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EXPERIMENTAL STUDY ON THE EFFECT OF EMBEDMENT DEPTH OF BURIED FLEXIBLE PIPE SUBJECTED TO STATIC LOAD

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ABSTRACT

The experimental work of this study deals with the problem of buried UPVC pipe in sand with different pipe responses subjected to incremental static loading where the backfill densities changed (loose, medium, and dense with different burial depth (1.5 d,2 d, and 3d). The objectives of the current study are to study the effect of changing the buried depth on the behavior of a buried flexible pipe in a sand soil through experimental model.

It was found that the effect of the applied surface load on the crown strain is reduced by increasing the burial depth by about 19.6% when the embedment depth changes from 1.5 d to 2 d and 29.4% when it changes from 1.5 d to 3 d in loose sand. While these percents become to 13.1% and 32.2% in the medium sand and to 21.4% and 40% in the dense sand. It is concluded from these results that the increase in the depth of burial and sand density sponsor by reducing the strain on the perimeter of the pipe and thus the pipe is protected from the distortions that lead to breakage the pipe.

INTRODUCTION

The behavior of underground structures is usually complicated in comparison with super structures. This is mainly due to the soil-structure interaction, which in many cases can hardly be predicted. Among the underground structures, lifelines are of great importance and sensitivity because they are quite spread in the urban areas and serve the vital needs of the societies. Although different codes and provisions are suggested for the safe design of lifelines, the so designed and constructed lifelines could not escape damaging when subjected to severe loadings particularly strong blasts or earthquakes.

In spite of extensive theoretical studies which have been carried out to model the soil-pipe interaction, leading to many mathematical relations and empirical equations, most of them present shortcomings in considering the actual response of the pipe against the soil and vice versa.

One of the common ways to get actual information involving soil-pipe interaction is to develop a physical model capable of providing different conditions. The main parameters associated with the field behavior of the pipe can then be studied and measured somewhat accurately.

PVC (Poly Vinel Chloride) pipes are classified as flexible pipes. They flex without breaking when loaded externally from soil weight and vehicular traffic. When a PVC pipe encounters external loading, its diameter will begin to deflect, meaning its sides will move outward and slightly downward as shown in Figure (1). If the pipe is buried in supportive soil, the stiffness of the soil will resist the deflection. This action and reaction is the key to how a PVC pipe carries external loads (Eagle, 2009).

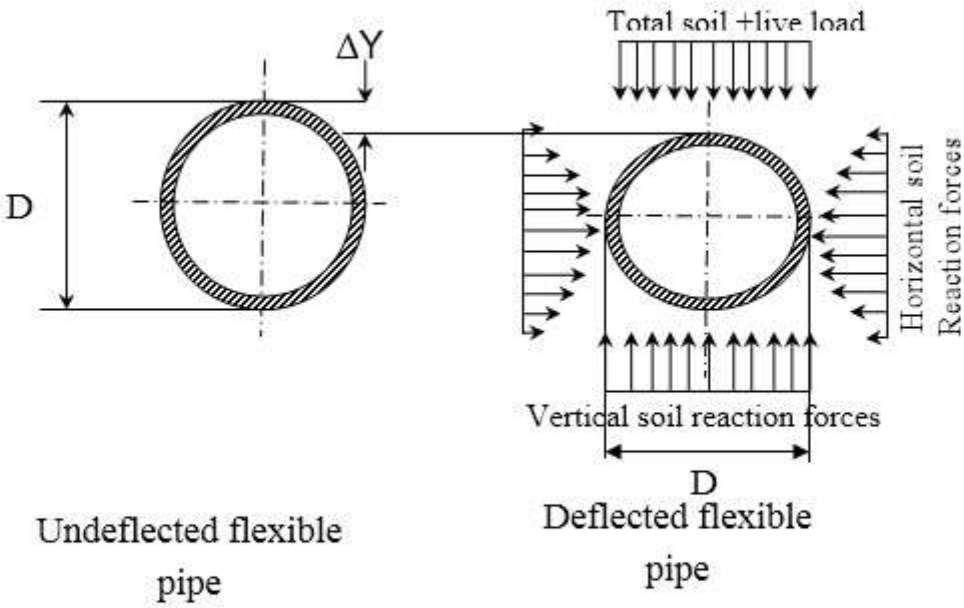

Figure 1: Flexible pipe deflection (Eagle, 2009).

The combination of the embedment soil stiffened and the pipe stiffness form a system that acts to support external loads. By itself, the pipe may not support much weight, but the soil/pipe system can have tremendous load capacity a PVC pipe's resistance to deflection in an unburied state is measured by its "pipe stiffness". Pipe stiffness is usually less significant than soil stiffness in PVC pipe installations, but in general, a higher pipe stiffness results in a higher load capacity. Soil stiffness is most affected by the level of compaction achieved, and to a lesser extent by the soil type

Because PVC pipe flexes rather than breaks when loaded, the failure criterion is not fracture strength. Instead, a limit is placed on pipe diametric deflection. This limit is expressed in terms of percentage reduction in diameter due to external loading. Industry recommendations for maximum deflection are (5-
7.5) %.

A "failure" of a flexible pipe system from external loading is defined by the point at which the top of the pipe begins to experience inverse curvature. Previous researches have shown this point occurs at a minimum of 30% deflection. The pipe deflection can be estimated by the use of "Iowa Equation". A simplified version of the equation is presented below:
Modified Iowa Equation (Eagle, 2009).

$$\%\ \text{Deflection} = \frac{0.1\,(W+P)100}{0.149\,(PS) + 0.061\,E'} \qquad (1)$$

Where:
% Deflection = predicted percentage of diametric deflection,
W = Live load (lb/in^2) pressure transmitted to the pipe from traffic on the ground surface,
P = Prism load (lb/in2) pressure acting on the pipe from the weight of the soil column above the pipe,
PS = Pipe stiffness (lb/in^2) a flexible pipe's resistance to deflection in an unburied state, and
E' = Modulus of soil reaction (lb/in^2) stiffness of the embedment soil.

Kim and Santammarina, (2008) investigated the small strain and zero-lateral strain responses of mixtures of small rigid sand particle sand largest of rubber particles. Their results showed that the sand skeleton controls the mixtures response when the volume fraction of rubber particles is less than 0.3, while the rubber skeleton prevails for volume fraction of rubber particles greater than 0.6. For this reason, they investigated proportions of rubber between 0 and 20% by mass, representing a maximum of 54% by volume, thus covering the range of use fullness identified by (Kim and Santamarina, 2008). Although other researchers have studied the stress-deformation and small strain shear-wave characteristics of rubbers and particle mixtures (Lee et al., 2010) and the potential use of rubber as insulating backfill material for buried pipelines (Christ et al., 2010), but there is a lack of investigation into the protection of buried pipes by use both of geocell reinforcement and waste rubber.

Moghaddas Tafreshi and Dawson, (2010) studied the performance of strip footing supported on 3D and planar geotextile-reinforced sand beds under a combination of static and repeated loads. On the whole, the results indicated that, for the same mass of geotextile material used in the tests, the 3D geotextile reinforcement system behaved more effectively than planar reinforcement as a retardant for the effects of dynamic loading. Despite such research on the beneficial usage of geocell reinforcement in ground improvement, there is little literature studying the behavior of pipe lines buried under soil supported by geocell inclusions.

The present study aims at determination of the effect of burial pipe depth on stresses and strains developed around the pipe.

EXPERIMENTAL WORK

Soil used

A suitable soil was supplied to the laboratory which is representative of the soils associated with buried pipelines. Routine soil tests were carried out to characterize its properties. The properties of sand used through experimentation are listed in Table 1.

Table 1: Properties of the used sand.

Index Property	Standards	Value
Specific gravity(Gs)	ASTM D-854	2.68
D_{10} (mm)		0.05
D_{30} (mm)		0.26
D_{60} (mm)		0.46
Coefficient of uniformity (Cu)		9.2
Coefficient of curvature (Cc)		2.94
Maximum dry unit weight (kN/m^3)	ASTM D 4253-00	18.47 kN/m^3
Minimum dry unit weight (kN/m^3)	ASTM D 4254-93	14.4 kN/m^3
Maximum void ratio		0.73
Minimum void ratio		0.485
Soil Classification according to (USCS)	ASTM D 422-07	SW
Friction angle	ASTM D 3080-07	Loose State: □ $=33^0$ c=0
Friction angle	ASTM D 3080-07	Medium State: □ $= 36^0$, c = 0
Friction angle	ASTM D 3080-7	Dense State: □ $=39^0$ c = 0

- Pipe

The pipe has an outer diameter of 110 mm and a wall thickness of 4 mm (Figure 2). The length of the pipe was selected to be 750 mm. The tensile strength at 10% axial strain of the pipe were 21 MPa.

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Figure 2: The pipes with strain gauges used in experiments.

Description of Experimental Apparatus

A testing tank given in Figure 3 was designed as a rigid steel box, 1200 mm in length, 1000 mm in width, and 1000 mm in height encompassing the soil and model pipe. The vertical surcharge stresses from the weight of the backfill material could be simulated by applying a uniformly distributed pressure at the surface of the backfill in the soil box test cell. A hydraulic jack system is used in this study to apply the axial load as shown in Figure 3. At the right column of frame, a manual system is fixed to control hydraulic intensity. Plastic tube is used to pump the hydraulic oil from the manual system to the piston. Abreaction system is used to expel the air from the hydraulic.

A special data acquisition system was developed by which all strains could be read and recorded automatically as shown in Figure 4 (for static tests). The system is able to read the data from eight channels simultaneously. Three contact pressure transducers were used to scan the normal and shear stresses on the base and sides of the pipe. A special displacement transducer was developed to detect the surface settlement as. A load cell was also placed in the loading shaft to detect the pattern of the applied loads on the footing surface accurately.

Figure 3: The soil box and frame used in static test.

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Figure 4: Data acquisition system.

RESULTS AND DISCUSSION

Effect of Embedment Depth of the Pipe on the Crown Strain

Figures 5 to 7 show the effect of the embedment depth of the pipe (h) on the crown strain, the embedment depth was 1.5d, 2d and 3d, respectively where d is the diameter of the pipe. It can be seen from these figures that the effect of the applied surface load on the crown strain is reduced by increasing the burial depth by about 19.6% when the embedment depth changes from 1.5 d to 2 d and 29.4% when it changes from 1.5 d to 3 d in loose sand. While these percents become to 13.1% and 32.2% in the medium sand and to 21.4% and 40% in the dense sand.

This decrease in the pipe strain as the burial depth increases can be explained with the stress- strain behavior. The pipe deformations decrease with decrease of stress on pipe. These results are compatible with those obtained by Bildik et al. (2012) who studied the effect of different parameters on the performance of buried pipe, their results showed that the pipe deformation decreases with increase on embedment ratio. Based on these percents, it can concluded that the best conditions to reduce the pipe crown strain are when the sand is dense and the burial depth is equal to 3d.

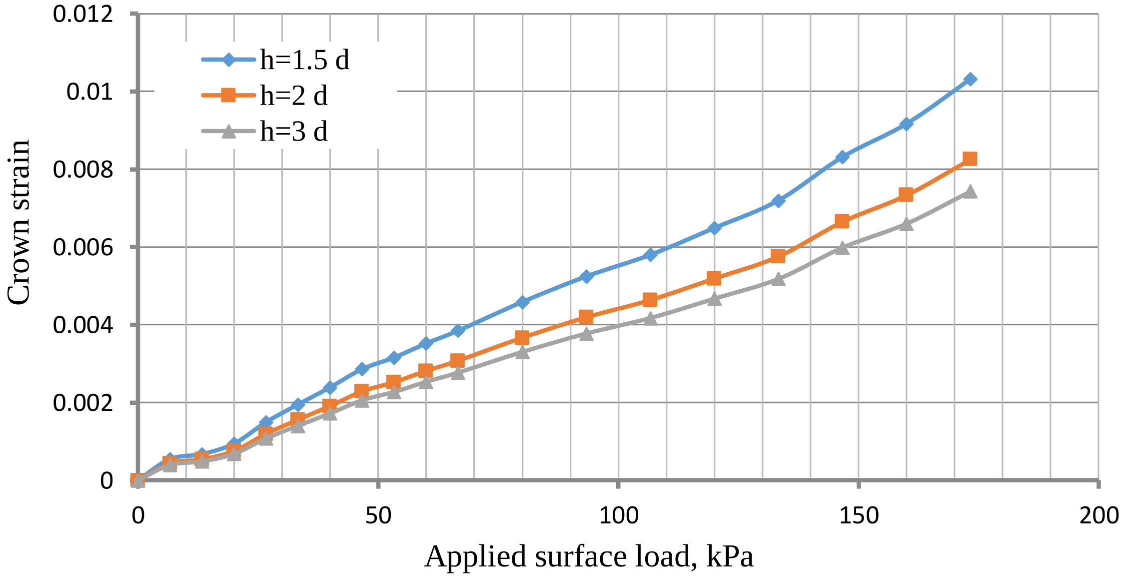

Figure 5: Effect of embedment depth of the pipe on the crown strain in loose sand.

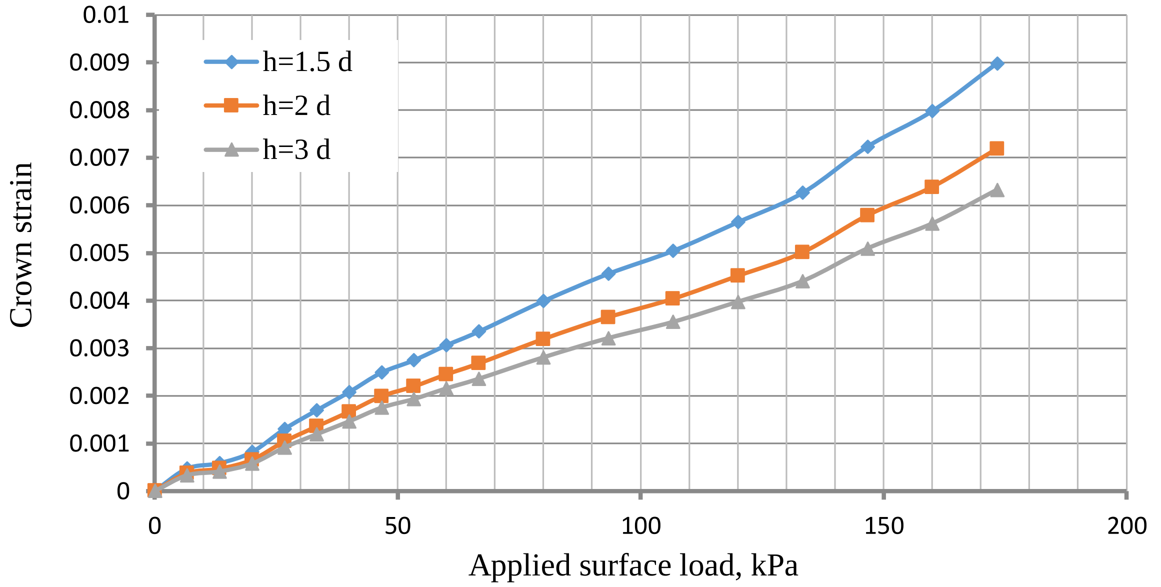

Figure 6: Effect of embedment depth of the pipe on the crown strain in medium sand.

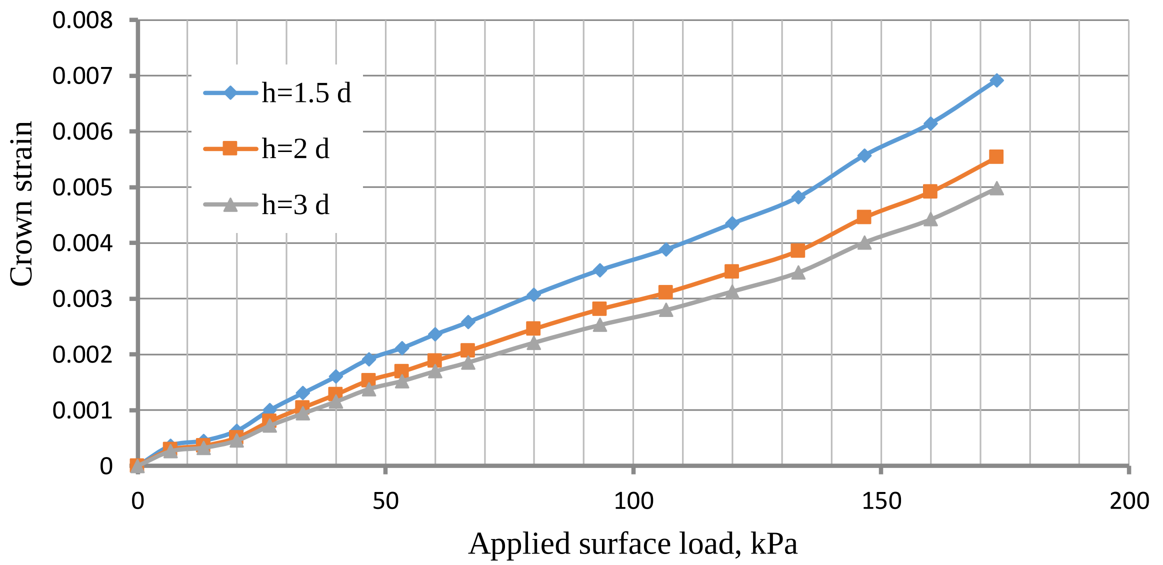

Figure 7: Effect of embedment depth of the pipe on the crown strain in dense sand.

Effect of Embedment Depth on the Invert Strain

Generally, the invert strain reduces as the burial depth increases. This is due to the effects of overburden pressure. This means that in the shallow burial depth, the poorer performance of the pipe is maintained, while great embedment can improve pipe performance. This is compatible with previous studies (e.g. Mir Mohammed Husseini, and Mogaddas Tafreshi, 2002, Bildik et al., 2012 , Moghaddas Tafteshi and Dwson, 2012.)

It can be shown from Figures 8 to 10 that the effect of burial depth (h) on the invert strain of the pipe is clear, it is obviously noticed that when the burial depth of the pipe increases, the invert strain decreases but in less percent

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of decreasing of the crown strain; it is found that the invert strain is approximately 22.4% lesser than the crown strain due to the restriction of the stiff bedded soil.

It can be seen from these figures that the invert strain is reduced by increasing the burial depth by about 19.2% when the embedment depth changes from 1.5 d to 2 d and 30.7% when it changes from 1.5 d to 3 d in loose sand. While these percents become to 22.2% and 33.3 % in the medium sand and changes to 12.7 % and 28.9 % in the dense sand.

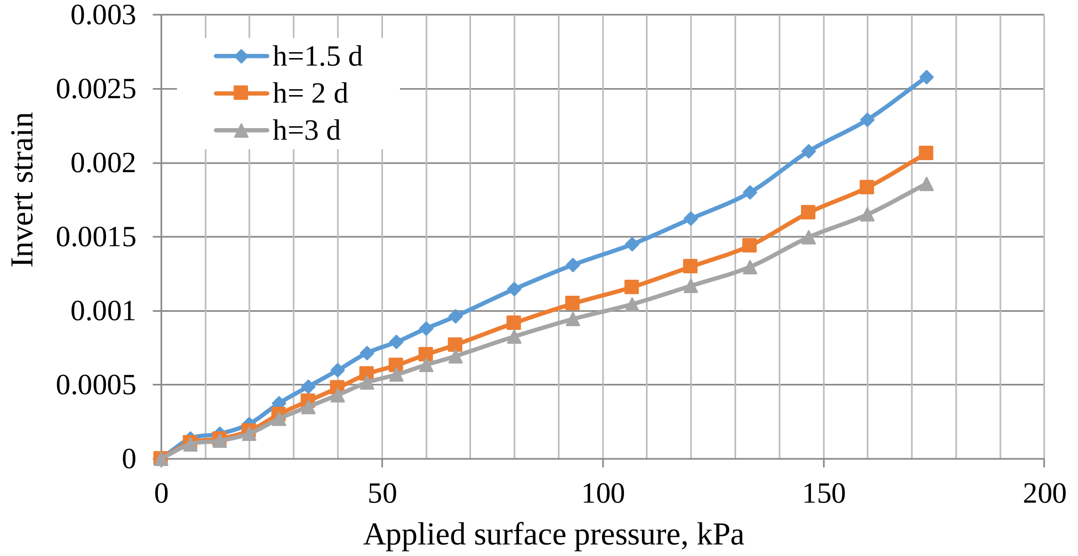

Figure 8: Effect of embedment depth of the pipe on the invert strain in loose sand.

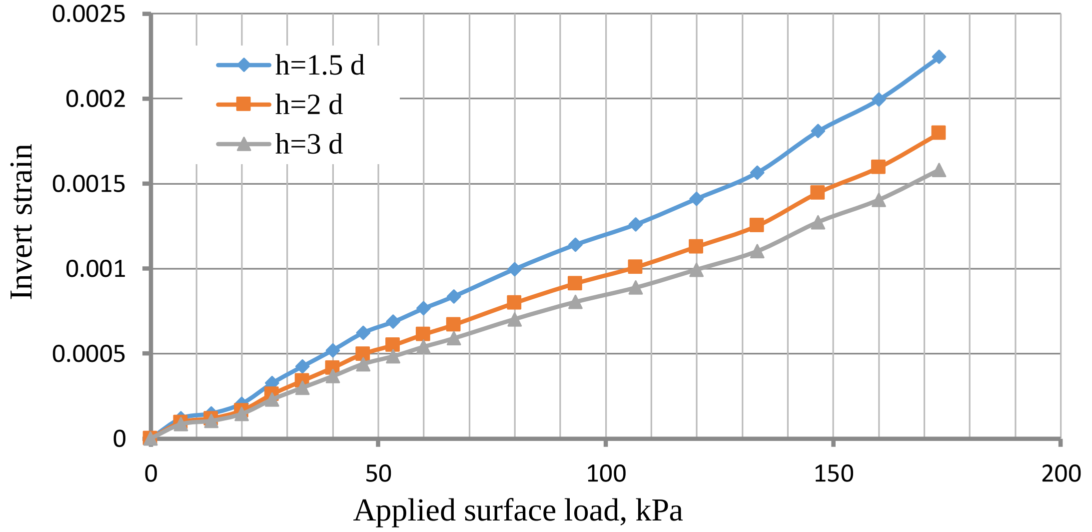

Figure 9: Effect of embedment depth on the invert strain in medium sand.

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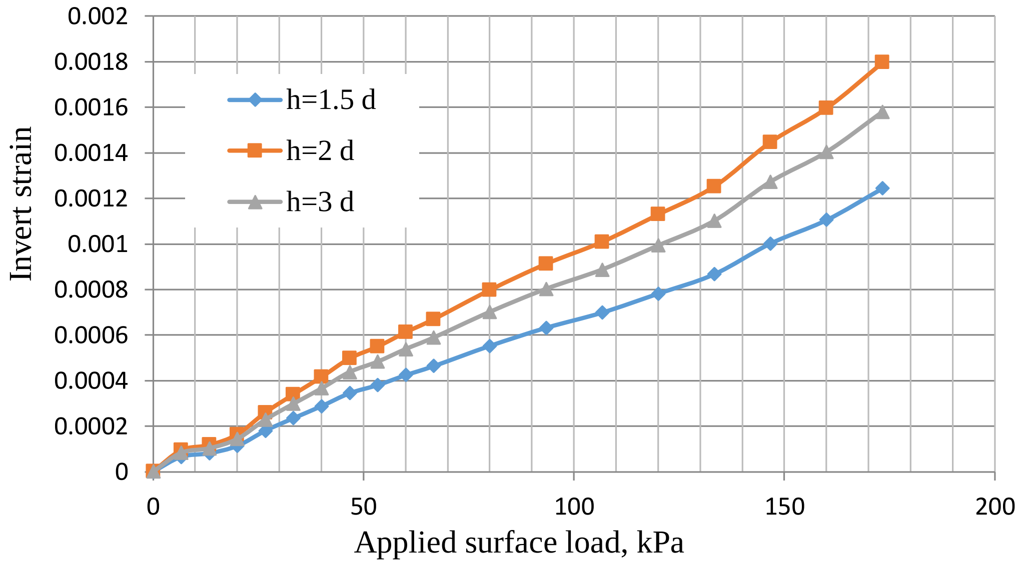

Figure 10: Effect of embedment depth on the invert strain in dense sand.

Effect of Embedment Depth on the Springline Strain

Figures 11 to 13 present the effect of the burial depth of the pipe on the side strain in the pipe (spring line strain) in loose, medium and dense sand, respectively. It can be noticed that the spring line strain decreases by about 30% when the embedment depth of the pipe increases from 1.5 d to 2 d and 38 % when it increases from 1.5 d to 3 d, respectively when the pipe is buried in loose sand. While these percents become 28.8% and 33.3% when the pipe is buried in medium sand and 28.6% and 37.1 when it is buried in dense sand, respectively. It is concluded from these results that the increase in the depth of burial and sand density sponsor by reducing the strain on the perimeter of the pipe and thus the pipe is protected from the distortions that lead to breakage the pipe.

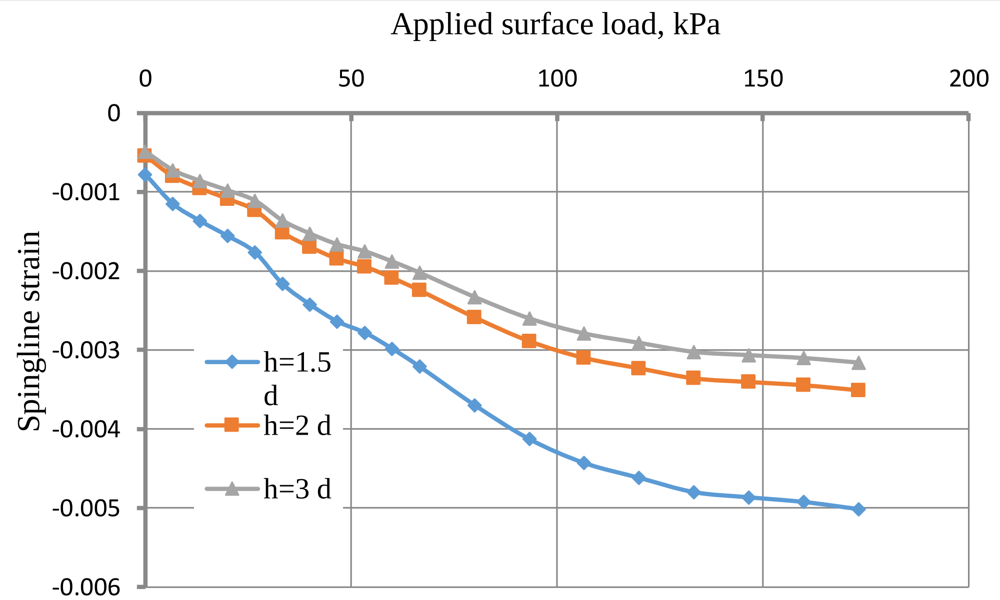

Figure 11: Effect of embedment depth of the pipe on the springline strain in loose sand.

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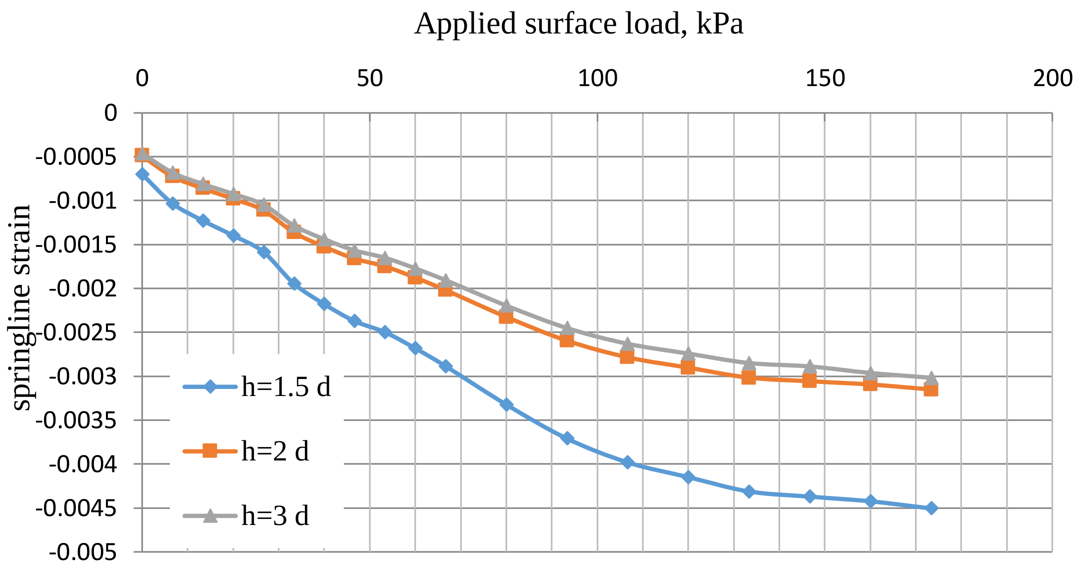

Figure 12: Effect of embedment depth of the pipe on the springline strain in medium sand.

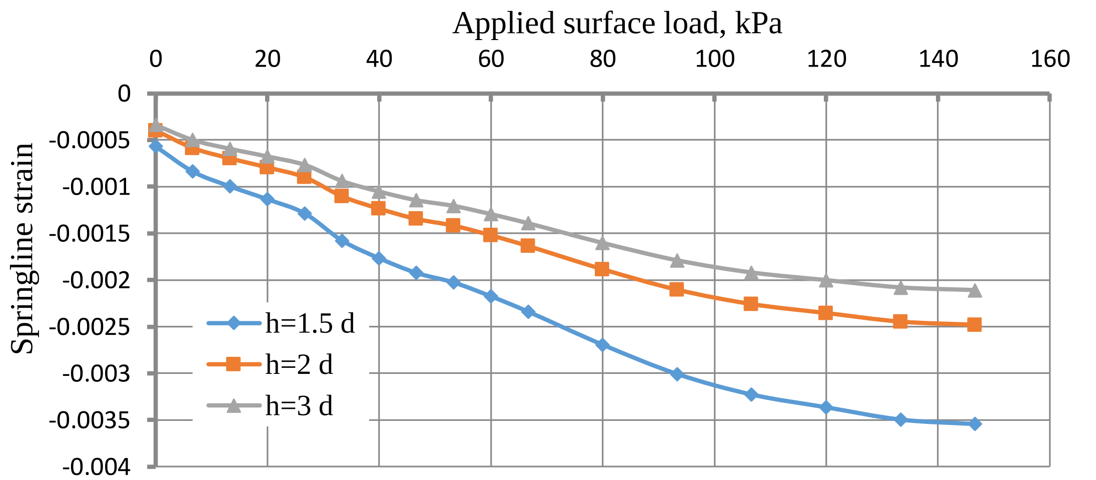

Figure 13: Effect of embedment depth of the pipe on the springline strain in dense sand.

CONCLUSIONS

In confine of this study, the following results are obtained:

1. Increasing the burial depth leads to decrease in the pipe strain for pipes embedded in sand of different densities.
2. The applied surface load on the crown strain is reduced by increasing the burial depth by about 19.6% when the embedment depth changes from 1.5 d to 2 d and 29.4% when it changes from 1.5 d to 3 d in loose sand. While these percents become to 13.1% and 32.2% in the medium sand and to 21.4% and 40% in the dense sand.
3. Based on the above percents, it can concluded that the best conditions to reduce the pipe crown strain are when the sand is dense and the burial depth is equal to 3d.

4. The invert strain is reduced by increasing the burial depth by about 19.2% when the embedment depth changes from 1.5 d to 2 d and 30.7% when it changes from 1.5 d to 3 d in loose sand. While these percents become to 22.2% and 33.3 % in the medium sand and changes to 12.7 % and 28.9 % in the dense sand.

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