Defence Science Journal, Vol. 63, No. 4, July 2013, pp. 376-380, DOI : 10.14429/dsj.63.2770

Effect of Explosive Sources on the Elastic Wave Field of Explosions in Soils

Chun-Hua Bai[!], Jian Chen[*], Bo Zhang[#], and Zhong-Qi Wang[!]

[!]Beijing Institute of Technology, Beijing-100 081, China
[*]China Shipbuilding Information Center, Beijing-100192, China
[#]East China University of Science and Technology, Shanghai-200237, China
[*]E-mail:cjlmusic@126.com

ABSTRACT

A seismic wave is essentially an elastic wave, which propagates in the soil medium, with the strength of initial elastic wave being created by an explosion source that has a significant effect on seismic wave energy. In order to explore the explosive energy effect on output characteristics of the elastic wave field, four explosives with different work capacity (i.e., TNT, 8701, composition B and THL) were used to study the effects of elastic wave pressure and rise time of stress wave to the peak value of explosions in soils. All the experimental data was measured under the same geological conditions using a self-designed pressure measuring system. This study was based on the analysis of the initial pressure of elastic waves from the energy output characteristics of the explosives. The results show that this system is feasible for underground pressure tests, and the addition of aluminum powder increases the pressure of elastic waves and energy release of explosions in soils. The explosive used as a seismic energy source in petroleum and gas exploration should have properties of high explosion heat and low volume of explosion gas products.

Keywords: Seismic exploration, seismic-wave energy, explosive source, energy output, explosions in soils

NOMENCLATURE

ρ	Density
Q	Detonation heat
V	Volumes of detonation gas
P	Pressure
H	Depth
m	Quality
TNT	Trinitrotoluene
Composition B	RDX/TNT
R	Ratio distance
ω	Energy output index
σ	Poisson's ratio of soil medium
E	Deformation modulus of soil medium
r_p	Radius
v	Velocity
8701	RDX/High polymer
THL	TNT/RDX/AL

1. INTRODUCTION

Explosions are considered as the most effective seismic energy source in petroleum and gas exploration, and most commonly conducted using solid explosive sources with different charges or structures[1]. The transient and strong disturbance caused by explosions in soils is used in this method, with the help of seismic reflection waves generated in strata, to sketch out the seismograms for the determination and analysis of strata structure to achieve exploration[2]. Explosions in soils is the source to generate seismic waves, which is also the key issue for source studies[3]. Previous studies showed that if there is much higher energy of the seismic waves, there would be more reflections of the seismic waves collected, thus more abundant geological depth information can be achieved[4-6].

The formation of seismic waves caused by explosives that are exploded in soils is a very complex physical process, which involves the nature of explosives and dynamic mechanical properties of soil medium, and relates to the coupling and matching relationship between them[7]. The total energy caused by explosions in soils can be divided into shock wave energy and detonation gas expansion energy. Ouchterlony[8-9], *et al*., José[10], *et al*., and Vladimír[11] analyzed the distribution of explosion energy in soils (Fig.1) based on their theoretical model and test method as well as field test data to improve the energy efficiency of explosives.

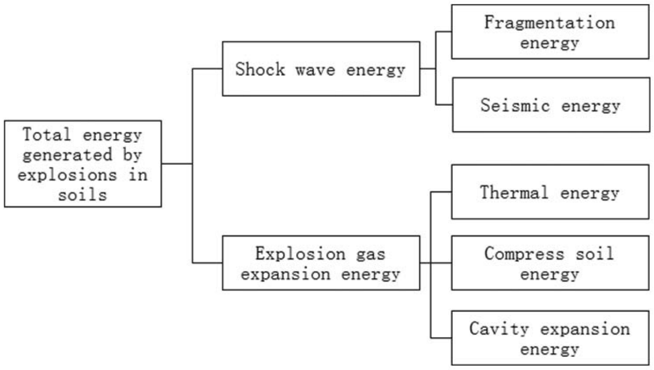

Figure 1. Distribution of the energy in the underground explosion[10].

Received 30 October 2012, revised 18 April 2013, online published 19 July 2013

For the past few years, many scholars have conducted a number of researches on how to improve the explosion energy of seismic waves, and matching relation between source and explosives. Nicholls[12], who studied geometric and impedance coupling problems of explosives through a number of experiments, proposed that when the radius of grain is equal to that of the well, and impedance of explosives and excitable media are equal, the generated energy has the maximum value. Silverman[13] invented slender grain with low detonation velocity based on the matching relation between detonation velocity of explosives and seismic wave velocity to improve the seismic wave energy. Song[14], *et al*. and Li[15], *et al*. studied the multi-level delay overprinting source to improve seismic wave energy according to overprinting principle of seismic wave. Gao[16], *et al*. studied the effects of source depth on the excitable seismic wave energy. Zhang[17], *et al*. investigated the effect of explosives mass on excitable energy through the experiments. These previous studies focused on charging structure, explosive mass and depth, and relevant theories of the source, but not much attention has been given on the properties of the explosive source. Moreover, the explosion process in soils was not taken into consideration in these studies.

The main purpose of this paper is to design a pressure test system for the soil explosions, and the pressure changes of elastic waves generated by explosives including TNT-8701-composition B and THL (TNT/RDX/AL) which are measured on the same level but different distances for the explosives. The effects of four explosive sources with different capacities to perform work on the excitation of seismic wave energy are analyzed from the aspect of explosion energy output structure in the soil, and some useful conclusions are obtained for the design of explosive sources.

2. EXPERIMENT

2.1 Experimental Materials

Four explosives with different work capacity were selected in this experiment, including TNT, 8701, composition B and THL. For each explosive, the values of explosion heat Q, volumes of detonation gas V and characteristic value ω, which is characterized the energy output index as a criterion of the effects of seismic source charge on seismic wave energy are shown in Table 1. Comparative tests were made for the same quantity (0.7 kg) of each explosives (Fig. 2). The characteristic value ω of each explosive can be calculated as[18]:

$$\omega=\rho_0 Q\cdot\rho_0 V=\rho_0^2 QV \tag{1}$$

where ω is the characteristic value of explosives in J/m^3; ρ_0 is the density of the explosive in kg/m^3; Q is the detonation heat of the explosive in J/kg; and V is the volume of detonation gas produced by the explosive in m^3/kg. The energy output characteristics of each explosive are associated with the detonation heat and volume of detonation gas, and thus, in this paper, we use these two parameters to characterize the energy outputs of explosives.

2.2 Test Method

The stress wave parameters were measured by means of apparatus comprising pressure transducer, data collector device, signal amplifier devices and computer, and the test equipment is shown in Fig. 4. Specifically, the features of this system are as follows: Pressure test; Synchronous trigger and timing; Parameter setting; Data processing.

First, the explosive source was detonated by the initiator, a thin metal trigger plate which had a short circuit when instantaneous explosion occurred, while the data was collected by synchronous trigger device. Then, the pressure signal was received by a transducer and the output corresponding signal voltage was amplified by the signal amplifier. Finally, after filtering, the signal was converted into a pressure-time curve which was stored into the computer.

TNT 8701 comp B THL

Figure 2. Explosive source of different working capacity.

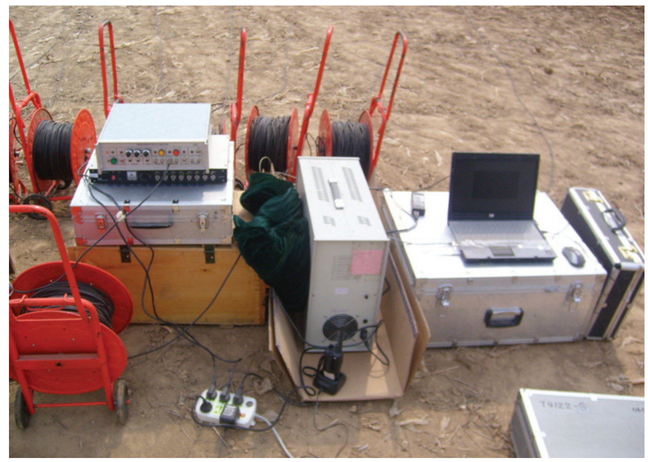

Figure 3. Pressure test equipment.

Table 1. Detonation parameters of explosive[3]

Explosive	Q/Jkg^{-1}×10^6	V/m^{3}kg^{-1}	ω/Jm^{-3}×10^{12}
TNT	4.51	0.62	6.72
8701	5.41	0.87	11.31
Comp B	4.62	0.82	9.1
THL	6.29	0.42	6.35

2.3 Experimental Setup

In order to determine the minimum distance, i.e., ΔL , which is between the excitation and receiver points, with the position of the receiver point outside the plastic zone to effectively obtain the internal elastic wave signal. The radius of the plastic zone is calculated as follows[19].

$$r_p = 0.75\cdot\left[\frac{Q\cdot H\cdot m}{E\cdot(1-2\sigma)}\right]^{\frac{1}{3}} \tag{2}$$

where Q is the release of energy in an explosion by a unit mass of explosive in J/kg; E is the deformation modulus of soil medium; H is the depth of explosive column underground in m; m is the mass of explosive column in kg; σ is the Poisson's ratio of soil medium. Under the condition of this experiment, $Q = 4\times10^6$ J/kg, $E = 10^6$ kg/cm^2, $\sigma = 0.4$, $H = 1$ m, $m = 0.7$ kg, and according to the results of the calculation, ΔL produced by the explosion is about 1.81 m, and less than 2 m for the other explosive sources. Considering the actual situation and calculation error, ΔL is determined to be 3 m.

Figure 4 shows the pressure transducer setup. The transducers were installed at the same depth with the charge in specially drilled holes. They were then covered with the soil removed from the hole, which was replaced in layers and tamped to the natural density. The explosive column and sensor were set on the same level of depth in order to avoid wave reflections due to the pressure transducer, so as to effectively obtain the pressure of elastic wave field. The experimental setup sketch is shown in Fig. 5.

Figure 4. Placement of the pressure transducer.

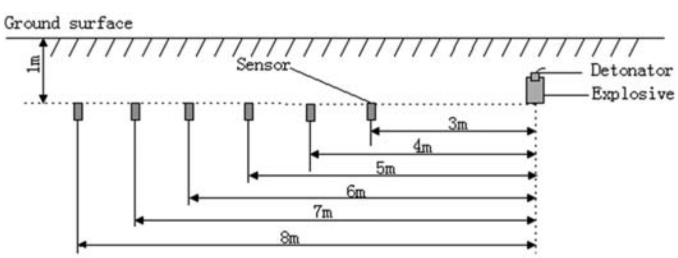

Figure 5. The experimental setup sketch.

3. EXPERIMENTAL RESULTS AND ANALYSIS

The authors analyze the feasibility of the pressure test system, and then discuss the peak pressures and rise times of pressure to the peak value at different distances. To obtained values of peak pressure and rise time of pressure to peak value were quite useful for the output characterization of explosive energy. The same methods were also used to characterize explosion effects in soil, in order to determine the effects of explosive sources on seismic wave energy for underground explosion.

3.1 Feasibility Analysis of Pressure Test System

For the purpose of verifying the feasibility of the pressure test system, for 1kg of TNT, the pressure signals produced were compared with the ground surface velocity of the explosion. Figure 6 shows the comparison of pressure and vertical ground velocity caused by the explosion. Fig. 6 (a) shows the elastic wave curve of 3 m from the center of the source at depth of 1 m, while Fig. 6 (b) shows the vertical vibration velocity of 10 m from center of the source.

As can be seen from Fig. 6, the application time of the measured elastic waves and the vibration time have the same order of magnitude, within the same scope. Moreover, there is some corresponding relationship between them. The maximum value of the elastic waves corresponds to the minimum value of the vertical vibration velocity, which is consistent with the law of conservation of energy. Accordingly, the measured elastic wave curve can be seen as typical elastic wave signals, indicating that the system can meet the requirements of measurement on mechanical properties of soils for explosions in the soils.

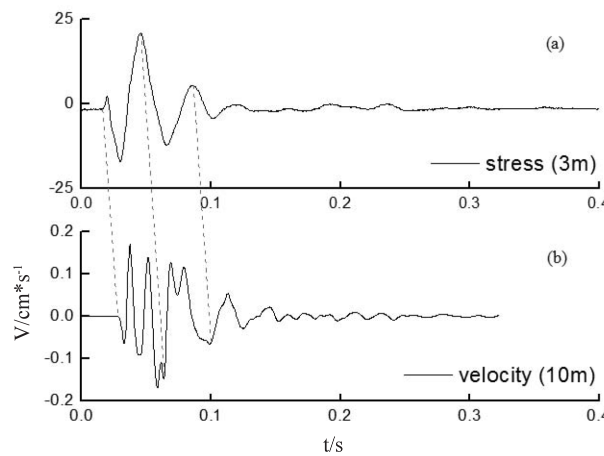

Figure 6. Comparison of signals between the (a) underground elastic wave, and (b) vertical velocity on the ground.

3.2 Pressure Test

The energy output structure of explosions in soils is the major factor that affects seismic wave energy and is the key for formulation design of explosives. The peak pressure value of stress in the elastic zone is quite useful for the characterization of seismic wave energy. Figure 7 shows the peak pressure values of elastic waves as a function of the distance for the explosion of four sources under the same conditions (i.e., with the same mass, type and depth).

As can be seen in Fig. 7, at the same distance, the peak values of shock waves caused by explosive shocks has the following order: THL> 8701> composition B> TNT. What can be found from the combination in Table 1 is that there is no obvious relationship between the peak values of elastic waves and the characteristic values of explosives. However, by comparing the explosion heat with specific volume, it can be found that the peak values of elastic waves are proportional to the explosion heat and inversely proportional to the specific volume.

The reason for the observation discussed above is connected to the energy output structure of explosives. The

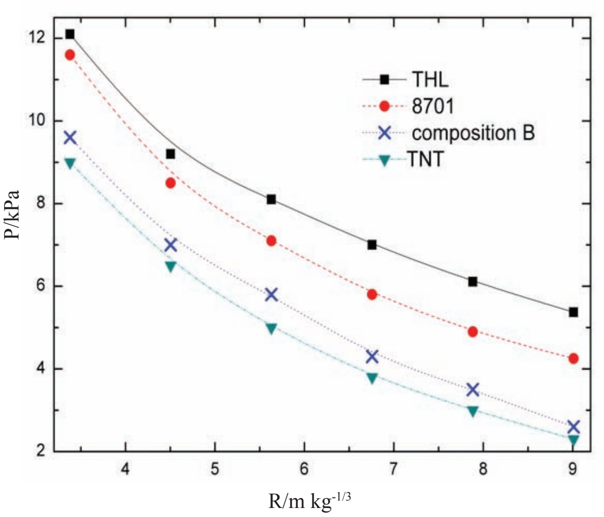

Figure 7. The peak pressure values of elastic waves at different distance.

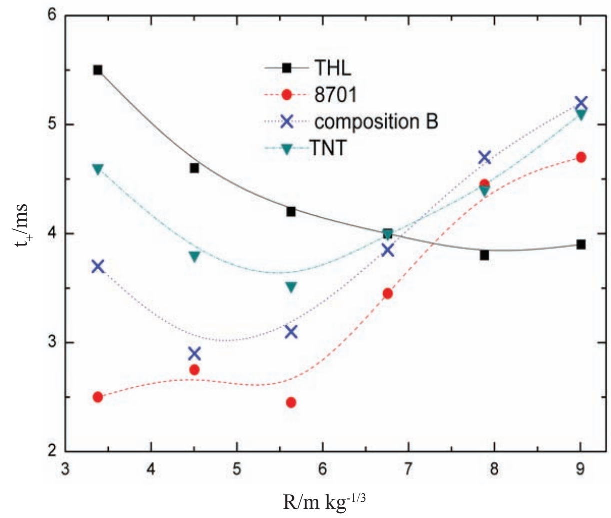

Figure 8. The rise time of elastic wave to the peak value at different scaled distance.

total energy caused by explosions in soils can be divided into shock wave energy and the energy of detonation gas expansion. The former is consumed for the destruction, compression and deformation of soil, while the latter is mainly for expanding the cavity. Meanwhile, there will be three zones coupled with explosion: the broken, plastic and elastic zones. Thus it can be seen that the energy output structure of explosives determines the contribution of energy to each zone. Although improving the specific volume is a method for the improvement of capacity to perform work, the detonation gas has little contribution on the improvement of seismic wave energy, because it decreases the amount of seismic energy that is generated. Therefore, it cannot improve the capacity of explosives, as it is determined by both detonation gas and specific volume.

3.3 Rise Time of Elastic Wave Analysis

Figure 8 shows the rise times of maximum pressures at different distances. It is observed that the rise times have greater differences generated by four explosives, and there are sensible differences near the explosion source. As the distance is increased, the differences decrease rapidly. This change is divided into two stages, in the first stage, the rise time decreases with distance in the near-field of the explosion; in the second stage, the rise time begins to increase when it exceeds a threshold value. Overall, it is found that the rise times of elastic waves to the peak values initially decrease and then increase with the distance.

For TNT, composition B and 8701, the rise rate of pressure decreased as distance is increased. By contrast, the rise rate of pressure is slower when the distance is increased from 7 m/kg$^{1/3}$ to 9 m/kg$^{1/3}$. The reason for this is that the heat output of detonation and long time for energy release is increased due to the second reaction of aluminum powder. At the same time, the energy loss decreased and the volume strength increased during the initial stage of detonation. This means that by maintaining a higher sustained energy release, it is possible to increase the amplitude and energy of seismic waves.

4. CONCLUSIONS

In this study, the effects of four explosive sources (TNT, 8701, composition B and THL) on the elastic wave field of explosions in soils were studied. It is observed that THL has the maximum peak pressure. Explosives should have high detonation heat and low gas volume properties as a seismic energy source used in petroleum and gas exploration. The presence of aluminum in the explosive composition will increase the energy release, and reduce the gas volume produce. As follows from the analysis of the graphs, by maintaining a higher sustained energy release with a higher initial pressure, it is possible to increase the energy of seismic waves.

ACKNOWLEDGEMENTS

The first author would like to thank Prof. Qingming Liu, Beijing Institute of Technology, for his help in experiments of pressure test of this work. This work is supported by National Major Scientific and Technological Special Project during the Twelfth Five-year Plan Period, China (Grant No.: 2011ZX05006-002), Shanghai Postdoctoral Sustentation Fund, China (Grant No.:13R21411800), and Postdoctoral Science Foundation of China (Grant No.: 2012M520852).

REFERENCES

1. Conyers, L.B. An Introduction to applied and environmental geophysics. John Wiley & Sons Ltd., England, 2011.
2. Telford, W.M.; Geldart, L.P. & Sheriff, R.E. Applied Geophysics. Cambridge University, England, 1990.
3. Lv, Chunxu. Theory of industrial explosive. Weapon Industrial Press, Beijing, 2003, 448p.
4. Quigley, J. & Thompson, P.A. comparison of seismic explosives-a case history. 2004.
5. Kobielak, S. & Krauthammer, T. Dynamic response of buried silo caused by underground explosion. *Shock Vibration*, 2004, **11**(5-6), pp. 665-684.
6. Yankelevsky, D.Z.; Feldgun, V.R. & Karinski, Y.S. Underground explosion of a cylindrical charge near a

buried wall. *Inter. J. Impact Engg*. 2008, **35**(8), 905-919.
7. Henryeh, J. Blasting dynamic and its applications. Xiong, Jianguo, Tran. Beijing, 1987. pp. 179-183.
8. Ouchterlony, F.; Nyberg, U.; Olsson, M.; Bergqvist, I.; Granlund, L. & Grind, H. Where does the explosive energy in rock blasting rounds go. *Sci. Technol. Energetic Mater.*, 2004, **65**(2), 54-62.
9. Ouchterlony, F.; Nyberg U.; Olsson M.; Bergqvist I.; Granlund L. & Grind H. The energy balance of production blasts at Nordkalk's Klinthagen quarry. *In* the Proceeding EFEE 2nd World Conference on Explosives & Blasting Technology, *Edited by* R Holmberg, 2003, pp.193-203.
10. Sanchidrián, J.; Segarra, P. & López, L. Energy components in rock blasting. *Inter. J. Rock Mech. Min.*, 2007, **44**(1), 130-147.
11. Vladimír, Sedlák. Energy evaluation of de-stress blasting. *Acta Montanistica Slovaca*, 1997, **2**(2), pp.11-15.
12. Harry, R. Nicholls. Coupling explosive energy to rock. *Geophysics*, 1962, **27**(3), 305-316.
13. Daniel, Silverman. seismic wave generation. US Patent No. 2,770,312, 13 Nov 1956.
14. Song, Yulong; Lv, Gonghe & Wang, Xinhong. Analysis of seismic energy produced by shock wave of vertical stack source. *Oil Geophysical Prospecting*, 2004, **39**(4), 371-374.
15. Li, Wenbin.; Wang, Xiaoming & Zhao, Guozhi. Study on energy of seismic wave from shock of superimposed seismic source in vertical direction. *Explosive Materials*, 2004, **33**(1), 9-11.
16. Gao, Jun.; Wan, Yingpeng & Huang, Bo. Choosing shooting depth based on characteristics of explosive-activated wavelet. *Oil Geophysical Prospecting*, 2009, **44**(Supplement 1), 1-4.
17. Zhang, Zhi.; Liu, Cai & Shao, Zhigang. Theory and experimentation of the charge sizes in seismic source for seismic exploration. *Progress Geophysics*, 2003, **18**(4), 724-728.
18. Zhang, Housheng & Zhang, Shanshan. A study of the application of the characteristic value of explosives as the energy output index. *Acta Armamentarii*, 1984, **1**(4), 36-41.
19. Wang, Enhua. Seismic prospecting method of enhancing the deep zone resolution and its application research. Chengdu University of Technology, 2001. PhD Thesis.

Contributors

Dr Chun-Hua Bai obtained his PhD from Beijing Institute of Technology (BIT), China in 1988. Presently, he is working as a professor at State key Laboratory of Explosion Science and Technology, BIT and his research areas are explosion dynamics and fuel air explosives.

Dr Jian Chen obtained his PhD from Beijing Institute of Technology, China, in 2013. Presently, he is working as an Engineer at China Shipbuilding Information Center, and his research areas are : Safety assessment and explosion in soils.

Dr Bo Zhang obtained his PhD from Beijing Institute of Technology, China, in 2013. Presently, he is working as an Assistant Professor at East China University of Science and Technology, and his research areas are : Explosion dynamics, deflagration and detonation.