International Journal of Advance Research in Science and Engineering
Vol. No.4, Special Issue (01), Spetember 2015
www.ijarse.com
IJARSE
ISSN 2319 - 8354

COMPARATIVE STUDY OF ELASTIC AND PLASTIC ANALYSIS OF INDIAN STEEL MEMBERS SUBJECTED TO FIRE USING SAFIR AND ANSYS SOFTWARE

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ABSTRACT

Fire is an extreme event, the occurrence of which affects the behavior of the structures significantly in terms of both serviceability and strength criteria; hence, provision of appropriate fire safety measures for structural members is an important aspect of steel structural design. However, the impact of fire on steel member at elevated temperature is analyzed by means of a three dimensional (3D) nonlinear transient thermo-mechanical finite element (FE) analysis.

Commercially available software package ANSYS and SAFIR is used for studying the transient response of the cross section at elevated temperatures. As a part of validation of results obtained from the present model, the experimentally analyzed behavior of steel member at elevated temperatures, reported in literature has successfully been simulated in SAFIR/ ANSYS SOFTWARE and to find out the differences of the steel members when test on fire.

I. BACKGROUND

All common building materials lose strength when heated to high temperatures. Although steel does not melt below 1,500oC, at a temperature of around 600oC, its yield strength declines to about one-third of its yield strength at ambient temperature. At 800oC, its yield strength is reduced to 11%, and at 900oC, to 6%. The elastic modulus of steel is similarly reduced with increasing temperatures, but at a higher rate. Due to internal cracking and chemical changes, concrete also loses strength and stiffness as temperature increases. Since concrete has much lower thermal conductivity than steel, a concrete encasement is often used as a fire protection for steel. The degradation of structural materials' stiffness and strength at high temperatures may, in some incidents, cause the structure to collapse under severe fire conditions. Materials such as steel obviously need to be designed to withstand the effects of a fire in order to ensure the safety of people and property.

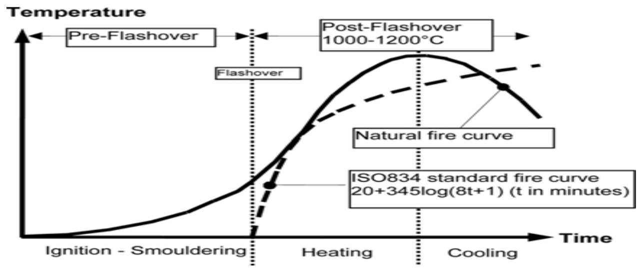


Figure 1.1: Natural Fire and ISO834 Standard Fire.

II. FIRE RESEARCH

Fire represents one of the most severe environmental hazards to which buildings and built infrastructure are subjected, and thus fires account for significant personal, capital and production loss in most countries of the world each year. Therefore, the provision of appropriate measures for protecting life and property are the prime objectives of fire safety design in buildings. Fire research and investigation of the fire performance of building elements date back to the nineteenth century, when the frequent and disastrous fires of buildings during accidental fires were first realized. Fire tests have been conducted at the National Institute of Standards and Technology, Gaithersburg, USA; Building Research Establishment, London Lund Institute of Technology, Sweden, etc. These tests were conducted by obtain reliable data as to the exact resistance of building practice and to give precise particulars regarding fire prevention, alarm, and extinguishing appliances.

III. RESEARCH OBJECTIVES

The main aim of the present study is to provide a better understanding of the elastic and plastic analysis of steel column subjected to fire (High temperature) this was achieved by carrying out the investigations with following objectives:

1. Modelling of steel member and analysing the effect of fire on it.
2. Using SAFIR/ANSYS softwares to analyse the elastic and plastic properties of steel member subjected to fire
3. Validating it with the experimental data available in the literature.
4. To compare the efficiency between the two software.

IV. BROAD GATE PHASE 8 FIRE

This section is a summary of findings published within “Structural Fire Engineering Investigation of Broad gate Phase 8 Fire” by Fire Safety Engineering Consultants (FSEC) Ltd., 1991. On June 23rd, 1990 a fire developed in the partially completed fourteen-storey Broadgate building. As the building was still under construction, fire and smoke detection systems were not yet operational, and the automatic sprinkler system was not active. Protection for beams and trusses was not complete, and columns had not been fitted with fire protective cladding. The fire began inside a contractor’s hut located on the ground floor, remaining unchecked for some time, spreading smoke throughout the building. The total cost of damage caused by the fire was 25 million pounds. Only 2 million of this has been estimated as damage to the structural steel frame or concrete floor.

The fire duration was approximately 4.5 hours, of which 2 hours could be described as severe burning. Flames out of the contractor's hut window were at least 10000C. Despite this, metallurgical testing has shown that the peak temperature of the steel framework was only around 6000C. Most of the structural steel work was exposed to the fire, due either to incomplete fire protection installation, or removal of what protection was in place by pressurized water from fire hoses. The most significant structural damage was axial shortening of columns and large deflections of trusses and beams, producing dishing of floors of up to 600mm in some areas. Because the steel temperatures did not get to above 7000C, and the loads within the unoccupied building were low; most of the deformed structural members were able to perform without transferring loads to cooler parts of the structure.
It was found that restraint conditions of members were important in the performance of heat-affected parts of the frame. For instance, small columns located close to a much larger column were found to have suffered more damage than the same sized smaller column without other adjacent larger columns. This is because as the smaller column would heat faster than the much larger column, its rate of axial expansion would be greater. This expansion would be restricted by the stiffness of the much larger column if it were present, causing large compressive stress within the smaller column. Similar effects were observed with beams and trusses that were fixed against rotation at end supports.
This differing rate of temperature change within different sized members is not considered in standard fire resistance tests, where each member is tested independently. The Broadgate fire has demonstrated that there is a need to consider the stability of the frame as a whole in fire engineering. Loss of capacity of individual members is not relevant, but most important is the maintenance of a reliable load path during, and after the fires duration for structural stability.

V. THEORY OF PLASTICITY REVIEW

Tresca was the first person to study the plastic behaviour of materials in 1864 by conducting an experiment on the punching and extrusion of metal, which led to conclusion that metal yielded plastically when the shear stress attained a critical value. From then on considerable work was done by many researchers, among them Saint-Venant and Levy. Later, many yield criteria were proposed, but the most significant was the von Mises yield condition in 1913. This yield criterion was deduced purely by mathematical considerations.
This was later interpreted by Hencky as implying that yielding occurred when the elastic shear strain energy reached a critical value. Von Mises also independently proposed an equation similar to Levy's equation. It was between 1920 and 1921 that Prandtl showed that the two-dimensional plastic problem is hyperbolic in nature and Hencky supplied the general theory underlying Prandtl's special solution. In 1926 Lode experimentally investigate the Levy-Mises equation by measuring the deformation of tubes of various metals under combined tension and internal pressure. This confirmed the validity of the Levy-Mises stress-strain relation to a first approximation. The generalisation of this theory of plasticity was made by Reuss in 1930 by including the elastic component of strain following the earlier suggestion of Prandtl.
Later, the concept of strain hardening was introduced by Schmidtl(1932) and **Odquist(1933).** Experimental confirmations of the Levy-Mises equations have been undertaken by many researchers. Among them were Hohenemser(1931-1932) and Schmidtl. By 1932 a theory had been constructed reproducing the plastic and

elastic properties of an isotropic metal at ambient temperature. This theory is known as flow or incremental theory of plasticity.

In 1924 Hencky proposed a rival theory which received attention from scientists for its analytical simplicity in problems where plastic strain is small. Nadai(1931) established this theory firmly and afterward many researchers employed it. This is known as the deformation theory of plasticity.

VI. STEEL STRUCTURES SUBJECTED TO FIRE

In this section a brief review of aspects of structural steel work subjected to fire is given. The strength of all engineering materials reduces as their temperature increases. Steel is no exception. However, a major advantage of steel is that it is incombustible and it can fully recover its strength following a fire, most of the times. During the fire steel absorbs a significant amount of thermal energy. After this exposure to fire, steel returns to a stable condition after cooling to ambient temperature. During this cycle of heating and cooling, individual steel members may become slightly bent or damaged, generally without affecting the stability of the whole structure. From the point of view of economy, a significant number of steel members may be salvaged following a post-fire review of a fire affected steel structure. Using the principle "If the member is straight after exposure to fire – the steel is O.K", many steel members could be left undisturbed for the rest of their service life. Steel members which have slight distortions may be made dimensionally reusable by simple straightening methods and the member may be put to continued use with full expectancy of performance with its specified mechanical properties. The members which have become unusable due to excessive deformation may simply be scrapped. In effect, it is easy to retrofit steel structures after fire. On the other hand concrete exposed to fire beyond say 600oC, may undergo an irreversible degradation in mechanical strength and spolling However it is useful to know the behaviour of steel at higher temperatures and methods available to protect it from damage done to fire. Provisions related to fire protections are given in section 16 of the IS 800 code.

VII. FIRE RESISTANT STEEL

Fire safety in steel structures could also be brought about by the use of certain types of steel, which are called 'Fire Resistant Steels (FRS)'. These steels are basically thermo-mechanically treated (TMT) steels which perform much better structurally under fire than the ordinary structural steels. These steels have the ferrite – pearlite microstructure of ordinary structural steels but the presence of Molybdenum and Chromium stabilises the microstructure even at 600 oC.

Table 1.1:Chemical Composition of Fire Resistant Steel

C		Mn	Si	S	P	Mo + Cr
FRS	≤0.20%	≤1.50%	≤0.50%	≤0.04%	≤0.04%	≤1.00%
Mild Steel	≤0.23%	≤1.50%	≤0.40%	≤0.050%	≤0.05%	

The fire resistant steels exhibit a minimum of two thirds of its yield strength at room temperature when subjected to a heating of about 600 oC. In view of this, there is an innate protection in the steel for fire hazards. Fire resistant steels are weldable without pre-heating and are commercially available in the market as joists, channels and angles.

VIII. VALIDATION

The ANSYS finite element structural model was validated by comparing the predictions from the analysis with test data reported in literature. The validation process covered both the thermal and mechanical predictions from the analysis. In the reported experiments, unprotected, axially-restrained steel beams were tested under a random design fire scenario. In the analysis, the beams were exposed to fire from four sides.

A number of FE models are available in literature studying the behavior of Steel Member such as beam and columns under mechanical loading with or without fire. As a part of validation process a problem done by Newman (1990).

IX. TRANSIENT HEAT TRANSFER ANALYSIS

A two dimension transient analysis was carried out of unprotected steel under elevated temperature by using SAFIR Software and ANSYS Software.

9.1 Problem Specification

The experimental results used for validating the model in SAFIR are based on the investigation carried out by Newman (1990).Using this numerical example given below as done in the design of steel structures book.

Calculate the temperature rise on an ISMB 400, ISLB400 and ISLC400 heated on four sides after 15min to ISO 834 fire.

9.2 Modelling and Results Discussion

From IS808 for ISMB400 the dimensions are as given below,

Area=78.46cm2, where D=400mm, B=140mm, t=8.9mm

Where D= Depth of the section

B= Width of the flange

t= Thickness of the web

A= Cross sectional Area of the section

HP= Heating Parameter

STEP 1:

The first step is to calculate the heating parameter as given by the formula for unprotected steel member heated in for sides as HP= 2D+4B-2t,

Therefore HP= 2D+4B-2t=2 x 400+4 x 140 - 2x8.9=1342.2mm, Hp =1.342m

STEP 2:

After obtaining the heating parameter, we can get the section factor as the ratio between the heating parameter to the cross section area,

Hp/A =1.342x1002/78.46=171m-1

STEP 3:

To obtained Δt=25,000Hp/A=25000171=146mm

Δt=120s.

The governing equations are

ΔTs= *(1/CsPs)(Hp/A)hnet*Δt

With hnet= αc(Tt – TS)+σφε[(Tt + 234)4 – (Tt + 234)4]

=25(Tt – TS)+1×0.8x5.67x10-8[((Tt + 234)4-(Tt + 234)4]

And Ts=1/(600x7850) ×171 × hnet×120oC=4.36x10-3hnet

At t=0, both To and Ts are 20. Tt is given by

Tt = To +345log (8t+1)

The values of Ts are calculated at t=0,2,4,6,8,…minutes and the values of To hnet(Tt – TS) and *ΔT*s at t=1,3,5,7,…min. the calculations are carried out in the spreadsheet form as shown in table 3.1 below.

Where, Ts = Temperature on the material

*Δ*Ts = Change in Temperature

T = Time in second

t(min)	Ts(◦C)	h	ΔTs(◦C)	Tt(◦C)
0				20
1	349.2	14,693	64	
2				
3	502.3	26,110	113.8	84
4				
5	576.4	30,847	113.5	332.3
6				
7	625.8	30,850	134.5	446.8
8				
9	662.8	26,099	113.8	466.8
10				
11	692.5	18,132	47.3	580.6
12				
13	717.3	10,843	47.3	659.6
14	738.6	6,473	28.2	671
16				672

Table 1.2: Temperature Result for the Manual Calculation

International Journal of Advance Research in Science and Engineering
Vol. No.4, Special Issue (01), Spetember 2015
www.ijarse.com
IJARSE
ISSN 2319 - 8354

X. ANALYSISRESULTOF SAFIR AND ANSYS SOFTWARE

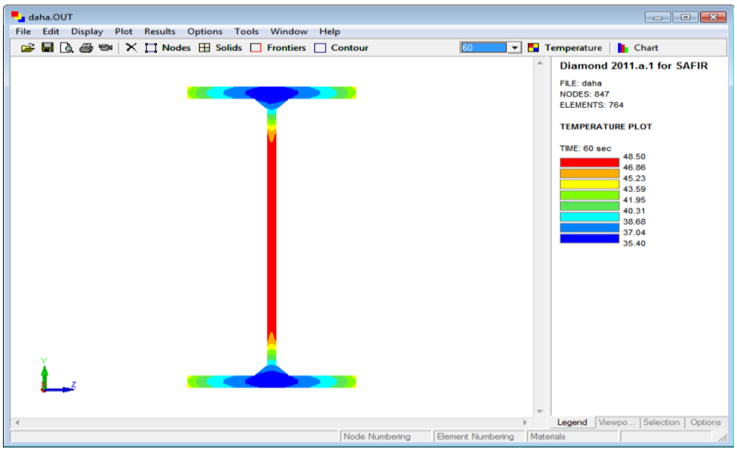


Figure1.1:Temperature Calibration at the First 60s For the SAFIR Software

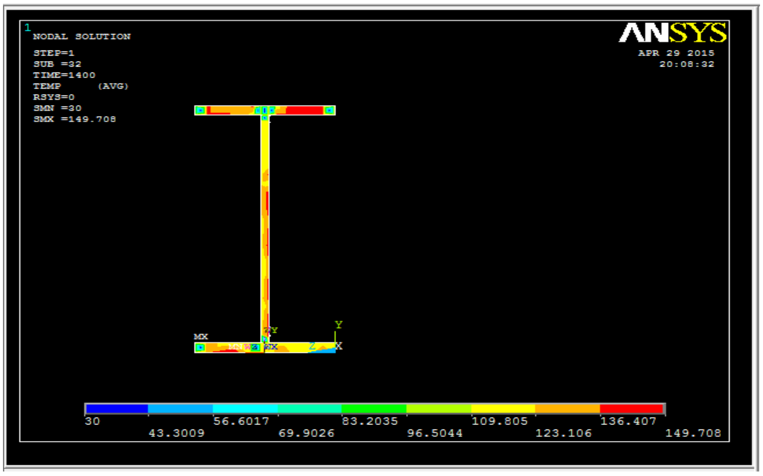
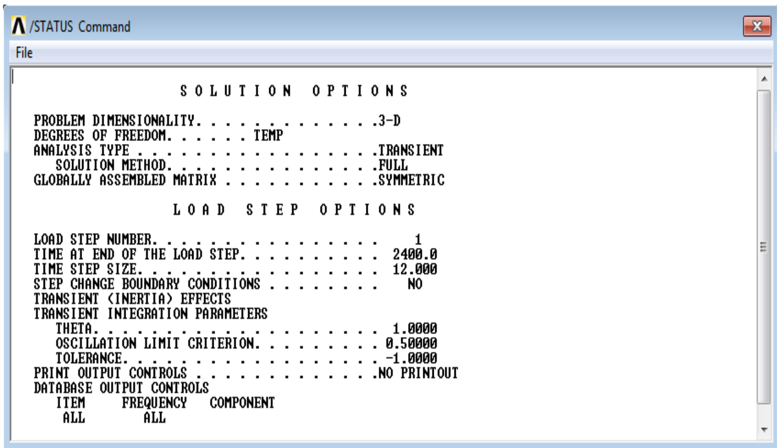


Figure 1.2:Temperature Calibration For the ANSYS Software



/STATUS Command

File

S O L U T I O N   O P T I O N S

PROBLEM DIMENSIONALITY. 3-D
DEGREES OF FREEDOM. . . . . . TEMP
ANALYSIS TYPE . . . . .TRANSIENT
SOLUTION METHOD. . . . . .FULL
GLOBALLY ASSEMBLED MATRIX . . . . .SYMMETRIC

L O A D   S T E P   O P T I O N S

LOAD STEP NUMBER. 1
TIME AT END OF THE LOAD STEP. 2400.0
TIME STEP SIZE. 12.000
STEP CHANGE BOUNDARY CONDITIONS . . . . NO
TRANSIENT (INERTIA) EFFECTS
TRANSIENT INTEGRATION PARAMETERS
THETA. 1.0000
OSCILLATION LIMIT CRITERION. 0.50000
TOLERANCE. . . . .-1.0000
PRINT OUTPUT CONTROLS . . . . .NO PRINTOUT
DATABASE OUTPUT CONTROLS
ITEM FREQUENCY COMPONENT
ALL ALL

Figure 1.3: Solution Option Command

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XI. TABULAR RESULT

Table 1.3:Comparison Between ISMB 200, ISLB 200 and ISLC 200 for SAFIR Software

MEMBER	TEMP AT 60second	TEMP AT 900second	TEMP AT 1200second	TEMP AT 2400second
ISMB 200	65.3	695.8	738.6	899.7
ISLB 200	68.6	703.3	740.7	880.2
ISLC 200	66.7	697.6	738.7	879.9

Table 1.4:Comparison Between ISMB 400, ISLB 400 and ISLC 400 for SAFIR Software

MEMBER	TEMP (°C) AT 60second	TEMP (°C) AT 900second	TEMP (°C) AT 1200second	TEMP (°C) AT 2400second
ISMB 400	50.8	671.4	728.3	876.4
ISLB 400	54.3	676.9	732.7	877.7
ISLC 400	54.3	676.8	732.6	877.6

Table 1.5:Comparison of Result Between SAFIR and ANSYS Software

MEMBER	SAFIR SOFTWARE TEMP VALUE (°C)			ANSYS SOFTWARE TEMP VALUE (°C)			DIFFERENCES TEMP VALUE (°C)		
	at 60s	At 900s	At 2400s	At 60s	At 900s	At 2400s	**At 60s**	**At 900s**	**At 2400s**
ISMB 200	65.3	695.8	879.7	121.1	983.0	922.3	**54.8**	**87.2**	**42.6**
ISLB 200	68.8	703.3	880.2	132.6	797.0	942.5	**63.8**	**93.7**	**62.3**

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ISLC 200	66.7	697.6	879.9	129.4	737.1	945.4	**62.7**	**95.5**	**65.5**
ISMB 400	50.8	671.4	876.4	96.4	768.5	777.5	**45.6**	**105.9**	**97.1**
ISLB 400	54.3	676.9	877.7	103.3	792.2	897.5	**48.0**	**115.3**	**19.8**
ISLC 400	54.3	676.8	877.6	98.4	770.2	785.7	**44.1**	**93.4**	**91.9**

Table 1.6:Comparisonof Result Between Manual Calculation and SAFIRSoftware

MEMBER	MANUAL CALCULATION TEMP VALUE (^oC)			SAFIR SOFTWARE TEMP VALUE (^oC)			DIFFERENCES TEMP VALUE (^oC)		
	At 60s	At 900s	At 2400s	At 60s	At 900s	At 2400s	**At 60s**	**At 900s**	**At 2400s**
ISMB 400	50.9	671.5	876.6	50.8	671.4	876.4	**0.1**	**0.1**	**0.2**

Table 1.7:Comparisonof Result Between Manual Calculation and ANSYS Software

MEMBER	MANUAL CALCULATION TEMP VALUE (^oC)			ANSYS SOFTWARE TEMP VALUE (^oC)			DIFFERENCES TEMP VALUE (^oC)		
	At 60s	At 900s	At 2400s	At 60s	At 900s	At 2400s	**At 60s**	**At 900s**	**At 2400s**
ISMB 400	50.9	671.5	876.6	96.4	768.5	777.5	**45.5**	**97.0**	**99.1**

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XII. GRAPHICAL RESULT

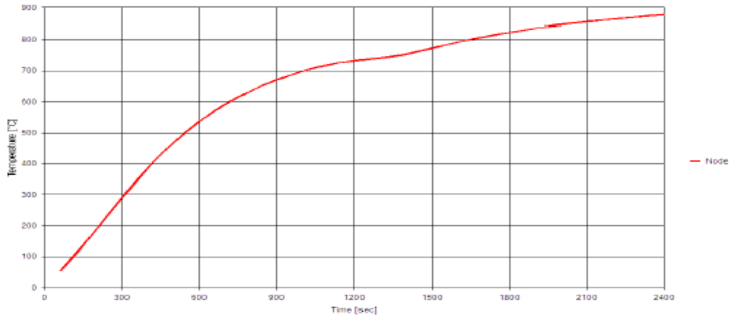

Figure 1.4: Graph of ISMB 400 Forthe SAFIR Software

The graph of temperature against time, at time 60second the temperature value is 50.8 ^{o}C and at 900second is 671.4 ^{o}C and at 2400second is 876.4 ^{o}C.

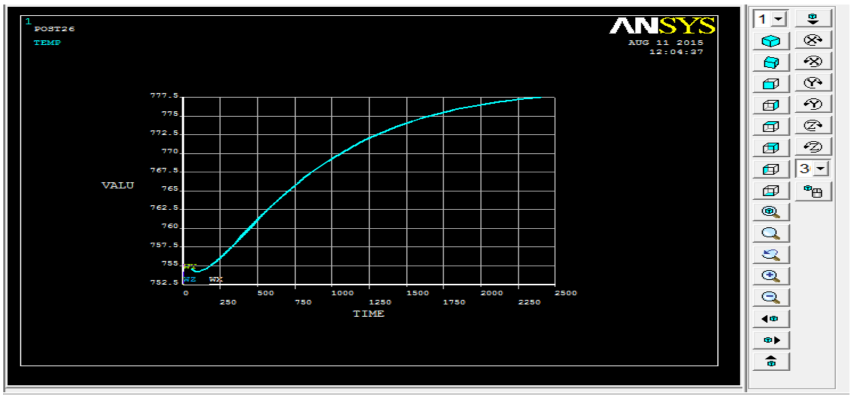

Figure 1.5: Graph of ISMB 400 for the ANSYS Software

XIII. CONCLUSION

- The result obtain from the ISMB 200, ISLB 200 and ISLC 200, It found that the ISMB 200 will resist temperature more than the ISLB 200 and ISLC 200 as it have the temperature value less at both 60second, 900second and 2400second.
- Again by considering ISMB 400, ISLB 400 and ISLC 400, It found that the ISMB 200 will resist temperature more than the ISLB 400 and ISLC 400 as it have the temperature value less at both 60second, 900second and 2400second.
- By considering ISMB 200 and ISMB 400, the ISMB 400 will resist temperature more than the ISMB 200 as it has the less temperature value at both time. This show that the more the size of the member the more it resist temperature.
- From the table of comparison between the two Software, the difference, the difference in temperature is very large, this shows that, the two software results differ.
- When taking the difference between manual calculation and both the two software, the difference between the manual calculation and SAFIR Software values are close to each other having ±0.2 as a differences. But

for the ANSYS Software having the difference of ±99.1. This shows that, the SAFIR Software is more accurate when considering fire analysis using software.

XIV. RECOMMENDATION

Both the ANSYS Software and SAFIR Software are used when analysis case on fire for both transient analysis and static analysis. But in considering transient analysis case, I recommend to go for SAFIR SOFTWARE, because it give more accurate result as discussed in conclusion.

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