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Parametric studies of buried pipes using finite element analysis

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ABSTRACT: In this study, behaviour of buried pipes was investigated numerically by finite element methods. The effects of location and embedment ratio of pipes, properties of soil and surcharge effects were investigated. Based on the results, it can be concluded that the location and embedment ratio of pipes, surcharge loads and properties of sand are main parameters that affect the buried pipes. The results show that pipe rigidity is important item on pipe behaviour.

1 INTRODUCTION

Underground conduits have served to improve people’s living standards since the beginning of civilization. Underground conduits serve in diverse applications such as sewer lines, drain lines, water mains, telephone and electrical conduits, culverts, oil lines, coal slurry lines, subway tunnels, and heat distribution lines (Moser and Folkman 2008). The safety of buried pipes, as one of the most important urban facilities, under different loading conditions depends highly on the safe design and performance of these buried structures. This cannot be achieved unless their actual behaviour is well understood and their design is considered (Tafreshi and Khalaj 2008). In the last two decades, a lot of studies were performed in order to investigate soil-pipe interaction (Hurd 1986; Adams 1989; Webb 1996; Masada 2002; Suleiman 2003; Kawabata 2004; Sargand 2005).
Marston and Anderson (1913) developed a method for buried conduit and a theory for calculating diameter change was used by Spangler (1941). Rogers et al. (1995,1996) investigated the influence of the installation procedure on the subsequent performance of a buried flexible pipe. The results of tests examining four different installation conditions indicated that the pipe wall strain data correlated well with pipe displacement and the pipe wall displacement profile can be predicted from strain measurements with care. Brachman et al. (2000) designed a laboratory facility for evaluating the performance of small diameter pipes when buried under deep and extensive overburden material. They reported that reducing boundary friction to less than 5^o and limiting the boundary deformation to less than 1mm with a vertical surcharge of 1000 kPa provide a good idealization of field condition for a deeply buried pipe. Faragher et al. (2000) carried out a full-scale controlled field test to investigate the behaviour of embedded flexible pipes under repeated loadings in real installation conditions. It was observed that the vertical deformation of pipe increased rapidly during initial loading cycles while the rate of deformation reduced markedly as further cycles of loading were applied. Hosseini and Tafreshi (2002) presented a laboratory work on small-diameter thin steel pipes

subjected to repeated loads. They found that the soil density and the pipe embedded depth would be the most important factors affecting the soil–pipe interaction. Arockiasamy et al. (2006) performed field tests on polyethylene, PVC, and metallic large-diameter pipes subjected to highway design truck loading. The field test results indicated that the buried flexible pipes, embedded with highly compacted sand with silt, demonstrated good performance without exhibiting any visible joint opening or structural distress. In literature, there are a lot of studies investigating buried soil-pipe behaviour by using finite element method such as Bjeerrum et al. (1972), Abel and Mark (1973), Chang et al.(1980), Mada (2005), and Suleiman (2004).
In this study, behaviour of buried pipes was investigated numerically by finite element methods. The effects of location and embedment ratio of pipes, properties of soil and surcharge effects were investigated.

2 FINITE ELEMENT METHODS

In this study, the behavior of a buried non-pressure pipe with diameter of 1000mm was analyzed with finite element programs in different soil properties. The two-dimensional FEM models of pipe-soil interaction were performed by using computer program PLAXIS. In this study, Plaxis analyses are carried out to investigate effects of the embedment ratio of the pipe (H/D), the relative density of sand, the distance of the center of the surcharge loads to pipe (x), and the load intensity of surcharge (Q) on the behavior of the pipes. Investigated parameters are shown in Figure 1. An elasto-plastic hyperbolic model known as the Hardening Soil Model (HSM) was selected from those available in PLAXIS to describe the non-linear sand behavior in the study. The finite element model used in the simulation is shown in Figure 2. The pipes embedded at a depth H in cohesionless ground. The soil parameters of soil used in this investigation are selected from a study (Dickin and Laman, 2007) and shown in Table 1.

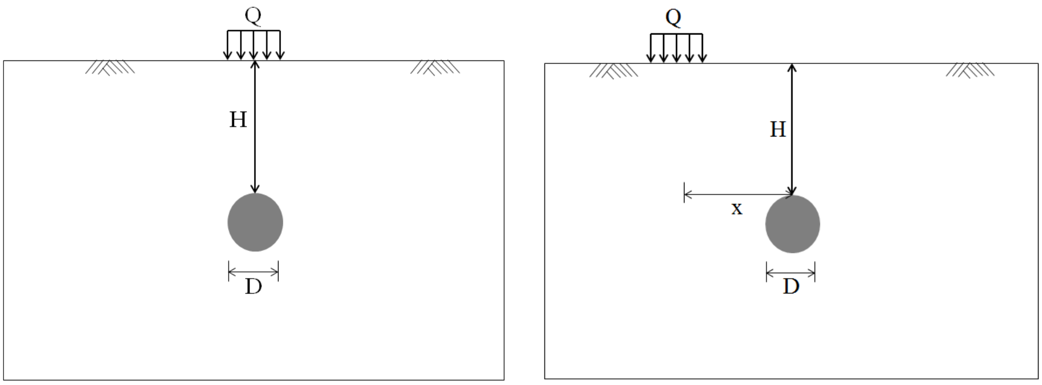

Figure 1. Investigated parameters and definition of the problem.

Table 1. Values of soil parameters used in PLAXIS analyses (Dickin and Laman, 2007)

Properties of sand	Loose sand	Dense sand
Unit weight , γ (kNm^{-3})	14.50	16.40
Secant stiffness, E_{50} (kNm^{-2})	5000	20000
Initial stiffness , E_{OED} (kNm^{-2})	5000	20000
Unloading/reloading stiffness, E_{UR} (kNm^{-2})	15000	60000
Cohesion ,c (Nm^{-2})	0	0
Friction angle, ϕ degrees	35	51
Dilatancy angle ,ψ degrees	0	20
Poisson's ratio ,ν	0.20	0.20
Power for stiffness stress dependency, m	0.65	0.50
At rest earth pressure coefficient, K_0	0.43	0.34

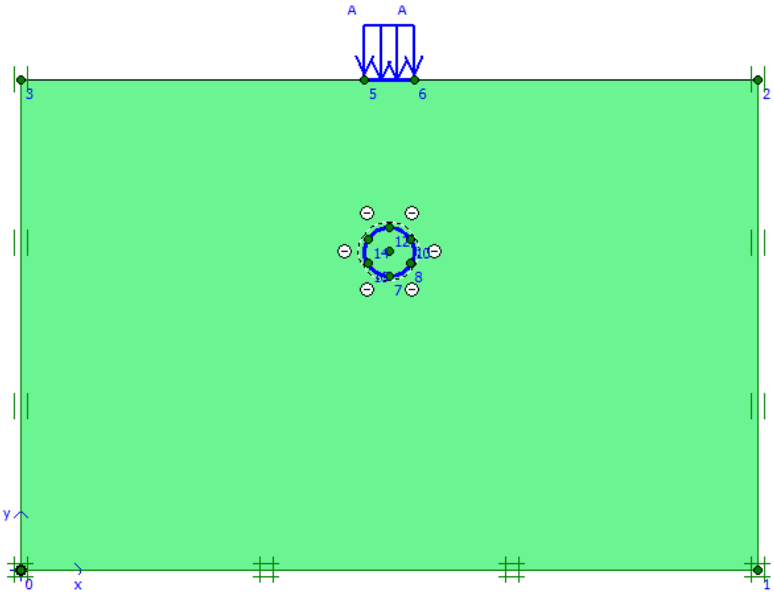

Figure 2. Finite element model of the problem.

Two pipe material types, concrete and polyethylene (PE), with significantly different moduli of elasticity, E, were considered in this study. The parameters of interest describing their response, namely, the Young's modulus, E, and Poisson's ratio, v, as well as the material unit weight, γ used for the various types considered are shown in Table 2. PLAXIS uses curved beam elements based on the Mindlin's theory (PLAXIS V8, 2002) to simulate a pipe. The input parameters for the beam elements are; Normal stiffness, EA, Flexural rigidity, EI, Equivalent thickness, d_{eq}, Weight, W and Poisson's ratio, v. The weight of the beam is not considered in this analysis. From the user manual of PLAXIS, the beam thickness d_{eq} is calculated from $d_{eq} = \sqrt{12\,EI/EA}$. As defined previously, the moment of inertia is $I=t^3/12$ for a solid pipe wall of unit length. The input parameters for each type of material corresponding to their diameters and D/t=0.10 ratios are shown in Table 2 (Bircan, 2010).

Table 2. Values of pipe parameters used in PLAXIS analyses

Parameters	Concrete Pipe	Polyethylene Pipe
Unit weight , γ (kNm^{-3})	25.00	19.00
Normal stiffness, EA (kN/m)	$2x10^6$	10^5
Flexural rigidity , EI (kNm^2/m)	1666.67	83.33
Equivalent thickness, d_{eq} (m)	0.100	0.100
Weight, W (kNm^{-2})	0	0
Poisson's ratio ,ν	0.15	0.45

3 RESULTS

In this part, finite element results are presented. Numerical analyses are carried out to investigate the effect of surcharge load, relative density of sand, rigidity of pipe and pipe location to surcharge load. The results are compared using displacement and stress criteria.

3.1 EFFECT OF EMBEDMENT RATIO AND INTENSITY OF SURCHARGE LOAD

The effect of embedment ratio and intensity of surcharge load are investigated using finite element methods. Figure 3 shows a relation between the intensity of surcharge load-displacement curves and it can be explained that pipe displacements increase linear with increase in surcharge load. The results show that intensity of surcharge load affect the pipe behavior mainly.

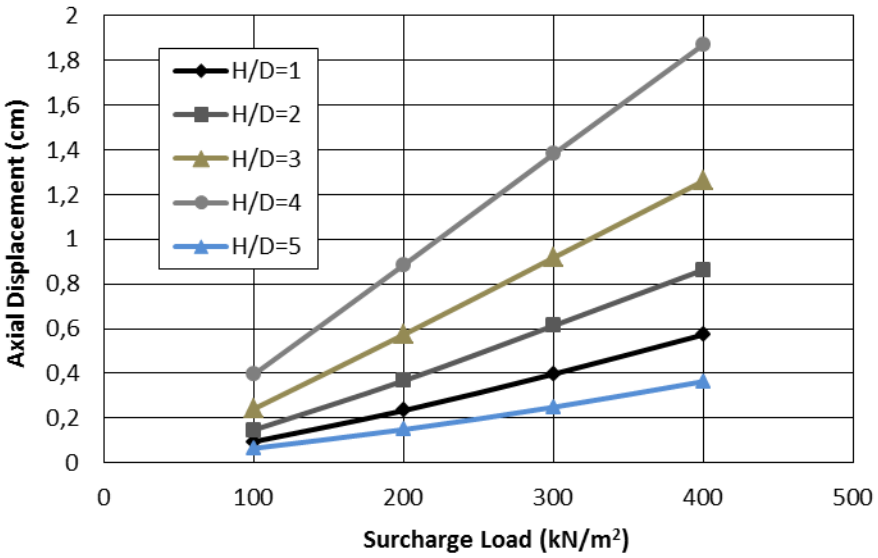

Figure 3. Pipe displacement-surcharge load behavior (Dense sand and concrete pipe).

The results show that pipe displacements decrease with increase on embedment ratio. Figure 4 shows a relation between vertical stress-embedment ratio curves and the results show vertical stress decrease with increase on embedment ratio. The variation of vertical stress with embedment ratio from the PLAXIS analyses showed generally similar behavior with Boussinesq theory (Boussinesq, 1885). This decrease in the pipe displacement can be explained with stress-displacement behavior. The pipe displacements decrease with decrease on stress on pipe.

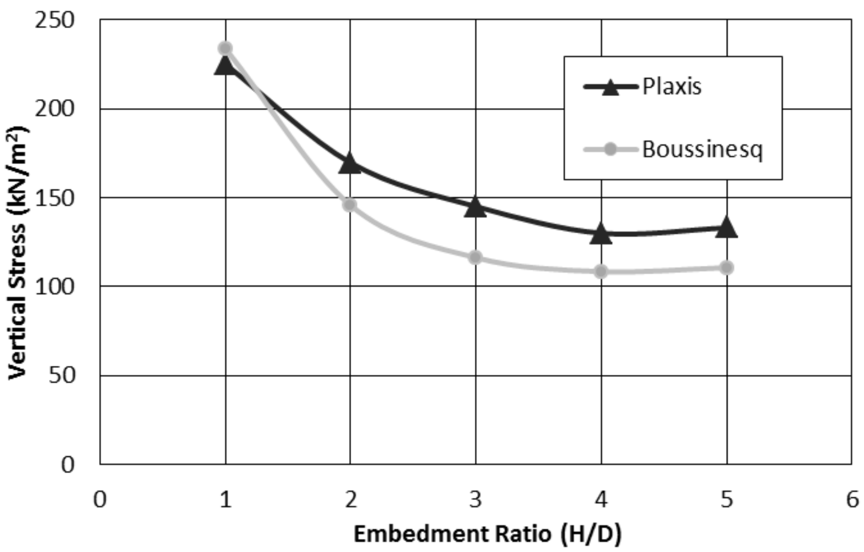

Figure 4. Vertical stress-embedment ratio behavior (Dense sand, concrete pipe and Q=400 kNm/m^2).

3.2 EFFECT OF RELATIVE DENSITY

The effect of relative density is investigated at two surcharge load and two densities. Figure 5 shows relative density effects on pipe axial displacement. The results show that pipe displacement is strongly influenced by the relative density of sand. The pipe displacement at loose sand condition is nearly 9 times bigger than dense sand conditions for H/D=1. This ratio decreases to 6.5 times for H/D=5.

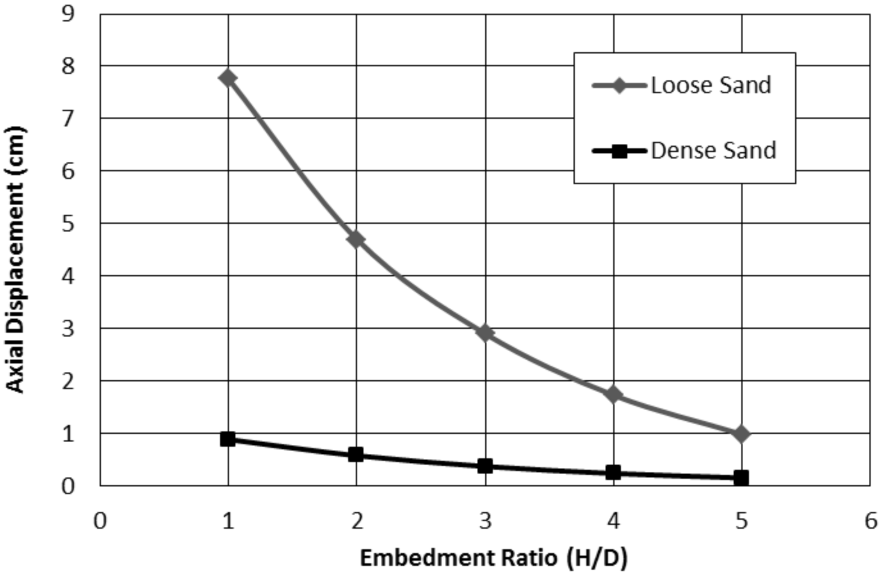

Figure 5. The effect of relative density of sand (Q=200 kNm/m^2 and concrete pipe).

3.3 EFFECT OF PIPE RIGIDITY

In the study, effect of pipe rigidity is investigated and used two materials for modeling the problem. The properties of pipe materials are shown in Table 2. The results show that pipe displacements decrease with increase on rigidity of pipe. Figure 6 shows that the concrete pipe displacements are less than PE pipes.

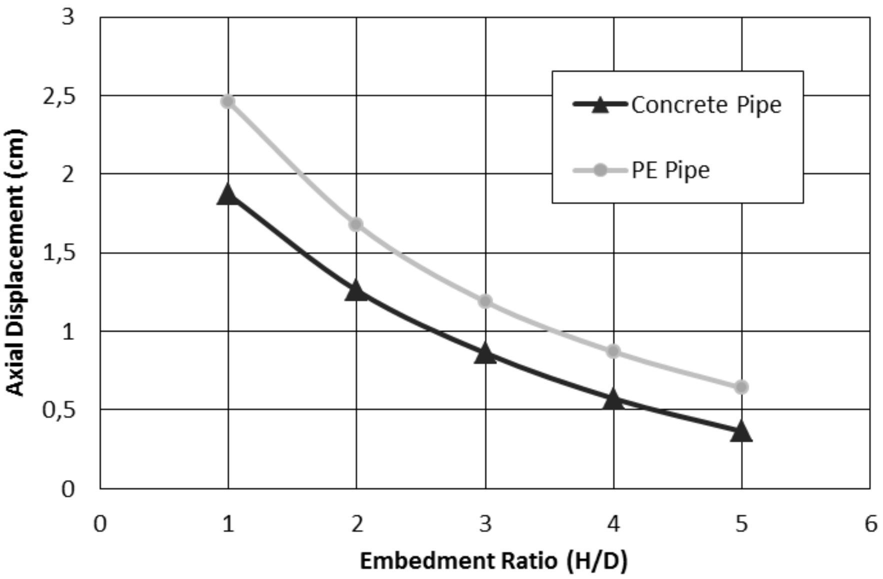

Figure 6. The effect of rigidity of pipe (Q=400 kNm/m^2 and dense sand).

3.4 EFFECTS OF LOAD LOCATION

Figure 7 shows a relation between the location of surcharge load-displacement curves for PE and concrete pipes. The results show that pipe displacement decrease with increase on distance of pipe. The maximum displacement conditions occurred at load on the center of the pipe.

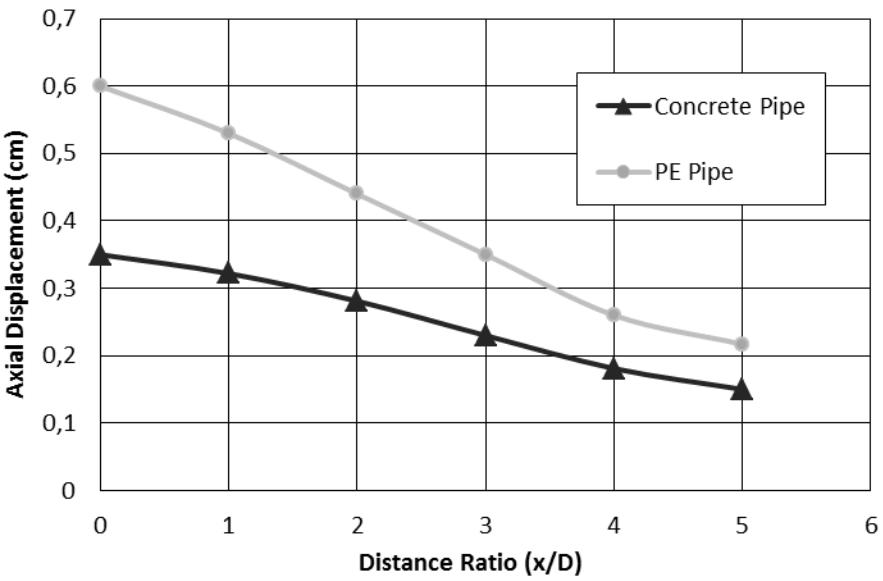

Figure 7. The effect of load location (Q=400 kNm/m^2 and dense sand).

4 CONCLUSIONS

In this study, buried pipe behavior is investigated by finite element method. The undertaken analyses have been done with different surcharges and different soil conditions. Based on the results, the following main conclusions can be drawn:

- The intensity of surcharge load affect pipe behaviour. The pipe displacements increase linearly with increase in surcharge load.
- The results show that pipe displacements decrease with increase on embedment ratio. This behaviour can be explained using stress-displacement behaviour. The vertical stress decrease with increase on embedment ratio. The variation of vertical stress with embedment ratio from the PLAXIS analyses showed generally similar behaviour with Boussinesq theory.
- The pipe behavior is strongly influenced by the relative density of sand. The pipe displacements decrease with increase on relative density of sand.
- The results show that pipe displacements decrease with increase on rigidity of pipe and the concrete pipe displacements are less than PE pipes.

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