UPLIFT BEHAVIOUR OF STRATA-GRID ANCHORED PIPELINES EMBEDDED IN GRANULAR SOILS

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SYNOPSIS

This paper presents the results of a program of experimental research which was conducted to establish the enhancement of uplift capacity of buried pipelines, which could be derived from the utilization of a woven synthetic geogrid known as strata-grids. The strata-grid is placed immediately above the buried pipeline in an inclined configuration, to derive the desirable anchorage characteristics. Experiments were conducted on strata-grid anchored pipelines which were embedded in either sand backfill or crushed granular 'A'-type backfill. It is observed that the incorporation of strata-grids results in a significant increase in the uplift capacity and that the increased capacity is sustained for large uplift movements of the buried pipeline.

INTRODUCTION

In recent years buried pipelines have been used quite extensively for the transportation of energy and mineral resources such as oil, liquified natural gas, coal slurries and mine tailings. Such long distance pipelines have also been proposed for water resources management and agricultural endeavours. Buried pipelines should take into consideration the mutual interaction between the pipeline and the surrounding soil. The interaction can be induced by effects of external loads such as traffic and embankment construction, ground movements induced by frost heave, ground swelling, ground faulting during earthquakes and inundation of the terrain. Recent advances in the study of soil-pipeline interaction are given by Ariman et al. (1979), ASCE (1980), Pickell (1983), Jeyapalan (1985) and Selvadurai (1985).

Buried long distance pipelines invariably encounter terrains or situations where the pipelines are subjected to uplift loads. Both temporary and sustained uplift forces on such pipelines can be induced by thermal deformations at overbends (Selvadurai and Lee, 1982), pipe floation due to flooding (Moore and Dight, 1980) and frost action (Nixon et al. 1983). The problem of pipe uplift is not restricted to long distance metallic pipelines used in energy transportation. With the increased use of advanced materials, buried pipelines composed of wound glass fibre composites, high density polyethylene and pipes with insulating layers have found extensive use in a variety of civil engineering and agricultural engineering endeavours. Such

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pipelines, due to their low specific weight, do not provide an adequate resistance to uplift at nominal depths of embedment. Conventional anchoring techniques for buried pipelines include the provision of either ground anchors, the incorporation of concrete anchor sleeves or the provision of an increased backfill in the form of a berm. Ground anchors are difficult and costly to install and the long term reliability and resistance of these devices to corrosion in waterlogged areas presents a serious problem. Concrete anchor sleeves also require considerable construction and installation costs and the effectiveness of these anchoring technique can be influenced by the gradual rotation of the sleeve by repeated cycles of uplift due to water level changes. Furthermore, the concentrated contact between the concrete sleeve and the pipe also leads to accelerated stress induced corrosion and fatigue damage of the pipeline. Increase of overburden requires extensive construction practices and materials handling. To this may be added the environmental unacceptability of the berm construction and costs for the maintenance of the berm construction.

The uplift behaviour of pipelines embedded in granular soil media has been investigated by Matyas and Davis (1983, 1988) and Trautmann et al. (1985). Similarly, the lateral or horizontal capacity of pipe sections have been investigated by Audibert and Nyman (1977) and Trautmann and O'Rourke (1985). These articles also contain comprehensive accounts of literature dealing with the evaluation of the load-displacement behaviour of buried pipelines. In a majority of these investigations the weight of the soil and its shearing resistance provides the primary resistance to uplift. Since the enhancement of the uplift capacity is of primary importance in establishing the efficiency and long term performance of pipelines which are subject to uplift, it is pertinent to enquire whether such improvements in the up-lift capacity can be derived by the incorporation of soil reinforcement methodologies (Jones, 1985). Selvadurai (1989) has documented the application of geogrids for anchoring of buried pipelines which are subjected to uplift loads. In that study the uplift behaviour of a 150 mm diameter pipe which is embedded in a granular mortar sand was investigated. These experimental studies indicated significant enhancement in the uplift capacity of pipelines which are reinforced by TENSAR geogrids (Netlon Ltd., 1984). Guided by these observations a more extensive experimental research programme was developed for the study of uplift mechanics of a large diameter pipeline which is embedded in fine and coarse grained granular soils and reinforced by CONWED Strata-grid.

THE EXPERIMENTAL FACILITY

The series of experiments were designed to evaluate the uplift capacity of a section of a pipeline which induces a state of near two-dimensional plane strain within the soil medium. The experiments were performed in a concrete test box with the following inside dimensions; 2400 mm in length, 1650 mm in width and 1605 mm in depth. The wall thickness of the U-shaped concrete box measured 260 mm (Figure 1). The larger sides of the concrete box were lined with highly polished stainless steel surfaces which reduces the frictional resistance to soil deformation along the

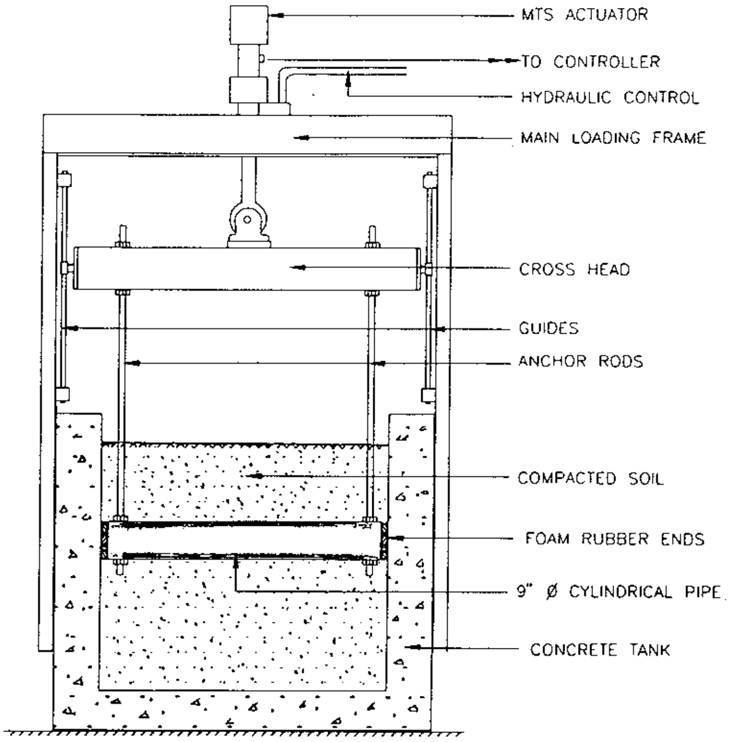


Fig. 1 The Test Facility for Conducting Pipe Uplift Tests - Cross Section

plane ends of the pipe. The pipe section used in this series of tests was approximately 215 mm in diameter and approximately 1610 mm in length. The clearance of approximately 20 mm between the flat ends of the pipe and the stainless steel sides of the test facility was to ensure that little or no frictional tractions would develop at the ends of the pipe. In order to prevent the soil from becoming lodged in this gap region, the plane ends of the pipe are fitted with a layer of soft foam rubber. The pipe section is connected to a moving horizontal frame by two threaded rods (Figure 2). The threaded rods are covered with a plastic tubing to minimize the development of frictional forces. The movement of the horizontal loading platform induces an upward pipe movement in a controlled and uniform fashion. The loading platform is constrained to move in a vertical direction by two roller bearings that exert virtually no frictional resistance. The controlled movement of the loading platform is achieved by an MTS servo-controlled hydraulic actuator which exerts a controlled rate of uplift movement. The MTS actuator and the hydraulic manifold system are mounted on a steel reaction frame which is anchored to the sides of the concrete tank. The uplift loads applied to the pipe section are measured by a load cell located in the MTS actuator and the movements of the rigid platform are also monitored by two LVDT's which are located at its extreme ends. The uplift load-displacement behaviour of the pipe are monitored via an MTS controller and a HP9836A computer.

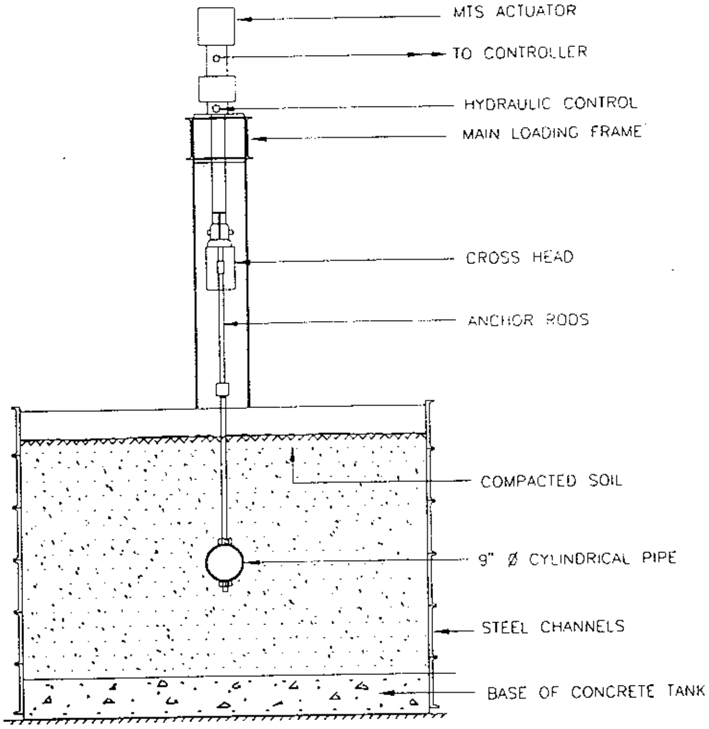


Fig. 2 The Test Facility for Conducting Pipe Uplift Tests - Longitudinal Section

EXPERIMENTAL PROCEDURE

Two types of granular soils were used in the experimental investigations. The sand used in the experiments is described as a mortar sand and could be classified as a poorly graded sand (SP) according to the Unified Classification System and the coarse granular soil is classified as a crushed granular 'A' according to a Ministry of Transportation of Ontario Specification (Bauer et al. 1991). Throughout the experiments the moisture content in the granular materials was maintained between 4% to 5%. The physical properties and certain basic shear strength properties of the two granular materials are summarized in Table 1.

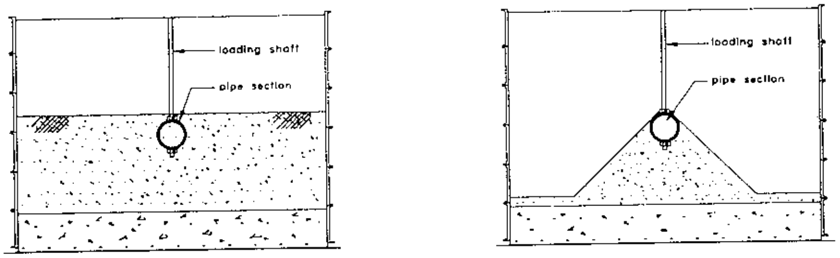
The experimental research programme consisted of two distinct categories of tests. In the first series of experiments, the uplift capacity of the pipeline seciton was determined in the absence of the geogrid reinforcement. These tests were conducted for both soil types for a single depth of embedment of 1040 mm (the embedment is measured to the invert level of the pipe). This corresponded to an embedment depth to pipe diameter ratio of 4.5. The experimental procedure adopted in conducting these tests can be summarized as follows. The pipe section along with the connecting rods are first removed and an initial layer of the soil is compacted to a depth of approximately 400 mm. This layer forms the base on which the pipe section could rest during compaction of the soil above the pipe section. The compaction is performed by a vibratory mechanical compactor (Mode Vibra pla/c). The layers are

Table 1 Granular Materials Used in Pipe Uplift Tests

Property or Characteristic	Granular Soil Type	
	Mortar Sand	Crushed Granular 'A'
D_{10}	0.27 mm	0.25 mm
C_u	3.00	35.20
C_c	0.95	3.10
Moisture Content (m)	4% to 5%	4% to 5%
Bulk Unit Weight (γ)	17.5 kN/m^3 (i.e.m^3)	19.2 kN/m^3
Angle of Internal Friction (ϕ)	approx. 40°-42°	approx. 45°-48°

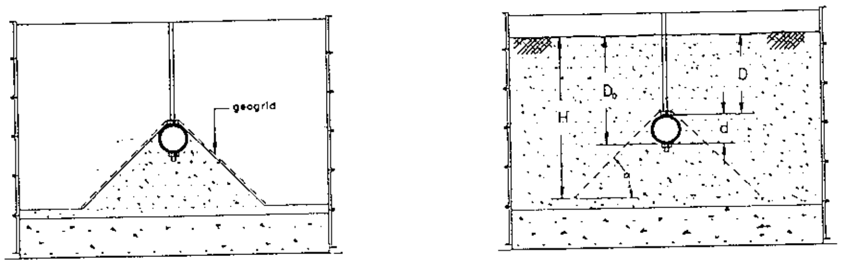
compacted in approximately 150 mm lifts. Each layer was compacted twice to ensure an even compaction. The pipe section was placed on the initially compacted layer and aligned to ensure correct application of the uplift load. The loading rods were left unconnected throughout the compaction of the granular soil in the test tank. Once the granular soil is compacted to the desired depth, the loading rods were connected to the loading platform. By maintaining the loose connection between the loading platform and the connecting rods it was possible to ensure that the pipe section was free of any preload which could be accumulated during the compaction procedure. The inability for the pipe to experience movement during soil compaction could also result in premature soil failure; this is eliminated by maintaining a loose connection between the loading rods and the loading platform. The experimentation involves a great deal of materials handling. This is achieved by using a power driven excavator (Melroe Bobcat Model # 743).

In the second series of experiments, strata-grid reinforcement (CONWED Product Strata-grid 5033) was used to develop the uplift anchorage. The procedure for the installation of the georgrid reinforcement can be summarized as follows. The soil layer was initially compacted to a depth of approximately 620 mm. This compacted granular soil was partially excavated to form inclined surfaces as shown in Figure 3. The geometry of the excavated granular soil was such that in its final position the strata-grid would have a development length (measured from the crown of the pipe to the end of the reinforcement) of approximately 915 mm and it would be inclined at approximately 45° to the axis of loading. The pipe section was placed over the central ridge (Figure 3) and the strata-grid was draped over the crown of the pipe (Figure 4). The strata-grid was not subjected to any pre-tension during the installation. In subsequent placement of the granular soil, the compaction was first achieved within the excavated sections until the original level of compaction was re-established. Uniform layers of the granular soil are subsequently placed and compacted using procedures identical to those outlined previously. Also, in this case the loading rods are maintained aligned but unconnected to the cross head during the compaction procedures. When the granular soil is compacted to the required depth the loading rods are connected to the loading platform. The rate of movement of the loading platform is controlled via an MTS controller. In this experimental research program the rate of movement of the loading platform corresponded to approximately 2.6 mm/min.



(A) SOIL IS COMPACTED TO THE UPPER LEVEL OF THE PIPE SECTION

(B) SOIL IS EXCAVATED AND FORMED TO RECEIVE THE GEOGRID REINFORCEMENT



(C) THE GEOGRID REINFORCEMENT IS PLACED OVER THE PIPE SECTION

(D) SOIL IS COMPACTED TO THE REQUIRED DEPTH

Fig. 3 Procedure for the Installation of the Geogrid Reinforcement

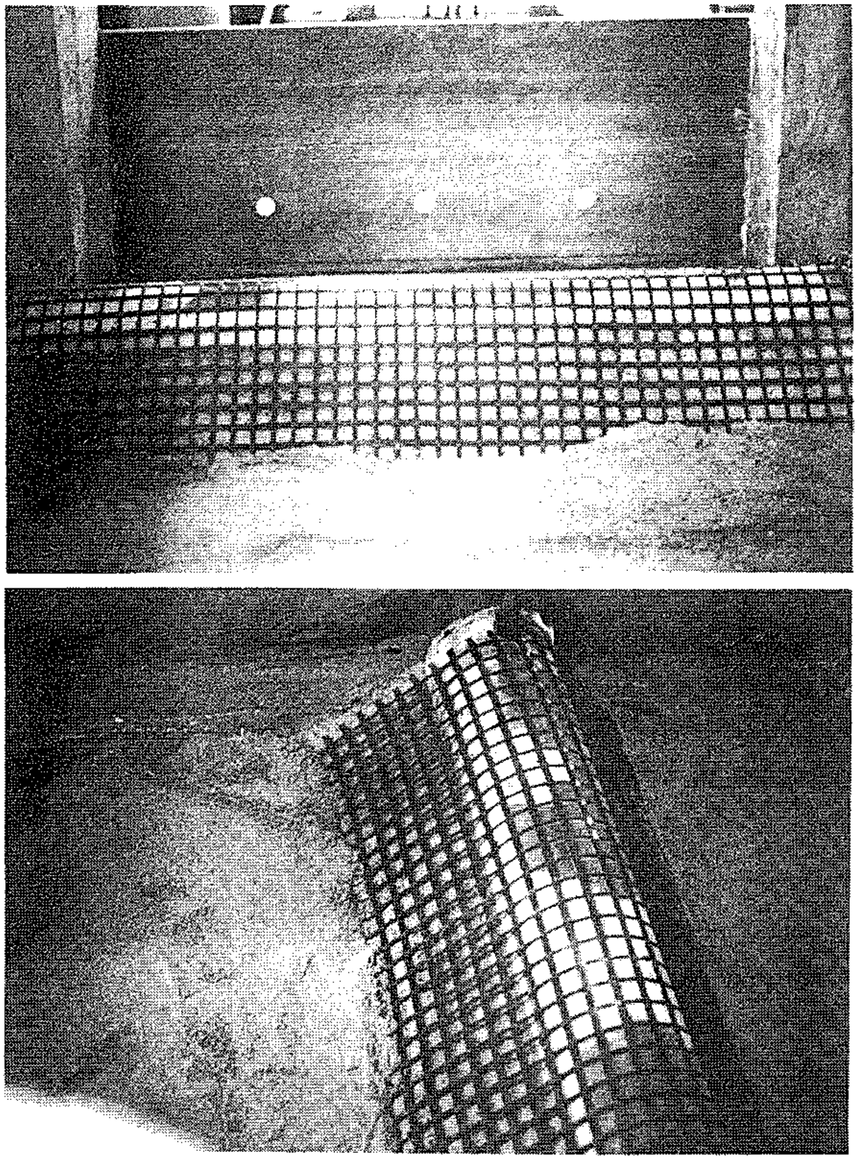


Fig. 4 Geogrid Reinforcement for Uplift Resistance - A Stage in the Installation

EXPERIMENTAL RESULTS

A series of three experiments each were conducted to determine the uplift load capacity of the unreinforced pipe section that was embedded separately in the fine grained mortar sand and the coarse grained crushed granular 'A' soil. The experimental results for the mortar sand are shown in Figures 5 to 7 and similar results for the crushed granular 'A' material are shown in Figures 8 to 10. Since standardized procedures were used for the compaction of the soils the test results displayed a very good degree of repeatability in the load-displacement behaviour. It may be noted that for the case of the unreinforced embedded pipe section, the uplift load reaches a peak value and as the deformation increases there is a progressive decrease in the

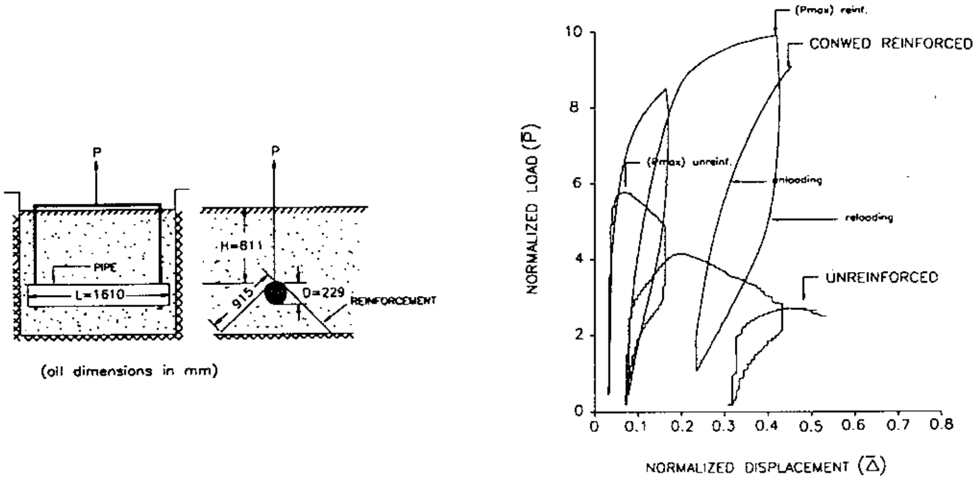


Fig 5 Load-Displacement Behaviour for a Pipe Section Embedded in Mortar Sand $(\overline{P} = \frac{P}{\gamma DHL}; \overline{\Delta} = \frac{\Delta}{D}; \Delta$ **= pipe displacement)**

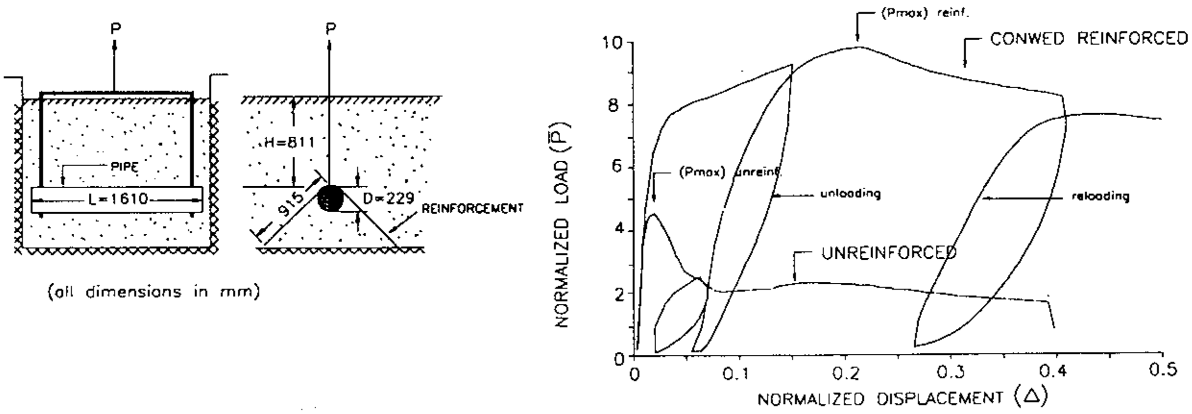


Fig 6 Load-Displacement Behaviour for a Pipe Section Embedded in Mortar Sand $(\overline{P} = \frac{P}{\gamma DHL}; \overline{\Delta} = \frac{\Delta}{D}; \Delta$ **= pipe displacement)**

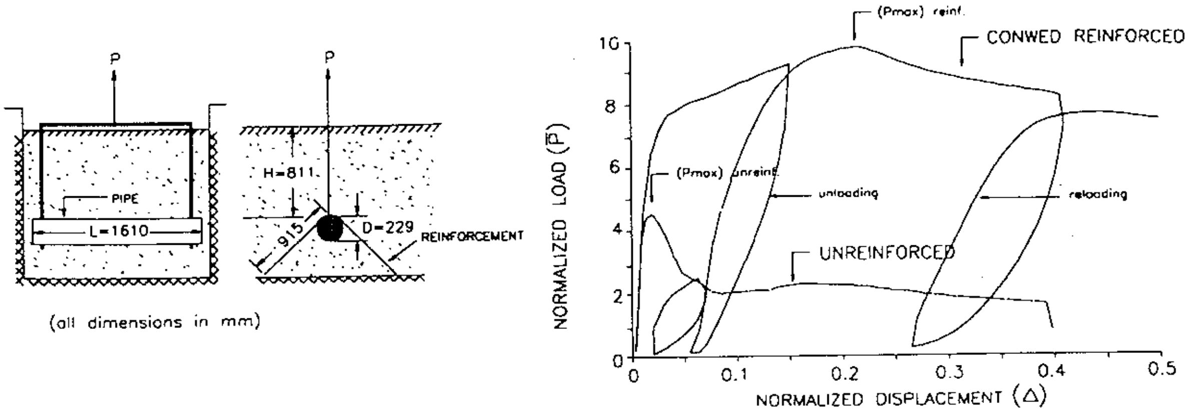


Fig 7 Load-Displacement Behaviour for a Pipe Section Embedded in Mortar Sand

$$(\overline{P} = \frac{P}{\gamma\, DHL}\,;\ \overline{\Delta} = \frac{\Delta}{D}\,;\ \Delta = \text{pipe displacement})$$

uplift capacity. The decrease is significant and the recorded maximum reduction averaged for the 3 tests is approximately 50% for the mortar sand and 35% for the crushed granular ‘A’. This occurs at a pipe displacement of 0.4 D where D is the diameter of the pipe. A series of three experiments each were also conducted to determine the influence of strata-grid reinforcement on the uplift capacity of pipe sections embedded separately in mortar sand and crushed granular ‘A’ soil. Again, the results of the series of tests displayed a great deal of similarity in the load-displace-

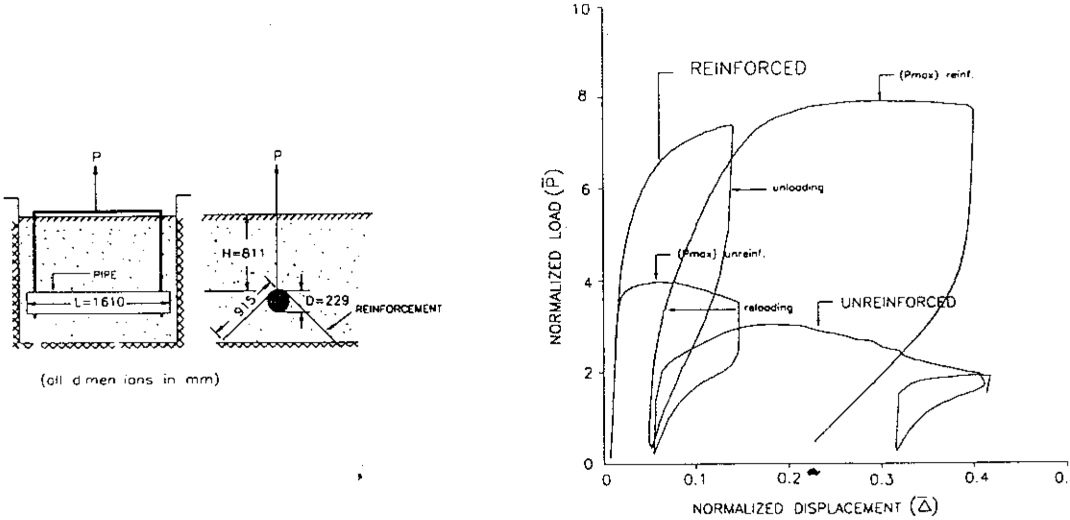


Fig 8 Load-Displacement Behaviour for a Pipe Section Embedded in Crushed Granular ‘A’ Soil

$$(\overline{P} = \frac{P}{\gamma\, DHL}\,;\ \overline{\Delta} = \frac{\Delta}{D}\,;\ \Delta = \text{pipe displacement})$$

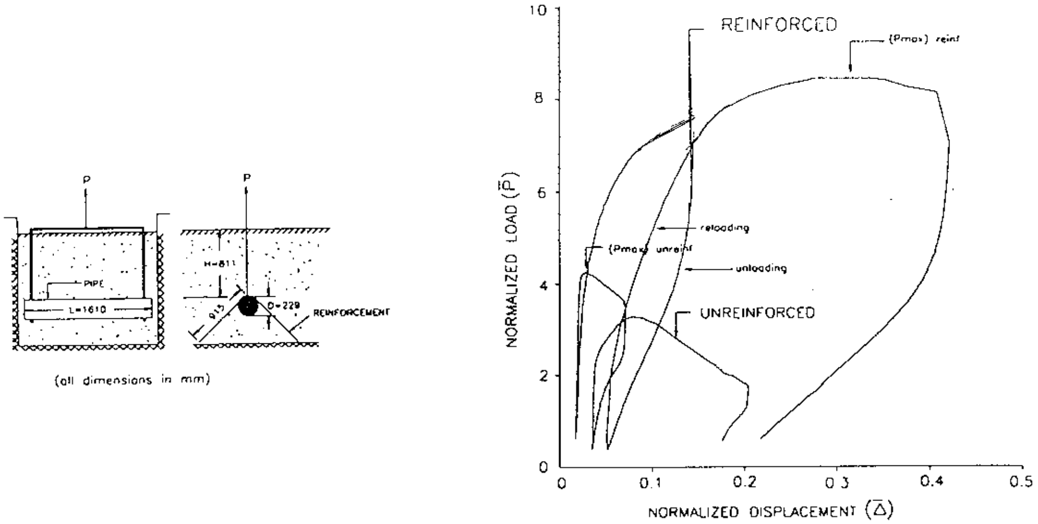


Fig 9 Load-Displacement Behaviour for a Pipe Section Embedded in Crushed Granular 'A' Soil

$$(\overline{P} = \frac{P}{\gamma DHL} ; \overline{\Delta} = \frac{\Delta}{D} ; \Delta = \text{pipe displacement})$$

ment behaviour. The results for the tests conducted on the strata-grid incorporated pipe sections are also presented in Figures 5 to 7 (for the mortar sand) and Figures 8 to 10 (for the crushed granular 'A' soil). It is evident that the uplift load carrying capacity of the pipe section is enhanced by the presence of the strata-grid reinforcement. Also, the load-displacement results do not indicate any evidence of strength

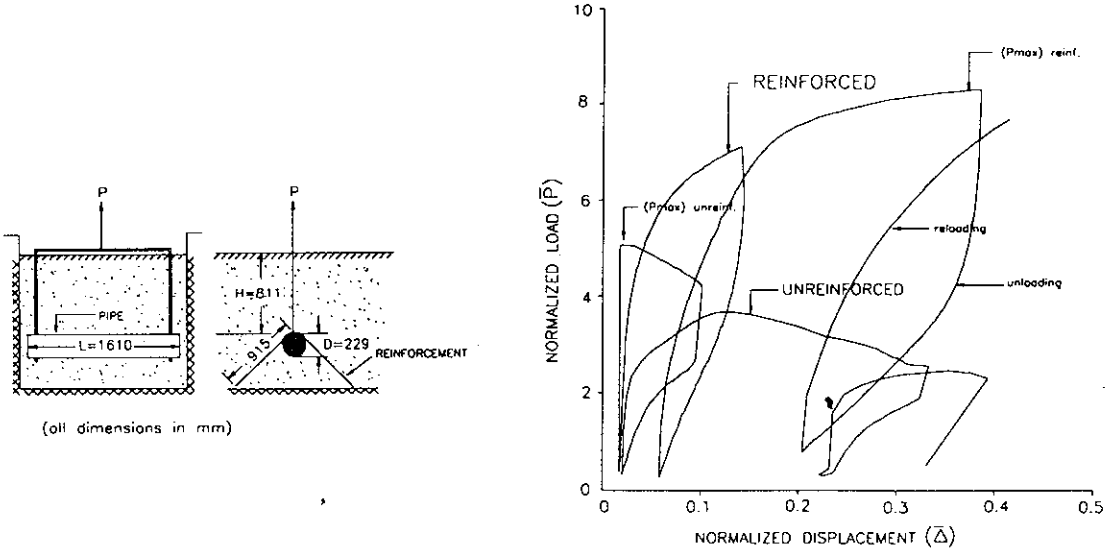


Fig 10 Load-Displacement Behaviour for a Pipe Section Embedded in Crushed Granular 'A' Soil

$$(\overline{P} = \frac{P}{\gamma DHL} ; \overline{\Delta} = \frac{\Delta}{D} ; \Delta = \text{pipe displacement})$$

deterioration with increasing pipe displacement. The results of the load-displacement curves given in Figures 5 to 10 also indicate the responses obtained during load-unload cycling. It is evident that while softening behaviour is observed in an unreinforced system the reinforced system is capable of maintaining the load carrying capacity without appreciable reduction. These results can also be summarized by considering the monotonic load-displacement response observed for both unreinforced and reinforced pipes embedded in mortar sand and crushed granular 'A' soil. These are shown in Figures 11 and 12.

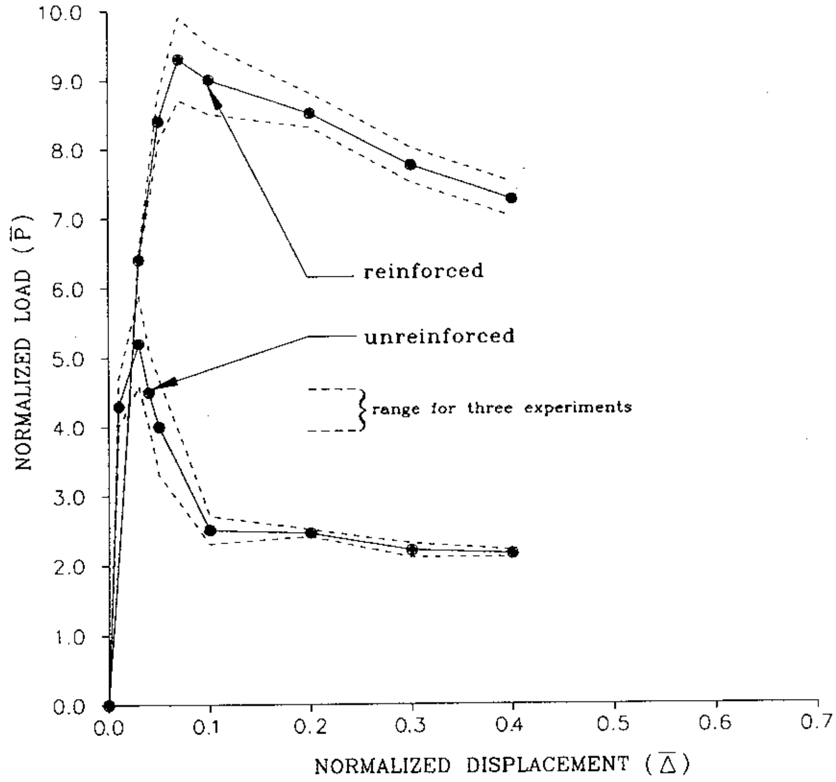


Fig 11 Monotonic Load-Displacement Behaviour of Pipe Section Embedded in Mortar Sand

$$(\overline{P} = \frac{P}{\gamma\, DHL};\ \overline{\Delta} = \frac{\Delta}{D};\ \Delta = \text{pipe displacement})$$

The Figure 13 indicates the typical soil failure pattern observed during the pipe uplift experiments conducted in the fine grained mortar sand. Initially, at small values of pipe displacement a tension crack appears at the section along the axis of the pipe. As the pipe displacements increase, wedge shaped failure surfaces are observed at the soil surface remote from the pipe location. Also a rectangular wedge of soil moves with the pipe section. This pattern of soil movement is also observed in pipe uplift experiments which incorporate geogrid reinforcement. Virtually identical failure patterns are observed for unreinforced and strata-grid reinforced pipe sections embedded in the coarse grained crushed granular 'A' soil. The Figure 14 indicates the results derived for the pipe embedded in the coarse granular soil.

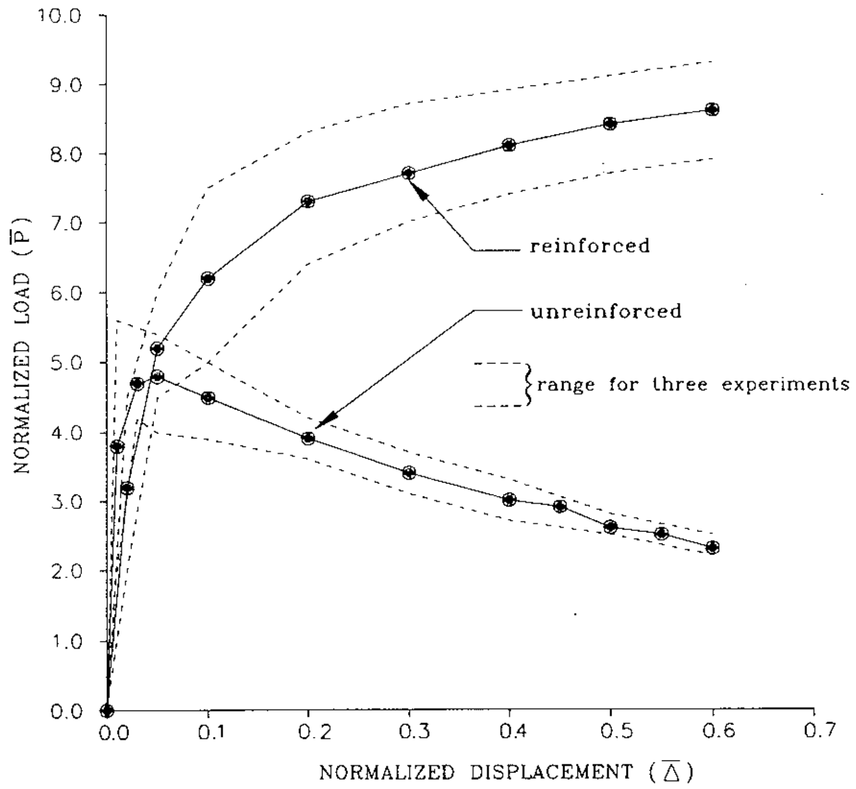


Fig 12 Monotonic Load-Displacement Behaviour of Pipe Section Embedded in Crushed Granular 'A' Soil

$$(\overline{P} = \frac{P}{\gamma DHL} ; \overline{\Delta} = \frac{\Delta}{D} ; \Delta = \text{pipe displacement})$$

CONCLUSIONS

This paper summarizes the results of a series of experiments which were conducted to ascertain the influence of strata-grid reinforcement on the uplift capacity of pipe sections embedded in compacted, moist, fine grained and coarse grained granular soils. The organization of the current series of experiments was influenced by the previous experiments conducted on small diameter (150 mm diameter) pipe sections embedded in mortar sand. In general the uplift capacity of the embedded pipe section can be influenced by a number of factors including (i) the depth/diameter ratio of the buried pipe, (ii) the surface characteristics of the pipe (i.e., either a rough interface or a smooth interface), (iii) the anchorage length of the strata-grid reinforcement, (iv) the grid geometry and properties of the reinforcement, (v) the inclination of the strata-grid in relation to the direction of application of the uplift load and (v) the degree of compaction of the granular soil. Admittedly it is not possible to investigate the influence of all of these variables in the development of uplift enhancement in buried pipes which incorporate strata-grid reinforcement. A limited number of the salient variables are investigated in this experimental research program. The results of the current series of experiments suggest the following conclusions.

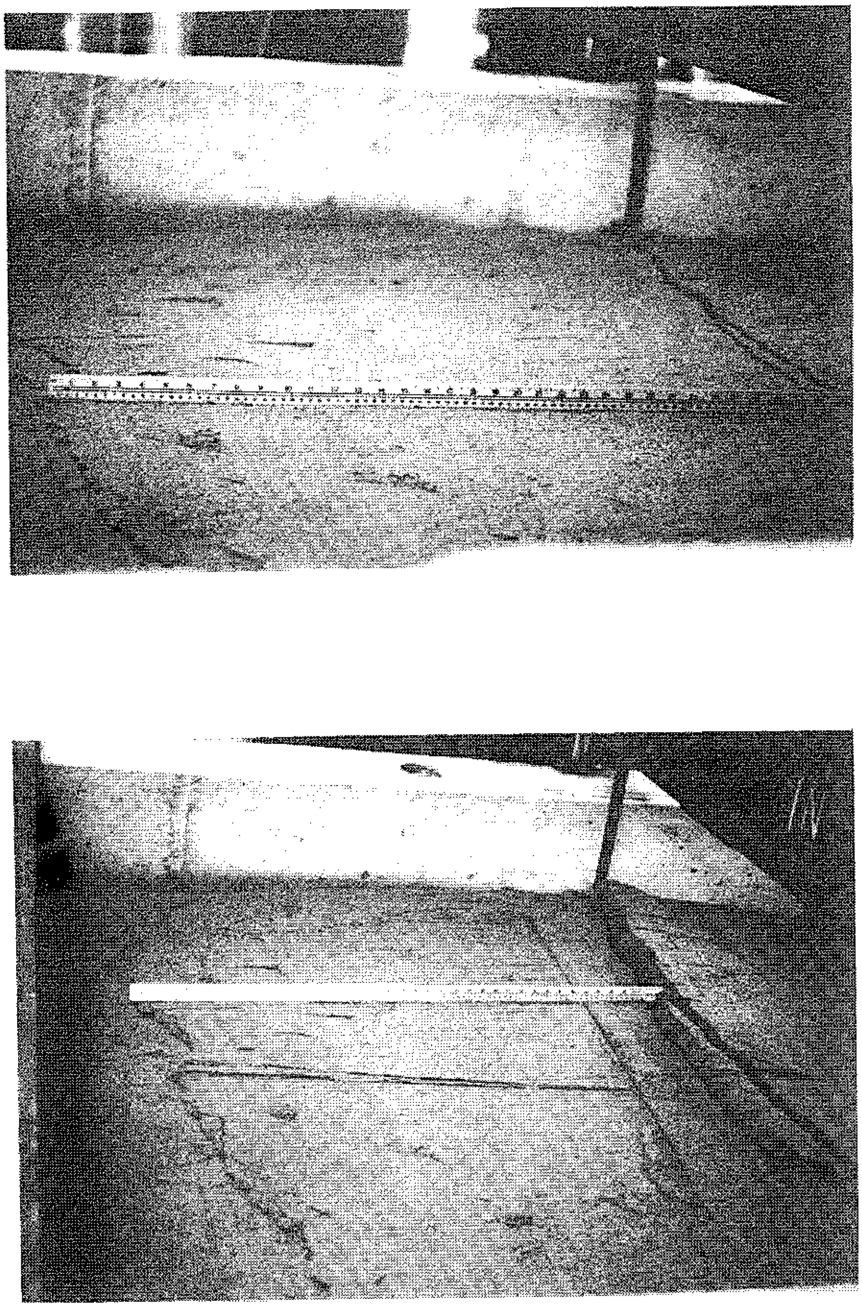


Fig. 13 Soil Failure Patterns Observed During Pipe Uplift Experiments - Results for Mortar Sand

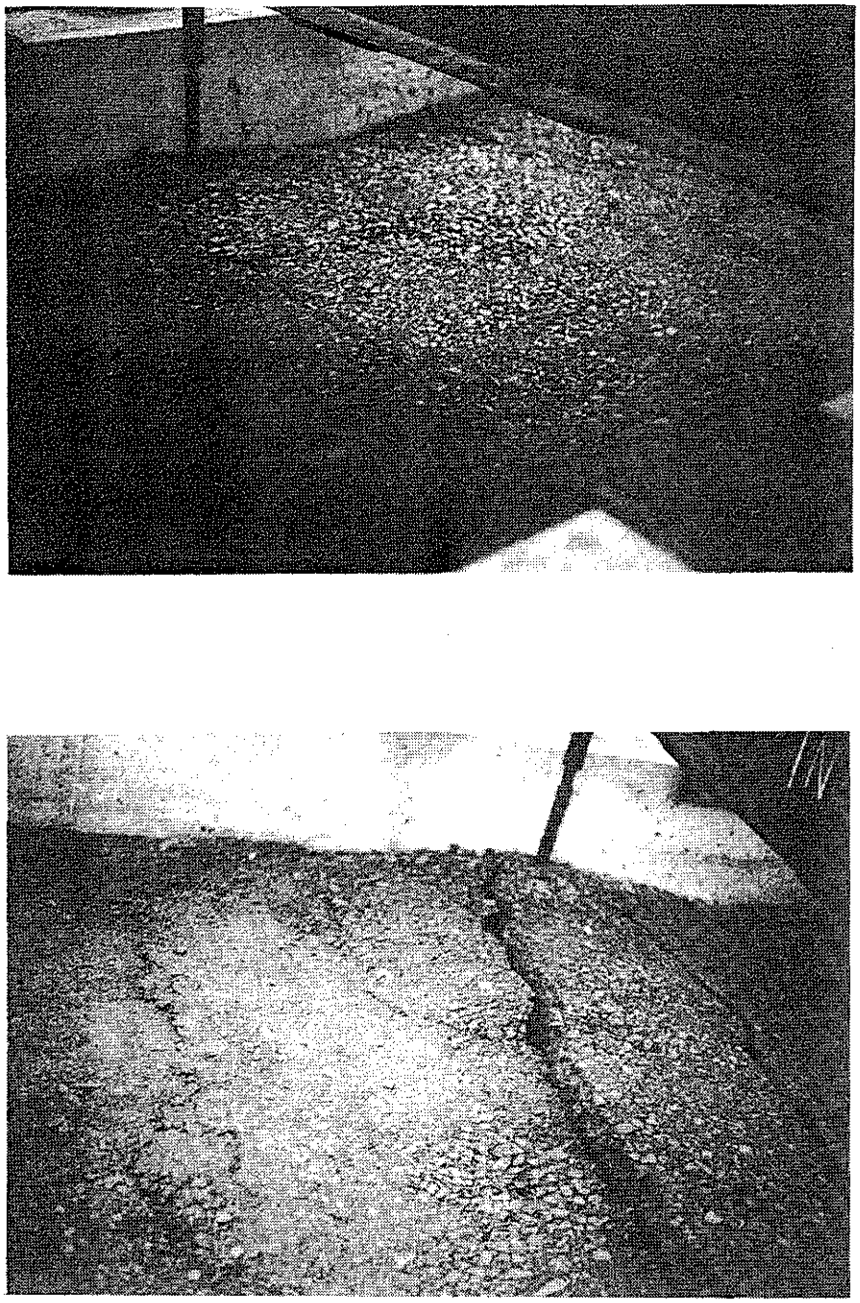


Fig 14 Soil Failure Patterns Observed During Pipe Uplift Experiments - Results for Crushed Granular 'A' Soil

1. The uplift resistance of buried pipes can be substantially increased by the utilization of strata-grids which contribute to the generation of an anchoring mechanism.
2. Experiments conducted on both fine grained granular soils and coarse grained granular soils indicate that at the peak load levels, the increase in the uplift capacity in the reinforced system can be of the order of approximately 80% in both fine grained and coarse grained granular soils. It is also noted that comparable experimental results obtained for tests conducted with smaller diameter pipe tests indicate that the increase due to reinforcement is of the order of 100%.
3. One of the most important observations of the experimental results is that the incorporation of strata-grids can lead to a pipe anchorage system where the increased uplift capacity can be maintained with increasing uplift displacements of the pipe section. This is in contrast to the performance of the unreinforced system which displays a significant load reduction or softening beyond the peak load.
4. At significant pipe displacements of the order of 0.4 D where D is the diameter of the pipe, the uplift enhancement due the geogrid is of the order of 225% in the case of pipes embedded in the fine grained mortar sand and is of the order of 160% for the case of pipes embedded in the coarse grained granular soil.
5. The development of a 'ductility' in the load-displacement response for a strata-grid reinforced pipeline can be of great benefit to increasing and maintaining the uplift capacity of the buried pipeline for significant pipe displacements. Such large displacements can be induced at overbend regions in buried pipelines which are subjected to thermal and pressure loads. When uplift loads are applied in a cyclic fashion, the irreversible soil movements around the pipeline will cause the jacking of the pipeline to the soil surface. This process induces additional axial stresses in the pipeline and the reduction in soil cover will lead to loss of serviceability of the buried pipeline. The additional uplift capacity generated by the provision of strata-grid anchorages will also result in the retention of the pipeline in an embedded condition.

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