Open Access Accepted: Nov. 2020 Vol. 1, Issue 1, Jan. 2021 , Pp 1-10

Effects of Seismic Loads from Underground Accidental Explosions Occurring Between Ground Surface and Buried Pipes

Akinola Johnson OLAREWAJU
Civil Engineering Department, Federal Polytechnic Ilaro, Ogun State, Nigeria

Abstract: *Underground accidental explosions are caused by the detonation of explosive materials (solid, liquid or gas) stored below the ground surface. In this study, effects on underground pipes due to varying degrees of underground accidental explosions between the ground surface and buried concrete and steel pipes were studied using ABAQUS, a finite element numerical code. Concrete and steel pipes buried in loose sand and dense sand at various depths 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, mises, stress and strain at the crown, invert and spring-line of buried pipes. The results showed that irrespective of the ground media, at a given loading wave velocity, displacement remains relatively constant as the embedment ratio increases. Even though there is variation in the results due to dilations and compressions caused by the transient stress pulse of compression wave, some of the observed parameters reduce as the depth of burial of pipes increased.*
Keywords: *Underground, Explosion, Pipes, Loading Wave Velocity*.

Introduction

Underground accidental explosion normally occur when an explosive material (solid, liquid or gas) explodes below the ground surface. 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 and Shino, 2011). The load emanating from the blast wave is termed loading wave velocity and it denotes the blast load which the buried explosive charge delivered to the buried structures (Olarewaju, 2012; Olarewaju, 2013; Olarewaju, 2019). 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 that will produce the explosive loads on underground structures, there is need to study the consequences of these complexity. Because of the 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 due to underground accidental explosions occurring directly above the buried pipes. This is with view to providing design information and guidelines for the design of 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. This study is aimed at determining by simulation, the impact of underground accidental explosions that occurs below the ground surface and directly above the buried pipes (Olarewaju, 2012; Olarewaju, 2013).

Background Study

Explosive materials 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 and Andrew, 2009; Olarewaju, 2012; Olarewaju, 2013). 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 accidental explosions depends mainly on stiffness of the constituents rather than strength (Liang-Chaun, 1978; Olarewaju, 2012; Olarewaju, 2013). 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 below the ground surface, 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; Olarewaju, 2013). 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 grater distance from the source of the explosion

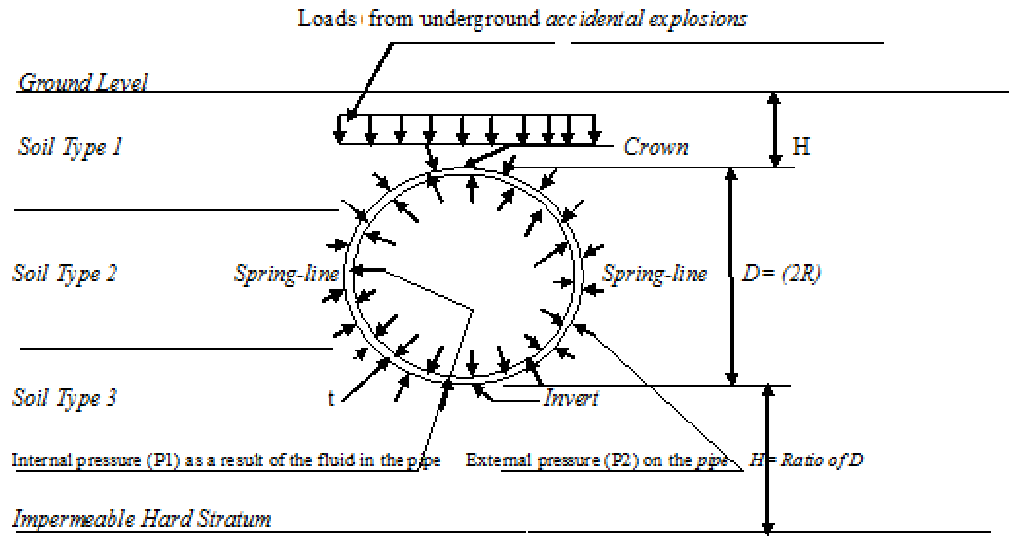
(Robert, 2002; Eric and Shino, 2011). The United States of America has conducted a lot of deep underground tests, especially since September 1961 according to The Effects of Nuclear Weapon (1977; Olarewaju, 2012; Olarewaju, 2013; Olarewaju, 2019).

Methodology

In this study, 1m diameter pipes buried horizontally in loose sand and dense sand at various depths below the ground surface were modelled using ABAQUS software (finite element numerical code). According to Olarewaju, (2013), 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 grater 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. 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 difference scheme in ABAQUS/Explicit, a finite element numerical code (Olarewaju, 2012; Olarewaju, 2013; Olarewaju, 2019).

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

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; ABAQUS/Explicit: Advanced Topic, 2009). Underground accidental explosions were assumed to have taken place outside the vicinity of the buried pipes and as a result, vertical explosion loads were represented by the loading wave velocities and other underground explosion loads parameters. The parameters were assumed to have taken place at various stand-off distances at different arrival time in loose sand and dense sand. These underground loading parameters were determined analytically and numerically (UFC, 2008). The observed parameters are displacement, pressure, mises, stress and strain at the crown, invert and spring-line of pipes buried in loose sand and dense sand as shown in Figure 1 (Olarewaju, 2012; Olarewaju, 2013; Olarewaju, 2019).



Figures 1: Problem definition for the effects of buried pipe due to loads from underground accidental explosions taking place between the ground surface and buried pipes

Results and Discussion

The results of displacement, pressure, mises, stress and strain at the crown, invert and spring-line against pipes buried at varying embedment ratios in loose sand and dense sand for vertically applied loads from underground accidental explosions occurring between the ground surface and buried pipes are graphically presented in Figures 2 to 14 respectively. From the results, irrespective of the ground media, at a given loading wave velocity, displacement in the pipes remain relatively constant (Olarewaju, 2012). In addition, 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 variation in the result due to dynamic nature of the load, as the embedment ratio increases, pressure, mises, stress, strain at the crown, invert and spring-line of pipes buried in loose sand and dense sand, respectively, reduces. 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 occurring above the buried pipes but below the ground surface. It is an indication that as the displacement increases linearly (Olarewaju, 2012) 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 (Olarewaju, 2012; Olarewaju, 2013; Olarewaju, 2019). Apart from displacement which is relatively constant for a given loading wave velocity, other observed parameters (pressure, mises, stress and strain) reduces as the depth of burial of concrete and steel pipes of 10mm and 20mm thicknesses increase. This is due to the confinement of pipes by soil at greater depth of burial. Underground structures are divided into fully buried structures and partially buried structures which could 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.

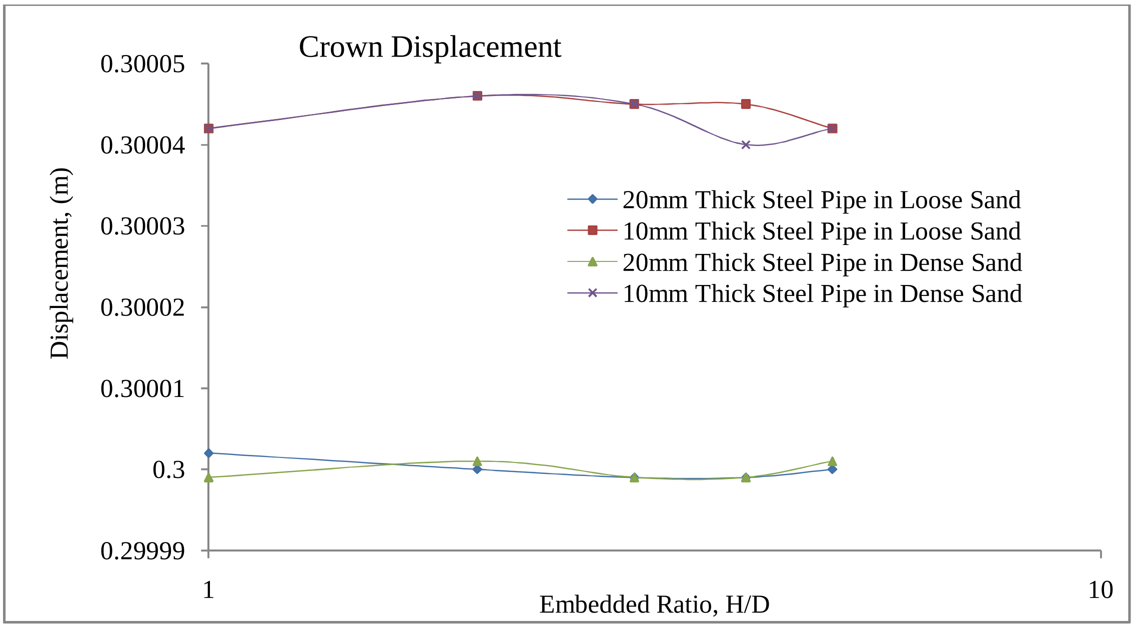


Figure 2: Displacement against depth of burial for loads from underground accidental explosions

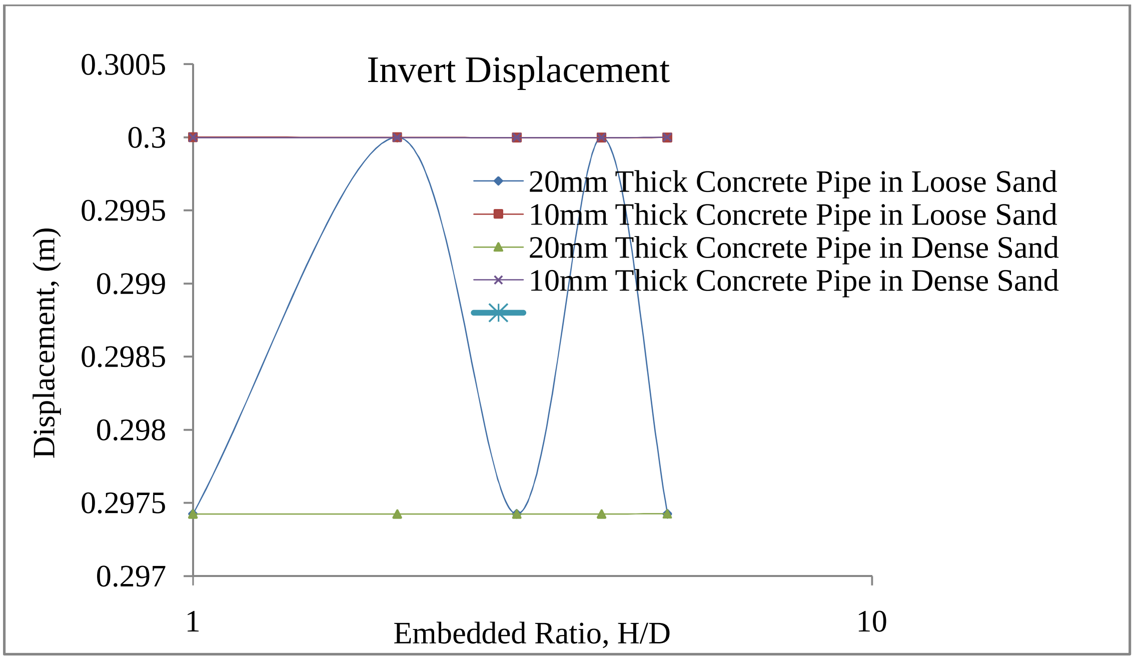


Figure 3: Displacement against depth of burial for loads from underground accidental explosions

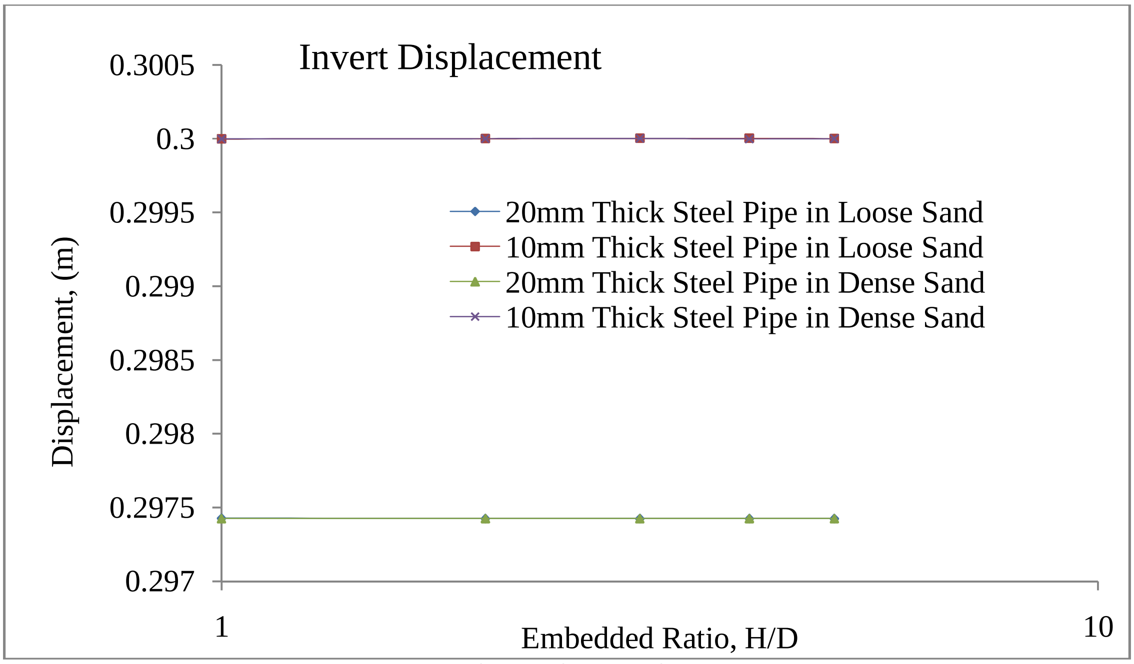


Figure 4: Displacement against depth of burial for loads from underground accidental explosions

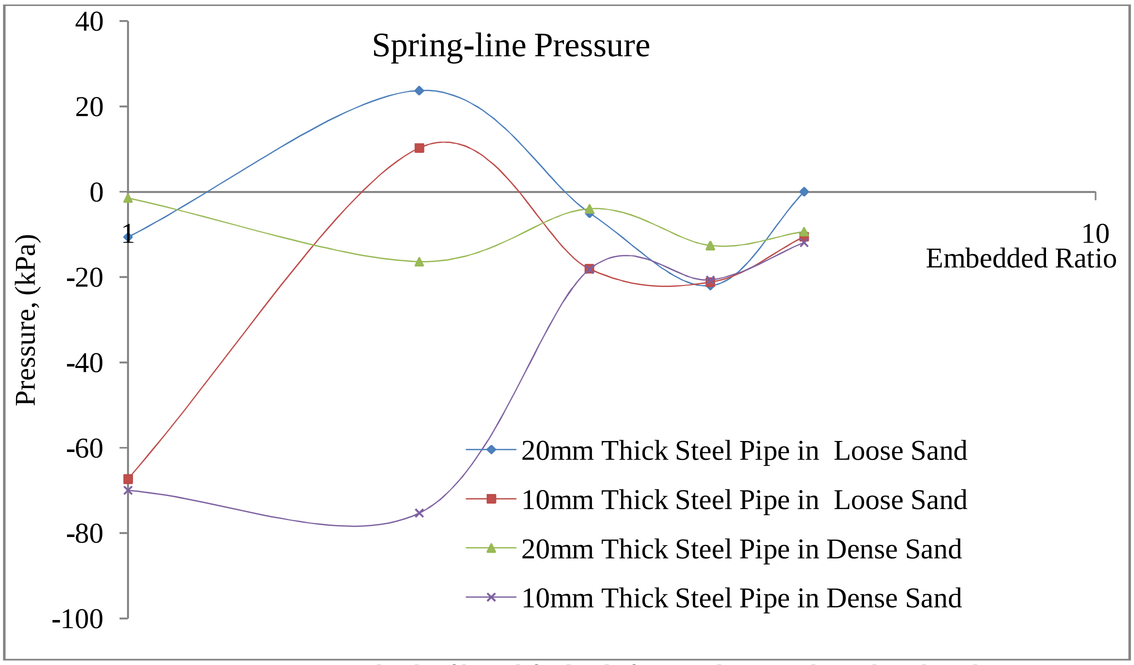


Figure 5: Pressure against depth of burial for loads from underground accidental explosions

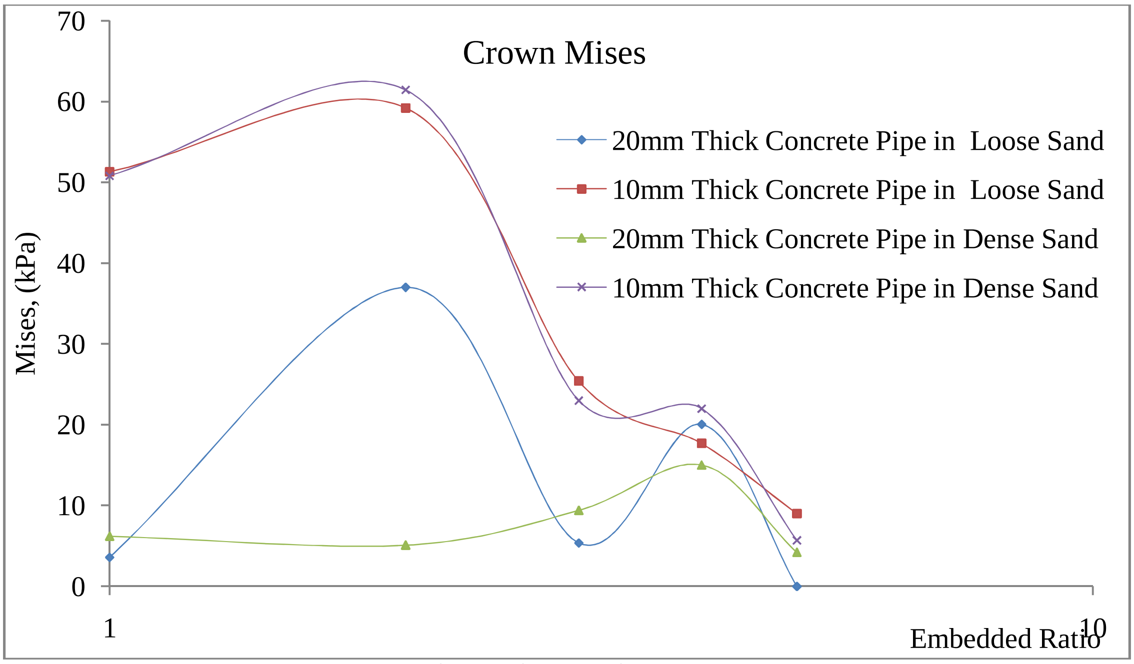


Figure 6: Mises against depth of burial for loads from underground accidental explosions

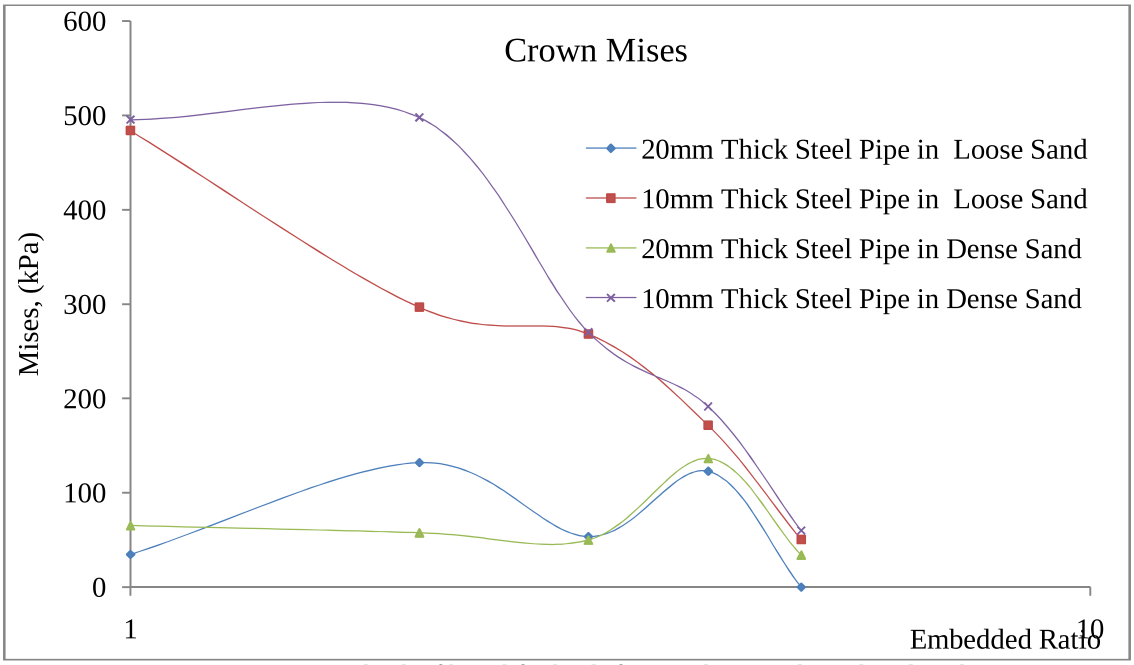


Figure 7: Mises against depth of burial for loads from underground accidental explosions

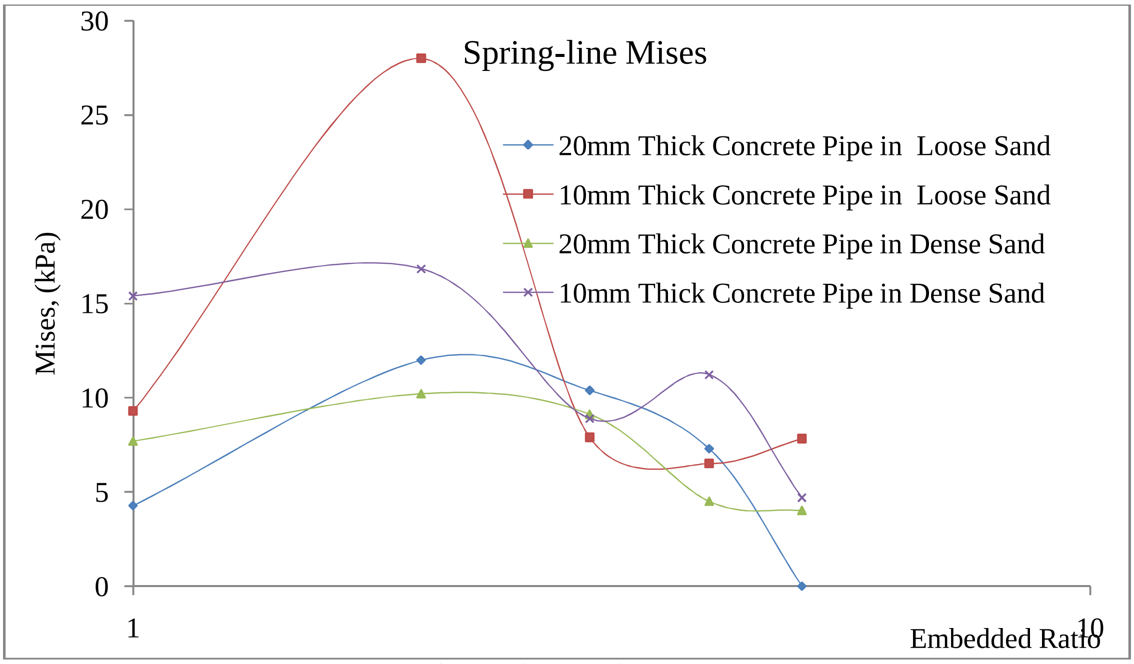


Figure 8: Mises against depth of burial for loads from underground accidental explosions

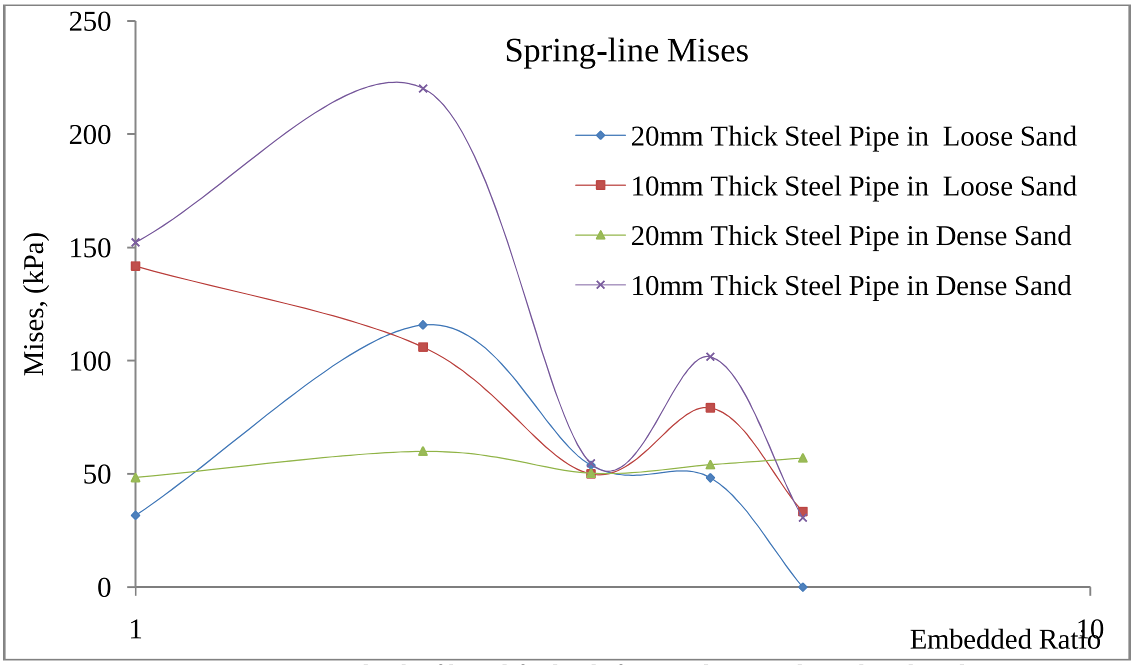


Figure 9: Mises against depth of burial for loads from underground accidental explosions

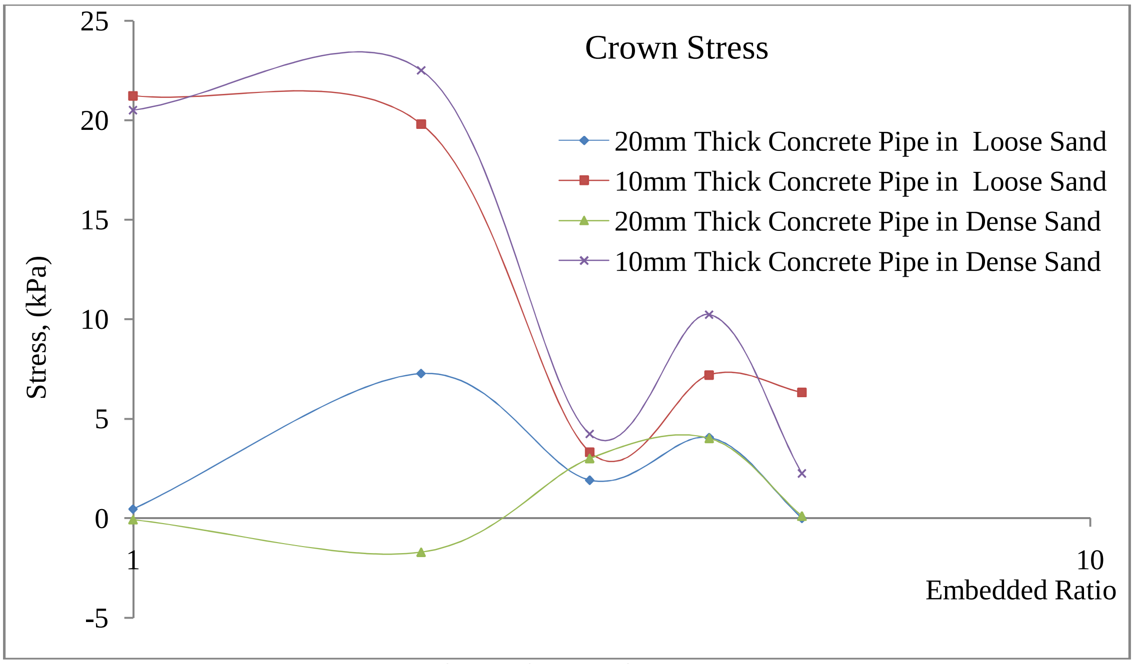


Figure 10: Stress against depth of burial for loads from underground accidental explosions

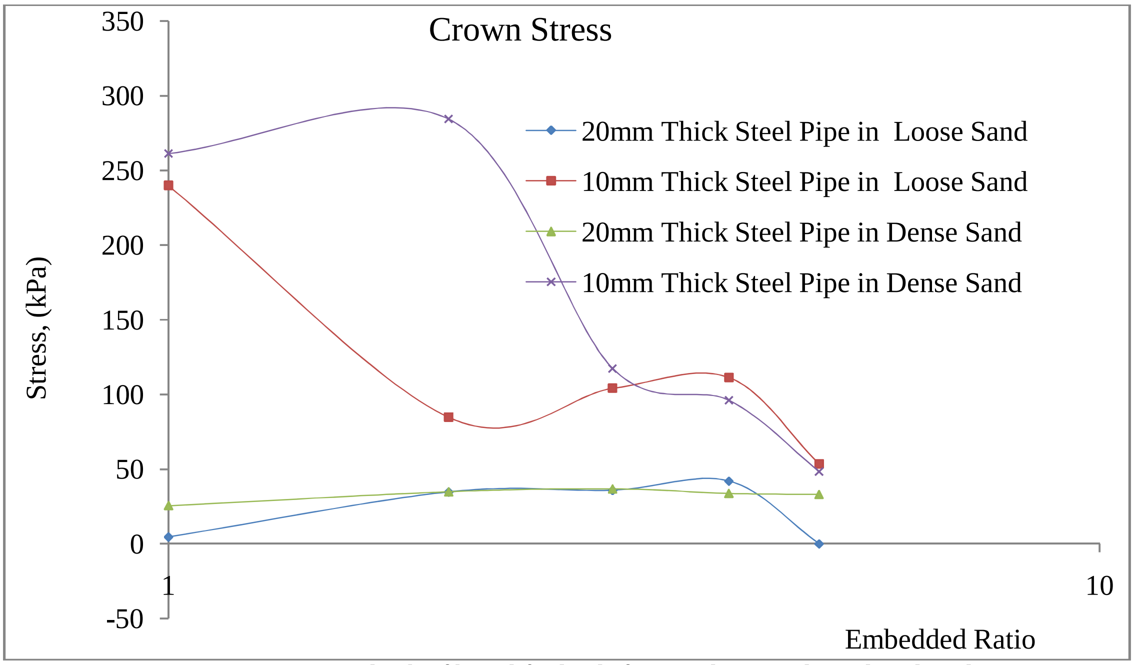


Figure 11: Stress against depth of burial for loads from underground accidental explosions

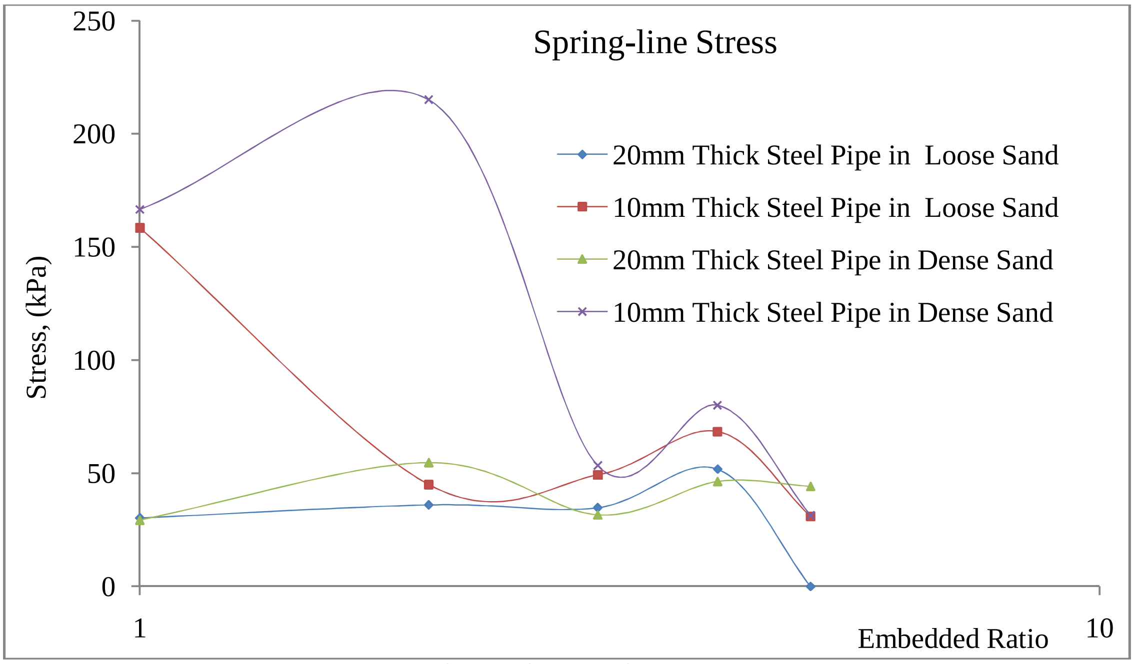


Figure 12: Stress against depth of burial for loads from underground accidental explosions

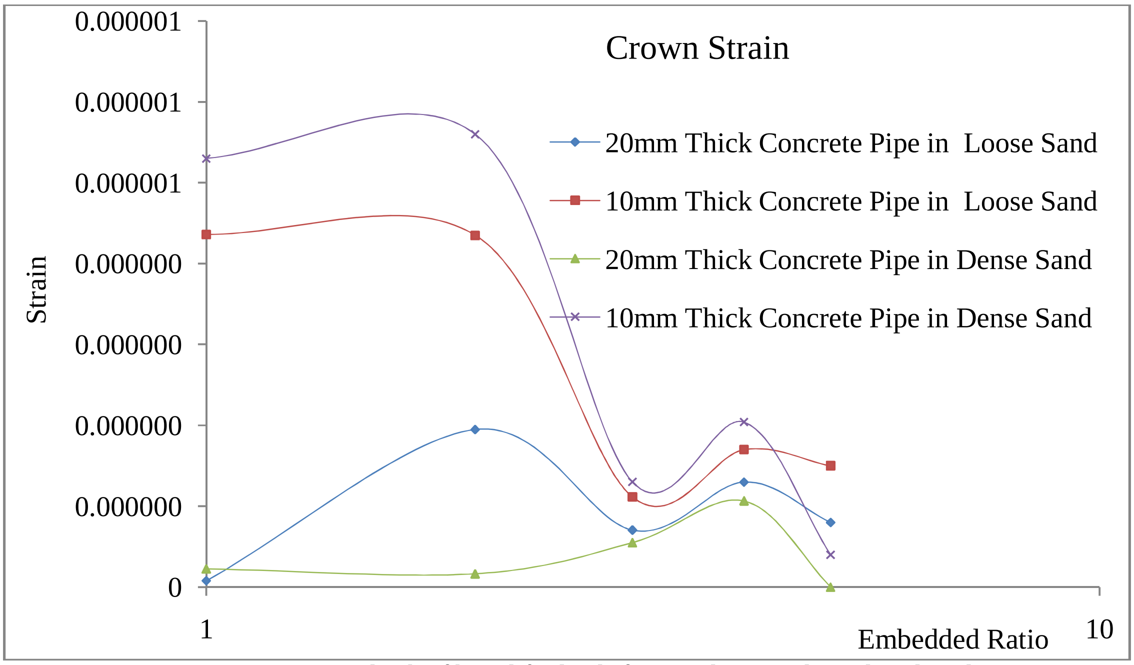


Figure 13: Strain against depth of burial for loads from underground accidental explosions

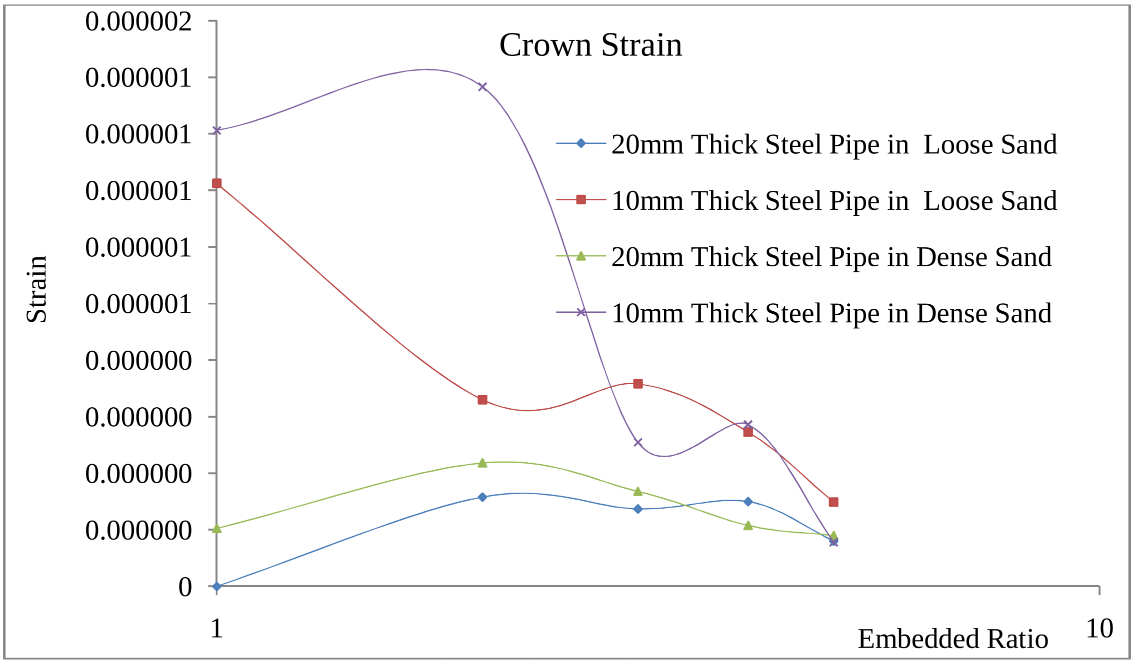


Figure 14: Strain against depth of burial for loads from underground accidental explosions

Conclusion

In this study, the impact of underground accidental explosions occurring below the ground surface and directly above buried pipes has been examined. Normally pipes are generally laid 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. This is imperative most especially around military formations where defensive and explosive weapons are stored underground, filing 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 as a result of less overburden, structural materials yield more easily at lower depth of burial due to underground accidental explosions, whereas at grater depth of burial, due to confinement, response of underground structures such as pipes is minimal. In designing underground installations 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, invariably it would result to material failure (Liang-Chaun. 1978; Olarewaju, 2012; Olarewaju, 2013; Olarewaju, 2019).

References

Abaqus Inc, (2009). Abaqus Analysis User's Manuals – Documentation, Version 6.7- and 6.8-EF, D'S Simulia, Providence, Rhode Island, USA.

Abaqus Inc, (2009). Abaqus/Explicit: Advanced Topics, D'S Simulia, Providence, Rhode Island, USA.

Abaqus Inc, (2009). Geotechnical Modelling and Analysis with Abaqus, D'S Simulia, Providence, Rhode Island, USA.

AubreyJ.org, (2006). United States Department of Energy, All in Public Domain, http://www.doe.gov.bridge

Craig, R. F. (1994). *Soil Mechanics*, (Fifth Edition), GB: Chapman and Hall Press.

Eric T., & Shino . (2011). Stricken Japan nuclear plant rocked by 2nd blast. Fukushima Dai Ichi Nuclear Plant Plagued By Cooling Issues. The Associated Press, 14th March.

Kameswara R N. S. V. (1998). *Vibration Analysis and Foundation*, (First Edition), New Delhi, Wheeler Publishing Co. Ltd.

Liang-Chaun P. (1978). *Soil-pipe interaction: Stress analysis methods for underground pipelines*, (pp, 67-76), AAA Technology and Specialties Co., Inc., Houston, Pipeline Industry.

Olarewaju, A. J., Kameswara Rao, N.S.V and Mannan, M.A. (2012). Chapter 20: Response of Underground Pipes to Blast Loads, Book Title: "Earthquake-Resistant Structures - Design, Assessment and Rehabilitation", Abbas Moustafa (Editor), ISBN: 978-953-51-0123-9, Geology and Geophysics, InTech Publisher, Croatia, Europe, February, pp 507 - 524, http://www.intechopen.com/books/earthquake-resistant-structures-design-assessment-and-rehabilitation

Olarewaju, A. J. (2012). Study on the Impact of Varying Degrees of Underground Accidental Explosions on Underground Pipes by

Simulation, *Earth Science Research (ESR) Journal*, July 6, ISSN 1927-0542 (Print), ISSN 1927-0550 (Online), Volume 1, Number 2, Canadian Center of Science and Education, Canada, doi:10.5539/esr.v1n2p189 URL: http://dx.doi.org/10.5539/esr.v1n2p189, pp 189 -199.

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, Published May 20, pp 331 - 356. http://www.intechopen.com/books/earthquake-engineering-from-engineering-seismology-to-optimal-seismic-design-of-engineering-structures

Olarewaju, A. J., (2019). *Guidelines for Numerical Analysis and Seismic Design of Modeled Underground Structures*, 13 Chapters of Research Work, First Edition, Paperback ISBN: 978-93-5335-841-9; E-Book ISBN: 978-93-5335-842-6, AkiNik Publications, New Delhi, India (249 Pages)

Peter, D. S., & Andrew, T., (2009). Blast Load Assessment by Simplified and Advanced Methods, Defence College of Management and Technology, Defence Academy of the United Kingdom, Cranfield University, UK. http://www.civ.uth.gr/costc26/documents/10th%20meeting_Malta/WG3/smith%20COST%20C26%20Blast%20load%20assessment.pdf

Robert, W. D. (2002). *Geotechnical Earthquake Engineering Handbook*, NY: McGraw-Hill.

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, http://www.cddc.vt.edu/host/atomic/nukeffct/enw77b2.html

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, USA.

United States Department of Energy, (2000). United States Nuclear Tests July 1945 through September 1992, Nevada Operations Office Las Vegas, Nevada DOE/NV--209-REV 15, 1–162.