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Influence Of Fire On Steel Bridge Over Vistula River In Puławy

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ABSTRACT

Fire danger on bridges is presented. Fire simulations and stress analyses were performed on new build steel arch bridge over Vistula river in Puławy (Poland). Truck fire on the bridge was simulated with use of CFD algorithms in FDS system. Different fire power and burning trucks locations in relation to the bridge and suspension system were considered. The analysis of high temperature influence on stresses in steel arch and suspension system has been made. Influence stress matrix method was used to perform parametric analyses. Dangerous locations of burning truck for bridge safety were determined during simulations. The coefficient was proposed to estimate structure safety against fire.

INTRODUCTION

The conclusion form the traffic studies shows that the probability of fire in the area of bridge is relatively low. However, the importance of bridge structures, as a parts of road and transportation systems, for local economy and industry is significant. Damaged bridges are usually hard to detour and affect traffic quality in the region. It seems to be reasonable to consider the fire danger of bridges during design process, especially for structures along main roads and highways.

Although bridges are usually made of flame resist materials, traffic accidents can lead to fire develop, Fig 2.. High temperatures occurring during fires, cause additional stresses and thermal strains in structure [1, 2]. Steel is one of the most popular materials in civil engineering, the world's biggest bridges are made of steel. Unfortunately it is very sensitive to high temperatures, it's loads capacity is decreasing in fire's conditions. It can result in damage of bridge elements or, in case of large fires, the structure may even collapse, Fig. 1.

Fig. 1. Bridge collapsed after fire [12]

Fig. 2. Fire on the Big Four Bridge [13]

In extreme cases the bridge equipment, as a plastic cover of suspension system or paint on the steel elements, may begin to burn. The bridge fires cause usually no human casualties but the costs of bridge repair or road close due to fire damage are significant and highly disturb traffic in the area.

The paper presents the algorithm for estimation the temperature of the suspended bridge when fire appears on deck. As an example the new build steel arch bridge over Vistula river in Puławy was analysed Fig. 3. The main span of bridge is 212m long, deck is suspended to two steel arches by the 28 hangers. The arch is a box in cross section. Each hanger is build from 4 steel bars, 82 mm in diameter. The deck is composed with concrete slab and steel grill. It was assumed the temperature, caused by the fire, affects only elements above deck as arch elements and suspension cables. The other issues are fires under bridges, especially in case of girders bridges, where main structure elements ale located below the deck.

Fig. 3. New arch bridge in Puławy

FIRE SIMULATIONS ON THE BRIDGE

There are many mathematical models describing fires in civil engineering structures. Most of them are prepared for fires in closed area of rooms in buildings [7, 8, 9]. Only several models can be used in open space [10, 11] for example to simulate bridge's fires. Complex geometry of bridge and the surrounding terrain can be modelled with use of CFD, the algorithm based on fluid dynamics equations [8]:

$$t_i \quad \{T_d^i, T_z^i, T_g^i, T_w^i\} \qquad (2)$$

$$T \quad col\{t_1,\ldots,t_i,\ldots t_k\} \qquad (3)$$

$$d_i \quad \{t_i,\; t_z^i,\; t_y^i\} \qquad (4)$$

As the results of simulations one can receive temperatures of objects included in computational domain. The temperatures of the bridge elements can be written as in (2). When the fire affects more then one bridge element, temperature can be presented as a vector (3). The temperature t_i, as in (2), can be transformed into thermal loads for structure (4). The scheme of the transformation is shown in Fig. 4. Fig. 5, 6 shows the example temperature distribution in the bridge structure.

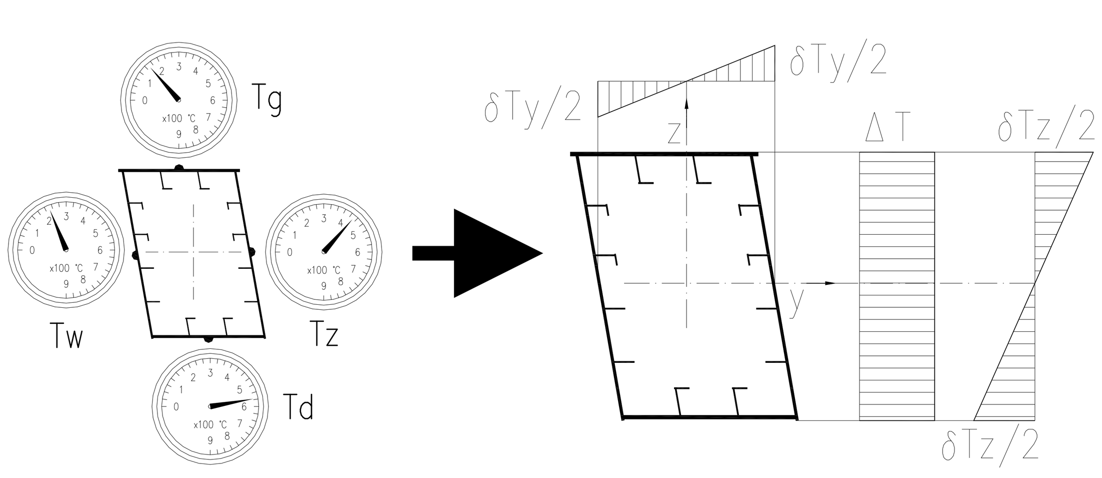

Fig. 4. Temperature transformation

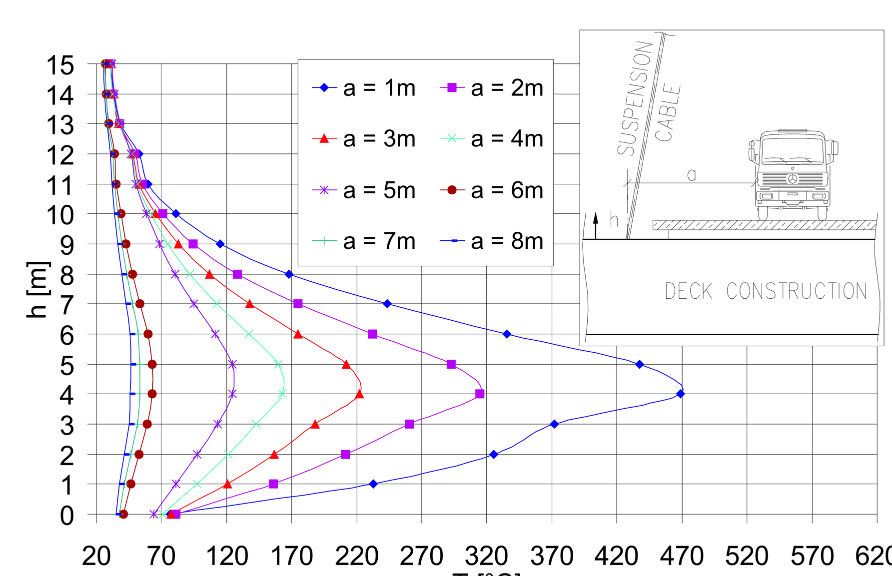

Fig. 5. Hanger temperature

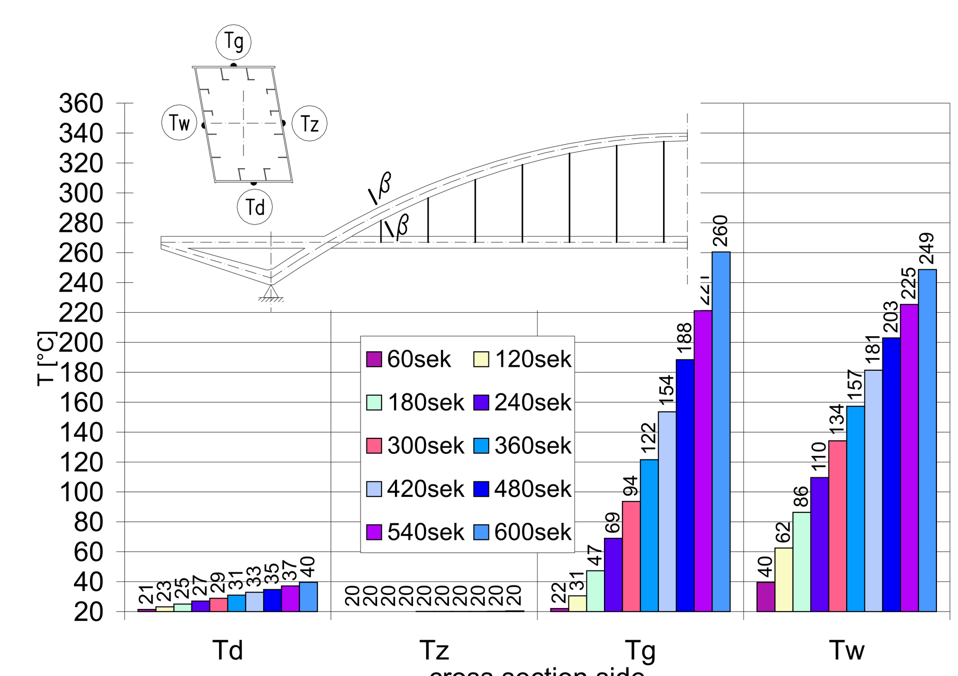

Fig. 6. Arch's cross section temperature

THERMAL INFLUENCE FUNCTIONS

The scheme of analysed bridge and the example locations of elements E and e are shown in Fig. 7. Stresses are analysed in element E, heat is acting on element e. The differences of the temperature of structure generate thermal stresses in element E. However size of fire is usually smaller than the bridges and it can be located in various places on bridge deck. When the most dangerous location of fire, for the stresses in element E, is known, it makes the analyses faster and easier because the only one location of fire could be simulated.

To find such a location the influence function and kinematical excitations for stresses [6] can be used. Excitations forces cause deformation of whole bridge structure, also the element e. Displacement on direction of any force is equivalent to stresses in element E, it is the direct result form definition of influence function. Example infuence functions are shown in Fig. 8 and 9.

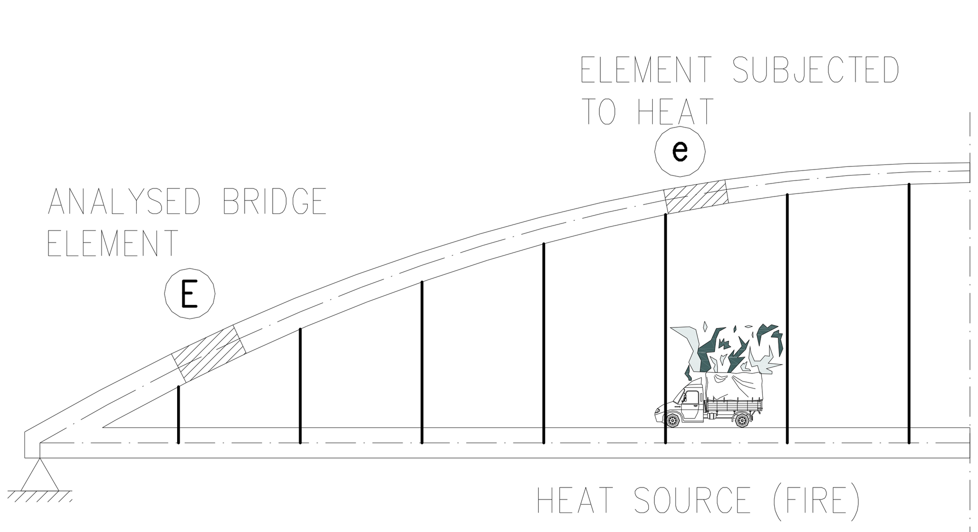

Fig. 7. Ffire on the bridge scheme

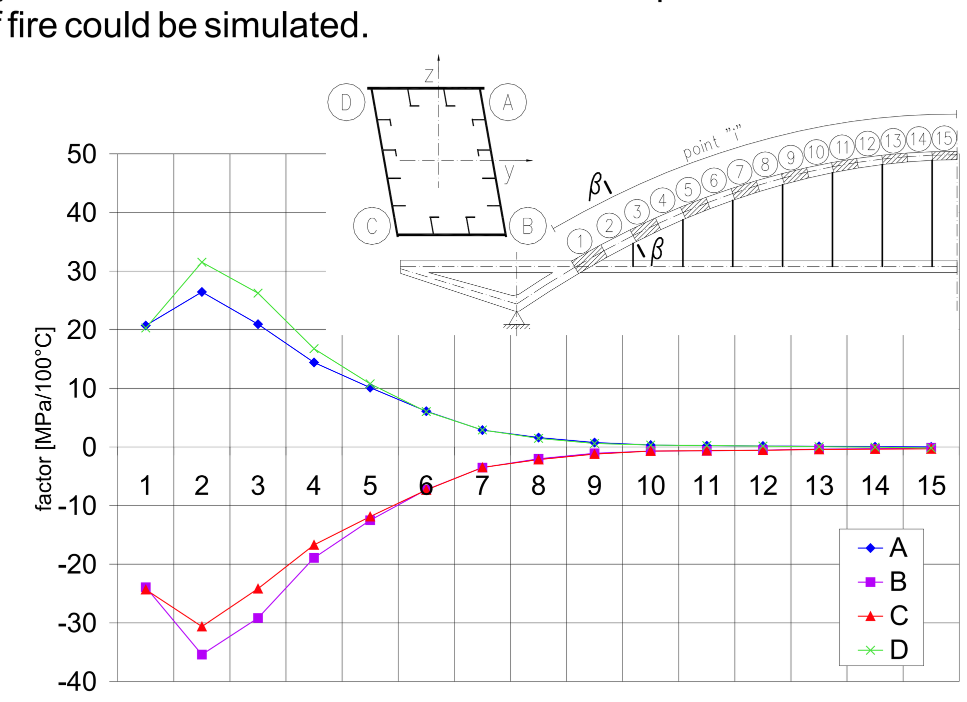

Fig. 8. Thermal influence function I

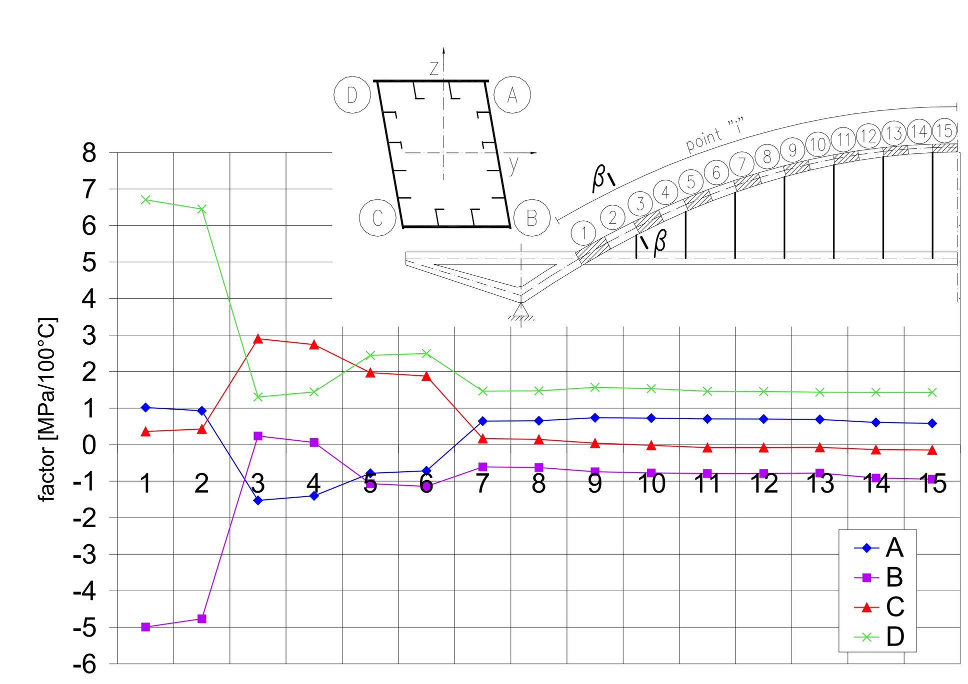

Fig. 9. Thermal influence function I

BRIDGE SAFETY ESTIMATION

To estimate bridge safety the coefficient was proposed. This parameter compares thermal stresses with the stresses generated by the live loads in analysed element E. Live loads match the class A loads form polish design code for bridges. If <1 safety of the bridge is preserved, if >1 the thermal stresses in arch elements exceed stresses generated by live loads and the thermal stresses can lead to bridge's elements or equipment damage. As shown in Table 1, fires with 30 MW peak HRR are not hazardous for analysed bridge. However 120 MW peak HRR fire generate dangerous thermal stresses in bridge structure.Presented algorithm shows the bridge's structure stresses dependence on high temperature generated by fires on the deck. The temperatures during fire reach significant value for bridge safety and should be considered. Use of thermal stress influence functions simplifies the simulations and analyses.

Table 1. Values of coefficient

distance from deck edge to fire [m]	Peak HRR							
	30 MW				120 MW			
	cross section				cross section			
2,40	3,03	0,51	0,34	0,44	7,31	3,28	3,26	4,41
5,70	1,23	0,46	0,31	0,40	2,80	2,08	1,96	2,75
9,00	0,67	0,31	0,17	0,17	1,81	1,43	1,10	1,13

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