CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION TO THE THESIS

This thesis explores the design of flexible pipes, buried in shallow trench conditions with dry sand backfill and subjected to traffic loading. Primarily the study reported here is an attempt to understand the complex soil-structure interaction between pipe and soil, as observed in a comprehensive load test series conducted around 1990 on pipe installations, mainly within a laboratory facility, at the University of South Australia (Cameron, 1990 and 1991). The pipes were spirally-wound uPVC pipes, ranging in diameter between 300 and 450 mm, generally.

The objective of the full-scale tests was to provide guidelines for safe cover heights for trafficking the backfill. As some unexpected results were obtained in the buried pipe testing program, it was felt that some benefit may arise from finite element modelling of the buried pipe installations. This thesis is a consequence of that decision to undertake numerical modelling.

The research was undertaken on a part-time basis over a number of years under the supervision of Professor John Carter at the University of Sydney, as the author continued employment at the University of South Australia. In order to conduct finite element analyses, the physical properties of the components of the buried pipe tests needed to be well understood. Studies were conducted of the fundamental behaviour of the soil fill, leading to the development of a constitutive model for the soil. Properties provided by industry of the spirally-wound, pipe were checked. Generally the soil and pipe tests were conducted by, or under the supervision of, the author.

Various checks were conducted to validate the soil model before it was implemented in an element of a finite element program, AFENA (Carter and Balaam, 1995). Initially finite element analyses were limited to plane strain or axi-symmetric analyses. For simulation of the buried pipe tests, this limitation proved to be a shortcoming. This research proved to be a catalyst for further development of AFENA and so, ultimately, three-dimensional finite element analyses were performed for each installation.

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

1.2 THE TEST SERIES OF UPVC PIPE TRENCH INSTALLATIONS

Between 1989 and 1991, a series of full-scale tests were conducted for a plastic pipe manufacturer to determine safe cover heights for trafficking of pipe installations in trenches (Cameron, 1990 and 1991). Both construction traffic and traffic on a paved surface were to be investigated. The target allowable vertical deflection of the pipes was 5% of the diameter. The author designed and supervised laboratory soil box tests in a three metre long “trench”. As well, a few field tests were conducted to validate the findings in the laboratory soil box tests.

A summary of the tests is provided in Chapter 4. In all, eighteen soil box tests are reported, of which three were tested with a simulated thin, street pavement cover. An additional four field tests are reported, making a total of 22 full-scale, flexible pipe loading tests.

All the pipes were made of uPVC, spirally-wound and ribbed with a T-profile. This thesis is restricted to discussion and analysis of pipes of nominal internal diameter of 300, 375 and 450 mm, although a few tests were conducted on 250 and 600 mm nominal diameter pipes. Within the 300 mm diameter pipe range, two different cross-sections were evaluated. Therefore in this thesis, the performances are reported of three pipe diameters, which include four pipe stiffnesses.

Poorly-graded, sand used in the production of concrete, was chosen as a suitably low quality backfill for evaluation of safe cover heights. All tests in the laboratory were conducted with dry sand. The sand was either tamped or vibrated into place and the density index of the sand was estimated by means of dynamic penetration resistance. The minimum height of backfill cover to the crown of the pipe was 0.3 m, while the maximum was 0.8 m.

Deflections of selected pipe cross-sections were recorded during loading of the surface of the backfill. The movement of the loading plate was monitored also. Earth pressures within the installation were measured in approximately half of the tests.

The pipe tests preceded the numerical analysis reported in this thesis, and provided the incentive for the numerical modelling and additional testing of the backfill material and the pipe profile.

1.3 NON-NUMERICAL ANALYSES OF THE BURIED PIPE TESTS

A review of the literature on buried pipes is contained in Chapter 2. Numerous publications relating to flexible buried pipes are discussed, but unfortunately few related directly to traffic loading of pipes with shallow backfill cover. The data from the buried pipe tests are analysed in Chapter 9 with respect to the pertinent literature.

1.4 SOIL TESTING AND A CONSTITUTIVE MODEL FOR THE SAND

An engineering description of the sand is provided in Chapter 5. In order to develop a constitutive model for the sand to implement in numerical modelling of the soil-pipe installations, a series of triaxial tests were undertaken to explore the elastic and yield behaviour of the soil. All tests were conducted on dry sand. The results of the triaxial testing are included in Chapter 5.

Based on a review of the literature on constitutive modelling of sand (Chapter 3), a model was developed, which required a number of material constants. The theoretical basis for the model is provided in Chapter 6. The material constants were deduced from the triaxial test data using single element modelling performed on a spreadsheet (refer Chapter 6). The constitutive model for the sand was implemented into finite element program AFENA (Carter and Balaam, 1995). The implementation of the soil model was checked by finite element modelling of the triaxial tests, and comparing the predicted behaviour with the predictions from the single element modelling. Details are given in Chapter 6.

1.5 VERIFICATION OF PIPE PROPERTIES

The cross-sectional properties of the pipe were considered best deduced experimentally, due to the T-shaped, spirally wound profile of the pipes. Unfortunately, the uPVC pipes are no longer manufactured in the profiles that were tested originally. However, a sample of a 375 mm diameter pipe remaining from an original buried pipe test was studied and the test methods and results are detailed in Chapter 4. Properties of the plastic and the pipe profile were compared with industry recommendations and Australian Standards (Standards Australia and Standards New Zealand, 1998, referred to as AS/NZS2566.1-1998), wherever possible. Pipe stiffness tests were conducted on lengths of the pipe. Then coupons of the pipe were shaped from the pipe for testing and evaluation of tensile strength and tensile stiffness.

1.6 FINITE ELEMENT ANALYSES OF THE SAND AND THE BURIED PIPES

The first application of the model as implemented in AFENA was the difficult problem of surface loading of the sand through a rigid, circular plate. The axi-symmetric finite element model for this case is explained in Chapter 6. Plate load tests had been conducted on the sand in a 44-gallon drum, adding the further complication of a side boundary condition to the model. The influence of the sidewall condition (perfectly smooth, perfectly rough or interface joint) on the analytical predictions is reported in the Chapter.

Chapter 7 is devoted to the initial modelling of the laboratory and field tests of the buried pipe installations in two dimensions (2D or plane strain). The pipe was simply modelled with beam-column elements. The soil in the trench was zoned according to the installation procedure, each zone having an initial void ratio based on penetration testing of the sand prior to testing. The interface between the sand and the trench wall was simulated with an interface joint element. Generally, 2D modelling was found to be unsatisfactory, as experimental observations were not well matched with the solutions from the 2D finite element analyses (FEA).

Subsequently, a three-dimensional version of the element incorporating the adopted soil model (element type 43) was added to program AFENA. Since it was proposed to model the pipe as simply a pipe of an equivalent single thickness, the pipe stiffness tests were numerically modelled to appraise the adequacy of the simulation. These finite element analyses of the pipe loading tests and the three-dimensional analyses of the buried pipes are reported in Chapter 8.

The remainder of the Chapter is concerned with the 3D FEA of the buried pipe installations. Analyses were unable to be conducted with an interface joint at the sidewall. Initial findings led to investigation of the assumed rigidity of the sidewall in the laboratory pipe installation tests and the related finite element analyses. The influence of relaxation of the side boundary condition on the load-deflection response of the buried pipes is presented.

1.7 DESIGN IMPLICATIONS

Chapter 9 reviews the experimental work and finite element analyses reported in the previous Chapters for the design of shallow buried pipes of similar flexibility, with sand backfill. Soil properties for design purposes are backcalculated from the experimental data and compared with current design recommendations. A recommendation is made concerning the likely distribution of pressures due to traffic loading of a non-paved backfill, based on the finite element analyses. The simple methods of estimating pipe deflections currently available to designers are evaluated using this approximation of stress above the pipe.

Chapter 10 provides a general summary and a list of the major conclusions arising from this thesis.

1.8 REFERENCES TO THE CHAPTER

Cameron, D. A. (1990). Simulated Vehicular Loading of Rib-Loc Pipes Buried in Non-paved, Backfilled Trenches. Techsearch Report, School of Civil Engineering, South Australian Institute of Technology, September.

Cameron, D. A. (1991). Simulated Vehicular Loading of Rib-Loc Pipes Buried in Non-paved, Backfilled Trenches – Report No. 2. Techsearch Report, School of Civil Engineering, South Australian Institute of Technology, February

Carter, J. P. and Balaam, N. P. (1995). AFENA – a General Finite Element Program for Geotechnical Engineeering. School of Civil and Mining Engineering, University of Sydney, Sydney, Australia

Standards Australia and Standards New Zealand (1998). Buried Flexible Pipes. Part 1: Structural Design. AS/NZS 2566.1, Standards Australia, Homebush, NSW.