B for Various Emissivities

4.3 Effect on Fire Resistance

Fig. 12 indicate the fire resiştance of each column (with different emissivity) under maximum allowable load of the column (1770.5kN) and the result from this graph can be summarised as in Table 3.

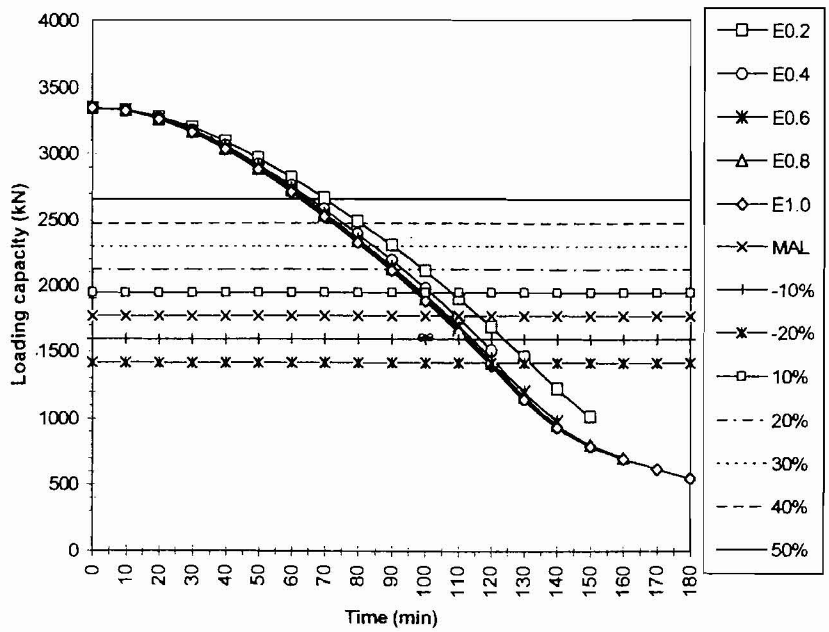

Fig. 12 Fire Resistance for 20 mm Insulation Thickness at Various Emissivities

Table 3 Fire Resistance for Various Emissivity of Ceramic

Emissivity of ceramic	0.2	0.4	0.6	0.8	1.0
Fire Resistance (min)	116	109	107	105	104

5.0 DISCUSSION ON STEEL SIZE

5.1 Effect on Loading Capacity

In this case the column that has been chosen for test are W250x80, W250x149, W310x158 and an additional sample. Table 4 shows the dimensions of the columns.

Table 4 Dimensions of Various Steel Section

Dimension	Width b (mm)	Depth d (mm)	Web w (mm)	Flange t (mm)	Cross-sectional area a (mm)	
W250x80	255	256	9.4	15.6	10069.1	Ms1
W250x149	263	282	17.3	28.4	18834.4	Ms3
W310x158	310	327	15.4	25.1	19852.4	Ms2
Add. Sample	160	160	20	30	11600.0	Sp0

Figure 13 shows the plot of loading capacity or strength against time for different steel size with different maximum allowable load. The reason why the maximum allowable load has been used is because maximum allowable load is related to column size. The bigger the column is the higher it's maximum allowable load. From this fig, the loading capacity are not in order of the steel size (cross-section area) after 55 minutes of burning. For column with steel W310x159, the strength will dramatically dropped after 20 minutes and its loading capacity will be however then column with steel W250x149 after 55 minutes of burning. A further research need to be done to answer why this phenomena occurs.

5.1 Effect on Fire Resistance

From the Table 5 , it is clear that the resistance cannot be base on cross-section are of steel. A nice relationship cannot be obtained based on cross-section area, depth and width of the steel. The relationship can only be found based on either web thickness or flange thickness as shown in Fig 13.

Table 5 Fire Resistance for Various Steel Section

Columns	Ms1	Ms2	Ms3	Sp0
Fire Resistance (min.)	69	81	96	107

From the figure, it shown that a thicker web or flange will give a higher fire resistance. Fig 14 shows the formula of the graph as follows:

$$y = 0.75x^3 - 7.6x^2 + 27.05x - 4.6$$

$$y = 0.0667x^3 - 1.75x^2 + 10.883x + 0.2$$

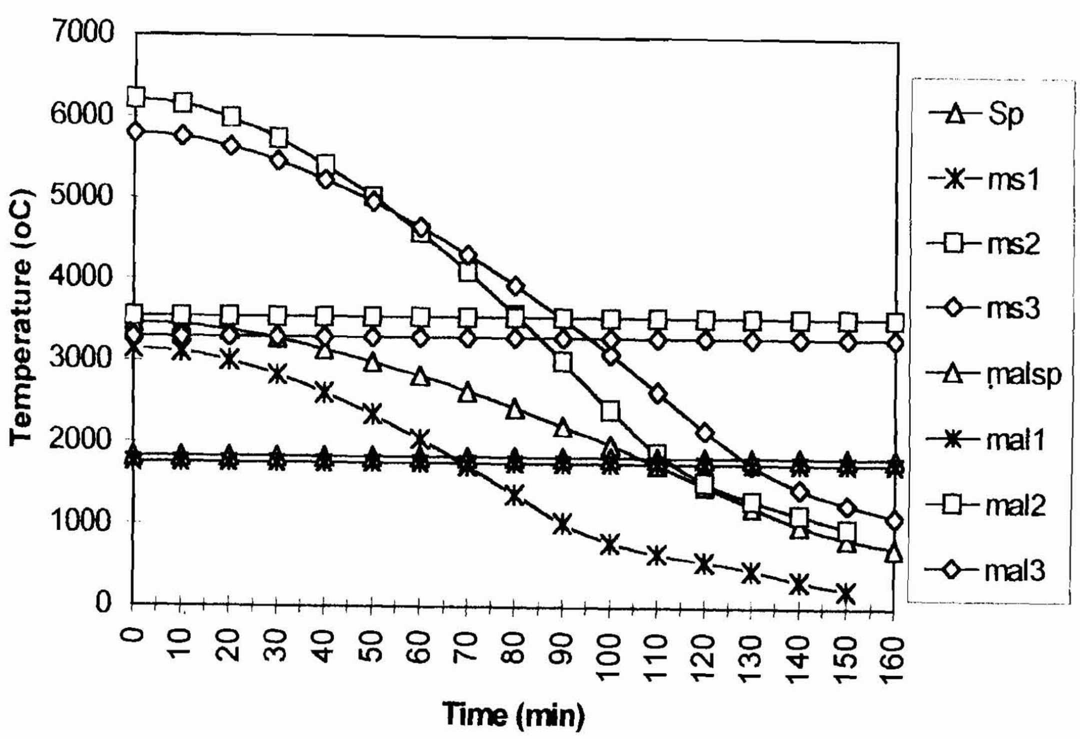

Fig. 13 Fire Resistance Due to Strength of a Various Steel Size

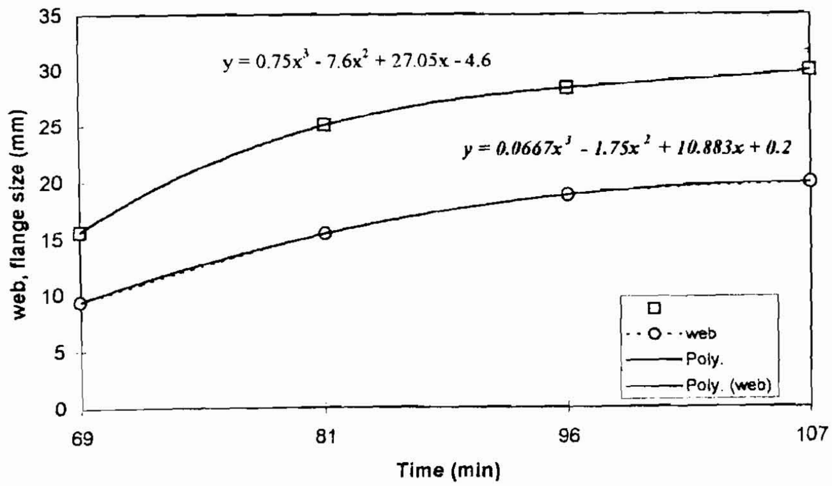

Fig. 14 Relationship between Web and Flange Size to Fire Resistance

6.0 CONCLUSION

This paper managed to present a sensitivity analysis which resulted several new expression that may be applicable for practical uses. However a more in depth study is needed a final conclusion can be made.

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