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BLAST EFFECT ON CONSTRUCTION BARRIERS FROM EXTERNAL LOAD INCLUDING ANGLE INCIDENCE

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ABSTRACT

The paper presents the method of determining the impact of an external explosion on construction barriers, taking into account the angle of the shock wave. For the presented two variants of the analysis, i.e. for the load placed at a distance of 5 and 10 m from the construction barrier, the initial pressure of the reflected wave, the duration of overpressure and the course of load variability over time were determined. For the assumed parameters of the barrier and the blast load, the values of overpressure were determined, taking into account the angle of incidence and the angle of reflection. Additionally, a comparative analysis of the proposed method with other methods available in the literature was made. The convergence of the results did not exceed 10%. The proposed method allows to determine the boundary between the Mach and the incident waves.

Key words: construction mechanics, blast load, incident wave overpressure

INTRODUCTION

The most common methods of determining explosive loads in an analytical manner include the methods of Sadovskiy (1952), Sachs (1955), Henrych (1979), Baker, Cox, Weslina, Kulesz and Strehlow (1983), Bulson (1997). However, some of the more recent studies are the methods of Cormie, Smith and Mays (2009), Hussein (2010), Kelliher and Sutton-Swabi (2011), Draganić and Sigmund (2012), Parisi and Augenti (2012), Siwiński and Stolarski (2015), most of these methods are based on approximation and analytical studies and are often transformations of Baker's and Henrych's methods. In the Polish literature, there are descriptions of methods for determining explosive loads, including, among others, in a textbooks by Krzewiński (1982, 1983), the monographs by Włodarczyk (1994), and Cudziło, Maranda, Nowaczewski, Trębiński and Trzciński (2000), a technical study by Krzewiński and Rekucki (2005). An alternative method of determining the explosive loads is to use ready-made procedures, e.g. the TM5-1300 procedure, developed by the US Department of the Army and included in the study of Brun, Batti, Limam and Gravouil (2011). In turn, the most common software for determining explosive loads is the ConWep program, which was used, among others, by in the papers of Kelliher and Sutton-Swaby (2011), and Lin, Zhang and Hazell (2014). Another used software of this type is the ATBLAST (Fu, 2012). In the publication by Birnbaum, Clegg, Fairlie, Hayhurst and Francis (2012), consider the comparison of the variability over time of the explosion load determined according to various analytical procedures and with the use of software. It was found that the analytical procedures show a high agreement of the results with computer methods, which is most likely a result of using the same or similar starting assumptions.

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This paper presents a phenomenological approach to the method of determining the load on building structures due to the explosion of an explosive charge located outside the structure. The overpressure on the front of the incident wave was determined on the basis of tabulated algorithms for determining the characteristics of the external impact, generalised on the basis of procedures known in the literature, based on the article by Siwiński and Stolarski (2015). The paper presents the differentiation of the type of wave affecting the building barrier depending on the angle of incidence. Examples of determining the explosive load on buildings have been developed with simplifying assumptions consisting of: (1) using approximation formulas, (2) treating the construction barrier as a rigid body subject to only the explosive load, (3) disregarding the influence of load waves reflected from opposite or neighbouring buildings located in the street development.

The purpose of the paper is to present the distribution of shock waves depending on the angle of incidence and reflection angle on the surface of a rigid construction barrier.

EXTERNAL EXPLOSION PARAMETERS

Detailed information on the procedure of determining the external load is presented in the paper by Siwiński and Stolarski (2015). Figure 1 shows a diagram of the propagation of a Mach wave, that is, a blast wave with a smooth, evenly distributed waveform and an incident wave defined by the reflection angle. The Mach wave can be defined as the resultant of the incident wave and the reflected wave from the ground with an almost even distribution. The incident wave is represented by the continuous line, the wave reflected from the ground is represented by the dashed line. On the other hand, the straight lines indicate the Mach waves above the triple point, the building is affected by the incident wave, and below the triple point, the Mach wave. The triple point is the point where the three depicted waves intersect and marks the boundary between the waving and incident waves. The triple point is found using a reflection angle of 40° according to Cormie, Smith and Mays (2009).

ANALYSIS OF THE EXTERNAL BLAST LOAD

The analysis of the load from detonation of the external charge was carried out for the conditions of an undisturbed standard atmosphere, also known as the international standard atmosphere – ISA (Cudziło et al., 2000).

The calculation procedure was performed for the following assumptions:

- spherical shape of the charge,
- distance between the charge and the building: Variant 1: r = 5.0 m, Variant 2: r = 10.0 m,
- charge placed 2 m above ground level,
- a construction barrier as non-deformable, with a variable height of 10 and 14 m and a width of 36 m,
- rigid connection to the ground,

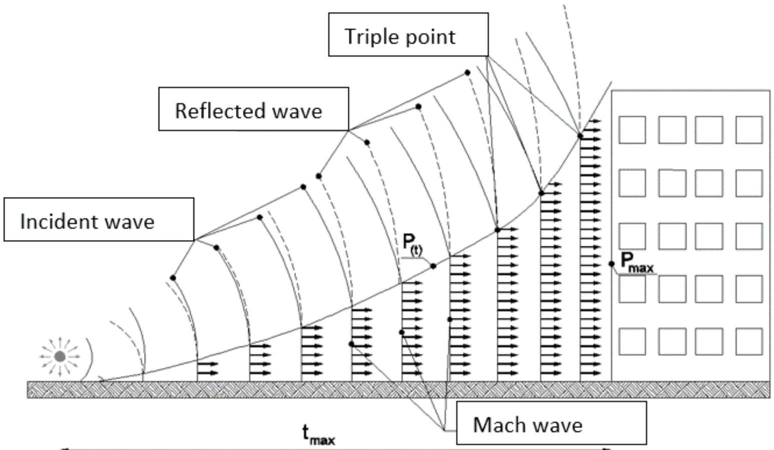

Fig. 1. Wave propagation diagram (own elaboration)

- an explosive charge TNT,
- charge density ρ_0 = 1,560 kg·m^{-3},
- load weight m = 10 kg.

The analysed construction barrier is treated as a separate object, for the analysis of which only the load from the explosive charge is taken into account.

Parameters included in the calculation under conditions of an ISA:

- atmospheric pressure value, initial pressure in the medium ρ_0 = 101,325 Pa ≅ 0.1 MPa,
- temperature T = 288 K,
- speed of sound in the medium α_0 = 340 m·s^{-1}.

In order to determine the value of overpressure, the surface of the construction barrier was divided into sectors and equal squares with a side width of 2 × 2 m, as shown in Figure 2.

Figures 3 and 4 show the results of changes in overpressure in time for the S1-3 Sector for the adopted assumptions, respectively for Variants 1 and 2.

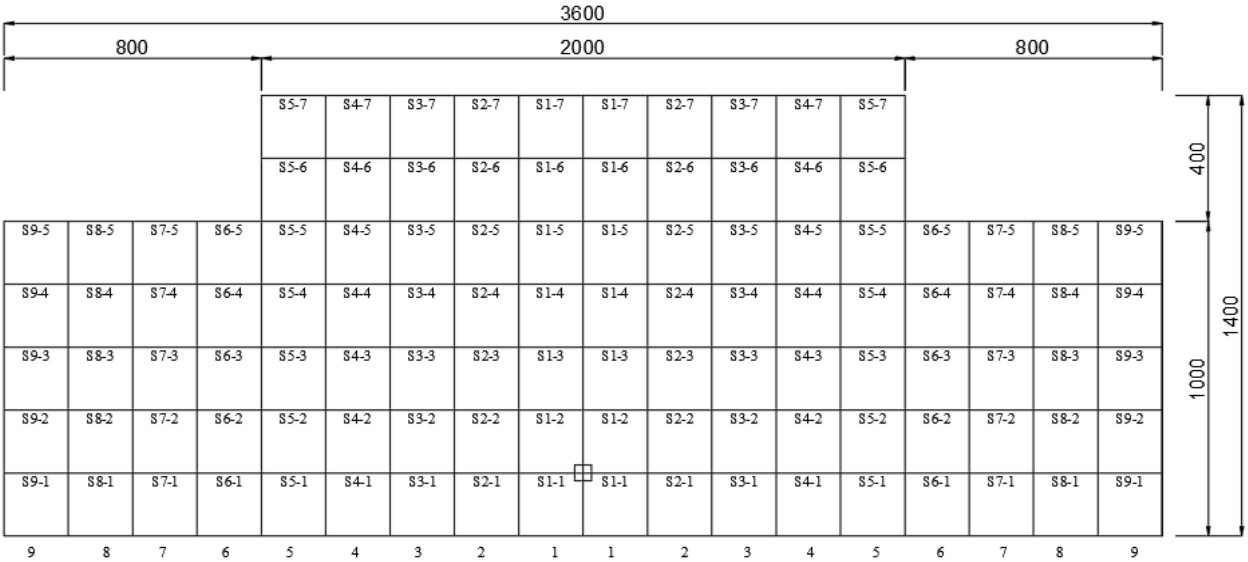

Fig. 2. Division of the construction barrier into sectors in cm (own elaboration)

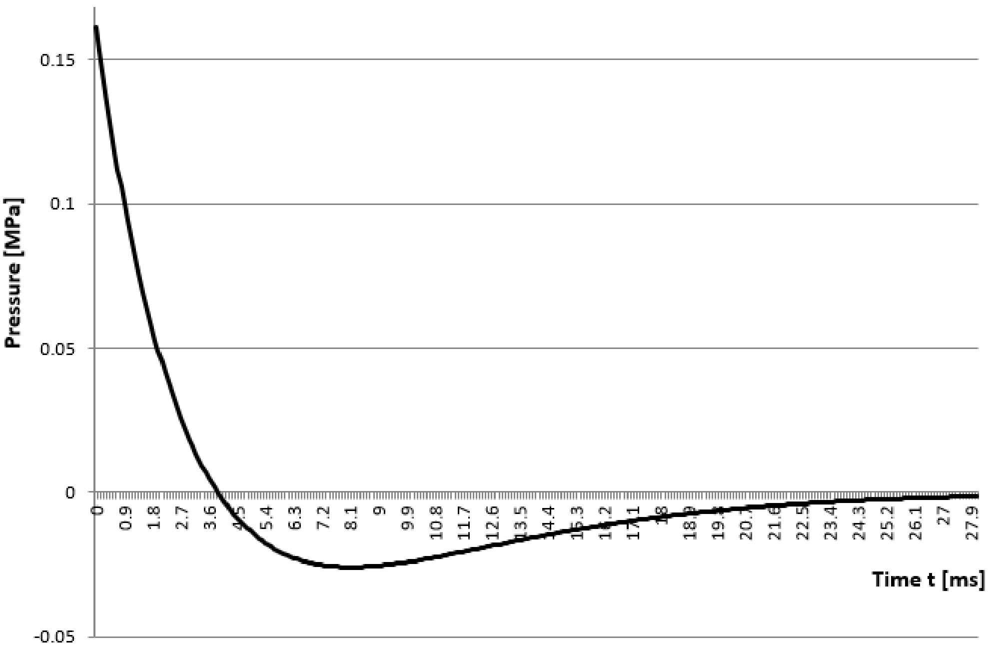

Fig. 3. Overpressure in time for Variant 1 in the S1-3 Sector (own elaboration)

In order to compare and verify the obtained results, calculations of the value of overpressure at the front of the incident wave (Δp_{od}) were performed for selected sectors using the method of Cormie et al. (2009).

Figure 5 shows the distribution of the reflectance coefficient ($C_{r\alpha}$) determined with respect to the range of incident overpressure:

$$\Delta p_{od} = C_{r\alpha}\, \Delta p^{+}.$$

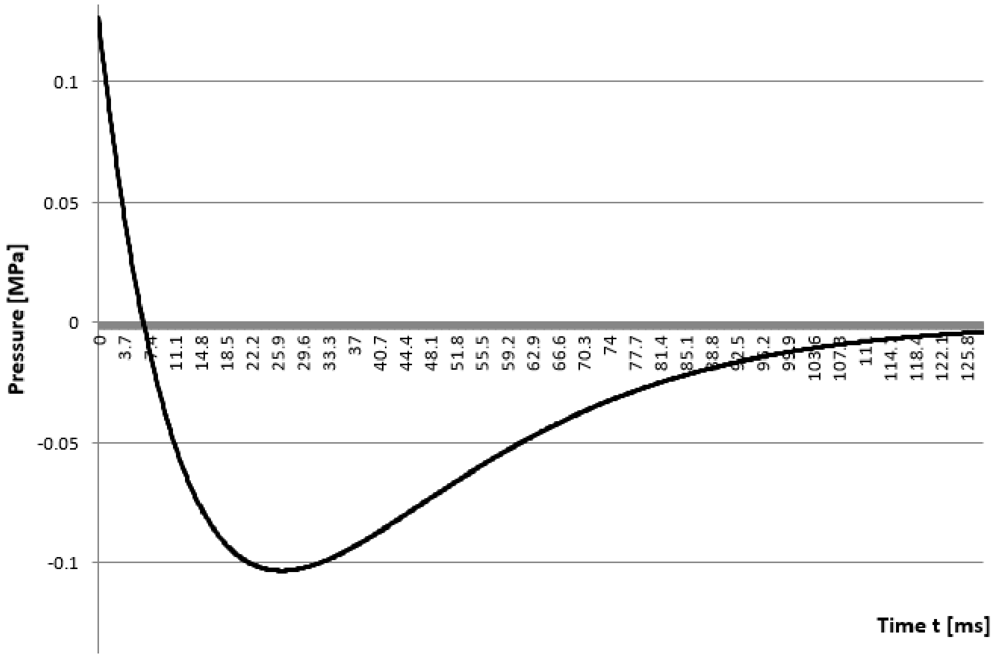

Fig. 4. Overpressure in time for Variant 1 in the S1-3 Sector (own elaboration)

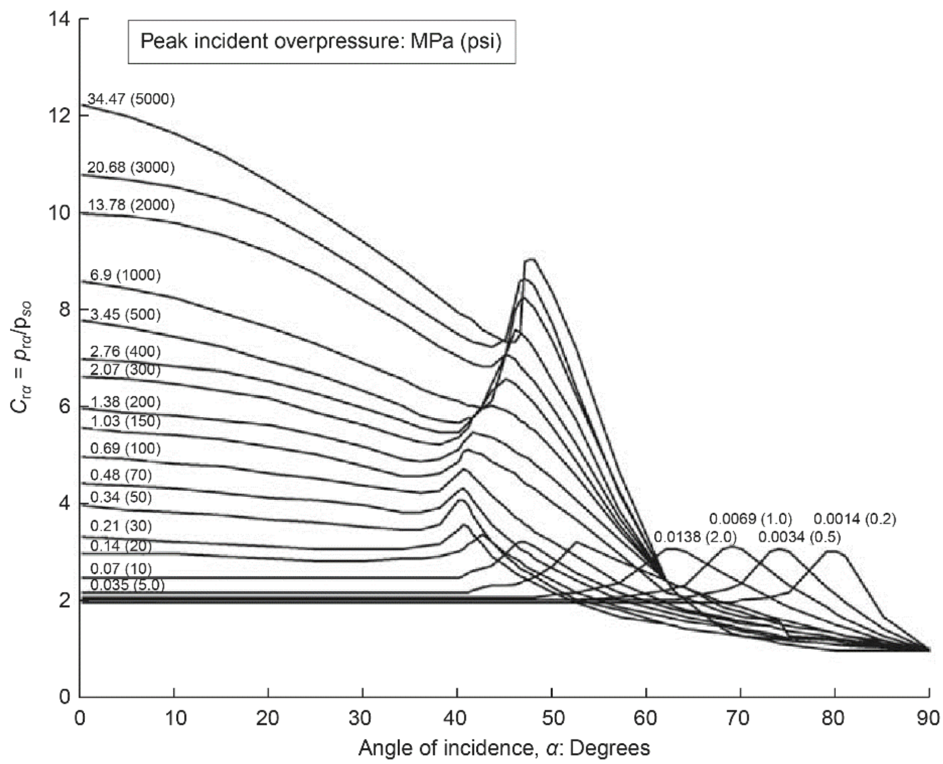

Fig. 5. Effect of angle of incidence on reflection coefficient (Cormie, Smith & Mays, 2009)

The value of the $C_{r\alpha}$ coefficient was determined on the basis of the Figure 5, on the basis of the value of the angle $\alpha = 40°$ and the value of the maximum overpressure (Δp^+).

Then the value of the overpressure on the reflected wave front was calculated. A calculation example for the S1-1 Sector, Variant 1 presents as follows:

$C_{r\alpha} = 3.5$,

$\Delta p^+ = 0.219$ MPa,

$\Delta p_{od} = 3.5 \cdot 0.219 = 0.766$ MPa.

Comparing the results obtained from both methods ($\Delta p_{od} = 0.766$ MPa and $\Delta p_{od} = 0.752$ MPa), it was found that the calculated values are similar, the difference is 2%, which allows to confirm the correctness of the proposed method.

In order to take into account the distribution of explosion gases along the height and width of the sectors, the distribution shown in Figure 6 and described in detail in the paper by Siwiński and Stolarski (2017) was applied.

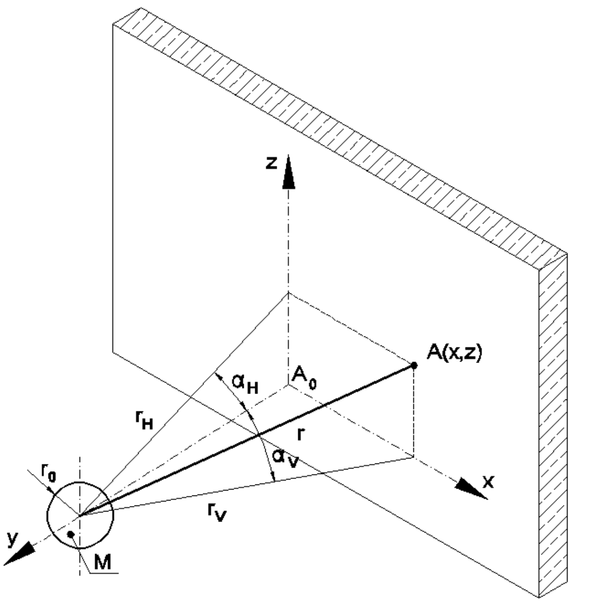

Fig. 6. Diagram of the location of loads in relation to any point on the construction barrier surface (own elaboration)

DETERMINATION OF THE COURSE OF THE DIVIDING LINE ON THE SURFACE

Based on the size of the incidence angle and the reflection angle $\alpha = 40°$, Figures 7 and 8 show the schemes for determining the location of the dividing line at the height of the construction barrier for Variants 1 and 2. On the considered surface of the construction barrier, a parabola-shaped line was marked, the course of which defines the pressure value that should be taken for further calculations (p_{od}, Δp^+). The course of the angle of incidence was determined for each of the sectors.

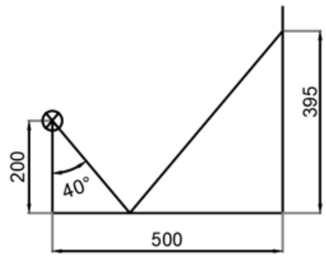

Fig. 7. Schemes for determining the location of the dividing line at the height of the construction barrier for Variant 1 in cm (own elaboration)

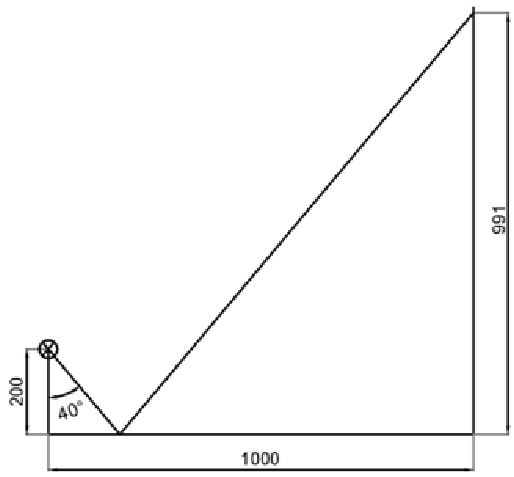

Fig. 8. Schemes for determining the location of the dividing line at the height of the construction barrier for Variant 1 in cm (own elaboration)

Based on the above dependencies, the course of the dividing line was determined, which is the boundary between the Mach and the incident waves, and they are shown in Figure 9 for Variant 1 and in Figure 10 for Variant 2. For sectors located below the line, the value of Δp_{od} was assumed, while for sectors located above the line, the value of pressure was Δp^{+}.

In Figures 9 and 10, two values of overpressure are presented on selected sectors, where the value above is the value determined according to the proposed procedure, and the value below is the overpressure determined according to Cormie et al. (2009). We can notice that the values are very close. The maximum differences are about 9.5% in the sectors with the highest overpressure and drop to about 3.0% in the sectors with less overpressure, with the pressures determined by the own procedure being higher. Figures 11 and 12 show the change in the peak pressure value along the width of the partition (along

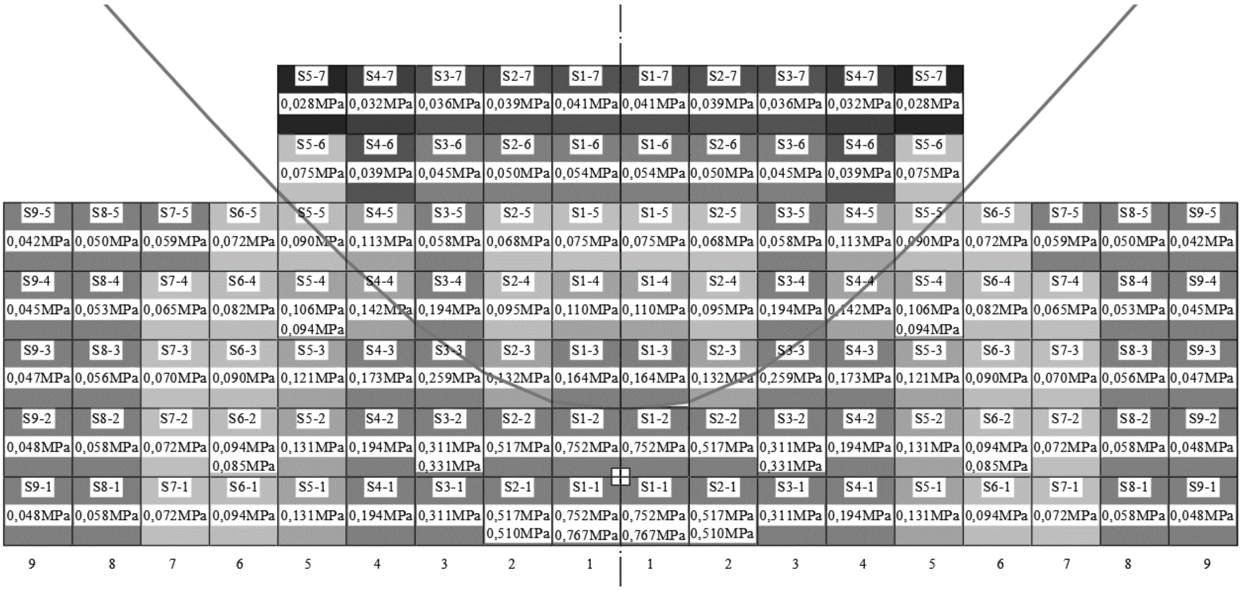

Fig. 9. Determined distribution of overpressure on the partition surface – Variant 1 (own elaboration)

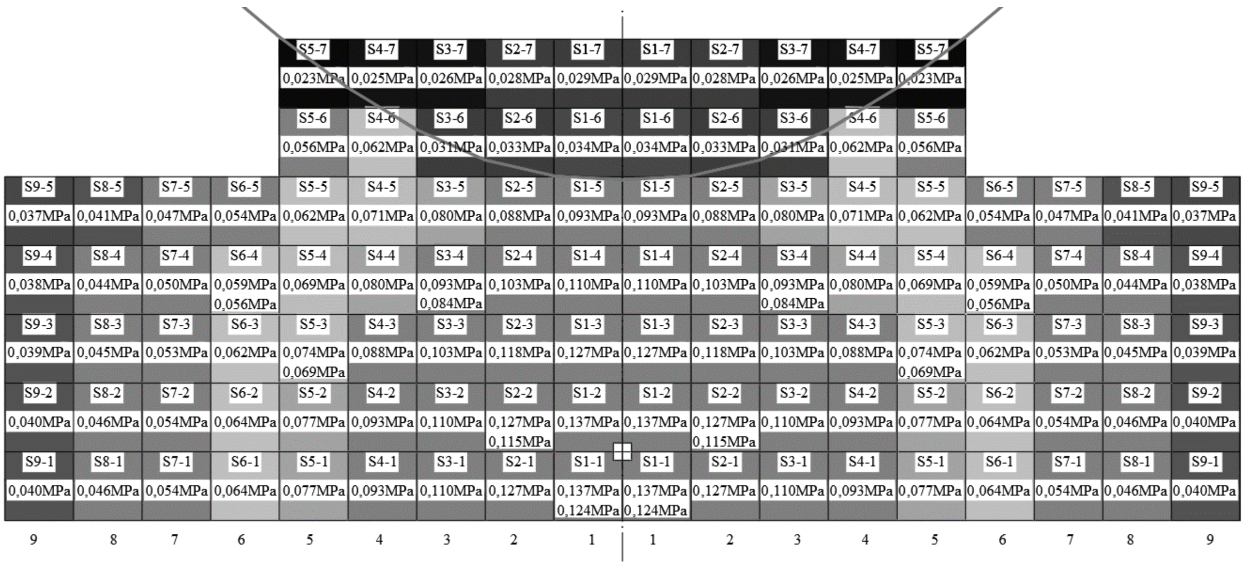

Fig. 10. Determined distribution of overpressure on the partition surface – Variant 2 (own elaboration)

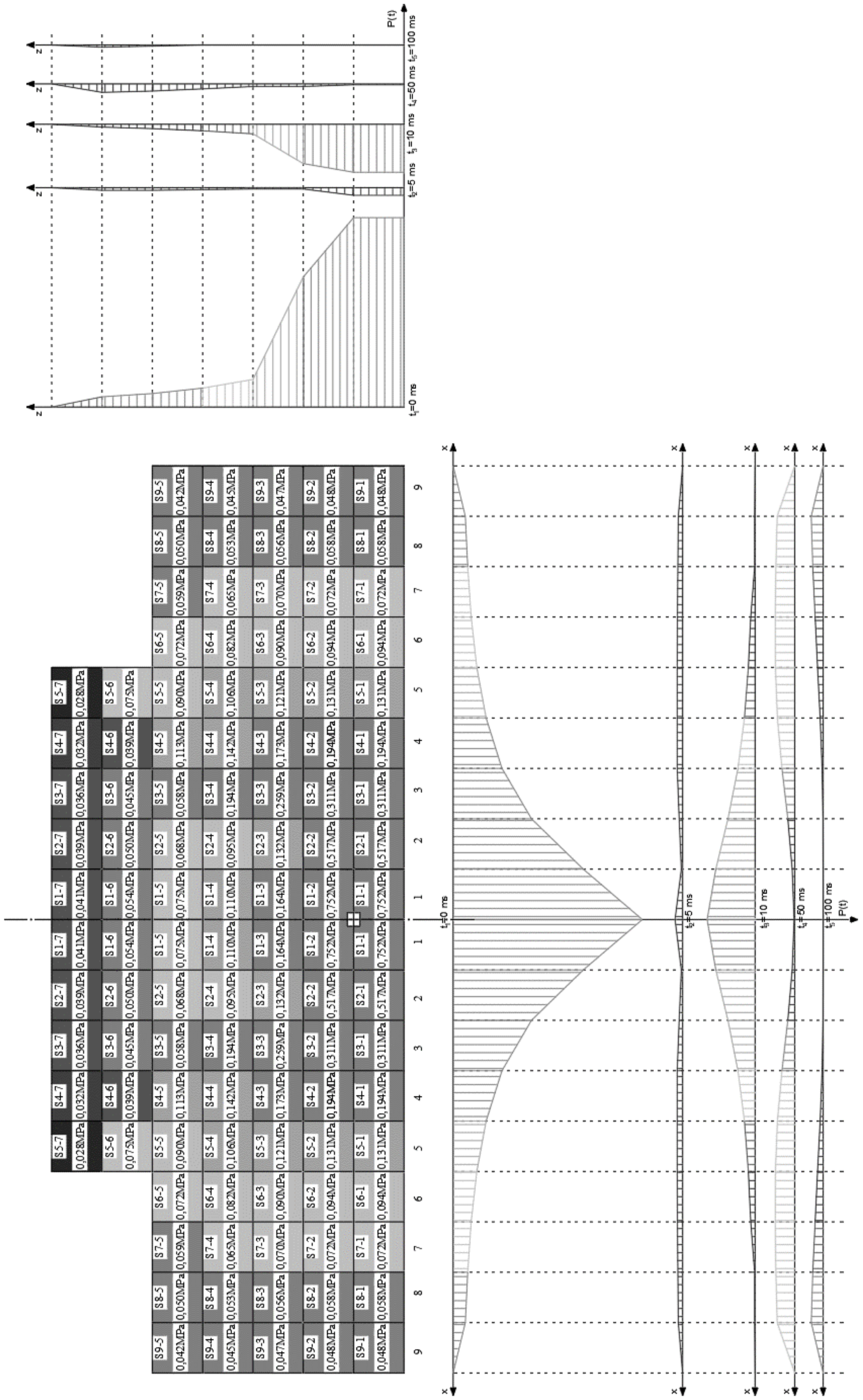

Fig. 11. Distribution of overpressure on the construction barrier surface at times t_1 to t_5 – Variant 1 (own elaboration)

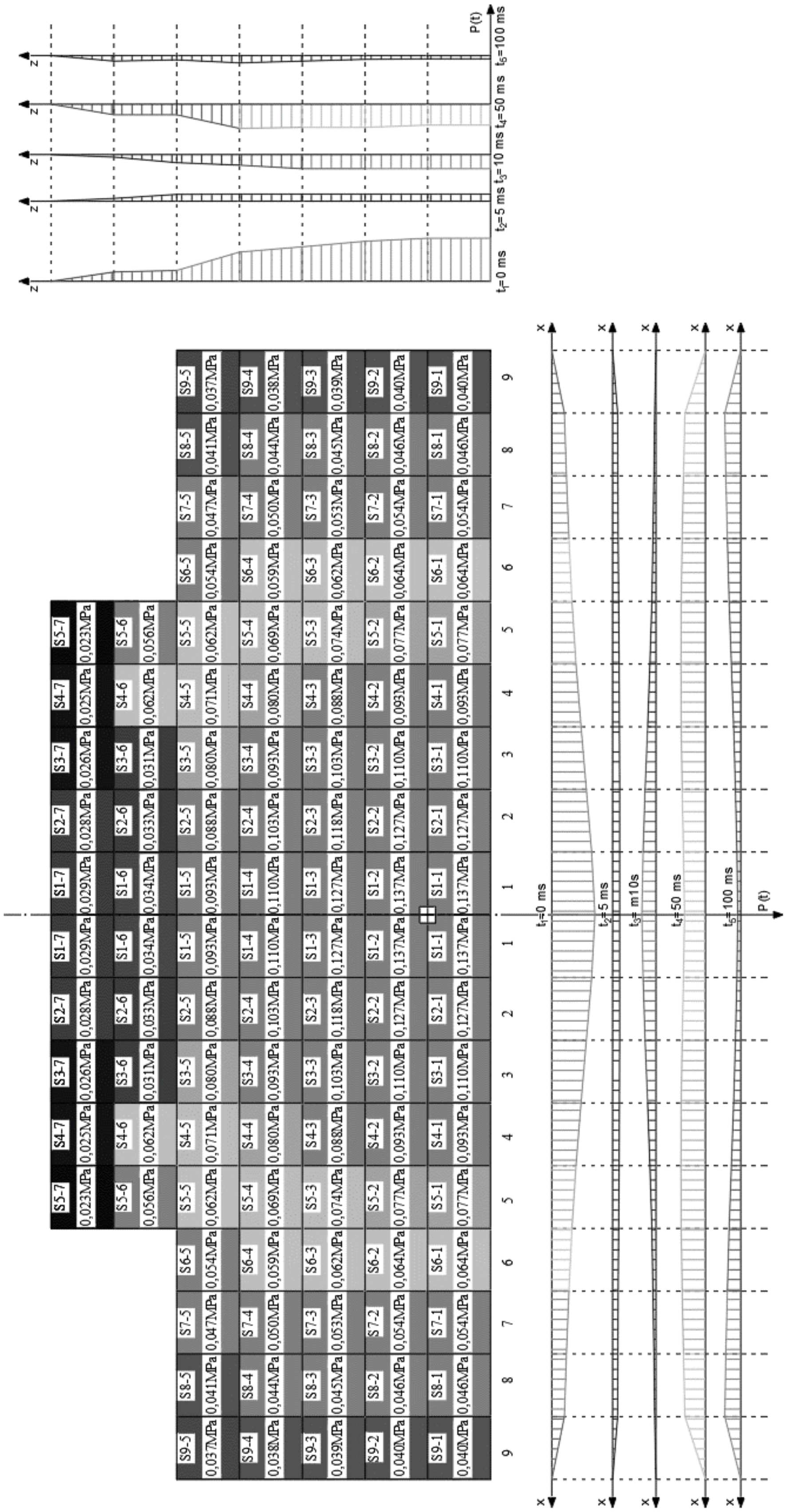

Fig. 12. Distribution of overpressure on the construction barrier surface at times t_1 to t_5 – Variant 1 (own elaboration)

the x axis) and along its height (along the z axis), in the following time moments: $t_1 = 0\ \mathrm{m{\cdot}s^{-1}}$, $t_2 = 5\ \mathrm{m{\cdot}s^{-1}}$, $t_3 = 10\ \mathrm{m{\cdot}s^{-1}}$, $t_4 = 50\ \mathrm{m{\cdot}s^{-1}}$ and $t_5 = 100\ \mathrm{m{\cdot}s^{-1}}$.

We can notice a significant difference in the amount of pressure for both variants, which is caused by the location of the charge at a different distance from the partition. Then, in the case of both variants, a large drop in the pressure value is observed for the time moments (t_1 and t_2). In the case of Variant 1 it is a decrease by 83%, while in the case of Variant 2 it is a decrease by 96% compared to t_1. For Variant 1, the pressure value increases between t_2 and t_3, while between t_3 and t_5 it decreases, to a value close to 0. We can also notice that the peak value of the overpressure moved away from the charge location. In Variant 2, the value of the overpressure between t_2 and t_4 increases and decreases to a value approaching 0 between t_4 and t_5.

SUMMARY AND CONCLUSIONS

As a result of the analysis of the formulas for determining the explosive interactions of various authors, a method was developed that allows to determine the basic parameters of blast waves, taking into account the angle of incidence and reflection angle. A phenomenological approach was proposed to define the change in pressure over time in individual sectors separated on the surface of the object. The results of the analysis of the impact of changes in the parameters of the explosive charge on the load variability over time are presented. An example of determining the pressure variation in time in the surface sectors is presented. The convergence of the results did not exceed 10%. Based on the research carried out, the following conclusions can be presented:

- taking into account the angles of incidence and reflection allows for a more accurate determination of the overpressure distribution on the surface of the construction barrier,
- taking the vertical and horizontal angles of incidence into account has a significant impact on the course of the Mach wave line,
- the charts at particular points in time make it possible to present the course of overpressure in individual sectors.

Authors' contributions

Conceptualisation: J.S. and K.K.; methodology: J.S.; validation: J.S.; formal analysis: J.S.; investigation: J.S.; resources: J.S. data curation: J.S.; writing – original draft preparation: J.S. and K.K.; writing – review and editing: J.S. and K.K.; visualisation: J.S.; supervision: J.S.; project administration: J.S.; funding acquisition: J.S.

All authors have read and agreed to the published version of the manuscript.

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ODDZIAŁYWANIE WYBUCHU ZEWNĘTRZNEGO NA PRZEGRODY BUDOWLANE Z UWZGLĘDNIENIEM KĄTA PADANIA

STRESZCZENIE

W pracy przedstawiono sposób określania oddziaływania wybuchu zewnętrznego na przegrody budowlane z uwzględnieniem kąta padania fali uderzeniowej. Dla przedstawionych dwóch wariantów analizy, tj. dla ładunku umieszczonego w odległości 5 i 10 m od przegrody, wyznaczono ciśnienia początkowe fali odbitej, czasy trwania nadciśnienia oraz przebieg zmienności obciążenia w czasie. Dla założonych parametrów przegrody oraz ładunku wyznaczono wartości nadciśnień z uwzględnieniem kąta padania. W rozważaniach nad wpływem wybuchu zewnętrznego wykorzystano różne procedury znane w literaturze, na których podstawie opracowano algorytm postępowania przy wyznaczaniu charakterystyk oddziaływania na przegrody budowlane z podziałem na falę odbitą i falę padającą. Dodatkowo dokonano analizy porównawczej proponowanej metody z innymi metodami opisanymi w literaturze. Zbieżność wyników nie przekroczyła 10%. Zaproponowana metoda pozwala na wyznaczenie linii granicznej pomiędzy falami Macha a falą padającą.

Słowa kluczowe: mechanika konstrukcji, oddziaływania wybuchowe, nadciśnienie fali padającej