

Evaluation of support steel at elevated temperatures

M.L.Conner & P.J.Carrato

Bechtel Eastern Power Corporation, Gaithersburg, Md., USA

M.Giangrasso

ENEA-DISP, Roma, Italy

1 INTRODUCTION

At temperatures up to 925°C (1700°F), steel members can temporarily support loads due to redistribution of stresses through plastic action. Building steel is normally fire protected; this paper, however, addresses steel which supports pipe, cable tray, conduit or other light structures which may not be protected from a fire. In determining the effect of a fire of 925°C (1700°F), several factors must be considered:

1. Duration of the fire
2. Proximity of the steel to the fire
3. Characteristics of steel at elevated temperature
4. Configuration of the structure
5. Functionality requirements of components supported by the structure.

The performance of a structure subjected to temperatures above 925°C (1700°F) is determined by the interrelation of these factors. For example, an applied load affects a structure's response to elevated temperature. Material properties are altered during an increase in temperature. Also of importance is the time required for the supported component to perform its safety related function after the out-break of a fire.

ASTM E-119 (American Society of Testing and Materials, Fire Tests of Building Construction and Materials) provides a standard curve of eight hours duration for applying a fire load to structural steel. This curve is slightly less conservative than the Italian standard curve. The ASTM E-119 and Italian standard curves are shown in Figure 1. The Italian curve is more conservative by approximately 75°C (167°F) at higher temperatures. This study assumes that the postulated fire, represented by the ASTM E-119 (Reference 1) standard curve, is uncontrolled for one hour producing a maximum temperature of 925°C (1700°F).

The most accurate method of determining fire intensity for a specific room or compartment is to simulate a fire based upon the available combustible materials and ventilation in the area. A specific analysis will determine both the duration and ultimate temperature produced for the specific fire. However, the ASTM E-119 standard fire, which conservatively increases rapidly to 925°C (1700°F) in one hour, is chosen as the design fire since it has been accepted on a limited basis by the United States Nuclear Regulatory Commission. If the ASTM E-119 standard curve is used, the amount of combustibles which will vary throughout a nuclear plant is not considered.

2 DISCUSSION OF TIME-DEPENDENT CHARACTERISTICS

Thermal load alters the material properties of steel members. The modulus of elasticity and yield strength decrease rapidly at temperatures approaching 925°C (1700°F), and changes in the micro-structure of the metal can result in material creep which may control the response. Failure can occur as a result of creep-rupture of the material at temperatures approaching 925°C (1700°F).

Carefully controlled experiments are used to establish creep-rupture characteristics. In many cases, operating plant conditions may differ from the laboratory conditions employed to perform thermal load tests thus limiting the application of some test data. A controlled environment, which limited or eliminated the amount of oxygen in the test chamber, is used for most tests. Thus, oxidation of the material, which can accelerate the time to failure, must also be considered for evaluating actual plant conditions.

3 STRUCTURAL EVALUATION

When structural steel systems experience sufficient reduction in yield strength due to increased temperature load, plastic hinges form. In cantilever structures, this unrestrained deflection results in collapse of the member. In certain structures such as a trapeze-shaped support, formation of plastic hinges do not result in collapse since load on the cross member is resisted by catenary action. Test results produced master rupture curves (Larson 1952) which relate time, temperature, and stress to ultimate strength. These curves were employed to determine structural steel behavior at temperatures approaching 925°C (1700°F). Larson and Miller, in Larson 1952, provide the relationship between time and temperature as follows:

$$(1) \quad T (C + \log t) = \text{constant}$$

where: T = Absolute Temperature ($^{\circ}\text{R}$)
 t = Time in hours to rupture
 C = 20.0

Figure 2 (Larson 1952) is the master rupture curve for low-carbon steel similar to steel used to support components such as cable tray, piping, etc. The "constant" is determined from the equation above, and the ultimate steel strength is found from Figure 2.

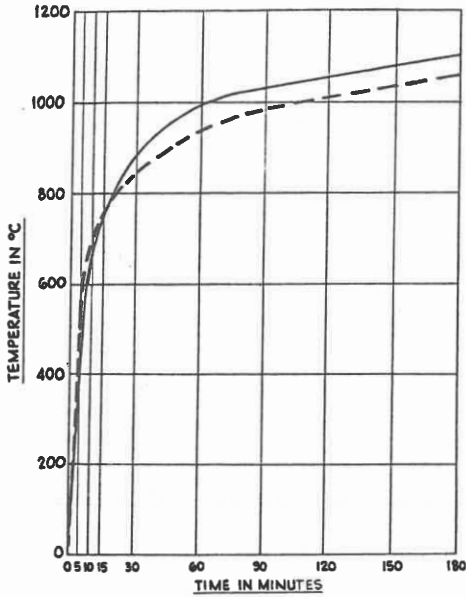
The following is an example of an ultimate strength determination.

A trapeze type support, Figure 3, for cable tray which must function for 60 minutes after a fire starts (cable is assumed to be protected from the fire) is to be evaluated.

The critical stress on the support is calculated to be 1.0 ksi (71 kg/cm²). This example assumes a critical creep rupture condition may result at the end of 45 minutes. From the ASTM E-119 curve, the maximum temperature at the end of 45 minutes is 892°C (1638°F). The appropriate constant is calculated from equation (1) as follows:

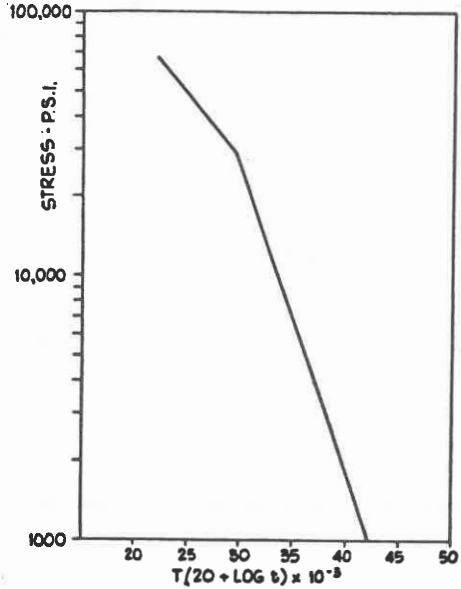
$$\begin{aligned} t &= 15 \text{ minutes} = (60-45)/60 \text{ hours} \\ T &= 1638 + 460 = 2098^{\circ}\text{R} \\ C &= 20.0 \\ \text{Constant} &= 40 \times 10^3 \end{aligned}$$

With this constant, enter Figure 2 and read a rupture stress of 2.0 ksi (141 kg/cm²). Since the rupture stress exhibits a significant

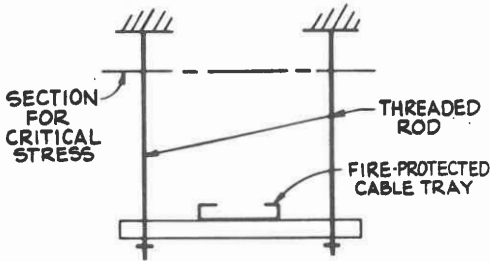


TIME - TEMPERATURE CURVE
FIGURE 1

LINE CODE
 --- ASTM E119 STANDARD CURVE
 ——— ITALIAN STANDARD CURVE FOR N.P.P.



MASTER RUPTURE CURVE FOR LOW CARBON STEEL
FIGURE 2



TYPICAL CABLE TRAY SUPPORT

FIGURE 3

margin over the actual stress (i.e. $2.0/1.0 = 2.0$) the support is structurally acceptable for the 60 minute period required for the cables to perform their safety-related function.

The approach presented contains additional conservatism in that it assumes the temperature of the steel exactly follows the E-119 curve. Thus, the time required to thoroughly heat the steel is ignored in calculating the constant of equation (1). In an actual application of the method, numerous time-temperature-stress relationships would have to be evaluated, in order to ensure the most conservative case has been checked.

4 CONCLUSIONS

Using available test data, the time-dependent response of unprotected structural steel to temperatures approaching 925°C (1700°F) is examined. Considering the effects of creep, creep-rupture, structural configuration, and oxidation, steel support members are evaluated to determine resistance to a standard ASTM E-119 fire of one hour. Unprotected structural steel subjected to light loads (2-4 ksi) typical of cable tray and conduit supports, depending on the support configuration, can resist a standard fire for a limited time without loss of functionality.

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