

Structural Fire Analysis of Beams and Slabs Using ANSYS and FEAST Software Program

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Abstract

In recent years, building fire has become more frequent event and fire accidents have increased all over the world. Major problem with fire is it provides very less time to handle the situation and due to elevated temperature, reduction in strength of structural member with increase in fire exposure time has been observed. To evaluate this reduced strength of structural members and design for fire load, it is necessary to have the parameters such as fire load, fire exposure time and temperature variation across the structural members. In this paper, evaluation of fire load, equivalent time of exposure and temperature distribution of beams and slabs using finite element analysis software FEAST and ANSYS has been done. For temperature variation, transient heat thermal analysis, in which temperature is increasing continuously over the time, is used. For this analysis, beams and slabs are exposed to surface fire on different surfaces and the temperature distribution of cross section has been evaluated. The results are compared and found to be matching with the European Standard procedure.

Keywords: Fire load, Fire exposure time, calorific value, Transient Heat Thermal analysis.

1. Introduction

Recent trends suggest that fire accident has increased all over the world. Fire provides very less time to handle the situation and with fire, due to elevated temperature strength of structural member gets reduced with increase in fire exposure time. To calculate the reduced strength of structural members and design according to fire load, it is important to know the fire load, equivalent fire exposure time and temperature variation across the structural members with increase in time. Effect of fire on material properties and structural members are two important aspects for evaluating damage in the building. Studies by many researchers shows degradation of strength at higher temperature. Gadilohar and Kumar [1] considered a public building and fire load and fire exposure time in different compartment was calculated. Hadole and kumar [2], performed non-linear static pushover analysis to assess seismic behaviour of fire affected models. Author considered 44 different fire possibilities in order to find out worst fire scenario for building. To handle structural fire related issues different codes are available. McCann et al. [3] compared the reduction factors given in EN 1992- 1-2 with stress-strain behaviours of carbon steel determined from the normalised property of stress-strain behaviour at ambient temperature. Kodur V. et al [4] proposed a method in which empirical equation is used for the prediction of

rebar temperatures under a specified fire exposure. Kadhum M. [5] studied the effect of burning by fire flame on the behaviour and load carrying capacity of rectangular reinforced concrete (RC) rigid beams. Hager et al [6] presented effect of elevated temperature on physical properties of concrete and studied the colour change of concrete at various temperature ranges. Along with physical properties changes to mechanical properties were also discussed. Dahmani L. and Kouane M. [7] illustrated the principal aspects connected with the numerical evaluation of thermal stress induced by high gradient temperature in the concrete beam. Hsu and Lin [8] presented a simplified approach for the evaluation of the residual strength of RC beams subjected to fire. In this approach critical cross section is divided into a number of strips and along each strip temperature is calculated using finite difference method. Tan and Yao et al [9] presented simplified approach for predicting fire resistance of column subjected to different thermal boundary conditions and developed strength reduction factors for steel and concrete subjected to 1-face, 2-face, 3-face and 4-face heating by using SAFIR software tool.

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Arioz O. [10] studied the effect of high temperature ranging from 200°C to 1200°C on compressive strength of concrete with different types of aggregates and found significant reduction in compressive strength of concrete. Youssef M.A. et al [11] proposed stress-strain model of concrete incorporating effect of temperature. Jau and Hang et al [12] studied the effect of non-uniform fire on strength of reinforced concrete column subjected to 2 hour and 4 hour of fire exposure along with axial loading and biaxial bending. Rein G. et al [13] proposes a novel methodology to determine the design fire of modern buildings that are outside the range of applicability of nominal methods. Eurocode-1(EN 1991-1-2:2002) [14] and Eurocode-2(EN 1992-1-2:2004) [15] provides detailed procedure for assessment of fire affected members. Eurocode uses ISO: 834 curve (ISO, 1999a) [16] as a standard fire curve. National Building Code of India [17] provides simplified tables for different fire rating to safeguards structural elements. Extent of damage in structural members depends on combustible matter present in the compartment, rate of increment of temperature in the compartment, temperature variation in the structural elements across the cross section. Hence in this study estimation of fire load and temperature variation in structural members is done.

2. Problem description

In this paper a residential building is analysed, its fire load estimation and temperature variation of beams and slabs using FEAST and ANSYS software is done. The amount of combustibles, which are responsible for the heat flux in a compartment, is quantitatively known as fire load and its calculation procedure is described below:

2.1. Fire load estimation

A) Surveying Methods

The preliminary survey includes access to the building and listing out the contents along with their relevant characteristics.

The data survey methods are defined as below:

- Weighting Method – direct weighing method is utilized to obtain the mass and mass chart is prepared.
- Inventory method –the product of the calculated volume and standard density of the material gives the mass.
- Combination Method – mass is obtained by opting both weighing method and inventory method.
- Questionnaire method – mass is obtained from standard tabular data based on self-administered questionnaires.

The fire load in a compartment is defined as:

$$q_c = \sum m_v H_v \quad (1)$$

Where

q_c = fire load (MJ)

m_v = mass of object (kg)

H_v = object's calorific value (MJ/kg)

B) Fire Load Density

The total fire load density of a compartment is the ratio of fire load of combustible materials in that compartment to the floor area of that compartment. Total fire load density

includes fixed fire load density and moveable fire load density. In residential building use of room have major effect on fire load density. The quantitative measurement of fire load density for numerous combustible objects is done as follows:

$$Q_f = q_c / A_r \quad (2)$$

Where

Q_f = fire load density (MJ/m²)

q_c = fire load (MJ)

A_r = floor area of the room (m²).

C) Equivalent fire exposure time

The time taken to attain the maximum temperature in the compartment can be termed as equivalent time of fire exposure or the time equivalent.

The equivalent exposure time formula according to Eurocode is:

$$T_e = K_b \cdot K_c \cdot w \cdot Q_f \quad (3)$$

Where

T_e = exposure time (in minutes)

K_b = conversion factor

K_c = correction factor to account for different compartment linings

w = ventilation factor

Where ventilation factor (Guergah et.al, 2018) is given by:

$$W_f = \left(\frac{6}{H} \times 0.3 \right) \times \left(0.62 + \frac{90 \times (0.4 - \alpha_v) \times 4}{(1 + b_v \times \alpha_h)} \right) \quad (4)$$

α_v = A_v / A_f

α_h = A_h / A_f

b_v = $12.5 \times (1 + 10 \times \alpha_v - 2 \times \alpha_h)$ (5)

H = height of compartment

A_v = area of vertical opening in the facade

A_h = area of horizontal opening

A_f = floor area of the compartment

D) Maximum temperature in the compartment can be calculated from the following curves:

To calculate temperature in a compartment, different Time-Temperature curves are given in EN-1991-1-2 which are shown below:

- Standard temperature time curve
- External fire curve
- Hydrocarbon fire curve

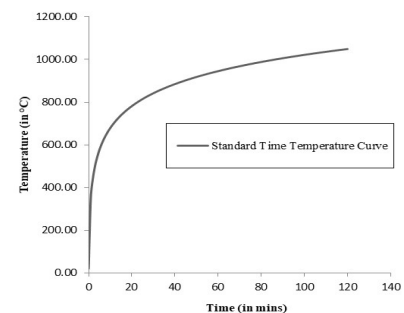


Fig 1. Standard Time Temperature Curve

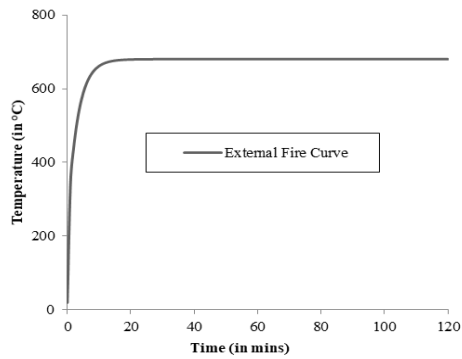


Fig 2. External Fire Curve

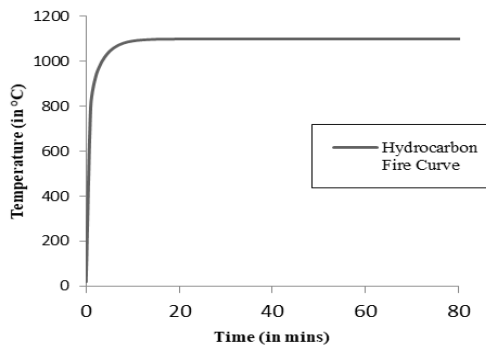


Fig 3. Hydrocarbon Fire Curve

3. Description of building

In this paper, a six storey (G+5) residential building is considered for fire assessment. The floor area of each storey is 108 m² and each storey consists of three bedrooms, a drawing room, a kitchen, a washroom, balconies, toilets, and entrance lobby. The building consists of rectangular columns and rectangular beam with different dimension and each storey height is 3.15m. The grade of concrete is M30 and grade of steel is Fe 415 is used for construction size of beam is 230x 400 and slab thickness is 200 mm.

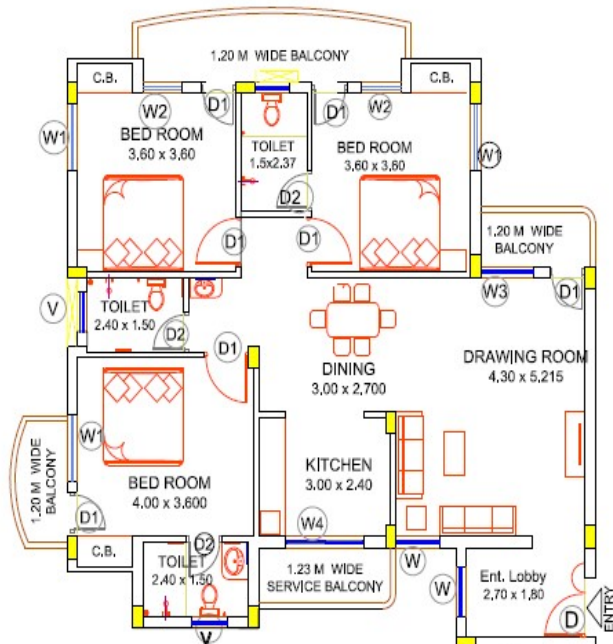


Fig 4. Detailed plan of surveyed residence

4. Software Analysis

Analysis of structural elements has been done using FEM software ANSYS and FEAST. In both the software, meshing size used is 40 mm. To find temperature variation, Transient thermal analysis. Beams are exposed to fire from three faces, while slabs are exposed from bottom. Fire loading is given according to standard temperature time curve.

Details of Modeling:

Size of beam = 230mm x 400 mm

Thickness of slab = 200 mm

Material properties of concrete used for the analysis:

As per euro code EN 1991-1-2:2002 curves are given for thermal properties of concrete with rise in temperature i.e. thermal conductivity, specific heat and density which are shown below:

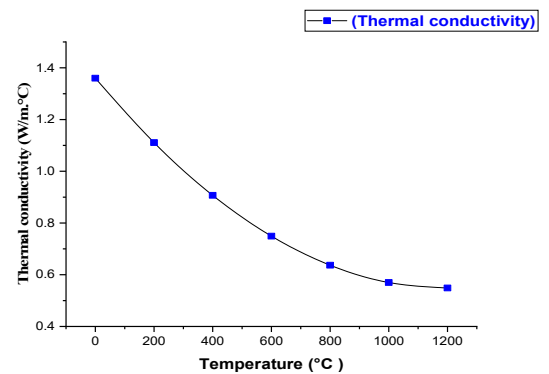


Fig 5: Variation of Thermal conductivity of concrete

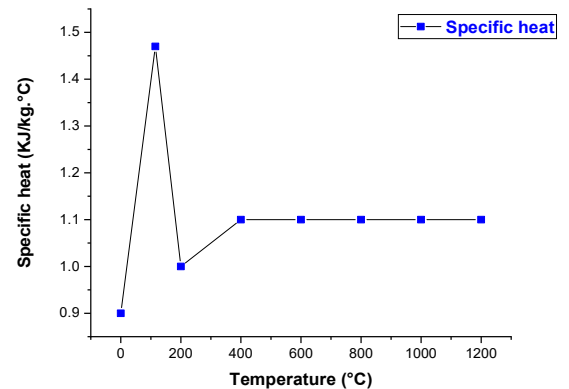


Fig 6: Variation of specific heat of concrete

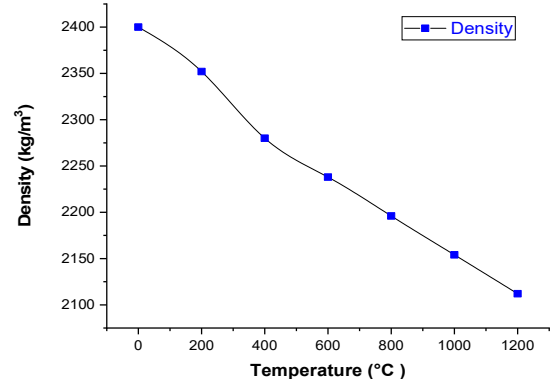


Fig 7: Variation of Density of concrete

Modelling in FEAST software

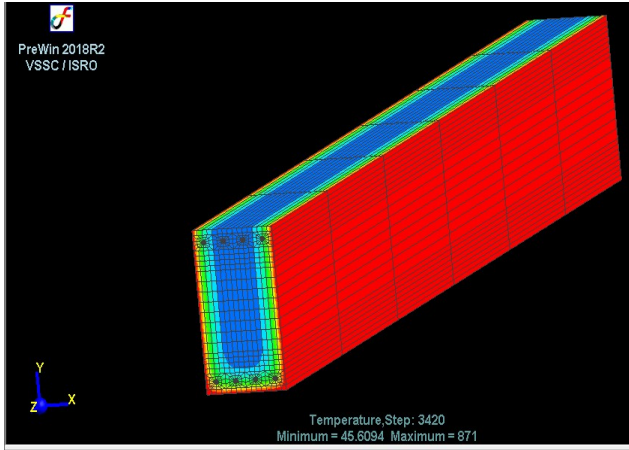


Fig 8 (a) -Model of beam in FEAST.

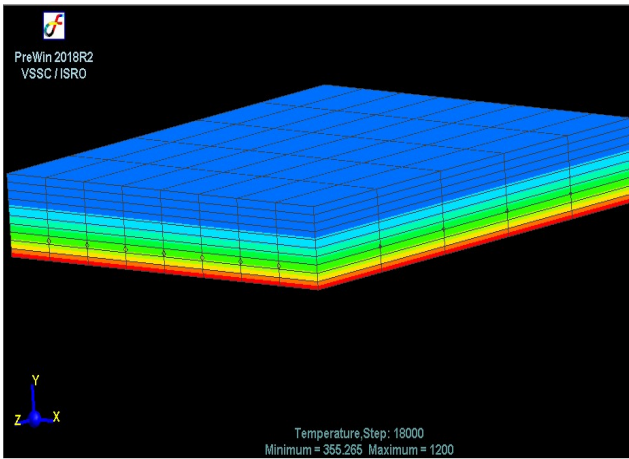


Fig 8 (b) -Model of slab in FEAST.

Modelling in ANSYS software

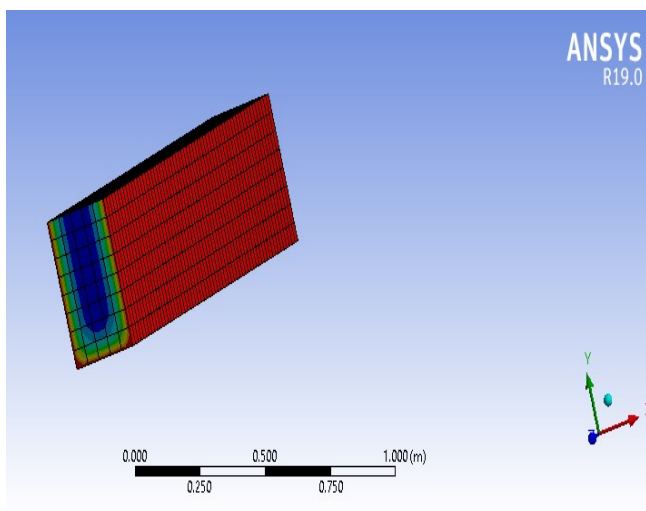


Fig. 9(a) Model of beam in ANSYS.

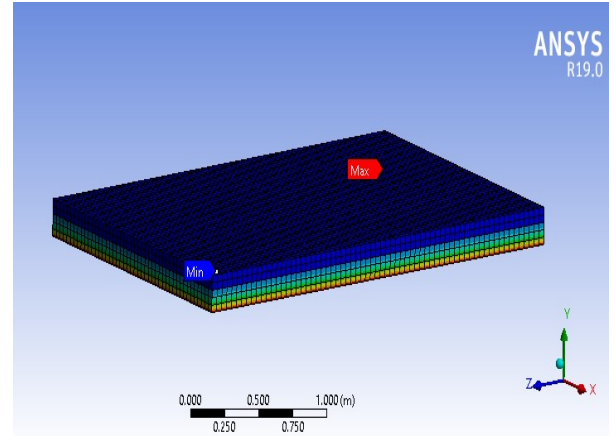


Fig. 9(b) Model of slab in ANSYS.

5. Results and discussion

The floor area of each storey is 108 m². Each storey consisting of three bedrooms, a kitchen, a drawing room, a dining room, balconies, a wash area and bathrooms is surveyed and a summary of floor area Fire load and Fire load Density with ventilation factor is calculated and shown in table

The maximum value of Fire Load Density (1030.92 MJ/m²) is obtained in Kitchen.

Maximum temperature rise in the various rooms of the considered building has been calculated using Parametric Fire Curve Equations (EN 1991-1-2:2002)

Table 1. Fire load estimation of various compartments of building.

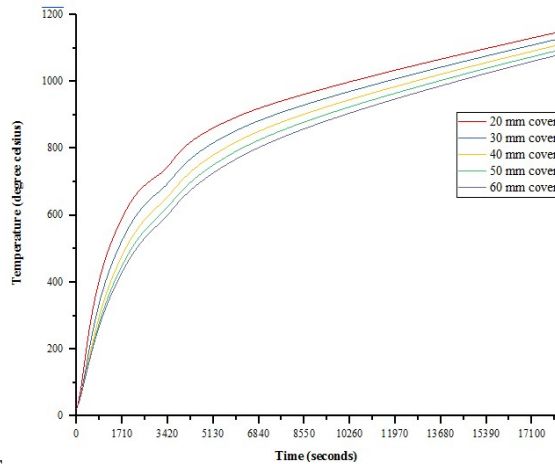
Compartment	Fire load (MJ)	Fire Load Density (MJ/m ²)	Floor area (m ²)	Ventilation factor (Wf)
Bed room 1	8648.20	667.30	12.96	0.85
Bed room 2	8256.20	573.35	14.40	1.38
Bed room 3	8648.20	667.30	12.96	0.85
Bathroom 1	1504.00	417.78	3.55	1.66
Bathroom 2	1504.00	417.78	3.60	1.66
Bathroom 2	1504.00	423.07	3.60	1.65
Kitchen	7422.60	1030.92	7.20	0.79
Dining room	2667.40	329.31	8.10	0.94
Drawing room	6658.50	296.93	22.42	1.33
Balcony 1	1071.60	357.20	3.00	0.81
Balcony 2	1071.60	335.71	3.19	0.86
Balcony 3	1071.60	297.67	3.60	0.76
Balcony 4	1071.60	146.39	7.32	0.77

Table 2. Estimation of gas temperature and equivalent time of different compartments.

SL.NO.	Compartment	Equivalent fire exposure time (min)	Tmax (°C)
1	Bed Room 1	39.55	883
2	Bed Room 2	55.49	933
3	Bed Room 3	39.55	883
4	Bathroom 1	48.57	913
5	Bathroom 2	48.57	913
6	Bathroom 3	48.74	914
7	Kitchen	57.04	937
8	Dining Room	21.68	793
9	Drawing Room	27.67	829
10	Balcony 1	20.15	782
11	Balcony 2	20.16	782
12	Balcony 3	15.92	747
13	Balcony 4	7.85	642
14	Entry Lobby	8.90	661

Finite element analysis results

Graph between time and temperature is plotted from the results obtained from analysis by FEAST and ANSYS software for different cover



sizes

Fig 10(a). Temperature variation of Rebar of beams in FEAST software

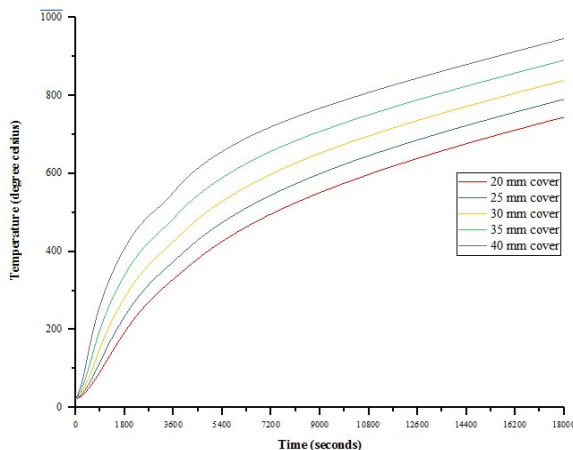


Fig 10(b). Temperature variation of Rebar of slabs in FEAST software

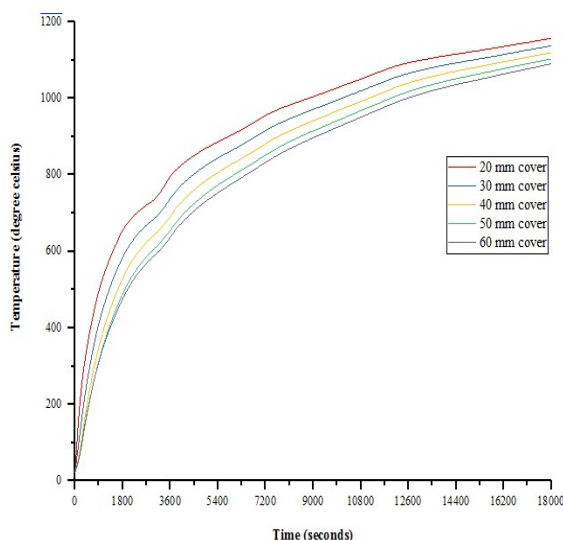


Fig 11 (a). Temperature variation of Rebar of beam in ANSYS software

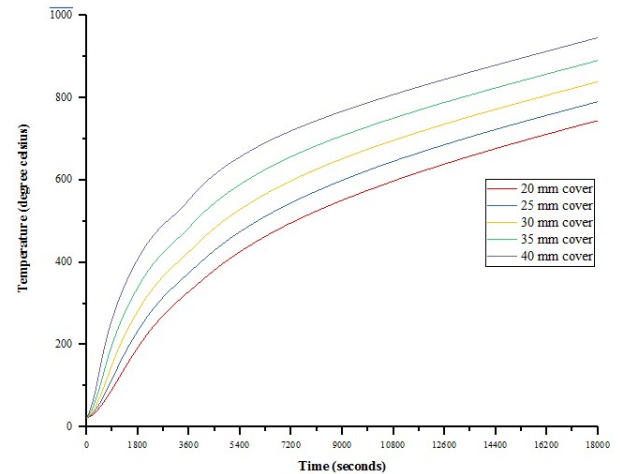


Fig 11. Temperature variation of Rebar of slab in ANSYS software

Conclusion

Fire accidents can result in damage as well as collapse of structure. Hence, proper assessment of fire safety shall be done for determining amount of damage and chances of collapse. In this paper, for case study, G+5 storey building has been considered and its realistic fire load is calculated. Calculation of realistic fire load indicated that temperature in different rooms/compartments can vary from 700°C to 950°C under an isolated fire event. It was observed that maximum temperature that can be reached is 937 °C in kitchen and its equivalent time of exposure was found to be 57 minutes.

Finite element analysis of beam and slabs for temperature distribution across the cross section is done using FEM software FEAST and ANSYS. By this temperature distribution rebar temperature can be determined for different equivalent fire exposure time. In this case as maximum equivalent fire exposure time was 57 minutes in kitchen and temperature results by FEAST software observed at cover size, 20mm is 745 °C for beam and 537°C for slabs. Rebar temperature observed by ANSYS software at cover size 20 mm is 775°C for beam and 543°C for slabs. European code (EN 1991-1-2:2002) results for 20 mm cover size for 57 minutes is 740°C and 520°C for beam and slab respectively. Hence it can be concluded that software results are in good agreement with European code results. As the cover size increasing, temperature at rebar is decreasing. These results can be used to determine fire ratings and reduction of strength of structural members. This simplified procedure can be applied to various buildings for assessing the behaviour under fire event.

Disclosures

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