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Behavior of Buried Pipelines in Geosynthetics Reinforced Soil Slopes

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Abstract. Development of any nation depends largely on its industrial growth. These industries use pipelines as a carrier for oil, natural gas, water and other fluids. These days pipelines are mostly buried beneath the earth surface for their enhanced stability and protection. During their course of laying they have to travel larger distances and pass through a variety of contours with severe adverse topographies. Therefore, the stability of these pipelines gets considerably reduced whenever they pass through a slope or below an embankment. In view of this, numerical analysis has been carried out to investigate the influence of geosynthetics reinforcement on the overall behavior of buried pipelines. Three dimensional finite element software was used to simulate reinforced soil layers, PVC pipe, model footing and loading conditions along with slope characteristics. Based on the numerical results, the optimum position of pipe with respect to slope crest and its embedment depth are recommended in this study. This will help in reducing depth of cover and additional costs incurred during trenching operation as well as increasing the service life of these pipelines. Further, these numerical results have been compared with existing experimental results on pipelines located in reinforced soil.

Keywords: Buried Pipelines, Reinforced Soil, Load Settlement Curve

1 Introduction

Buried pipelines are one of the most critical parts of any urban infrastructure and smooth functioning of it can be helpful in deciding the economical development of a nation. In recent years, scarcity of suitable horizontal land has forced the engineers to place these buried pipelines under sloping terrain. Also at times these pipelines have to pass below an existing embankment. The bearing capacity of these pipelines gets significantly reduced and settlement increases as compared to the pipelines lying below a horizontal land under loading. In such cases the promising performance of geosynthetics owing to its high tensile strength can be utilized to stabilize the embankments or existing slopes. This will help in increasing the stability of the buried pipelines by increasing its bearing capacity and decreasing its settlement under heavy loads. An understanding of the behaviour of buried pipeline located in reinforced slopes under loading is of much practical importance to geotechnical engineers.

Many researchers such as (Lee and Manjunath, 2000; El Sawwaf , 2004; Alamshahi and Hataf, 2009; Altalhe et al., 2013) have investigated on the use of geosynthetics reinforcement and reported that the ultimate bearing capacity as well as load settlement behaviour of a footing placed near the slope can be considerably improved by incorporating the use of geosynthetic reinforcement.

Recently the behaviour of buried pipelines located on horizontal surface has been clearly demonstrated by several investigators. (Srivastava et al., 2013; Bildik and Laman, 2019). Also use of geosynthetics such as geocell mats, EPS blocks etc. to improve the stability of buried pipelines by decreasing the upcoming vertical pressure on pipe's crown has been extensively reported by several researchers. (Mehrjardi et al., 2015; Hegde and Sitharam, 2015; Almohammed et al., 2018; Tafreshi et al., 2019).

Bildik and Laman (2019) in particular, performed parametric study and investigated on the stress behaviour of buried pipelines located under a strip footing on horizontal surface. The results indicated a serious increase in bearing capacity and decrease in hoop stress when embedment ratio and horizontal distance of pipe to footing were increased. Also increase in bearing capacity and decrease in pipe hoop stress was observed in case of perpendicular installation of pipeline than parallel installation with respect to footing.

Although other researchers have studied the role of geosynthetics on the behaviour of buried pipelines lying beneath horizontal surfaces, but there is still a lack of investigations in case of buried pipelines located near the slopes. This paper seeks to aid understanding on the role of geosynthetics in increasing the stability of buried pipelines located on slopes.

The main purpose of this investigation is to examine the role of geosynthetics in increasing the stability of buried pipelines located in slopes.

2 Methodology

2.1 Numerical Investigation

Finite element analysis was performed to model the response of footing on buried PVC pipelines for different embedment depths, relative density of sand, slope angle and setback distance of the footing. Analysis was carried out for both reinforced and unreinforced slopes. In the present problem, five calculation phases are defined in total. They are initial phase, pipe simulation phase, footing simulation phase, geogrid simulation phase and loading phase. The initial phase is automatically generated and contains initial stress and model geometry details. Except soil, all other structural elements and loadings are deactivated in this phase. The K0 procedure is used for initial stress calculation and staged construction is selected as the type of loading. The second phase is added after the initial phase and named as pipe simulation phase. In this phase pipe is activated. Similarly footing and geogrid is simulated in the following phases and activated respectively. Lastly loading phase is added after the geogrid simulation phase. In this phase loading is activated along with all other structural elements. After successfully assigning each calculation phase, the finite element model is analyzed for the existing loads and boundary condition.

2.2 Modelling using finite element mesh and boundary condition

Finite element analysis using PLAXIS^{3D} is done in this research. Parametric study is performed on different models and compared with both reinforced and unreinforced slope in order to investigate the role of geosynthetics in increasing the stability of buried pipelines. Experimental work reported by Lee and Manjunath (2000) was chosen to validate the finite element model in this study. The numerical model consists of single sand layer with an initial slope of 20°, geosynthetics in the form of geogrid, rectangular strip footing and buried PVC pipe. The size of the test tank is kept the same as that of experimental analysis carried out by Lee and Manjunath (2000). The model was fully fixed (both horizontal and vertical movement restricted) at the base and normally fixed (horizontal movement restricted) on the sides. The dimension of the soil model is shown below:

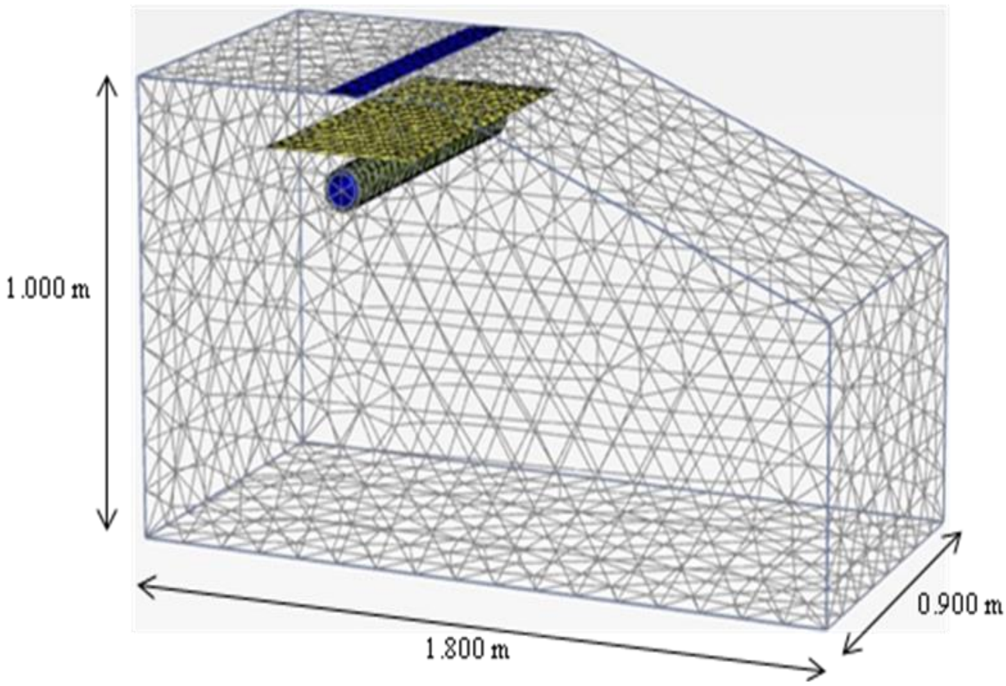

Fig. 1. Distribution of nodes and elements in the generated mesh

In the present study, the soil is modelled as hardening soil (HS) model. The desired relative density is achieved by varying different soil parameters as shown :

Table 1. Soil parameters used in present study

Parameter	Relative Density 85%	Relative Density 65%	Relative Density 45%
Unsaturated unit weight, γ_{unsat} (kN/m^3)	18.20	17.52	16.85
Saturated unit weight, γ_{sat} (kN/m^3)	21.02	20.50	19.98
Material Model	Hardening Soil	Hardening Soil	Hardening Soil
Drainage Type	Drained	Drained	Drained
E_{50}^{ref} (kPa)	60000	42000	24000
E_{oed}^{ref} (kPa)	60000	42000	24000
E_{ur}^{ref} (kPa)	180000	126000	72000
Power in stiffness laws (m)	0.8	0.8	0.8
Unloading-reloading Poisson's ratio (ν)	0.3	0.3	0.3
Cohesion, c (kN/m^2)	1.0	1.0	1.0
Friction angle, φ (°)	38	35	30
Angle of dilatancy, ψ (°)	8.0	5.0	0.0
Interface Reduction Factor, R_{inter}	1.0	1.0	1.0

Table 2. Material Properties used in numerical Analysis

Parameter	Model Footing	PVC Pipe	Geogrid
Unit weight, γ(kN/m^3)	78.50	13.83	-
Material Type	Elastic	Elastic	-
Young's Modulus, E (kN/m^2)	210×10^6	93.3×10^4	-
Shear Modulus, G (kN/m^2)	80.77×10^6	35.61×10^4	-
Poisson's Ratio (ν)	0.30	0.31	-
Axial Stiffness (kN/m)	-	-	68

3 Results and Discussion

3.1 Validation of numerical model

Initially, the present numerical model has been validated with existing experimental work reported by Lee and Manjunath (2000). Subsequently, the detailed numerical analysis has been carried to investigate the behaviour of buried pipe under reinforced soil slope. Typical load displacement response obtained from numerical analysis has been compared with experimental results (Lee and Manjunath, 2000) as shown in Fig. 2. The model dimensions and the properties of the material were adopted same as reported in the experimental model tests by Lee and Manjunath (2000). From Fig. 2, it can be seen that the present result is well comparable to experimental results with marginal error. This error is possibly due to the error occurred in simulating the soil properties reported. Therefore, it can be said that the present model can be used to simulate the behaviour of buried pipe in reinforced soil slope.

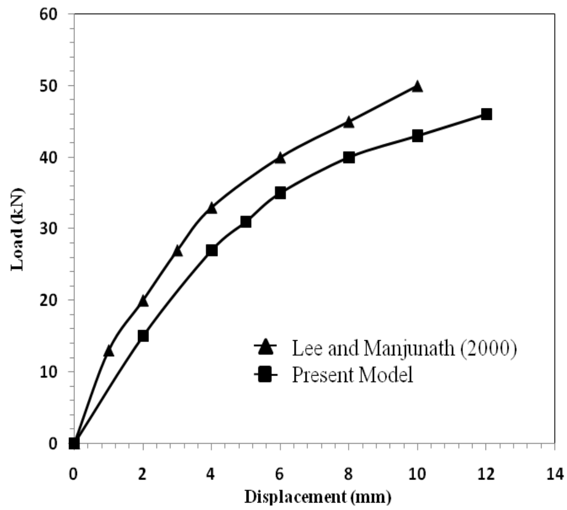

Fig. 2. Validation of numerical results with experimental work

The response of the footing in terms of its load carrying capacity is observed for varying slope angle, relative density of soil and edge distances of the footing. The soil model providing the safest values in terms of load carrying capacity of the footing as well as conforming to the actual analysis in consideration is fixed before introducing pipeline and geogrid into the system.

3.2 Response of footing for different parameters

Influence of slope angle on footing placed at different edge distances

The response of footing is observed for varied footing position (i.e. b/B ratio) and slope angle (β = 20°, 26.5° and 30°) through numerical model. In total six different position of the footing is considered in this study starting from b/B = 0, 1, 2, 3, 4 and 5 where b/B = 0 denotes that footing is located on the edge of the slope. The response of the footing at b/B = 2 for different slope angles is shown in Fig. 4.1. It can be seen that the load carrying capacity is maximum for level ground (β = 0°) and gradually reduces with increase in slope angle. However, the slope having β = 20° is found to be safest as compared to other slope angles. Hence, β = 20° has been considered for further analysis.

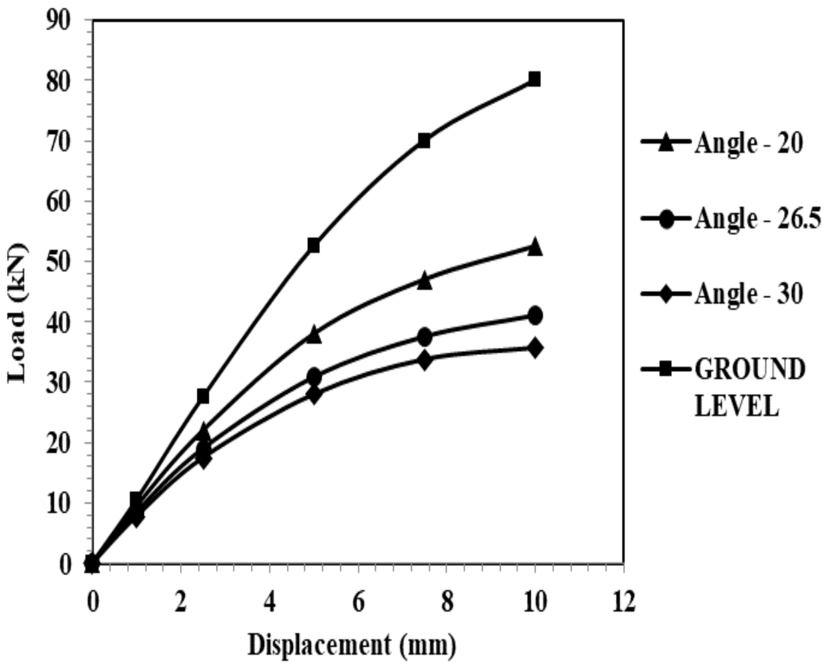

Fig. 3. Response of footing at different slope angles

Influence of relative density of soil on footing placed at different edge distances

The behaviour of footing is observed for varied footing position (i.e. b/B ratio) and relative density (85%, 65% and 45%) through numerical model. Soil parameters such as unit weight, angle of internal friction, dilatancy angle etc. are varied in order to simulate different relative densities of soil. For each relative density, analysis is done for fixed slope angle (β = 20°) and varied b/B ratios of 0.0, 1.0, 2.0, 3.0, 4.0 and 5.0. The response of the footing at b/B = 2 for different relative densities is shown in Fig.

4.2. It is observed that the load carrying capacity is maximum when relative density is 85% and gradually reduces with decrease in relative density. Therefore, sand having relative density of 85% has been considered for further parametric study.

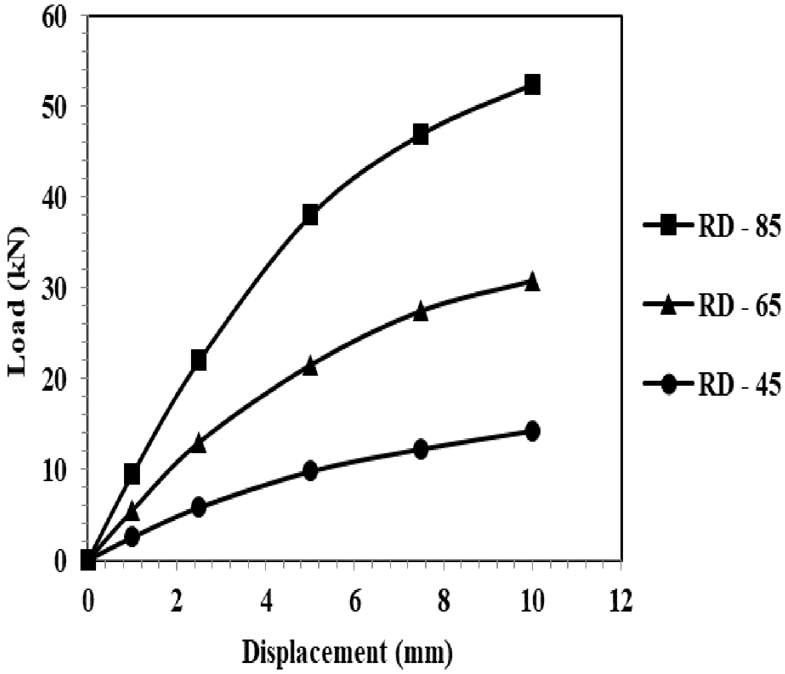

Fig. 4. Response of footing at different relative densities of soil

Response of footing placed at different edge distances

The behaviour observed for varied footing position (i.e. b/B ratios) is discussed in this section. The slope angle and relative density is kept constant (β = 20° and RD = 85%). Analysis is also carried out with strip footing lying in level sand surface for comparison. The response of the footing placed at different edge distances is presented in Fig. 4.3. An increasing trend in bearing capacity is observed when position of the footing is shifted away from the slope crest. This increase in bearing capacity with increasing edge distance is attributed due to the diminishing effect of the slope. This explanation seems to be consistent with the experimental results of Lee and Manjunath (2000).
When position of the footing is at b/B = 5, the BCR value nearly achieves 80% of the value of case of footing placed on a level surface. This shows that if the edge distance is further increased, then footing will starts to behave as if placed on a level surface. Therefore to stay with the actual analysis of considering the slope effect in monitoring the role of geosynthetics on buried pipe, the position of the footing is fixed at b/B = 2.

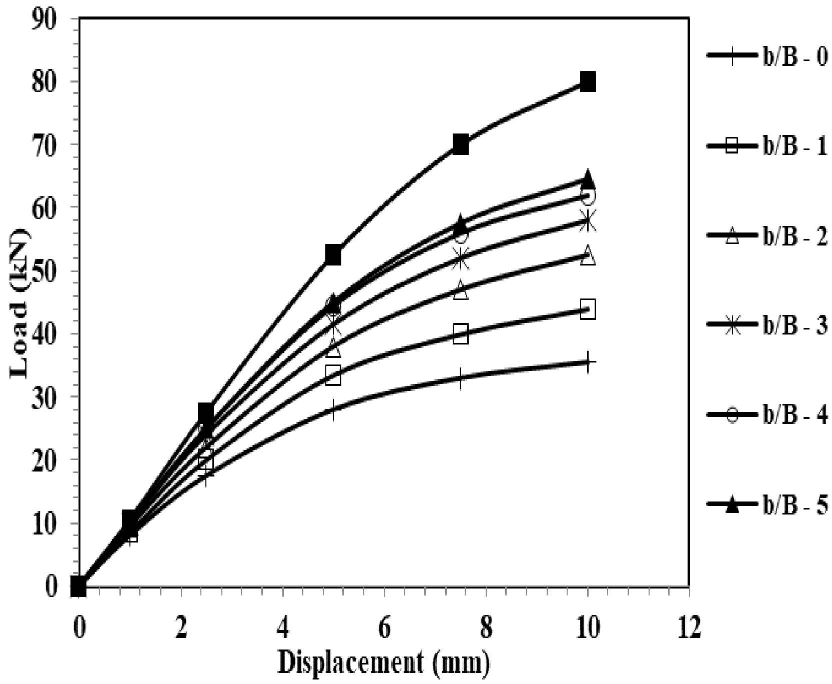

Fig. 5. Response of footing at different edge distances

Once the slope angle, relative density and footing position is decided, PVC pipe is introduced in the model and placed under the footing. Also before carrying out the analysis with reinforced slope, the optimum position of the reinforcement needs to be fixed.

Influence of reinforcement embedment depth on footing

The load carrying capacity of the footing due to different embedment depth of geogrid is observed in this study. A series of analysis is carried out for various embedment depth to footing width ratio (u/B) of 0.25, 0.50, 0.75, 1.00, 1.25, 1.50 and 1.75 by keeping the edge distance of the footing (b/B = 2) and slope angle ($\beta = 20°$) constant. Load-settlement curves for seven different u/B ratios as mentioned earlier are shown in Fig. 4.6. Also the ultimate load carrying capacity of the footing is tabulated in Table 4.1. From the results, it is observed that load carrying capacity of the footing increases with increase in embedment depth of reinforcement till u/B = 1.25. Beyond u/B = 1.25, the performance of geogrid to reduce as evident from the decrease in load carrying capacity of the footing. Therefore optimum depth of reinforcement is considered to be u/B = 1.25.

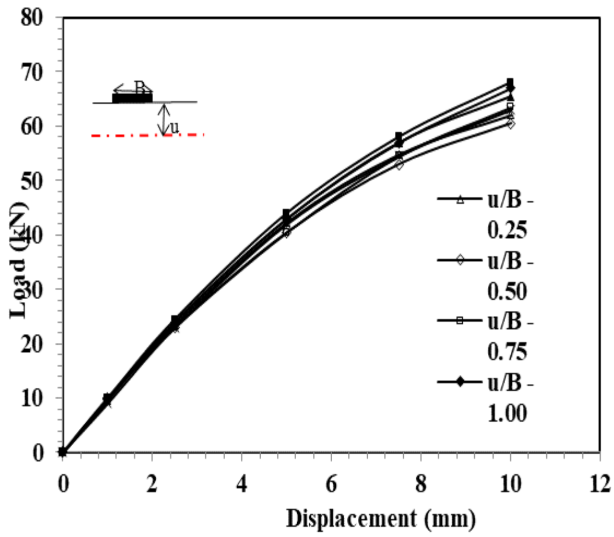

Fig. 6. Response of footing at different reinforcement embedment depth

Table 3. Ultimate load carrying capacity of footing at different u/B ratios

u/B	Ultimate load carrying capacity of the footing (kN)
0.25	47.50
0.50	49.20
0.75	52.30
1.00	58.70
1.25	60.00
1.50	58.00
1.75	57.00

3.3 Response of footing due to vertical movement of pipe

Unreinforced slope

The response of footing in the form of bearing capacity ratio is observed for different vertical position of the pipe in unreinforced sand. The position of the pipe is varied from d/B ratios equal to 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5. Analysis is also carried out with strip footing lying on sand without pipe for comparison. Load-settlement curves for seven different d/B ratios are presented in Fig. 4.4. It is observed that BCR value of footing goes on increasing as the pipe moves in vertically downward direction. The BCR value reached 96% of case of without pipe at d/B = 3.5. This implies that if the pipe is placed beyond d/B = 3.5, the BCR value is reached the same BCR value of case of without pipe. The results show that the bearing capacity of the footing is directly affected when pipe is buried within the stress bulb. Also the effect of load on pipe is almost negligible when it is placed beyond d/B = 3.5. This explanation seems to hold a reasonable agreement with the experimental work conducted by Bildik and Laman (2019). Fig. 4.5 and 4.6 shows the displacement contour of the model without pipe and with pipe in unreinforced slope respectively. Upon comparing with no pipe case, the safety of the buried pipe can be ascertained as it is lying in between less displaced contour. Therefore the vertical position of the pipe (embedment depth) is fixed at d/B = 3.5 in case of unreinforced sand.

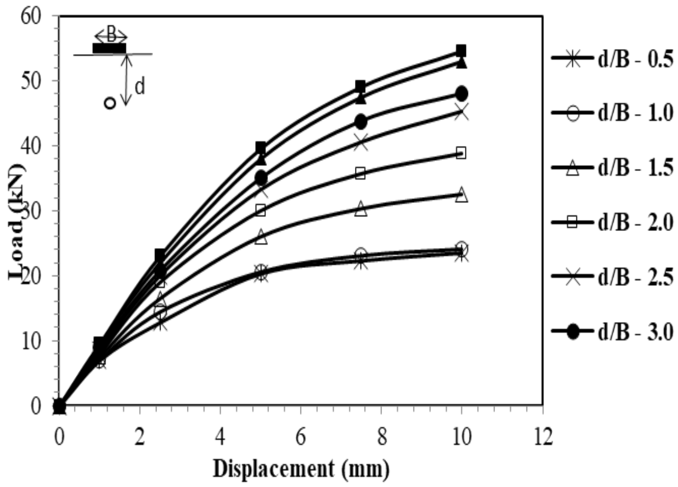

Fig. 7. Response of footing for different embedment depth

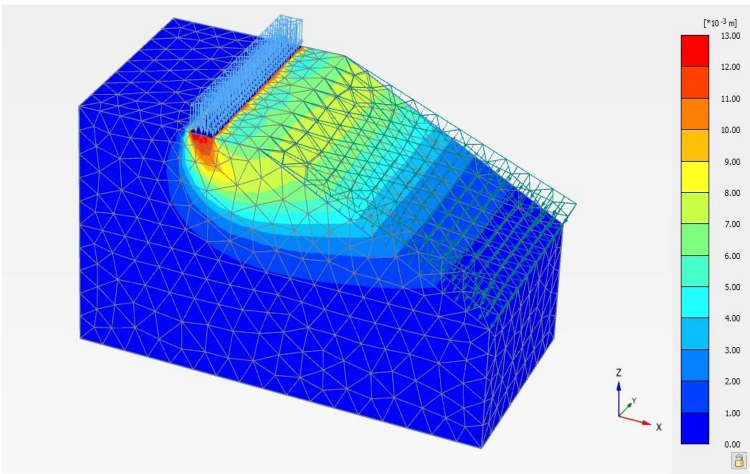

Fig. 8. Displacement contour of model without pipe in unreinforced slope

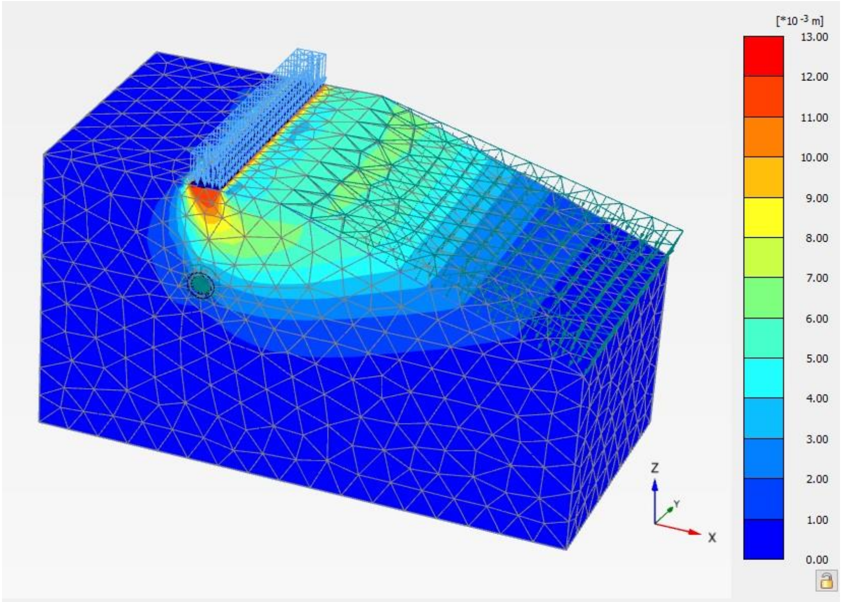

Fig. 9. Displacement contour of model with pipe in unreinforced slope (d/B = 3.5)

Reinforced slope

The response of footing in the form of bearing capacity ratio is observed for different embedment depth of the pipe in reinforced sand. Since the buried pipe needs to be protected by geogrid therefore it should be placed atleast below the optimum depth of the reinforcement i.e. u/B = 1.25. Analysis is carried out for d/B ratios of 2.0, 2.5 and 3.0 and compared with strip footing lying on sand without pipe. Load-settlement curves for three different d/B ratios are presented in Fig. 4.7. Also the ultimate load carrying capacity of the footing is tabulated in Table 4.1. It is observed that BCR value of footing goes on increasing as the embedment depth of pipe increases. The BCR value reached 97% with pipe at d/B=3.5 as compare to without pipe. When compared with unreinforced sand, similar BCR value is achieved when d/B = 3.5. Improvement in BCR value at a lesser depth signifies the performance of geogrid. Also the displacement contours of the model without pipe and with pipe in reinforced slope are shown in Fig. 4.8 and 4.9. The safe position of the buried pipeline can be justified as it can be seen lying in between less displaced contours when compared with no pipe condition. Therefore, the embedment depth of pipe is fixed at d/B = 3.0 in case of reinforced sand. Hence, with reinforcement the depth of pipe can be reduced by 0.5 times of B.

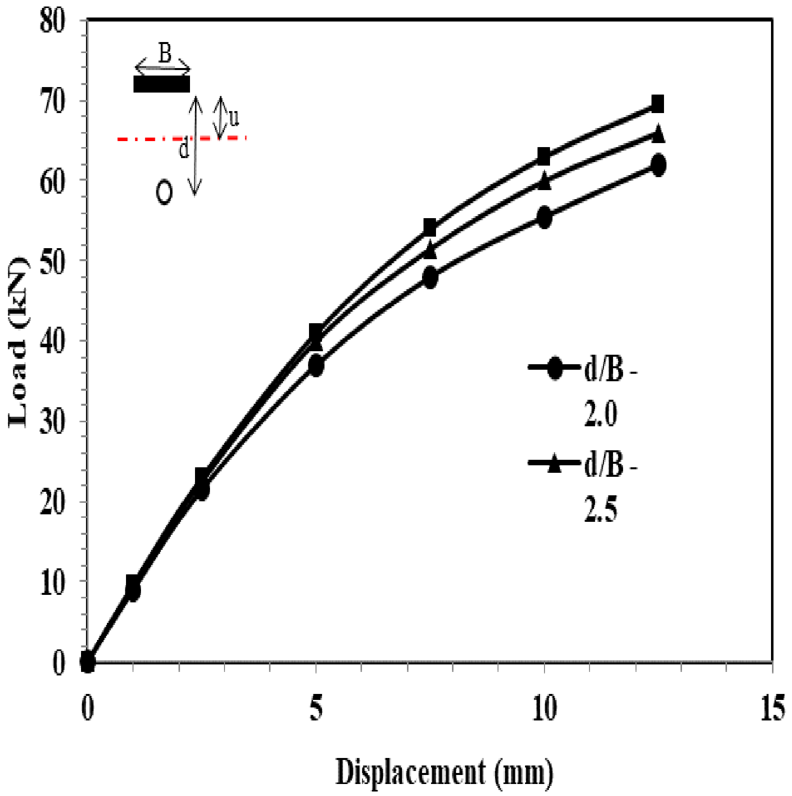

Fig. 10. Response of footing for different embedment depth in reinforced sand

Table 4. Ultimate load carrying capacity of footing for different *d/B* ratios

d/B	Ultimate load of footing with pipe (kN)	Ultimate load of footing without pipe (kN)	BCR
2.0	50.0	56	0.89
2.5	53.0	56	0.94
3.0	54.5	56	0.97

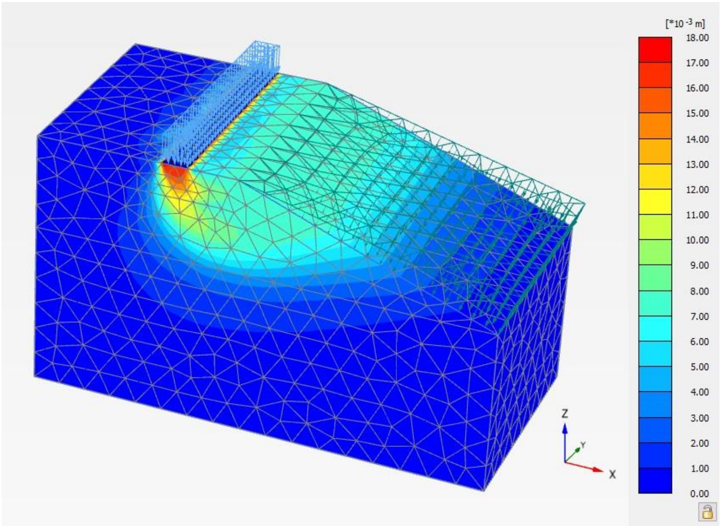

Fig. 11. Displacement contour of model without pipe in reinforced slope

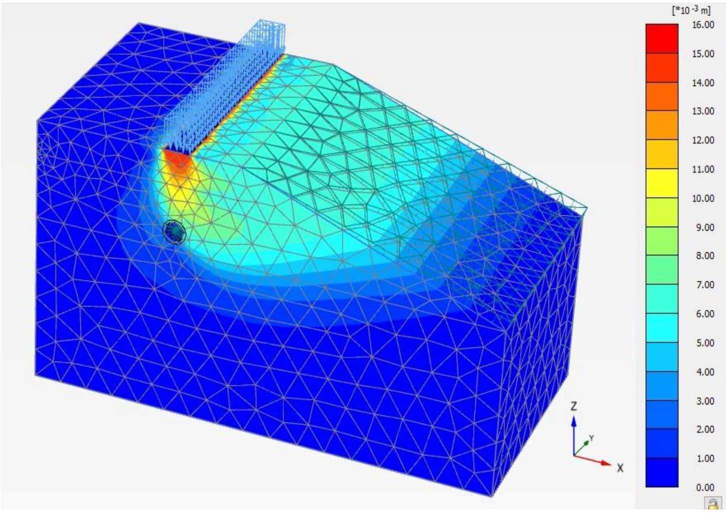

Fig. 12. Displacement contour of model with pipe in reinforced slope (d/B = 3.0)

From section 3.2 and 3.3, the following statements can be justified with respect to unreinforced and reinforced slope.

• The bearing capacity of the footing is directly affected when pipe is buried within the stress bulb in case of both unreinforced and reinforced slope.

• The effect of load on pipe is almost negligible when it is placed beyond d/B = 3.5 in case of unreinforced slope and d/B = 3.0 in case of reinforced slope.

• Improvement in BCR value at a lesser depth in case of reinforced slope signifies the performance of geogrid.

5 Conclusions

1. Load carrying capacity of the footing can be improved by the inclusion of geosynthetics.
2. Embedment depth of pipe lying on soil slope can be reduced with the use of geogrid. This will help in reducing the extra cost of trenching during laying of buried pipelines in soil slopes.
3. Geosynthetics in the form of geogrid is helpful in improving the overall stability of buried pipelines in soil slopes.

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