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Research paper

Strains, thermal relaxation and strength loss of prestressing steel at fire temperature. Guidance on the practical use of the Eurocode 2-1-2 model

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Abstract: The paper gives guidance on the use of the EC2-1-2 model of degradation of the mechanical properties of prestressing steel at high temperature useful for estimating the loss of prestressing force in members exposed to fire. Adequate estimation of this force is crucial when calculating the fire resistance of prestressed members. If only the reduction in steel strength determined on the basis of the EC2-1-2 model is considered for the analysis, it may cause a significant underestimation of the prestress loss under fire conditions. In order to adequately estimate this force, it is necessary to sum up the strain of the prestressing tendons resulting from the degradation of their mechanical properties under the influence of high temperature and the free thermal elongation of the steel. The paper points out the existence of analogies between the elongation of prestressing steel heated under fire conditions and concrete creep under ordinary conditions. The guidelines for estimating thermal stress relaxation in tendons and determining the reduction in the secant modulus of prestressing steel under fire conditions are also provided.

Keywords: designing, elongation, fire, prestressing steel, strain, tendon

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1. Introduction

Currently, the prediction of fire resistance of prestressed members is most often carried out based on simple *Tabulated Data* given in EC2-1-2 [1] and in the case of repetitive precast prestressed concrete members – also on the basis of the results of standard fire tests [2]. However, it can be expected that in the future, the evaluation of the fire resistance of prestressed members, especially non-typical ones, will increasingly be carried out based on computational analyses in which fire is considered as an accidental design situation [3–5]. Description of such analyses can be found for example in papers [2, 6]. In these analyses, it is crucial not only to adequately estimate the reduction in the strength of the prestressing steel, but also, or rather primarily, to determine the elongations of the prestressing tendons caused by the temperature increase. These elongations can be much larger than those occurring under ordinary conditions. This can lead to significant stress relaxation in the tendons and a reduction in the prestressing force, even in the initial phase of fire. In addition, large deformations of the tensile reinforcement can cause reduction in the design (and actual) ultimate load capacity of the cross-section [7–11]. On the other hand, in some cases, the loss of prestressing force might be hampered due to the thermal bowing of the member [12] (a phenomenon caused by a thermal gradient in member cross-section). It is also worth mentioning that the reduction in the prestressing force may significantly affect other parameters related to the performance of the prestressed member, such as deflection and stress distribution within the cross-section.

This paper presents practical guidance on the use of the model for the degradation of the mechanical properties of prestressing steel at high temperature, given in the EC2-1-2 [1] and the previous version of this standard [13], useful for predicting the deformation of prestressing tendons in members exposed to fire conditions. The existence of analogies between the elongation of prestressing steel heated under fire conditions and concrete creep under ordinary conditions is also pointed out. Guidelines useful for estimating thermal stress relaxation in tendons and determining the reduction in the secant modulus of prestressing steel under fire conditions are given. The above information was related to the currently commonly used seven-wire strands made of Y1860 steel.

2. Mechanical properties of prestressing steel at fire temperature in the view of the standard model

According to Eurocode [1, 13], a general stress-strain relationship model is recommended for determining the mechanical properties of prestressing steel at fire temperature (Fig. 1). It consists of three straight segments and an ellipse section inscribed between two of them. The formulas describing this curve and the coefficients required to calculate the coordinates of the key points on the diagram are given in [1] (and [13]). This model was proposed in 1986 simultaneously by A. Rubert, P. Schaumann [14, 15] and Y. Anderberg [16, 17], based on tests results of various types of steel (mainly structural, but not prestressing).

Based on the model [1, 13], it is not possible to formulate a general diagram on the vertical axis of which the ratio of the stress in the tendons to their tensile strength would

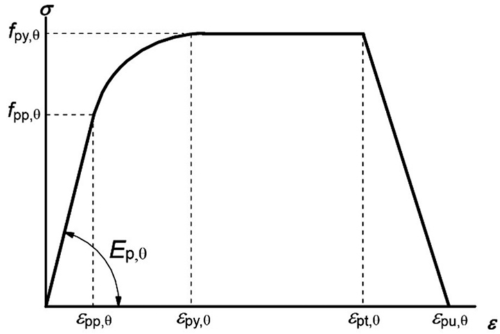

Fig. 1. General model of stress-strain relationship for tension of prestressing (and reinforcing) steel at high temperature [1, 13]

be traced. For practical application of the model, it is necessary to assume the ratio of steel strength to its secant modulus. Therefore, further analysis carried out in this work was related to commonly used strands made of Y1860 steel (e.g., Y1860S7 seven-wire strands). Its characteristic tensile strength is f_{pk} = 1860 MPa, and its characteristic modulus of elasticity is E_{pk} = 195 GPa [18, 19]. Other parameters and the detailed method of labeling strands are given in [18], and the general requirements for currently used prestressing steels are also given in Eurocode [19] and in [20].

According to previous Eurocode [13], the maximum stress that can occur in prestressing reinforcement at fire temperature (θ) can be determined by the Eq. (2.1):

$$f_{py,\theta} = k_{py,\theta} \cdot \beta f_{pk} \tag{2.1}$$

in which the values of the $k_{py,\theta}$ coefficient are given in the table [13], for temperature values that are successive multiples of 100°C. The value of the coefficient β = 0.9 appearing in Eq. (2.1) was recommended by the Polish National Annex to [13]. In the current Eurocode [1], the Eq. (2.1) was replaced by the Eq. (2.2):

$$f_{py,\theta} = k_{py,\theta} \cdot f_{p01,k} \tag{2.2}$$

The diagrams of the values of the $k_{py,\theta}$ coefficient for bars, strands, and wires are given in Fig. 2a, the diagram for the Y1860S7 steel considered here – in Fig. 2b.

When calculating the fire resistance of bent reinforced concrete members in which the tensile zone is exposed to fire conditions, it is crucial (and usually sufficient) to determine the reduction in the steel yield strength as a function of temperature.

Applying an analogous approach to prestressed members, one could calculate their fire resistance (e.g., using simplified methods) by taking for analysis only the reduced tensile strength of the tendons, determined by the coefficients given in [1] (Fig. 2a or Fig. 2b).

Adopting to the analyses of prestressed members, carried out for fire conditions, only the information given in Fig. 2 would result in a complete disregard of the elongation of the prestressing tendons and the associated significant thermal stress relaxation expected in the

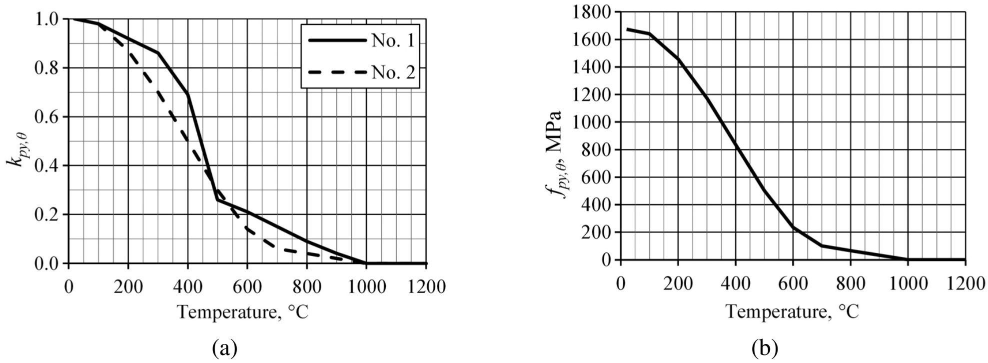

Fig. 2. (a) Values of the coefficient $k_{py,\theta}$ for determining the reduction in strength of prestressing steel at high temperature [1]: diagram No.1 – bars, No.2 – strands and wires; (b) Reduction in strength of Y1860S7 strands at high temperature

tendons. When designing members for fire resistance, states other than the design structural failure of the member are rarely considered. It appears, however, that the deformation of prestressing tendons heated to fire temperature may be so significant that the member failure (design, but also actual), in an unfavorable case, may occur earlier than would be apparent from an analysis of the cross-section load-bearing capacity assuming only the information taken from Fig. 2. It is therefore necessary to adequately estimate also the expected deformation of the tendons. This deformation can be determined from the general model [1, 13] (Fig. 1).

Figure 3a shows diagrams of the stress-strain relationship obtained by introducing the mechanical properties of the Y1860 steel strands into the general standard model (Fig. 1), and Fig. 3b shows an excerpt from Fig. 3a in the strain range up to 0.03.

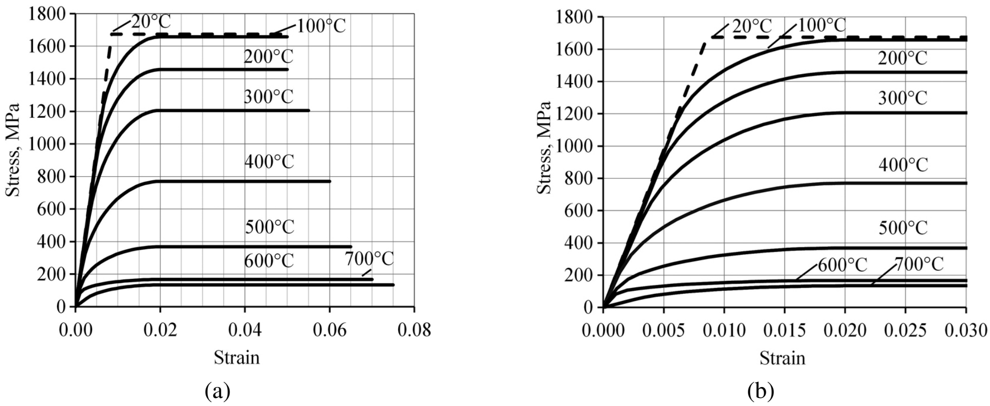

Fig. 3. (a) Stress-strain relationship diagrams for Y1860 prestressing steel strands at high temperature, obtained by introducing the parameters of Y1860S7 strands into the general standard model [1, 13] (Fig. 1); (b) Enlarged excerpt from Fig. 3a

Considering Fig. 3b, it is easy to notice that the strain values of tendons heated to high temperature are much larger than those occurring under ordinary conditions. However, the actual deformations of tendons in members exposed to fire conditions may be even greater.

The following sections discuss how the actual deformations of tendons in members exposed to fire conditions can be estimated from the model [1, 13]. However, this requires first paying attention to the available means of testing steel at high temperature and to what conditions tendons in members subjected to fire are typically subjected to.

3. Means of testing steel at high temperature

At ordinary temperature, a two-dimensional strain-stress relationship is usually used to determine the mechanical properties of steel. When considering fire conditions, however, the mechanical properties of steel must be described by three variables: strain, stress, and temperature. In the standard model [1, 13], the two-dimensional stress-strain relationship (Fig. 1) is given for temperature values equal to successive multiples of 100°C. The model is, therefore, three-dimensional.

It would be inconvenient and impractical to conduct experiments with three input (tested) variables (factors), not least because of the difficulty of unambiguously interpreting the results obtained. This causes two basic approaches to conducting tests in practice [8, 12, 17, 21–23]:

– at steady (fixed) temperature,
– at increasing (variable) temperature.

In the first approach, stress-strain relationships are determined at various temperatures that are changed but fixed in a given experiment. The experimental conditions can be modified, but the most common test conducted at high temperature is similar to the tensile test of steel performed at room temperature. This ensures that the results can be compared and makes the tests performed at a fixed temperature relatively easy to implement in practice. The aforementioned model of Y. Anderberg [16, 17] based on the results of tests performed at a fixed temperature.

During the tests performed at variable temperature (transient-state), the specimen load is usually determined. Then, with the values of stress in the specimens changing, but fixed in a given test, the specimens are heated in a certain way, and the values of strain (elongation) are measured. The model of A. Rubert, P. Schaumann [14, 15] introduced in Eurocode [1, 13] was derived by such transient-state tests.

The results obtained using the two approaches mentioned above cannot be compared directly [8, 21, 22]. Information on comparing the test results and converting the stress-strain curves from the transient-state test results can be found in papers [10, 17, 23].

The total elongation of a prestressing tendon at high temperature ($\varepsilon_{p,tot}$) can be expressed as the sum of four components [8, 17, 21, 22]:

$$\varepsilon_{p,\mathrm{tot}} = \varepsilon_{p,0} + \varepsilon_{p,\sigma} + \varepsilon_{p,\sigma\theta} + \varepsilon_{p,\mathrm{cr}} \tag{3.1}$$

In Eq. (3.1):
$\varepsilon_{p,0}$ – indicates free thermal elongation of steel (without load);

$\varepsilon_{p,\sigma}$ – indicates elongation of steel resulting from loading at ordinary temperature; optionally, the elastic and plastic components could be further distinguished here;

$\varepsilon_{p,\sigma\theta}$ – indicates elongation caused by the simultaneous effect of load and high temperature; this is the increase in strain caused by the degradation of the mechanical properties of steel under the influence of increasing temperature; several components can be distinguished from this quantity (see Fig. 1);

$\varepsilon_{p,\mathrm{cr}}$ – indicates elongation due to steel creep, resulting from the simultaneous effect of load and high temperature, but over a sufficiently long period; this deformation, at time intervals corresponding to actual fires, i.e., up to about 4 hours, is small [10, 21] and will not be considered further in this paper.

During tests performed at fixed temperature, strain measurement is usually not initiated until the target temperature has stabilized in the specimen. This causes that the results of tests conducted at fixed temperature mostly do not include the free thermal elongation of steel ($\varepsilon_{p,0}$). Thus, during testing at high temperature, only the strain determined by the Eq. (3.2) is measured:

$$\varepsilon_{p,\theta} = \text{const} = \varepsilon_{p,\sigma} + \varepsilon_{p,\sigma\theta} \tag{3.2}$$

This strain comprises the sum of the specimen strain resulting from the loading at ordinary temperature and the incremental strain resulting from the degradation of the mechanical properties of steel caused by increasing the temperature. However, testing members at fixed temperature do not reflect the conditions under which the reinforcement of members exposed to fire is usually found [8, 21, 22].

These conditions can be more adequately represented by the tests performed at increasing temperature. Before the beginning of a fire, structural members are usually loaded, which means that stresses are already present in their reinforcement [8, 21, 22].

In the tests conducted at increasing temperature, before heating begins, the specimen is tensioned (at ordinary temperature) until the presumed stress occurs in the specimen. It depends on the test program whether the strain resulting from loading at ordinary temperature ($\varepsilon_{p,\sigma}$) is measured, or whether the measurement of the specimen elongation begins after it has been loaded. In the first case, it is possible to determine the total strain of the reinforcement ($\varepsilon_{p,\mathrm{tot}}$), expressed by Eq. (3.1). However, if the elongation of the specimen due to loading at ordinary temperature ($\varepsilon_{p,\sigma}$) is not recorded during the test, then only the elongation expressed by the Eq. (3.3) is obtained as the result:

$$\varepsilon_{p,\sigma} = \text{const} = \varepsilon_{p,0} + \varepsilon_{p,\sigma\theta} \tag{3.3}$$

It is also worth mentioning that in the absence of clear data on how the degradation of the mechanical properties of steel caused by the simultaneous effect of load and high temperature ($\varepsilon_{p,\sigma}$) depends on the rate of heating, this rate should be set so that the actual rate of temperature increase in the tendons of a member exposed to fire is represented as accurately as possible [10].

4. Elongation of prestressing steel in members exposed to fire conditions

The model presented in Fig. 1 and Fig. 3 was fitted to the conditions where the steel temperature is set, and its strain changes in relation to the stress. Therefore, it does not capture the total strain of the steel, but only the part of it expressed by the Eq. (3.2). In order to determine the total strain, i.e. that which should be expected in members exposed to fire conditions, the free thermal elongation of the steel must be added to the strain calculated from the model [1, 13].

Typically, the value of the thermal expansion coefficient of steel is assumed to be constant, ranging from 1.0 to $1.2 \cdot 10^{-5}$ [1/°C]. However, a more accurate relationship describing the free thermal deformability of prestressing steel is given in Eurocode [1, 13] (Fig. 4).

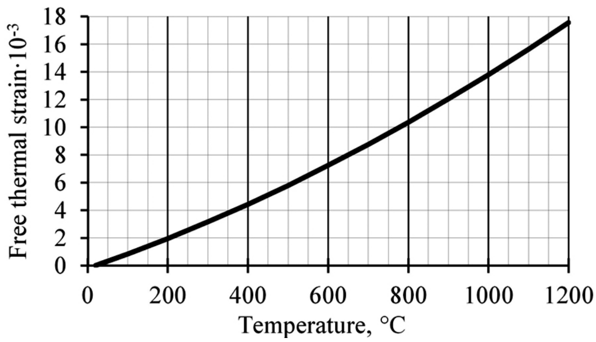

Fig. 4. Free thermal strain of prestressing steel ($\varepsilon_{p,0}$) as a function of temperature [1, 13]

Figure 5 presents diagrams of the stress-strain relationship for Y1860S7 prestressing strands, obtained according to the principle given at the beginning of this section.

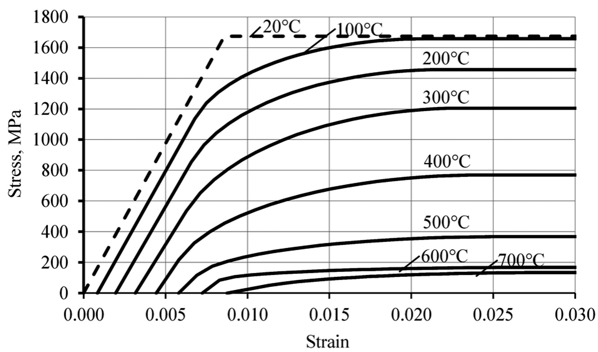

Fig. 5. Diagrams of the stress-strain relationship at high temperature suitable for estimating the total elongation of Y1860S7 tendons in members exposed to fire conditions

The values of elongation set on the horizontal axis of the diagram are the sum of the strain calculated from the standard model [1, 13] (Eq. (3.2), Fig. 3) and the free thermal strain of steel (Fig. 4). The strain values given in Fig. 5, determined by Eq. (4.1), are suitable for estimating the elongation of prestressing tendons (Y1860) in members exposed to fire.

(4.1) $$\varepsilon_{p,\mathrm{fi}} = \varepsilon_{p,0} + \varepsilon_{p,\sigma} + \varepsilon_{p,\sigma\theta}$$

5. Analogy of the elongation of prestressing tendons in members exposed to fire conditions to the creep of concrete under ordinary conditions

The standard model [1, 13] and the model based on it given in Fig. 5 are in fact three-dimensional, therefore, it is possible to represent these models in a different coordinate system.

Figure 6 shows diagrams of the dependence of tendon elongation, at a fixed stress value, on temperature. These diagrams were based on Fig. 5, as a result of transferring the corresponding points in the strain-stress coordinates from that figure to the strain-temperature coordinate system.

The strain values plotted on the horizontal axis of Fig. 6 (as in Fig. 5, determined by the Eq. (4.1)) are suitable for estimating the elongation of prestressing tendons (Y1860S7) in members exposed to fire.

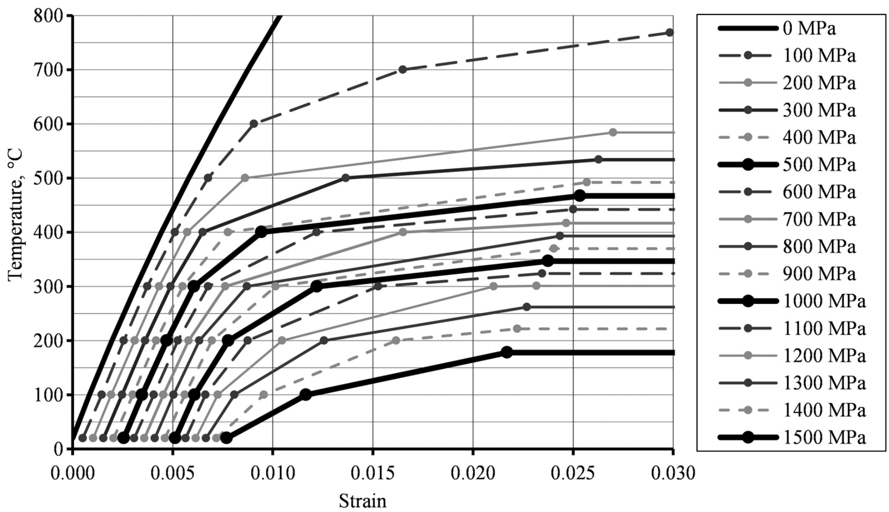

Fig. 6. Temperature-strain relationship diagrams suitable for estimating the total elongation of Y1860S7 tendons in members exposed to fire

Considering the diagrams shown in Fig. 6, a particular analogy can be seen between the elongation of tendons of prestressed members exposed to fire and the creep of concrete under ordinary conditions. At the beginning (and before the start) of the fire, there are strains in the tendons determined by the position of the points on the diagrams described by the ordinate 20°C. Incidentally, it is worth noting that for calculating these strains ($\varepsilon_{p,\sigma} = \sigma_p/E_p$), it is necessary to take the stress in the tendons occurring at the beginning of the fire. This should be the stress calculated after taking into account prestressing losses [24–26]. During a fire, as the temperature increases, at a constant stress, there is a significant increase in tendon elongation, described by the diagrams given in Fig. 6.

For example, at a stress of 1,000 MPa, after heating the tendons to a temperature of 300°C, an increase in strain from a value of about 0.005 to a value of about 0.012 (by approximately 140%) is to be expected. This corresponds to a creep factor value of 1.4.

In Table 1, depending on the stress in the tendons occurring at the start of the fire and the temperature, the following values are listed:

– total tendon elongation ($\varepsilon_{p,\mathrm{fi}}$); these are the values taken from Fig. 6, determined by Eq. (4.1);

Table 1. Values of total elongation ($\varepsilon_{p,\mathrm{fi}}$, defined by Eq. (4.1)) of Y1860S7 prestressing tendons heated to fire temperature and values of the coefficient $\phi_{p,\mathrm{fi}}$ (defined by Eq. (5.1))

σ_p [MPa]	$\varepsilon_{p,\sigma}$		**Total elongation ($\varepsilon_{p,\mathrm{fi}}$) and values of the coefficient $\phi_{p,\mathrm{fi}}$ in fire temperature**								
			100°C	**200°C**	**300°C**	**400°C**	**500°C**	**600°C**	**700°C**	**see col.12**	***[°C]**
0	0	$\boldsymbol{\varepsilon_{p,0}}$	0.0008	0.002	0.0032	0.0044	0.0058	0.0072	0.0088	–	–
100	0.0005	$\boldsymbol{\varepsilon_{p,\mathrm{fi}}}$	0.0015	0.0026	0.0037	0.0051	0.0068	0.0091	0.0165	0.0298	768
		$\boldsymbol{\phi_{p,\mathrm{fi}}}$	2.0	4.2	6.4	9.2	12.6	17.2	32.0	58.6	
200	0.001	$\boldsymbol{\varepsilon_{p,\mathrm{fi}}}$	0.0019	0.0031	0.0043	0.0057	0.0086			0.027	584
		$\boldsymbol{\phi_{p,\mathrm{fi}}}$	0.9	2.1	3.3	4.7	7.6			26.0	
400	0.0021	$\boldsymbol{\varepsilon_{p,\mathrm{fi}}}$	0.003	0.0042	0.0055	0.0078				0.0257	492
		$\boldsymbol{\phi_{p,\mathrm{fi}}}$	0.4	1	1.6	2.7				11.2	
600	0.0031	$\boldsymbol{\varepsilon_{p,\mathrm{fi}}}$	0.0041	0.0053	0.0068	0.0122				0.025	442
		$\boldsymbol{\phi_{p,\mathrm{fi}}}$	0.3	0.7	1.2	2.9				7.1	
800	0.0041	$\boldsymbol{\varepsilon_{p,\mathrm{fi}}}$	0.005	0.0063	0.0087					0.0243	393
		$\boldsymbol{\phi_{p,\mathrm{fi}}}$	0.2	0.5	1.1					4.9	
1000	0.0051	$\boldsymbol{\varepsilon_{p,\mathrm{fi}}}$	0.0061	0.0078	0.0122					0.0238	347
		$\boldsymbol{\phi_{p,\mathrm{fi}}}$	0.2	0.5	1.4					3.7	
1200	0.0062	$\boldsymbol{\varepsilon_{p,\mathrm{fi}}}$	0.0073	0.0105	0.021					0.0232	301
		$\boldsymbol{\phi_{p,\mathrm{fi}}}$	0.2	0.7	2.4					2.7	
1400	0.0072	$\boldsymbol{\varepsilon_{p,\mathrm{fi}}}$	0.0095	0.0162						0.0222	222
		$\boldsymbol{\phi_{p,\mathrm{fi}}}$	0.3	1.3						2.1	

* Column 12 lists the temperatures for which a given stress level equals the reduced steel tensile strength $f_{py,\theta}$. The values of $\varepsilon_{p,\mathrm{fi}}$ and $\phi_{p,\mathrm{fi}}$ corresponding to this temperature are shown in column 11.

– the coefficient ($\varphi_{p,\text{fi}}$) calculated according to Eq. (5.1), expressing the ratio of the increase in tendon elongation due to fire temperature to the elongation at the beginning of the fire; Eq. (5.1) has a form analogous to the definition of the creep coefficient of concrete under ordinary conditions.

$$\varphi_{p,\text{fi}} = \frac{\varepsilon_{p,\text{fi}} - \varepsilon_{p,\sigma}}{\varepsilon_{p,\sigma}} = \frac{\varepsilon_{p,0} + \varepsilon_{p,\sigma\theta}}{\varepsilon_{p,\sigma}} \tag{5.1}$$

6. Reduction of secant modulus of prestressing steel and thermal stress relaxation in tendons in members exposed to fire conditions

Based on the diagrams given in Fig. 5 or the strain values summarized in Table 1, it is possible to calculate the secant modulus of prestressing tendons in members exposed to fire ($E_{p,\text{fi}}$), according to the Eq. (6.1):

$$E_{p,\text{fi}} = \frac{\sigma_p}{\varepsilon_{p,\text{fi}}} \tag{6.1}$$

Table 2 shows the values of the relative reduction in the secant modulus of tendons (Y1860S7) in members exposed to fire conditions, depending on the stress occurring in the tendon and its temperature. The values were calculated as the ratio of the secant (resultant) modulus of tendons ($E_{p,\text{fi}}$, according to Eq. (6.1)) to their modulus of elasticity at ordinary temperature (E_p = 195 GPa).

Table 2. Values of relative reduction in the secant modulus of prestressing tendons (Y1860S7) under fire temperature (given values were calculated as the ratio of $E_{p,\text{fi}}$ according to Eq. (6.1) to E_p = 195 GPa)

σ_p [MPa]	**Relative reduction in the secant modulus under fire temperature**								
	100°C	**200°C**	**300°C**	**400°C**	**500°C**	**600°C**	**700°C**	**see col.10**	***[°C]**
100	0.3535	0.2003	0.1373	0.1004	0.0757	0.0566	0.0311	0.0172	768
200	0.5346	0.3309	0.2374	0.1792	0.1190			0.0270	584
400	0.6809	0.4919	0.3728	0.2643				0.0257	492
600	0.7595	0.5854	0.4550	0.2525				0.0250	442
800	0.8136	0.6485	0.4713					0.0243	393
1000	0.8422	0.6587	0.4200					0.0238	347
1200	0.8483	0.5880	0.2926					0.0232	301
1400	0.7521	0.4441						0.0222	222

* Column 10 lists the temperature values for which a given stress level is equal to the reduced steel tensile strength $f_{py,\theta}$. The $E_{p,\text{fi}}$ / E_p values corresponding to this temperature are shown in col. 9.

It is easy to observe that the secant modulus of prestressing steel heated to fire temperature is much smaller than at ordinary temperature. Incidentally, it is worth noting that the values given in Table 2 are much smaller than the coefficients describing the relative reduction in the secant modulus of prestressing steel (referring to the elastic range; $E_{p,\theta}$ given in [1, 13].

When analyzing prestressed members, estimating the thermal relaxation of the stress occurring in the tendons (which can be done on the basis of Fig. 6) can be of greater practical importance than determining the reduction in the secant modulus.

Table 3 presents the values of:

- the initial stress occurring in tendons before the fire (σ),
- the stress ($\sigma - \Delta\sigma$) to which the initial stress (σ) will decrease as a result of heating the tendons to a certain temperature, assuming that the strain is constant,
- the stress reduction in the tendons ($\Delta\sigma$) caused by heating,
- the thermal stress relaxation in the tendons ($\Delta\sigma/\sigma$) calculated from the parameters above.

Table 3. Stress reduction and thermal relaxation in prestressing tendons (Y1860S7) as a function of temperature

σ [MPa]		**Stress reduction under fire temperature**					
		100°C	**200°C**	**300°C**	**400°C**	**500°C**	**600°C**
1500	$\sigma - \Delta\sigma$	1261	1003	720	401	170	39
	$\Delta\sigma$	239	497	780	1099	1330	1461
	$\Delta\sigma/\sigma$	16%	33%	52%	73%	89%	97%
1400	$\sigma - \Delta\sigma$	1195	943	661	361	135	
	$\Delta\sigma$	205	457	739	1039	1265	
	$\Delta\sigma/\sigma$	15%	33%	53%	74%	90%	
1300	$\sigma - \Delta\sigma$	1119	870	592	322	93	
	$\Delta\sigma$	181	430	708	978	1207	
	$\Delta\sigma/\sigma$	14%	33%	54%	75%	93%	
1200	$\sigma - \Delta\sigma$	1015	772	512	258	36	
	$\Delta\sigma$	185	428	688	942	1164	
	$\Delta\sigma/\sigma$	15%	36%	57%	79%	97%	
1100	$\sigma - \Delta\sigma$	912	674	417	187		
	$\Delta\sigma$	188	426	683	913		
	$\Delta\sigma/\sigma$	17%	39%	62%	83%		
1000	$\sigma - \Delta\sigma$	824	591	339	115		
	$\Delta\sigma$	176	409	661	885		
	$\Delta\sigma/\sigma$	18%	41%	66%	89%		

Figure 7 shows diagrams of thermal stress relaxation in tendons as a function of temperature ($\Delta\sigma/\sigma$, according to Table 3). This relaxation is very significant and does not "strongly" depend on the value of the stress present in the tendons before the start of the fire. For example, after the tendons are heated to a temperature of 300°C, a reduction in prestressing force of more than 50% is to be expected.

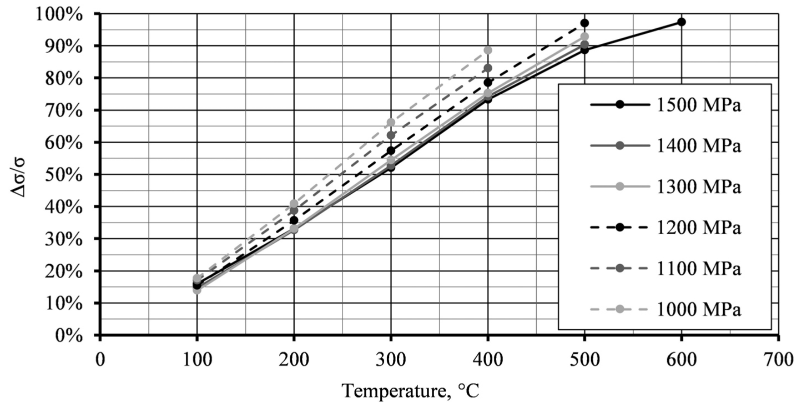

Fig. 7. Thermal stress relaxation in prestressing tendons (Y1860S7) as a function of temperature

However, on the other hand, during a fire, tendons are rarely heated along their entire length. As a result, the actual reduction in force in the tendons should not be as significant as would be expected from Fig. 7.

7. Summary and concluding remarks

The paper provides guidance on using the high temperature degradation model of the mechanical properties of prestressing steel, given in EC2-1-2, which is useful for estimating the reduction in prestressing force in members exposed to fire conditions.

Adequate estimating this force is crucial when calculating the fire load capacity of prestressed members.

Adopting for analysis only the reduction in the steel strength determined from the EC2-1-2 model may be the cause of a significant underestimation of the decrease in prestressing force under fire conditions, or the cause of an overestimation of the design capacity of the section at the ultimate limit state in the exceptional fire design situation.

In order to adequately assess the reduction in prestressing force in members exposed to fire conditions, it is essential to correctly estimate the elongation of tendons caused by the temperature increase. For this purpose, it is necessary to sum up the strain in the tendons caused by the degradation of their mechanical properties under the influence of temperature and the free thermal elongation of steel.

The values given in the paper: the total strain of steel, the relative reduction in the resultant (secant) modulus of steel, and the thermal stress relaxation under the influence of fire temperature, refer to strands made of Y1860 steel.

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Odkształcenia, relaksacja termiczna i zmniejszenie wytrzymałości stali sprężającej w temperaturze pożarowej. Wskazówki na temat praktycznego wykorzystania modelu Eurokodu 2-1-2

Słowa kluczowe: odkształcenia, pożar, projektowanie, stal sprężająca, wydłużenie

Streszczenie:

W artykule przedstawiono praktyczne wskazówki na temat wykorzystania modelu pogorszenia właściwości mechanicznych stali sprężającej w wysokiej temperaturze, podanego w EC2-1-2, przydatne do prognozowania zmniejszenia siły sprężającej w elementach narażonych na warunki pożarowe. Adekwatne oszacowanie tej siły ma kluczowe znaczenie podczas obliczeń nośności ogniowej elementów sprężonych. Przyjęcie do analiz wyłącznie obniżenia wytrzymałości stali określonego na podstawie modelu EC2-1-2 może być przyczyną znacznego niedoszacowania zmniejszenia siły sprężającej w warunkach pożaru. Do adekwatnego oszacowania tej siły konieczne jest zsumowanie odkształcenia cięgien sprężających powstałego na skutek pogorszenia ich właściwości mechanicznych pod wpływem wysokiej temperatury oraz swobodnego wydłużenia termicznego stali. W pracy wskazano również na występowanie analogii między wydłużaniem się stali sprężającej ogrzewanej w warunkach pożarowych, a pełzaniem betonu w zwykłych warunkach oraz podano wytyczne przydatne do oszacowania relaksacji naprężeń w cięgnach i określenia zmniejszania się siecznego modułu odkształcalności stali sprężającej w warunkach pożarowych. Powyższe informacje odniesiono do aktualnie powszechnie stosowanych splotów wykonanych ze stali Y1860.

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