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ESTIMATION OF BLAST LOADS FOR STUDYING THE DYNAMIC EFFECTS OF COEFFCIENT OF FRICTION ON BURIED PIPES BY SIMULATION

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ABSTRACT

In the study of dynamic behavior of buried structures due to blast by simulation, ground media, structures, blast loads, etc. are required. In this study, different types of blast scenarios and blast loads for various explosives were considered using [10]. Consequently, ground movement parameters were estimated and blast load durations for studying the dynamic effects of coefficient of friction on buried pipes due to blast loads by simulation were estimated. Simulated models for ‘slip’ and ‘no-slip’ conditions were analyzed using explicit code in ABAQUS with ‘no-slip’ condition serving as control. Dimensional analysis was used to further process the results. From the results, it was observed that the ground shock parameters attenuate greatly in ground media as the distance increases. In addition, it was observed that duration of blast play a significant role in the behavior of buried structures while the observed parameters reduced at coefficient of friction of 0.8 compared to the conventional coefficient of friction for static analysis. Parameters thus determined would help in the dynamic behavior study of buried structures due to blast using numerical codes like ABAQUS. This is with a view to designing buried structures like pipes to resist the effects of blast. Consequently, the environmental risk and hazards caused by blasts would be greatly reduced.

Keywords: Blast, Buried, Coefficient of Friction, Simulation, Environment

1. INTRODUCTION

Buried structures and facilities such as basements, foundations, mall facilities, storage facilities, etc could be fully buried or partially buried and these can be any structures of diver’s shapes. Considering the severity of destruction due to blast; sufficient tremors could be created to damage substructures over a large area. At *138kpa* of blast wave, reinforced concrete structures will be leveled resulting to loss of lives and property, disruption in production, land degradation, air pollution, etc. Blast occurs from terrorist’s attacks, accidental explosion, wars, insurgent, nuclear reactors, accidental explosions from military formations, accumulation of explosive gases in pipes, etc. In view of these, there is need to estimate the blast load for the purpose of studying the dynamic behavior of simulated buried structures as well as the effects of coefficient of friction. The constituents of blast are basically the explosive, ground media, structural components as well as blast characteristics. In studying dynamic soil-structure interaction through modeling, experimental results are required in other to simulate the prevailing situations between all the constituent materials [8].

2. BACKGROUND STUDY

The analysis of soil-pipe interaction through modeling using numerical tools, it involves determination of variables such as pressure, displacement, strain stresses, etc around the pipe. Analytically according to [6] and [9], axial friction force is determined using this expression,

$$F = \mu(Wp2\gamma DH + Wp)(\frac{1}{12}) \qquad (1)$$

where F = axial friction force (N/mm), $\boldsymbol{\mu}$ = coefficient of friction between pipe and soil. $\boldsymbol{\gamma}$ = density of backfill soil (kg/m^3), D = outside diameter of pipe (m), H = depth of soil cover to top of pipe (m), W_p = weight of pipe and content (kg/m). The soil density and friction coefficient (under static loads) are obtained from soil tests.

In impact related problems such as blast, it requires solution to equation of motion and analytical method may not provide accurate solutions to all the required variables. This is due to the dynamic nature of the problem as well as the blast duration which is short (transient). The non-linearity of the response of underground pipes due to blast loads lies in the definition of material (in this study, the material is considered as linear, elastic, homogeneous and isotropic), contact problem definition (boundary conditions), large displacements and rotations due to large loads (non-linear geometry) and time increment to ensure stability [2]. These responses could be suitably and easily studied by direct simulation, i. e. modeling using a suitable finite element numerical code, in this case, ABAQUS.

Considering the dynamic behavior of buried structures, a lot of works have been done on dynamic soil-structure interaction majorly for linear, homogeneous, and semi-infinite half space either linear or nonlinear using analytical or numerical methods [5], [7]. In this paper, blast loads will be examined with a view to providing design parameters for the design of buried structures to resist the effects of blast loads in other to reduce environmental risk and hazards. From experience, the most common ways by which blast scenarios are expected to occur are: surface blast above the ground surface; open trench blast; underground blast below the ground surface with the explosives completely buried in the ground; and blast right inside the structures (whether the structure is buried in the ground or within the ground and the surface or on the ground surface).

According to [10], the violent release of energy from a detonation converts the explosive material into a very high pressure gas at very high temperatures. It is followed by pressure front associated with the high pressure gas which propagates radially into the surrounding atmosphere as a strong shock wave, driven and supported by the hot gases. This pressure increase or shock front travels radially from the source of explosion with a reducing shock velocity which is always in excess of the sonic velocity of the medium [8]. The shock front arrives at a given location at time (ms). After the rise to the peak value of over pressure, the incident pressure decays to the ambient value in time which is the positive duration. The negative phase with a duration which is usually longer than the positive phase and characterized by a negative pressure (usually below ambient pressure) have maximum values as well as reversal of the particle flow. The incident pulse density associated with the blast wave is the integrated area under the pressure-time curve.

3. METHODOLOGY

In this study, in line with [10], blast load parameters were determined. For verification of blast load duration and dynamic effects of coefficient of friction on buried pipes, the soil of 100 m by 100 m by 100 m deep and pipes materials of 1.0 m internal diameter, 20 mm and 100 mm thick were modeled as elastic, homogeneous and isotropic as shown in Figs. 1 and 2 using the two elastic constants as obtained from different researchers and pipe manufacturers [1], [2], [3], [4]. Simulated models for 'slip' and 'no-slip' conditions were analyzed using explicit code in ABAQUS with 'no-slip' condition serving as control. In the 'no-slip' condition, it was assumed that perfect bond exist between the pipes and the soil while for 'slip' condition, coefficient of friction were varied.

The governing dynamic equation of motion is given as:

$$[m]\,[\ddot{U}] + [c]\,[\mathring{U}] + [k]\,[U] = [P]; \quad \text{for } U\,(t = 0) = U_o, \text{ and } \mathring{U}\,(t = 0) = \mathring{U}_o = v_o \qquad (2)$$

where m, c, and k are element mass, damping and stiffness matrices, t is the time, U and P are displacement and load vectors and dots indicate their time derivatives [5]. The explicit dynamics analysis procedure in ABAQUS (finite element based numerical code) was used to solve eq. 2 [3]. The boundary conditions shown in the model (Fig. 3) were defined with respect to global Cartesian axes [2].

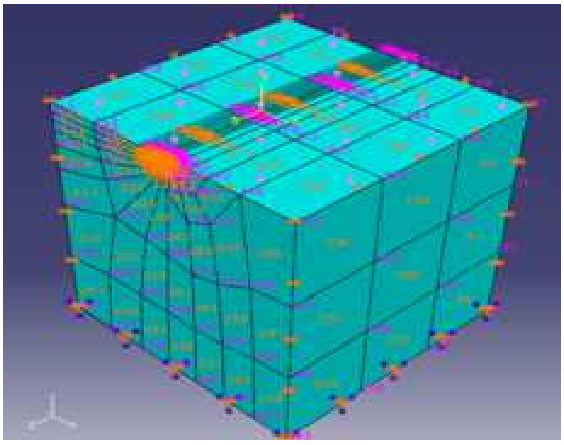

Fig. 1 Finite element model

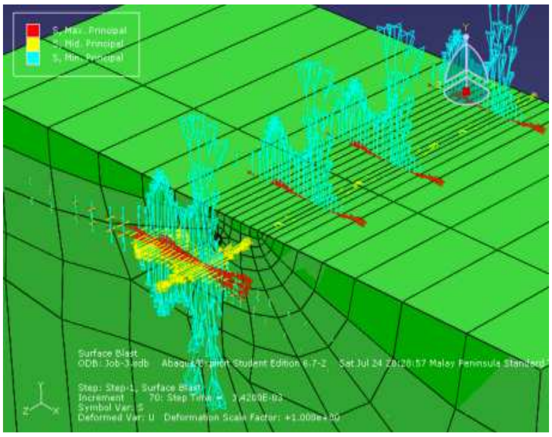

Fig. 2 Stress components in the finite element model

Dimensional analysis was used to analyze the results of the dynamic effects of coefficient of friction on buried pipes due to blast loads [4]. All the dimensions are power law monomials of the form

$$[\alpha] = K\,L^{a}\,M^{b}\,T^{c} \qquad (3)$$

where α is the dimension of a physical quantity which would have a dimensionless quantity ([α] = 1), K and (a, b, c) are constants. This property is called dimensional homogeneity which forms the key to dimensional analysis [4].

4. RESULTS AND DISCUSION

In the case of underground blast, ground shock parameters which are equally known as the soil movement parameters translate into loading which the soil delivers to the buried structures. These parameters depend on both the seismic velocity and peak particle velocity. For a totally or partially buried charge located at a distance from the structure, ground movement parameters determined for stand-off distances are shown in Figs. 3. In addition, the results of the peak side-on overpressure and peak reflected pressure for surface blast for explosives ranging from 500kg TNT to 10000kg TNT are presented in Figs. 4 and 5. Furthermore, displacement and pressure of pipes buried in loose sand, dense sand and undrained clay for various periods due to surface blast are presented in Figs. 6 and 7 respectively. The results of various observed response/behavior parameters at the crown, invert and spring-line of buried pipes against varied coefficient of friction due to blast are presented in Figs. 8 to 16. These results are further processed using dimensional analysis and the dimensionless responses at the crown, invert and spring-line of buried pipes are presented in Figs. 17 to 23.

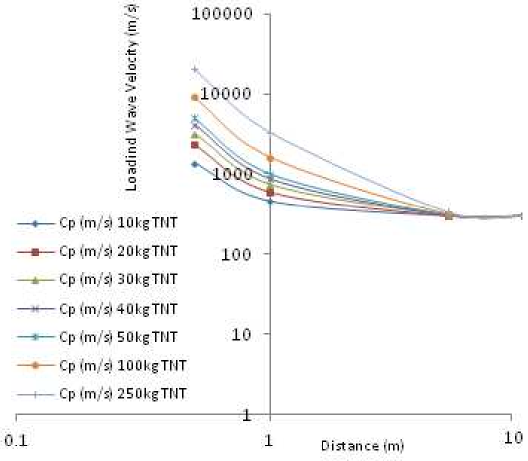

Fig. 3 Loading wave velocity against distance due to underground blast

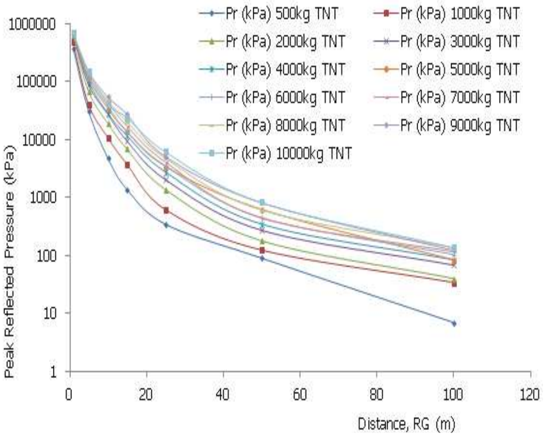

Fig. 4 Peak reflected pressure against distance due to surface blast

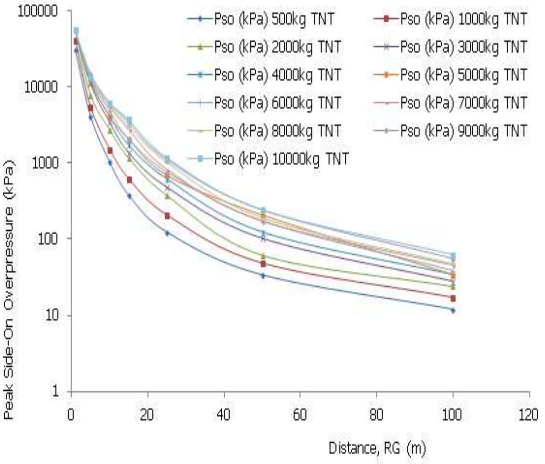

Fig. 5 Peak side-on overpressure against distance due to surface blast

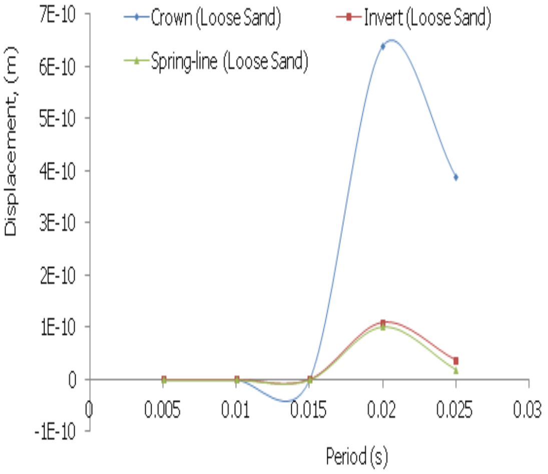

Fig. 6 Displacement against periods in pipes buried in loose sand

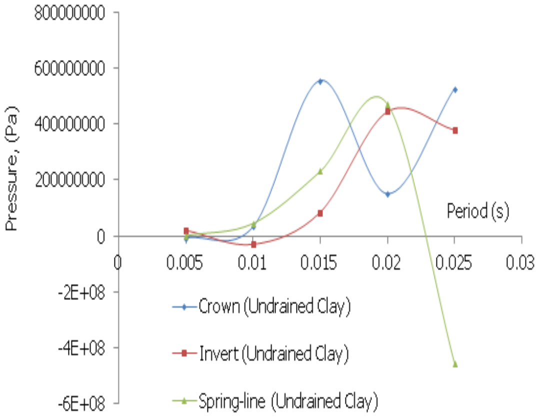

Fig. 7 Pressure against periods in pipes buried in undrained clay

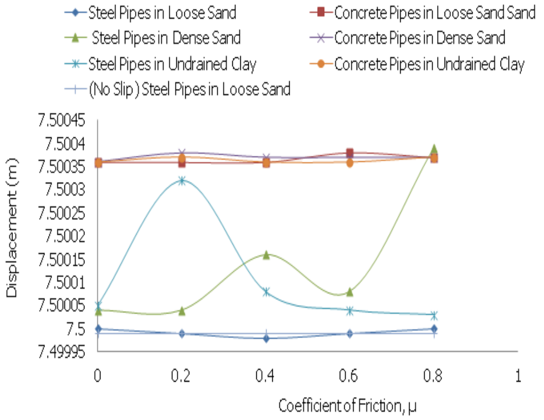

Fig. 8 Crown displacement against coefficient of friction due to blast loads

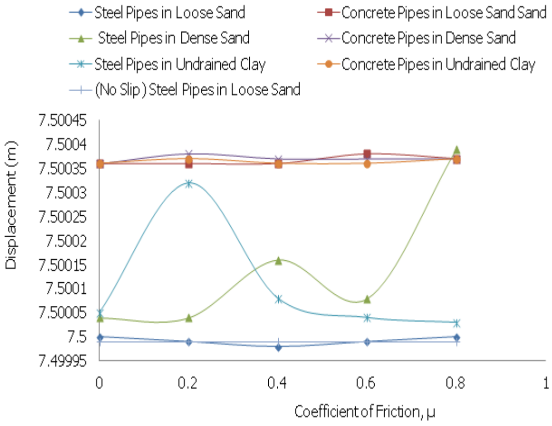

Fig. 9 Invert displacemnent against coeffificient of friction due to blast loads

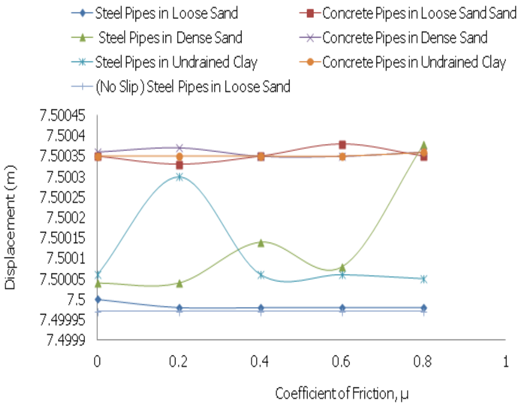

Fig. 10 Spring-line displacement against coefficient of friction due to blast loads

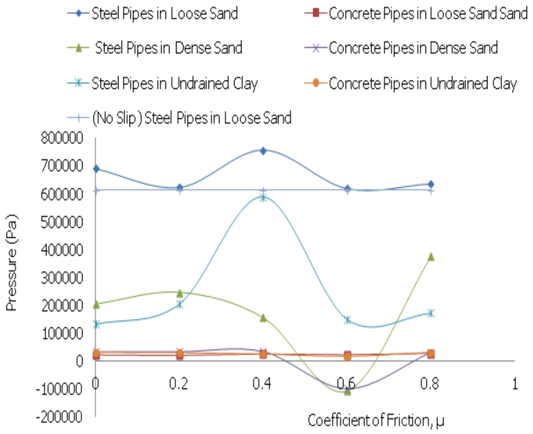

Fig. 11 Crown pressure against coefficient of friction due to blast loads

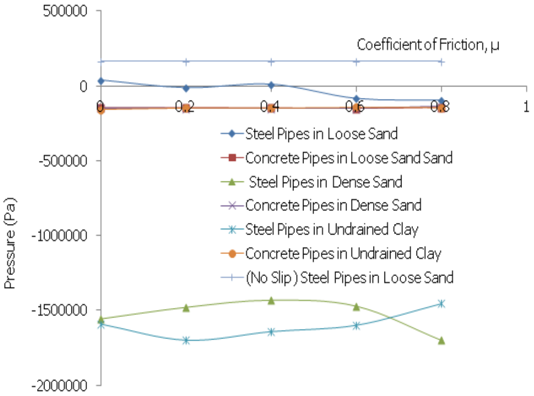

Fig. 12 Invert pressure against coefficient of friction due to blast loads

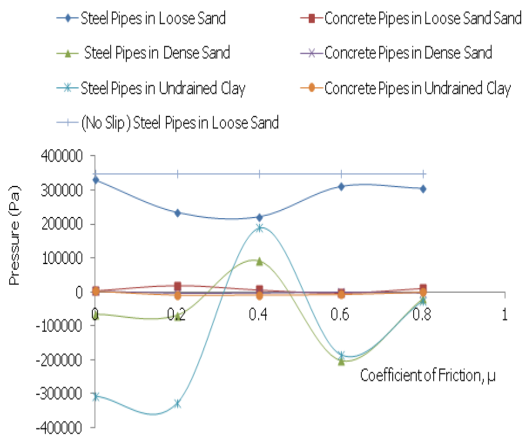

Fig. 13 Spring-line pressue against coefficient of friction due to blast loads

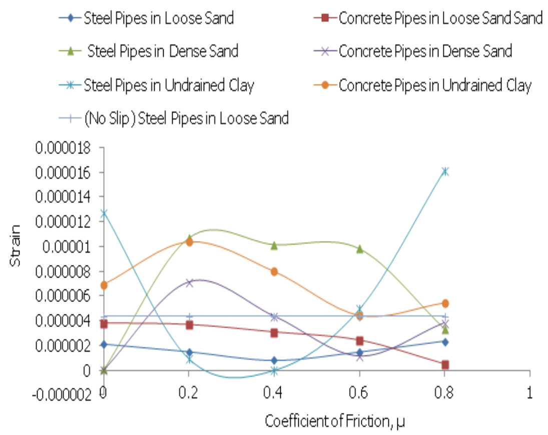

Fig. 14 Crown strain against coefficient of friction due to blast loads

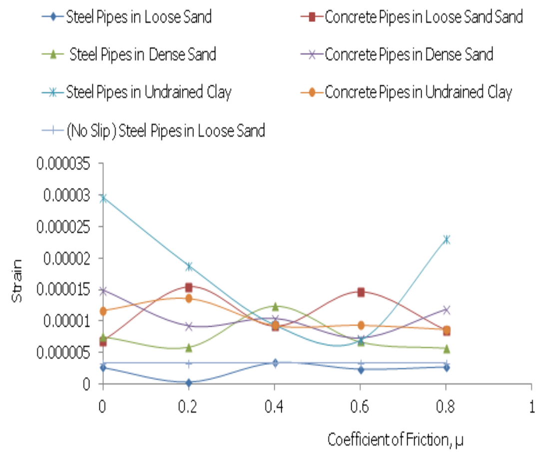

Fig. 15 Invert strain against coefficient of friction due to blast loads

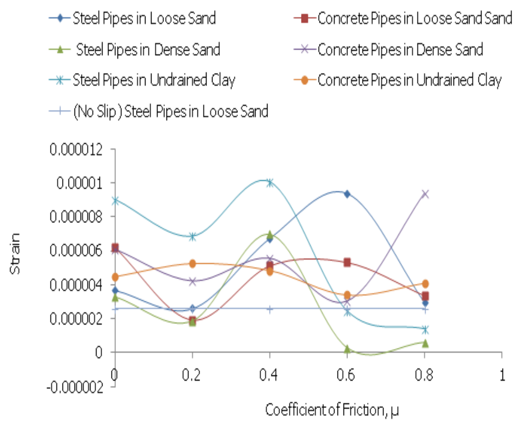

Fig. 16 Spring-line strain agains coefficient of friction due to blast loads

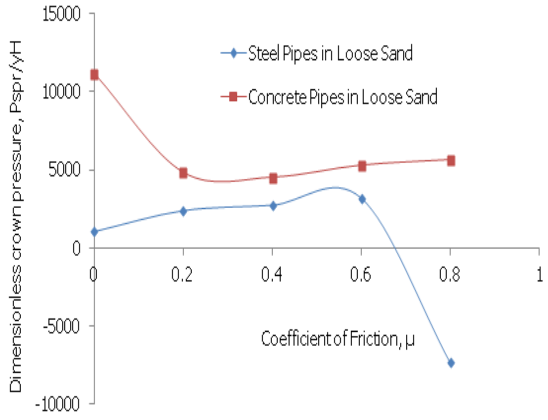

Fig. 17 Dimensionless spring-line pressure against coefficient of friction due to surface blast

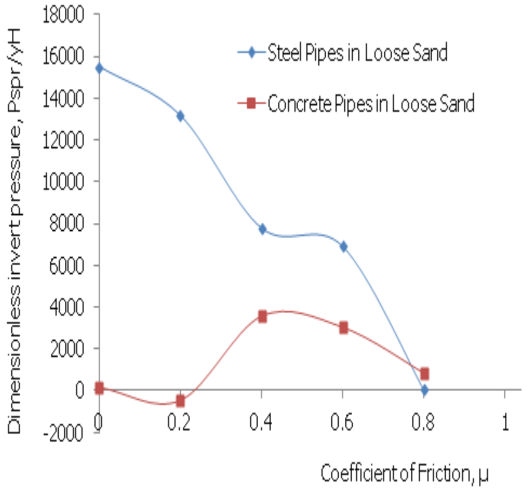

Fig. 18 Dimensionless spring-line pressure against coefficient of friction due to surface blast

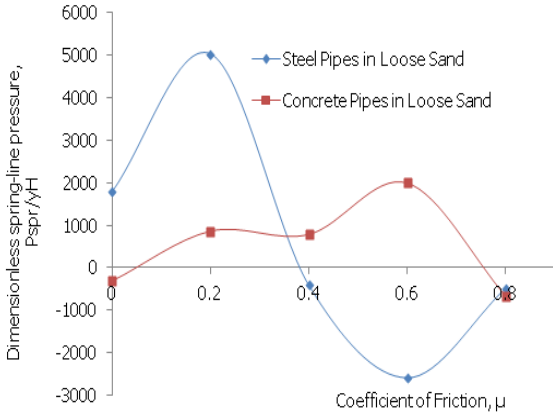

Fig. 19 Dimensionless spring-line pressure against coefficient of friction due to surface blast

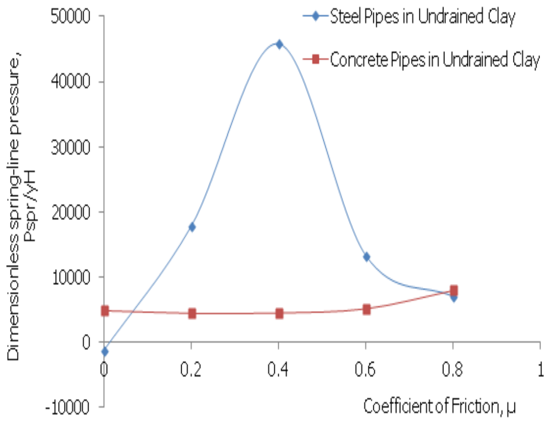

Fig. 20 Dimensionless spring line pressure against coefficient of friction due to surface blast

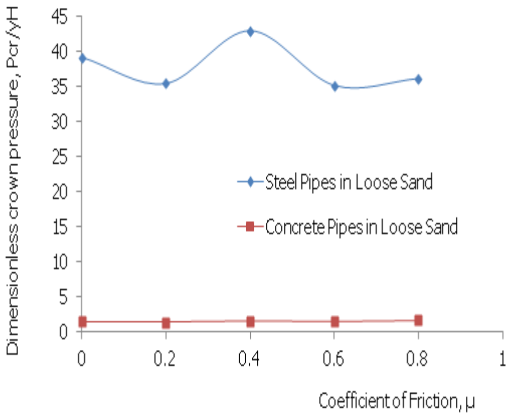

Fig. 21 Dimensionless crown pressure against coeffcient of friction due to underground blast

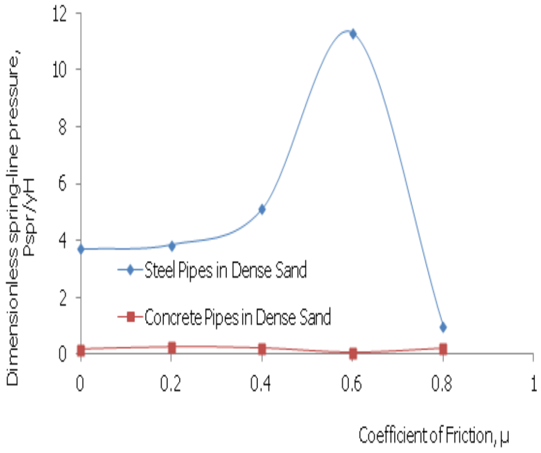

Fig. 22 Dimensionless spring-line pressure against coefficient of friction due to underground blast

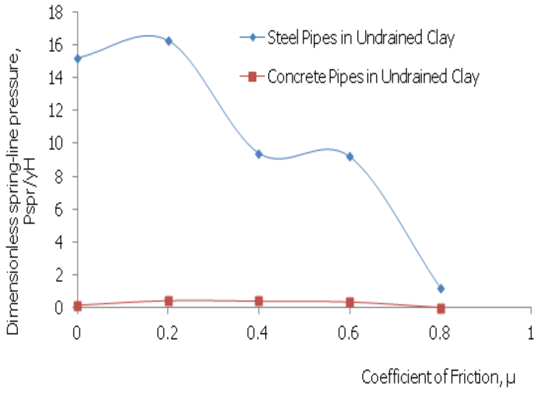

Fig. 23 Dimensionless spring-line pressure against coefficient of friction due to undetrground blast

It must be noted that P is the intensity of surface pressure, P (cr, inv and spr) are the crown, invert and spring-line pressure respectively, H is the cover depth while D is the diameter of pipe, x is the displacement at the crown, invert and spring-line of pipes, P is the surface pressure intensity, γ is the unit weight of soil and r is the radius of pipe (Figs. 17 to 23).

From Figs. 5 and 6, it was observed that energy attenuates greatly as the distances from the blast increases. In the case of underground blast, energy reduced to seismic velocity of the ground at less than 10m from the source of blast. Energy impulse from underground blast decreases as it travels for two main reasons, firstly, due to three dimensional dispersion of energy from blast, and secondly, due to work done in plastically deforming the soil matrix. Arrival time of blast wave depends on compression seismic velocity of the ground media. The arrival time is higher in saturated clay compared to other ground media. For the behavior of underground structures, especially pipes, arrival time of blast wave is the determining factor because it depends on the compression wave seismic velocity of soil. For structures above the ground surface, blast duration is the governing factor. In line with [10], the blast wave parameters for the direct induced ground shock are the overriding factor for designing and studying the behavior of underground structures. At short duration which is common to blast, for low blast pressure due to surface blast, there is no behavior (i.e. response) of underground pipes even at small depth of burial.

One of the major challenges in the prediction of blast loads and duration is the complexity and difficulty in identifying the exact location, points or heights where the explosion will take place for surface blast. However, this problem is overcome by the fact that for parameters and guidelines to be suggested, there must be behaviors of underground structures (in this case pipes) due to blast loads. Efforts is tailored towards arriving at specific blast loads parameters and duration that produce behaviors or responses on underground pipes. Even if these loads are increased, response will also increase as well. In [10], the side-on overpressure and peak reflected pressure in the range of 2500psi to 8000psi and 30000psi to 100000 psi respectively do not have duration specified in the chart. For these pressures, durations have to be specified. This is scaled distance in the range of 0.1 to 0.45 and this does not mean that there is no duration for such blast pressures at such scaled distances. However, judgment has to be applied, to adjudge duration to such events. For scaled distances of 0.45 to 1.3 and 2.5 to 6, durations are almost the same irrespective of charge weight considered. It was observed from Figs. 6 and 7 that at less than 5ms of surface blast load duration, there is little or no behavior of underground pipes. This is noticeable in loose sand compared to other ground media. But as the duration of blast load increases, behaviors also increase. Since there must be behaviors in underground structures in order to provide design parameters and guidelines, duration of blast to be used should not be less than 20ms. Conservatively, to study the behaviors of underground structures due to blast, duration of 25ms is adequate for ground media [8].

For the purpose of the estimation of blast loads for various blast scenarios mentioned earlier on, in the dynamic behavior study of underground structures using finite element based numerical codes, in order to convert blast parameters from 0% increase of charge weight to 10% increase of charge weight, the following could be used as multiplication factor: 1.108 could be used for vertical and horizontal displacement while 1.0472 could be used for both vertical velocity and horizontal velocity. In addition, 1.02982 could be used for both vertical and horizontal acceleration. To convert the same blast parameters as above from 0% increase of charge weight to 20% increase of charge weight specified by [10], 1.220 could be used for both vertical and horizontal displacement while 1.0936 could be used for both vertical velocity and horizontal velocity and 1.0595 could be used for both vertical and horizontal acceleration [8], [10.

From the results of the dimensionless responses of underground pipes shown in Figs. 17 to 23 obtained from Figs. 8 to 16 using dimensional analysis, it was observed that the observed parameters reduce at coefficient of friction of 0.8 for both surface and underground blasts. For all the ground media studied for the various categories of blasts considered in the dynamic analysis, in the design of underground pipes to resist effects of blast loads, coefficient of friction of average of 0.8 could be used. However, for practical applications for design purposes to resist effects of static loads, when test data are not available, the coefficient of friction of 0.3 (for Silt), 0.4 (for Sand) and 0.5 (for gravel) can be used. These coefficients of friction are the lower bound values equivalent to the sliding friction and static coefficient of friction can be as much as 70% higher than those stated above [6], [9].

4. CONCLUSION

This paper has highlighted the basic steps in the estimation of loads arising from blast for the purpose of simulating the dynamic effects of coefficient of friction on underground pipes. Blast phenomenon and various blast scenarios applicable to underground structures were also examined and various durations for studying the behaviors of underground structures due to blast were equally examined. Dynamic effects of coefficient of friction on buried pipes were studied and coefficients of friction of friction were equally varied. Finite difference method in ABAQUS numerical code [1] was used to solve the equation of motion throughout time and dimensional analysis was used to evaluate the results. Practicable coefficient of friction for practical applications in the design of buried pipes was suggested.

5. ACKNOWLEDGEMENTS

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