Simulation of air blast waves and the loading of glass sheets

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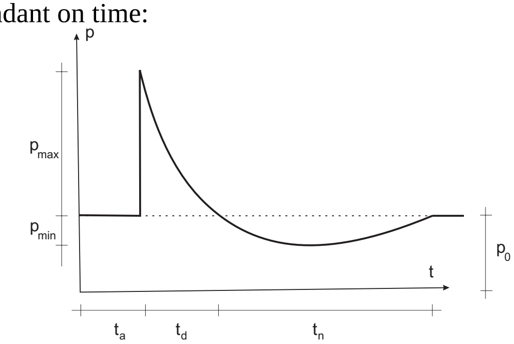
The objective of this work is to contribute to alleviating the vulnerability of passenger transport infrastructures against terrorist attacks. The nature of land mass passenger transport is an open system which cannot be controlled like airplanes. Therefore, this open system is much more vulnerable which evidently is shown by the attacks in Madrid and London. The investigation shall give recommendations to ensure stations, trains and undergrounds railway systems against terrorist attacks.

If an explosive detonates the region close to the explosive is, in most cases, totally damaged. The loading of the materials in this region is very high and occurs very fast. Failure of material in this region can only be avoided by heavy and thus expensive modifications. Due to the fact that this region is relatively small, these local effects are not part of this investigation.

From the location of the detonation an air blast wave develops. This air blast wave has a characteristic form. The resulting pressure in a defined distance can be described by the modified Friedlander equation which is dependant on time:

$$p(t) = p_0 + p_{\max}\left(1 - \frac{t}{t_d}\right)^{-\frac{bt}{t_d}}$$



Further parameters involved in this equation are the atmospheric pressure p_0, the maximum overpressure p_{max} and the duration of the positive pressure t_d. The parameter b describes the decay of the curve. All parameters for the pressure-time curve can be taken from different diagrams and equations (e.g. Kingery [1]). The behaviour of the air blast wave also depends on the boundary conditions. The pressure of a reflected wave can be up to 8 times higher than a free field pressure. Therefore, the geometrical configuration around the detonation has to be considered.

Most structures in land mass transport systems, in particular trains and underground railways, are closed structures. Therefore, an air blast wave is not evolved as a free field wave. Due to different effects like reflections, street channelling (see e.g. Rose [2]) a fluid calculation of this problem is essential. The numerical simulation is done here with the explicit solver EUROPLEXUS [3] which allows for a coupled fluid structure calculation.

The behaviour of the explosive can be regarded with different methods. A solid TNT model describes the explosive by solving a JWL Equation (see Dobratz [4]). The pressure ratio between the pressure inside the explosive and the atmospheric pressure is quite high. Therefore, the element size in this region has to be very small. The structure in fact, for example a railway station, is relatively large. This results in large computation times. To reduce these costs, a calculation can be done with tetrahedrons varying in sizes combined with partitioning (not all elements are calculated at every time step, see Halleux [5]). Alternatively a mapping algorithm can be used which maps one-dimensional results into a three-dimensional calculation by using the internal variables (e.g. with AUTODYN, see Fairlie [6]).

In most cases the behaviour of the explosive itself is not of interest. The detonation results in overpressure that develops around the location of the explosion. Thus, the question arises whether a bubble with an overpressure can also be used for the reproduction of an air blast wave. This bubble should be much bigger than the explosive in order to allow the use of larger elements. A method will be presented to calculate the overpressure in a bubble by a given size of the charge and a given size of the bubble. This method will be compared with a solid TNT calculation and with experimental data from Kingery [1]. The calculation of an urban environment shows good correlation with experiments.

The windows of the trains are in most cases built with laminated security glass (LSG) whereas the construction of the trains is in most cases built with steel or aluminium which is much stiffer than glass. Experience shows that mostly the glass sheets of the investigated structures fail. Therefore, the behaviour of the glass is a very important part of the investigation due to the fact that a broken glass sheet results in a releasing surface. In such a case the impulse of the air blast wave decreases.

LSG is built with two sheets of float glass combined together with an interlayer (PVB). The idea of this type of composite is that after the cracking of the glass the interlayer can sustain additional displacements. The splinters of the glass are restrained from flying away. There are different ways simulating LSG which vary in the number of elements through the thickness. The differences between a smeared model with two layers proposed by Timmel [7] and models with three layers through the thickness loaded by an air blast load will be presented.

References:

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