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LOADING TO STRUCTURES BY REMOTE EXPLOSION

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Abstract: *There are many events which are not solved as extreme design situations in present standards used for bridge design, maintenance and refurbishment - the safety of the users must be a priority of the bridge design. Explosions which endanger bridges can be caused by two cases – an explosion due to terrorist attack and the explosion due to an accident. It is necessary to study both of these cases. The blast loading of a structure can cause fatalities due to the blast wave and possible consequent progressive collapse. The paper summarizes numerical methods used for evaluation of fast dynamic phenomena and methods for determination of substitute loading of an explosion adjacent to a structure.*

Keywords: ***Design situation, bridges, remote explosion, blast wave, computational tool.***

1. Methods for determination of substitute loading of an explosion

In a case of a remote explosion it is not necessary to perform sophisticated numerical simulations; the results can be obtained easily by the methods for determination of substitute loadings of an explosion. These allow us to specify loadings on structures according to position of the detonation epicentre and its strength. The damage of a structure can be then specified from the effect of this loading (Karasová et al., 2010).

1.1. The procedure of solution

Moving solid is affected by inertial, damping and elastic forces. These forces are in equilibrium with external loading. The equation of motion (Eq. 1) is strongly time dependent.

$$M \cdot u''(t) + C \cdot u'(t) + K \cdot u(t) = p(t) \tag{1}$$

The solution of motion equation can be carried out easily by direct numerical integration. It is necessary to perform time discretization for the solution. The solution can be carried out by method of implicit or explicit time integration.

The effects of impulse waves can be evaluated by empirical methods. These methods are based on reduced and dimensionless characteristics. The basis for the solution of the impulse wave parameters became "cube root law" Eq. (2), by Hopkinson (1915). If two charges of same material and geometry, but different weight detonate, they produce similar impulse waves in the same reduced distances. A reduced distance Z is approximated by formula

$$Z = \frac{R}{W^{1/3}} \tag{2}$$

where R is the epicenter distance, W explosive weight (TNT equivalent)

Many formulae by different authors exist for overpressure in the front of impulse wave. One of the most widely used formulae is based on equations developed by Russian authors and given by

$$p_{+} = \frac{0{,}1}{Z} + \frac{0.43}{Z^{2}} + \frac{1.4}{Z^{3}} \tag{3}$$

where Z is the reduced distance Eq. (2), p_{+} is overpressure in the front of impulse wave.

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The reflected wave - overpressure p_{ref} is created by normal impact of impulse wave on a barrier. The reflected wave loads the structure on the front side. The overpressure in reflected wave multiplies the overpressure in reflected wave 2 to 8 times for a given distance Z.

$$p_{ref} = 2p_+ + \frac{6p_+^2}{p_+ + 0{,}72} \tag{4}$$

1.2. The effect of instantaneous pulse

The univariant system can be represented by material, which is fixed to an immaterial post. By stretching (compressing) of the post, the force increases linearly, as long as the deflection obtains to the value of full elastic deflection v_e. The post is stretched by a constant force R_0 as long as the post breaks. We expect that the system, which is impacted with an instantaneous pulse S, is at rest. The pulse gives the system an initial velocity $v'(0) = S/m$. The material m has a kinetic energy of

$$K = \frac{1}{2} m v'^2(0) = \frac{1}{2}\frac{S^2}{m} \tag{5}$$

and the work necessary for stretching the post to a deflection v_m is

$$L = \frac{1}{2} R_0 v_e + R_0 (v_m - v_e) \tag{6}$$

Equating $K = L$, the pulse can be formulated as

$$S_0 = \sqrt{m v_e R_0 (2k_m - 1)}\,;\, k_m = \frac{v_m}{v_e} \tag{7}$$

An overshoot to negative direction by $v_m \geq 2v_e$ does not arise. The material should make undamped oscillation with an amplitude v_e around the new neutral position moved by $v_t = v_m - v_e$. Due to the influence of damping, the vibration amplitude is smaller. The vibration stops and the material stays at rest, deflected in constant deformation v_t from the starting position.

1.3. Determination of the dynamic coefficient

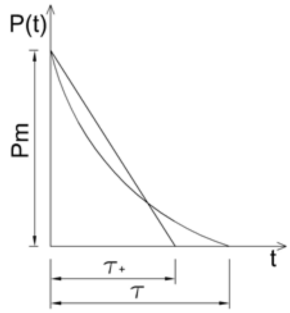


Fig. 1: A substitute of real impulse wave progress by a triangle.

If the impulse wave overpressure time t_+ is big in comparison to the period of natural vibration T of the structural element, the maximal deflection arises in a fraction of total overpressure time t_+. Only small part of the curve P(t) reflects structural loading.

The solution for triangle force

$$P(t) = P(1 - \frac{t}{\tau_+}) \tag{8}$$

N. M. Newmark formulated following empirical formula for the dynamic coefficient:

$$\frac{1}{\delta} = \frac{T}{\pi.\tau_+}\sqrt{2k_m - 1} + \frac{1 - \frac{1}{2k_m}}{1 + 0.7\frac{T}{\tau}} \tag{9}$$

where $T=2\pi/\omega$– a period of natural vibration, ω– radial frequency of natural vibration, τ_+ - an alternate pressure time, $k_m= v_m / v_e$ – a modulus of ability of deformation, $\delta= R_0 / P$ – a dynamic coefficient (a ratio of system resistance R_0 and a maximal force P).

2. Loading caused by remote explosion

A computational tool for assessing the effect of remote explosion was developed. It combines the described methods and produces comprehensive results. Several case studies for most important bridges in Prague were performed using this tool REMEX - *http://concrete.fsv.cvut.cz/~foglar/*.

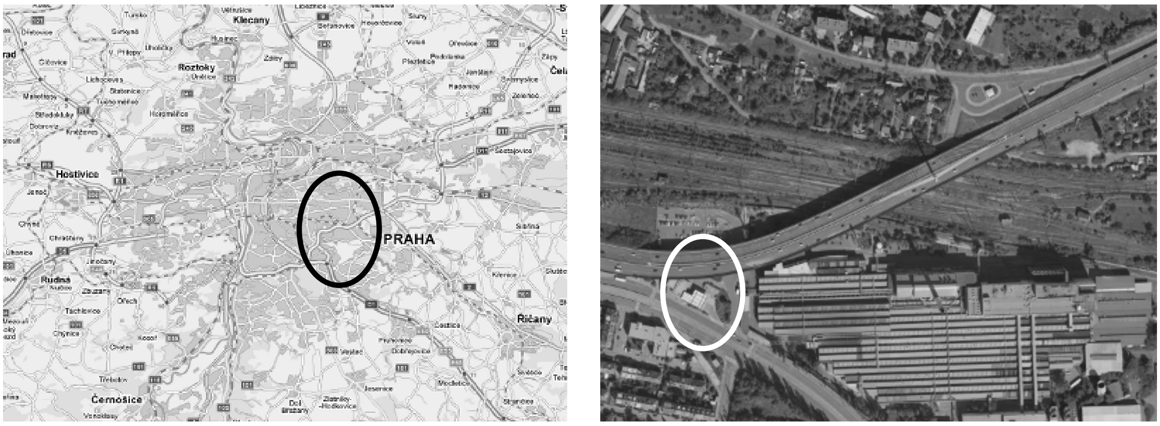
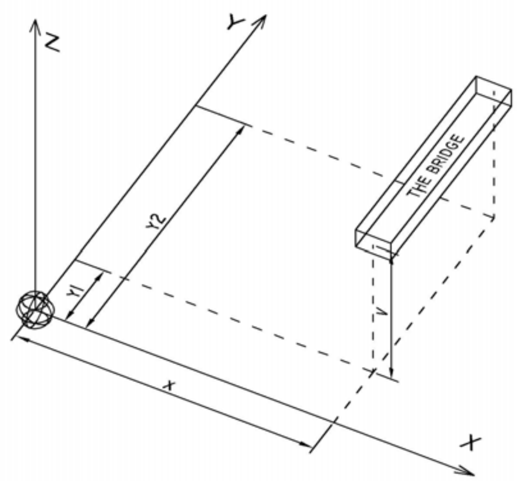


Fig. 2: Petrol station near the cable-stayed bridge in Prague (source: www.mapy.cz).



THE BRIDGE LOADING

THE CHARGE PARAMETERS

weight of the charge	W	50	kg
kind of the charge	Semtex		5
the equivalent TNT charge weight	Cw	118.57	kg
the vertical distance to bridge axis	coordinate x	50	m

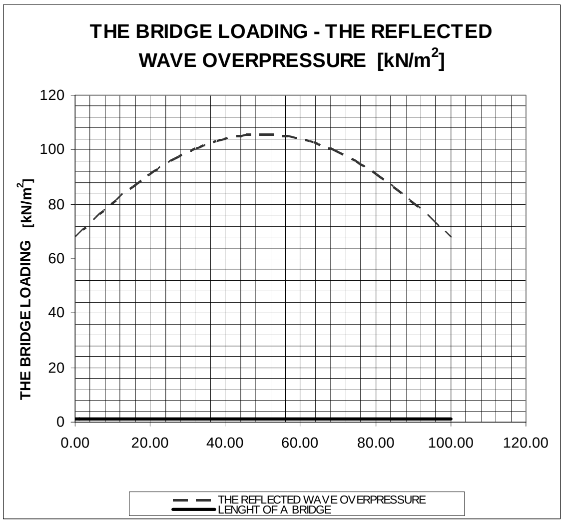
THE BRIDGE PARAMETERS

the lenght of the bridge		100	m
the bridge start	coordinate y_1	-50	m
the bridge end	coordinate y_2	50	m
the bridge elevation	coordinate z	8.5	m

Fig. 3: The input data for solution.

The rates of distant detonation (due to fire and consequent detonation of a petrol station) were analysed as well. The scheme (Fig. 3) shows determination of charge parameters and 3-D relations between epicentre and endangered structure (Sochorová E. & al. 2011).

Fig. 4 shows overpressure (underpressure) in front of impulse wave and loading of the bridge. These values are adequate for 50 kg of Semtex explosive placed 50 m far from the centre of a 100 m long bridge structure.



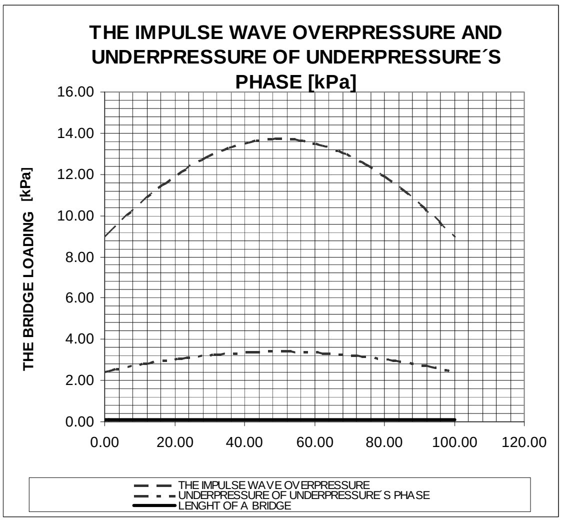


Fig. 4: Overpressure (underpressure) at the front of an impulse wave, loading of a bridge.

Another possible outcome of the explosion of the petrol station is the infringement of the foundation soil. One of the basic boundary conditions for using this tool is that the foundations of the bridge are not damaged by the explosion.

The values of overpressure and behaviour of the impulse wave were produced by the described computational tool. The caused loading can be used as extreme loading from the point of view of bridge design.

3. Conclusions

The paper summarized numerical methods used for evaluation of fast dynamic phenomena and methods for determination of substitute loading of an explosion adjacent to a structure.

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