

Study on the Impact of Varying Degrees of Underground Accidental Explosions on Underground Pipes by Simulation

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Abstract

Underground accidental explosions are caused by the detonation of explosive materials (solid, liquid or gas) stored below the ground surface. In this study, response of underground pipes due to varying degrees of underground accidental explosions was studied using ABAQUS code. Pipes buried in loose sand, dense sand and undrained clay at 1m depth below the ground surface were modelled. The material properties as revealed by several researchers were used. Pipe and soil materials were limited to linear, elastic, homogeneous and isotropic. The observed parameters are displacement, pressure, stress and strain at the crown, invert and spring-line of underground pipes. The results showed that irrespective of the ground media, displacement increases linearly as the loading wave velocity increases. Even though there is wide variation in the results due to dilations and compressions caused by the transient stress pulse of compression wave, observed parameters increases as the loading wave velocity increases.

Keywords: underground accidental explosion, pipes, structures, response, loading wave velocity, observed parameters

1. Introduction

Underground accidental explosion normally occur when an explosive material (solid, liquid or gas) explodes below the ground surface. Underground explosion can take place, broadly speaking, in sand as well as undrained clay with varying degrees of impact on underground structures. Depending on the mass and depth of burial of explosive charge as well as the geotechnical property of the ground medium, the consequence of underground accidental explosion is tremors which could be felt tens and hundreds of kilometres away from the point of burst of the buried explosive materials (Eric & Shino, 2011). The load emanating from the blast wave is termed loading wave velocity. It denotes the blast load which the buried explosive charge delivered to the buried structures. The underground accidental explosion loads in terms of loading wave velocity reduce to seismic velocity of soil at less than 10m from the source for explosive range of 10kg TNT to 250kg TNT buried in soils and undrained clay (Olawaju et al., 2010b; 2010d; 2010h). Seismic velocity is a term describing the rate of propagation of an elastic wave through the earth due to disturbance in the earth caused by explosion or earthquake and it depends on the density and elasticity of the ground medium (Robert, 2002).

Due to complexity in accurately determining the mass of the explosive materials (i.e., solid, liquid and gas) that will produce the explosive loads on underground structures, there is need to study the consequences of these complexity. This is with a view to determining the extent and magnitude of the responses of underground structures like pipes due to varying degrees and impact of underground accidental explosions. Underground structures are divided into fully buried structures partially buried structures which can be any structure of diverse shapes such as, shelters, basement structures, underground mall facilities, underground parking spaces, silos, storage facilities, retention basins, shafts, tunnels, pipes, underground railway, metro stations, to mention a few.

Pipes are underground installations which are used to convey petroleum products, sewage, industrial and domestic wastes, liquid gas, acid, gas in petrol-chemical industries, atomic reactor, means of transportation in underground, means of access in mining industries, storage facilities, piling for jetties berths and foundations, caissons, surface and underground main lines for irrigation and drainage, penstocks for hydro-electric projects, etc. Due to huge investment involved in the construction of underground pipes and tremendous usage across the world, there is need to study the responses of underground installations (like pipes) due to underground accidental explosions. This is with view to providing design information and guidelines for underground pipes to resist the effects of underground accidental explosions. Explosion-load-evaluation of underground structures at low depth of burial is important in designing explosion-resistant underground structures like pipes. This study is aimed at determining by simulation, the impact of varying degrees underground accidental explosions on underground pipes.

2. Background Study

Explosive materials (solid, liquid or gas), are stored above the ground surface, on the ground surface and below the ground surface depending on the volatility and proximity to the surrounding settlement. This is mostly carried out at: military formations where defensive weapons like war heads, bombs, grenades, etc are stored; filling stations where fuels and other crude oil derivatives are stored; manufacturing industrial sites where propane are stored underground; etc. Explosion loads could be evaluated using empirical, semi-empirical and numerical techniques as the case may be (Unified Facilities Criteria, 2008; Peter & Andrew, 2009; Olarewaju et al., 2010a; 2010b; 2010d; 2011a; 2012). According to Unified Facilities Criteria (2008), explosive materials for underground explosions, confined and unconfined for surface explosions are expressed in kilogram (kg) trinitrotoluene (TNT) equivalent for an explosive. This is the mass of TNT that would give the same blast performance as the mass of the explosive in question.

Soil-pipe interaction due to short discontinuous events like underground accidental explosions depends mainly on stiffness of the constituents rather than strength (Liang-Chaun, 1978; Olarewaju et al., 2010c; 2010g). Underground explosions (nuclear or otherwise) could be carried out for different purposes such as earthmoving mechanisms and crater formation, even though it may have spiral effects. When explosive material (i. e. nuclear weapon, bombs, etc) explodes under the ground, a sphere of extremely hot, high-pressure gases, including vaporized weapon residues, soil and rock, is formed. This is the equivalent of the fireball in an air or surface burst. The rapid expansion of the gas bubble initiates a ground shock wave which travels in all directions within the ground medium away from the burst point. When the upwardly directed shock (mainly compression) wave reaches the earth's surface, it is reflected back as a rarefaction (or tension) wave. If the tension exceeds the tensile strength of the surface material, the upper layers of the ground will split off into more-or-less horizontal layers (The Effects of Nuclear Weapons, 1977).

A plowshare program test was conducted on the 6th July 1962 at the Nevada test site for the promotion of underground nuclear explosion to develop peaceful usage for the atomic energy. In this test, explosive of 104×10^3 tons displaced 12×10^6 tons of soil and released seismic energy of 4.75 Richter scale equivalents (United States Department of Energy, 2000; AubreyJ.org, 2006 - in public domain). The impacts of underground accidental explosions are mostly felt at greater distance from the source of the explosion (Robert, 2002; Eric & Shino, 2011). The United States of America has conducted a lot of deep underground tests, especially since September 1961 according to The Effects of Nuclear Weapon (1977).

3. Methodology

In this study, 1m diameter pipes buried in loose sand, dense sand and undrained clay at 1m depth below the ground surface were modelled using ABAQUS software (finite element numerical code). According to Olarewaju et al. (2012), it is more necessary to evaluate the explosion resistance of underground structures at lower depth of burial. This is because the inter-atomic bonds of the material yield more at lower depth of burial than those buried at greater depth. The contact between the soil and pipe was defined for 'no slip' condition. Therefore it is assumed that perfect bond exist between the soil and the pipe. The soil and pipe materials were assumed to be linear, homogeneous and isotropic. As a result, the material properties as revealed by various researchers and pipe manufacturers were used (Craig, 1994; Kameswara, 1998). In line with Geotechnical Modelling and Analysis with ABAQUS (2009), boundary conditions were defined with respect to global Cartesian axis.

In line with ABAQUS Analysis Users' Manual (2009) and ABAQUS/Explicit: Advanced Topic (2009), analysis were carried out on simulated models by solving the governing equation of motion of the system shown in

Equation 1 (with the initial conditions) using the time integration technique of the finite different scheme in ABAQUS/Explicit (Olawaju et al., 2010c; 2010h; 2011c).

$$[m][\ddot{U}] + [c][\dot{U}] + [k][U] = [P] \tag{1}$$

where m , c , k , U and P are the global mass matrix, global damping matrix, global stiffness matrix, displacement and load vectors respectively while dot indicate their time derivatives (Kameswara, 1998; ABAQUS Analysis User’s Manual, 2009; ABAQUS/Explicit: Advanced Topic, 2009).

The observed parameters are displacement, pressure, stress and strain at the crown, invert and spring-line of pipes buried in loose sand, dense sand and undrained clay as shown in Figure 1 (Olawaju et al., 2010a; 2010g; 2011c). Underground accidental explosions were assumed to have taken place outside the vicinity of the buried pipes and as a result, explosion loads for explosives range of 10kg TNT and 250kg TNT were represented by the loading wave velocities for sand and undrained clay as shown in Figures 2 and 3 respectively.

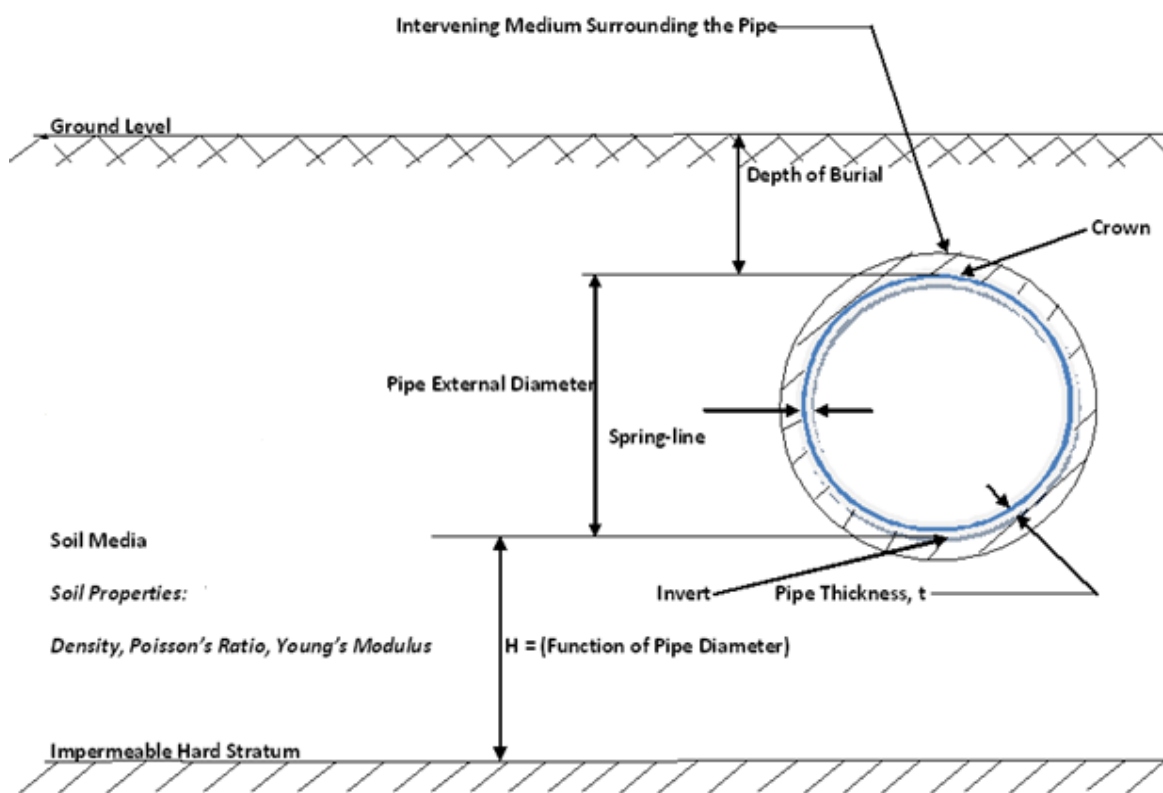


Figure 1. Problem definition for the response of underground pipe due to varying degree of impact of underground accidental explosions (Olawaju et al., 2010a; 2010g; 2011c)

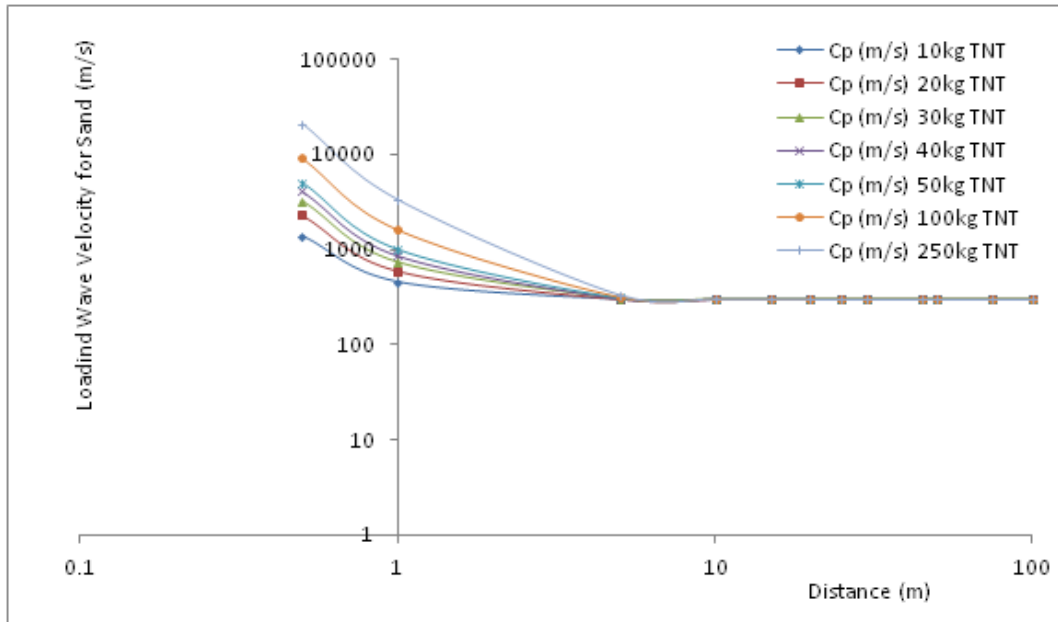


Figure 2. Loading wave velocity for sand at stand-off distance for varying weight of explosives (Olarewaju et al., 2010d; 2010e; 2010f; 2010h; Olarewaju et al., 2012)

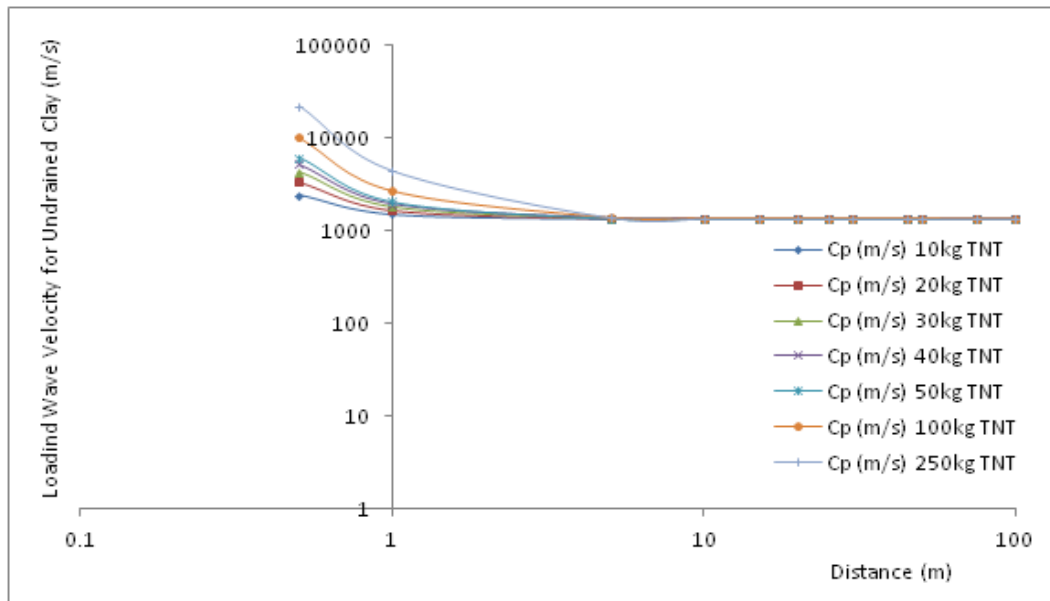


Figure 3. Loading wave velocity for undrained clay at stand-off distance for varying weight of explosives (Olarewaju et al., 2010d; 2010e; 2010f; 2010h; Olarewaju et al., 2012)

4. Results and Discussion

The results of loading wave velocities for explosives ranging from 10kg TNT to 250 kg TNT in sand and undrained clay due to underground accidental explosions, as obtained from Olarewaju et al. (2010d, 2010e; 2010f; 2010h) and Olarewaju et al. (2012) are presented in Figures 2 and 3 respectively. In addition to this, due to underground accidental explosions, the result of displacement at the crown, invert and spring-lie of pipes buried in loose sand, dense sand and undrained clay are presented in Figures 4, 5 and 6 respectively. Furthermore, due to underground accidental explosions, the result of pressure at the crown, invert and spring-line of pipes

buried in loose sand, dense sand and undrained clay are presented in Figures 7, 8 and 9 respectively. Due to underground accidental explosions, the result of stress at the crown, invert and spring-line of pipes buried in loose sand, dense sand and undrained clay are presented in Figures 10, 11 and 12 respectively. Finally, due to underground accidental explosions, the result of strain at the crown, invert and spring-line of pipes buried in loose sand, dense sand and undrained clay are presented in Figures 13, 14 and 15 respectively.

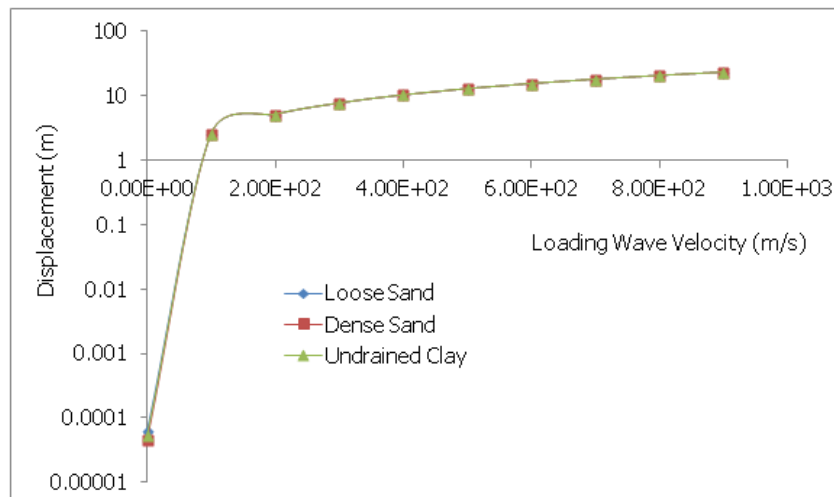


Figure 4. Displacement at the crown of underground pipes due to varying underground accidental explosions

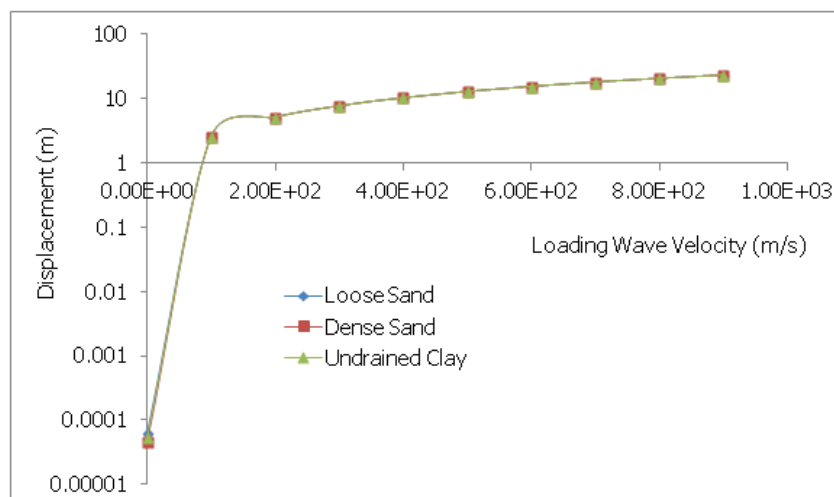


Figure 5. Displacement at the invert of underground pipes due to varying underground accidental explosions

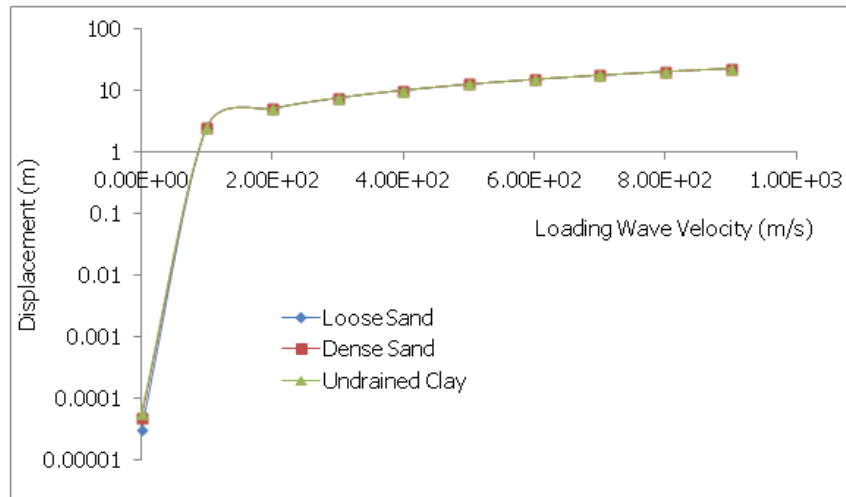


Figure 6. Displacement at the spring-line of underground pipes due to varying underground accidental explosions

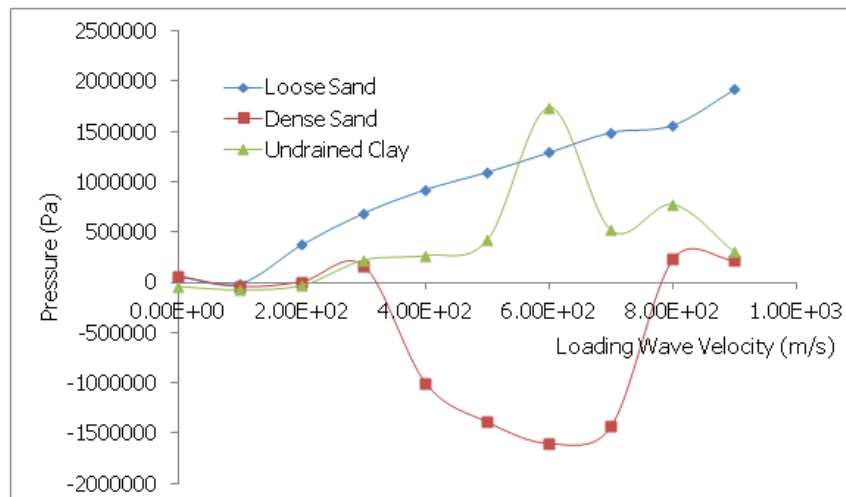


Figure 7. Pressure at the crown of underground pipes due to varying underground accidental explosions

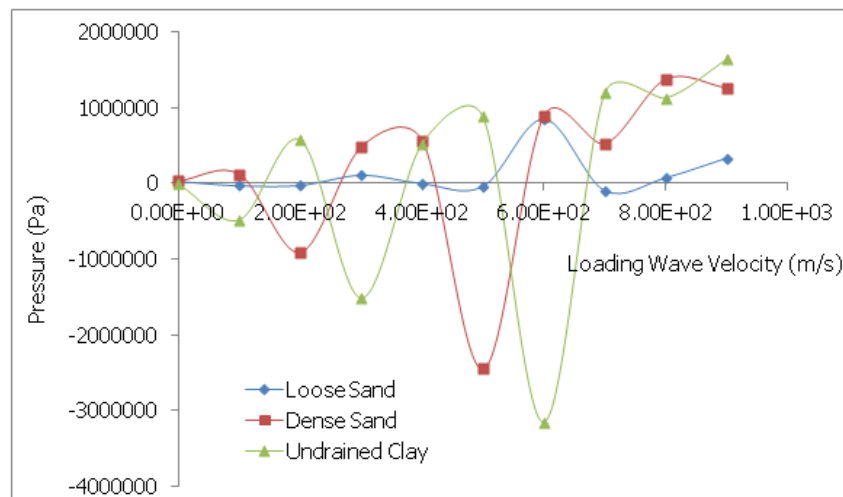


Figure 8. Pressure at the invert of underground pipes due to varying underground accidental explosions

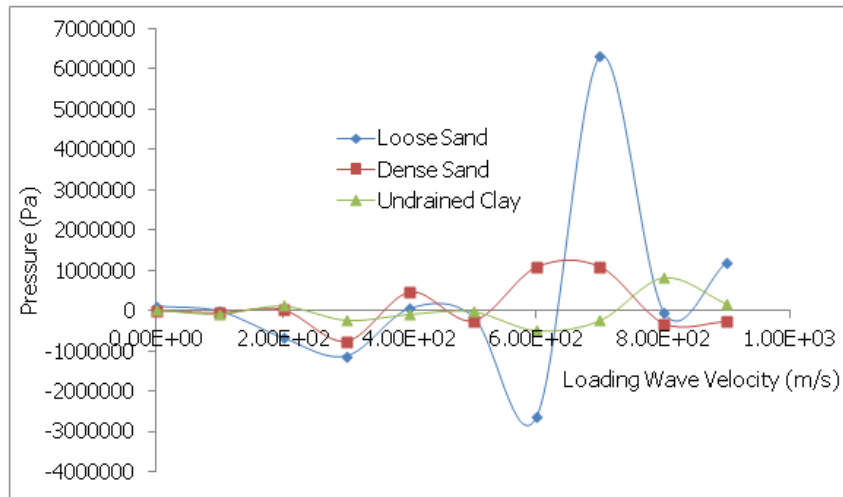


Figure 9. Pressure at the spring-line of underground pipes due to varying underground accidental explosions

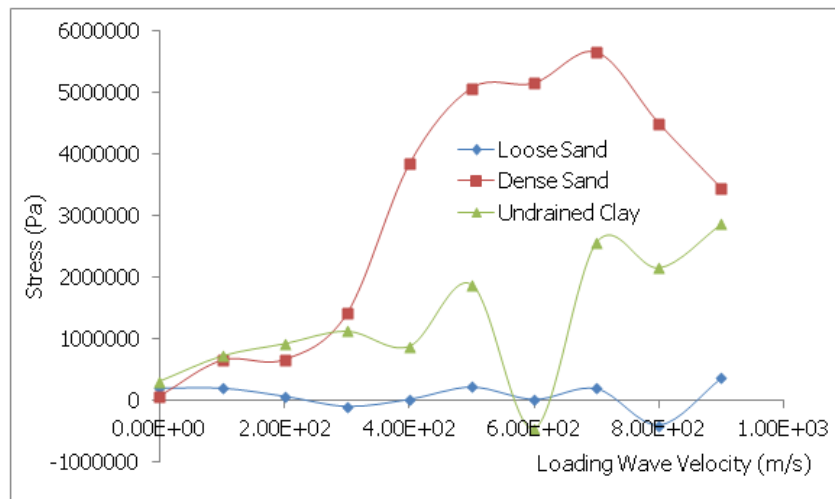


Figure 10. Stress at the crown of underground pipes due to varying underground accidental explosions

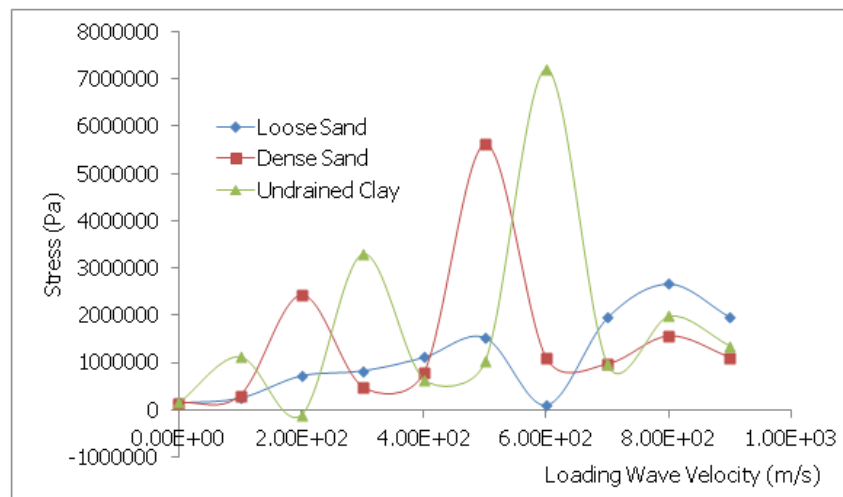


Figure 11. Stress at the invert of underground pipes due to varying underground accidental explosions

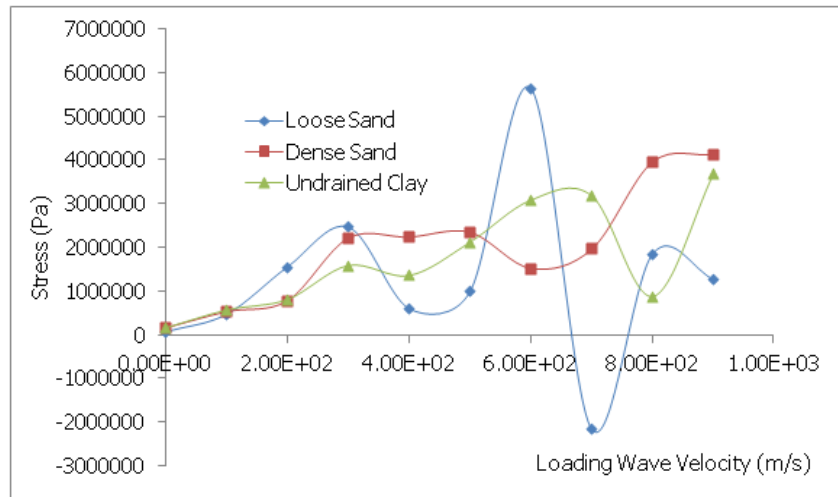


Figure 12. Stress at the spring-line of underground pipes due to varying underground accidental explosions

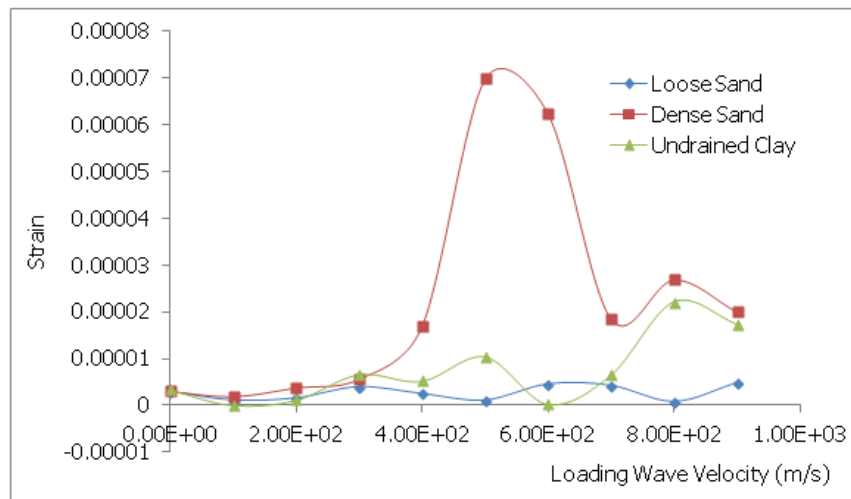


Figure 13. Strain at the crown of underground pipes due to varying underground accidental explosions

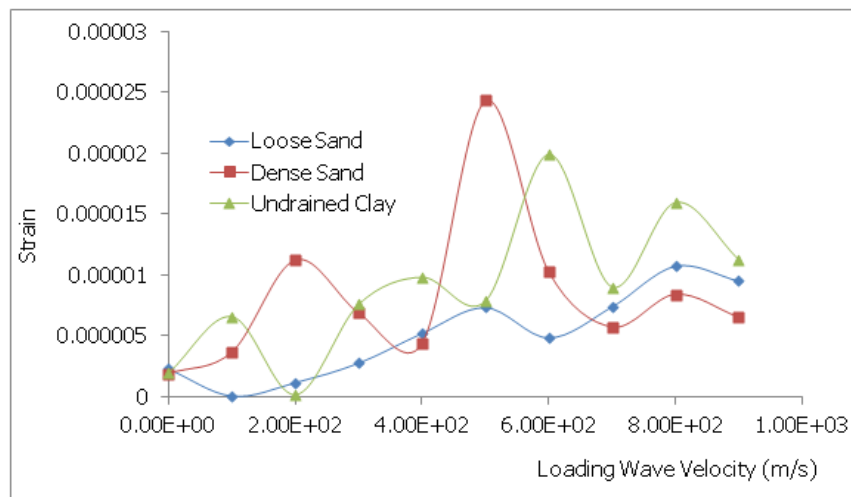


Figure 14. Strain at the invert of underground pipes due to varying underground accidental explosions

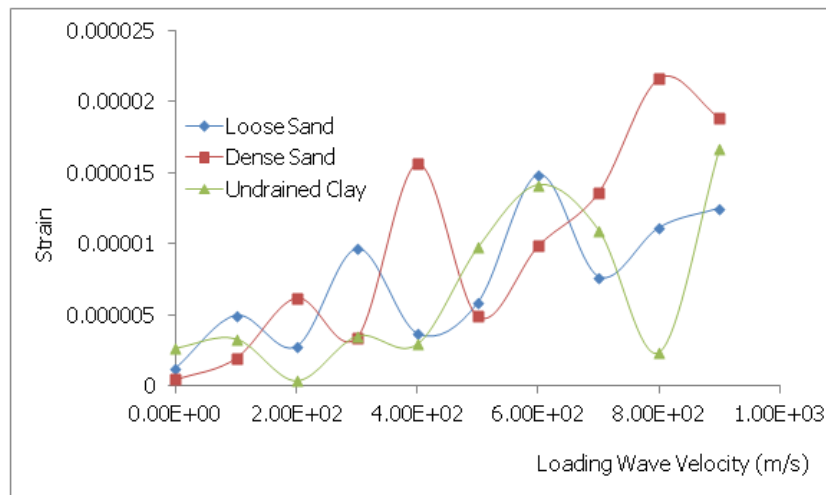


Figure 15. Strain at the spring-line of underground pipes due to varying underground accidental explosions

For the weight of explosives considered (i.e., 10kg TNT to 250kg TNT), loading wave velocity in sand and undrained clay reduces to seismic velocity of soil at a distance of less than 10m from the point of burst of underground accidental explosions as shown in Figures 2 and 3 respectively. This is because much of the energy from the explosive yield is spent in heating, melting, fracturing and plastically deforming the soil matrix around and within the vicinity of the source of underground explosion (Olarewaju et al., 2010i). The remaining energy is released to the ground medium in the form of seismic velocity. For the loading wave velocities investigated, the maximum pressure observed at the crown, invert and spring-line of pipes buried in loose sand, dense sand and undrained clay are 1.8 Mpa (N/mm^2), 3.3 Mpa and 6.2 Mpa as shown in Figures 7, 8 and 9 respectively. In addition to this, as shown in Figures 10, 11 and 12, the maximum stress at the crown, invert and spring-line of pipes buried in loose sand, dense sand and undrained clay are 5.7 Mpa, 7.2 Mpa and 5.5 Mpa respectively. Finally, the maximum strain at the crown, invert and spring-line of pipes buried in loose sand, dense sand and undrained clay are 0.00007, 0.000024 and 0.000022 as shown in Figures 13, 14 and 15 respectively.

Displacement at the crown, invert and spring-line of pipes buried in loose sand, dense sand and undrained clay increases linearly as the loading wave velocity increases as shown in Figures 4, 5 and 6 respectively. Irrespective of the ground media, displacement in the pipes is linear. In addition, as shown in Figures 7, 8 and 9, pressure changes from positive to negative in the buried pipes in all the ground media considered due to dilations and compressions caused by the transient stress pulse of compression wave from the underground accidental explosion. Furthermore, even though there is wide variation in the result due to dynamic nature of the load, as the loading wave velocities from underground accidental explosions increases, pressure shown in Figures 7, 8 and 9, stress shown in Figures 10, 11 and 12 as well as strain shown in Figures 13, 14 and 15 at the crown, invert and spring-line of pipes buried in loose sand, dense sand and undrained clay, respectively, increases. This study has shown that displacement is the most important criteria to be given priority in the design of underground pipes to resist effects of underground accidental explosions. It shows that as the displacement increases linearly due to increased loading wave velocity from underground accidental explosions, moment and stress induced in underground pipes will also increase and may eventually lead to material failure if the yield limit is exceeded.

5. Conclusion

In this study, the impact of varying degrees of underground accidental explosions on buried pipes has been examined. Pipes are generally laid (i. e. buried) at varying depth of burial depending on application, geotechnical properties of the ground media, etc. With time, due to hydraulic erosion, wind erosion, and other forms of erosion, the topmost part of the soil cover that forms the overburden on the underground structures like pipes is washed away. As a result of this, there is need for accidental explosion resistant evaluation of underground installations like pipes in order to have an optimal design of underground structures like pipes that would resist the effects of underground accidental explosions. This is imperative most especially around military formations where defensive and explosive weapons are stored underground, filling stations where automotive gas oil (AGO), premium motor spirit (PMS), dual purpose kerosene (DPK) are stored underground, manufacturing industrial areas where propane are stored underground, etc.

It is important to note that due to less overburden, structural materials yield more easily at lower depth of burial due to underground accidental explosions, whereas at greater depth of burial, due to confinement, response of underground structures such as pipes is minimal (Olarewaju et al., 2010f; 2011c; 2011d). In designing underground installations like pipes to resist effects of unpredictable varying magnitude of underground accidental explosions, displacement is one of the paramount factors to be given priority compared to other observed parameters (i. e. pressure, stress and strain). This is because displacement (i. e. with respect to given distances) of underground installations like pipes results in moments and stresses that will be induced. If the moment and stress induced in underground pipes due to displacement is large and it approaches the yield stress of the material of underground installations (i.e. pipes), invariably it would result to material failure. This study has demonstrated that higher loading wave velocity would result to higher displacement which invariably would result to higher induced moment and stress if multiplied by the corresponding distances (Liang-Chaun. 1978).

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