International Journal of Applied Geophysics and Computational Fluid Mechanics, IJAGCFM, ISSN: 2550-7222
http://ijari.org.ng *Vol. 1, Issue 1, Nov. 2019*

Effects of Loading Wave Velocity on Various Behaviors of Underground Structures (Pipes)

Akinola Johnson **OLAREWAJU**

Civil Engineering Department, School of Engineering, Federal Polytechnic Ilaro, Ogun State, Nigeria
E-mail: *akinolajolarewaju@gmail.com*

Abstract: *Behavior of underground pipes due to underground accidental explosion was studied using finite element based numerical code, ABAQUS. Using numerical method, the values of the loading wave velocities, C_p (m/s) were estimated and the ground movement parameters were used to study the behaviors of modeled steel and concrete pipes buried in loose sand, dense sand and undrained clay. The boundary condition of the model is either fixed or roller. Raleigh damping is meant to reflect physical damping in the actual material. Contrary to our usual engineering intuition, introducing damping to the solution reduces the stable time increment. A small amount of numerical damping is introduced in the form of bulk viscosity to control high frequency oscillations. For the elastic, homogeneous and isotropic materials considered, the values of Young's modulus, E, Poisson's ratio, υ and densities of steel, concrete, loose sand, dense sand and undrained clay as revealed by several researchers and pipe manufacturers were used to observed the behavior of underground pipes due to loads from underground accidental explosion and parameters varied. Time integration technique of finite difference and finite element in ABAQUS/Explicit numerical code was used to solve the governing dynamic equation of motion. From the results,, for a given loading wave velocity, displacement in pipes is almost constant at all embedment ratios considered irrespective of the material properties. Irrespective of the ground media, as the seismic velocity increases, displacement increases linearly and for low stiffness pipes buried at low depth of burial, especially in undrained clay soil, there is need for explosion resistance evaluation*

Keywords: *Accidental, Explosions, Buried, Underground, Parametric.*

.

Introduction

Shallow underground explosion may be regarded as one which produces a substantial crater resulting from the throw-out of earth and there is an optimum depth of burst, dependent on the energy yield of the detonation and the nature of the soil medium, which gives a crater of maximum size. For shallower depths of burst, the behavior approaches that of a surface burst, whereas for explosions at greater depths the phenomena tend toward those of a deep underground detonation. When a nuclear weapon is exploded under the ground, a sphere of extremely hot, high-pressure gases, including vaporized weapon residues, soil and rock, is formed and 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 away from the burst point. When the upwardly directed shock wave reaches the surface of the earth, it is reflected back as a rarefaction 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). According to same source, a deep underground explosion is one occurring at such a depth that the effects are essentially fully contained and the surface above the detonation point may be disturbed and ground tremors may be detected at a distance. There is no significant venting of the weapon residues to the atmosphere, although some of the non-condensable gases present may seep out gradually through the surface. The United States has conducted many deep underground tests, especially since September 1961 and almost all of the explosion energy has been contained in the ground, except only in the few cases of accidental venting or seepage of a small fraction of the residues, the radioactivity from these explosions has also been confined (The Effects of Nuclear Weapons, 1977; Olarewaju et al., 2012; Olarewaju, 2013; Olarewaju, 2015).

Background Study

Quite a lot of works have been done on dynamic soil-structure interaction majorly for linear, homogeneous, and semi-infinite half space and to start with, the behavior of elastic half space was carried out by Lamb (1904) after which Newcomb (1951) and Converse (1953) derived empirical relation for the determination of resonance frequency in vibrated soil. It was established that softer soils have lower natural frequency. From their results, the natural frequency is higher at lower bearing pressures on soil while hard clays have less natural frequency than sand stones. In the work of Ronanki (1997), the behaviors of buried circular pipes under three-dimensional surface static and seismic loadings were obtained and method used is the finite element based software package, SAP-80. Parametric studies were equally carried out but only the displacement at the crown and spring-line of pipes were observed for the parameters considered and it was assumed that the soil is an infinite, elastic, homogeneous and isotropic medium. The pipe was also assumed to be circular, straight, horizontal, long without joints, elastic and perfect bond exists between the pipe and the adjacent soil. In underground explosions, most of the energy is spent in fracturing, heating, melting, and vaporizing the surrounding soils and rocks with only a very small amount being converted to seismic energy and the fraction of the small amount of total energy that goes into seismic energy is a measure of the seismic efficiency of explosions. This work is aimed at investigation the effects of loading wave velocity on various behaviors of underground pipes. The loading wave velocity is one of the ground movement parameters generated during underground accidental explosions and translate into loading that is delivered to buried structures (The Effects of Nuclear Weapons, 1977; Olarewaju et al., 2012; Olarewaju, 2013; Olarewaju, 2015).

Methodology

In this study, 1m diameter steel and concrete pipes buried in loose sand, dense sand and undrained clay at 1m depth below the ground surface (Figure 1) were modeled using finite element numerical code. It is more necessary to evaluate the explosion resistance of buried structures at lower depth of burial 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 which serves as control, therefore it is assumed that perfect bond exist between the soil and the pipe thereafter the coefficient of friction was also varied. In addition to this, the loading velocity was equally varied to investigate varying loading conditions and different types of soil conditions and types of pipes were equally investigated by varying the stiffness of pipes and soil. The soil and pipe materials were assumed to be linear, homogeneous and isotropic and as a result, the material properties as revealed by various researchers and pipe manufacturers were used (Kameswara 1998). In line with Geotechnical Modeling and Analysis with ABAQUS (2009), boundary conditions were defined with respect to global Cartesian axis. 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 different soils. In line with ABAQUS Analysis Users’ Manual (2009) and with varying parameters, analysis were carried out on simulated models by solving the governing equation of motion of the system (Eq. 1) (with the initial conditions) using the time integration technique of the finite different scheme in ABAQUS/Explicit.

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

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). The observed parameters are displacement, pressure, mises, stress and strain at the crown, invert and spring-line of pipes buried in loose sand, dense sand and undrained clay (Olarewaju et al., 2012; Olarewaju, 2013; Olarewaju, 2015; ABAQUS Analysis User’s Manuals. 2009; ABAQUS/Explicit: Advanced Topics, 2009; Geotechnical Modeling and Analysis with ABAQUS, 2009).

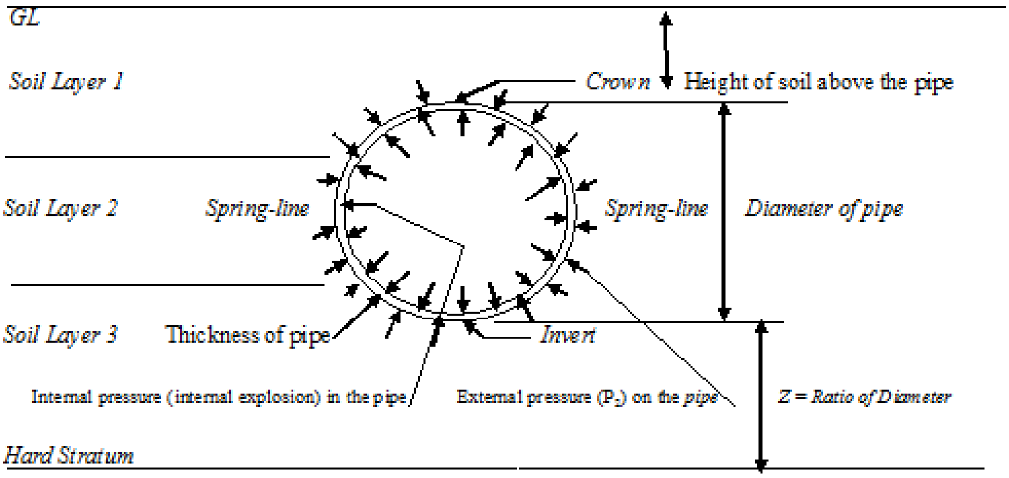

Figure 1: Cross-section of pipe in different soil layers (Olarewaju et al., 2012; Olarewaju, 2013; Olarewaju, 2015; ABAQUS Analysis User’s Manuals. 2009; ABAQUS/Explicit: Advanced Topics, 2009; Geotechnical Modeling and Analysis with ABAQUS, 2009)

Results and Discussion

The results of displecement, pressure, mises, stress and strsin at the crown, invert and spring-line of buried pipes for The results of displacement, pressure and mises on pipes for varying coefficient of friction in explosion below ground surface with ‘No Slip’ as control for velocity of 300 m/s and period of 0.025 ms are presented in Figures 2 to 7 respectively. The results of displacement, pressure, mises, stress and strain for varying veocity load on pipes due to explosion below the ground surface are presented in Figures 8 to 13 respectively. The results of displacement and mises on pipes for varying Young's Modulus of soil in explosion below ground surface with 'No Slip' as control for velocity of 300 m/s and period of 0.025 ms are presented in Figures 14 to 15 respectively. Finally, the results of displacement, mises, strain in pipes for varying Young's Modulus of pipes (stiffness) in explosion below ground surface with 'No Slip' as control for velocity of 300 m/s and period of 0.025 ms are presented in Figures 16 to 18 respcetively. Even though there is wide variation in the results shown in Figures 2, 9, 11 and 13 due to dilations and compressions caused by the transient stress pulse of compression wave, the observed parameter of varying velocity (Figures 9 to 13) increases (with some variations) as the loading wave velocity increases. The results showed that irrespective of the ground media, displacement (Figure 9) increases linearly as the loading wave velocity increases. From the results, depth plays little or no role in the behavior of buried pipes due to accidental explosions below the ground level. From the result of the measured parameters (Figures 2 to 7), it was observed that coefficient of friction has little effect due to accidental explosions below the ground level. In addition to this, displacement of low stiffness pipes buried in undrained clay due to underground accidental explosions is constant irrespective of the ground medium (Figure 15) while at pipe stiffness of 300kPa, strain at the crown, invert and spring-line of buried low stiffness pipes is 0.00006. A remarkable behavior due to underground accidental explosions, in pressure and stress was noticeable at pipe stiffness of 100kPa and above. For low stiffness pipes buried at low depth of burial, especially in undrained clay soil, there is need for explosion resistance evaluation. This is because materials yield more at lower depth of burial compared to deeply buried low stiffness pipes (Olarewaju et al., 2012; Olarewaju, 2013; Olarewaju, 2015; ABAQUS Analysis User's Manuals. 2009; ABAQUS/Explicit: Advanced Topics, 2009; Geotechnical Modeling and Analysis with ABAQUS, 2009).

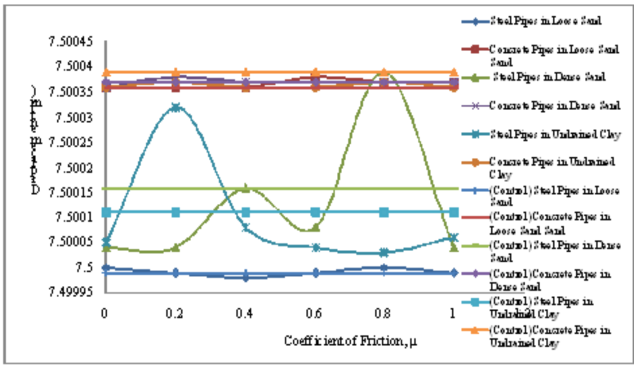

Figure 2: Crown displacement for varying coefficient of friction with 'No Slip' as control

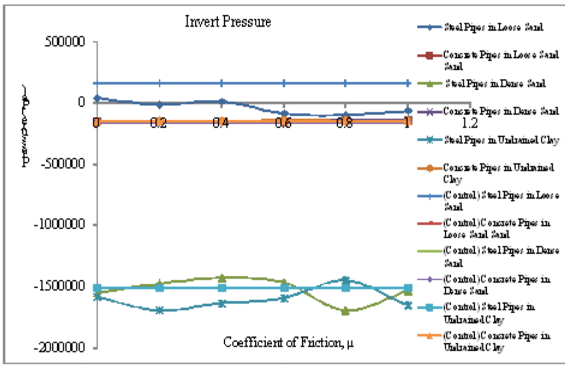

Figure 3: Invert pressure for varying coefficient of friction with 'No Slip' as control

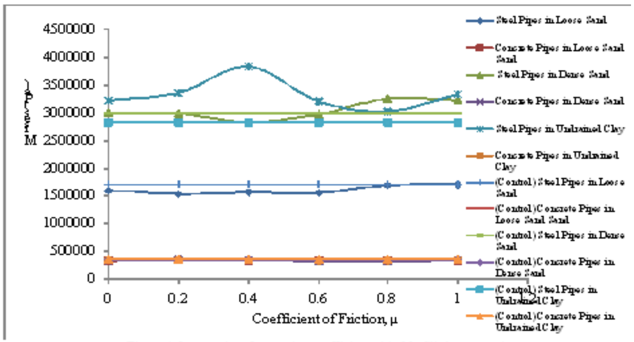

Figure 4: Invert mises for varying coefficient with 'No Slip' as control

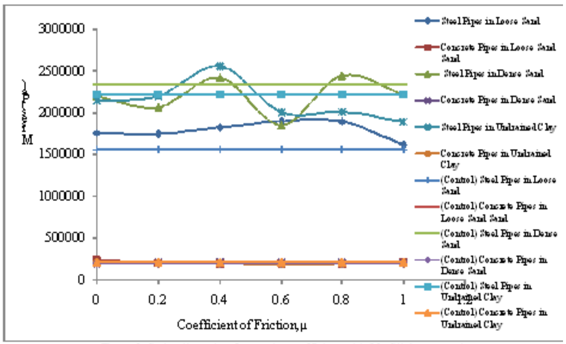

Figure 5: Spring-line mises for varying coefficient with 'No Slip' as control

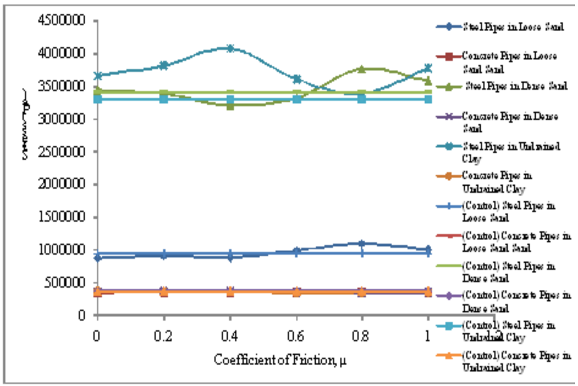

Figure 6: Invert stress for varying coefficient 'No Slip' as control

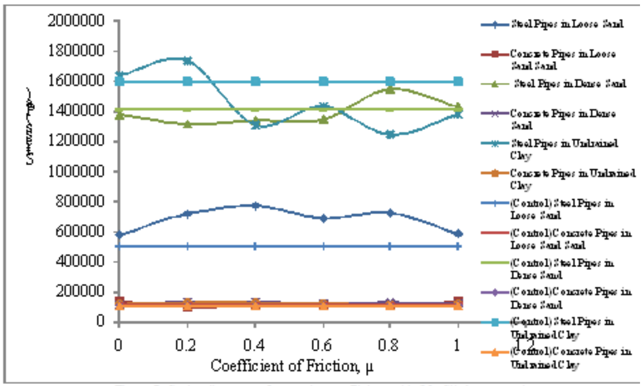

Figure 7: Spring-line stress for varying coefficient with 'No Slip' as control

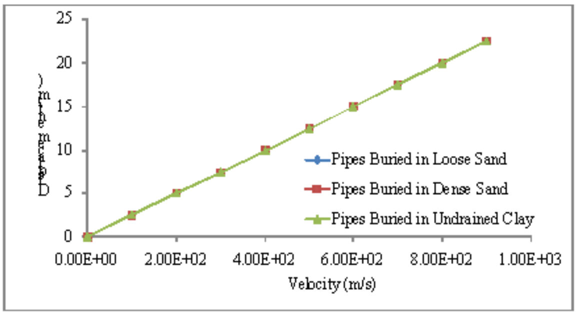

Figure 8: Crown displacement for varying veocity load on pipes

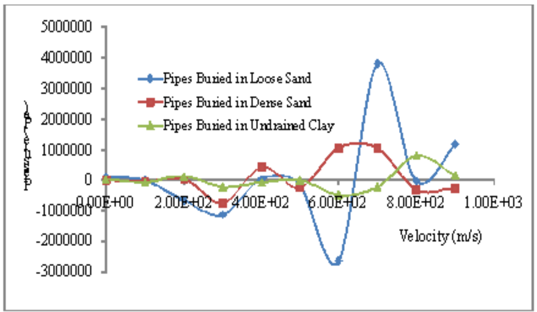

Figure 9: Spring-line pressure for varying veocity load on pipes

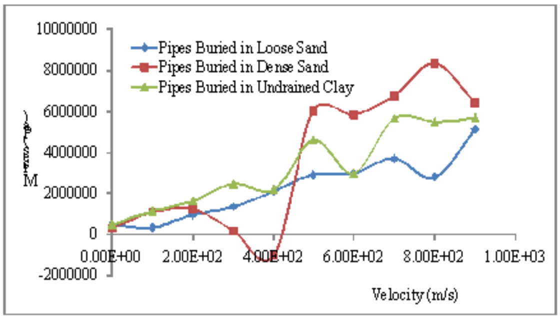

Figure 10: Crown mises for varying veocity load on pipes

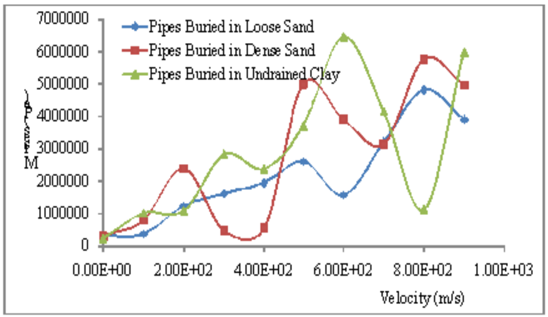

Figure 11: Invert mises for varying veocity load on pipes

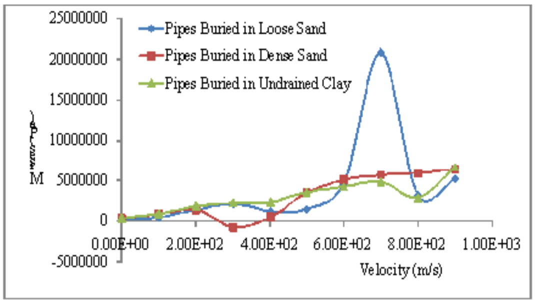

Figure 12: Spring-line mises for varying veocity load on pipes

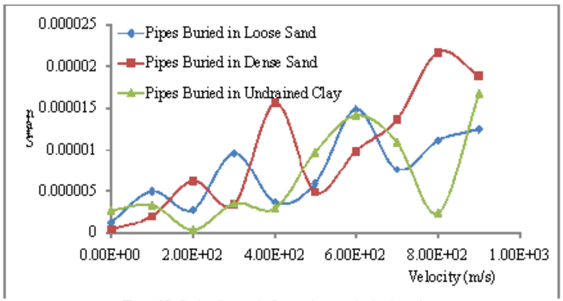

Figure 13: Spring-line strain for varying veocity load on pipes

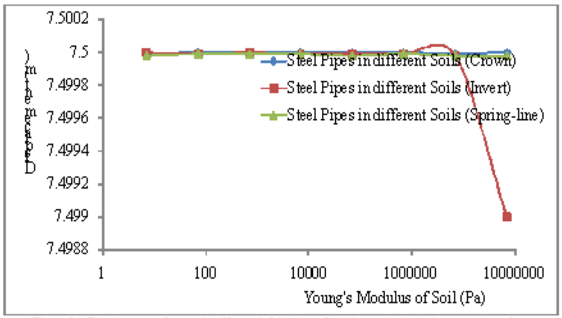

Figure 14: Displacement for varying Young's Modulus of soil in explosion below ground surface

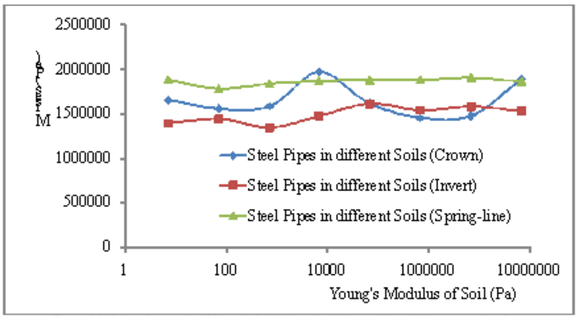

Figure 15: Mises for varying Young 's Modulus of soil in explosion below ground surface

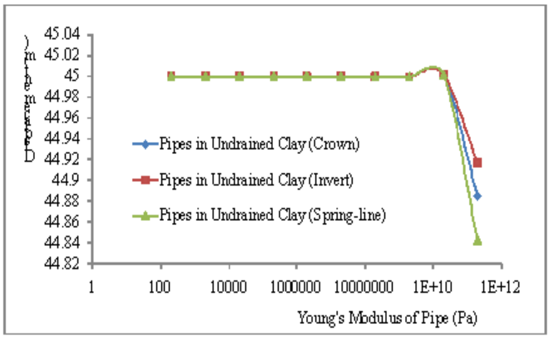

Figure 16: Displecement for varying Young's Modulus of pipes (stiffness) in explosion below ground surface

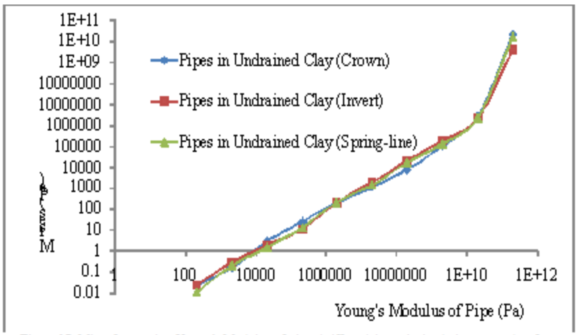

Figure 17: Mises for varying Young's Modulus of pipes (stiffness) in explosion below ground surface

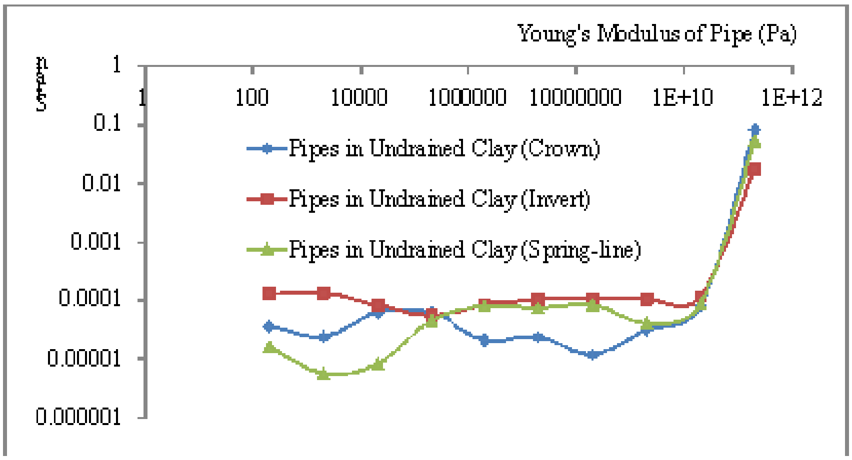

Figure 18: Strain for varying Young's Modulus of pipes (stiffness) in explosion below ground surface

From the results (Figures 2 to 7), observed parameters (displacement, pressure, mises and stress) of control ("No Slip") is constant while friction coefficient range of 0.2 to 1.0 in all the ground media investigated shows some degree of variation. In addition to this, in all the ground media investigated the results of mises and strain (Figures 10 to 13) increases as the loading wave velocity increases. Irrespective of the geotechnical properties of the ground media (stiffness inclusive), displacement and mises is constant (Figures 14 and 15) for the varying stiffness of soil. Irrespective of the stiffness of the pipes (i. e. different pipes), displacement is constant (Figures 16 and 18) up to pipe stiffness of 1 x 10^{10} (Pa) when there is sharp reduction but here is increase in the value of mises (Figure 18) as the pipe stiffness increases. If a buried charge detonates, the loading wave velocity reduces to the seismic velocity of soil. In the result of this study on the effects of coefficient of friction on the behavior of underground pipes due to underground accidental explosion for the various behaviors of the observed parameters for displacement, pressure, mises, stress and strain respectively, there is bound to be variations in these observed parameters due to the dynamic nature of loads form underground accidental explosion. Irrespective of the ground media whether loose sand, dense sand or undrained clay, displacement in underground pipes due to underground accidental explosion is linear. It shows that as the seismic velocity increases, displacement also increases linearly. In designing underground pipes to resist effects of varying magnitude of underground accidental explosion, for seismic velocity of less than 800 m/s, displacement is one of the paramount factors to be given priority compared to other observed parameters like pressure, stress and strain. This is because displacement induces moments and stresses in underground pipes. 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 pipes, invariably it would result to material failure (Olarewaju et al., 2012; Olarewaju, 2013; Olarewaju, 2015; ABAQUS Analysis User's Manuals. 2009; ABAQUS/Explicit: Advanced Topics, 2009; Geotechnical Modeling and Analysis with ABAQUS, 2009). Details of these and many more could be found in Olarewaju (2020).

Conclusion

Under underground accidental explosion, for a given loading wave velocity, displacement in pipes is almost constant at all embedment ratios considered irrespective of the material properties. Irrespective of the ground media, as the seismic velocity increases, displacement increases linearly and for low stiffness pipes buried at low depth of burial, especially in undrained clay soil, there is need for explosion resistance evaluation. This is because materials yield more at lower depth of burial compared to deeply buried low stiffness pipes and special consideration should be given to the curtailment of displacement in buried pipes so as to reduce the induce moments (Olarewaju et al., 2012; Olarewaju, 2013; Olarewaju, 2015; ABAQUS Analysis User's Manuals. 2009; ABAQUS/Explicit: Advanced Topics, 2009; Geotechnical Modeling and Analysis with ABAQUS, 2009). Details of these and many more could be found in Olarewaju (2020).

References

ABAQUS Inc. 2009. ABAQUS/*Explicit: Advanced Topics*, Dassault Systemes Simulia, Providence, Rhode Island, USA,

ABAQUS Inc. 2009. ABAQUS *Analysis User's Manuals - Documentation*, Dassault Systemes Simulia, Providence, Rhode Island, USA,

ABAQUS Inc. 2009. ABAQUS *User's Manuals - Documentation*, Dassault Systemes Simulia, Providence, Rhode Island, USA,

ABAQUS Inc. 2009. *Geotechnical Modeling and Analysis with* ABAQUS, Dassault Systemes Simulia, Providence, Rhode Island, USA,

Converse, F. J. 1953. Compaction of sand at resonant frequency, Symposium on Dynamic Testing of Soils, ASTM Special Technical Publication No. 156, 124-137.

Kameswara Rao, N. S. V. 1998. *Vibration Analysis and Foundation Dynamics* (1st edition), Wheeler Publishing Co. Ltd., New Delhi, India, 190-197, 522-571.

Lamb, H. 1904. On the propagation of tremors over the surface of an elastic solid, Philosophical Transactions of the Royal Society, 203, 1-42.

Newcomb, W. K. 1951. Principles of Foundation Design for Engines and Compressors, Trans of the ASME, 73, 307 318.

Olarewaju, A. J. (2013). A Study on the Response of Underground Pipes Due to Blast Loads, Ph.D Thesis, School of Engineering and Information Technology (SKTM), Universiti Malaysia Sabah, Kota Kinabalu, Sabah, Malaysia.

Olarewaju, A. J., 2015. Chapter 13: A Study on the Dynamic Dimensionless Behaviours of *Underground Pipes Due to Blast Loads Using Finite Element Method*", Book Title: "Earthquake Engineering – From Engineering Seismology to Optimal Seismic Design of Engineering Structures'' Abbas Moustafa (Editor), ISBN: 978-953-51-2039-1, Geology and Geophysics, InTech Publisher, Croatia, Europe, May 20, pp 331 - 356.

Olarewaju A. J., (2020): Guidelines for Numerical Analysis and Seismic Design of Modeled Underground Structures – *From Accidental Explosion Parameters, Consolidation Characteristics, Ground Water Characteristics to Settlement Potentials of Palm Kernel Shell Stabilized Sedimentary Formations*, First Edition, AkiNik Publications, New Delhi, India.

Ronanki, S. S. 1997. Response Analysis of Buried Circular Pipes under 3 Dimensional Seismic Loading. M.Tech Thesis, Civil Engineering Department, Indian Institute of Technology, Kanpur, India.

The Effects of Nuclear Weapons, 1977. Chapter II: Description of Nuclear Explosions – Underwater and Underground Blast. Trinity Atomic Web Site, Nuclear Weapons: History, Technology, and Consequences in History Documents, Photos, and Videos, file:///I:/Blast%20Project/Down%20Loaded%20Journals/The%20Effects%20of%20Nuclear%20Weapons,%201977%20Underwater%20and%20Undergro.htm, 10/05/2010

Unified Facilities Criteria, 2008. Structures to Resist the Effects of Accidental Explosions, UFC 3-340-02, Department of Defense, US Army Corps of Engineers, Naval Facilities Engineering Command, Air Force Civil Engineer Support Agency, United States of America.