A NEW PHYSICAL MODEL TO STUDY THE BEHAVIOR OF BURIED PIPES UNDER CYCLIC LOADING CONDITION

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SUMMARY

The failure of lifelines during heavy earthquakes has been the cause of major damages to urban facilities. Nevertheless, design of buried pipes such as gas and oil transmission lines has remained one of the main unsolved problems due to complexity of soil-pipe interaction. In order to achieve a relatively more clear understanding of soil-pipe behavior under cyclic loading condition, a new and special testing apparatus has been developed in soil lab. of Amirkabir University of Technology. The apparatus is able to produce a range of monotonic and cyclic loads with desired amplitudes and frequencies. The test pipes can be accommodated inside a model trench of known soil at desired depth and the cyclic or monotonic vertical loads can be applied at any required point on the top of the trench. The normal and shear stresses induced on the boundaries of the trench as well as the radial deformation of the pipe are measured carefully. The applied load and the so induced stresses and strains are controlled and recorded by a special data acquisition system automatically. In the present paper the design criteria, the capabilities and detail structure of the apparatus are presented and discussed.

INTRODUCTION

The satisfactory performance and safety of underground structures depend highly on the appropriate designing them for different loading conditions. This can not be achieved unless the soil-structure interaction is known and considered somewhat accurately. Among the underground structure, the lifelines are of great importance and sensivity due to serving the vital needs of the societies and being developed in large areas and regions. Although different codes and provisions are suggested for the safe design of lifelines, the so designed and constructed lifelines could not have escaped damaging while subjected to sever dynamic loadings particularly heavy earthquakes. It is in main part due to the complicated mutual soil-pipe behavior under these loading conditions. In spite of extensive analytical studies which have been carried out to model the interaction of buried pipes under different conditions and many mathematical relations and empirical equations which have been developed, most of them face with shortcomings in considering the actual response of the pipe against the soil and vice versa. One of the safest ways to get actual information involving soil-pipe interaction is to develop a physical model capable of providing different conditions to study and measure important parameters in these cases. Many researchers have concentrated on the topic and developed different testing apparatus to study the soil-pipe interaction experimentally. Among them one of the most accurate and comprehensive one is that carried out by Bendito De Souza Bueno (1987) in Leeds university. Although extensive tests have been performed in that piece of research involving single and double buried pipes under different conditions, and valuable information obtained in this regard, the testing system was only able to apply monotonic loads and, hence no possibility was provided for studying dynamic loading conditions. To extend the above work and to develop a new system capable of studying buried pipes under both static and cyclic loads; a physical model has been designed and constructed quite recently. The main and general parts of the system consist of the loading system, the testing tank, the sand preparation device, and the data acquisition system which are shown in figure 1 . The general characteristics and detail information of each part are described and presented in the following sections.

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THE LOADING SYSTEM:

The loading system has consisted of the loading frame, pneumatic cylinder, and the controlling unit (figure 2). The loading frame is a stiff and heavy U shape steel element comprises of a horizontal beam of box section of 200x115x6 mm., welded at its two ends to the pair of the vertical elements of the same section (200x115x6) as columns. The span of the beam is 990 mm., and the height of the columns is 1443 mm. The loading frame supports the pneumatic cylinder on the top of the beam and the testing tank by two sides pivots provided in the middle of the columns. A continuos slot of 850x80 mm., has been provided on the beam to allow the loading shaft passes through and gets in touch with the loading plate on the top of soil inside the testing tank. The beam section is selected so that bears the maximum applied load to the system without undesirable deflection. The loading frame is sat on a stiff and stable steel base with I shape which carries the whole forces and weight of the system. The pneumatic cylinder is a double acting of 18 cm., external diameter. The chamber of the cylinder has internal diameter of the cylinder is 16 cm., which accommodates the moveable diaphragm and allows it to fluctuate by the compressed air. Since the end of the moving shaft of the cylinder has to be always in touch with the loading plate on the top of the soil, the moving shaft is adjusted to have the minimum displacement. The horizontal position of the cylinder can be changed by means of a simple gear system and handle provided at one end of the beam. The cylinder may produce monotonic or cyclic loads depending on the intensity of the input compressed air. The cyclic vertical loads with different amplitudes (up to 10 kg/sq.cm), frequencies (up to 1 Hz), and number of load cycles can be produced and controlled by the cylinder. The controlling unit is an electro-mechanical system, which is mounted on the top of the right column of the loading frame. It has consisted of a mechanical valve, which can allow or prevent flowing the compressed air to the cylinder. An electrical device controls the position of the on-off valve proportional to the desired amplitude and frequency of the cyclic loads. It can also count the numbers of the applied cycles and ends the load generating process at the selected and desired number of cycles. A fine air filter is also positioned in the path of the compressed air to refine and induce uniform flow of the air in the cylinder.

THE TESTING TANK:

The testing tank is a rigid steel box of 80x80x20 cm., which accommodates the soil and model pipe, and stands vertically along its square face while testing is in progress. It is connected to the sides columns by means of two horizontal pivots, about which can rotate and be fixed in the horizontal or vertical directions alternatively. Since in the special testing arrangement (will be described later), the model pipe should be set in its predetermined position prior to filling the tank, the testing tank must have the ability of being set horizontally during the preparation stage. After completing the preparation and before applying the load, the tank has to be set in the vertical position by gently rotating it 90 degrees. In order to allow the visual observation of the sand-pipe system, as well as the photo scanning, the front face of the tank has been made of a 20 mm thick plexy glass while the other faces are of steel plates of 8 mm thick in the sides and of 12 mm in the back. To prevent undesirable deformation of the plexy glass during application of the test loads, a special metal supporting has been provided which can move in different level and support the outer face of the glass at any critical section. The plexy glass can be removed during sand deposition process and replaced and fixed in its place by steel strips and 19 clamping bolts, after preparation was completed. The horizontal section of the testing tank and details of fixing system used to hold the plexy glass are shown in figure 3.

Seven circular holes of 50 mm diameter and 100 mm central distances in the horizontal level, 20 cm above the tank base, have been provided in the back face of the tank to accommodate the displacement transducer at any required point which the model pipe may be set. Since only one pipe and one displacement transducer are used in each test, 7 circular plates are used to seal the rest of the holes appropriately. Also 9 square holes of 4 cm dimension have been provided for placing the contact pressure transducers. Seven of the holes are located on the base and the two others on the sides of the testing tank. Due to using only three pressure transducers, (one in the base and two on the sides), in each testing arrangement, the remaining six holes are again sealed by means of six square plates of the same size. The details of the circular and square holes provided on the base and faces of the tank to allow instrumentation of different testing set up, are shown in figure 4.

THE SAND PREPARATION DEVICE:

The method was used to deposit the sand in the testing tank at a known and uniform density was based on that developed by Koulbuzewski (1961), which is known as the raining technique. A moveable steel tank of 30x30x45 cm ending into an inclined funnel system of 10x10 cm outlet was mounted above the testing tank and used as a hopper to pour the testing material from different heights. A simple sliding system consists of a perforated plate was provided in the outlet of the funnel to start or stop raining of the sand. A heavy steel bar resting on the top of the pneumatic cylinder supported the hopper. A lifting system consists of cables and pulleys was designed to move the hopper along its supporting bar vertically. By this system the raining tank was lifted to the required level proportional to achieve the desired density when the sand was poured from this level into the testing tank. The more the height of pouring the more the density of the depositing sands in the tank. The flow velocity of the raining also affects the density of the sand deposit. Before depositing the sand in the tank, the raining system was calibrated using different heights of pouring and different perforated plates in the outlet of the hopper. Consequently, the proportional perforated plate and height of pouring for any desired density of the sand deposition were obtained. Prior to start raining, the testing tank was set to the horizontal position and the model pipe was placed at the desired point (figure 5). The depth of the embedment of the pipe was adjusted by limiting the top of the tank by means of a wooden wall at this stage. Then the free end of the pipe was sealed and the sand was poured to the tank. The sand surface was gently leveled and the plexy glass was placed and fixed. The testing tank was then rotated quite gently to the vertical position, the wooden wall was removed and the tank was ready to be tested under different loading conditions. To apply the loads as a uniform surcharges, a loading pad of steel plate of 20x10x2 cm was used and put on the top of the soil in the tank at the center of which the shaft of the pneumatic cylinder was connected by means of a ball bearing system. To minimize the friction between testing tank and the deposited sand, all metal faces of the tank have been covered by a special soft paper. The amount of the friction angle was thus developed at the sand-tank interface, reduced to some 1.0 degrees, which is small enough to be ignored in symmetric conditions of the test arrangements.

THE DATA ACQUISITION SYSTEM AND INSTRUMENTATION:

A special data acquisition system was developed by which all stresses and strains could be read and recorded continuously. The system is able to read the data form sixty channels simoultanesly, although sixteen channels only were needed in this apparatus. The extra capacity of the system is for further researches and extended programs, which can be implemented by this, testing apparatus. Three contact pressure transducers are used to scan the normal and shear stresses on the base and boundaries of the trench. A special displacement transducer was used to detect the radial deformation of the model pipes. It has eight spring steel arms which can be in touch with eight points on the circumference of the pipe and can scan any changes in the radius of the pipe at the relevant point. Before applying the load, this transducer was placed inside the pipe through one of the circular hole on the back of the testing tank. A cylindrical load cell was also used and positioned in the loading shaft to detect the pattern of the applied loads on the trench surface accurately. Special software has been written by which the whole reading and recording procedures of the data could be done automatically. The software is able to process and display different graphs during the test for all 16 channels on the screen simultaneously. The general view of the data acquisition system and the transducers are shown in figure 6.

THE MODEL PIPES:

The dimensions of the testing tank in this model were selected so that no considerable influences were made on the pipe behaviors by the rigid boundary conditions of the tank for the model pipes of 100 mm., diameter. Consequently flexible pipes of 100 mm., diameter and 200 mm., length were used in this system. The pipes were made of thin steel plates of 0.4 mm.; thick by point welding at its two ends overlapped some 8 mm. In order to prevent entering sand particles into the pipe when it was embedded inside the trench, the two ends of the so built pipe were stuck by strip foam before setting it in the trench. To reuse the tested pipes for several times, they were usually removed, before failure occurred completely. Nevertheless, some tested pipes might get permanent deformation even in those conditions and could not be used again. However, to study the entire modes and states of failure, some tests had to be continued till the complete collapse of the pipes. To prevent damaging the displacement transducer in these cases, it had to be removed before failure occurred, or the pipes had to be tested without the transducer was set inside them.

SUMMARY AND CONCLUSIONS:

A new physical model was developed to study the behavior of buried pipes under cyclic and monotonic loading conditions. The model consists of four different main parts, namely; the loading system, the testing tank, the sand preparation device, and the data acquisition system, each of which was designed and constructed to satisfy the actual condition as much as possible to model the buried pipe in the laboratory. The applied load can be generated and controlled by a pneumatic system monotonically and cyclically. Different load cycles by different amplitudes and frequencies up to unlimited number of cycles can be applied to the system. The soil deposit can be prepared at any desired density, using the raining technique. The model pipe can be embedded at different depth and different position of the soil and the load can be applied on the soil surface at the centerline of the pipe or eccentrically. The shear and normal stresses on the boundaries of the soil as well as the radial deformation of the pipe can be scanned by special transducers. The test data can be recorded by a robust data acquisition system capable of processing and displaying different required graphs during the test for all channels. A lot of different tests under different conditions were carried out by this model the results of which are of importance but out of scope of this paper.

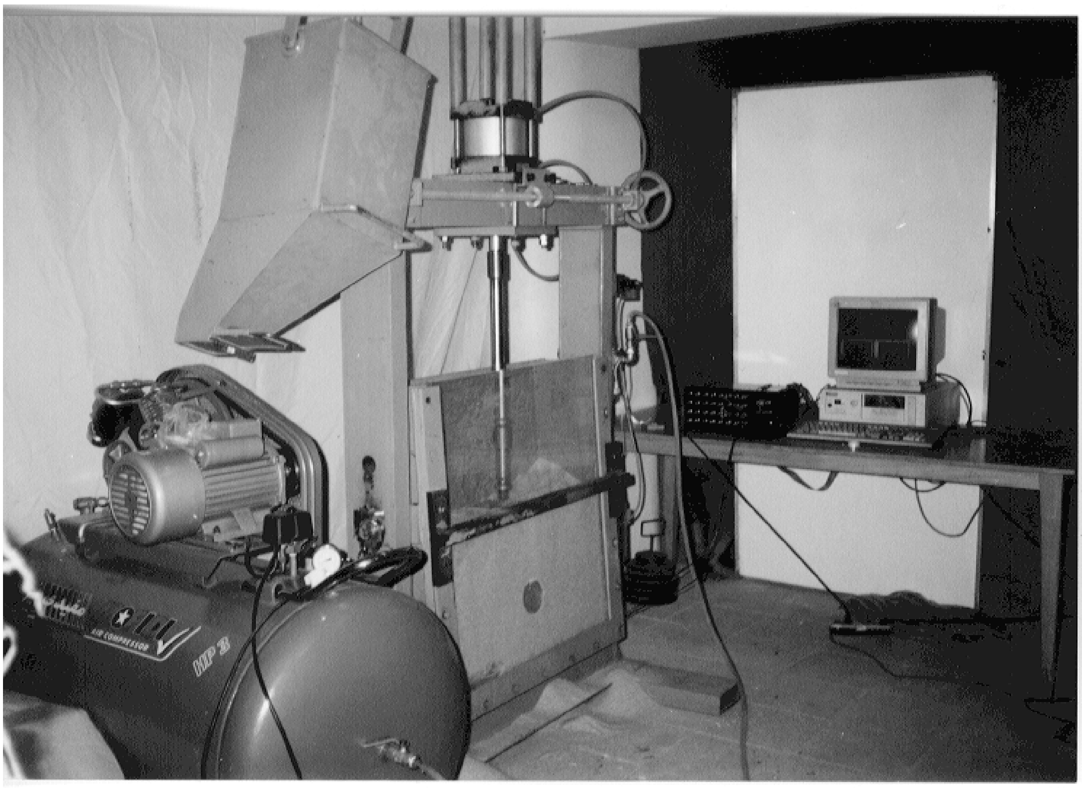

Figure 1- the general view and main parts of the buried pipes testing system.

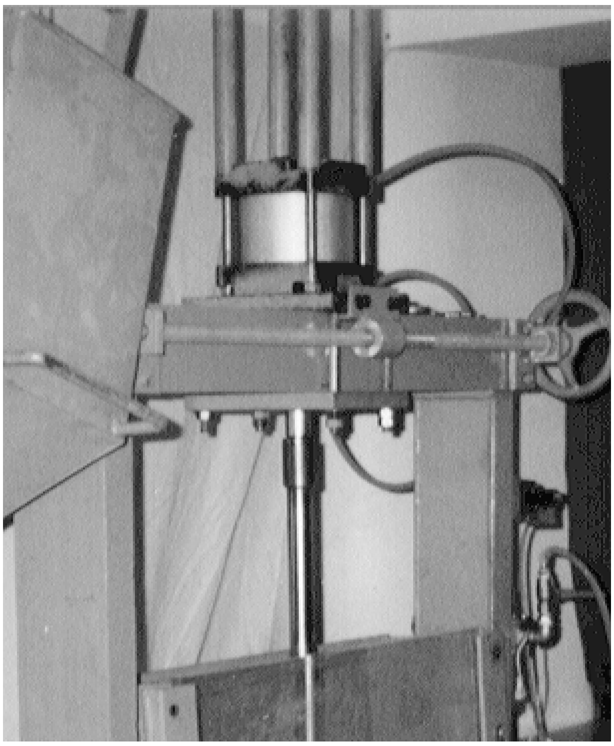

Figure 2- the loading frame, the pneumatic cylinder, and its attachments to generate monotonic and cyclic loads.

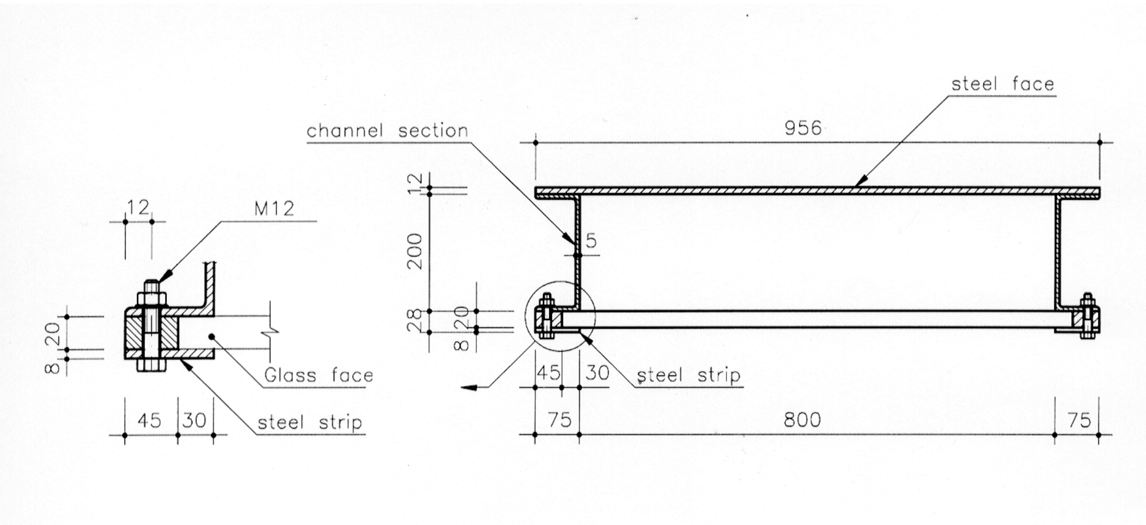

Figure 3- the horizontal section of the testing tank and details of fixing plexy glass. (dimensions in mm)

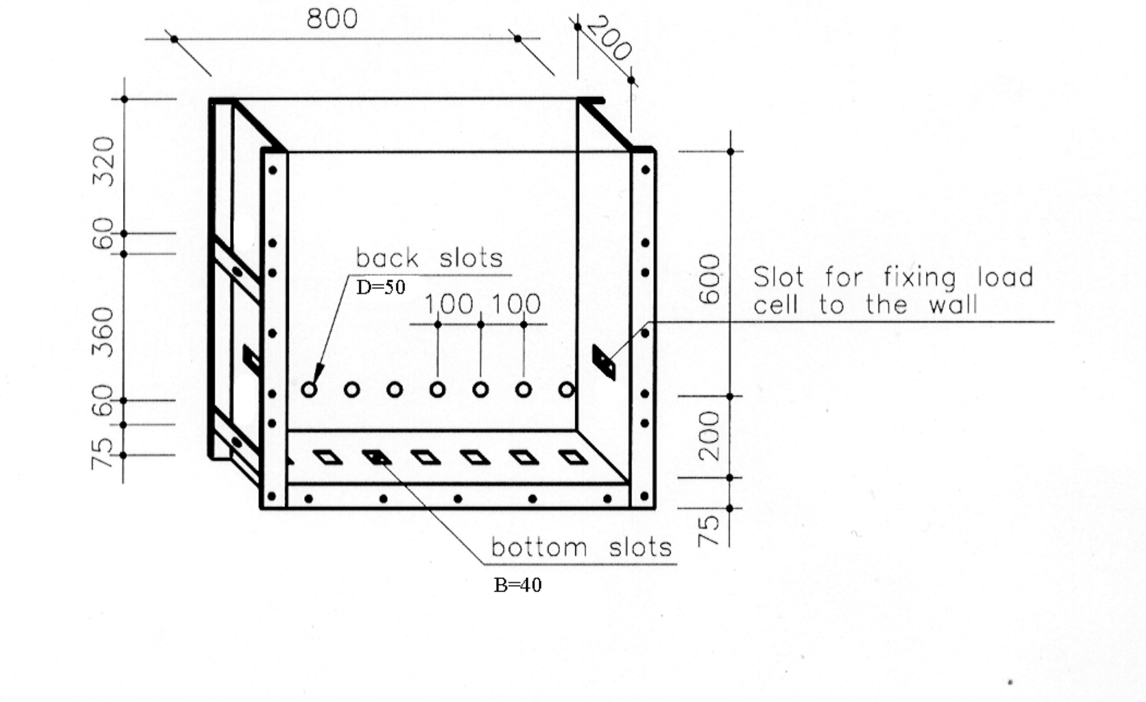

Figure 4- the position of the circular and square holes provided in the boundaries of the testing tank for setting transducers. (dimensions in mm)

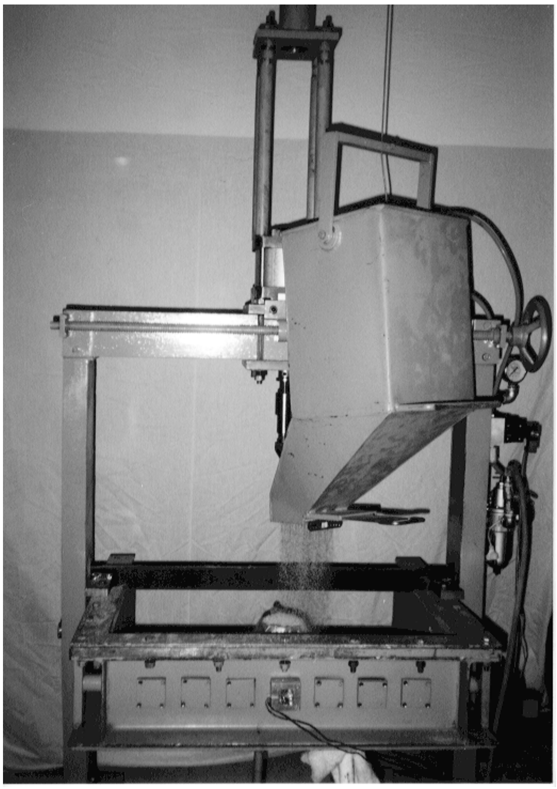

Figure 5- the sand raining device and arrangement of the testing tank during preparation stage.

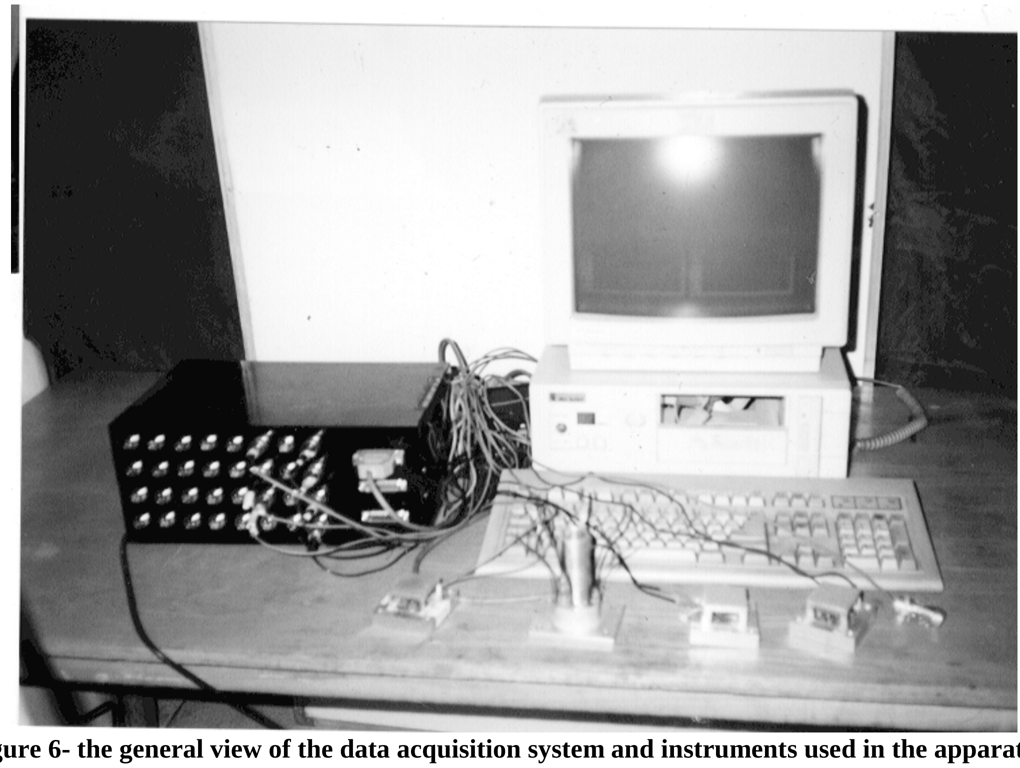

Figure 6- the general view of the data acquisition system and instruments used in the apparatus..

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