Effects of Varying Parameters on Underground Structures (Pipes) Due to Seismic Action of Surface Accidental Explosion

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Abstract: *Behavior of underground pipes due to accidental explosion above the ground surface was studied using finite element based numerical code, ABAQUS. Pressure load parameters from accidental explosions above the ground surface but very close to the ground surface were estimated using Unified Facilities Criteria (2008). Using the ground movement parameters, behaviors of modeled steel and concrete pipes buried in loose sand, dense sand and undrained clay were examined and parametric studies carried out. 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 buried at 1m depth due to loads from accidental explosion above the ground surface 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. The observed parameters are displacement, pressure, mises and strain at the crown, invert and sprig-line of pipes buried in different soil media. From the results, there is no remarkable changes in the behavior of all the coefficient of friction investigated while there is reduction in mises, stress and displacement as the thickness of steel and concrete pipes increases. There is reduction in crown and spring-line as the Young's modulus of soil and pipe increases while all the observed paremeters increases as the pressure loads increases in steel and concrete pipes.*
Keywords: *Accidental, Explosions, Underground, Surface, Pipes, Seismic, Parameters*.

Introduction

Most installations at the aboveground level, underground and within the ground have now become targets of war (Syria, Yemen, etc.), terrorist attack, etc. in the past years and elements of target are industrial centers, military installations, centers of communication, defense control centers, to mention a few depending on functions and importance of the facility. Most defense formations of the army, navy, air force, and paramilitary across the globe have underground formations in their domains where most of their defensive explosive weapons like nuclear bombs and the likes are stored. In the oil and gas industry, the main sources of accidental explosion are the accumulation of explosive gas in pipes during two phase flow especially in bends, and leakage from reciprocating compressor catching fire and exploding. It has been reported that accidental explosion can create sufficient tremors to damage substructures over a wide area and due to the immeasurable consequences of explosion due to earth tremors, it could be thought of as an artificial earthquake. Consequent upon these phenomena are loss of lives and destruction of property. Due to severity of destruction caused by accidental explosion, loads emanating can create sufficient tremors to damage substructures over a wide area. Accidental explosion at Fukushima nuke plant in Japan was felt 40 km away from the source. There is need to mitigate the consequences of surface accidental explosion in underground structures and these measures could be in the form of designing underground structures like to resist the effects of accidental explosion or by repairing structures damaged by it (Olarewaju et al., 2012; Olarewaju, 2013; Olarewaju, 2015).

Background Study

The behavior of elastic half space was first carried out by Lamb (1904) while Boh et al (2007) used nonlinear finite element analysis to study the responses of structures in the oil and gas industry. They came up with recommendations for design to resist blast and explosion to help in overcoming the limitations of commonly used analytical methods. George et al. (2007) proposed analytical method for the calculation of explosion-induced strains to buried pipelines and the result provided an improved accuracy at no major expense of simplicity as well as accounting for the effect of local soil condition. James Marusek (2008) also used finite element analysis to study underground shelters due to blast loadings from conventional weapon detonation and elasticity was chosen to model the behavior of the soil material. Accidental explosion load was represented as short duration load and parametric studies carried out. In the work of Huabei (2009) who recently obtained the behaviors of subway structures under blast loading using finite element numerical code, ABAQUS. The subway was placed in different soil layers and numerical simulations were carried out. Mitigation measures used to improve ground stiffness and strength was also analyzed. Parametric studies for pipes are the effect of various parameters on the responses and various effects that could be considered are the effect of various modular ratios, various values of radius-to-thickness ratio as well as non-homogeneity linearly varying the Young's modulus, E, of the pipe, soil and intervening medium material, etc. (Olarewaju et al., 2012; Olarewaju, 2013; Olarewaju, 2015)

Methodology

In this study, pipes buried at 1m depth in infinite elastic, homogeneous and isotropic soil media was study using ABAQUS numerical code. Accidental explosion was assumed to take place far away from the buried pipes. As a result, the material property was assumed to be linear, elastic, homogeneous and isotropic and therefore the two elastic constants (i. e. Young's modulus, E and Poisson's ratio, v) as revealed by various researchers and pipe manufacturers were used in the study (Kameswara, 1998). Poisson's ratio of 0.5 indicates a constancy of volume (Robert, 2002) which is applicable to undrained clay. Load parameters from accidental explosions above the ground surface but very close to the ground surface were estimated using Unified Facilities Criteria (2008). Steel and concrete pipes were laid horizontally with no joint while 'No-slip' contact condition between the pipes and soil was assumed and this serves as control for all the observed parameters in the analysis, therefore it is assumed that perfect bond exist between the soil and the pipe. The coefficient of friction and pipe thickness were also varied. In addition to this, the pressure load was equally varied to investigate varying loading conditions. Furthermore, different types of soil conditions and types of pipes were investigated by varying the stiffness of pipes and soil. Boundary conditions were defined with respect to global Cartesian axis and time integration technique in ABAQUS/Explicit was used to solve the equation of motion (Equation 1) with initial conditions (ABAQUS Analysis User's Manual, 2009).

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

where *m, c', k, U* and *P* are the global mass matrix, damping matrix, stiffness matrix, displacement and load vectors respectively while dot indicate their time derivatives. Parameters observed are displacement, pressure, mises, stress and strain at the crown, invert and spring-line pipes buried in soil media of loose sand, dense sand and undrained clay (Kameswara, 1998; 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).

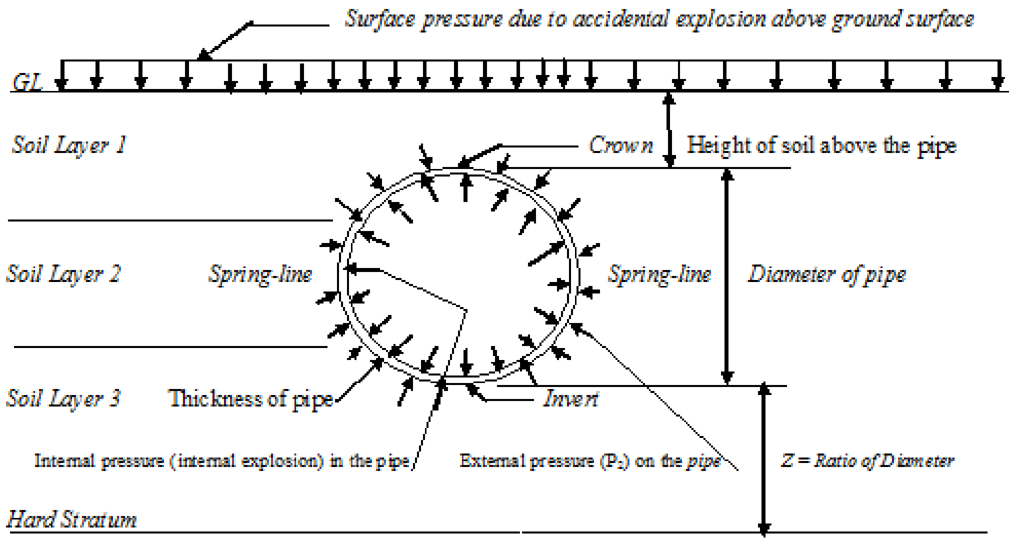

Figure 1: Cross-section of pipe in different soil layers (Olarewaju et al., 2012; Olarewaju, 2013; Olarewaju, 2015; ABAQUS Analysis User's Manuals. 2009; ABAQUS/Explicit: Advanced Topics, 2009; Geotechnical Modeling and Analysis with ABAQUS, 2009)

Results and Discussion

The results of displecement, pressure, mises, stress and strsin at the crown, invert and spring-line of buried pipes for varying coefficient of friction in explosion above the ground surface with 'No Slip' as control are presented in Figures 1 to 6 respectively. In addition to this, the results of displecement, and mises at the crown, invert and spring-line for varying concrete and steel oipe thickness buried in undrained clay are presented in Figures 7 to 11 respectively. Furthermore, the results of displacement, pressure, mises and strain at the crown, invert and spring-line of buried pipes of vraying Young's Modulus of soil, pipe and intervening medium for coefficient of friction of 0.3 in explosion above the ground surface for "No Slip" and Load intensity of 2000000Pa at the period of 0.025 ms are presented in Figures 12 to 16 respectively. Finally, the results of mises at the invert and spring-line of buried concrete pipes with varying pressure loads for coefficient of friction of 0.3 in explosion above the ground surface are presented in Figures 17 to 19 respectively. From the results, there is no remarkable changes and differences in the behavior of all the coefficient of friction investigated but all the observed parameters are lower than the control of "No Slip" (Figures 2 to 6) in all the ground media. In addtion to this, there is reduction in mises (Figure 8), stress (Figure 9) and displacement (Figures 10 and 11) as the thickness of steel and concrete pipes increases. This is because as the thickness of pipe increases, stiffness and other stength properties incresaes. Furhermore, there is increase in the displacement (Figure 12), mises (Figures 13 and 15) of pipes buried in undrained clay and partial increase in invert (Figure 14) but reduction in crown and spring-line (Figure 14) as the Young's modulus of soil and pipe increases. But there is no significant increase or reduction in the observed parameters in the intervening medium. (Figure 16). Finally, in the case of varying pressure loads due to surface accidental explosion, all the observed paremeters increases as the pressure loads increases in steel and concrete pipes. The observed parameters are the mies at the crown, invert and spring-line of steel and concrete pipes buried in loose sand, dense sand and undrained clay (figures 17 to 19) 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). Details of these and many more could be found in Olarewaju (2020).

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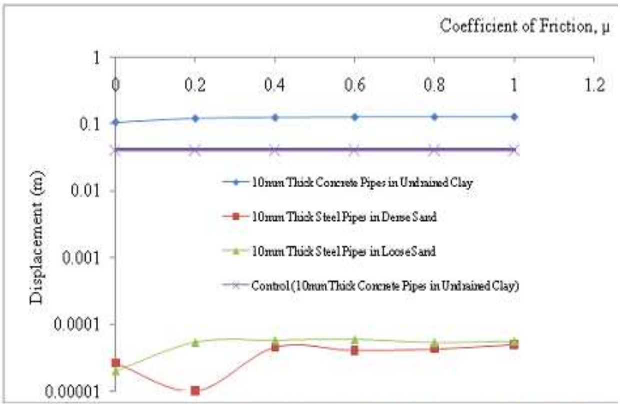

Figure 2: Invert displacement for varying coefficient of friction in explosion above the ground surface with 'No Slip' as control

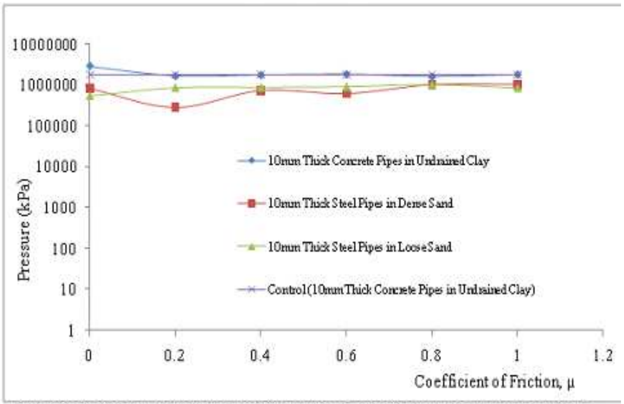

Figure 3: Spring-line pressure for varying coefficient of friction in explosion above the ground surface with 'No Slip' as control

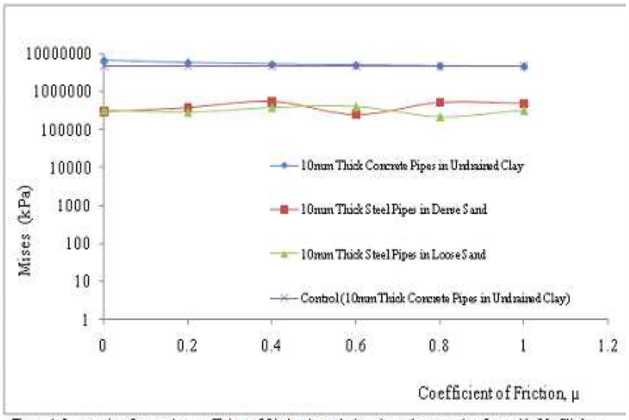

Figure 4: Invert mises for varying coefficient of friction in explosion above the ground surface with 'No Slip' as control

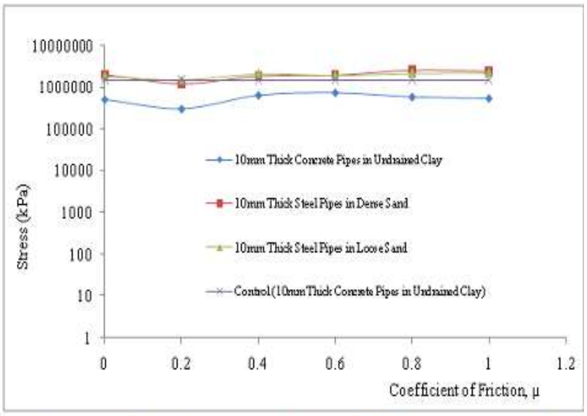

Figure 5: Crown stress for varying coefficient of friction in explosion above the ground surface with 'No Slip' as control

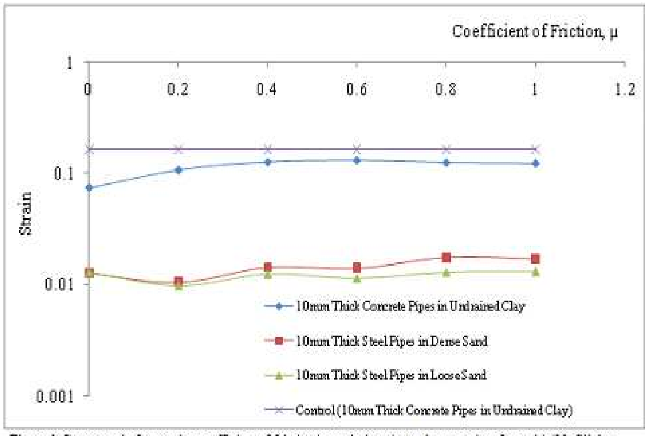

Figure 6: Crown strain for varying coefficient of friction in explosion above the ground surface with 'No Slip' as control

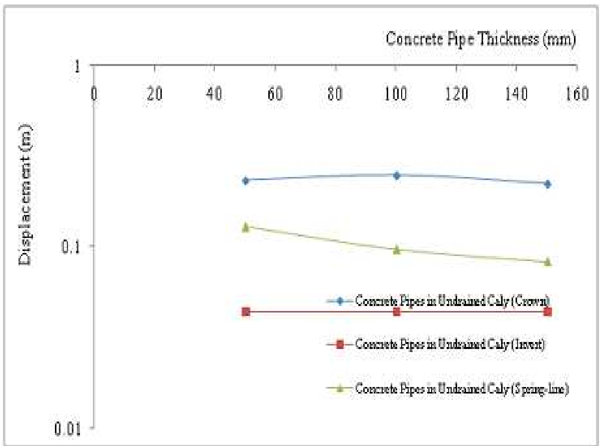

Figure 7: Displacement of concrete pipes for coefficientof friction of 0.3 in explosion above the ground surface

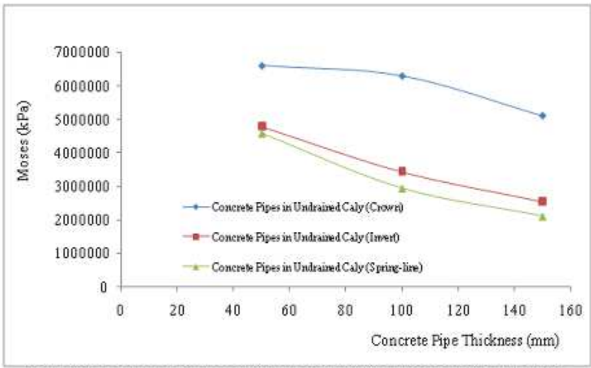

Figure 8: Mises of concrete pipes for coefficient of friction of 0.3 in explosion above the ground surface

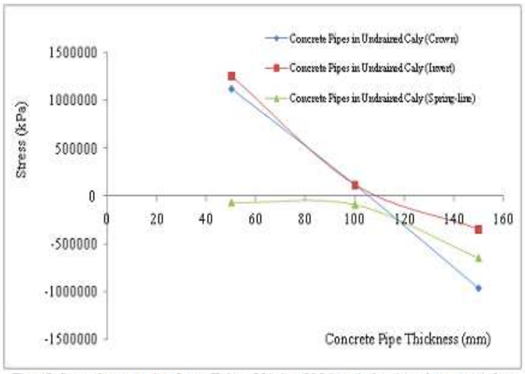

Figure 9: Stress of concrete pipes for coefficient of friction of 0.3 in explosion above the ground surface

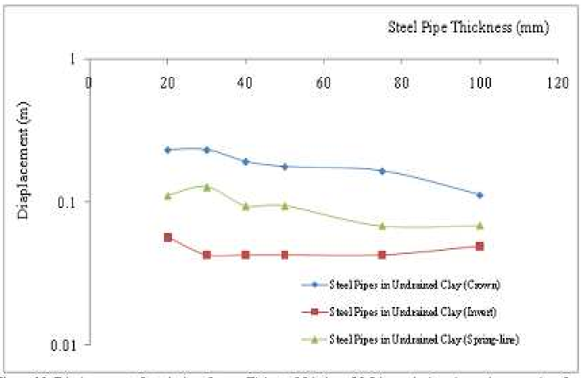

Figure 10: Displacement of steel pipes for coefficient of friction of 0.3 in explosion above the ground surface

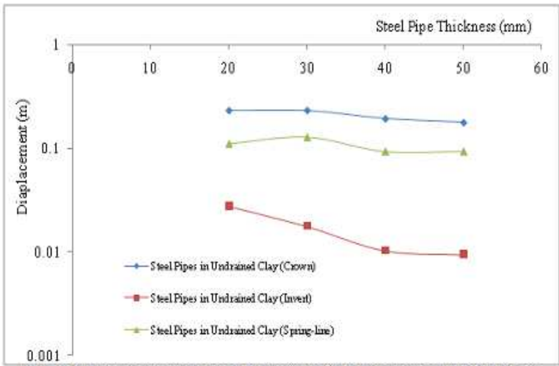

Figure 11: Displacement of varying steel pipe thickness in undrained clay for coefficient of friction of 0.3 in explosion above the ground surface

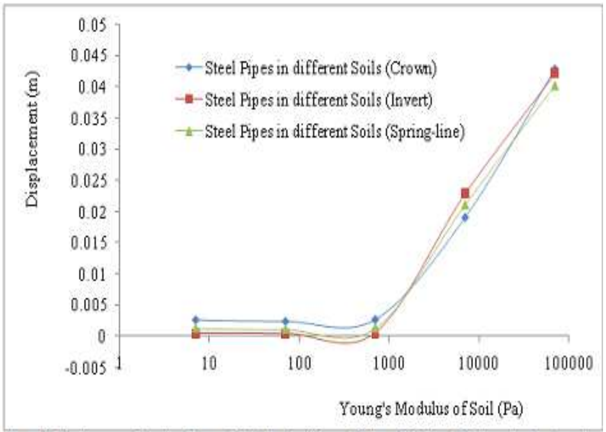

Figure 12: Displacement of varying Young's Modulus of soil for coefficient of friction of 0.3 in explosion above the ground surface for "No Slip" and Load intensity of 2000000Pa at the period of 0.025 ms

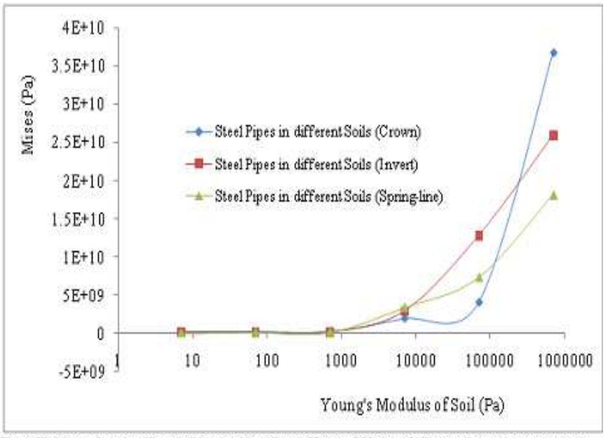

Figure 13: Mises of varying Young's Modulus of soil for coefficient of friction of 0.3 in explosion above the ground surface for "No Slip" and Load intensity of 2000000Pa at the period of 0.025 ms

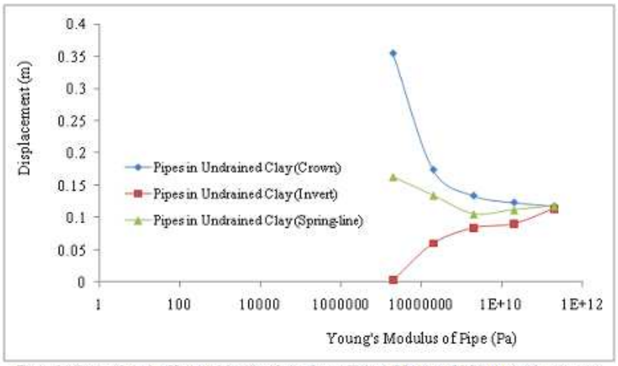

Figure 14: Strain of varying Young's Modulus of pipe for coefficient of friction of 0.3 in explosion above the ground surface for "No Slip" and Load intensity of 2000000Pa at the period of 0.025 ms

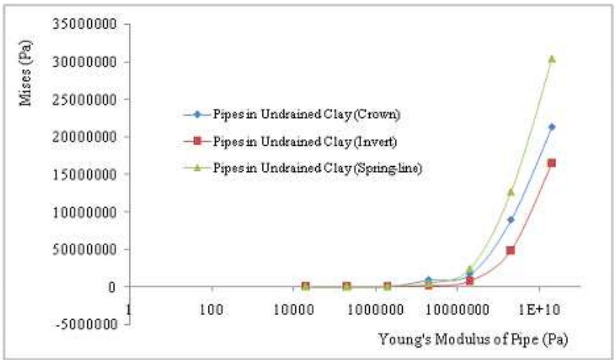

Figure 15: Mises of varying Young's Modulus of pipe for coefficient of friction of 0.3 in explosion above the ground surface for "No Slip" and Load intensity of 2000000Pa at the period of 0.025 ms

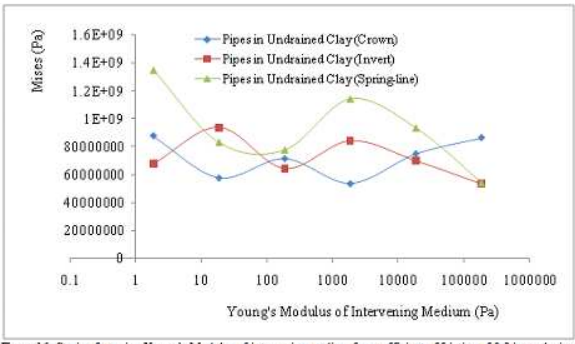

Figure 16: Strain of varying Young's Modulus of intervening medium for coefficient of friction of 0.3 in explosion above the ground surface for "No Slip" and Load intensity of 2000000Pa at the period of 0.025 ms

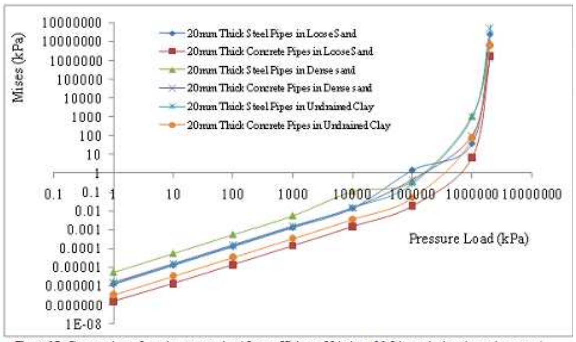

Figure 17: Crown mises of varying presure load for coefficient of friction of 0.3 in explosion above the ground surface for "No Slip" at the period of 0.025 ms

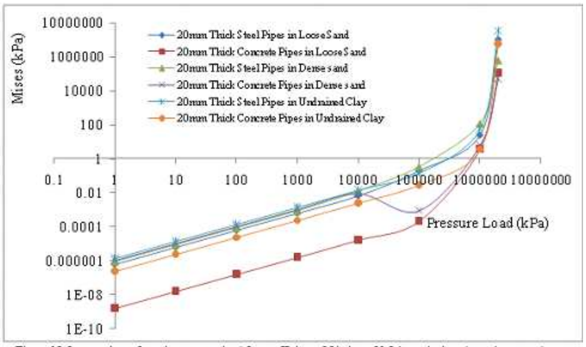

Figure 18: Invert mises of varying presure load for coefficient of friction of 0.3 in explosion above the ground surface for "No Slip" at the period of 0.025 ms

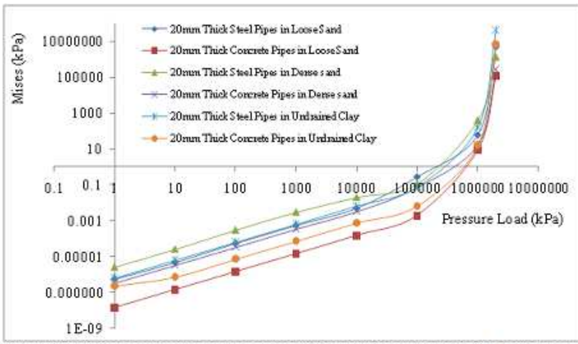

Figure 19: Spring-line mises of varying presure load for coefficient of friction of 0.3 in explosion above the ground surface for "No Slip" at the period of 0.025 ms

Conclusion

Thos work has examined the effects of varying parameters on underground pipes due to seismic action of surface accidental explosion. Under the action, at low pipe thickness, the observed parameters in steel and concrete pipes buried in undrained clay is low at the invert but remain almost constant at the crown, invert and spring-line as the thickness increases even though there is variation in the results. For coefficient of friction of 0.3 investigated, appreciable values of the observed parameters was noticeable at a pressure of over 100 kPa while appreciable values of strain was noticeable at a pressure of over 500 kPa. For pipes buried in undrained clay, as Young's modulus of pipe increases, strain reduces but pressure and stress increase. At lower value of Young's modulus of soil, displacement, pressure, stress and strain at the crown, invert and spring-line of pipes reduce. As the Young's modulus of soil increases, displacement, pressure, stress and strain increase with crown having the maximum value of stress and invert having the maximum value of pressure. Displacement is high at the crown but low at the invert and spring-line of pipes having low value of Young's modulus and buried in undrained clay 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). 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,

Boh, J. W., Louca, L. A. and Choo, Y. S. (2007). *Finite Element Analysis of Blast `Resistance Structures in the Oil and Gas Industry*, Singapore and UK, ABAQUS User's Conference, 1-15.

George, P. K., George, D. B. and Charis, J. G. (2007). *Analytical calculation of blast induced strains to buried pipelines*. International Journal of Impact Engineering, **34**, 1683-1704.

Huabei Liu, (2009). *Dynamic Analysis of Subways Structures under Blast Loading*, University Transportation Research Center, New York, USA.

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.

Marusek A. James, 2008. *Personal Shelters*, ABAQUS User's Conference, US Department of the Navy, 1-12.

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.

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.