Gas explosion effects on methane–tank elements

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Abstract: - The paper deals with general aspects of the effects of explosion on buildings and in particular on methane-tanks The first part of the paper is devoted to authors proposals on correlation between dynamic coefficient with ductility and ratio pulse time to natural period .The second part presents the influence of the blast pressure on structural elements of a methane-tank and necessary measures in the design of new structures as well as rehabilitation procedures for existing elements.

Key-Words: - gas explosion, methane-tank, blast pressure, reinforced concrete structure, rehabilitation, structural analysis

1 Introduction

Any explosive detonation in a gaseous medium gives rise to a sudden pressure which increases in that medium. This pressure is characterized by an almost instantaneous rise from the ambient pressure to a peak incident pressure P_{so}.

Blast pressure is characterized by the explosive weight, expressed as the equivalent weight of TNT and the radial distance between explosion centre and target. In general, in order to characterize the blast pressure it is used a global parameter called scaled range Z [1, 2].

The main parameters of blast pressure for dynamic analysis of concrete members are: the natural period T for free vibrations, the ductility factor ρ, the dynamic coefficient μ and the pulse time of the blast pressure t_d.

This paper deals with the correlation between this parameters and blast pressure.

2 The relevant parameters of blast pressure

The peak load P_{so} may be obtained from the correlation ratio of the equivalent static load P_{st} to peak load with ductility ratio and pulse time to natural period ratio (fig. 1) [3]. The ductility factor represents the ratio between ultimate strain of compressed fibre and ultimate strains of tensioned fibre. The pulse time of the blast pressure can be expressed with equation (1):

$$t_d = 10 \cdot \frac{R}{Z} \qquad (1)$$

where: R – radial distance between centre and target
Z – scaled range

The natural period is obtained from equation (2) with the static deflections (a_{st}) due to gravity load applied in the vibration direction.

$$T \cong 2 \cdot \sqrt{a_{st}} \qquad (2)$$

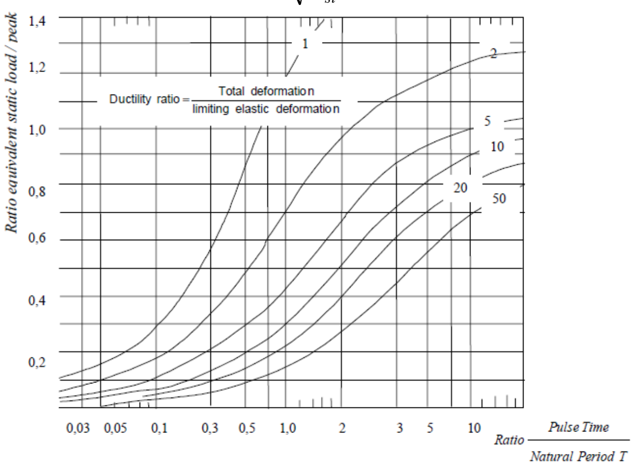

Fig. 1 - Ratio of the equivalent static load function on ductility ratio, pulse time and natural period [3]

The pulse time of blast pressure represents the positive phase of duration, as it can be seen from the variation of the blast pressure with time (fig. 2). The positive phase is extremely short, leaving almost no time for elements to respond before the negative phase begins.

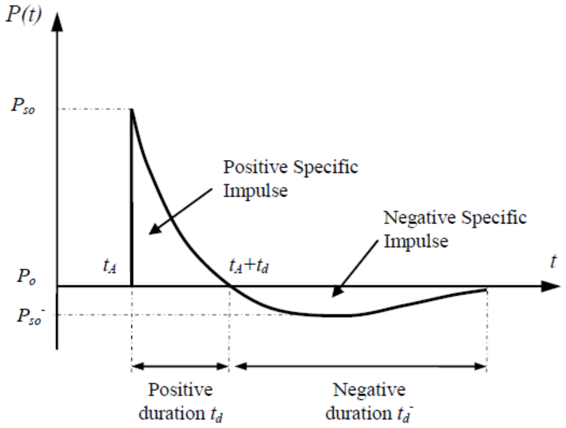

Fig. 2 – Variation of the blast pressure with time [4]

Based on the correlation ratio (fig. 1), it is possible to find a relationship between dynamic coefficient, ductility factor, and pulse time to natural period ratio as follows.

3 Authors proposal for correlation between the parameters of blast pressure

The correlation ratio of the peak load to the equivalent static load with ductility ratio and pulse time to natural period ratio proposed by authors is presented in figure 3.

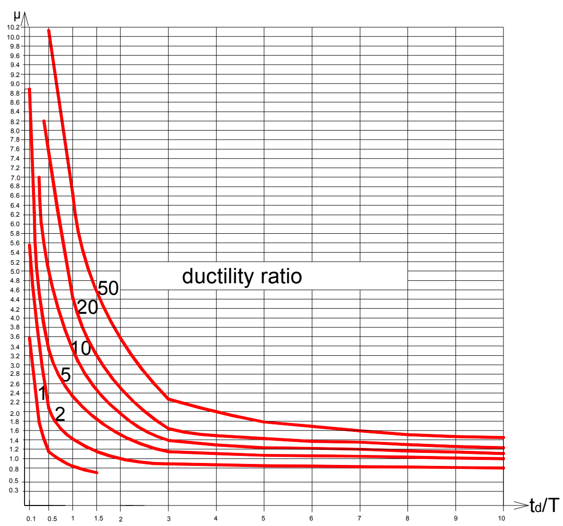

Fig. 3. – Correlation ratio of the dynamic coefficient with ductility ratio and pulse time to natural period ratio

Based on this representation of dynamic coefficient according to ductility ratio and pulse time to natural period ratio, two equations (3) and (4) were derived by authors for the calculus of dynamic coefficient.

- for $t_d/T < 1$

$$\mu = \sqrt{\rho \cdot \frac{T}{t_d}} \tag{3}$$

- for $t_d/T > 1$

$$\mu = 1.4 - \frac{1}{\sqrt{\rho}} + \sqrt{\rho} \cdot \left(\frac{T}{t_d}\right)^2 \tag{4}$$

The curves for the values of dynamic coefficient calculated according with equations (3) and (4), were drawn over the curves from figure 1, resulting the following figure:

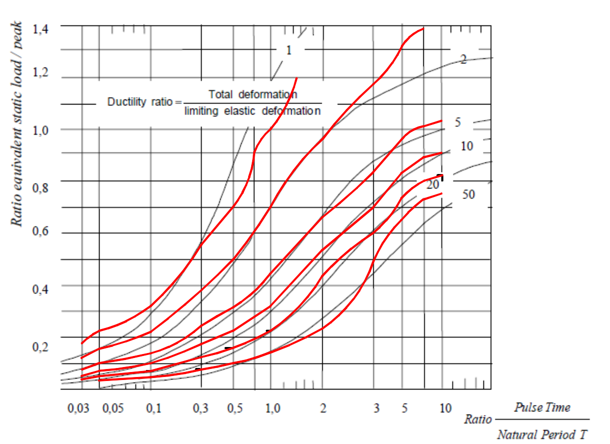

Fig. 4. - Ratio of the equivalent static load function on ductility ratio, pulse time and natural period – overlapping curves

It can be seen that the curves are approaching satisfactory to those determined by other authors [3]. This fact means that the equations for the calculus of dynamic coefficient were properly derived.

4. Structural analysis of a methane-tank

4.1. Parameters for methane-tank calculation

The relevant parameters of blast pressure were determined for the cylinder wall and the dome roof of a methane-tank from Wastewater

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Treatment Plants Oradea. The tank is a cylindrical structure 10.75 m in height and 19 m in diameter (fig. 5) [5].

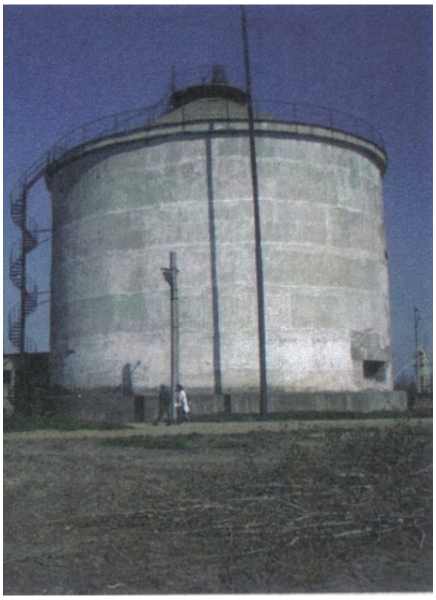

Fig. 5. Methane- tank from Wastewater Treatment Plants Oradea

The results for the relevant parameters of the structural members subjected to blast pressure are presented in Table 1 [6].

Table 1. - Relevant values of structural members subjected to blast pressure

Parameter	Wall of the tank	Dome roof
Cracking bending moment m_{cr} (kN·m)	45.26	19.8
Maximum bending moment m_{max}(kN·m)	173.18	96.9
Maximum static load P_{st} (kN/m^2)	60.17	35.3
Static deflection a_{st} (mm)	0.596	0.351
Natural period T (ms)	48.82	37.5
Ratio pulse time on natural period t_d/T	0.85	1.1
Ductility factor ρ	4.67	4.67
Peak load P_{so} (kN/m^2)	146.2	74.5
Dynamic coefficient $\mu = P_{so}/P_{max}$	2.43	2.11

The bending moment was calculated with equation (5).

$$m_{cr} = \frac{f_{ctm} \cdot I_1}{y_t} \qquad (5)$$

where: : f_{ctm} – the mean value of axial tensile strength of concrete
I_1 - the second moment of the area of the uncracked section
y_t=h–x
h – the overall depth of a section
x – depth to the neutral axis

The natural period was obtained from equation (2).
The static deflections for the cylinder wall and dome roof were calculated according to equation (6) and (7).

$$a_{st} = \frac{P_{st} \cdot r^2}{E \cdot \delta} \qquad (6)$$

where: P_{st} – maximum static load
r – radius of the tank, r =9.675 m
E – modulus of elasticity of concrete
E = 27000 N/mm^2 (C16/20)
δ – wall thickness, δ = 35 cm

$$a_{st} = \frac{z}{E \cdot \delta}\left(N_\theta - \mu \cdot N_x\right) \cdot ctg\alpha \qquad (7)$$

Maximum static load P_{st} was determined based on load capacity $N_{\theta,cap}$ which can be expressed with equation (8) for the cylinder wall.

$$N_\theta = P_{st} \cdot r \qquad (8)$$

In the case of dome roof the efforts can be expressed with equations (9) and (10).

$$N_x = \frac{-g}{2 \cdot \sin^2 \alpha}\left(z - \frac{z_1^2}{z}\right) \qquad (9)$$

$$N_\theta = \pm g \cdot z \cdot ctg^2\alpha \qquad (10)$$

The pulse time of blast pressure was calculated according to equation (1). The peak load P_{so} was obtained from the correlation ratio of the peak load to the equivalent static load with ductility ratio and pulse time to natural period ratio (fig. 3).
Based on the relevant parameters values in table 1, it were obtained the assumed model of blast pressure and structure elements response (fig. 6) [6].

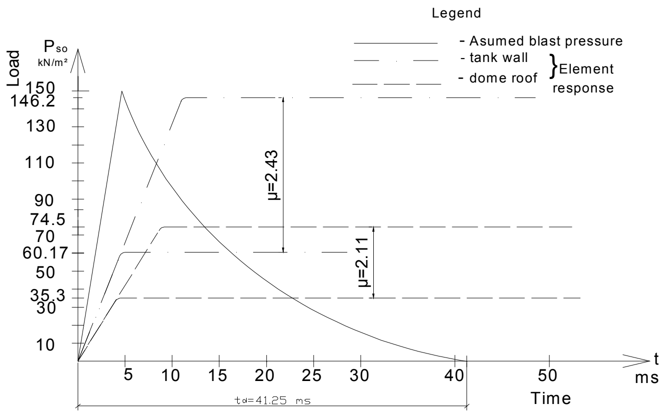

Fig. 6 . – Model of blast pressure and elements response

4.2. Effects of explosion on stress state

The analysis of the state of stress in the methane-tank was performed using the program AXIS. The bending moments diagrams were obtained taking into account the following load assumptions:

- case 1º- load assumptions that are used in current design (fig. 7) as permanent load, dead load and live load
- case 2º - load assumptions that comprise the blast pressure too (fig. 8).

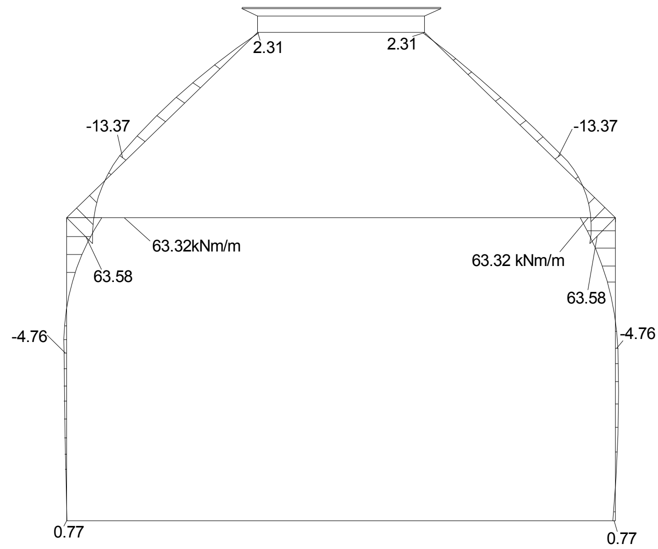

Fig. 7. – Bending moments diagram Case 1º

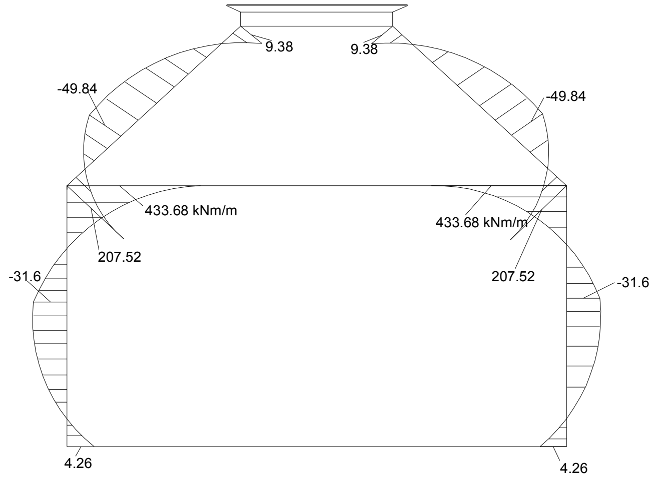

Fig. 8. – Bending moments diagram Case 2º

The bending moments are significantly higher in the second case than in the first one, which means that the stress state is affected by the blast pressure.

5. Conclusions

From the correlation between some parameters of blast pressure and the structural analysis of a methane-tank the following conclusions can be drawn:

- The effects of explosion on structural elements are function of peak incident pressure.
- Two equations were derived for the calculus of dynamic coefficient. Based on the values of dynamic coefficient calculated according to these equations it was performed the correlation between dynamic coefficient, ratio ductility, pulse time and natural period.
- The structural analysis of a methane-tank revealed that the stress state is affected by the blast pressure.
- The authors propose to take into account the blast pressure in design for new structures as well as for strengthened structures with high risk of explosion.

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