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Application of EN 1991-1-2 Annex E, using's software package

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Abstract. The fire may occur anywhere and in any phase in the lifetime of a building. Fire resistance requirements should be based on the parameters influencing fire growth and development. For calculating the characteristic fire load, the characteristic fire load has to be determined using the table of EN 1991-1-2 Annex E. The aim of this paper is to present the methodology used in this tool and to show an example of application. The fire resistance of a steel beam submitted to compartment fires which supports a non-collaborating concrete slab in a compartment is estimated in case of an unprotected and a protected steel section. It will be possible, having this gas temperature, to calculate the temperature of a steel profile. Different results can be extracted from the software. The software package that will be used to perform this calculation is Ozone V2. Ozone V2 has been developed as a practical design tool to realize a performance based analysis of the behavior of simple steel elements in a compartment fire situation.

The figures provided for the input data by the graphic interface are indicative values. They can be modified by the user who has full responsibility for the choice of these input data. A combination of a two and a one zone model is included. The criteria of transition offers to the user an automatic decision procedure to know whether a two or a one zone model is appropriated to the fire stage which is model.

Keywords: Compartment fire, Zone model, Fire resistance of a steel, Software package

1. Introduction

Annex E presents a method for calculating design fire load densities based on characteristic values from survey data for different occupancies. The characteristic values are modified according to the risk of fire initiation the consequence of failure related to occupancy and compartment floor area. Active fire safety measures are taken into account through a reduction in the design fire density.

In order to use EN 1991-1-2 Annex E it is necessary to have different information about the building: Size of the compartment, boundary properties, ceiling height, opening area, fire surface.

When simulating numerically the fire development, different simplifications of the fire dynamics can be made. The fire resistance of a steel beam submitted to compartment fires which supports a non collaborating concrete slab in a compartment is estimated in case of an unprotected and a protected steel section. The software package that will be used to perform this calculation is Ozone V2.

2. Zone models

Zone models are numerical tools commonly used for the evaluation of the temperature development of the gases within a compartment during the course of a fire. Based on a limited number of hypotheses, they are easy to use and provide a good evaluation of the situation provided they are used within their real field of application. Zone method, developed in Denmark, and included in EN 1992-1-2. Since the first numerical one zone models have been made by Petersson, major developments of the numerical fire modelling have been done. Among other things, multi-zones, multi-compartment and computational field dynamics models have been developed. Although zone models are the less

sophisticated numerical fire model, they have their own field of application and thus are essential tool in fire safety engineering applications.

In the scope of the ECSC projects NFSC 1 & 2 [2], [3] the two-zone model OZone, has been developed at University of Liège together with PROFILARBED-Research and has been validated, taking as reference the results of 54 experimental tests.

3. Two-zone models

Zone model is the name given to numerical programs which calculate the development of the temperature of the gases as a function of time, integrating the ordinary differential equations which express the conservation of mass and the conservation of energy for each zone of the compartment. They are based on the fundamental hypothesis that the temperature is uniform in each zone.

The data which have to be provided to a zone model are:

- geometrical data, such as the dimensions of the compartment, the openings and the partitions;
- material properties of the walls;
- fire data, as RHR curve, pyrolysis rate, combustion heat of fuel.

3.1 One- zone model

The one-zone model is based on the fundamental hypothesis that, during the fire, the gas temperature is uniform in the compartment. One-zone models are valid for post-flashover conditions.

The data have to be supplied with a higher degree of detail than for the parametric curves and are the same, as those required for a two-zone model.

Figure 1. shows how a compartment fire is modelled, with different terms of the energy and mass balance represented.

4. Criteria of transition from two to one zone model and/or of modification of the input of energy

The criteria of the transition from two to one zone and/or of modification of the fire source model.

- Criterion 1 (C1) : $T_U > T_{FL}$

High temperature of the upper layer gases, composed of combustion products and entrained air, leads to a flashover. All the fuel in the compartment is ignited by

radiative flux from the upper layer. The flashover temperature (T_{FL}) is set to 500°C.

- Criterion 2 (C2) : $Z_s < Z_q$ and $T_z > T_{ignition}$

If the gases in contact with the fuel have a higher temperature than the ignition temperature of fuel ($T_{ignition}$), the propagation of fire to all the combustible of the compartment will occur by convective ignition. The gases in contact (at temperature T_z) can either belong to the lower layer of a two zone, the upper layer (if the decrease of the interface height (Z_s) leads to put combustible in the smoke layer - Z_q is the maximum height of the combustible material) or the unique zone of one zone models. $T_{ignition}$ is assumed to be 300°C.

- Criterion 3 (C3) : $Z_s < 0.2 H$

The interface height goes down and leads to a very small lower layer thickness, which is not representative of two zone phenomenon.

- Criterion 4 (C4) : $A_{fi} > 0.25 A_f$

The fire area is too high compared to the floor surface of the compartment to consider a localised fire.

Criteria 1 or 2 lead necessarily to a modification of the rate of heat release. If the fire load is localised the simulation will continue using a 2ZM and if the fire load is uniformly distributed, a 1ZM will be considered. If one of the criteria C3 or C4 is fulfilled, the code will switch to a one zone model but the RHR will not be modified, except if criterion C1 or C2 happens simultaneously.

5. Worked example

The fire resistance of a steel beam which support a concrete slab (without composite action) in compartment is estimate in case of an unprotected and a protected steel section (fig.1)

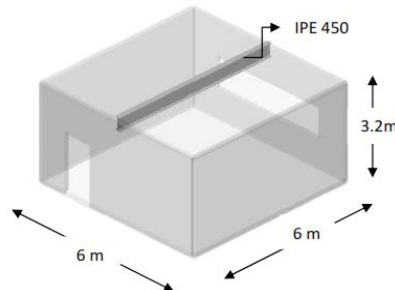


Fig.1. Schematic view of the compartment.

The data are:

- The compartment is used as a library;
- The square floor is 6 m on 6 m wide. The height is 3.2 m (inner dimension);
- All partitions are made of normal weight concrete (unit mass: 2300 kg/m³; Conductivity: 2W/mK; specific heat: 1000J/kgK) and are 15 cm thick;
- There are two openings, one door (width: 1 m; height: 2 m) in first wall and one window (sill at 1m; soffit at 2m; width: 4 m) in the third wall. Both openings are supposed to be opened from the beginning of the fire;
- The beam is an IPE450. Steel S355;
- The beam is simply supported from the middle of wall one to the middle of wall three and the load is uniformly distributed;
- The design bending moment at mid span in the fire situation is 120 kNm;
- The protection material is sprayed vermiculite (unit mass: 350 kg/m³; conductivity: 0.12W/mK; specific heat: 1200J/kgK).

Step 1: Define the compartment: The compartment is defined: internal dimensions, openings positions and sizes and partitions characteristics.

Step 2: Define the design fire: The suggested value of the NFSC method [4,5] for a library are:

- Fire load uniformly distributed with a characteristic value $q_{f,k} = 1824 \text{ MJ/m}^2$;
- $H = 17.5 \text{ MJ/kg}$; $m = 0.8$;
- The fire growth rate is fast (1 MW is released by the fire after 150 s);
- The maximum rate of heat release density is 500 kW/m^2 ;
- The partial safety factor which consider the benefits of the automatic fire detection by heat is $\gamma = 0.87$;
- The partial safety factor which consider the benefits of off site fire brigade is $\gamma = 0.78$;
- The fire risk area is equal to 36 m^2 thus $\gamma = 1.12$;
- The danger of fire activation is medium thus $\gamma_{q,1} = 1$;
- The design fire load density is then: $q_{q,2} = 1069.1 \text{ MJ/m}^2$.

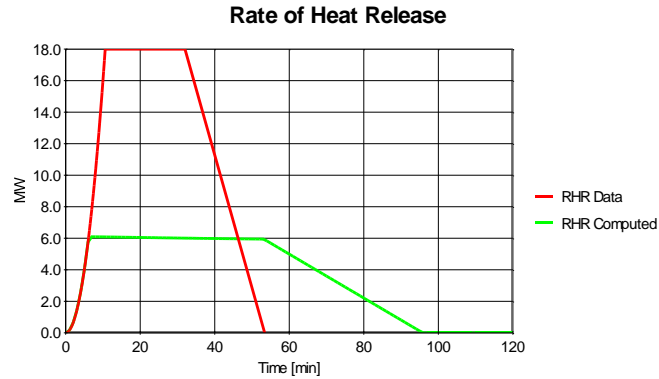


Fig.2. Input and calculated rate of heat release.

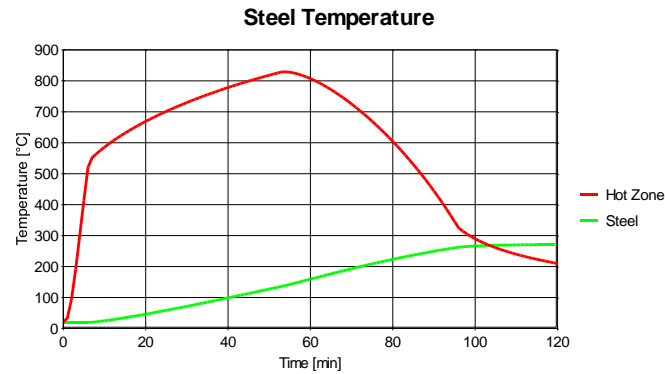


Fig.3. Calculated compartment temperatures

Step 3: Run the compartment fire model: The main output are the rate of heat release curve calculated (Fig. 3), the hot zone temperature and the cold zone temperature (Fig.4).

Step 4: Calculate the steel temperature: The steel temperature is evaluated for the unprotected and protected section (Fig. 5).

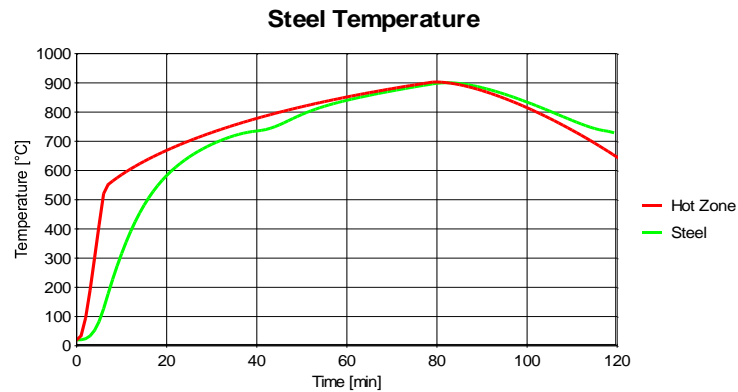


Fig.4. Calculated compartment temperatures

Step 5: Calculate the member resistance: Thanks to EN 1993-1-2, it will be possible, having the gas temperature, to calculate the temperature of an unprotected steel profile. The fire resistance of the unprotected steel section IPE450 is 36.63min. while for protected steel section IPE450 is 120 min.[6]

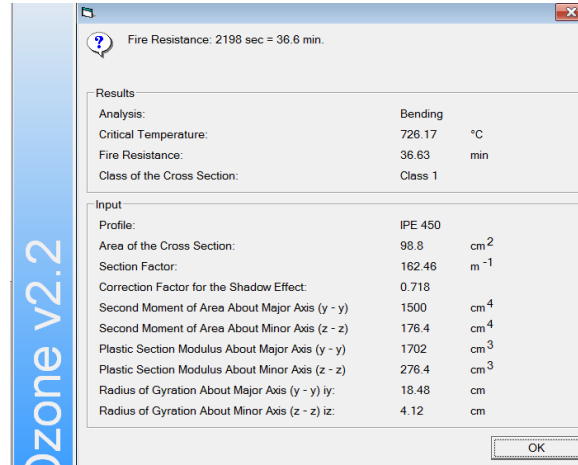


Fig.5. Calculate the fire resistance of the unprotected steel section IPE450

Conclusions

The figures provided for the input data by the graphic interface are indicative values. They can be modified by the user who has full responsibility for the choice of these input data. A combination of a two and a one zone model is included. The criteria of transition offers to the user an automatic decision procedure to know whether a two or a one zone model is appropriated to the fire stage which is model.

In order to introduce glazing surface into the OZone software, openings must be added to the façade and a “stepwise” variation must be chosen. With this “stepwise” variation, it is possible to define a scenario of opening depending on the temperature.

The heating up of a structural element depends on the type of element (e.g. pure steel or composite steel/concrete) and of the nature and amount of fire protection.

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