CHAPTER 1

INTRODUCTION

1.1 GENERAL

Pipelines are important lifelines of modern urban infrastructure. Buried pipes are used mainly for water supply and drainage systems besides many other applications such as transportation of energy and mineral resources such as oil, liquefied natural gas, coal slurries and mine tailings. Long distance pipelines have also been proposed for water resources management and agricultural endeavours. The pipes used for these purposes may be rigid or flexible although the distinction between the two categories is blurring. Rigid pipe includes reinforced concrete, vitrified clay, and ductile iron. The design of rigid pipes is controlled by the yield strength of the material. Flexible pipe includes Steel, PVC, Aluminium, Fiber glass and High Density Polyethylene (HDPE). The design of flexible pipes is controlled by deflection or elastic buckling. In fact with good quality backfill, buckling is usually not a concern and deflection controls the design (Duncan 1977).

Since the early years of the 20th century in North America, cast iron pipes were extensively used to build water distribution systems, and concrete pipes were used to build sewer and drainage systems. The average life of these conventional pipes is about 50-70 years. Therefore, the infrastructures of most cities are near the end of their design life. In addition, the municipalities have to deal with the extension of their systems to keep up with the constant population growth. In order to replace or install new pipelines,
the technology of today brought new material types providing good alternatives, and often better products.

Studies using innovative materials in pipes have evolved more interest among all aspects of pipeline engineering. Many new materials such as plastic resins appeared on the market. According to Bjorklund (1996) in his article about the future use of plastic pipes, thermoplastic pipes account for 90% of the market for water distribution in the Northern countries and 75% for drains and sewer applications. There are three main types of plastic pipes used in water-industry applications. They are Polyethylene (PE), Polyvinyl chloride (PVC) and Fibre-reinforced plastic (FRP).

Polyethylene is characterised by its density. High density (HDPE) is strong, low density (LDPE) is relatively weak but highly ductile, and the medium density (MDPE) gives good compromise of strength and toughness. PVC is a thermoplastic and it is stronger than polyethylene, allowing thinner sections and reducing both weight and cost. However, it is more brittle and less tolerant of site handling. FRP pipes are relatively lightweight, and can be easily tailored to specific applications. They are also relatively easy to handle, but are susceptible to impact. The popularity of plastic pipes is due to constant improvements being made in manufacturing technologies and advantages over the conventional concrete and ductile iron pipes in terms of light-weight, cost efficiency and long term chemical stability.

This thesis explores the design of flexible plastic pipes, buried in shallow trench conditions with dry sand backfill and subjected to static loading. Primarily the study reported here is an attempt to understand the complex soil-structure interaction between the pipe and the soil. The tests were conducted on PVC pipes of 200 mm diameter.
The main objective of the study is to reduce the deformations and stresses of buried pipe under static loading by reinforcing the soil around or above the buried pipe. Apart from conducting model tests on pipes of 200 mm diameter it is felt essential to carry out numerical analysis for the conditions of tests conducted for better understanding of the buried pipe-soil system and also to bring out influence of various pipe and soil parameters on response of buried pipe. This thesis is a consequence of that decision to undertake parametric analyses of the buried PVC pipe by numerical modeling.

In order to conduct finite element analysis the physical properties of the components of the buried pipe tests needed to be well understood. Studies were conducted on the preliminary properties of the soil fill leading to the selection of a suitable soil model. Properties provided by the manufacturer for PVC pipes were checked. Finite element analysis was limited to plane strain problem. For simulation of the buried pipe tests this limitation proved to be a shortcoming. This research proves to be a catalyst for further development in the study of buried pipes.

The knowledge gained from these studies led to the preliminary recommendation of simple design for buried pipes in trenches backfilled with sand and subjected to static loading conditions.

1.2 TEST SERIES OF PVC PIPES

The pipes taken for the study are made of PVC. This thesis is restricted to discussion and analysis of pipes of nominal diameter of 200 mm buried in dry sand with and without geogrid reinforcement. The geogrid reinforcement (CE121) of single layer is placed at different locations above the pipe crown and two layers at the spring line and tested for each condition independently. Uniformly graded sand was chosen as the backfill. All the tests in the laboratory were conducted with dry sand. The sand was either
tamped or vibrated into place to ensure perfect installation condition. The minimum height of backfill cover to the crown of the pipe was 200 mm while the maximum was 600 mm. These conditions simulate minimum and maximum cover to depth ratio (H/D) of 1 and 3 respectively. Deflections and strains of selected pipe cross sections were recorded during loading of the surface of the backfill. The settlement of the loading plate was also monitored.

The pipe tests preceded the numerical analyses reported in this thesis and provided an incentive for the two dimensional finite element analysis of the buried pipe using ‘PLAXIS’.

1.3 SCOPE OF THE INVESTIGATION

Although considerable work has been done to study the response of buried pipes analytically (using elastic theory) and numerically (using approximate methods such as finite element and finite difference techniques) there is a limited experimental work in the area of buried pipes.

In the present investigation experimental studies were conducted on buried flexible PVC pipe subjected to surface pressure applied over a finite area. Circular PVC pipe was buried in loose and dense conditions of sand bed and their response was studied for cover to depth ratios of 1, 2 and 3 which simulates shallow trench conditions. Various important parameters considered were strain, crown deflection of the pipe, surface pressure, depth of embedment, and the relative density of the soil. In addition a comparison was done between the tests with and without geogrid reinforcement in soil. Finally the effect of geogrid reinforcement on the structural behaviour of a buried pipe was evaluated. The finite element analysis was performed with the ‘PLAXIS’ finite element code. In the analysis model tests conducted are simulated and analysed numerically. The results thus obtained are compared
with the experimental results and validated. Parametric analyses were carried out by varying the trench width, stiffness of the pipe and the area of loading to gain further insight on the behaviour of the buried pipe.

1.4 OBJECTIVES OF THE PROPOSED WORK

It is proposed to investigate the stress and deformation behaviour of buried pipes and methods to minimize the deformations and stresses around the pipes. To achieve the said objectives, it is aimed at to investigate the following by conducting model tests on PVC pipe and analysing numerically.

1. The load-deformation behaviour of the buried pipe and stress variation across the cross section of the pipe under static loading.

2. The influence of depth of embedment and density of the backfill on the deformation and stresses in pipe subjected to static loading.

3. The deformation behaviour of buried pipe when the soil is reinforced with single layer of geogrid and evaluate the structural performance of the pipe.

4. Numerical validation of the behaviour of buried pipe and parametric analysis using PLAXIS FE code.

1.5 ORGANISATION OF THE THESIS

A brief discussion on the importance, necessity and application of plastic pipes in the current scenario, significance of soil-structure interaction, objectives and scope of the work and the organizational summary of the dissertation are included in chapter 1.
A review of the literature on buried pipes is included in chapter 2. Numerous research works relating to study of buried pipes are discussed but limited works are related directly to experimental studies on buried flexible pipes.

In chapter 3 the details regarding the experimental set up and buried pipe tests conducted on the 1g model in the laboratory are discussed. The methods adopted for the preparation of the sand bed and the different densities of the backfill are outlined. The instrumentation adopted for the measurement of deflections and strains on the buried pipe has also been illustrated in this chapter.

The experimental results on buried pipes with and without the provision of geogrid reinforcement are presented for various cases in chapter 4. Deformations and stresses observed at the crown and springline of the pipe installed in two different densities of the backfill and levels of embedment are discussed. The reduction in deformations and stresses in pipes tested due to the provision of geogrid reinforcement at different levels has also been discussed and graphically illustrated. The results indicated the realistic behaviour of the buried pipes in different densities of the backfill under static loading conditions.

Chapter 5 presents the finite element studies conducted using ‘PLAXIS’ software on the buried pipes with and without the provision of geogrid reinforcement in two densities of the backfill. Typical results of deformation and stresses obtained using the FEM code is validated with the experimental results. Few parametric studies were conducted using the FE code for simple boundary conditions and loading.
The summary and conclusions drawn from the study based on the experimental and numerical analyses, and the recommendations for further research in this area are presented in Chapter 6.