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SIMPLIFIED CALCULATION OF FLEXURAL STRENGTH DETERIORATION OF REINFORCED CONCRETE T-BEAMS EXPOSED TO ISO 834 STANDARD FIRE

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Abstract

Reinforced concrete (RC) T-shaped cross-section beam (so-called T-beam) is a common structural member in buildings where beams and slabs are monolithically cast together. In this paper, a simplified calculation method based on Russian design standard SP 468.1325800.2019 is introduced to determine the flexural strength of RC T-beams when exposed to ISO 834 standard fire. The idea of 500 °C isotherm method, which is stipulated in both Eurocodes (EC2-1.2) and SP 468, is applied associated with specifications of temperature distribution on T-beams' cross sections and the temperature-dependent mechanical properties of concrete and reinforcing steel. A case study is conducted to explicitly calculate the flexural strength deterioration (FSD) of T-beams compared to that at ambient temperature. A calculation sheet is established for parametric studies, from which the results show that the FSD factor of RC T-beams is adversely proportional to the dimensions of the beam's web and flange. However, the effect of these components of T-beams is not significant.

Keywords: beam; reinforced concrete; T-shaped; flexural strength; standard fire.

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1. Introduction

In buildings' structural system, beams are horizontal members carrying gravity loads from slabs and transferring to other vertical members such as columns and walls via flexural mechanism. In reinforced concrete (RC) construction, it is common that slabs are monolithically cast together with beams to form up T-shaped cross-sections, of which the slab and the beam are the flange and the web, respectively (Fig. 1). This type of assemblage can be referred to as T-section beams, so-called T-beams [1–3]. In this paper, the interior T-beams with slabs as flanges on both sides will be considered.

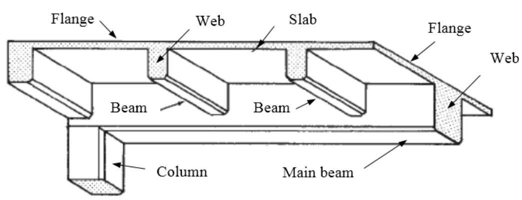

Figure 1. T-beams in cast-in-place RC structures [1]

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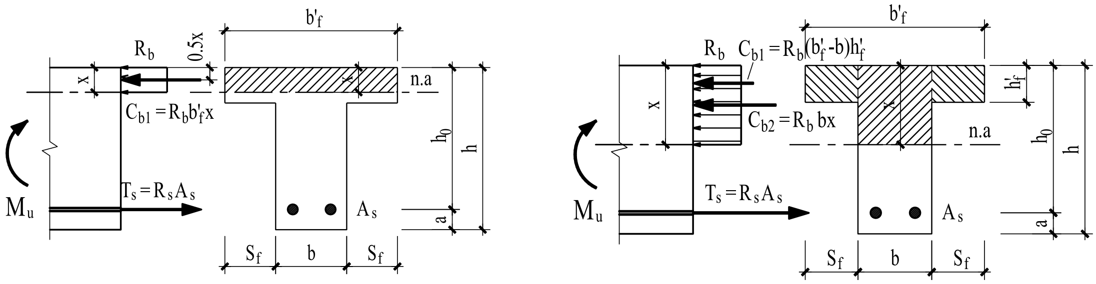
At ambient condition, RC beams are designed to resist bending moment on normal sections and shear force on inclined sections [1–3]. In particularly, the flexural strength of RC beams can be calculated by the resultant forces T_s and C_b of the tensile stresses in main longitudinal reinforcing bars (rebars) within tension zone and of the compressive stresses in concrete compression zone, respectively. It can be shown in Fig. 2 that at Ultimate Limit States (ULS), the terms T_s and C_b and then the flexural strength M_u are all dependent on the materials' design strengths at ambient condition, which are respective R_s and R_b for reinforcement and concrete, as well as on the other geometric properties of the beam cross-section [3].



(a) Neutral axis in flange

(b) Neutral axis in web

Figure 2. Analysis of flexural strength of T-beams at ambient condition [1–3]

When subjected to fire, both concrete and reinforcement experience significant reduction in mechanical properties, leading to the deterioration of the beam's flexural strength. The resistance of RC members can be generally established using simplified calculation methods with a limited scope in modern design codes [4–6]. In Vietnam, the national building code for fire safety QCVN 06:2021/BXD [7] only specifies regulations for fire resistance level of RC structural members in terms of minimum cross-section size and the thickness of concrete cover, whereas there is no detailed design provision for rational calculation of structures in fire [8]. In the world, structural fire engineering on RC beams has attracted researchers' interest for years [9–13]. A number of related research works for column, beam and slab have been published recently in Vietnam [14–19], among which the flexural strength deterioration (FSD) of rectangular RC beams was investigated using simplified calculation and finite element methods [18, 19]. However, there have been still limited research outcomes for RC T-beams due to the lack of information of temperature distribution within T-beam cross-section at elevated temperatures. This fact motivates the authors to determine the FSD of RC T-beams under ISO 834 fire exposure [20] using specifications in Russian design standard SP 468 [6]. Temperature-dependent mechanical properties of concrete and reinforcing steel and simplified calculation based on the idea of 500 °C isotherm method are introduced and illustrated by a case study. A Microsoft Excel spreadsheet is established to investigate the effect of the flange dimensions on the FSD factor. It is shown that the FSD factor of RC T-beams is adversely proportional to the web and flange dimensions. However, the effect of these components of T-beams is not significant.

2. Temperature distribution in RC beams' cross-section under ISO 384 fire

2.1. ISO 834 fire exposure

The standard ISO 834 fire exposure [20] has been commonly used to determine temperature distribution in the cross-section of structural components in European countries. In this standard fire exposure, the temperature-time relationship is expressed as follows:

$$T_g = 20 + 345\log_{10}(480t + 1) \tag{1}$$

where T_g (°C) is the temperatures and t is the in-hour time counted from the fire starts.

It is noteworthy that there is also another popular standard fire exposure, namely, ASTM E119 [21], which has been traditionally used for long time in the North America countries. The formula of this standard fire curve is shown below:

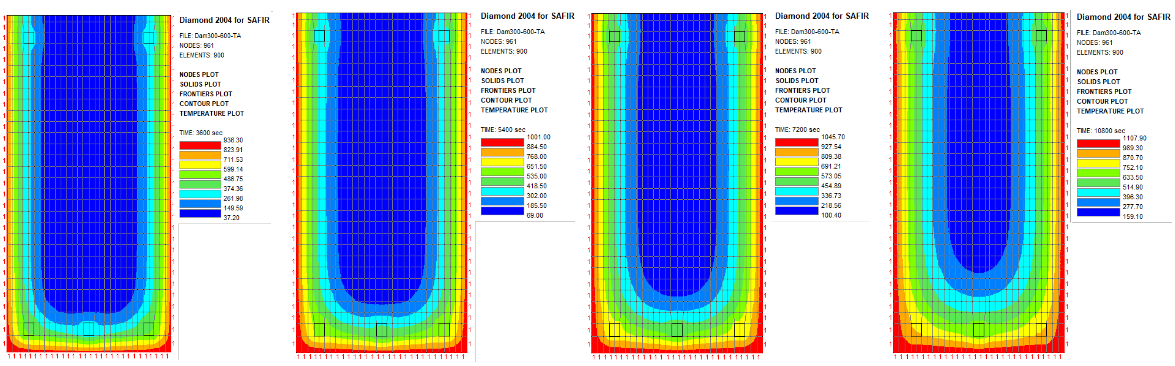
$$T_g = 20 + 750\left(1 - e^{-3.79553\sqrt{t}}\right) + 170.41\sqrt{t} \tag{2}$$

Although the fire curves following ISO 834 [20] and ASTM E119 [21] are quite similar, the standard fire exposure ISO 834 [20] is used in this research work since it is adopted in the Eurocodes as well as Russian design standard.

2.2. Temperature distribution within rectangular beams' cross-section

In fire tests and real situation, beams are usually heated from beneath, meaning that there are three sides of the beam exposed to fire. When there is ISO 834 fire, it can be assumed that at a certain time t of the fire exposure, temperatures at all the points on those three surfaces of the beams can be determined following Eq. (1). Then, temperatures of different points within the beam's cross-section can be determined by heat balance analysis, so-called thermal analysis. Those temperatures are lower than the gas temperature since it takes time for the heat transfer process to take place. In RC members, thermal analysis can be conducted based on materials' thermal properties and heat transfer methods such as radiation, convection, and conduction. Compared to structural steel, concrete has much better fire-resistant properties, such as lower thermal conductivity and greater specific heat capacity. It is also assumed that for simplification, the effect of rebars in concrete is ignorable, i.e. the temperature in a rebar is equal to that of its surrounding concrete.

An example of temperature distribution on rectangular RC beam obtained from Finite Element Software SAFIR [10] is shown in Fig. 3. It can be observed that: (i) At a certain fire exposure time, the inner points of the beam's cross-section are cooler than the outer points; (ii) The points having similar temperature form up the so-called isotherm contours; and (iii) As the time goes by, the hotter temperature contours move inwards to the core of the cross-section.



(a) At 60 min (b) At 90 min (c) At 120 min (d) At 180 min

Figure 3. Example of temperature distribution on rectangular RC beams

Tempreature distributions at a certain time of stadard fire exposure on a number of typical beam cross-section are given in the Eurocodes and Russian design standard.

Fig. 4 illustrates the tempreature distributions at 60, 90 and 120 min (which is respectively noted as R60, R90 and R120) of a quarter of RC beam having rectangular cross-section of $b \times h = 300 \times 600$ (mm), that is given from Appendix A of EC2-1.2 [5].

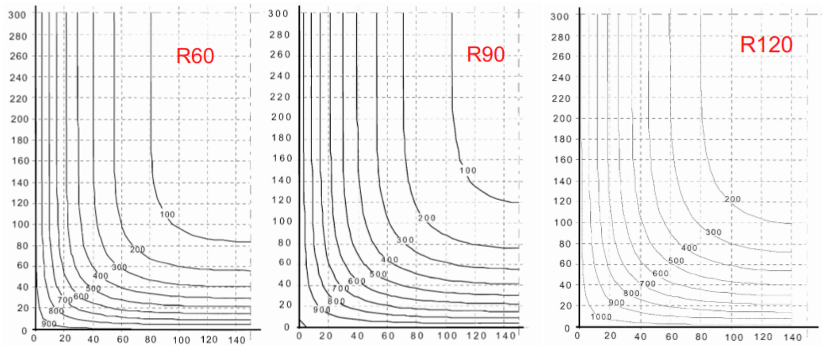


Figure 4. Temperature distribution on a quarter of rectangular beams to EC2

The temperature distributions at 30, 60, 90, 120, 180 and 240 min of ISO 834 fire exposure on a half of $b \times h = 300 \times 600$ (mm) rectangular beam are also specified in Appendix B of Russian design standard SP 468 [6], which is shown in Fig. 5.

It can be observed from Figs. 4 and 5 that: (i) At a certain time in ISO 834 fire exposure, there is similarity between EC2 and SP 468 in the tempeature contours at the cross-section lower parts; (2) EC2 provides finer gridlines of 20 mm, compared to that of 30 mm specified in SP 468; and (iii) SP 468 is capable of providing more accurate data in the upper parts since it is on a half of the cross-section.

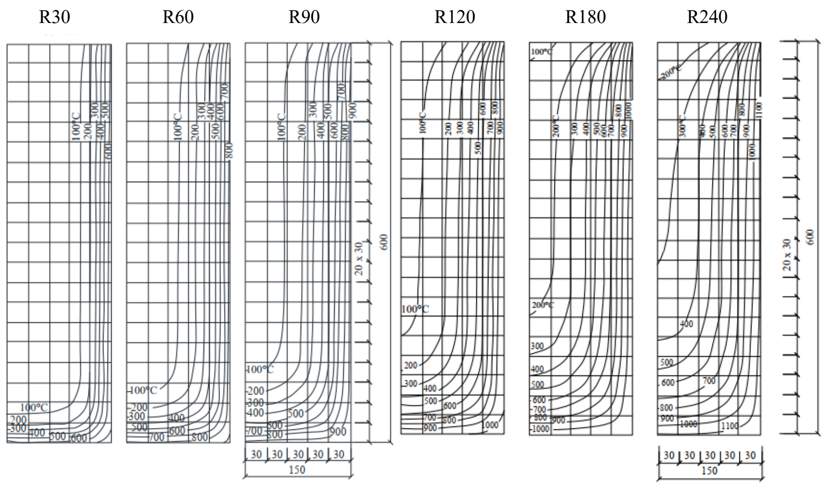


Figure 5. Temperature distribution on a half of rectangular beams to SP 468

2.3. *Temperature distribution within T-beams' cross-section*

It should be highlighted that there is no specification for temperature distribution on T-beam cross-section in EC2-1.2. Meanwhile, SP 468 overcomes this difficulty. Fig. 6 shows the SP 468 tempartune profiles at 90 and 120 min of a half of the T-beam having 300 mm width, 600 mm height, flange width of 200 mm and flange overhang of 400 mm.

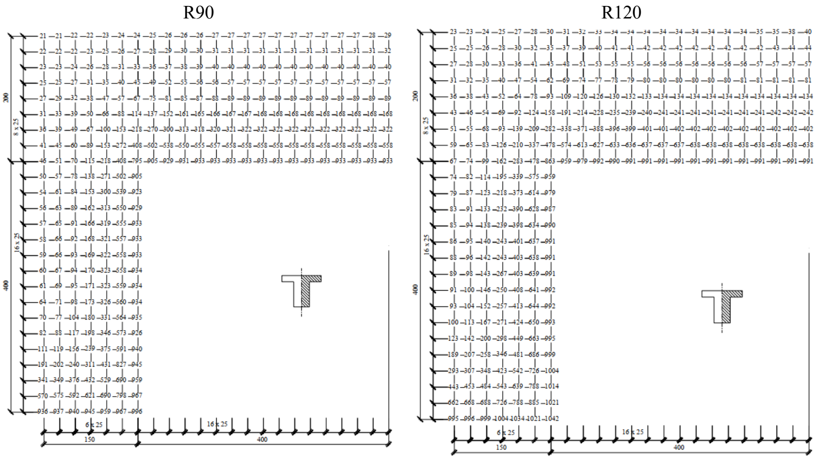


Figure 6. Temperature distribution on a half of T-beams to SP 468

It can be observed from Fig. 6 that the temperature profile on T-beam is not shown in the form of contours in SP 468. Alternatively, temperature values are given at each intersection of the gridlines of 25 mm, which can be utilized to establish the temperature profile along the depth of the flange as shown in Fig. 7.

It is noted in Fig. 7 that the slab depth is considered from its bottom surface, which is directly exposed to fire. It can be shown that after 90 min of ISO 834 fire exposure, the 500 °C isotherm contour is at a distance of about 30 mm from the bottom face of the flange. Similarly, the corresponding values of R30, 60, 120, 180 and 240 are 8, 20, 38, 51 and 63 mm, respectively.

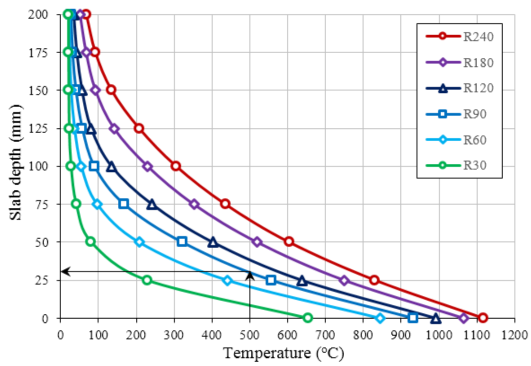


Figure 7. Temperature distribution on flange of T-beams to SP 468

3. Temparature-dependent mechanical properties of materials

Since concrete is non-combustible material, with the variation of its thermal conductivity and heat capacity, concrete is very sufficient in fire shielding. However, there is either significant reduction in the strength and deformation properties at elevated temperatures. When exposed to fire, due to the heat transfer in concrete, temperature at the embedded rebars also elevates. This fact also results in reductions in strength of reinforcing steel at elevated temperatures. Besides, the rate of these changes takes place more rapidly than that of concrete.

In SP 486 [6], the materials temperature-dependent mechanical properties are defined by multiplying those at ambient condition with working condition factors as follows:

$$R_{bn,fi} = \gamma_{b,fi} \cdot R_{bn}; \quad R_{b,fi} = \gamma_{b,fi} \cdot R_b \text{ and } E_{b,fi} = \beta_{b,fi} \cdot E_b \tag{3}$$

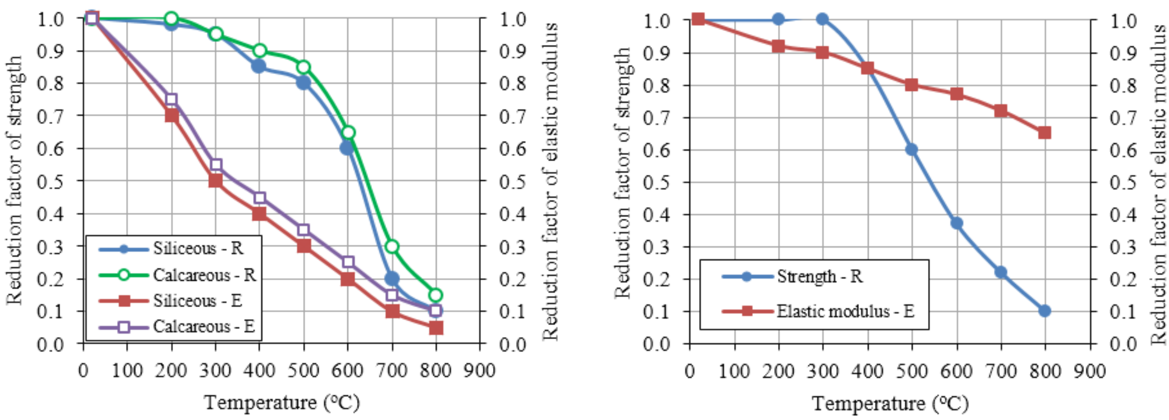
$$R_{sn,fi} = \gamma_{s,fi} \cdot R_{sn}; \quad R_{s,fi} = \gamma_{s,fi} \cdot R_s \text{ and } E_{s,fi} = \beta_{s,fi} \cdot E_s \tag{4}$$

where R_{bn} and R_{sn} are the respective specified concrete compressive strength and reinforcing steel tensile strength at ambient condition; R_b and R_s are the corresponding design strengths of these materials at ambient condition; E_b and E_s are the respective elastic moduli of concrete and rebars at ambient condition. All the terms having subscript "*fi*" are the corresponding temperature-dependent strength and elastic modulus. The working condition factors are also the reduction factors as shown in Table 1.

Table 1. Working condition factors (reduction factors) to SP 468

Materials	Reduction factor	Temperature (°C)							
		20	200	300	400	500	600	700	800
Siliceous aggregate concrete	$\gamma_{b,fi}$	1.00	0.98	0.95	0.85	0.80	0.60	0.20	0.10
	$\beta_{b,fi}$	1.00	0.70	0.50	0.40	0.30	0.20	0.10	0.05
Calcareous aggregate concrete	$\gamma_{b,fi}$	1.00	1.00	0.95	0.90	0.85	0.65	0.30	0.15
	$\beta_{b,fi}$	1.00	0.75	0.55	0.45	0.35	0.25	0.15	0.10
Hot-rolled reinforcing steel	$\gamma_{s,fi}$	1.00	1.00	1.00	0.85	0.60	0.37	0.22	0.10
	$\beta_{s,fi}$	1.00	0.92	0.90	0.85	0.80	0.77	0.72	0.65

The reduction factors for temperature-dependent mechanical properties of concrete and reinforcing steel to SP 468 are shown in Figs. 8(a) and 8(b), respectively.



(a) Concrete

(b) Reinforcing steel

Figure 8. Temperature-dependent mechanical properties of materials to SP 468

It should be highlighted that in order to calculate at Accidental Limit States (ALS) according to SP 468 [6], the beam flexural strength in fire $M_{u,fi}$ shall be determined using specified strengths of both concrete and reinforcing steel to compare with the effect of action M_{fi} from unfactored loads. Meanwhile, at ambient condition the materials' design strengths are used to calculate flexural strength M_u for the comparison with the effect of action M from factored loads at ULS. At a certain time t of the ISO 834 fire exposure, i.e. 90 min, the FSD factor is determined as $k_{FSD} = M_{u,fi}/M_u$. With a given reduction factor of the effect of action $k_{fi} = M_{fi}/M$, the fire resistance based on load bearing criteria of T-beams can be determined by comparing k_{FSD} with k_{fi}. If k_{FSD} is still higher than k_{fi}, it is said that the fire resistance of the beam is higher than R90.

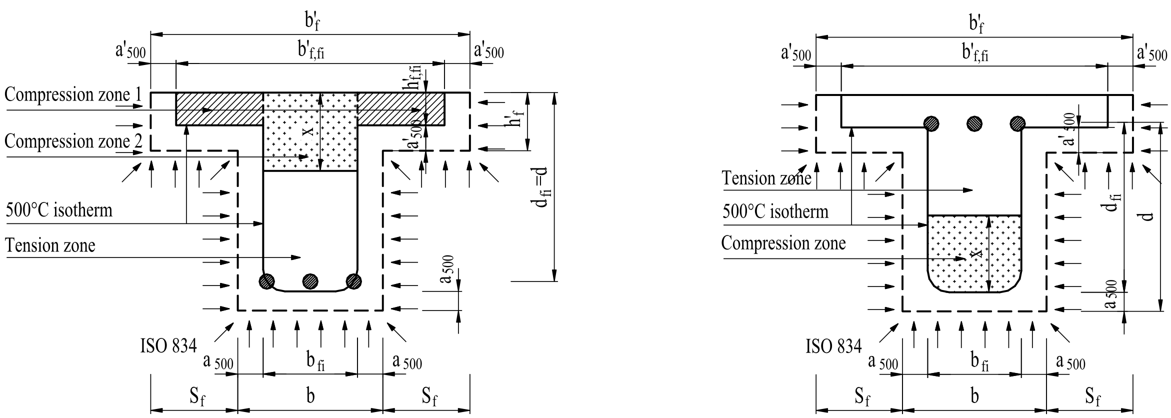
4. Flexural strength of T-beams under ISO 834 fire exposure

4.1. 500 °C isotherm method for rectangular beams

The 500 °C isotherm method for rectangular beams is introduced in Appendix B (informative) of EC2-1.2 [5] as well as in SP 468 [6]. This method is applicable for a standard fire exposure and any other time-heat regimes, which cause similar temperature fields in the fire exposed member. The simplified calculation method comprises a general reduction of the cross-section size with respect to an outer heat-damaged zone at the concrete surfaces. The thickness of the damaged concrete, a_{500}, is made equal to the average depth of the 500 °C isotherm in the compression zone of the cross-section. The damaged concrete layer, i.e. concrete with temperatures excess 500 °C, is assumed not to contribute to the load bearing capacity of the member, whilst the residual concrete cross-section retains its initial values of specified strength and modulus of elasticity [5]. The investigations for a rectangular beam exposed to ISO 834 fire on three sides were conducted by the authors in 2019 [18] and 2021 [19].

4.2. 500 °C isotherm method for T-beams

When a T-beam is exposed to fire at three beneath sides, the 500 °C isotherm contours for the beams introduced in Figs. 4, 5 and 6 can be all applied for calculation owing to their similarity [5, 6]. The only difference is the contribution of the flange in the case of sagging bending (Fig. 9).



(a) Compression zone in flange (sagging moment)

(b) Tension zone in flange (hogging moment)

Figure 9. Simplified calculation method for T-beams

It can be seen that the concrete at the lower part of the flange having a thickness of a'_{500}, where directly exposed to fire and having temperature higher than 500 °C, can also be eliminated. This idea is similar to the concept of a_{500} applied for the web, which is the depth of the 500 °C isotherm contour. In this simplified calculation, the value of a'_{500} can be determined based on SP 468 as introduced in Section 2.3. This concrete layer thickness a'_{500} is mostly dependent on the lower surface of the slab that is directly exposed to fire, whereas the remaining distance to the slab's upper surface only affects the temperature of concrete within this cooler part. Hence, it can be adopted that when the flange depth is different from 200 mm, the results obtained in Section 2.3 can still be utilized for simplification.

The calculation steps for determination of T-beams' flexural strength when exposed to ISO 834 fire from two sides and the lower surfaces are as follows:

- Determination of 500 °C isotherm contours at both web and flange at a certain time of ISO 834 fire based on specifications of both EC2-1.2 [5] and SP 468 [6];

- Determination of the effective dimensions of the T-beam's cross-section in fire, such as b_{fi}, $b'_{f,fi}$, $b'_{f,fi}$ and d_{fi} after eliminating the outer damaged concrete layer having temperature higher than 500 °C (Fig. 9). The curves at the corners of the 500 °C isotherm contours can be simplified to intersect each other at 90° angle;

- Determination of temperatures at centroid of tensile rebars based on the temperature profile of SP 468 [6]. It is noted in Fig. 9(a) that some rebars can be out of the reduced cross-section. However, as shown in Fig. 8(b), the reduction factor of reinforcing steel strength at temperatures higher than 500 °C is lower than 0.6 and higher than zero. Hence, these rebars can still be accounted for in the calculation of the beam's flexural strength in fire;

- Determination of the temperature-dependent strength of rebars based on SP 468;

- Calculation of the beam's flexural strength using ordinary expressions for cross-sectional analysis and the pre-determined temperature-dependent strength of the rebars. It should be noted that for T-beams, it is necessary to determine the neutral axis's position. In case the distance x from the extreme compressive concrete fiber to the neutral axis is smaller than $h'_{f,fi}$ (Fig. 9(a)), then the neural axis is in flange and the concrete compression zone is in rectangular shape of $b'_{f,fi} \times x$, otherwise the neutral axis is in web and the compression zone can be divided into a rectangular block within the web having the dimensions of $b_{fi} \times x$ and another combined rectangular block within the flange with the dimensions of $(b'_{f,fi} - b_{fi}) \times h'_{f,fi}$ (Fig. 9(a)).

In this simplified calculation, the compressive strength of concrete within the 500 °C isotherm contours is assumed to maintain the specified value at ambient condition, whereas the compression zone height is to be adjusted for equilibrium condition with the resultant force from the rebars in tension zone.

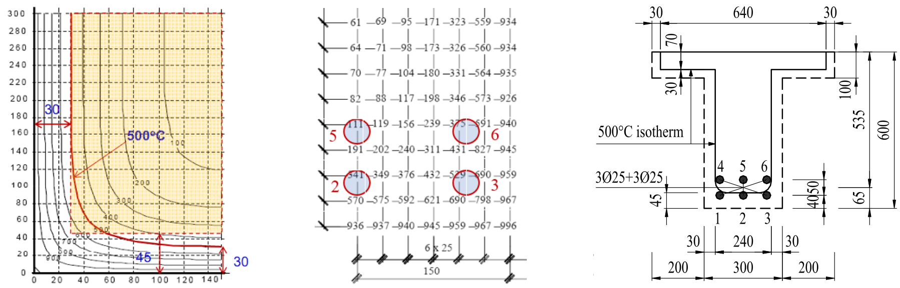
It can also be noted from Fig. 9 that the aforementioned procedure is applicable for T-beams under sagging moment. For the case of hogging moment, the flange is in tension zone and ignorable. Then, the beam can be referred to as rectangular in cross-section.

The case study conducted in the next section will illustrate the application of the proposed method to determine the reduction in flexural strength of T-beams in fire.

5. Investigation of FSD factor of T-beams under ISO 834 fire

5.1. Case study

Consider a simply-supported T-beam designed with the width and the height of the cross-section are 300 and 600 mm, respectively. The 100 mm-thick flange has overhangs of 200 mm at both sides. At the mid-span of the beam, the main longitudinal rebars at lower part are arranged in two layers 3Φ25 + 3Φ25 (A_s = 2945.3 mm^2, reinforcement percentage of 1.8%). The axis distance is a = 65 mm and the effective height is h_0 = 535 mm (Fig. 10(c)). Concrete with compressive class B20 and CB400-V reinforcing steel are used for the beam. The design concrete compressive strength and reinforcing steel tensile strength at ambient condition are R_b = 11.5 MPa and R_s = 350 MPa, respectively. The corresponding materials' specified strengths are R_{bn} = 15 MPa and R_{sn} = 400 MPa, respectively. In this section, the FSD factor k_{FSD} at 90 min of ISO 834 fire will be determined based on the simplified calculation method introduced in Section 4.



(a) 500 °C isotherm (b) R90 temperatures at rebars (c) Cross section at R90

Figure 10. Case study - Effective cross section in fire

Based on the 500 °C isotherm contours taken from Section 2, the concrete layers with temperature higher than 500 °C have the thickness a_{500} of 30 mm at both sides of the web and 45 mm at the bottom of the beam (Fig. 10(a)). Hence, the effective dimension of the beam are $b_{fi} = 300 - 2 \cdot 30 = 240$ mm and $d_{fi} = 600 - 45 = 555$ mm. Based on the SP 468's 500 °C isotherm contours shown in Fig. 6 and the analysis shown in Fig. 7 of Section 2.3, the corresponding thickness a'_{500} of the concrete layer hotter than 500 °C in flange is 30 mm. Hence, the flange dimensions in fire can be determined as $b'_{f,fi} = 700 - 2 \cdot 30 = 640$ mm and $h'_{f,fi} = 100 - 30 = 70$ mm.

Based on the tempeature data given in Section 2, the temperature and the corresponding strength reduction factor of rebars can be determined based on interpolation as shown in Table 2. It is noted that each rebar's position is also taken into accouunt as shown in Fig. 10(b).

Table 2. Temperatures (°C) and strength reduction factors of rebars

No	R30	R60	R90	R120	R180	R240
1	280.8 (1.0)	532.1 (0.526)	677.3 (0.254)	775.5 (0.129)	901.5 (0)	990.2 (0)
2	170.8 (1.0)	351.6 (0.923)	478.4 (0.654)	574.4 (0.429)	722.8 (0.193)	834.2 (0.066)
3	280.8 (1.0)	532.1 (0.526)	677.3 (0.254)	775.5 (0.129)	901.5 (0)	990.2 (0)
4	157.1 (1.0)	347.3 (0.929)	505.8 (0.587)	594.6 (0.382)	746.3 (0.164)	851.9 (0.048)
5	36.4 (1.0)	88.0 (1.000)	159.0 (1.000)	251.4 (1.000)	424.2 (0.790)	561.8 (0.458)
6	157.1 (1.0)	347.3 (0.929)	505.8 (0.587)	594.6 (0.382)	746.3 (0.164)	851.9 (0.048)

It is noted in Table 2 that the value in brackets is the reduction factor $\gamma_{s,fi}$ following SP 468's specification in Table 1 and Fig. 8, whereas the remaining values are the temperatures at the reabrs. For example, after 90 min of ISO 834 fire, temperatures at rebars No. 1 and No. 3 are both 677.3 °C, resulting in a strength reduction factor of 0.254.

Figure 11 depicts the principle to establish the beam's flexural strength $M_{u,fi}$.

The resultant tensile force in the six rebars is $T_{s,fi} = \sum_{i=1}^{6} A_{si} R_{sn} \gamma_{s,fi} = 655.022$ kN.

Pre-determine the height of concrete compression block: $x = \dfrac{T_{s,fi}}{b'_{f,fi} R_{bn}} = 68.2$ mm.

Since this trial value is lower than the effective height of the flange $h'_{f,fi} = 70$ mm, the neutral axis is within the effective flange. Hence, the resultant force in compressive concrete is also $C_{b,fi} = C_{b1,fi} + C_{b2,fi} = T_{s,fi} = 655.022$ kN.

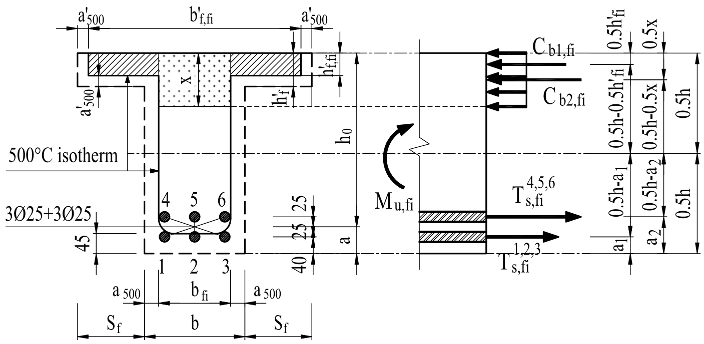


Figure 11. Case study - Flexural strength of T-beam in fire

Finally, the flexural strength of the T-beam in ISO 834 fire can be determined by taking moment of all the resultant forces in concrete and in rebars to the axis going through the mid-height of the cross-section and perpendicular to the flexural plane (Fig. 11):

$$M_{u,fi} = C_{b,fi}(0.5h - 0.5x) + \sum_{i=1}^{6} A_{si} R_{sn} \gamma_{s,fi} (0.5h - a_i) = 323.122\text{kN}$$

In ambient condition, with materials' design strengths of $R_b = 11.5$ MPa, $R_s = 350$ MPa and $\gamma_{s,fi} = 1.0$, one can get $T_s = 1030.835$ kN, $C_{b1} = 460.0$ kN, $C_{b2} = 570.835$ kN, $x = 165.5$ mm and $M_u = 481.271$ kNm.

Finally, the FSD factor of the T-beam at R90 is:

$$k_{FSD,90} = M_{u,fi}/M_u = 323.122/481.271 = 0.671$$

Based on the case study for R90, a Microsoft Excel spreadsheet was established by the authors to calculate for the other cases of R30, R60, R120, R180 and R240. The results obtained are shown in Table 3 and Fig. 12.

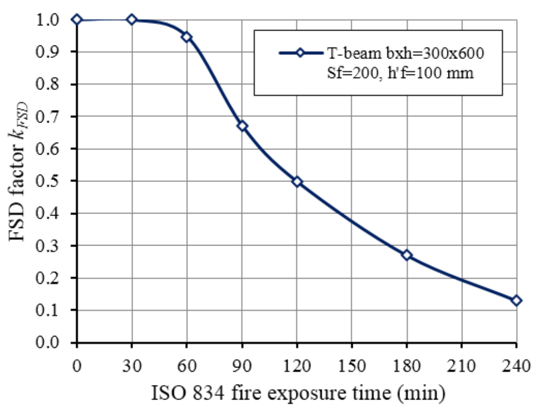


Figure 12. Case study - Calculation results

It should be noted in Table 3 that when the trial value of x is higher than the effective height of the flange h'_{fi}, the neutral axis is in the effective web. This also means that the whole effective flange can be mobilized for compression zone. Hence, the first resultant force in compressive concrete can be calculated as $C_{b1,fi} = h'_{f,fi}(b'_{f,fi} - b_{fi})R_{bn}$. The remaining resultant force in concrete contributed by the effective web then can be determined from equilibrium condition: $C_{b2,fi} = T_{s,fi} - C_{b1,fi}$. As a result, the actual height of concrete compressive block within the effective web is $x =$

Table 3. Calculation results

Parameters	R30	R60	R90	R120	R180	R240
a_{500} (mm)	9.0	21.0	30.0	40.0	56.0	75.0
a'_{500} (mm)	8.0	20.0	30.0	38.0	51.0	63.0
b_{fi} (mm)	282.0	258.0	240.0	220.0	188.0	150.0
$b'_{f,fi}$ (mm)	684.0	660.0	640.0	624.0	598.0	574.0
h'_{fi} (mm)	92.0	80.0	70.0	62.0	49.0	37.0
$T_{s,fi}$ (kN)	1178.097	948.957	655.022	481.252	257.414	121.736
x_{trial} (mm)	114.8	95.9	68.2	51.4	28.7	14.1
Neural axis	web	web	flange	flange	flange	flange
$C_{b1,fi}$ (kN)	554.760	482.400	655.022	481.252	257.414	121.736
$C_{b2,fi}$ (kN)	623.337	466.557	-	-	-	-
x_{actual} (mm)	147.7	120.6	68.2	51.4	28.7	14.1
$M_{u,fi}$ (kNm)	558.835	455.938	323.122	239.811	129.482	61.873
k_{FSD}	> 1.0	0.947	0.671	0.498	0.269	0.129

$C_{b2,fi}/(b_{fi}R_{bn})$. Finally, the flexural strength of the T-beam in ISO 834 fire can be determined by taking moment of all the resultant forces in concrete and in rebars to the axis going through the mid-height of the cross-section and perpendicular to the flexural plane. For example, at R60, it is:

$$M_{u,fi} = C_{b1,fi}(0.5h - 0.5h'_{fi}) + C_{b2,fi}(0.5h - 0.5x) + \sum_{i=1}^{6} A_{si}R_{sn}\gamma_{s,fi}(0.5h - a_i) = 455.938\text{kN}$$

5.2. Parametric study

Using the proposed Microsoft Excel spreadsheet, parametric studies were conducted to invesigate the effects of the overhang and the height of the flange on the FSD of T-beams. The results are shown in Figs. 13 and 14.

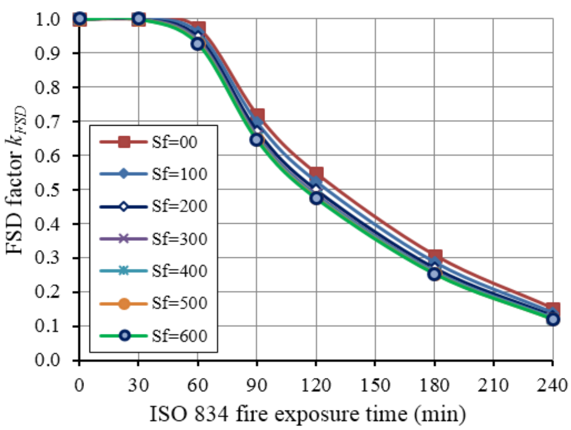


Figure 13. Investigation of the effect of flange overhang S_f on k_{FSD}

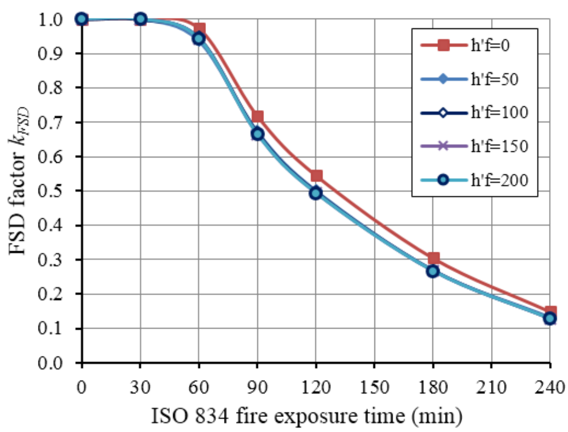


Figure 14. Investigation of the effect of flange height h'_f on k_{FSD}

Fig. 13 shows that when the flange overhang S_f is gradually increased from 0 (rectangular cross section), 100, 200, and so on to 600 mm, the FDS factor decreases.

It can also be observed from Fig. 14 that when the flange height h'_f is increased from 0 (rectangular cross-section), 50, 100, 150 and 200 mm, the FDS factor also decreases. Besides, the curves of h'_f = 150 and 200 mm are totally coincided, which means that there is no change in the FDS factor from a certain value of the flange height.

The parametric studies in Figs. 13 and 14 show that compared to rectangular RC beams having similar cross-section sizes, the T-beams have lower FSD factor when subjected to ISO 834 fire. However, this is because at ambient condition there is also an increment in flexural strength of T-beam compared to that of rectangular beams. Furthermore, it can also be observed that the flange overhang and height have not-significant contribution in the calculation of FSD, since the curves obtained from the investigation shown in Figs. 13 and 14 are quite close to each other.

6. Conclusions

A number of conclusions can be withdrawn from the simplified calculation conducted in this paper as follows:

- The Russian design standard SP 468.1325800.2019 has comprehensive specifications of temperature distribution on cross-sections as well as temperature-dependent mechanical properties of materials and can be sufficiently used for structural fire analysis in Vietnam condition;

- The 500 °C isotherm method specified in EC2-1.2 and SP 468 can be used as a simplified method to deal with the calculation of flexural strength of RC T-beams when exposed to ISO 834 fire;

- The case study conducted shows that the flexural strength of RC T-beams in fire can be explicitly calculated in a simple manor and compared to that at ambient condition to obtain the flexural strength deterioration (FSD) factor;

- The parametric studies conducted show that the FSD factor of RC T-beams is adversely proportional to the beams' web and flange dimensions. However, the effect of these components of T-beams is not significant.

The simplified calculation method introduced in this paper is only a simplified approach. Althought it is simple and practical, there are still future research works, such as finite element analysis and experimental studies in local conditions, that should be implemented for validation as well as for the development of the performance-based calculation method and data of the up-coming Vietnamese design standard for RC T-beams in fire.

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