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Experimental Study on Joint of HDPE Pipe with and Without GEO-GRID as Reinforcement

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ABSTRACT

A variety of buried pipe infrastructure is needed to service the needs of our communities. The conduit surrounded by soil is both loaded and supported by the earth and pore water. However the conditions considered in this work pertains to only earth pressure and not poor water pressure. The pipes are broadly classified as Rigid and Flexible. The aim of this project is to study deflection behavior of flexible pipe (HDPE) at the joint.: The experiment was carried out for 4 sets of reading at two different levels (0.4m and 0.8m) of burial with and without Geo-grids at both levels using an experimental set up of model trench (Fabricated steel tank) with desirable material as bedding and backfill, loading provisions to provide uniform loading. The basic concept behind the experiment involves measuring the deflection values of the pipe for different readings using proving ring and dial gauge**.**: In addition to this, this project aims to study the load deformation behavior of the buried pipe across the cross section (both crown and springing line) of the joints under uniform loading when soil is reinforced with geo-grid reinforcement, and evaluate the structural performance of the pipe and compare the results with theoretical results and infer the findings. Based on the conclusions, various recommendations can be made, in terms of the pipe's application in place of Conventional pipes and thereby reduce risk of leakage, damage and also compensating the cost of pipe systems, economically as the joints in pipeline are the weakest and most vulnerable.

Keywords: *Crown deflection; Geo-Grid, HDPE Pipes, Spangler Iowa deflection and Springing deflection.*

1. INTRODUCTION

Pipelines are the energy lifelines of almost every activity of our everyday life. Natural resources, like crude oil and natural gases, are the raw material for energy that the world consumes. While many forms of transportation are used to move these products to marketplaces; pipelines remain one of the safest, most efficient and economical ways to move these natural resources. (Moser AP,1990) Underground conduits have served to improve a man's standard of living since the dawn of civilization. It is now possible to use engineering science to design the underground conduits with a degree of precession. In addition, testing and research have produced quantities of empirical data which also can be used in the design process. Engineers and planners realise the subsurface infrastructure is an absolute necessity to the modern community.

There are two basic types of pipes: Rigid and Flexible (Sivakumar Babu et.al,2003). A so-called rigid pipe tends to retain a circular cross section regardless of the external cross section. A flexible pipe is generally a pipe that can deflect without structural distress to the pipe or to any coating or lining. Types of flexible pipes used generally are steel, ductile iron, Poly Vinyl Chloride (PVC), High-Density Polyethylene (HDPE), bar-wrapped concrete cylinder (old Reclamation designation), and fiberglass (Sivakumar Babu et.al,2003). The discussions in this report pertain only to flexible pipe.

A flexible pipe derives its soil-load bearing capacity from its flexibility. Under soil load, the pipe tends to deflect, thereby developing passive soil support at the sides of the pipe. At the same time, the ring deflection relieves the pipe of the major portion of the vertical soil load which is picked up by the surrounding soil in arching action over the pipe (Moser AP,1990).

The effective strength of flexible pipe-soil system is remarkably high. Three parameters which are most essential in the design or the analysis of any flexible conduit installation are Load (Depth of burial), Soil stiffness in pipe zone and pipe stiffness. Load on a buried pipe is created by placing backfill soil over the top of the pipe and any surcharge and/or live load on the backfill surface over the pipe. Flexible pipe is designed to transmit the load on the pipe from the top to the soil at the sides of the pipe. For the design of structural members, the strain or deformation of an element of the material being used can be determined from the ratio of the load or stress on the member to its modulus of elasticity (strain = stress/modulus of elasticity) (Zhan C and Rajani B,1997). The modulus is either known for the material or determined by laboratory tests.

The deflection of a buried conduit can be predicted in a similar fashion. A flexible pipe changes shape several times during the installation of a pipeline. Generally, the pipe is considered to deform from a perfect circle to an ellipse due to loading.

2. LITERATURE REVIEW

The experimental study on the joint behavior of HDPE pipes with and without geogrid reinforcement reveals significant insights into the structural integrity and performance under various conditions. The integration of geogrid reinforcement has been shown to enhance the resilience of HDPE pipes against external loads and ground movements, thereby improving their overall functionality.

2.1 Impact of Geogrid Reinforcement

2.1.1 Load Distribution:

Geogrid reinforcement effectively reduces the pressure transferred to buried pipes, enhancing their bearing capacity by up to 33.7% (Elshesheny et al., 2024).

2.1.2 Vertical Displacement Control:

Tests indicated that Geosynthetics, including geogrid, limit vertical displacement of pipes under localized ground subsidence (Zhou et al., 2020).

2.1.3 Stress Reduction:

The presence of geogrid significantly decreases vertical stresses and strains on the pipe, particularly when arranged to envelop the pipe (Pires & Palmeira, 2017).

2.2 Joint Behavior under Ground Movements

2.2.1 Kinematic Responses:

Experiments on bell-and-spigot joints of HDPE pipes showed that axial shortening and shear displacements increased with fault offsets, leading to leakage at critical thresholds ("Experimental study on gasketed bell-and-spigot joint behavior of lined-corrugated HDPE pipe subjected to normal fault", 2022).

2.1.2 Reinforcement Efficacy:

The use of geogrid reinforcement in unreinforced soils demonstrated improved performance under cyclic loading conditions, indicating its potential to maintain joint integrity (Elshesheny et al., 2019).

While the benefits of geogrid reinforcement are evident, it is essential to consider the potential limitations, such as increased complexity in installation and the need for careful design to ensure optimal performance under specific environmental conditions.

3. MATERIAL AND METHODS

3.1 Procurement of materials

3.1.1 HDPE pipe

HDPE pipe of 200mm outer diameter and thickness 9.2 mm were used in the study. The pipe was joined using butt fusion method and the deflections were observed at the joint. The specifications of the pipe are listed in Table 1.

Table 1 Properties of HDPE pipe.

Parameter	Value
Diameter (D)	200 mm
Thickness (t)	9.2 mm
Young’s Modulus (E)	1000 MPa

Moment of Inertia (I)	64.891 mm^3
Flexural Rigidity (EI)	64891 NM
Standard Dimension Ratio (SDR)	21.74

3.1.2 Geo-grid

The geo-grid is used to effectively reduce the stress over the pipe. The properties of the geo-grid are listed in Table 2.

Table 2 Properties of Geo-grid

Parameter	Value
Ultimate Tensile strength	30 kN/m
Aperture dimension	40 mm
Rib Thickness	1.5 mm
Rib Width	2.3 mm
Junction Efficiency	95%
Resistance to UV Degradation	100%

3.1.3 M - Sand

M Sand is used as a backfill. The M Sand used is of homogeneous in nature.

3.2 Apparatus

3.2.1 Fabricated loading machine

The steel tank of dimension 600mm x 800mm x 1200mm with the side plates consisting of holes of diameter 200mm with suitable tolerance for pipe to fit. The tank is fabricated such that two levels of burial can be done one at 0.8 m or 800mm and 0.4 m or 400mm. These are the two levels the experiment was performed. This tank behaves as a Trench. The steel tank is fabricated with the manual loading arrangement which produces a uniform load on the soil which is distributed to the pipe which in turn gives the deflection reading as shown in Figure 1.

Fig.1 Fabricated loading machine

3.3 Preliminary tests

The preliminary tests carried out on M Sand are Specific Gravity test as per IS 2720 (part III section 2- 1980) and Direct Shear test as per IS 2720 (Part XIII -1986). Results obtained are as follows. Specific gravity of the soil was found to be **2.66.** Slope and angle of internal friction are 0.63 and 32° respectively.

3.4 Experimental procedure

The experiment was carried out for 4 sets of reading at two different levels (0.4m and 0.8m) of burial with and without Geo-grids at both levels. The basic concept behind the experiment involves measuring the deflection values of the pipe for different readings using proving ring and dial gauge**.**

3.4.1 Preparation of dense bed by compaction

Dense bed of M-Sand was prepared up to 400 mm by suitable compaction method. Density of the compacted bed is calculated based on the volume and weight of the sand used and the pipe was placed above it.

3.4.2 Placement of HDPE pipe

HDPE pipe of 200mm diameter fitted with two dial gauges, one for the crown deflection and other for the springing line deflection at the joint was placed over the dense bed. The procedure is same for both the levels but the pipe is buried at 0.4m from top in case of 0.4m depth and at 0.8m from top in case of 0.8m depth as shown in Figures 2 and 3.

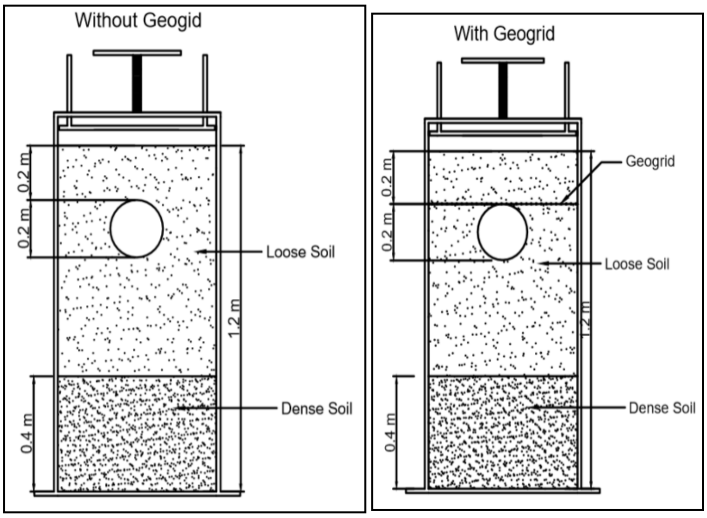


Fig.2 Line diagram of pipe buried at a depth of 0.4 m

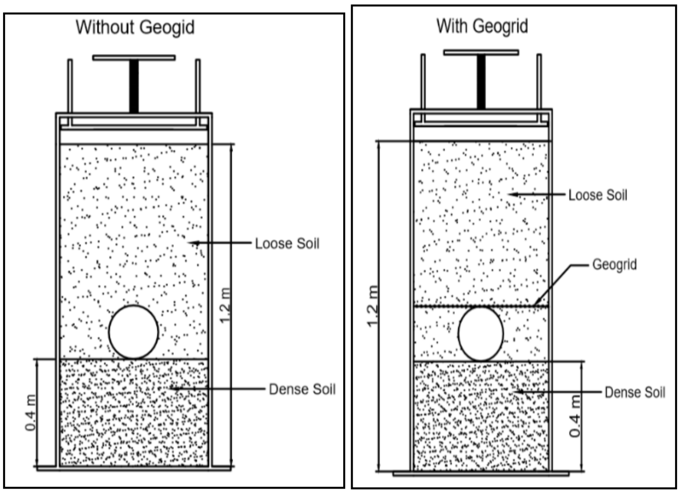


Fig.3 Line diagram of pipe buried at a depth of 0.8 m

3.4.3 Orientation of geo-grid

The geo-grid was placed as a mat above the pipe.

3.4.4 Preparation of loose backfill

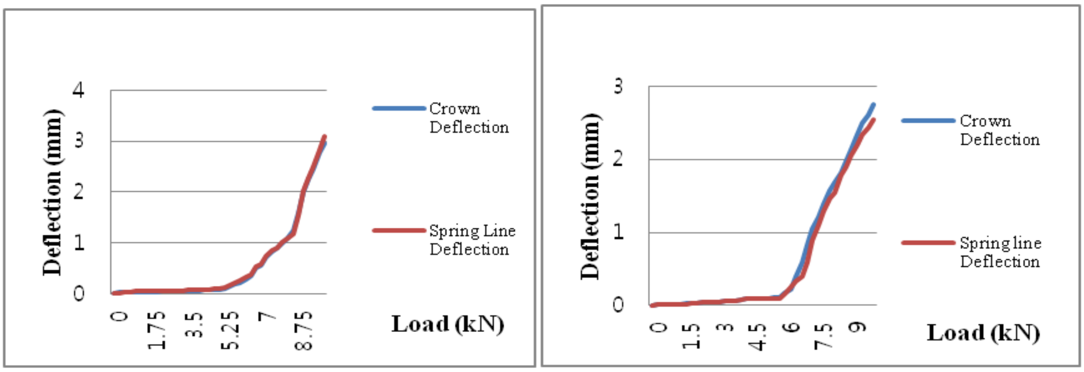
The loose backfill was prepared by pouring M- Sand using raining technique into the tank. It was prepared up to the height of tank.

3.4.5 Setting up proving ring

The tension proving ring along with magnetic base was attached to the loading frame. It is used to determine the load applied.

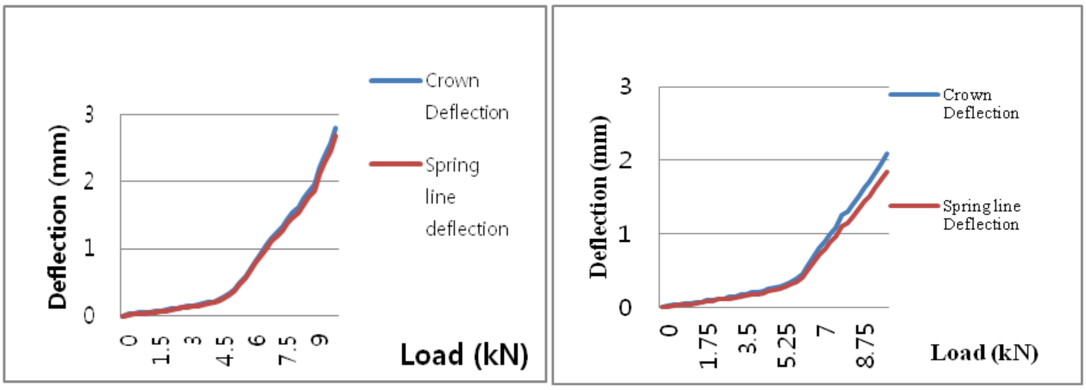
3.4.6 Application of load and deflection measurement

The load was applied to the loose bed by means of rotating lever arm. As the lever arm rotates the plate moves downwards and uniform loading was applied to the loose bed. Load was applied to the sand at an increment of 0.25 KN (25 kg) and the deflection for both crown and springing line direction was determined using dial gauge. Graph is plotted with load in y-axis and deflection in x- axis as shown in Figures 4 and 5.



(a)Without geo-grid **(b) With geo-grid**

Fig.4 Deflections at 0.4m



(a)Without geo-grid **(b) With geo-grid**

Fig.5 Deflections at 0.8 m

4. THEORY

4.1. Spangler Iowa deflection

M. G. Spangler studied the flexible pipe behavior to determine an adequate design procedure. Spangler incorporated the effects of the surrounding soil on the pipe's deflection. This was accomplished by assuming that Marston's theory of loads applied and that this load would be uniformly distributed at the plane at the top of the pipe. He also assumed a uniform pressure over part of the bottom, depending upon the bedding angle. On the sides, he assumed the horizontal pressure *h* on each side would be proportional to the deflection of the pipe into the soil. The constant of proportionality was called the modulus of passive resistance of the soil. The modulus would presumably be a constant for a given soil and could be measured in a simple lab test. He derived the Iowa formula through analysis as follows.

$$\Delta X = \frac{Kr^3 W_d D_L}{EI + 0.061er^4}, \qquad (1)$$

$$W_d = C_d \gamma B_d B_c , \; C_d = \frac{H}{B_d} \qquad (2) \text{ and } (3)$$

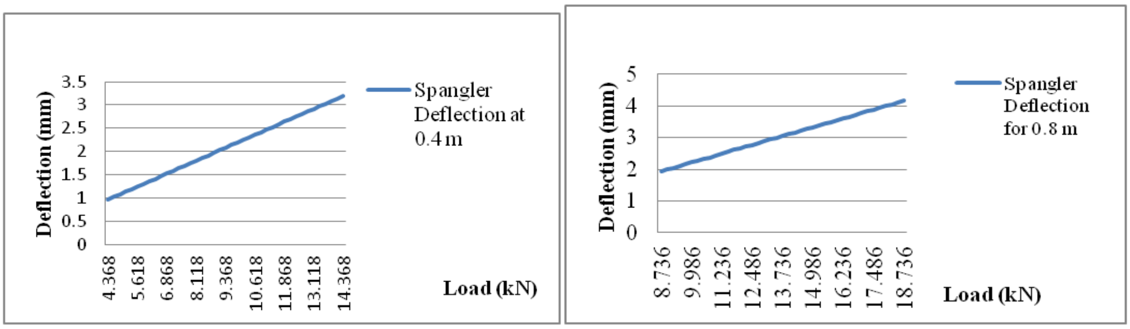
Where, D_L = Deflection lag factor, K = Bedding constant (It is obtained from the table based on bedding angle), W_d =Marston's load per unit length of pipe, E= Modulus of elasticity of the pipe material, I = Moment of inertia of pipe wall per unit length, e = Modulus of passive resistance of the side fill, ΔX = Horizontal deflection or change in diameter, r = mean radius of pipe, C_d = Load coefficient for ditch conduits, B_d= Horizontal width of ditch at top of conduit, B_c= Horizontal breadth of conduit, H = depth at which soil pressure is required, γ = unit weight of soil.

The above equation can be used to predict deflections of buried pipe if the three empirical constants K, D_L and *e* are known. The bedding constant K accommodates the response of the buried flexible pipe to the opposite and equal reaction to the load force derived from the bedding under the pipe.

In 1958, Reynold K Watkins, a graduate student of Spangler was investigating the modulus of passive resistance through model studies and examined the Iowa Formula dimensionally. The Analysis determined that 'e' could not possibly be a true property of the soil in that its dimensions are not those of true modulus. As a result of Watkins effort, another soil parameter was defined. This was the modulus of soil reaction, E' (Modulus of soil reaction) = e r. Consequently, a new formula called the modified Iowa formula was proposed:

$$\Delta X = \frac{Kr^3 W_d D_L}{EI + 0.061E'r^3} \qquad (4)$$

The above formula is used to calculate the deflection in this experiment. Graphs are plotted using the deflection obtained as shown in Figure 6.



(a) At 0.4m **(b) At 0.8m**

Fig.6 a and b Spangler Iowa Deflection

5. RESULTS AND DISCUSSION

1. The deflection on the pipe due to filling of M-Sand up to the crown of the pipe was found to be insignificant and therefore, the values were neglected.

2. With the help of the manual loading system, uniform surface load is applied on the sand backfill on the pipe, which is present above the dense sand bed.

3. Crown Deflection, in the case of HDPE pipe without Geo-grid reinforcement, at 0.8 m burial, is 2.8 mm and at 0.4m burial, the deflection is 2.95mm (As shown in Figure 7.) due to the applied uniform load of 10.0kN.

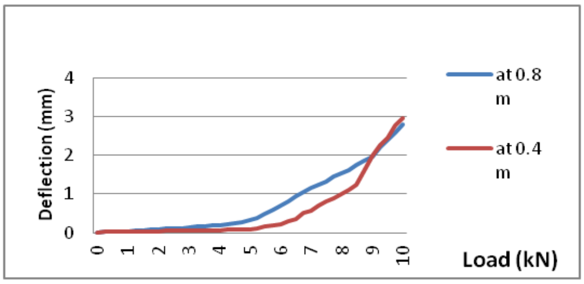


Fig.8 Crown deflections without geo-grid

4. Springing Deflection, in the case of HDPE pipe without Geo-grid reinforcement, at 0.8 m burial, is 2.68mm and at 0.4 m burial, the deflection is 3.09 mm (As shown in Figure 8.) due to the applied uniform load of 10.0kN.

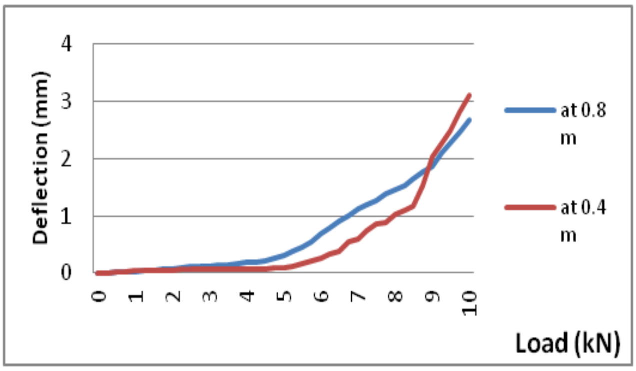


Fig.8 Springing line deflections without Geo-grid

5. Crown Deflection, in the case of HDPE pipe with Geo-grid reinforcement, at 0.8 m burial, is 2.09 mm and at 0.4 m burial, the deflection is 2.75 mm (As shown in Figure 9.) due to the applied uniform load of 10.0kN.

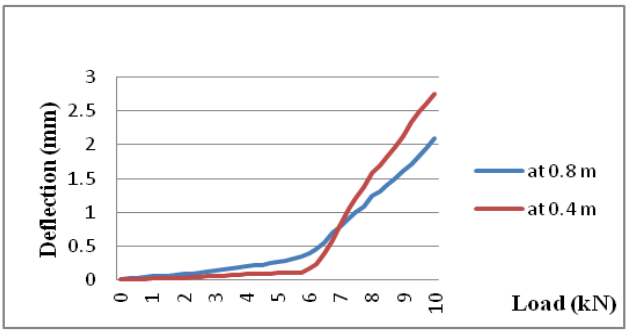


Fig.9 Crown deflections with Geo-grid

6. Springing Deflection, in the case of HDPE pipe with Geo-grid reinforcement, at 0.8 m burial, is 1.85 mm and at 0.4 m burial, the deflection is 2.54 mm (As shown in Figure 10.) due to the applied uniform load of 10.0kN.

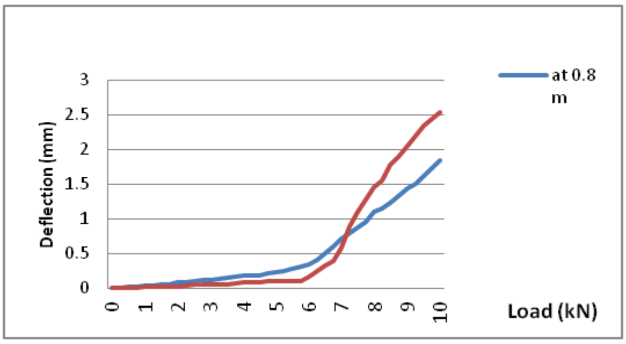


Fig.10 Springing line deflections with Geo-grid

7. The load v/s deflection characteristic of the HDPE Pipe was computed using the theoretical equation derived by Spangler.

8. In the case of theoretical computation, the application of uniform load of 10.0kN inclusive of the self-weight of the soil yields a crown deflection and springing line deflection at 0.4 m burial of 3.19 mm (As shown in Figure 11.) while for 0.8 m burial it yields a value for the same as 4.16 mm (As shown in Figure 12).

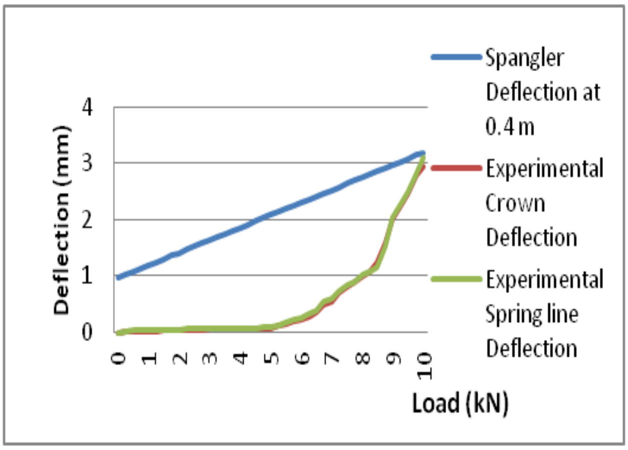


Fig.11 Theoretical v/s Experimental deflections at 0.4m

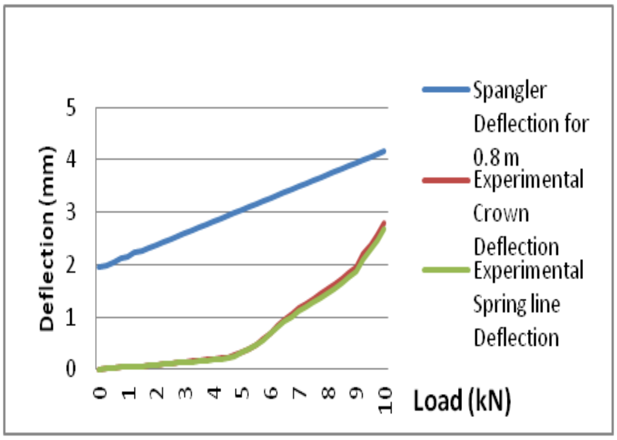


Fig.12 Theoretical v/s Experimental deflections at 0.8m

6. CONCLUSIONS

1. The project aimed at studying the behavior of HDPE pipe joint and studied the deflection behavior of the pipe joint by introducing a soil reinforcement material, i.e. Geo grid.
2. The experiment was carried out in a fabricated tank (trench condition) at two different depths of burial, namely, 0.4 m and 0.8 m.
3. The introduction of Biaxial Geo-grid as a soil reinforcement material turned out to be productive in this experiment. It played an important role in the modified behavior of the HDPE pipe at the joint. It improved the behavior of the pipe joint.
4. The springing line deflection due to application of uniform load was reduced by around 30 % due to the introduction of Geo-grid reinforcement at both 0.4 m and 0.8 m. The crown deflection due to the application of uniform load was decreased by about 7 - 10 %, which suggests that this specific orientation of Geo-grid Reinforcement was not suitable for arresting crown deflection and that the orientation of soil reinforcement plays a major role in reduction of deflection behavior of pipe.
5. The Spangler Iowa Equation Computation of Load v/s Deflection Characteristic of HDPE Pipe in Loose M-Sand Backfill under Uniform Load overestimated the experimental findings. This could be explained by the variation or difference between the assumptions made by Spangler while deriving the Iowa formula and the constraints of the experimental procedure.
6. The performance of flexible HDPE pipe at joint buried with M-Sand as backfill subjected to uniform load and its response under the influence of deflection was studied both with and without the presence of Geo-grid.
7. Outcome using Spangler Iowa Deflection Equation was used to study the deflection behavior of flexible pipe.

Though it may not be significant for joint study as Spangler Iowa equation helps in determining the deflection behavior of flexible pipe of a specified length, the outcome was used to interpret the results of this experiment.

8. The results suggest that this orientation of Geo-grid Reinforcement is best suited for arresting the Springing line Deflection of HDPE Pipe in Loose M-Sand backfill under Uniform load and Self-weight.

This experiment infers that the introduction of a soil reinforcement material reduced the deflection of the pipe, depending on its orientation and that the depth of burial or the depth of embedment can be reduced, i.e., shallow burial can be opted, in the presence of a soil reinforcement material (geo-grid in this case), thus, reducing the economy involved in excavation and placing of pipe.

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