Fourth Australia - New Zealand
Conference on Geomechanics,
Perth, 14-18 May 1984

# Large Scale Test Facility for Model Conduits and Arches Buried in Soil

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SUMMARY A facility has been constructed at Mile End S.A. for the purpose of testing various soil-structure systems under simulated earth and vehicle loadings. The initial tests have been conducted on a 0.75 m diameter corrugated metal pipe buried at about 1 m below the surface of a dense sand. The facility provides for a pneumatic sand handling and distribution system that incorporates a sand raining operation for selection and control of sand density. A custom designed micro computer has been installed to gather, process and store data from a variety of measuring instruments.

In the initial test programme pipe stresses and deflections and soil strains were all measured electronically. The data initially compiled on disc were transferred to a larger computer to be processed for presentation in high quality graphical form. Results show good agreement with recently developed theory that has previously been untested.

## 1 INTRODUCTION

A vital need exists for extensive and versatile testing programmes for buried conduits. Methods used for design at the present time are drawn primarily from proposals made between the early 1930's and the 30 years following (Spangler, 1933; Spangler, 1941; White and Layer 1960). These methods are based on what are now considered to be crude models and have associated with them problem-specific parameters (such as the modulus of soil reaction, E', and the settlement ratio, $r_{sd}$) the magnitudes of which have caused a considerable dilemma for designers over the years. For conventional pipe installations, failures of a catastrophic nature have been almost unknown and while size and loading remained small there was little interest in developing more sophisticated procedures.

With recent increases in size, type and frequency of buried conduit use, alternative methods have been proposed that have a more rigorous theoretical basis and that are formulated in terms of fundamental parameters of engineering mechanics (Burns and Richard, 1964; Kay and Krizek, 1970; Duncan, 1978; Flint and Kay, 1982; Kay and Hain, 1982). However, designers have been understandably reluctant to make use of the new proposals largely because, in the main, they have not been adequately verified by testing programmes.

In some of the recent developments, measurements taken from full scale field tests have been cited as support for the proposals but, owing to the fact that the measurements were invariably associated with a single case of working load behaviour, the value of such measurements for general confirmation purposes was limited.

If further progress is to be made at a reasonable cost, a large-scale model testing approach must be taken where the behaviour of a practical range of this type of structure can be evaluated through to failure conditions. This is not a simple matter, however. When scale models are used, some simplifications are incorporated and a very important question is that regarding the relevance of the model to the prototype. It is necessary to ensure that those aspects of the prototype that are inevitably improperly modelled have little significance in terms of the mode of behaviour that is under study.

A testing facility has been constructed by the Civil Engineering Department of the University of Adelaide that is considered to be appropriate for meeting the foregoing requirements and to be capable of providing test results suitable for evaluating design procedures. The aspects of the facility specifically incorporated into the design to ensure its efficiency and versatility are as follows :-

(a) The scale of the model is sufficiently large to enable testing with real soils.

(b) Plane strain conditions in the plane normal to the axis of the conduit structure are ensured by a sufficiently rigid test bin.

(c) The boundaries of the soil region are at a sufficient distance from the test structure to preclude significant interference with the structural response.

(d) There is no restriction on the shape or stiffness of the test conduit.

(e) The soil fill may be placed at various densities and a uniform density is obtainable through use of a sand-raining soil placement system.

(f) Fill cover heights may be varied up to 1.5 m (two diameters for a 750 mm diameter circular model conduit).

(g) Applied loads may be uniformly distributed or they may be concentrated in a variety of configurations.

(h) An automated micro-computer based instrumentation system facilitates acquisition and rapid processing of substantial quantities of data.

This paper provides details of the design, construction and capabilities of the test facility, details of measurement techniques used to determine the soil properties, and some typical results from the initial testing programme.

## 2 DESIGN OF TEST BIN

The inside dimensions of the test bin are 4 m long by 2 m wide by 3 m high. It is designed to test a 2 m long conduit up to 1 m in diameter with a minimum of 1.5 m of fill either side, 1 m of fill beneath the invert and up to 1.5 m of cover fill (see Fig. 1). The bin walls are constructed from 150 x 50 x 7 mm corrugated steel plates lined with 3 mm flat steel plates. The walls are contained by a number of hoop beams that are sufficiently stiff to ensure plane strain conditions for the test system. Greased 0.2 mm polythene plastic sheeting covers the interior surface of the bin wall to minimize wall friction.

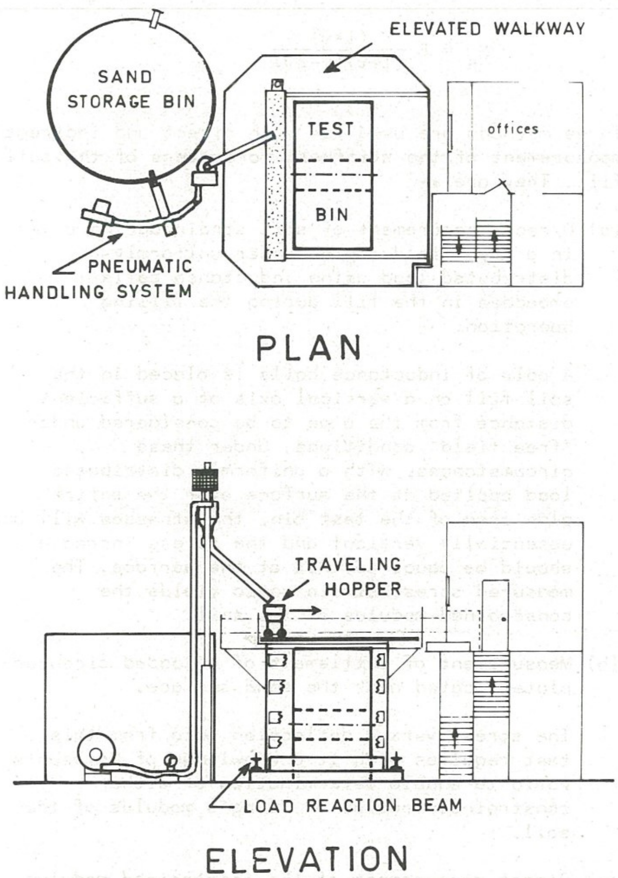


Figure 1 General arrangement of test facility

## 3 SAND TRANSPORTATION AND PLACEMENT SYSTEM

A washed and oven dried river sand is currently used for testing. This sand is of relatively uniform grain size at about 0.37 mm diameter. It was selected specifically for its negligible proportion of particles less than 0.074 mm diameter to minimize the dust problem when handling.

Preparation for each test requires the placement of about 35 t of sand in the test bin at a uniform density. This is achieved using a sand raining technique following a system used by Chapman (1974) and others. Specialised equipment designed specifically for the test facility is used.

A 4 m high x 4.5 m diameter storage bin for the sand is located adjacent to the test bin. Sand is transferred from the storage bin to a traversing distribution hopper located over the test bin by a pneumatic pipeline transportation system (Fig. 2). It is withdrawn from the base of the storage bin by a screw conveyor and falls through a venturi into a high velocity air stream in a 150 mm diameter pipeline. The pipeline carries the airborne sand to about 3 m above the test bin to a cyclone separator from which it discharges through a chute into the traversing hopper above the test bin. The air passes from the top of the cyclone, through a dust filter to the atmosphere.

The sand hopper is approximately 4 m long, and 0.5 m wide and has a capacity of about 1.3 $m^3$. It is supported by rails at each end and traverses

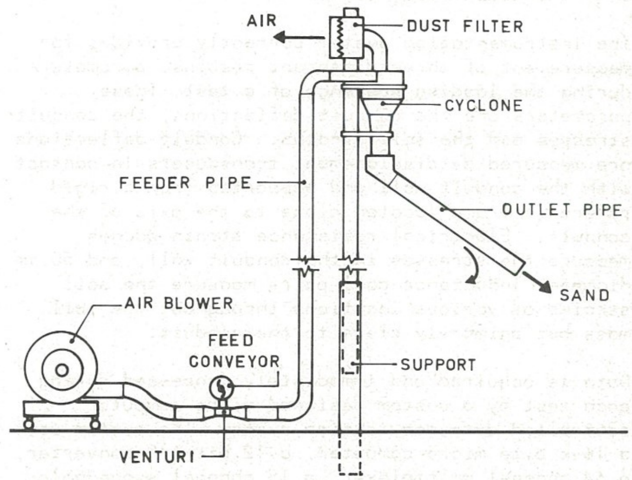


Figure 2 Pneumatic sand handling system

the 2 m width of the test bin at speeds of up to 0.8 m/min. When a control gate is opened the sand flows through 400 bushed holes, evenly spaced in a grid pattern over the base of the hopper, on to two parallel dispersion screens and then into the test bin.

The system as used to date has proven to be highly successful in placing a uniformly dense sand at a rate of approximately one 50 mm-thick layer each 25 minutes. Variation in placement density may be obtained by changing the diameter of the bushes in the sand hopper.

In traversing the test bin, the hopper rains sand over an area slightly larger than the plan area of the bin. This ensures that sand is evenly placed over the full area of the bin. The overflow is caught by a skirt system surrounding the bin and is funnelled into several small peripheral storage bins. These are intermittently emptied into the main storage bin as necessary.

## 4 LOADING SYSTEMS

Either uniformly distributed or concentrated loads of various complexity may be applied to the system. For uniformly distributed loads a pressurised rubber air bag 4 m x 2 m x 50 mm is used directly in contact with the sand surface over the area of the bin. The bag reacts against a cover plate that is restrained by a system of beams and struts below the main reaction beams that span the bin in the 2 m direction. The reaction beams are tied at each end to the base frame of the test bin by steel straps. The air bag is fabricated from specially produced 3 mm thick rubber sheeting and can apply a maximum uniform pressure of 210 kPa to the sand surface; that is, the equivalent to about 12 m height of soil fill.

Concentrated load configurations may be obtained by a system of seven hydraulic jacks each capable of supplying a 25 t load. The jacks bear against the seven reaction beams. Each jack can provide a line load or local areal load on the fill surface either individually or in combination with others to develop complex loading arrangements as required.

The reaction system is designed to be easily removed from the bin during the filling operation.

## 5 INSTRUMENTATION SYSTEM

The instrumentation system currently provides for measurement of three different response parameters during the loading sequence of a test. These parameters are the conduit deflections, the conduit stresses and the soil strains. Conduit deflections are measured by displacement transducers in contact with the conduit wall and supported from a rigid reference frame located close to the axis of the conduit. Electrical resistance strain gauges measure the stresses in the conduit wall, and 50 mm diameter inductance coil pairs measure the soil strains at various locations throughout the soil mass but primarily close to the conduit.

Data is acquired and immediately processed during each test by a custom designed micro computer controlled data acquisition system. The system uses a 16-k byte micro computer, a 12 bit A/D converter, a 64 channel multiplexer, a 15 channel expandable analog signal conditioning unit, and a single channel inductance coil controller. Half the multiplexer channels are dedicated to analog signals from the signal conditioning unit.

During a test the load is applied manually in the desired increments and appropriate details are incorporated interactively in the otherwise automatically acquired data. Calibrated results in units of mm or microstrain relative to both a selected datum and the last load are immediately printed. The results are also recorded on disc for transfer upon completion of the test to a larger computer system for further processing such as, for example, automatic plotting in graphical form.

The automatic data acquisition and processing system considerably simplifies the test programme. It permits the completion of a test that includes 30 load steps, acquisition of data from 26 different instruments at each step, processing of all results and plotting of any or all graphs as desired in one day. In addition the system is used prior to testing to determine calibration factors for the transducers. Programmes have been written to combine data from each type of transducer mounted in a suitable calibration rig with interactively entered parameter values. The readings are then interactively analysed with various curve fitting routines until acceptable fits are achieved. The calibration factors thus obtained are then entered into the main data acquisition programme.

## 6 MEASUREMENT OF SAND PROPERTIES

### 6.1 Stiffness

Research to date in this field indicates that the soil stiffness (or compressibility) parameters largely control the response of this type of structure. Accordingly, the soil property measurement component of the project is currently devoted primarily to measurement of soil stiffness.

For circular conduits, recent theory has been developed in terms of the soil constrained modulus, $M_s$, the stress/strain ratio in a uniaxial strain test (Burns and Richard, 1964; Kay and Krizek, 1970). However, work on non-circular conduits has been reported in terms of Young's modulus, E, (Flint and Kay 1983). Provided a realistic value can be obtained for Poisson's ratio, $\nu$, the two may be related by :-

$$M_s = E \frac{(1-\nu)}{(1+\nu)(1-2\nu)} \quad (1)$$

Three methods are used for both direct and indirect measurement of the stiffness parameters of the soil fill. They are :-

(a) Direct measurement of soil strain during a test in a free field region under uniformly distributed load using inductance coils embedded in the fill during the filling operation.

A pair of inductance coils is placed in the soil fill on a vertical axis at a sufficient distance from the pipe to be considered under "free field" conditions. Under these circumstances, with a uniformly distributed load applied at the surface over the entire plan area of the test bin, the stresses will be essentially vertical and the stress increase should be equal to that at the surface. The measured stress/strain ratio yields the constrained modulus of the soil.

(b) Measurement of settlement of a loaded circular plate located near the sand surface.

The stress versus deflection data from this test requires with it a knowledge of Poisson's ratio to enable determination of either constrained modulus or Young's modulus of the soil.

(c) Direct measurement of the constrained modulus in oedometer tests conducted on soil samples placed directly into a 150 mm diameter oedometer unit using the same technique as that employed in the test bin.

The 100 mm diameter oedometer unit used is specially designed to provide data on horizontal stress during the test. In addition to constrained modulus this enables computation of Poisson's ratio, (and thus Young's modulus) according to :-

$$\nu = \frac{\Delta\sigma_3}{\Delta\sigma_1 + \Delta\sigma_3} \qquad (2)$$

where $\Delta\sigma_1$ and $\Delta\sigma_3$ are the changes in vertical and horizontal stresses respectively.

6.2 Sand Uniformity

Two methods are used to determine the degree of uniformity of the sand fill :-

(a) Measurement of the weight of a known volume during the filling operation. During the sand raining processes containers of known volume are placed on the surface at regular intervals vertically and horizontally. When full, these are screeded level and weighed for unit weight determination.

(b) Measurement of the cone and sleeve resistances from a miniature cone penetrometer pushed vertically through the full depth of soil in the test bin at the completion of the filling operation. The penetrometer used is approximately 12 mm in diameter with a projected cone area of 100 $mm^2$. It is pushed through the fill in 400 mm increments at a rate of approximately 0.7 cm/sec. The cone and sleeve resistances are automatically measured, processed and tabulated by the data acquisition system. The cone resistance provides a guide to the variability in density and therefore variability in modulus for the soil.

7. DETAILS OF INITIAL TEST PROGRAMME

For the initial test programme standard circular corrugated metal conduit 750 mm in diameter with corrugations 68 x 13 mm and wall thickness 1.6 mm was installed. The geometry at completion of sand placement was as shown in Fig. 3. Sand was placed

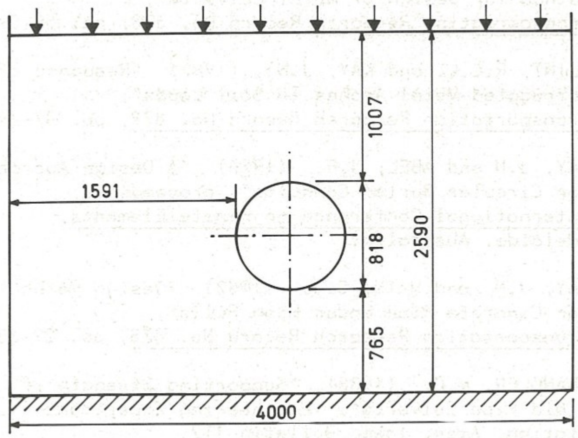


Figure 3 Pipe location for initial test

using the raining system in layers approximately 50 to 60 mm thick. The filling process was interrupted for two purposes. One was for measurement of soil unit weight at levels, near the base of the bin and near the top. The other was for installation of the inductance coils at various levels.

The general instrumentation arrangement is shown in Fig. 4. Displacement transducers were located at six points around the inside of the conduit walls to measure radial movement; electrical resistance strain gauges were located on either side of the conduit wall at eight locations to measure in-plane compression.

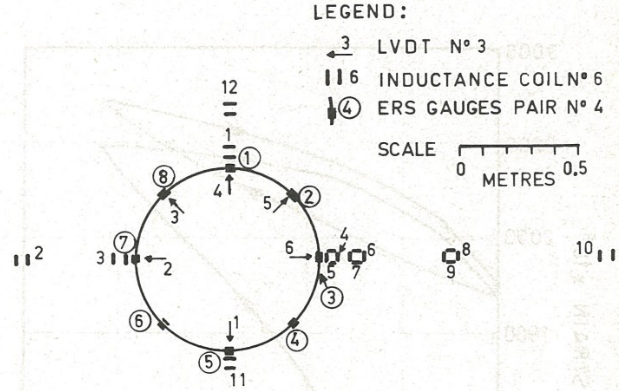


Figure 4 Instrumentation details for initial test

A uniformly distributed load was applied to the upper surface of the fill in increments of 15 kPa up to 210 kPa and then removed in decrements of 30 kPa to zero over a period of five hours. After a period of three days the loading and unloading cycle was repeated. At each loading stage the data from all instruments was processed, printed for immediate inspection and stored on disc for later processing.

8 RESULTS FROM INITIAL TEST PROGRAMME

Only typical test results are reported in this paper. A more complete report is in preparation. The changes in the vertical diameter are indicated in Fig. 5. As may be expected, the system

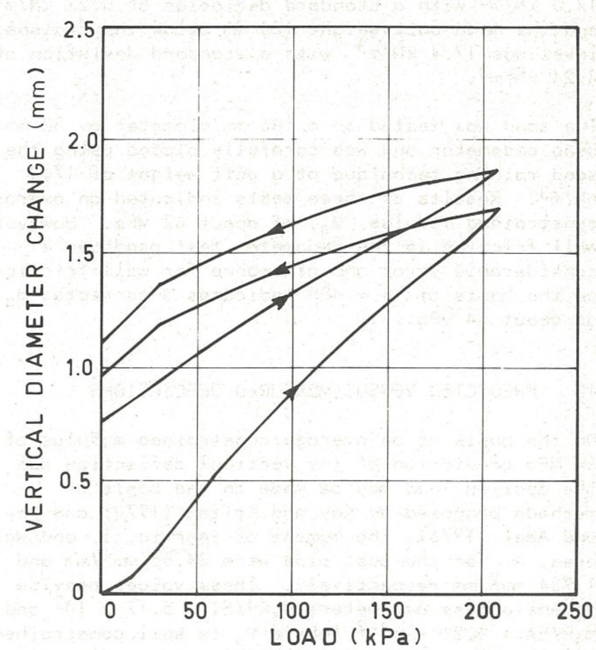


Figure 5 Change in pipe vertical diameter versus surface load

exhibited a considerably higher stiffness level during the reload phase. Some relaxation of the system occurred during the three day period at no load between the two load cycles.

A typical response is shown for inductance coil No. 9 in Fig. 6. The pipe deflection behaviour is notably similar to that of the free-field soil.

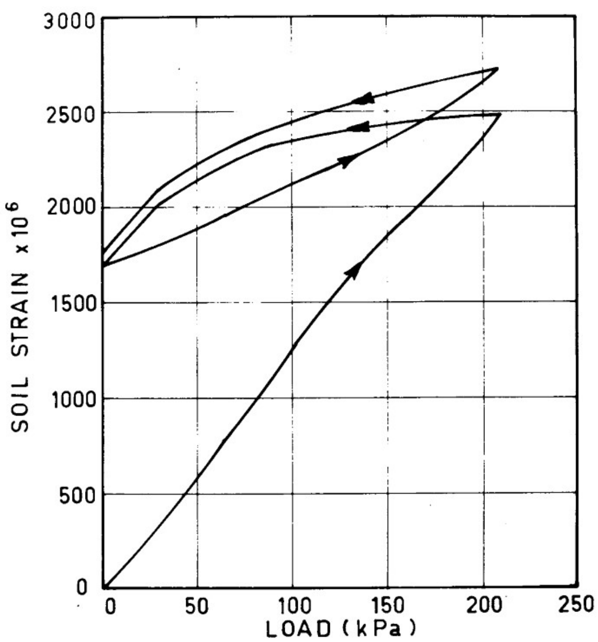


Figure 6 Soil strain versus surface load for inductance coil No. 9

9 RESULTS OF SAND PROPERTY MEASUREMENTS

The unit weight of the sand fill was measured at ten locations at each of the two levels in the bin. The mean unit weight 150 mm above the base was 17.0 $kN/m^3$ with a standard deviation of 0.21 $kN/m^3$ and the mean unit weight 120 mm below the finished level was 17.4 $kN/m^3$ with a standard deviation of 0.24 $kN/m^3$.

The sand was tested in a 106 mm diameter by 32 mm deep oedometer and was carefully placed using the sand raining technique at a unit weight of 17.3 $kN/m^3$. Results of three tests indicated an average constrained modulus, $M_s$, of about 67 MPa. However wall friction in the oedometer test produces a considerable error and allowance for wall friction on the basis of $\phi = 40^o$ indicates a corrected $M_s$ of about 54 MPa.

10 PREDICTED VERSUS MEASURED DEFLECTIONS

On the basis of an average constrained modulus of 54 MPa prediction of the vertical deflection due to the applied load may be made on the basis of methods proposed by Kay and Krizek (1970) and Kay and Abel (1976). The moment of inertia, I, and wall area, A, for the test pipe were 34.85 $mm^4/mm$ and 1.734 $mm^2/mm$ respectively. These values provide dimensionless parameters $M_sR^3/EI = 5.17 \times 10^2$ and $M_sR/EA = 6.21 \times 10^{-2}$ (where $M_s$ is soil constrained modulus, R is pipe radius and E is pipe Young's modulus taken as 205 GPa). For soil Poisson's ratio of 0.3 and no slip at the soil conduit interface the predicted diamater change is 1.96 mm while for the full slip assumption the predicted change is 2.34 mm. This may be compared with the measured change (Fig. 5) of 1.70 mm.

11 SUMMARY AND CONCLUSIONS

A testing facility has been described that permits laboratory evaluation of a wide range of conduit types under realistic field conditions. This will provide the opportunity for evaluating the numerous proposals of a more sophisticated nature that have been made in recent years for the design of various types of buried conduits.

The initial test programme conducted with the facility produced results that can be shown to be reasonably consistent with predictions based on recent proposals made for flexible circular conduits.

12 ACKNOWLEDGEMENTS

A large proportion of the funding for construction of the facility was obtained through the Victorian Railways. The site for the installation was made available by Australian National. Funds for testing were obtained in part from a grant by Armco (Australia) Pty. Ltd.

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