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BRIDGE STRUCTURE LOADED BY TERRORIST CHARGE

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Abstract: *During explosion of terrorist charge the structure is loaded by the blast wave. The charge mass of 100 kg TNT was situated firstly above the bridge floor and secondly under the bridge on the level of terrain in the vicinity of one its piers. The reinforced concrete continuous four span bridge beam of chamber sections, supported by thin square piers was used for the determination of the dynamic response of the whole structure. The dimensions and distribution of structure parts were modelled while respecting the structure geometry and its dimensions, in order to obtain the most precise model of the bridge's mass and stiffness. The calculated bridge response in time histories of displacements and angles of rotation of bridge parts are used for structure assessment.*

Keywords: Bridge, Explosive charge, Blast load, Dynamic analysis, Response assesment.

1. Introduction

Usually terroristic charge is located in vehicle on bridge or its proximity. After initiation and during resulting explosion of charge propagates blast wave, whose characteristics depend partly on size of explosive and on the spacing of charge from bridge surface. If come to explosion on roadway in vehicle, then parameters of blast load are effected by height of explosion above roadway and it is possible then this effect simplified interpolate among effect of surface or air burst comprehends at the bridge surface level, or at close vicinity above or near this surface. Propagating blast wave load the bridge surface below angle of incidence, given by the direction ray, connecting focus of explosion and immediate stand of loaded blast wave.

2. Bridge structure

The reinforced concrete bridge structure was used for the dynamic analysis of blast loading and bridge response. The bridge includes four long spans (30 m, 2×45 m, 30 m) with intermediate piers (12.25 m, 17.25 m, 15.25 m) and was made of concrete C 30/37. The computational model and its cross sections in the middle of spans and in supports are illustrated on Fig. 1. The dimensions and distribution of structure parts were modelled while respecting the structure geometry and its dimensions, in order to obtain the most precise model of the bridge's mass and stiffness. Besides bridge dead load, the mass of asphalt part of the roadway were included in the bridge mass.

The bridge was analyzed under blast load of the explosion 100 kg TNT above the mid span above the bridge floor in height 2 m or in the case of charge location under bridge in the vicinity of one its pier in height 2 m above terrain and in the distance 2 m from pier (Fig. 2).

The blast load exerted on bridge floor surface was considered as series of blast sequences (by equations 5 to 10) acting in the selected points of central part of the floor span (Fig. 2) and graduated in some zones in terms of intensity as well as the whole history action on the basis of the real overpressure and underpressure phase of blast wave – dynamic load histories, as a function of the impact wave velocity of propagation. The explosion load is usually burdened with a number of uncertainties, related to determining the amount of explosive medium, its location in relation to the loaded structure, and the conditions of surroundings (Makovička, 2008). These load effects were derived by the authors based on

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the experimental results of small charge explosions. They may be used for an engineering estimation of the probable blast loads. This methodology enables us to determine with sufficient accuracy the time course of the impacting shock wave and its interaction with the structure itself.

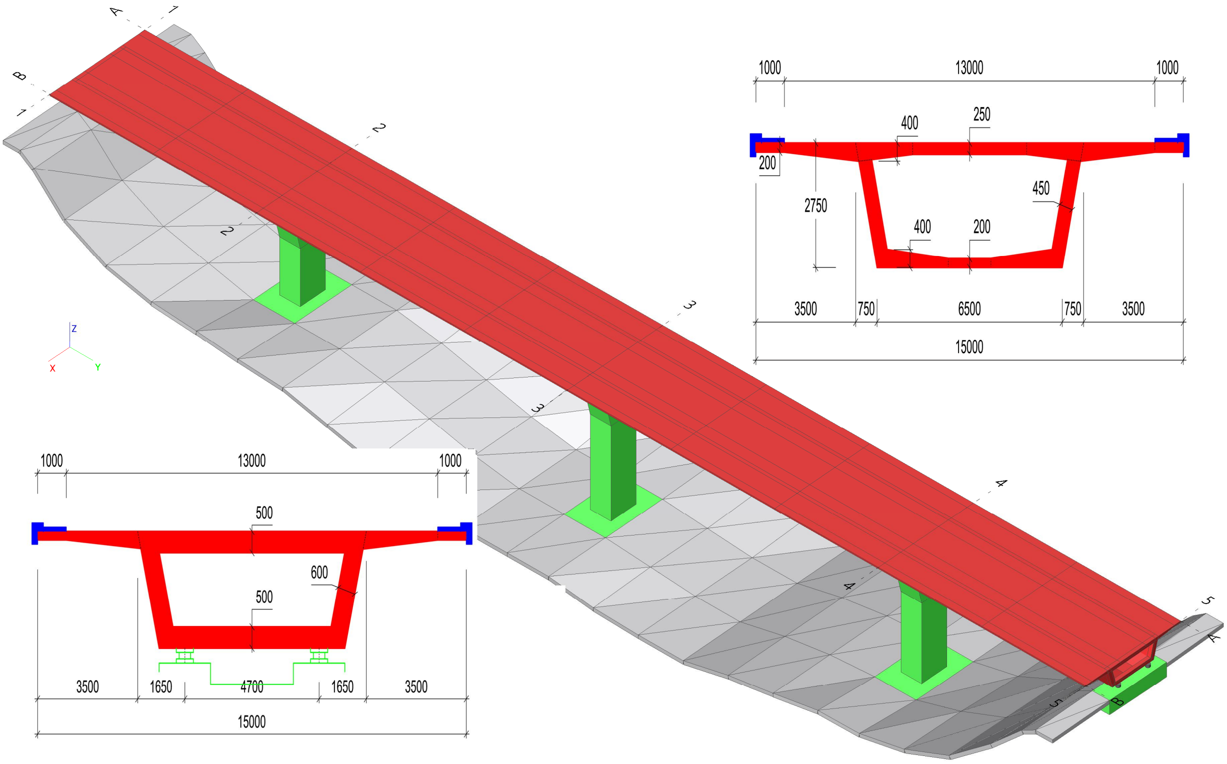

Fig. 1: Bridge structure.

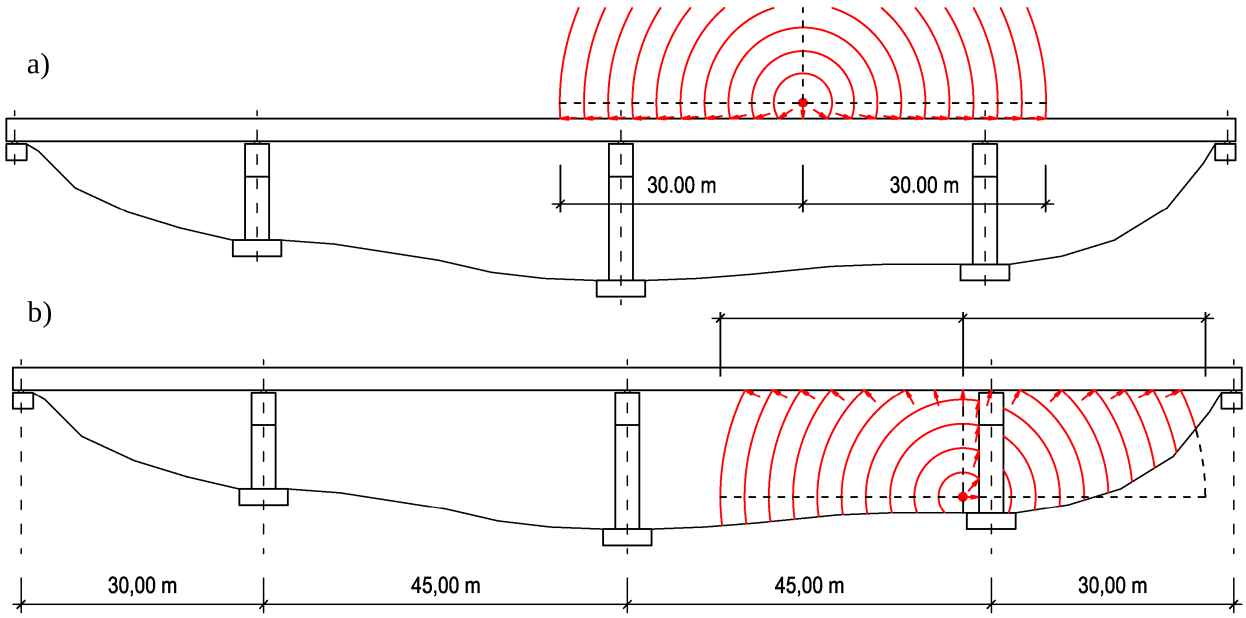

Fig. 2: Location of explosion, a) above the bridge, b) in the vicinity of pier.

3. Load history

The overpressure determined at the face of the air impact wave that spreads from the explosion site to the surroundings stems from the reduced distance (Makovička, 2014, 2015) is:

$$\overline{R} = R/\sqrt[3]{C_W} \qquad (1)$$

where $\overline{R}$ is the reduced separation distance from the epicentre of the explosion [m/kg$^{1/3}$], R is the distance from the explosion epicentre [m], and C_W is the equivalent mass of the charge [kg TNT].

On the basis of comparing various resources in the literature (namely Makovička & Janovský, 2008, Ngo et al., 2007) and our own results of tests walls structures during explosions of small charges, the authors of this paper proposed the application of realistic formulas. Their resulting form corresponds to the impact wave effects from a small solid charge in an open air during this explosion. Maximum overpressure p_+ and underpressure p_- at the face of the air impact wave, velocity v of the wave face propagation and its durations τ_+ and τ_- are applicable both to ground and above-ground explosions:

$$p_+ = 1.07/\overline{R}^3 - 0.1 \text{ [MPa]} \quad \text{for } \overline{R} \le 1 \text{ m/kg}^{1/3} \quad \text{[MPa]} \tag{2}$$

$$p_+ = 0.0932/\overline{R} + 0.383/\overline{R}^2 + 1.275/\overline{R}^3 \quad \text{for } 1 < \overline{R} \le 15 \text{ m/kg}^{1/3} \quad \text{[MPa]} \tag{3}$$

$$p_- = 0.035/\overline{R} \quad \text{[MPa]} \tag{4}$$

$$\tau_+ = 1.6 \cdot 10^{-3} \cdot \sqrt[6]{C_W} \cdot \sqrt{R} \quad \text{[s]} \tag{5}$$

$$\tau_- = 1.6 \cdot 10^{-2} \cdot \sqrt[3]{C_W} \quad \text{[s]} \tag{6}$$

$$v = 340 \cdot \sqrt{1 + 8.3 \cdot p_+} \quad \text{[m/s]} \tag{7}$$

After a normal (perpendicular) impact of the explosion wave on a solid obstacle, a reflected wave is formed with the reflection overpressure p_{ref} that loads the building structure from the front side. The overpressure value in the reflected wave corresponds to approximately twice the value of the overpressure for low overpressure values p+ of approximately up to 5 MPa (up to eight times the value for high overpressures of the order of several MPa) in the incident wave.

$$p_{ref+} \approx 2\, p_+ \tag{8}$$

$$p_{ref-} \approx 2\, p_- \tag{9}$$

4. Bridge response

The decomposition of dynamic load history to the natural modes of vibration is used for the forced vibration analysis by means of Scia Engineer program. 100 lowest natural modes and frequencies of vibration in the interval 1.9 Hz to 21.6 Hz were considered in the computation. The damping of the structure of the building has been set as a damping ratio of 4 %. The calculation of forced vibration has been made with 1000 time steps of 0.0005 s. The dynamic analysis was made for linear elastic behaviour of the structure material. As an example of the bridge deformation, vertical displacements are shown in Fig. 3, and Fig. 4 presents angle of rotations.

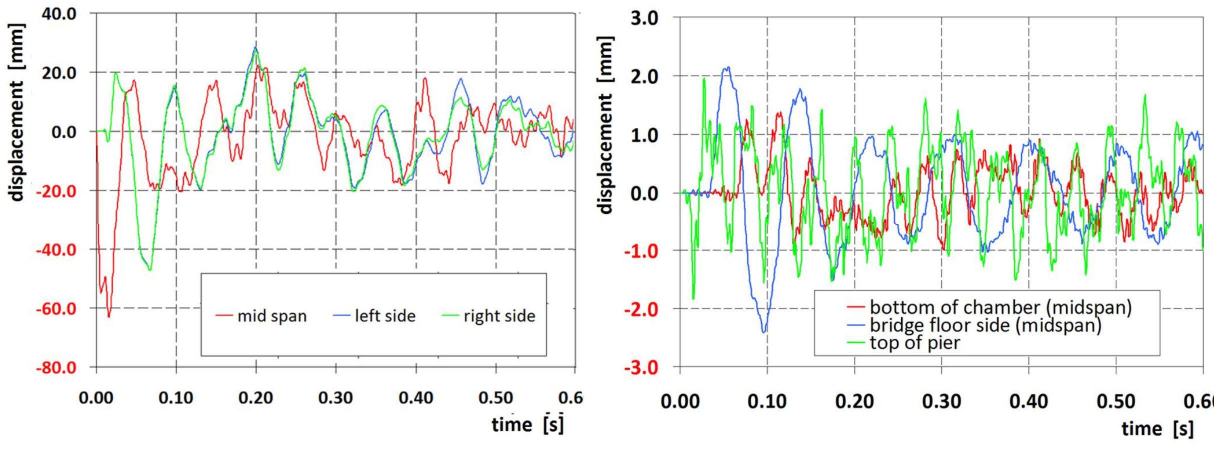

Fig. 3: Time histories of displacements U_z for above (at left) and under (at right) bridge explosion

The calculated rotations (angle ψ) of the middle surface of structural parts are used for structure assessment. The maximal angle of the rotation is 1.3 degrees round the both horizontal axes. The limit rotation for RC prestressed beam and plate structure for mean damages is 1 degree (Mc Cann, 2007; Makovička, 2008, 2015). It is clear that damages for above floor explosion are greater then the limit value. For the under bridge explosion the effects of explosion are much smaller. The bearing capacity of the whole bridge structure may in the case of above floor explosion be serious threatened.

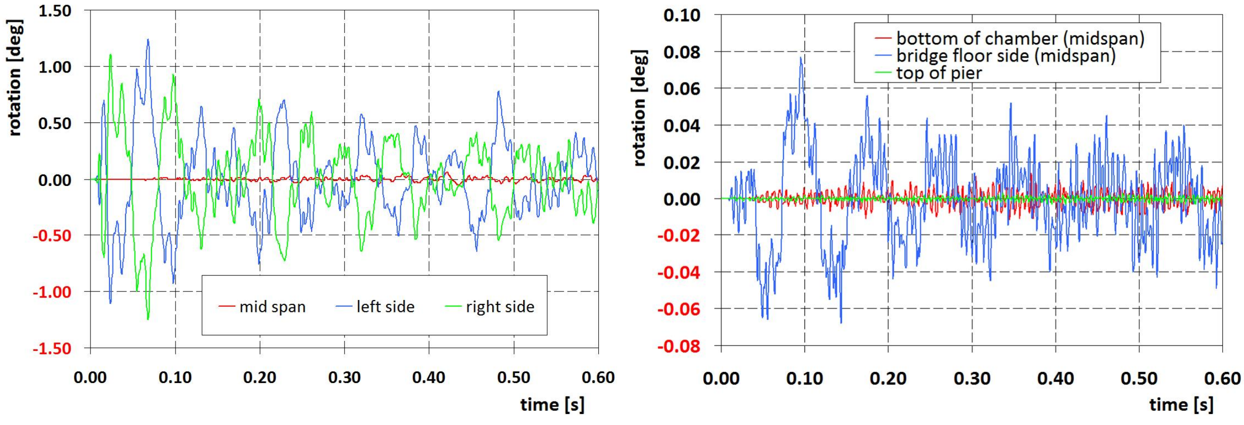

Fig. 4: Time histories of rotations F_y for above (at left) and under (at right) bridge explosion

5. CONCLUSIONS

Paper is determined to the problem of an explosion and the threat to the safety of the structure due to the explosion of an explosive charge installed in a car and initiated on the bridge or under bridge. The explosion load is usually burdened with a number of uncertainties, related to determining the amount of explosive medium, its location in relation to the loaded structure, and the conditions in the surroundings. These load effects were derived by the authors based on the experimental results of small charge explosions (Makovička. 2015). They may be used for an engineering estimation of the probable blast loads. This methodology enables us to determine with sufficient accuracy the time course of the impacting shock wave and its interaction with the structure itself.

The authors have used limit rotation values (angle of failure), as an efficient method for response assumption. Evaluating a structure on the basis of the limit rotation is a methodology under development at present, and is in accordance with recent research trends for structure loaded by blast wave of explosion. The results for the response of the bridge to this load are presented in parts, together with the principles for evaluating the structure according to the displacements and to the angle of failure corresponding to the given explosion load and its location.

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