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# EXPERIMENTAL VERIFICATION OF COLUMN AT EXTREME TEMPERATURE

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**ABSTRACT**

*Experimental studies have been carried out to predict the fire resistance of protected I-shaped steel insulated with ceramic fibre. The steel section selected were W250-80 and W310-158. The experimental results are compared with those obtained using the mathematical models develop by the same authors. The results indicate that the model is capable of predicting the fire.*

## 1.0 INTRODUCTION

Over the years, various specimens of protected steel columns, insulated with heat retardant material such as gypsum board, cementitious material and material fibre were tested. For the purpose of verification of the model given in the research paper [1], the results of tests on five columns with different cross-section sizes and insulation thickness will be used for comparison with calculated results. The columns were made of structural steel section blanketed with ceramic fibres that follow its contour. All columns were 3,810 mm long from endplate to endplate The thickness of the insulation were from 1 inch, 1-1/2 inch and 2 inches applied on steel section W250-80 and W315-58. All steel endplates were 25 mm thick. A specimen is illustrated in Fig. 1 and Fig. 2. The earlier figure shows the cross-section of the I-shape steel section and location of the thermocouple and strain gauges. The latter shows the whole length of the column from endplate to endplate.

The steel for the columns was cut to appropriate lengths and then the end plates were weld to the steel at column extremities. The centering and perpendicularity of the end plates were given special attention to ensure a high degree of accuracy. After welding the end plates, twelve holes with diameter of 7/8 inch were drilled in each endplate. The holes were created for studs of the furnace compressor piston at the bottom and support at the top.

The steel of the column had a specified yield strength of 300 MPa and the insulation does not contribute to the strength of the column. Chromel-alumel thermocouples with a thickness of 0.91 mm were installed at the mid-height of the column for measuring the temperatures of the steel section at different locations in the cross section. The locations of the thermocouples are described in National Standard of Canada CAN/ULC-S101-M89.

## 2. 0 TEST APPARATUS

The tests were done by exposing the columns to heat in a column test furnace. The test furnace was designed to produce the conditions to which member might be subjected during a fire. It consists of a steel framework supported by four steel columns with the furnace chamber inside the frame characteristics and instrumentation of the furnace which has a loading capacity of 1,000 tonnes, are described in detail in Ref. 13.

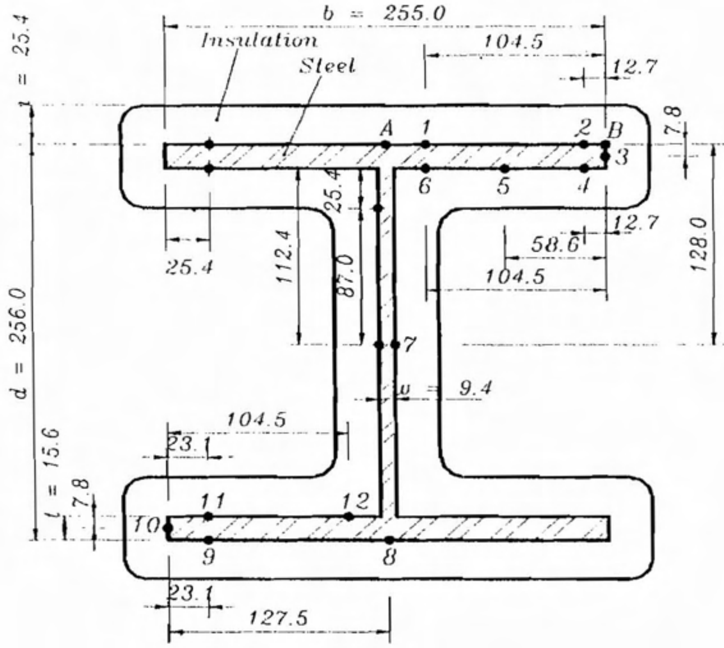


Fig. 1 W250-80 Steel Section with 1 Inch Ceramic

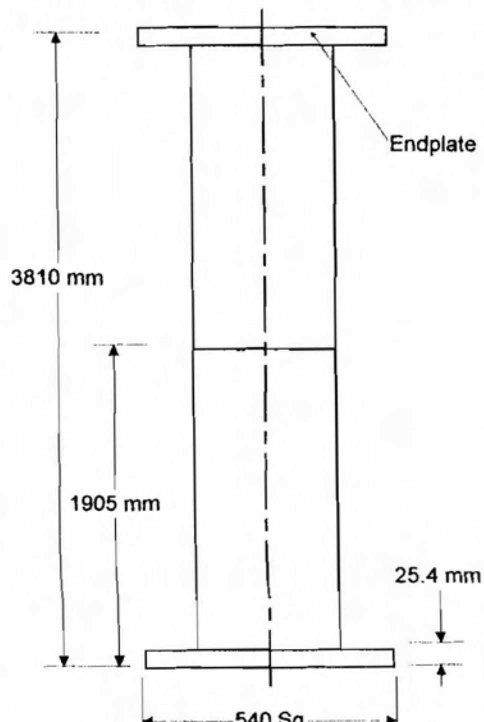


Fig. 2 The Column Length

## 3.0 TEST CONDITIONS AND PROCEDURES

The tests were done with both ends of the columns fixed i.e. restrained against rotation and horizontal translation. The columns were tested under a concentric load. The applied loads were from 59% and 86% of the factored compressive resistance of the columns($C_r$) as determined according to the Canadian Standards Association CSA/CAN-S16.1-M89 {"Limit States" 1989). The factored compressive resistances of each column, as well as the applied loads, are given in Table 1. The effective length factor K used in the calculation of the factored compressive resistance was that recommended in CSA/CAN-S16.1-M89 for the given end condition, i.e., 0.65. The effective length of the columns, *KL,* was thus assumed to be 2.48 m. However previous test had indicated a more accurate effective length of 2.0 m because the extreme ends of the column were not exposed to the fire intensity as much as the middle part of the column.

Table 1 Factored Compressive and Applied Loads

Resistances of Each Column

| Column No. | Section-Code and Sizes: G40.21-M 300W | Insulation Thickness mm (inch) | Factored Strength Cr (kN) | Max. Allowable Load (D+L) kN | Applied Load C (kN) | Ratio C/Cr |
|---|---|---|---|---|---|---|
| FS1 | W250 x 80 | 25 ( 1 ) | 2550 | 1908 | 1750 | 0.69 |
| FS2 | W250 x 80 | 38 (1-1/2 ) | 2550 | 1908 | 1700 | 0.67 |
| FS3 | W310 x 158 | 25 ( 1 ) | 5098 | 3856 | 3000 | 0.59 |
| FS4 | W250 x 80 | 25 ( 1 ) | 2550 | 1908 | 2200 | 0.86 |
| FS5 | W310 x 158 | 50 ( 2 ) | 5098 | 3856 | 3800 | 0.75 |

D -- dead load, L -- live load

During the test, the column was exposed to heating in a controlled way that the average temperature in the furnace followed as closely as possible, the ASTM E119-88 or CAN/ULC-S101 standard temperature-time curve.

## 4.0 RESULTS AND DISCUSSIONS

Using the mathematical model described in Ref. 1, the temperatures axial deformations, and strengths of the columns were calculated. In the calculations, the thermal and mechanical properties of the steel, given in Ref. 4, were used. The ceramic thermal properties was provided by the supplier *Unifrax Corporation* .

In the calculation of the time of fire resistance for calculated data, the graph of load capacity of column against time is used, failure occurs when load carrying capacity equal to the applied load. The strength decreases with time until it becomes so low that the column can no longer support the load. The time to reach this point is the fire resistance of the column. Fire resistance for measured data are determined when the axial expansion stop. This is because the test only produce data for temperatures and axial deformation but does not produce load capacity data. Hence the time for fire resistance is obtained using the graph of axial deformation against time where failure occurs when the column stop increasing in length.

In Figs. 3 to 7, the calculated average temperatures [1] are compared with the average temperatures measured at the external surface of the steel section. With the exception of the test conducted on the column FS3, there is good agreement between calculated and measured column temperatures. The temperatures measured initially showed a relatively cautious rise up to temperatures of approximately 50°C, followed by a period of relatively faster rate of temperature rise. This temperature behaviour may be the result of the steel section having reach some equilibrium for a particular time step after the initial cold start. As a whole, which are important from the point of view of predicting the fire resistance of the columns there is a good agreement between calculated and measured temperatures [1].

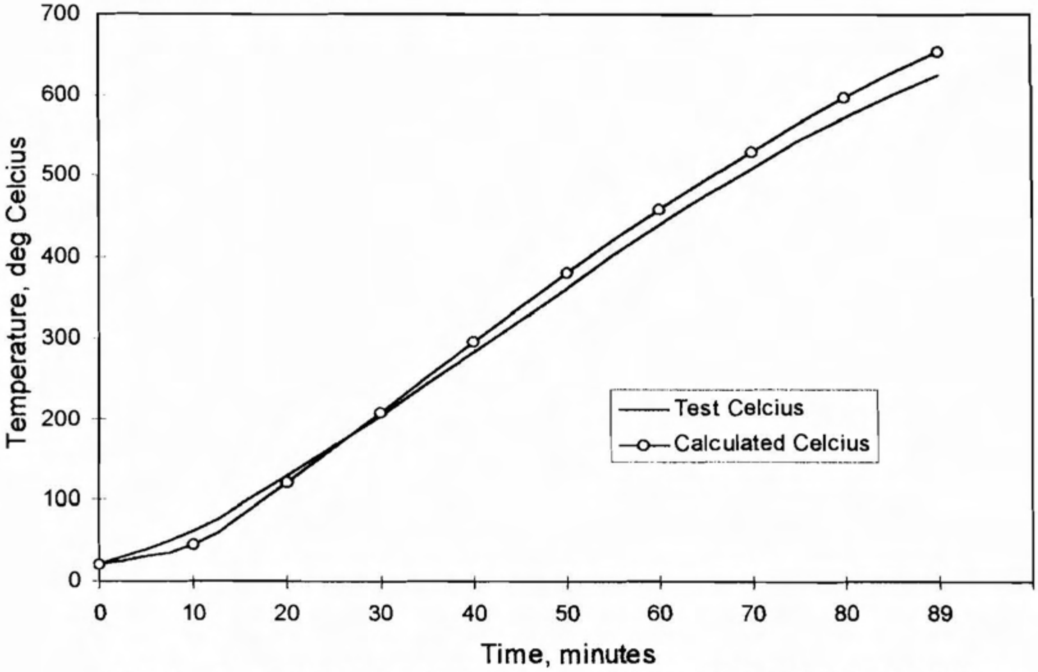


Fig. 3 Average Temperature of Column FS1 for Test and Calculated Data

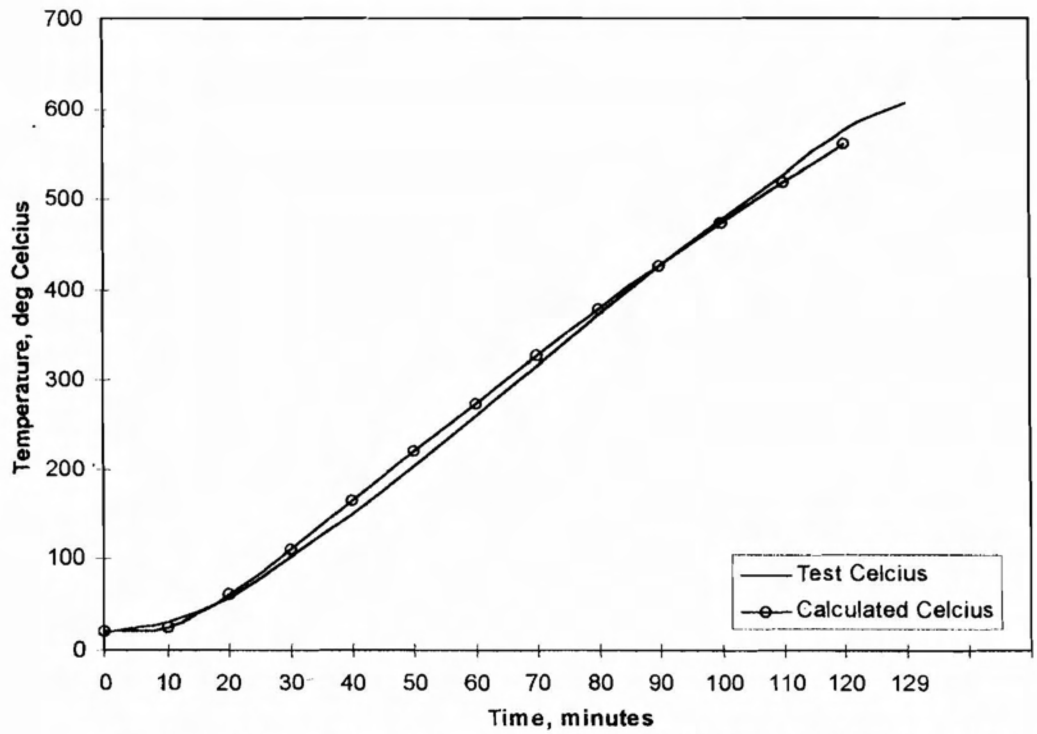


Fig. 4 Average Temperature of Column FS2 for Test and Calculated Data

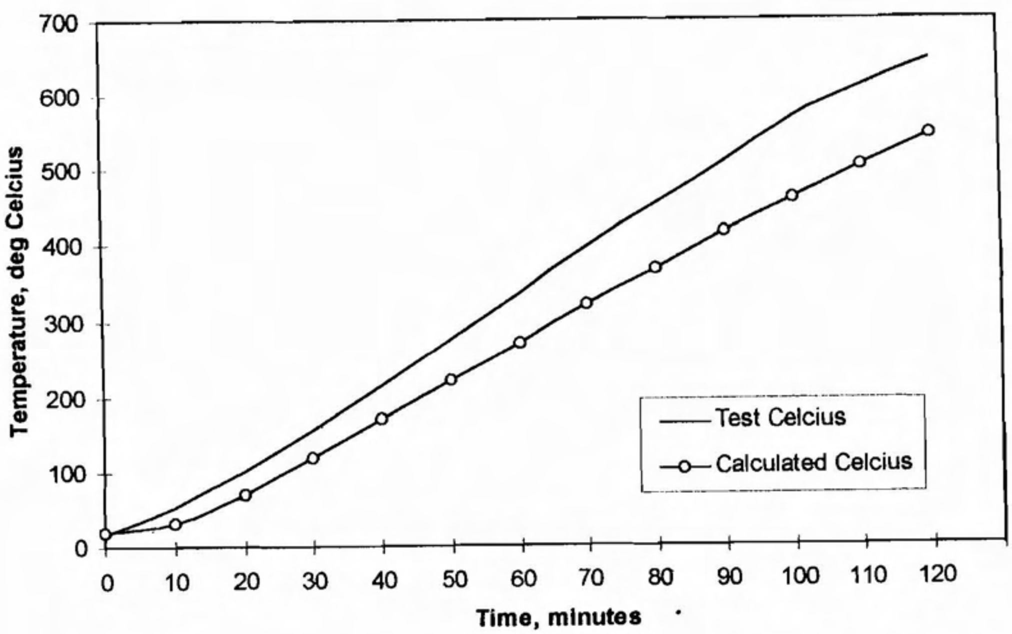


Fig. 5 Average Temperature of Column FS3 for Test and Calculated Data

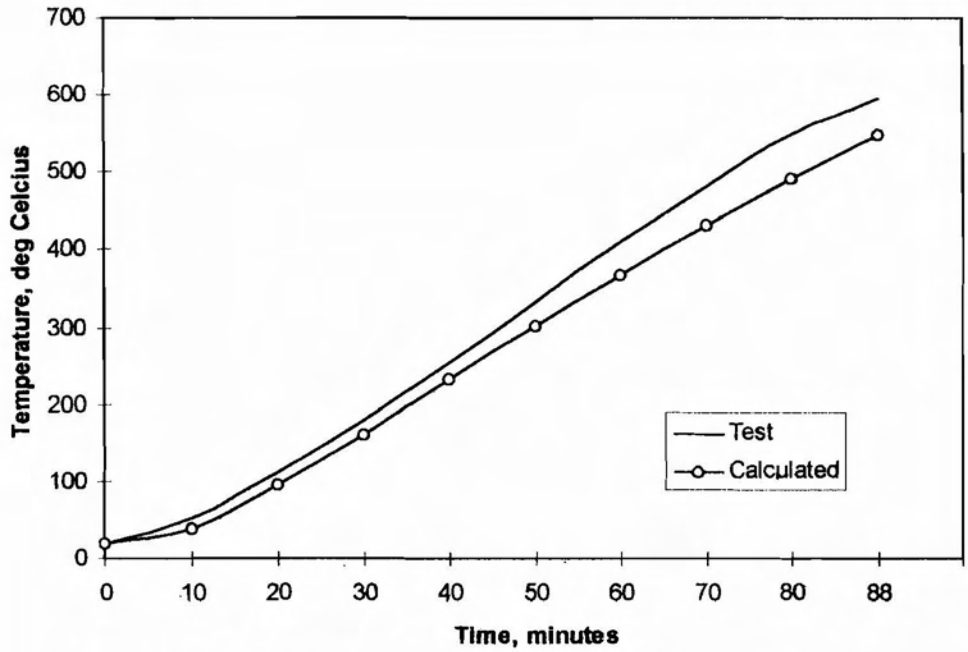


Fig. 6 Average Temperature of Column FS4 for Test and Calculated Data

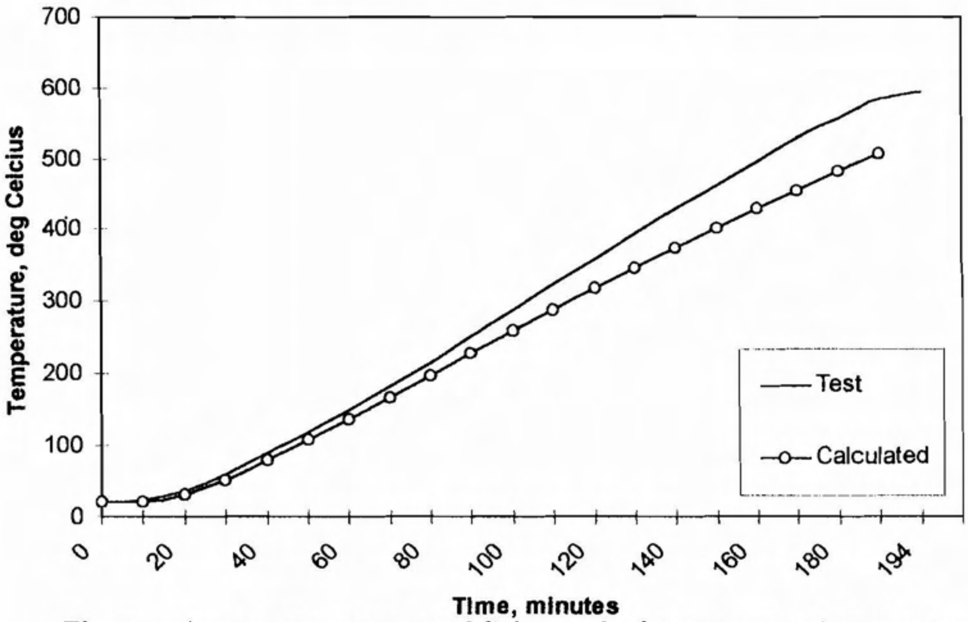


Fig. 7 Average Temperature of Column FS5 for Test and Calculated Data

In Figs. 8 to 11, the calculated and measured axial deformations of the columns during exposure to fire are shown. There is reasonably good agreement in the trend of deformations between calculated and measured results [1]. There are some differences, however, between the actual values of the calculated and measured deformations.

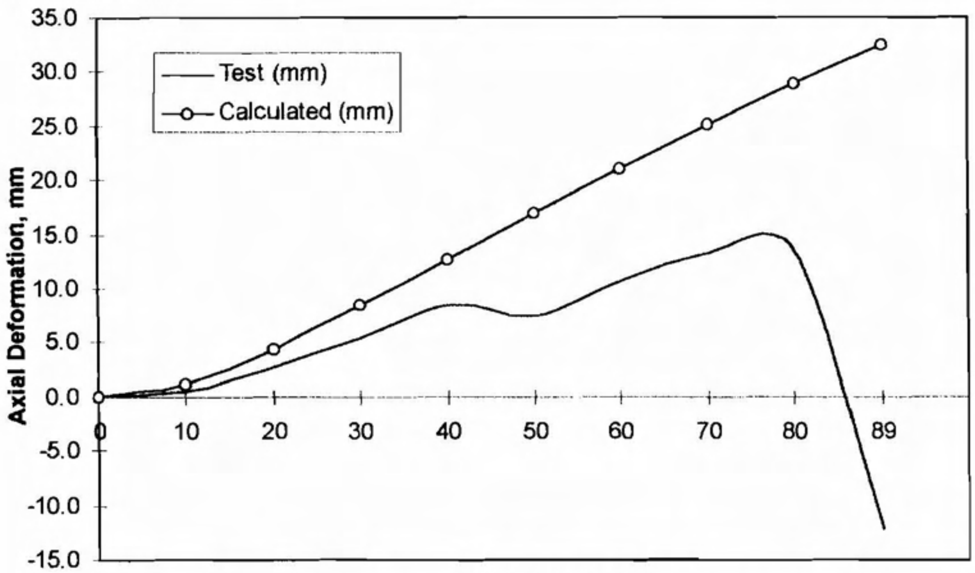


Fig. 8 Test and Calculated Values for Axial Deformation of Column FS1

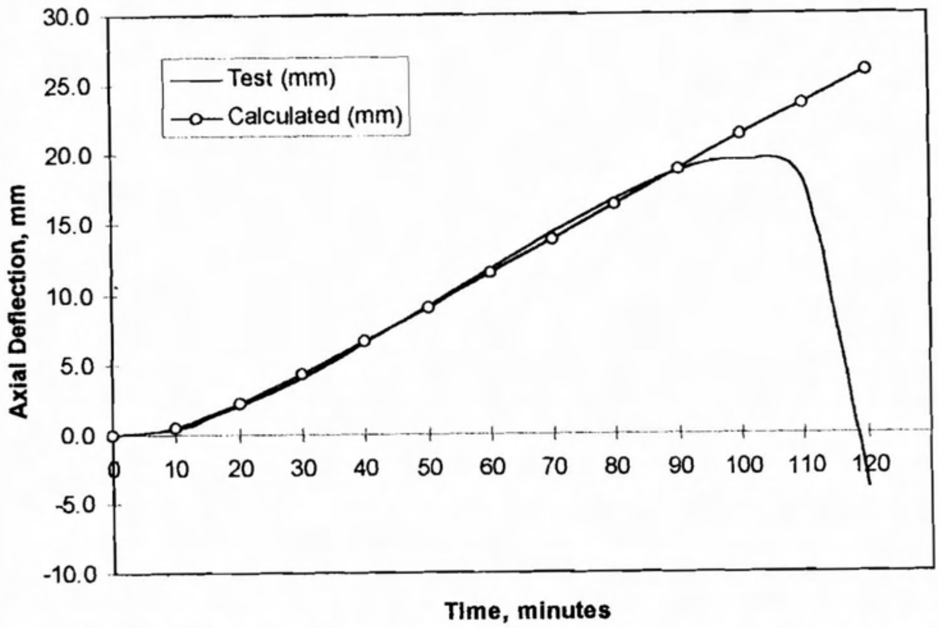


Fig. 9 Test and Calculated Values for Axial Deformation of Column FS3

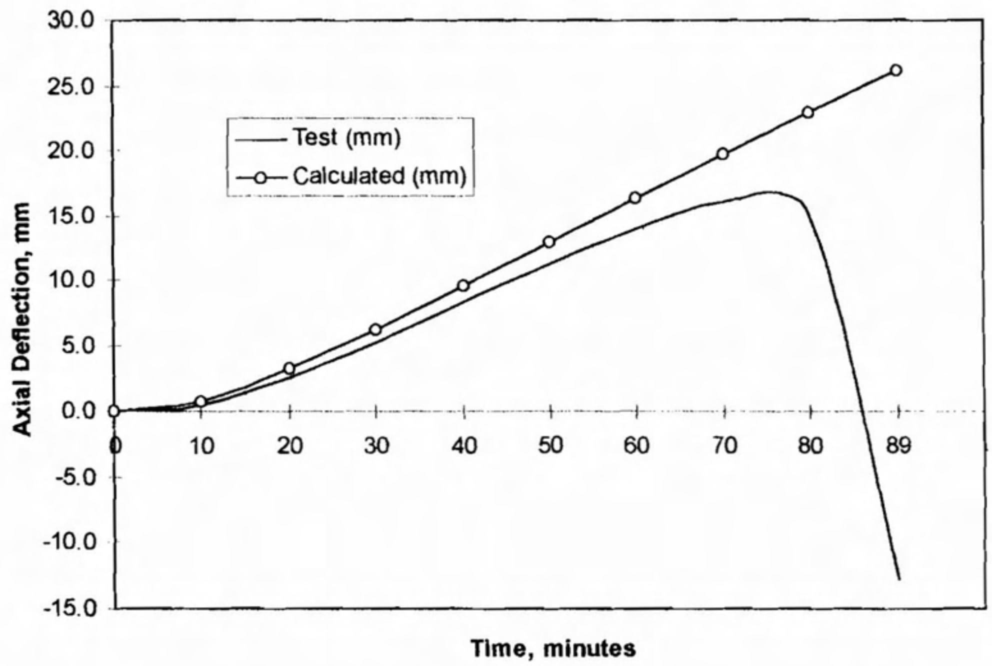


Fig. 10 Test and Calculated Values for Axial Deformation of Column FS4

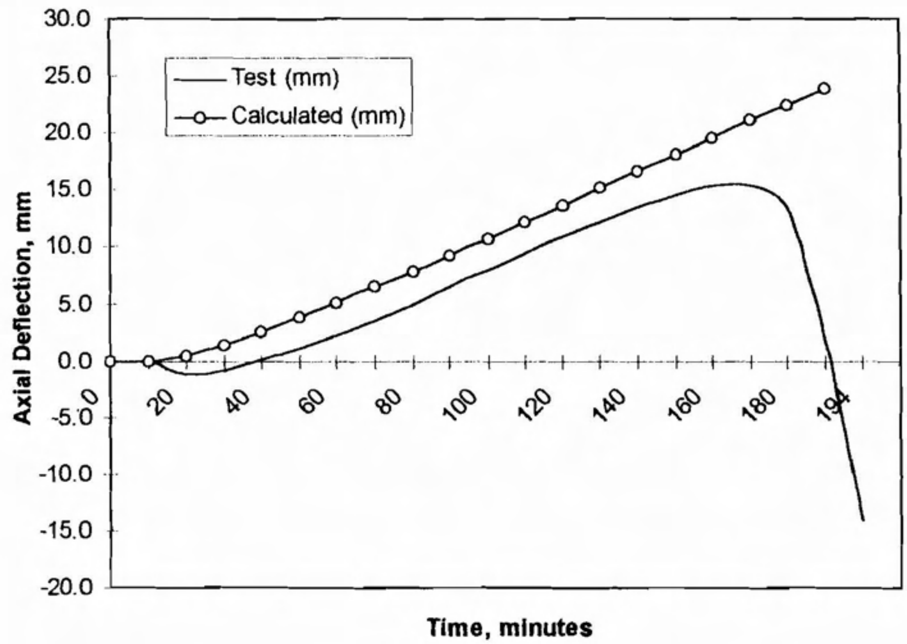


Fig. 11 Test and Calculated Values for Axial Deformation of Column FS5

It must be noted that the column deforms axially as a result of several factors namely, load, thermal expansion, nding and creep. The last ones cannot be completely taken into account in the calculations [1]. Since the axial deformations, which are in the order of 20 mm, are for columns with a length of about 3800 mm, small inaccuracies in these factors may cause noticeable differences between calculated and measured axial deformations. A difference of 10% between the theoretical and actual coefficients of thermal expansion of steels for example, will cause a difference of approximately 5 mm in the axial deformations.

The effect of creep, which is more pronounced at the later stages of fire exposure, may be even greater. The model defines the failure point as the point at which the column can no longer support the applied load and assumes that failure at this point is instantaneous. During the tests, failure was not instantaneous but the columns contracted considerably apparently as a result of continued loss of strength and creep, before they were crushed.

In Figs. 12 to 16, the calculated column strengths, as a function of the fire exposure time, are shown for the test loads given in Table 1. The results show that the calculated fire resistance of column FS1, FS2 and FS5 are less than 5% off the measured fire resistances. The specimens FS3 and FS4 showed a less accurate result giving the value of 15% and 20% respectively off the measured fire resistance. Lie indicated that a 10% off the measure value is considered excellent validation but a 20% off in accuracy is still acceptable.

Coincidentally, the three column that produce the better results were the first three specimens to be tested for its fire resistance in the furnace. There were technical difficulties before the last two experiments that required rectification which probably explained the less accurate results.

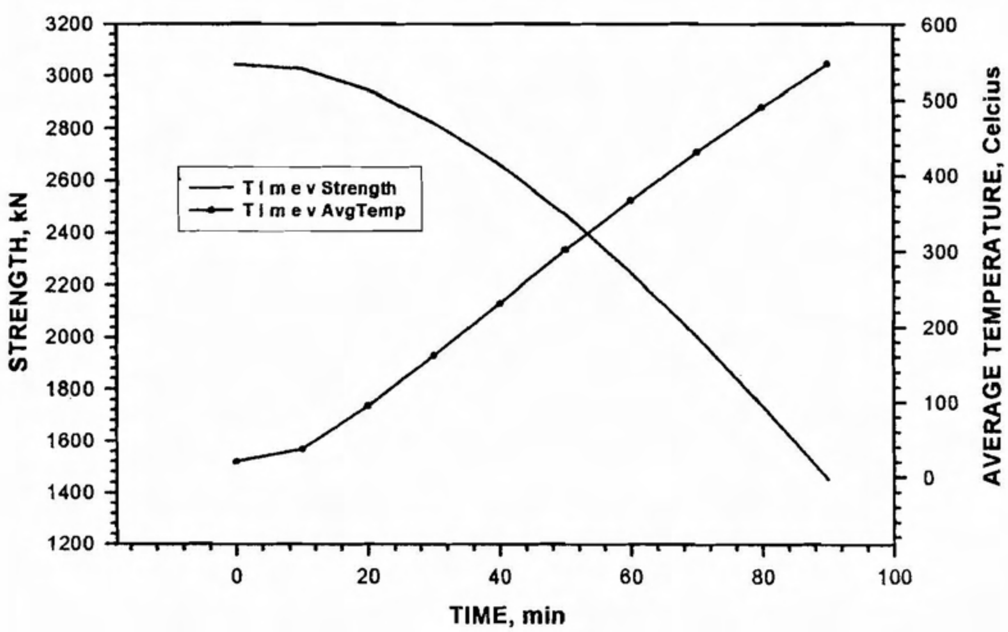


Fig. 12 Column FS1

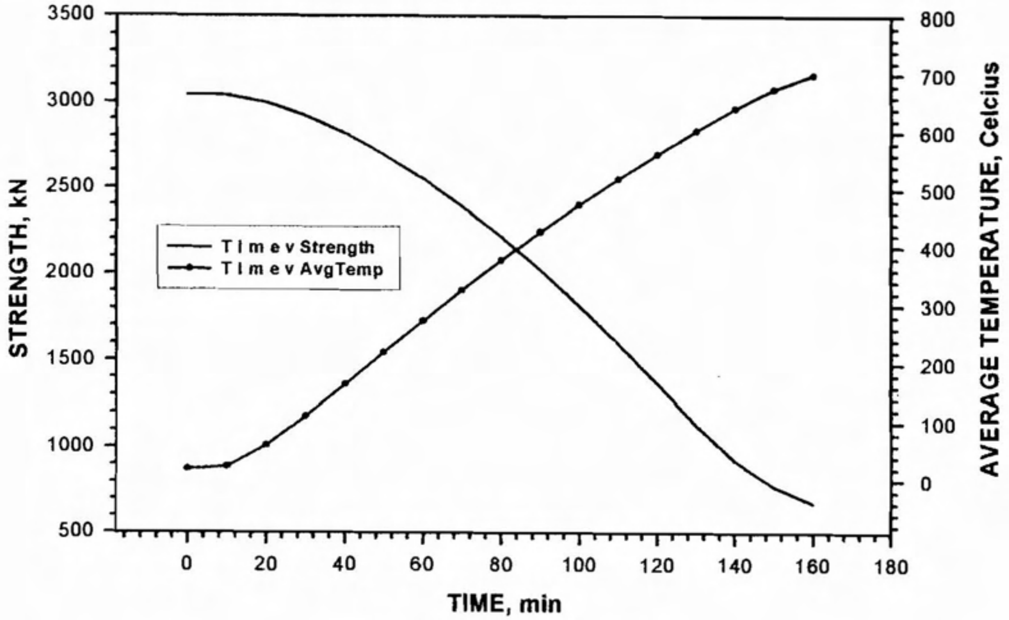


Fig. 13 Column FS2

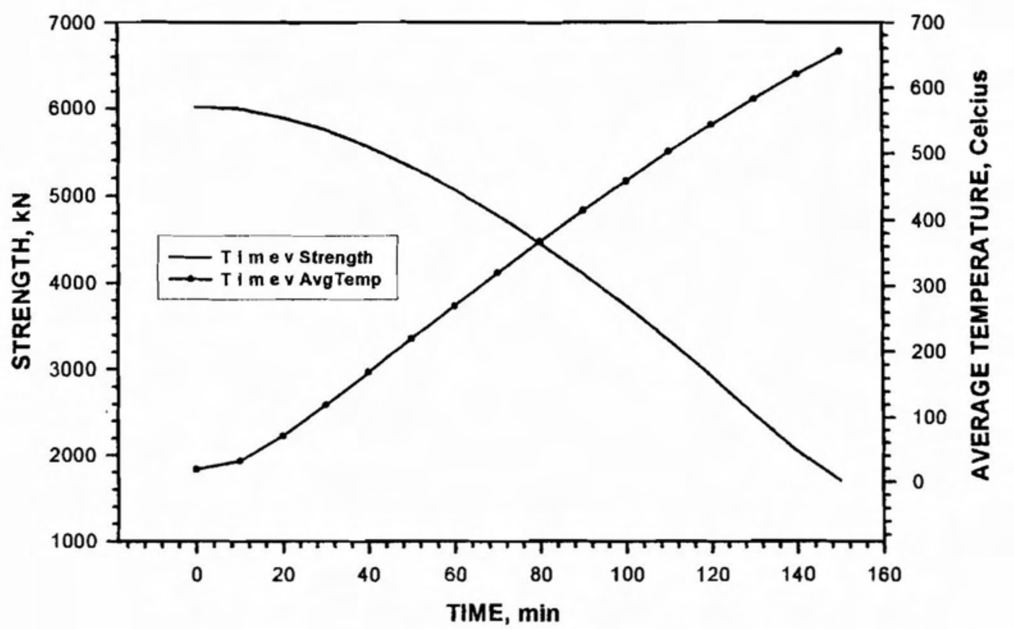


Fig. 14 Column FS3

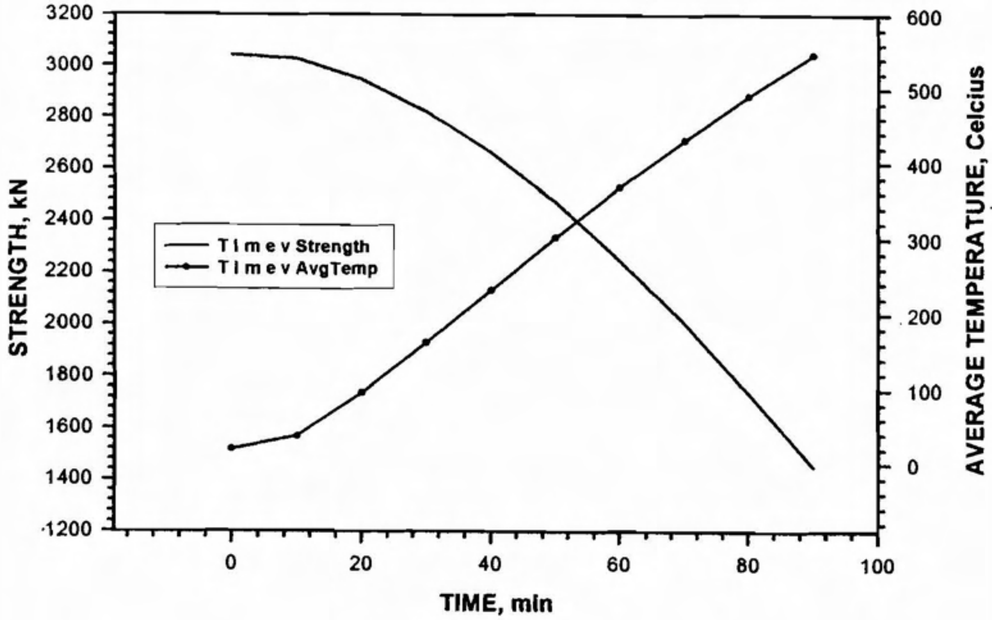


Fig. 15 Column FS4

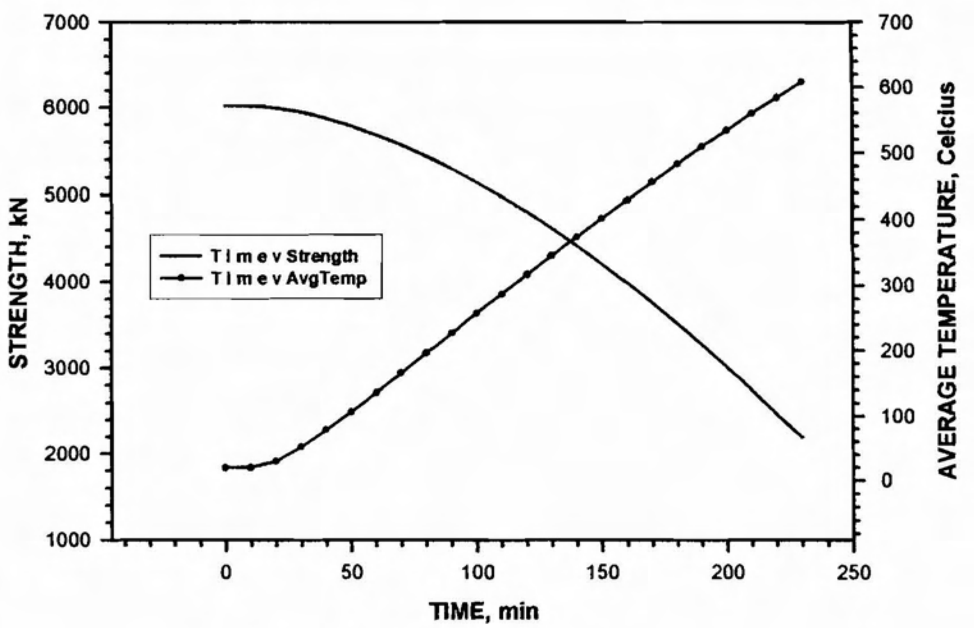


Fig. 16 Column FS5

Other liable factor for the inaccuracy of the results is the considerable contraction of the columns that the model can only partly take into account. In addition, the properties of the materials applied in the model may not be the best value to represent the specimens tested.

A factor that can severely affect the accuracy of the model is the mode of fixing the column at each end to the furnace compressor and support. The actual joints of the column during test is fixed end connection that could possibly give rise to moment stress in the column but in the program, it is assumed to have pin-ended joints and hence zero moment at both ends.

Another factor that can affect the accuracy of the program is that, the instantaneous crushing of the column tend to occur about 10 minutes to an hour from the theoretical failure. However, according to Lie, a definite standard on this type of failure is not found in any code and the actual instantaneous failure is still arbitrarily decided by the engineers concerned. Hence this mode of failure cannot be considered for any program until clearly specified in the code. However if this mode of failure is to be used as the failure criterion as most of the case in experimental tests, then all the measured fire-resistance will show a higher value. This means that the calculated fire resistance will indicate a conservative values which for practical purposes mean that the calculated fire resistances lie on the safe side.

## 5.0 CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn:

The mathematical model [1] employed in this study is capable of predicting the fire resistance of protected steel columns, made of I-shape steel section insulated with ceramic fibre with an accuracy that is adequate for practical purposes. The results indicate that the model is conservative in its predictions.

The model will enable the expansion of data on the fire resistance of ceramic protected steel columns which at present predominantly consists of data for concrete columns.

By using the mathematical model, the fire resistance of protected steel columns can be evaluated for any value of the significant parameters such as load, column-section dimensions, and thickness of insulation of ceramic fibre without the necessity of testing.

The model can also be used for the calculation of the fire resistance of columns made with I-shaped steel section insulated with material other than those investigated in this study - for examples cementitious or board that were not tested if the relevant material properties are known.

## 6.0 ACKNOWLEDGMENTS

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