Effects of Accidental Explosions on Low Stiffness Pipes Buried in Undrained Clay

Akinola Johnson Olarewaju

Civil Engineering Department,
School of Engineering,
Federal Polytechnic,
P.M.B. 50, ILARO,
Ogun State, Nigeria
e-mail: akinolajolarewaju@yahoo.com

ABSTRACT

Low stiffness pipes are flexible pipes which are used for various services across the world. In this study, due to accidental explosions, the responses of various low stiffness pipes buried in undrained clay soil were observed.. Explosion load parameters for 250kg TNT explosive exploding at less than 10m away from the buried low stiffness pipes were determined using Unified Facilities Criteria (2008). The soil and pipe material properties were considered as elastic, homogeneous and isotropic. Material properties as obtained from various researchers and pipe manufacturers were used. Equation of motion was solved using time integration technique in ABAQUS/Explicit, a finite element numerical code. From the results of this study, displacement of buried low stiffness pipes due to underground accidental explosions is constant irrespective of the ground medium while at pipe stiffness of 300kPa, strain at the crown, invert and spring-line of buried low stiffness pipes is 0.00006. Remarkable response due to underground accidental explosions, in pressure and stress was noticeable at pipe stiffness of 100kPa and above while that of surface accidental explosions is noticeable at pipe stiffness 10kPa 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.

KEYWORDS: Explosion; Underground; Surface; Low Stiffness Pipes; Response, Undrained Clay.

INTRODUCTION

There are different types and categories of pipes used for various services like water supply, irrigation, penstock for hydroelectricity, oil and gas supply, drainage, sewerage, etc (Olarewaju et al., 2010a; 2010c). Pipes are being recognised by their stiffness (i. e. Young's modulus, E). Low stiffness pipes are polyethylene pipes (PE), vitrified clay pipes (VC), polyvinylchloride pipes (pvc), etc while high stiffness pipes are concrete (plain or reinforced) pipes, steel pipes, ductile iron pipes, cast iron or grey iron pipes, etc (Tay, 1994; Olarewaju et al., 2011a). These pipes are laid in water, on the ground surface as well as buried in the ground. The various ground media where pipes are mostly laid in the tropical regions are loose sand, dense sand and undrained clay (Olarewaju et al., 2010d). In loose sand and dense sand, movement of water after rainfall is instantaneous, while in clay soil, movement of water takes a long period of time.

BACKGROUND STUDY

Clay soil contain minerals with major group comprising of montmorillonites, kaolinites and illites while the minor groups are allophone, chlorite, vermiculite, attapulgite, palygorkite, and sepiolite resulting in varying swelling and shrinkage characteristics as well as elastic property (Craig, 1994; Olarewaju et al., 2011). In the event of accidental explosions (either surface or underground), undrained behaviour of clay soil is relevant because there will be no pore water movement during the period of explosion (Huabei 2009; Olarewaju et al. 2011). This is because explosion is a short discontinuous event with short duration. Due to severity of destruction caused by accidental explosions, it has been reported that tremor resulting from explosion has been felt 40km away from the source (Eric and Shino, 2011).

Due to loadings from accidental explosions, the typically adopted constitutive relations of soils are elastic, elasto-plastic, or visco-plastic. Under elasto-plastic deformation of soil, it involves some plastic deformation that takes place within the vicinity of the explosion. Beyond this region, the soil could be taken as an elastic material at certain distance from the explosion. Visco-elastic soils exhibit elastic behavior upon loading followed by a slow and continuous increase of strain at a decreasing rate (Robert, 2002; Olarewaju et al., 2010h; 2011c). Soil-pipe interaction due to accidental explosions depends mainly on stiffness of materials of the components (Liang-Chaun, 1978; Olarewaju et al. 2010f; 2011b). This study is aimed at observing the response of buried low stiffness pipes due to accidental explosions. These are pipes that are buried in undrained clay soil.

METHODOLOGY

In this study, as shown in Figure 1, 1m diameter pipe 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. Therefore the two elastic constants (i.e., Young's modulus, E and Poisson's ratio, ν) as revealed by various researchers and pipe manufacturers were used in the study (Kameswara, 1998; Craig, 1994; Unified Facilities Criteria, 2008). Poisson's ratio of 0.5 indicates a constancy of volume (Chen, 1995; Robert, 2002) which is applicable to undrained clay. Steel and concrete pipes were laid horizontally with no joint. 'No-slip' condition between the pipes and soil was assumed in the analysis. Boundary conditions were defined with respect to global Cartesian axis in line with Geotechnical Modelling and Analysis with ABAQUS (2009).

Load parameters due to accidental explosions corresponding to 250kg TNT explosive exploding at less than 5m above the ground surface were determined using Unified facilities Criteria (2008) (Peter and Andrew, 2009; Olarewaju et al., 2010e). In the case of accidental underground explosion, explosion was assumed to take place at more than 15m away from the buried low stiffness pipes. Time integration technique in ABAQUS/Explicit was used to solve the equation of motion shown in Equation 1 with initial conditions (ABAQUS Analysis User's

Manual, 2009; ABAQUS/Explicit: Advanced Topics, 2009). Details of the analysis of the explosive load duration could be found in Olarewaju et al. (2011e). Parameters observed are displacement, pressure, stress and strain at the crown, invert and spring-line of slow stiffness pipes buried in undrained clay as shown in Figure 1 (Olarewaju et al., 2010h).

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

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.

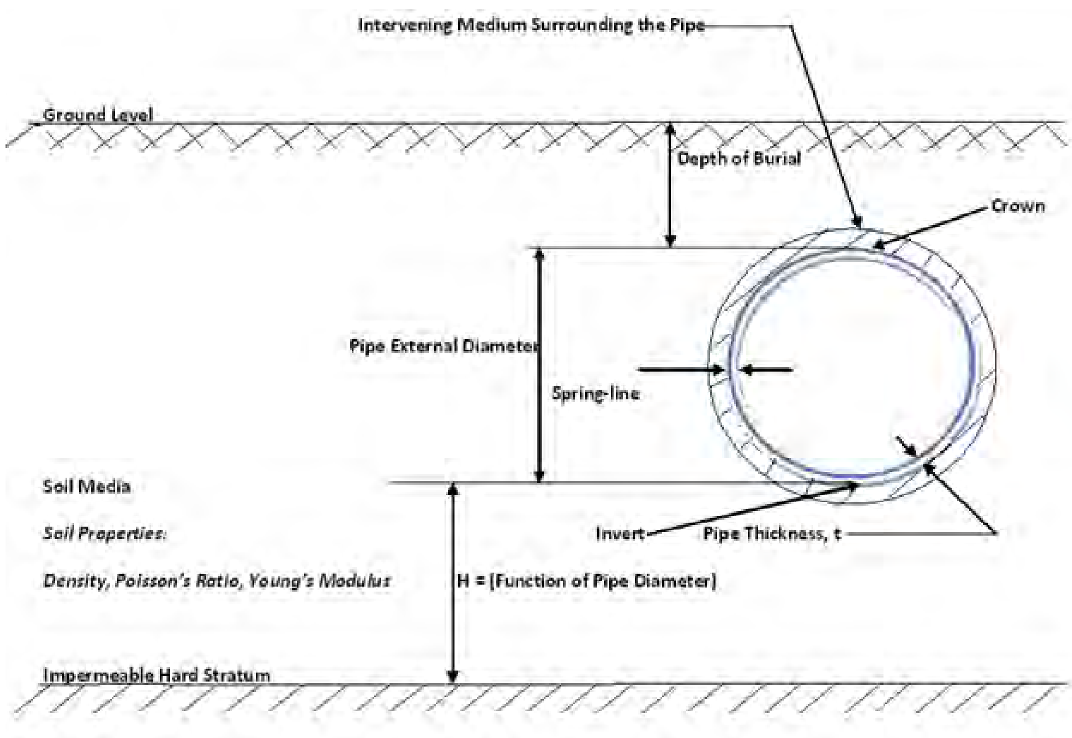

Figure 1: Problem definition for the response of low stiffness underground pipe due to surface and underground accidental explosions

RESULTS AND DISCUSSION

The results of displacement, pressure, stress, and strain at the crown, invert and spring-line of underground low stiffness pipes due to surface accidental explosions are presented in Figures 2, 3, 4 and 5 respectively. In addition to these, results of loading wave velocities for various explosives ranging from 10kg TNT to 250kg TNT exploding in undrained clay soil is presented in Figure 6. Finally, results of displacement, pressure, stress, and strain at the crown, invert and spring-line of underground low stiffness pipes due to underground accidental explosions are presented in Figures 7, 8, 9 and 10 respectively.

As a result of surface accidental explosions, as the stiffness of pipe increases, crown displacement increases more, followed by spring-line with no appreciable changes in the invert displacement as shown in Figure 2. In addition to this, from Figures 3 and 4, remarkable response in pressure and stress was noticeable at pipe stiffness of 10kpa and above. Furthermore, strain is highest at the spring-line but least at the invert of pipe at low pipe stiffness. As the stiffness of pipe increases, strain reduces as sown in Figure 5.

According to Olarewaju et al. (2011c), loading wave velocities are the load which the buried explosive charge delivered to the buried structures (i. e. pipes). In the case of underground accidental explosion, for the weight of explosives considered, loading wave velocity reduces to seismic velocity of soil at a distance of less than 10m from the point of burst of explosion as shown in Figure 6. This is because much of the energy from the explosive yield is spent in heating, melting, fracturing and plastically deforming the soil matrix around the source of the explosion (Olarewaju et al., 2010i). The remaining energy is released in the form of seismic velocity. This indicates the seismic efficiency of the explosives.

In addition to this, in accidental underground explosions, for a given loading wave velocity, displacement is constant as shown in Figure 7 irrespective of the ground media. Unlike surface accidental explosions, due to accidental underground explosions, remarkable response in observed parameters of pressure and stress is noticeable at pipe stiffness of 100kPa and above as shown in Figures 8 and 9 respectively. As shown in Figure 8, pressure changes from positive to negative within the soil medium and in the buried pipes due to dilations and compressions caused by the transient stress pulse of compression wave from the explosion (Olarewaju et al., 2010c; 2010f; 2010g). Finally, pipe stiffness of 300kPa has strain value of 0.00006 at the crown, invert and spring-line of pipes buried in undrained clay as shown in Figure 10.

According to David (2006), though undrained clay was not specifically mentioned, rigid (steel, plain concrete and reinforced concrete) pipes have low dependency on soil-pipe interaction. Flexible (plastic and metallic) pipes are designed to resist vertical displacements, buckling and ring bending strain (David, 2006). Frans (2001) clearly shows that the low stiffness pipes suffer less from subsidence than the one with the higher stiffness. At the same time a higher displacement is observed when using low stiffness pipes. It shows that flexible pipes deform and the load is transferred by the soil (Frans, 2001; David, 2006; Olarewaju et al., 2010g).

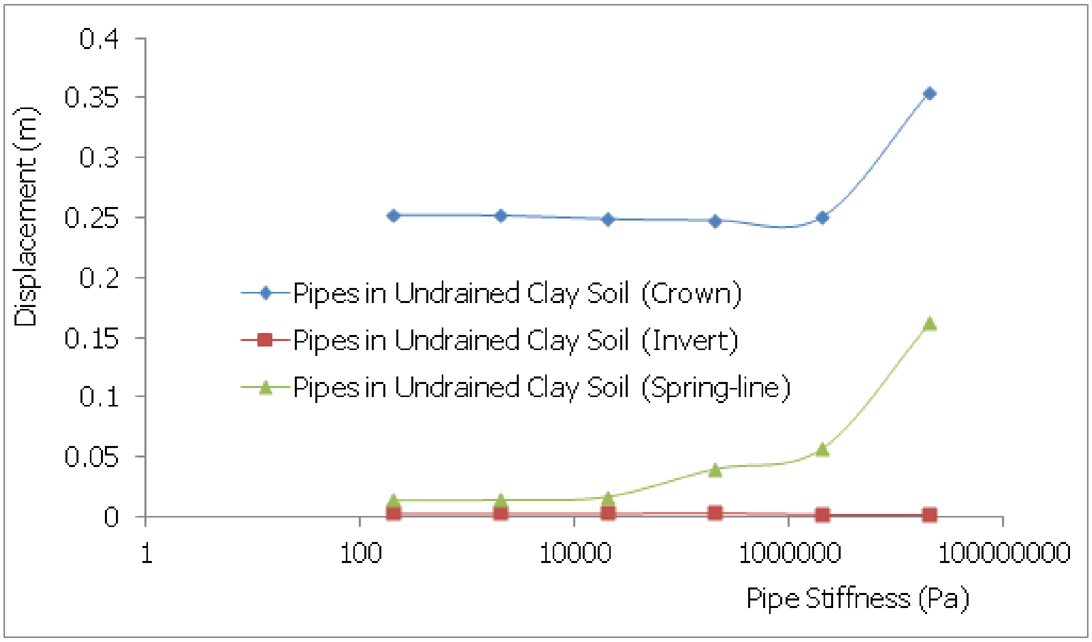

Figure 2: Displacement in underground low stiffness pipes due to surface accidental explosions

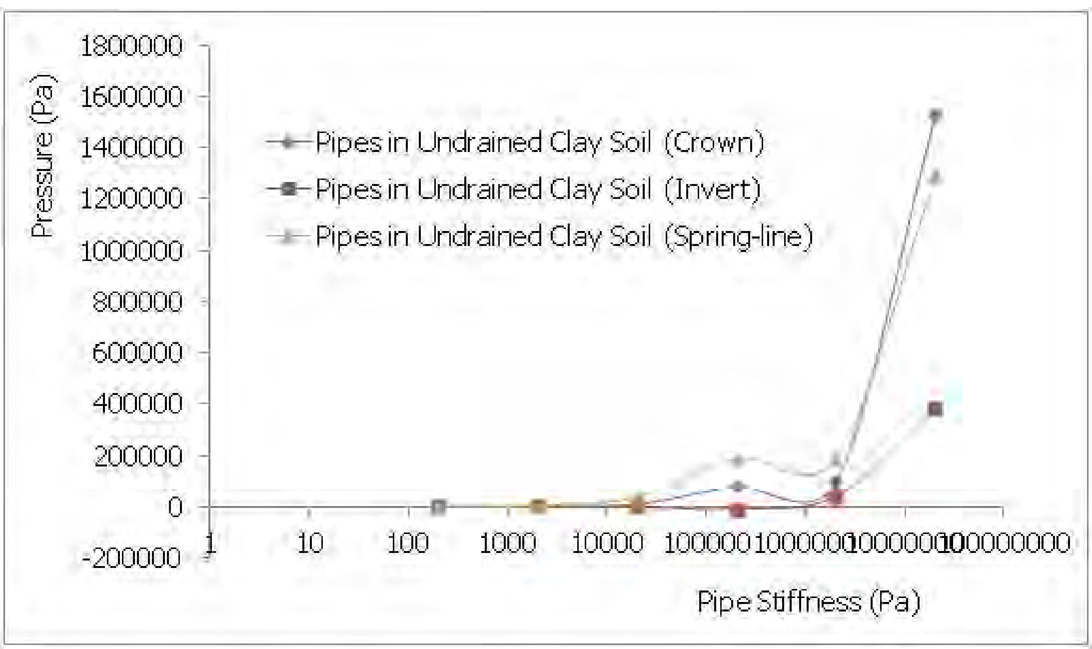

Figure 3: Pressure in underground low stiffness pipes due to surface accidental explosions

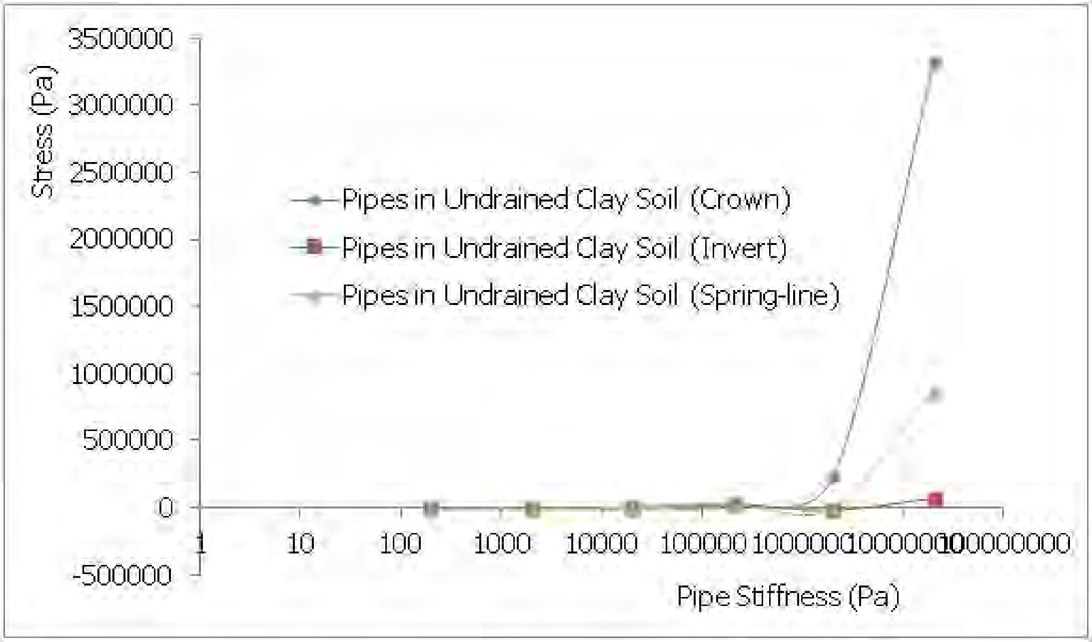

Figure 4: Stress in underground low stiffness pipes due to surface accidental explosions

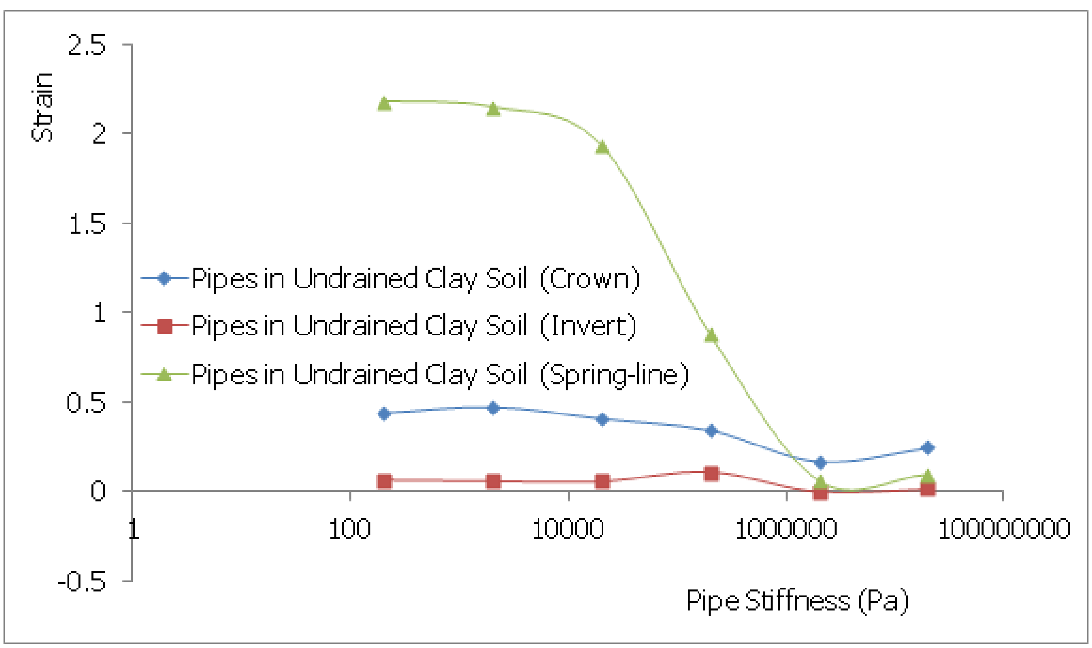

Figure 5: Strain in underground low stiffness pipes due to surface accidental explosions

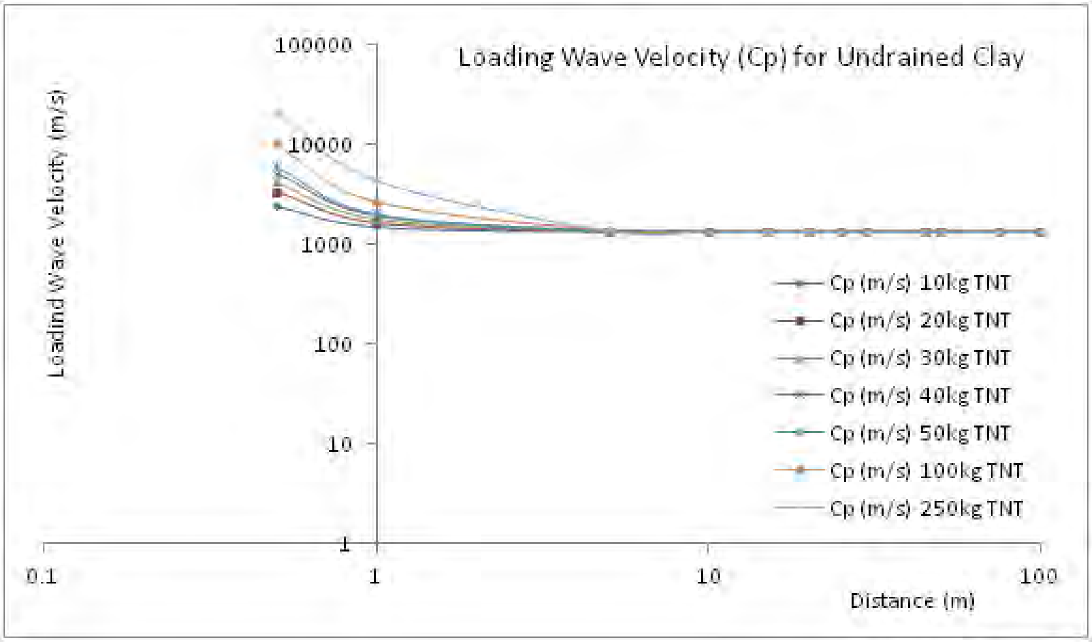

Figure 6: Loading wave velocity against distance due to underground accidental explosions (Olarewaju et al., 2010c; 2010e; 2010g; 2010f; 2011c)

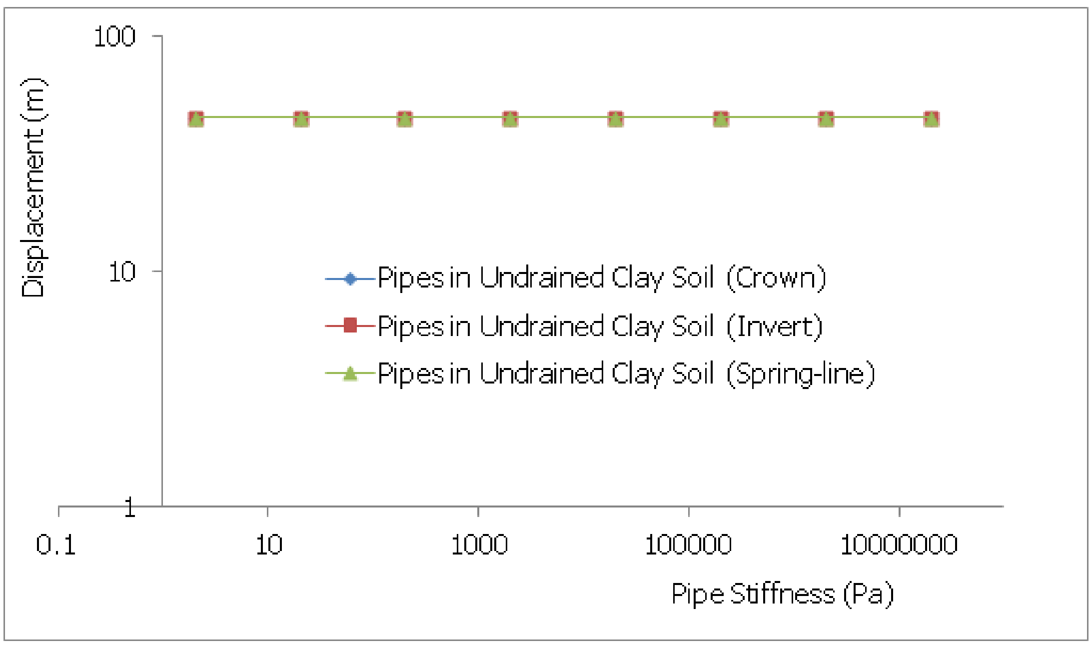

Figure 7: Displacement in underground low stiffness pipes due to underground accidental explosions

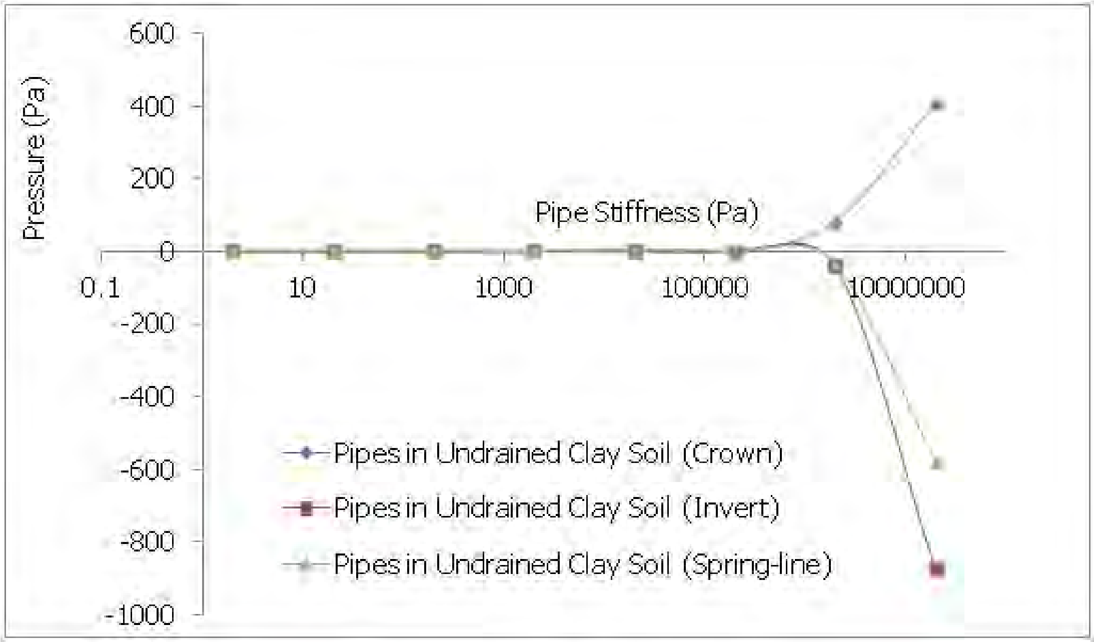

Figure 8: Pressure in underground low stiffness pipes due to underground accidental explosions

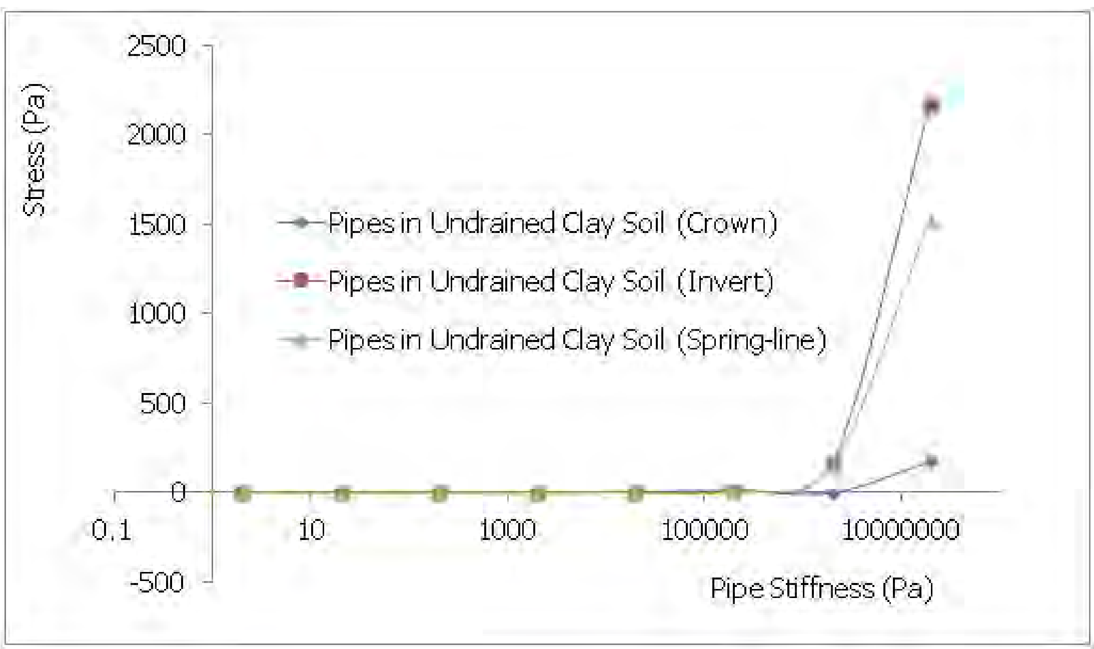

Figure 9: Stress in low underground stiffness pipes due to underground accidental explosions

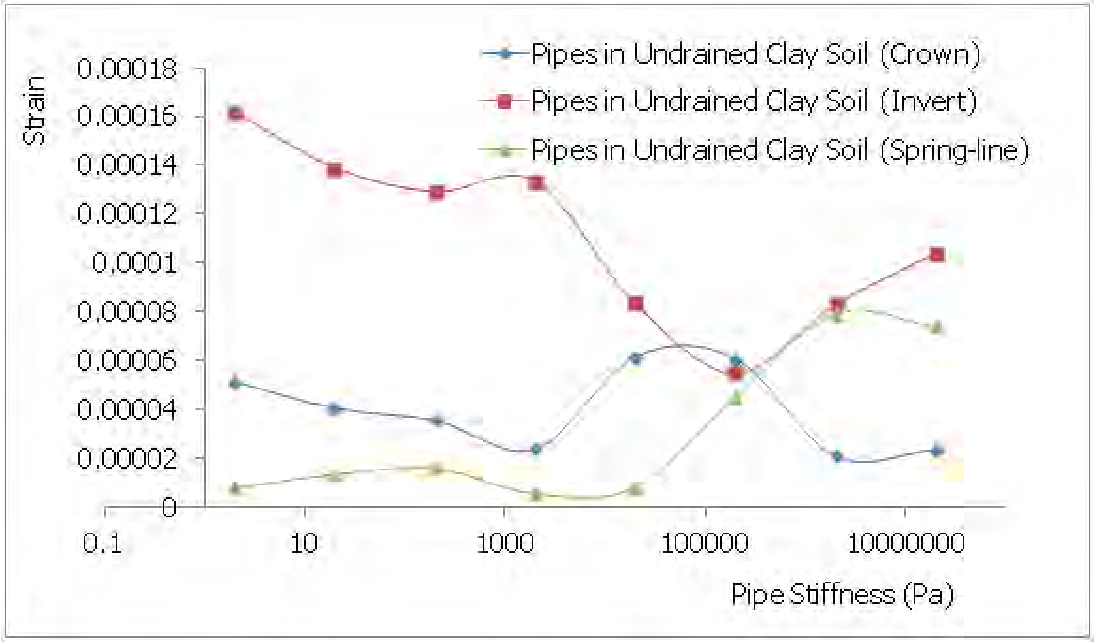

Figure 10: Strain in underground low stiffness pipes due to underground accidental explosions

CONCLUSION

In this study, due to surface and underground accidental explosions, the various responses of low stiffness pipes buried in undrained clay soil were observed. The explosive load considered is 250kg TNT exploding very close to the ground surface but a bit far from the low stiffness pipes buried in undrained clay (Unified Facilities Criteria, 2008; Peter and Andrew, 2009). In this case, the soil and pipe was considered as elastic materials. As a result, the two elastic constants as obtained from various researchers and pipe manufacturers were used to study the behaviour of the materials (Kameswara, 1998; Olarewaju et al., 2011d). Low stiffness pipes are considered as flexible pipes while high stiffness pipes are considered as rigid pipes. Responses in pressures and stresses were noticed at 10kPa pipe stiffness and above for surface accidental explosions while at 100kPa pipe stiffness, the same observed parameters were noticed for underground accidental explosions respectively.

REFERENCES

1. Abaqus Inc., (2009). Abaqus Analysis User's Manuals – Documentation, Version 6.7- and 6.8-EF, Dassault Systemes Simulia, Providence, Rhode Island, USA, 2009.
2. Abaqus Inc., (2009). Abaqus/Explicit: Advanced Topics, Dassault Systemes Simulia, Providence, Rhode Island, USA.
3. Abaqus Inc., (2009). Geotechnical Modelling and Analysis with Abaqus, Dassault Systemes Simulia, Providence, Rhode Island, USA.
4. Chen, W. F. (1995). The Civil Engineering Handbook, CRC Press, London. 1386.

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

6. David Mathews, (2006). Design and Installation Requirements for Various Pipe Types. CPAA-Technical Report, March, 1-14.

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

8. Frans Alferink. (2001). Soil-Pipe Interaction: A next step in understanding and suggestions for improvements for design methods, Waving M & T, The Netherlands, Plastic Pipes XI, Munich, 3rd-6th September.

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

10. Kameswara Rao, N. S. V. (1998). Vibration Analysis and Foundation, First Ed., Wheeler Publishing Co. Ltd., New Delhi, India.

11. Liang-Chaun Peng. (1978). Soil-pipe interaction – Stress analysis methods for underground pipelines, AAA Technology and Specialties Co., Inc., Houston, Pipeline Industry, May, 67-76.

12. Olarewaju, A. J., Kameswara Rao, N. S. V. and Mannan, M. A. (2010a). Response of Underground Pipes due to Blast Load, Proc. of 3rd Int. Earthquake Symposium Bangladesh, Bangladesh University of Engineering Technology, Dhaka, pp. 165-172, Mar.5th -6th.

13. Olarewaju, A. J., Kameswara Rao, N. S. V. and Mannan, M. A. (2010b). Blast Effects on Underground Pipes, EJGE: Journal of Geotech. Engng., May, (15/F), Oklahoma, United States of America, pp. 645-658..

14. Olarewaju, A. J., Kameswara Rao, N. S. V. and Mannan, M. A. (2010c). Behaviors of Buried Pipes due to Internal Explosion, Malaysia Construction Research Journal, Sept., Volume 9 / No. 2 / 2011, ISSN 1985-3807.

15. Olarewaju, A. J., Kameswara Rao, N. S. V. and Mannan, M.A. (2010d). Behavior of Buried Pipes Due to Surface Blast Using Finite Element Method, 1st Graduate Student Research Int. Conf., Brunei, on Contributions Towards Environment, Biodiversity and Sustainable Development, Universiti Brunei Darussalam, Dec. 13th –15th , pp. 17 (1-6).

16. Olarewaju, A. J., Kameswara Rao, N.S.V and Mannan, M.A., (2011a), Blast Effects on Underground Pipes Using Finite Element Method, Proc. of 12th Int. Conf. on Quality in Research (QiR), Faculty of Engineering, University of Indonesia, Bali, Indonesia, 4th–7th July, ISSN: 114-1284, pp 2511-2518.

17. Olarewaju, A. J., Kameswara Rao, N. S. V. and Mannan, M. A. (2010e). Blast Prediction and Characteristics for Simulating the Response of Underground Structures, Proc. 3rd Int. Conf. of Southeast Asian on Natural Resources and Environmental Management, Universiti Malaysia Sabah, Malaysia, Aug. 5th - 6th. pp. 384-391.

18. Olarewaju, A. J., Kameswara Rao, N. S. V. and Mannan,M.A. (2011b). Dimensionless Response of Underground Pipes Due to Blast Loads Using Finite Element Method, EJGE: Journal of Geotech. Engng., (16/E), Oklahoma, United States of America, March, pp. 563-574.

19. Olarewaju, A. J., Kameswara Rao, N.S.V and Mannan, M.A., (2011c). Chapter Title: Response of Underground Pipes Due to Blast Loads, Book Title: Earthquake Research and Analysis / Book 4, ISBN 979-953-307-680-4, In-Tech Open Access Publisher,

University Campus STeP Ri, Slavka Krautzeka 83/A 51000 Rijeka, Croatia, Europe, (Accepted for Publication, in press)

20. Olarewaju, A. J , Kameswara Rao, N. S. V. and Mannan, M. A. (2010f). Design Hints for Buried Pipes to Resist Effects of Blast, Proc. Indian Geotech. Conf., Indian Institute of Technology, Mumbai, New Delhi: Macmillan Press, Dec. 16th - 18th, pp. 881-884.
21. Olarewaju, A. J , Kameswara Rao, N. S. V. and Mannan, M. A. (2010g). Guidelines for the Design of Buried Pipes to Resist Effects of Internal Explosion, Open Trench and Underground Blasts, EJGE: Journal of Geotech. Engng., (15/J), Oklahoma, United States of America, June, pp. 959-971.
22. Olarewaju, A. J , Kameswara Rao, N. S. V. and Mannan,M.A. (2010h). Response of Underground Pipes due to Blast Loads by Simulation–An Overview, EJGE: Journal of Geotech. Engng., (15/G), Oklahoma, United States of America, July, pp. 831-852.
23. Olarewaju, A. J , Kameswara Rao, N. S. V. and Mannan, M.A. (2011d). Response of Underground pipes due to Surface Blast Using Finite Element Method, Int. Soil Tillage Organisation (ISTRO) Nigeria Symposium, University of Ilorin, Ilorin, Nigeria, Feb. 21st - 24th, pp. 241-251.
24. Olarewaju, A. J , Kameswara Rao, N. S. V. and Mannan, M.A. (2010i). Response of Underground Pipes Due to Underground Blast, Proc. of the Int. Agricultural Engng. Conf., IAEC , Shanghai, China, Sept. 17th - 20th, pp. (I) 321-329.
25. Olarewaju, A. J., Kameswara Rao, N.S.V and Mannan, M.A., (2011e). Simulation and Verification of Blast Load Duration for Studying the Response of Underground Horizontal and Vertical Pipes Using Finite Element Method, Journal of Geotech. Engng., EJGE, Volume 16, Bundle G, April, ISSN 1089-3032, Oklahoma, United States of America, pp 785-796.
26. Olarewaju, A. J., Balogun, M. O. and Akinlolu, S. O. (2011). Suitability of Eggshell Stabilized Lateritic Soil as Subgrade Material for Road Construction. Journal of Geotech. Engng. (EJGE), ISSN 1089-3032, April, 16 (H), April, Oklahoma, United States of America, pp 899-908.
27. 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.
28. Robert, W. D. (2002). Geotechnical Earthquake Engineering Handbook, NY: McGraw-Hill.
29. Tay Soon Chuan, (1994). Design Guidelines for Water Supply Systems, Standards and Practice Committee, Malaysian Water Association (MWA).
30. 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.

© 2012 ejge