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Numerically and empirically determination of blasting response of a RC retaining wall under TNT explosive

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Abstract. Blast loads may considerably affect the response of structures. In previous years, before computer analysis programs, the parameters of blast effects were calculated with empirical methods, consequently some researchers had proposed equations to find out the phenomenon. In recent year's computer analysis programs have developed already, so detailed solutions can be made numerically. This paper describes the blasting response of the structures using numerical and empirical methods. For the purpose, a reinforced concrete retaining wall is modelled using ANSYS Workbench software, and the model is imported to ANSYS AUTODYN software to perform explicit analyses. In AUTDYN software, a sum of TNT explosive is defined 5,5 m away from the wall and solution is done. Numerical results are compared with those of obtained from empirical equations. Similar study is also considered for equal explosive which is the 4 m away from the wall. The results are represented by graphics and contour diagrams of such as displacements and pressures. The results showed that distance of explosive away from the wall is highly affected the structural response of it.

Keywords: blasting response; explicit analysis; numerical and empirical methods; RC retaining wall; TNT explosive

1. Introduction

In the past few decades, terrorism and blast explosions have become one of the biggest problems all over the world, so the protection against terrorist attacks is still waiting an exact solution. The detonation of the explosive affects the environment including people and structures. In recent years, researchers developed new ways to improve protection against blast effects which are depended on experimental (See Fig. 1), numerical and empirical methods.

Detailed structures can be solved with computer analysis programs easily (AUTODYN, LS-DYNA etc.) instead of empirical methods. But in previous years (before computer analysis programs), blast load parameters were solved with equations, so that some researchers investigated and proposed empirical equations on blast load parameters.

Researches had started investigating number of studies since 1950's on blast effect theory. But, before examining the studies and parameters of blast effect; Hopkinson and Cranz (1915) made the

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Fig. 1 A photograph of explosion from an experimental study

first important study on blast effect which considers scaling method. Then Brode (1955), Newmark and Hensen (1961), Mills (1987), Henrych (1979), Kinney and Graham (1985), Sadovskiy (2004), and Kingery and Bulmash (1984) proposed equations for peak overpressure and some parameters on blast load. Developments in computer technology provides the researchers investigation of the subjects numerically. After 2010's some numerical studies are shared to literature concerning the blast response of structures. Mahmoud (2014), investigated response of structures as well as the associated structural damage to explosive loads considering and ignoring the supporting soil flexibility effect. This study showed that, the dynamic response is obtained by solving the governing equations of motion of the considered building model using a developed Matlab code based on the finite element toolbox CALFEM. Han and Liu (2016) investigated the failure mechanisms of circular cast-iron tunnels in saturated soil subjected to medium internal blast loading. This study showed that, a series of numerical simulations were carried out using Finite Element program LS-DYNA. It is highlighted from the study that the damage of tunnel lining was a result of internal blast loading as well as dynamic interaction between tunnel lining and saturated soil, and stress concentration induced by a ventilation shaft connected to the tunnel might result in more severe lining damage. Nam *et al*. (2016) studied about the Numerical evaluation of FRP composite retrofitted reinforced concrete wall subjected to blast load. In the study, the blast resistance of Carbon Fiber Reinforced Plastic and Kevlar/Glass hybrid fabric retrofitted reinforced concrete wall is analyzed by using the explicit analysis code LS-DYNA which accommodates the high-strain rate dependent material models. On the other hand, some investigations are done by the researchers related to blast response of engineering structures (Mazek 2014, Lee *et al*. 2016, Wahab and Mazek 2016).

In this study, blasting response of structures are numerically and empirically investigated on a reinforced concrete (RC) retaining wall. In the study, it is firstly talked about the importance of blasting response on introduction part citing doyen researchers related to subject. Then blast theory is contented considering empirical equations. In followed part, numerical studies are comprehensively presented considering finite element modeling, analyses and presentation of analyses results. Lastly, conclusions obtained from the study are taken place.

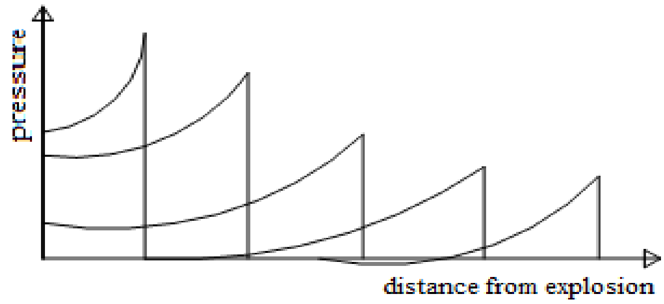


Fig. 2 Pressure wave-distance interaction related to blasting

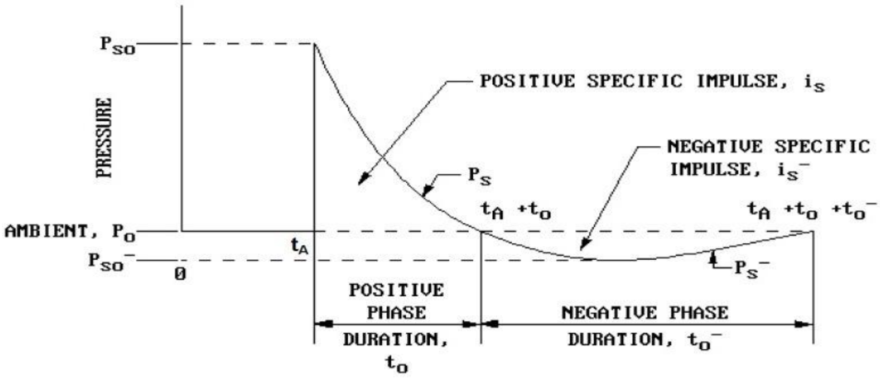


Fig. 3 Pressure wave-distance interaction related to blasting

2. Blast theory

An explosion is rapid increase in volume and released of energy in an extreme manner, usually with the generation of high temperature. The explosion is a phenomenon and the energy is released rapidly and abruptly. Explosion causes shock wave which expands spherically. It can subject big pressure on the nearest structures abruptly. Surfaces of the structures reflects blast wave but after reflection the pressure of the blast wave (see Figs. 2-3) decreases.

The act of explosion can be modelled as a pressure-time graph which can be drawn in Fig. 3. According to the graph in Fig. 3, “0” is the start time of explosion before the shock wave reaches to the structure (t_A) in the millisecond range and subjects (pressure reaches to P_{so} immediately) pressure to surface; this phase is called positive phase at (t_o) duration. The curve reaches to ambient pressure at (t_A+t_o), then the pressure decreases and slope reaches to negative phase (-P_{so}) at (t_o-) duration; this causes negative pressure then the curve reaches back to the ambient pressure at (t_A+t_o+t_o-). At positive phase; big amount of energy released and shock wave impacts to structure that spalling, bending, cracking situations are to be expected. Negative phase means vacuum which pulls debris fragments to explosion source. At the negative phase; absolute peak negative pressure (-P_{so}) is smaller than the absolute peak positive pressure (P_{so}); on the other hand negative phase (t_o-) duration is longer than the positive phase (t_A+t_o) duration. Po and duration are related to some important parameters such as charge weight (W), distance (R) from the surface, and type of the material. Generally duration of the explosion is approximately 2,5-3 milliseconds and value of P_{so} can reach to big overpressures.

Table 1 Conversion factors for explosives

Explosive	Specific Energy	TNT Equivalent
	Qx/kj/kg	Qx/QTNT
Compound B (60% RDX, 40% TNT)	5190	1.148
RDX	5360	1.185
HMX	5680	1.256
Nitroglycerin (liquid)	6700	1.481
TNT	4520	1.000
Explosive Gelatin	4520	1.000
60% Nitroglycerin Dynamite	2710	0.600
Semteks	5660	1.250
C4	6057	1.340

2.1 Cube root scaling law

Calculating the parameters of the blast load are depended on interpreting the basic units of the explosion; value of distance and the charge weight. These basic parameters are combined the result of experiments and introduced as scaling law. The most common blast scaling law is proposed by Hopkinson and Cranz Law (1915). This law has been used to explain great majority of equations by the researchers and this law is proposed as

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

where; Z: scaled distance, R: distance between explosive and structure and W: charge weight of the explosive (TNT; kg).

2.2 Basic parameters of the explosions

TNT is the basic unit for determining the scaled distance, Z. if the explosive type is different from the TNT, the explosive must be converted to the equivalent mass of the TNT and the equivalent weight is calculated with the use of the equation

$$W_e = W_{exp}\frac{H^d_{exp}}{H^d_{TNT}} \tag{2}$$

where; W_e= TNT equivalent weight (kg), $H^d{}_{exp}$= Heat of detonation of the actual explosive (MJ/kg), and $H^d{}_{TNT}$= Heat of detonation of TNT (MJ/kg). And the equivalent weight for some other explosives is given in Table 1.

Parameters of blast pressure for explosive materials had been started to study by 1950’s. There are some empirical equations of the main parameters. The peak overpressure (P_s) in bar which is related to scaled distance (Z) was proposed by Brode (1955)

$$P_{so} = \frac{6{,}7}{Z^3} + 1\ (bar)(P_{so} > 10\ bar) \tag{3}$$

Table 2 Constants for Kingery and Bulmash Equation

Z (m/kg$^{1/3}$)	A	B	C	D	E
0,2-2,9	7,1206	-2,1069	-0,3229	0,1117	0,0685
2,9-23,8	7,5938	-3,0523	0,40977	0,0261	-0,01267
23,8-198,5	6,0536	-1,4066	0	0	0

$$P_{so} = \frac{0{,}975}{Z} + \frac{1{,}455}{Z^2} + \frac{5{,}85}{Z^3} - 0{,}019\ (bar)(0{,}1\ bar < P_{so} < 10\ bar) \tag{4}$$

Newmark and Hansen (1961) proposed peak overpressure (P_s) in bars which occurs at ground surface

$$P_{so} = 6784.\frac{W}{R^3} + 93.\left(\frac{W}{R^3}\right)^{1/2}\ (bar) \tag{5}$$

Mills (1987) proposed peak overpressure (P_s) in kPa

$$P_{so} = \frac{1772}{Z^3} - \frac{114}{Z^2} + \frac{108}{Z}\ (kPa) \tag{6}$$

Henrych (1979) proposed peak overpressure(P_s) which is same as Brode (1955)

$$\begin{aligned} P_{so} &= \frac{14{,}072}{Z} + \frac{5{,}54}{Z^2} - \frac{0{,}375}{Z^3} + \frac{0{,}00625}{Z^4} (0{,}05 \le Z \le 0{,}3) \\ P_{so} &= -\frac{6{,}194}{Z} - \frac{0{,}326}{Z^2} + \frac{2{,}132}{Z^3} (0{,}3 \le Z \le 01) \\ (7)P_{so} &= \frac{0{,}662}{Z} + \frac{4{,}05}{Z^2} + \frac{3{,}288}{Z^3} (1 \le Z \le 10) \end{aligned} \tag{7}$$

Kinney and Graham (1985) presented a formulation to describe the peak pressure

$$P_{so} = P_o \frac{808\left[1+\left(\frac{Z}{4{,}5}\right)^2\right]}{\left\{\left[1+\left(\frac{Z}{0{,}048}\right)^2\right]\left[1+\left(\frac{Z}{0{,}32}\right)^2\right]\left[1+\left(\frac{Z}{1{,}35}\right)^2\right]\right\}^{0{,}5}}, (bar) \tag{8}$$

where; Z: Scaled distance, and Po: Ambient pressure

Sadovskiy (2004) proposed the following equation for peak overpressure

$$\Delta P_f = \frac{0{,}085}{Z} + \frac{0{,}3}{Z^2} + \frac{0{,}8}{Z^3}, (MPa) \tag{9}$$

Kingery and Bulmash (1984) proposed a polynomial equation to calculate peak pressure (and also AUTODYN uses this equation to solve blast load)

$$\Delta P_f = Exp[A + B.lnZ + C.(lnZ)^2 + D.(lnZ)^3 + E.(lnZ)^4], (kPa) \tag{10}$$

where constants (A, B, C, D and E) are presented in Table 2

According to the Mays and Smith (1955): wave front speed equation; U_s and dynamic pressure q_s is described as

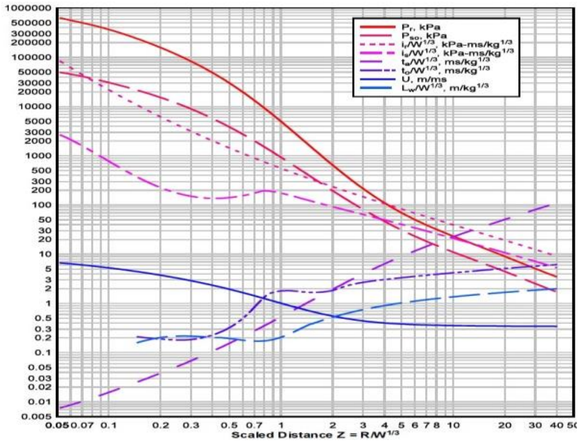


Fig. 4 Parameters of positive phase of shock spherical wave of TNT charges from free-air bursts

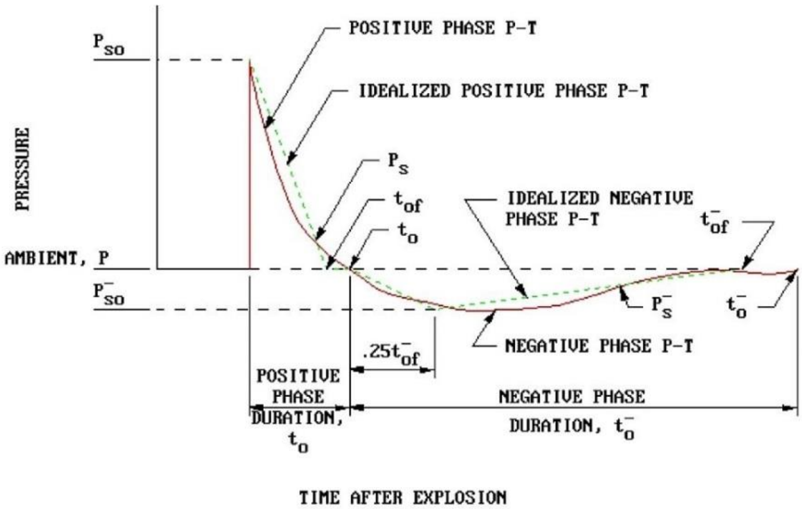


Fig. 5 Idealized pressure-time variation

$$U_s = a_0\sqrt{\frac{6p_s+7p_0}{7p_0}}, (m/s) \tag{11}$$

$$q_s = \frac{5p_s^2}{2(p_s+7p_0)}, (bar) \tag{12}$$

where; P_s: peak overpressure (bar), P_0: ambient pressure (bar), and α_0: speed of sound (m/s)

Most of the parameters can be seen in Fig. 4. According to Fig. 4, U: Shockwave speed (m/ms), Lw: blast wavelength (m), P_{so}: peak incident Pressure (bar), i_s: incident impulse (ms), i_r: reflected impulse (ms), t_o: duration of positive phase (ms), t_A: arrival time (ms), L_w: wave length (ms). Scaled distance Z; must be determined for each cases with Eq. (1) and according to the UFC 3-340-02 (2008) “Structures to Resist the Effects of Accidental Explosions” values of the parameters can be read and calculated from the Fig. 4, which depends on scaled distance (Z).

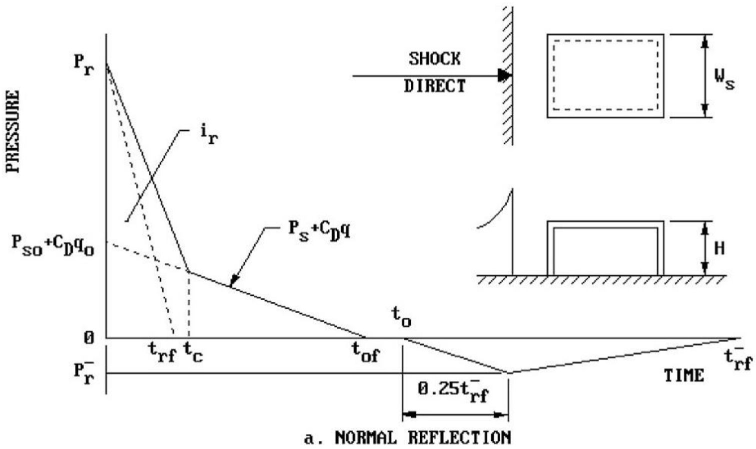


Fig. 6 Triangular assumption form of pressure time history graph

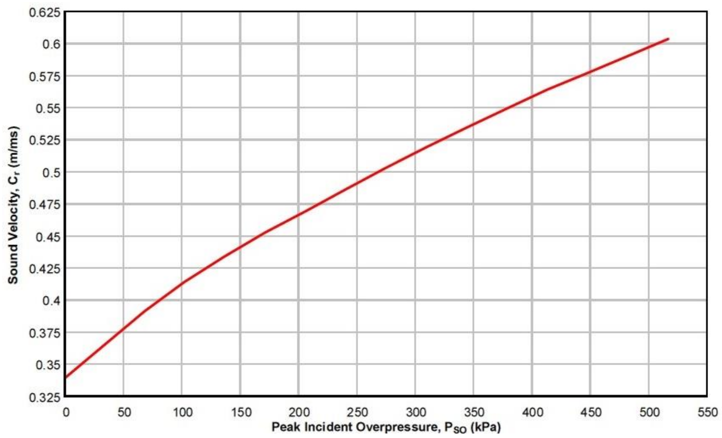


Fig. 7 Sound velocity in reflected overpressure graph

2.3 Blast effect on structure surface

Reduction of the dynamic pressure needs determining to analyze the blast load parameters which depends on peak overpressure values. According to the Fig. 5, the common the blast wave form (pressure time history) can be drawn and the detailed parameters of the blast load can be expressed by transforming the graph to triangular form.

2.3.1 Triangular form

When a blast load subjected to a structure, the wave surrounds the structure and causes pressure. A triangular assumption of pressure time history graph can be drawn (see Fig. 6) instead of pressure time history graph (see Fig. 3);

According to the triangular form; positive phase duration to is replaced by fictitious time t_{of}

$$t_{of} = \frac{2i_s}{P_{so}} \tag{13}$$

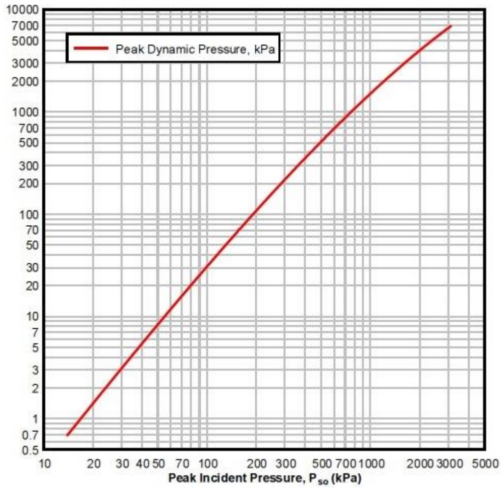


Fig. 8 Peak dynamic pressure-peak incident pressure graph

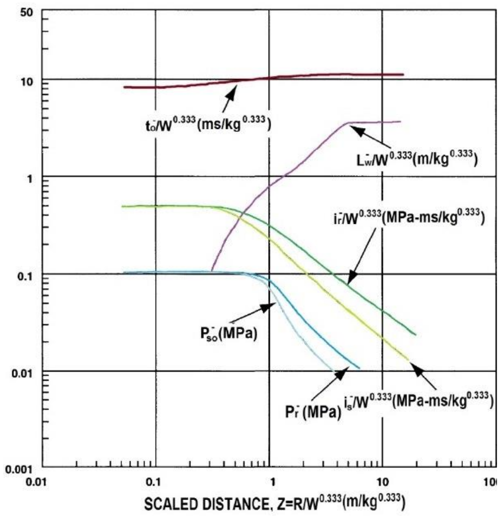


Fig. 9 Parameters of negative phase of shock wave of TNT charges

where; i_s: impulse value of positive phase, and P_{so}: peak overpressure. And the equation below can be written for negative phase as

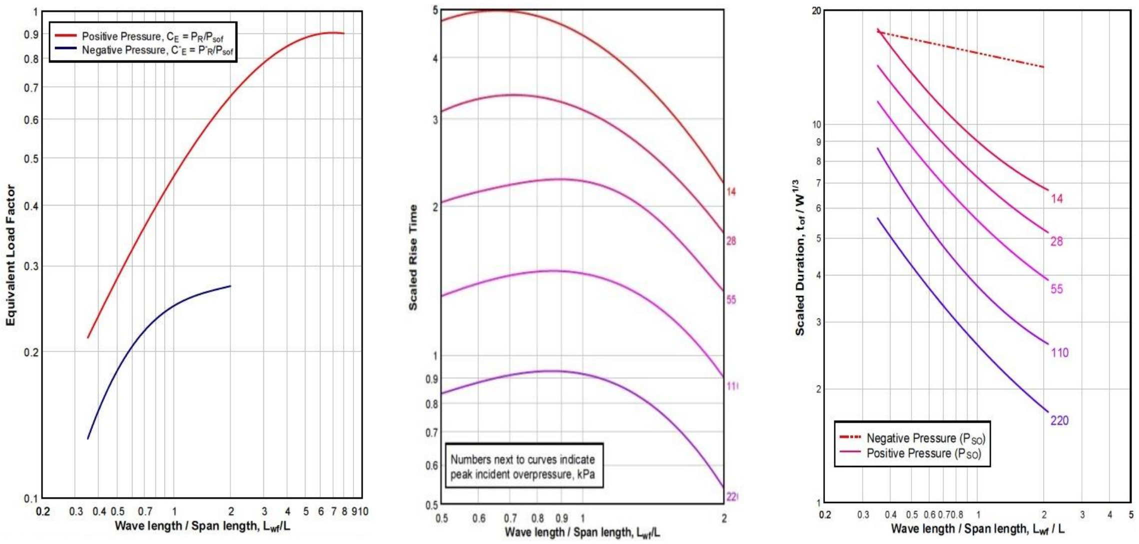
$$t_{of}^{-} = \frac{2i_s^{-}}{P_{so}^{-}} \tag{14}$$

The fictitious time of the positive phase is shorter than the negative phase on the other hand positive peak overpressure is greater than the negative one. The clearing time t_c is computed with equation below

$$t_C = \frac{4S}{(1+R).C_r} \tag{15}$$

Table 3 Drag coefficient values (C_D)

Peak Dynamic Pressure (kPa)	C_D (Drag Coefficient)
0-170	-0,40
170-350	-0,30
350-900	-0,20



(a) Value of load Factors; C_E and C_E^- (b) Rise time (t_d) value (c) Duration time (t_{of}) value

Fig. 10 The value of load factors C_E, C_E^-, t_d and t_{of}

where; S: shortest length of the surface size H or W/2, C_r: sound velocity which can be determined from Fig. 7, and R: the ratio of S/G; where G is the biggest of the surface size H or W/2.

The fictitious duration t_{rf} is calculated with equation below; (i_r and P_r can be read form Fig. 4)

$$t_{Crf} = \frac{2i_r}{P_r} \tag{16}$$

The peak dynamic pressure q_o can be calculated from Fig. 8. The value of P_{so}+$C_D q_o$ on Fig. 6 can be determined by taking C_D=1 (the drag coefficient). When the blast wave is subjected to the wall, the negative phase (t_{rf}^-) can be calculated besides that the positive phase. Some of the important parameters such as peak negative incident pressure, normal reflected impulse, scaled negative incident pressure and normal reflected impulse can be calculated by Fig. 9.

The duration of the negative phase (t_{rf}^-) can be calculated by following equation

$$t_{rf} = \frac{2i_r}{P_r} \tag{17}$$

After calculating the negative phase the minimum peak pressure value would be equal to (t_o+0,25 t_{rf}^-) on the triangular form of the pressure-time history graph.

The blast load can subject to the side walls of the structure which can be calculated by

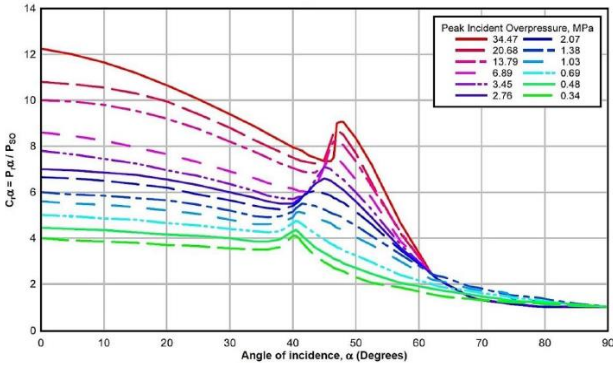


Fig. 11 Calculation of scaled reflected pressure coefficient due to angle

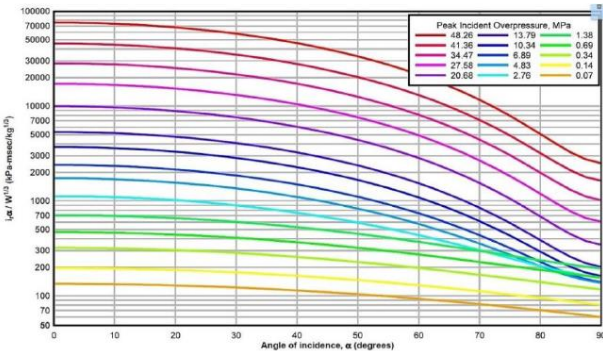


Fig. 12 Calculation of scaled reflected impulse due to angle

Fig. 13 Common example of a RC Retaining wall along the highway

following the similar path. According to the Fig. 10(a)-(c) where C_E (equivalent positive load factor), C_E^- (equivalent positive load factor), t_d (the rise time) and t_{of} (the duration time). The dynamic pressure q_o can be calculated from Fig. 8 and the value of coefficient C_D for negative phase can be chosen from Table 3.

The corresponding rise time is equal to the expression (0,25 t_{of}^-); t_{of}^- is the negative phase duration. By these equations and expressions all blast load parameters can be calculated and the idealized triangular pressure time history graph can be drawn. The angle of the shock wave which subjected to the point is important that effects; the pressure that occurs on surface, the displacement of the structure and the blast load parameters. Consequently; $C_{r\alpha}$ and $i_{r\alpha}$ parameters are read from the Figs. 11 and 12.

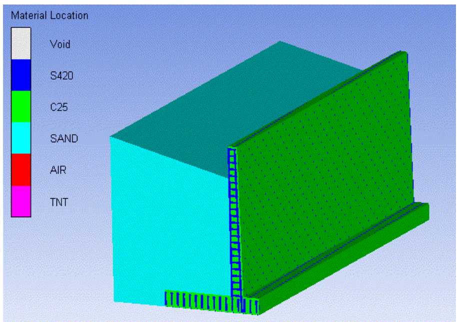


Fig. 14 3D Drawing model of the RC Retaining wall

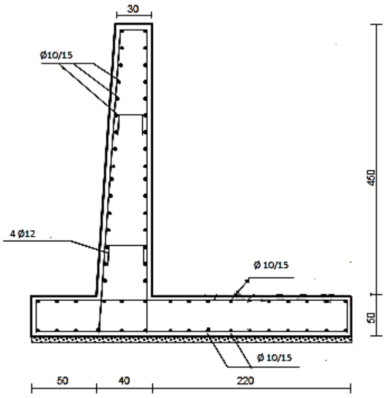


Fig. 15 3D Geometrical dimensions of the RC retaining wall (dimensions, cm)

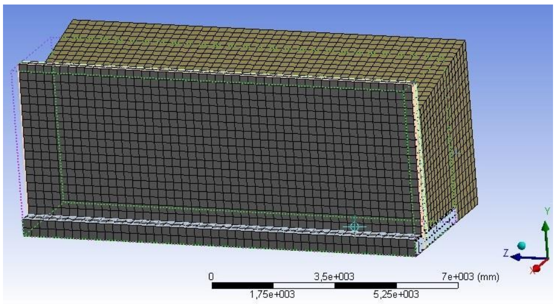
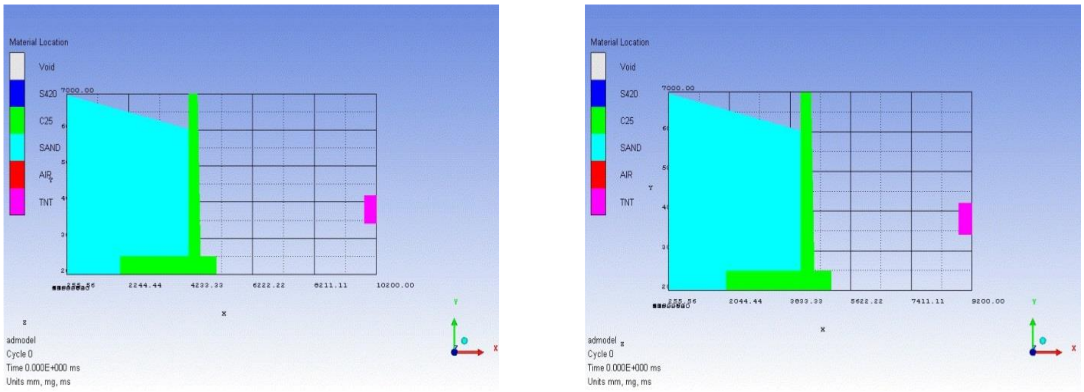


Fig. 16 3D Geometrical model of the RC retaining wall designed in ANSYS Workbench

3. Numerical example

3.1 Description of the structure and its finite element modeling

In this study, a reinforced concrete (RC) retaining wall is preferred to simulate which can be seen commonly along the highway (See Fig. 13). The drawing model of the RC wall selected for numerical example is given in Fig. 14. As seen in Fig. 14 that, main structural elements of the wall are concrete and steel bar. Also the model contains air, void and TNT. The geometrical dimensions of the wall are presented in Fig. 15. Also 3D finite element of the system is given in Fig. 16.



(a) Side view of model-1 and place of explosive (b) Side view of model-2 and place of explosive

Fig. 17 The place of blasting material (TNT)

Table 4 The material properties of components used in the modeling and analysis

Material Component	Material Type	Elasticity Modulus(MPa)	Density (g/cm3)	Compressive Strength (MPa)	Tensile Strength Strength (MPa)
Concrete	C25	3×10^4	2.40	25	1,8
Reinforcement	S420	2×10^5	7.83	420	420
Ground	Sand	1,4×10	2,64		
Air	Air	-	1.225×10^{-3}	-	-
Blasting	TNT	-	1.60	-	-

The dimensions and properties given here for RC wall and its members are suitably against to dead, live and earthquake loads according to Turkish Standard 500 (2000) and Turkish Seismic Code (2007).The structure is modelled (Lagrange model) in ANSYS Workbench at Explicit Dynamics (2016) and has; 3,10 m of width, 5 m of height and 12 m of depth (see Figs. 15 and 16) and has a fixed support at the bottom of foundation. For blast modeling (Euler model) ANSYS AUTODYN (2016) software is used. For the explosion, air material was defined firstly and the air material (Euler model) is modelled size with 15 m×10 m×16 m. Each connections (frictional and reinforcement) are defined in workbench. Frictional is defined for concrete wall-sand contacts and reinforcement is defined for concrete and steel bars.

Reinforcing bars are modelled with beam elements to be tied (bonded) to the volume of a solid element, without the restriction that the nodes of the beams and the volume elements initially need to reside at the same physical location. The bonded beam nodes are constrained to stay at the same initial parametric location within the volume element during element deformation. Typical applications involve reinforced concrete or reinforced rubber structures like tires and hoses.

For solid model (Lagrange Model) the mesh of the structure is set to 250 mm (see Fig. 15) but for air model (Euler Model) the mesh is set to 200 mm (see Fig. 18). AUTODYN advices users deciding to use a smaller grading of Euler mesh comparing with explicit model mesh in order that the blast load runs correctly.

According to geometrical properties, 3D finite element model of the wall constituted using ANSYS Workbench (2016) software. In finite element model of the wall consists of concrete and steel bar and explosion material is selected as 410 kg TNT and it is placed at the front of the wall

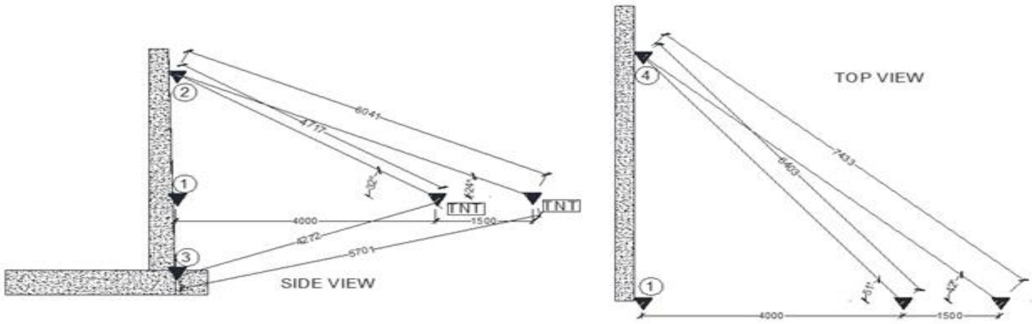
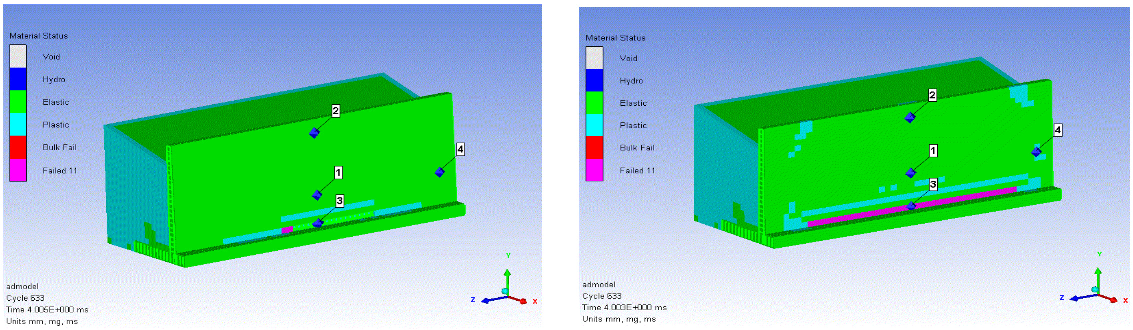


Fig. 18 Detailed plots of gauges on façade of the wall and TNT



(a) Model-1 (b) Model-2

Fig. 19 Deformed shapes of the models

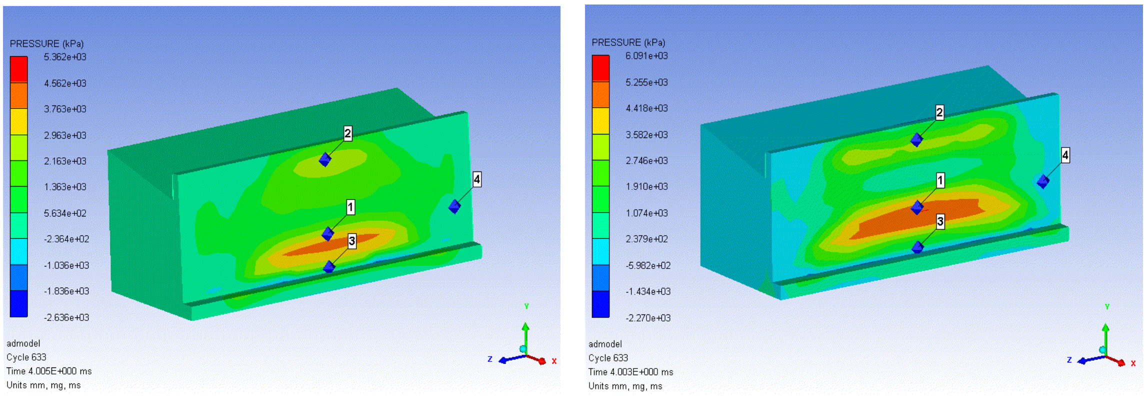
and a sand pile placed behind the wall which represses at +X direction and the mass of the sand is calculated as 330 tons. The blast is subjected to the wall for two different situations (firstly, distance between explosive material and the structure is selected as 5.5 m and for the second situation the distance is selected as 4 m) (see Fig. 17). Blast modeling is constituted using ANSYS AUTODYN (2016) software, also the explicit analysis of the wall is performed in this software for a duration of 3 milliseconds. The material properties of components used in the modeling and analysis such concrete, reinforcement, air and TNT are given in Table 4.

The geometric size of the air model is needed for explosive material TNT and blast action. During blast actions the waves of the explosion must take place in the defined air space so that, the interaction between explosive waves and solid model is successful. Both models, the explosive is modelled and meshed together with air (Euler) model which meshed into 2×4×4 (i.j.k) pieces. The volume of the explosive is calculated as 2×4×4=32 unit^3 and the density of the TNT is 1,60 g/cm^3 and the mass of the TNT is approximately 410 kg, finally, the detonation of the explosives for each model is placed at the middle of the TNT.

For detailed analysis, 4 gauges are plotted on the façade of the wall and be seen on contour diagrams and for more detail (see Fig. 18).

3.2 Analysis results

After performing explicit analysis considering explosion for two models, the deformed shapes of the wall is illustrated in Fig. 19. As seen in the Fig. 19, for both models, boundary intersection

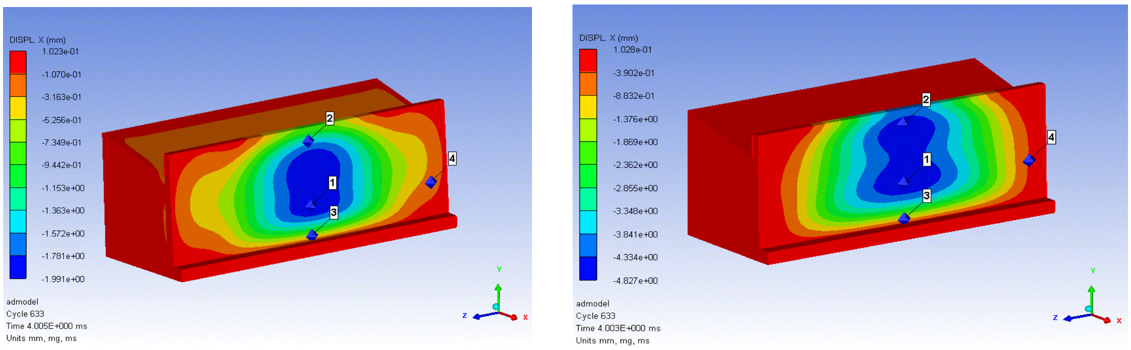


(a) Model-1 (b) Model-2

Fig. 20 Pressure contour diagram of the models

Table 5 Values of displacements at X direction

Gauges	Model-1(mm)	Model-2(mm)
#1	-1,94	-4,74
#2	-1,49	-4,72
#3	-0,45	-0,84
#4	-0,19	-0,30

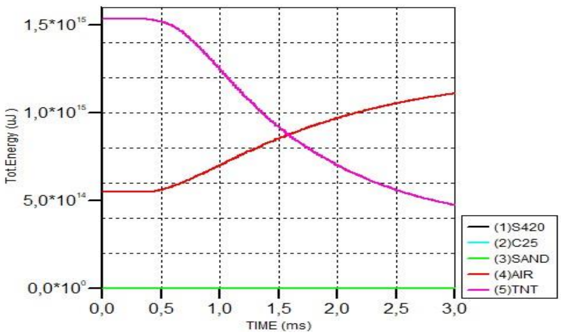


(a) Model-1 (b) Model-2

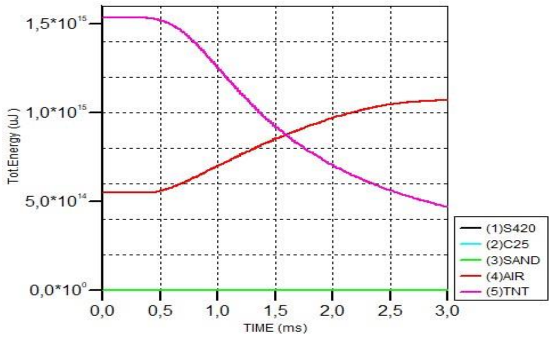
Fig. 21 Displacement contour diagrams of the models at X direction

part between vertical body and the foundation has failed (concrete fragmented and reinforcement bars highly yielded) has plastic areas but second model (with 1,5 m explosive distance) has more plastic areas and also more failed areas.

The pressure values of the blast load on the elements of the wall, obtained from blasting analysis are demonstrated in Fig. 20. After analyzing the blast load with AUTODYN the values of the parameters can be generated. One of the important parameter (peak overpressure) values can be seen on contour diagram and values can be read approximately. The time duration was set for 3 milliseconds at model phase in ANSYS Workbench. In general, the explosions are happened abruptly and the duration time is approximately 3 ms (for TNT explosives). TNT is the main unit of explosive while we study blast effect and the other explosive materials must be converted to the



(a) Model-1



(b) Model-2

Fig. 22 Total energy values of the models after explosion

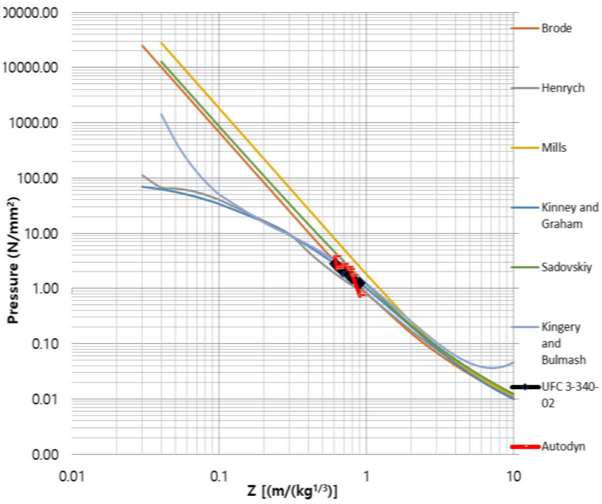


Fig. 23 Pressure values of different equations, proposes and autodyn for general Z values

Table 6 The pressure values of Model #1 of gauges (MPa)

Gauges	Z	Autodyn	Brode	Henrych	Mills	Kinney Graham	Sadovskiy	Kingery Bulmash	UFC 3-340-02
1	0,74	2,41	2,40	2,10	5,81	2,31	3,46	2,72	1,84
2	0,81	1,72	1,94	1,70	4,50	1,97	2,78	2,34	1,55
3	0,77	2,23	2,21	1,94	5,30	2,17	3,18	2,57	1,77
4	1,00	0,52	1,18	1,10	2,65	1,35	1,70	1,64	0,93

Table 7 The pressure values of Model #2 of gauges (MPa)

Gauges	Z	Autodyn	Brode	Henrych	Mills	Kinney-Graham	Sadovskiy	Kingery-Bulmash	UFC 3-340-02
1	0,61	3,78	3,18	1,89	7,84	2,81	4,55	3,24	2,77
2	0,69	2,73	2,20	1,46	5,24	2,16	3,15	2,55	2,10
3	0,64	2,33	2,75	1,70	6,70	2,54	3,94	2,96	2,58
4	0,91	0,74	1,07	1,09	2,36	1,24	1,53	1,51	1,23

equivalent mass of the TNT. The displacement trend shows the deformations of the most critical beam and slab which placed above the explosive at a very short duration. The beam and slab cracked and fragmented under the effect of impulse when the blast waves reached. If the duration of the explosive is set to longer, the displacement may trend larger under the effect of impulse.

The displacement counter diagram obtained from blasting analysis are demonstrated in Fig. 21. After the analysis, AUTDYN generates the displacement values of both general structure and the gauges. According to the contour diagrams, peak and base values are seen and can be read approximately from the diagram besides, the values of the gauges are shown in Table 5 below. According to the comparison chart, the values of Model-2 is bigger than the values of Model-1 normally that's because of Model-2 the distance between the detonation source to the point of interest is 4 m is shorter than Model-1's distance with the values of 4 m and 5,5 m, respectively.

Although both models have the same explosive material and charge weight mass, the total energies (see Fig. 22) and absorbed energies can be different due to the R (distance from the detonation source to the point of interest). On each models the energy which released from explosion is totally absorbed by the air on the other hand the solid materials (concrete and sand) can absorb released energy but too small that can be negligible.

3.3 Comparison of results

The aim of this paper is to calculate the blast load parameters with empirical method and compare with the values which generated from AUTODYN for two models to benchmark the values. The researches proposed peak overpressures which depends on scaled distance (Z), six equations which proposed by researchers plus UFC 3-340-02 criteria's gives values of peak overpressure.

When six equations combined plus UFC 3-340-02 and numerical results in one graphics (see Fig. 23), the differences can be seen clearly. Some equations gives quality results at smaller scaled distance (Z) values whereas, some equations gives quality results at bigger scaled distance values.

Both of our finite element models in which designed with AUTODYN and the formulations which proposed by the researchers and UFC 3-340-02 graphics; giving the peak overpressures, compared at the Tables 6 and 7. According to the table, the 4 equations results is similar with AUTODYN for Model-1 and four equations results is similar with AUTODYN for Model-2.

3.4 Empirical example: (UFC 3-340-02)

In this part of the study, results obtained from Model-1 are aimed to check with empirical equations. The Gauge #1 which is the plotted on the wall, is calculated with empirical formulas and idealized equivalent triangular pressure-time graph is drawn. According to the Figs. 15 and 18;

R (distance from the detonation source to the point of interest) = 5,50 m
W (charge weight of the explosive) = 410 kg
Width of the wall = 0,4 m
Height of the wall = 5,0 m
Solution
Step-1: (Calculation of Scaled Distance; Z)

$$Z = \frac{R}{W^{1/3}} = \frac{5,5}{410^{1/3}} = \frac{5,5}{7,43} = 0,74\ kg/m^{1/3}$$

$$W^{1/3} = 7,43\ m^{1/3}$$

Step-2: (Determining the parameters; P_{so}, t_A, Lw, t0 and is at Gauge#1 from Fig. 4)

$$P_{so} = 1{,}84\ MPa$$
$$P_r = 11{,}7\ MPa$$
$$t_A/W^{1/3} = 0{,}318 \rightarrow 0{,}318\,.\,7{,}43 = 2{,}36\ ms$$
$$L_w/W^{1/3} = 0{,}18 \rightarrow 0{,}18\,.\,7{,}43 = 1{,}337\ m$$
$$t_0/W^{1/3} = 1{,}033 \rightarrow 1{,}033\,.\,7{,}43 = 7{,}67\ ms$$
$$i_s/W^{1/3} = 189 \rightarrow 189\,.\,7{,}43 = 1{,}4\ MPa$$

Step-3: (Determining the parameters; reflected pressure and impulse from Figs. 11 and 13)
From Fig. 11, the α=0° Read; $C_{r\alpha}$=6,55 for P_{so}=1,84 MPa, then;
$P_{r\alpha}=C_{r\alpha}.\ P_{so}$=6,55. 1,84=12,05 *MPa*
From Fig. 12 , the α=0° Read; $i_{r\alpha}/W^{1/3}$=825 for P_{so}=1,84 MPa, then;
$i_{r\alpha}$=825.7,43=6,13 *MPa*
Step-4: (Front wall loading, positive phase)
C_r (sound velocity) can be calculated from Fig. 7 for P_{so}= 1,84 MPa
$C_r \approx 1{,}2$ m/ms
The calculation of clearing time t_c is calculated the equation below: (S is smallest surface's height H or half width W/2; R is the ratio of S/G, where G is the largest of the H or W/2)

$$t_c = \frac{4S}{(1+R)C_r} \models \frac{4.0{,}4}{(1+0{,}4/6).\,1{,}2} = 1{,}25\ ms$$

$$t_{of} = \frac{2.\,i_s}{P_{so}} = 2\frac{1{,}4}{1{,}84} = 1{,}52\ ms$$

q_o peak dynamic pressure is determined from Fig. 8
q_o=3,5 *MPa*
Then; $P_{so}+C_D q_o$ can be calculated, where C_D is 1,0;

$$P_{so} + C_D q_0 = 1{,}84 + 1{,}0\,.\,3{,}5 = 5{,}34\ MPa$$

$$t_r = \frac{2.\,i_{r\alpha}}{P_{r\alpha}} = \frac{2.6{,}15}{12{,}2} = 1{,}01\ ms$$

Step-5: (Negative phase loading);
For $P_{r\alpha}$ and $i_{r\alpha}/W^{1/3}$ the value of Z is read form Fig. 4
$P_{r\alpha}$=12,02 MPa then; Z=0,76 $i_{r\alpha}/W^{1/3}$=825 then; Z=0,748
For new Z values; negative $P_{r\alpha}$ and $i_{r\alpha}/W^{1/3}$ values are read from Fig. 7
Z=0,76 then, $P_{r\alpha}$=0,09 MPa
Z=0,748 then, $i_{r\alpha}/W^{1/3}$=0,095 thus; $i_{r\alpha}$=0,095.7,4=0,705 MPa-ms
Calculation of fictitious duration t_{rf}^-;

$$t_{rf} = \frac{2.\,i_{r\alpha}^-}{P_{r\alpha}^-} = 2.\frac{0{,}705}{0{,}09} = 15{,}67\ ms$$

$$Then;\quad 0{,}27.\,t_{rf}^- = 0{,}27.15{,}67 = 4{,}23\ ms$$

$$t_0 = 7{,}67\ ms \quad then;\quad t_0 + 0{,}27.\,t_{rf}^- = 7{,}67 + 4{,}23 = 11{,}9\ ms$$

And: $t_0 + t_{rf}^- = 7{,}67 + 15{,}67 = 23{,}34\ ms$

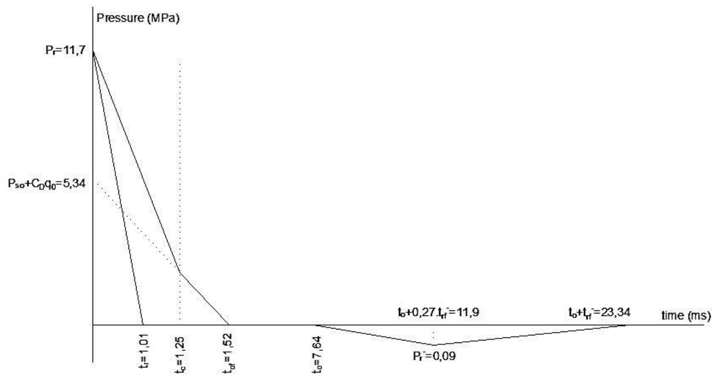


Fig. 24 Idealized equivalent triangular pressure-time graph

And according to the parameters which calculated above has analyzed and plotted on the graph below (see Fig. 24).

4. Conclusions

This paper focuses on the blasting response of a RC retaining wall under TNT explosive is investigated using numerical and empirical methods. For the purpose, two series analyses are performed numerically and numerical results are checked with empirical equations. At the end of the study following conclusions are articled:

• At bigger "scaled distance" values, the peak overpressure values which generated from AUTODYN, are consistent with Brode, Henrych, Kinney and Graham, Kingery and Bulmash, UFC 3-340-02, the other equations are inconsistent.

• At smaller "scaled distance" values: However, the peak overpressure values which generated from AUTODYN, are consistent with Brode, Kinney and Graham, Kingery and Bulmash, UFC 3-340-02; the difference can be seen clearly and the other equations are inconsistent too.

• The results which calculated from Mills (1987)and Sadovskiy (2004) are inconsistent with the others.

• According to the Fig. 25, at bigger Z (scaled distances); each values which proosed by the reserchers and UFC 3-340-02 are consistent on the other hand, when the Z values begins to decrease the values are became different.

• UFC 3-340-02 gives every detailed parameters, if investigating of blast load theory is needed and is used as a reference on blast loading because gives every detailed information and graphs about blast loading.

• When examining the proposes, the best results are; Brode (1955), Henrych (1979), Kinney-Graham (1985)and Kingery-Bulmash (1984)

• The results which taken from researchers; Mills (1987)and Sadovskiy (2004) are not compatible for smaller Z values but can be used for bigger Z values.

• Although the sand mass behind the wall, the displacements occur which had done due to the explosion, besides the sand mass decreases the displacement values significantly.

• Numerical analyses showed that the computer software such as AUTDYN can solve detailed structures faster rather than empirical equations.

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