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Finite Element Analysis of Buried UPVC Pipe

R. Nirmala[1*] and R. Rajkumar[2]

[1]Department of Civil Engineering, Sathyabama University, Rajiv Gandhi Road, Jeppiaar Nagar, Chennai - 600119, Tamil Nadu, India; nirmala.civil@sathyabamauniversity.ac.in
[2]Department of Civil Engineering, SSN College of Engineering, Chennai – 603110, Tamil Nadu, India; drrrk2010@gmail.com

Abstract

Background/Objectives: Understanding the mechanics of buried pipes is complicated due to the imprecision in the properties of the soil envelope. This paper deals with the study of behavior of flexible Un-Plasticized Poly Vinyl Chloride pipes buried in loose and dense sand backfill. **Methods/Statistical Analysis:** A design methodology is proposed for prediction of the performance of pipes using the finite element method ANSYS. The pipe soil interaction under static loading conditions is investigated. Height of the soil above the pipe varies with the ratios of diameter of the pipe. The numerical results are compared with the available values calculated using the theoretical approach Spangler Deflection theory. **Findings:** Provision of geogrid reinforcement above the crown of buried pipe is suggested to minimize the vertical deflection of buried Un-Plasticized Poly Vinyl Chloride pipes.

Keywords: Backfill, Pipe - Soil Interaction, Soil Envelope, Static Loading

1. Introduction

With the rapid Urbanization, the use of buried pipes plays a major role as a means of transport of fluids. This necessitates the study on design and analysis of behavior of buried pipes. The performance of pipes depends on the interaction between surrounding soil and pipe. The behavior of pipes buried in soil is considerably influenced by geotechnical considerations. The performance and stability evaluations are performed in terms of allowable deflection limit and buckling resistance. The nature of backfill in which the pipes are embedded and the installation conditions affect these performance limits[1].

Pipe is called flexible when the material of which it is made can be flexed or bent. It obtains its ability to support vertical entirely from the backfill material adjacent to its sides. However, it should be noted that, with large deflections of flexible pipe, structural buckling becomes a greater possibility, which will occur suddenly when critical loads or deflections are reached. Commonly, a 5% decrease in mean vertical diameter of a buried pipe is considered permissible[2].

The various research works has been carried out to analyze the behavior of buried pipes experimentally, theoretically and numerically. A numerical study on oil and gas steel pipelines subjected to static and dynamic loading conditions using 2D finite element method PLAXIS is performed. He concluded the factors such as types of soil, burying depth, pipe diameter, pipe thickness, number of soil layers and underground water table influenced the displacement of pipeline[3]. A Finite Element Program ABAQUS was used to evaluate the behavior of buried pipes. Based on the results, it is inferred that the composite pipe behaves more like the ordinary concrete pipe rather than the PVC pipe, in terms of its maximum stress and displacement. Also it is observed that the bedding angles of buried pipe influences the value of stresses and displacements[4].

The behaviour of buried flexible steel pipes using finite element analysis PLAXIS is analyzed in the study. Also, Design charts have been developed to predict deflection and buckling of flexible steel pipes for different thickness of pipes and different h/D ratios by considering loose and dense sands as backfill materials[5]. The various theoretical

** Author for correspondence*

equations presented by Modified Spangler formula, Watkins Theory and Greenwood and Lange Theory are used to predict the behaviour of buried Unplasticized Ploy Vinyl Chloride under static loading conditions. Modulus of backfill and Modulus of passive resistance of native soil are considered to be the important parameters for the analyzing the performance of pipe[6].

An experimental investigation on buried flexible PVC pipes under loose sand and dense sand conditions and subjected to surface pressure at shallow depths has been conducted. He incorporated the geogrid reinforcement to decrease the crown deflection of buried pipes[7].

2. Theoretical Equation

The deflection of buried plastic pipes is defined as the change in the base vertical diameter of the pipe taken with respect to the neutral axis of the pipe wall. The formula was firstly proposed by Spangler in 1941 to predict the horizontal deflection of buried flexible metal pipes. Spangler first established some relationships to define the capability of a flexible pipe to resist ring deflection when not buried in the soil. There are three relations:

$$\Delta Y = 0.149\, Fr^3/EI \tag{1}$$

$$\Delta X = 0.136\, Fr^3/EI \tag{2}$$

$$\Delta X = 0.913\, \Delta Y \tag{3}$$

Spangler derived his formula for deflection of buried pipes.

$$\Delta X = (D_l\, K\, W_c\, R^3) / (E\, I + 0.061\, e\, R^4) \tag{4}$$

Where,

ΔX - Horizontal deflection, mm
D_l - Deflection lag factor
K - Bedding constant
W_c - Marston's load per unit length of pipe, KN/m
R - Mean radius of the pipe, mm
E - Modulus of elasticity of the pipe material, N/ mm^2
I - Moment of inertia of the pipe wall per unit Length of pipe, mm^4/m
e - Empirical modulus of passive resistance of the sidefill modified by Watkins, N/ mm^2
ΔY - Vertical deflection, mm

3. Properties of Soil and Pipe

The Properties of backfill materials and Unplasticized Poly Vinyl Chloride (UPVC) pipe material used for the analysis are listed in Table 1.

Table 1. Properties of Materials

Properties	Loose Sand	Dense Sand	UPVC Pipe
Unit Weight (kN/m^3)	15	17	-
Young's Modulus (kN/m^2)	9000	19000	2.75 x 10^6
Poisson's Ratio	0.3	0.3	0.4

4. Finite Element Analysis

The model of the system consists of soil mass with dimensions 0.6 m x 1.0 m x 1.2 m. A UPVC pipe with diameters of 80 mm, 100 mm and 150 mm and of varying wall thickness was used. The layer of soil covering a height varies based of h/ D ratios 1, 2, 3 and 4. Two material zones were established inside the model, the sandy pipeline bedding and pipeline backfill. The finite element analysis program 'ANSYS' was used to study the soil-pipe interaction. The performance of buried UPVC pipes was compared with the values obtained from theoretical analysis. The numerical model of the buried UPVC pipe is shown in Figure 1. The surface loading was assumed to transfer through the loading plate of 100 mm width centrally placed over the pipe with the increments of 0.5, 1.0, 1.5 and 2.0 T

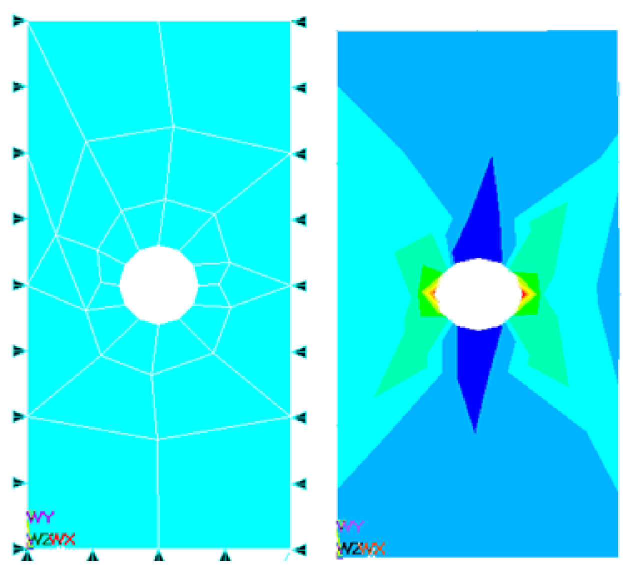

Figure 1. (**a**) Geometry Model (**b**) Deformed buried pipe model.

5. Results and Discussion

5.1 Vertical Crown deflection vs. Standard Dimension Ratio

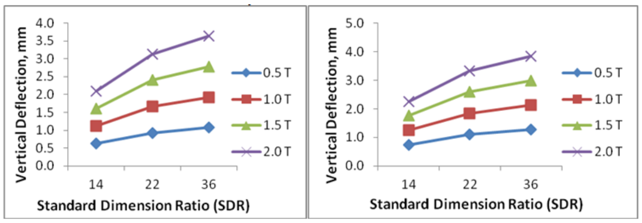

Figure 2. Vertical Crown Deflection of 80 mm and 150 diameter UPVC pipes for h/d = 1 for loose sand backfill subjected to incremental loading.

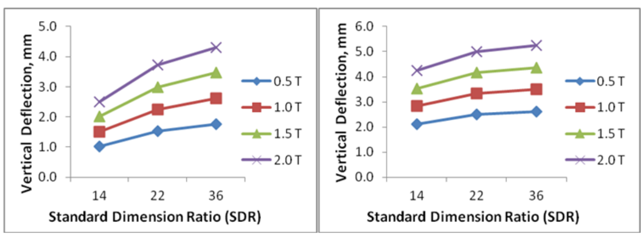

Figure 3. Vertical Crown Deflection of 80 mm and 150 diameter UPVC pipes for h/d = 4 for loose sand backfill subjected to incremental loading.

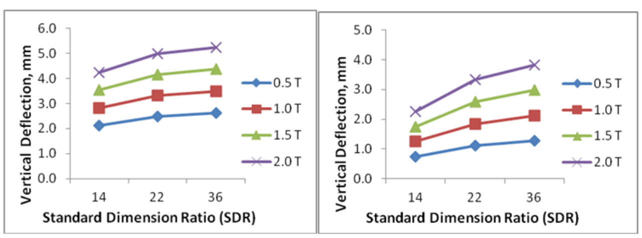

Figure 4. Vertical Crown Deflection of 80 mm and 150 diameter UPVC pipes for h/d = 1 for dense sand backfill subjected to incremental loading.

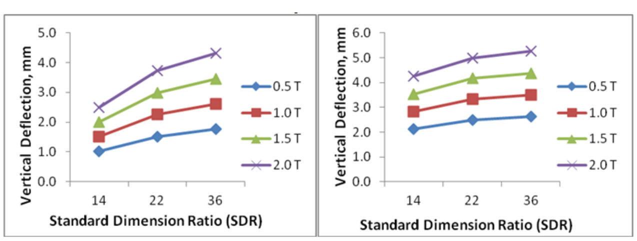

Figure 5. Vertical Crown Deflection of 80 mm and 150 diameter UPVC pipes for h/d = 4 for dense sand backfill subjected to incremental loading.

SDR represents Standard Dimension Ratio refers to Diameter by thickness ratio. Figures 2 to 5 gives the increase in SDR increases the vertical crown deflection of buried UPVC pipes. The increase in SDR is due to decrease in the thickness of UPVC pipes. It is observed that the vertical crown deflection is higher due to decrease in thickness of UPVC pipes. The deformation of the buried pipe with respect to Standard Dimension Ratio was not linear.

5.2 Vertical Crown Deflection vs. Load Applied

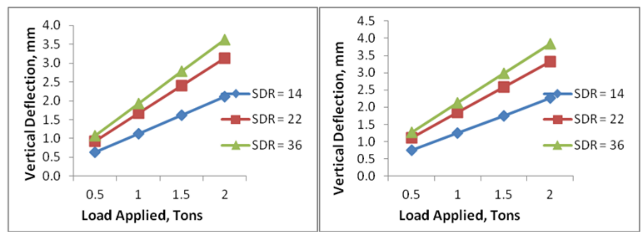

Figure 6. Vertical Crown Deflection of 80 mm and 150 diameter UPVC pipes for h/d = 1 for loose sand backfill compared with various SDR.

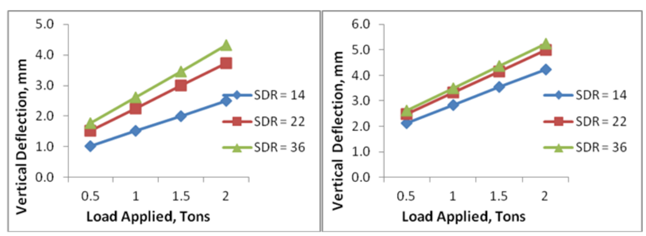

Figure 7. Vertical Crown Deflection of 80 mm and 150 diameter UPVC pipes for h/d = 4 for loose sand backfill compared with various SDR.

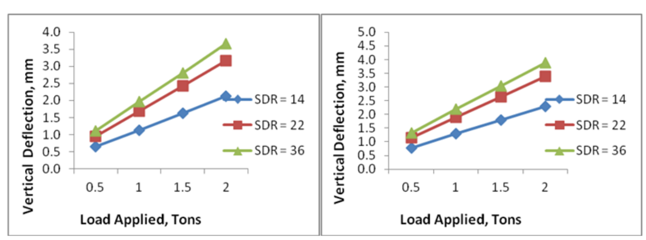

Figure 8. Vertical Crown Deflection of 80 mm and 150 diameter UPVC pipes for h/d = 1 for dense sand backfill compared with various SDR.

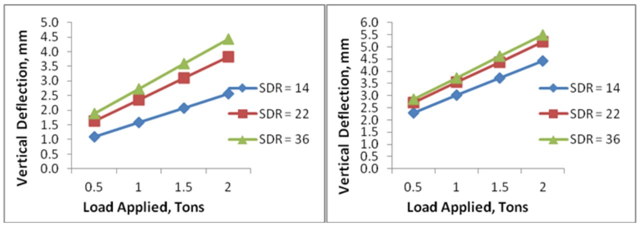

Figure 9. Vertical Crown Deflection of 80 mm and 150 diameter UPVC pipes for h/d = 4 for dense sand backfill compared with various SDR.

It is inferred from the Figures 6, 7, 8 and 9 that the incremental loading of 0.5 T, 1.0 T, 1.5 T and 2.0 T were applied. For incremental loading as well as for the increase in standard dimension ratio, the vertical crown deflection of buried pipes is also increased. The deformation of buried pipe in respect of surface loading is linear.

5.3 Vertical Crown Deflection vs. h/D Ratio

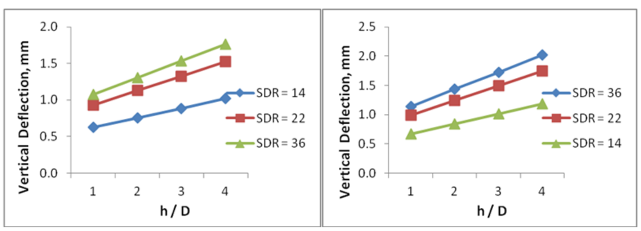

Figure 10. Vertical Crown Deflection of 80 mm and 100 diameter UPVC pipes for 0.5 T for loose sand backfill compared with various SDR.

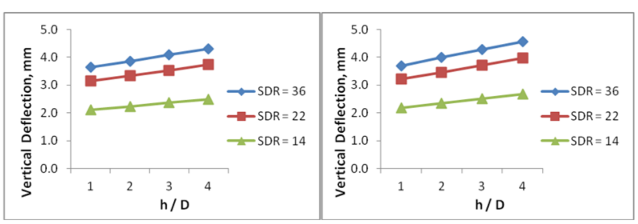

Figure 11. Vertical Crown Deflection of 80 mm and 100 diameter UPVC pipes for 2.0 T for loose sand backfill compared with various SDR.

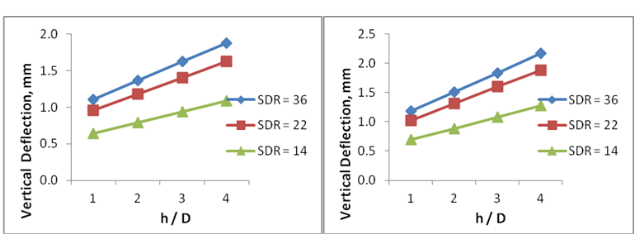

Figure 12. Vertical Crown Deflection of 80 mm and 100 diameter UPVC pipes for 0.5 T for dense sand backfill compared with various SDR.

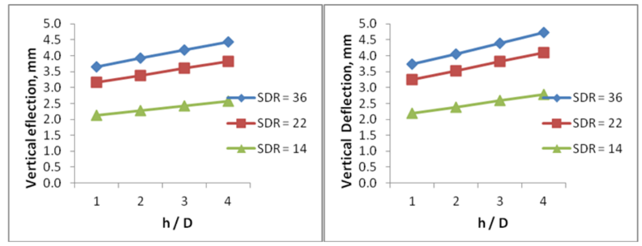

Figure 13. Vertical Crown Deflection of 80 mm and 100 diameter UPVC pipes for 2.0 T for dense sand backfill compared with various SDR.

From the Figures 10, 11, 12 and 13, it is inferred that the vertical deflection of buried UPVC pipes is increased with the depth of soil cover over the pipe. h/D ratio refers to the height of backfill above the pipe to the diameter of the buried pipe. The deformation of buried pipe with respect to h/D ratio is linear.

6. Conclusion

The height of backfill increases the deflection of buried pipes. Also the behavior of buried pipe varied due to the type of backfill material placed inside the test box. The Vertical deflection was observed to be higher in case of dense sand backfill than the loose sand. The incremental rise of surcharge load applied over the restricted area of buried pipe increases the deflection of buried UPVC pipes.

The numerical analysis of buried UPVC pipes are well compared with the theoretical studies based on Spangler theory in determining the Vertical crown deflection. Hence it is concluded that the depth of embedment of pipe, type of backfill, thickness of pipe and surcharge loads are the prime factors that affects the behaviour of buried pipes. The deflection of buried UPVC pipes could be minimized by providing geogrids reinforcement above the crown of pipe.

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