An Experimental Investigation of the Phenomenon of Pipe Jacking

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SUMMARY The migration towards the ground surface of gas pipelines buried in sand and below the water table has been termed "pipe jacking" or "sand jacking". The mechanism leading to pipe jacking has been assumed to be fluctuations in the level of the ground water table. The mechanism of pipe jacking reported in this paper is internal pressure fluctuations which cause diametric deformations of the pipe leading to pipe jacking. It was found that pipe jacking will occur at a rate directly related to the magnitude of the pressure fluctuation and inversely related to the depth of burial of the pipe.

1 INTRODUCTION

The term "pipe jacking" was first used by the American Society of Civil Engineers Pipeline Flotation Research Council (1966). The Pipeline Floatation Research Council also suggested a possible mechanism causing pipelines to jack; the proposed mechanism is shown in Figure 1.

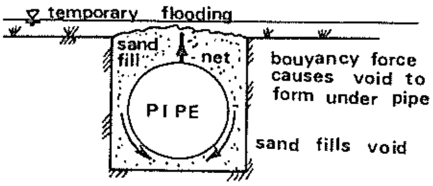

Figure 1 Pipe jacking mechanics

Buried gas pipelines with an average density less than that of the surrounding soil could potentially rise to the ground surface. Two modes of failure are usually recognised. Firstly the pipe may fail by floatation, a sudden failure where net bouyancy forces on the pipe exceeding the weight and strength of the overlying soil. Secondly, the pipe can "fail" by a slow migration towards the ground surface. In the case of pipes in sand, the migration is associated with movement of sand particles, that is, pipe jacking.

Pipeline floatation has been investigated by Bonar and Ghazzaly, 1973, for model pipelines buried in a slurry. The very low strength soil, or slurry, used by Bonar and Ghazzaly, was apparently intended to simulate a highly disturbed and very wet cohesive soil backfill. Their work is not relevant to cohesionless soils.

Inckel, 1972, conducted field tests on a prototype scale gas pipe buried in sand. The first experiments conducted by Inckel aimed at inducing liquifaction in the sand around the pipe and a floatation failure. In the second series of tests, the ground water table at the pipe was raised and lowered seven times, attempting to induce pipe jacking. Inckel did not detect any rise in the pipe, the pipe in fact settled slightly.

Large diameter natural gas pipelines are being built with relatively thin walls using high strength steels. Some sections of the proposed Sydney - Newcastle gas pipeline will have pipe of 864 mm O.D. and a wall thickness of 9.25 mm, that is, a wall thickness of only about 1% of the diameter, Telfer, 1979. The use of relatively thin walled pipelines subjected to fluctuating operating pressures can lead to distortion of the pipe sufficient to allow soil particles to migrate under the pipeline thus causing an upward migration of the pipeline, that is, pipe jacking. Fluctuating operating pressures in gas pipelines result from variations in the demand for gas by consumers.

The experimental investigation reported in this paper was conducted to evaluate the feasibility of the above pipe jacking mechanism. It was found that a model pipeline buried in rounded beach sand did "jack" when the pressure in the pipe was fluctuated. Further, the jacking rate increased as the pressure fluctuations increased in amplitude. The jacking rate decreased for greater depths of pipe burial and also for increased surface roughness of the pipe.

2 MODEL PIPELINE AND TEST PROCEDURE

2.1 The Model Pipeline

The model pipeline consisted of a 90 mm P.V.C. pipe, 1000 mm long. The pipe was connected to a pulsating pressure supply as shown in Figure 2. In order to reduce the volume of compressed air used for each pressure pulse, the pipe was filled with water, it was therefore necessary to counterweight the pipe via a pulley system to compensate for the weight of the water in the pipe. The counterweight used was equal to the weight of the water in the pipe. Hence the pipe was fully bouyant.

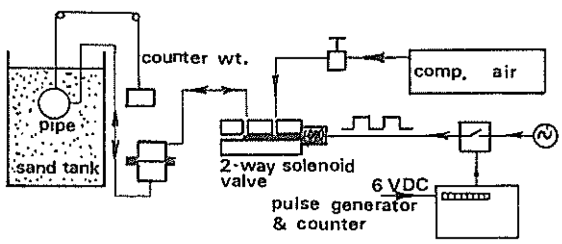

Figure 2 Model pipeline and pulse generation circuit

The diametric deformation of the model pipeline produced by internal static pressure is shown in Figure 3. The deformation of the pipe being "free" no soil interaction was present as would exist for a buried pipeline.

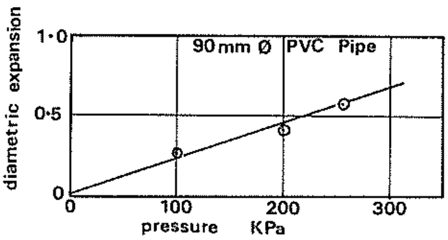

Figure 3 Model pipe deformation

The 90 mm diameter model pipeline was buried in a local beach sand from Thirteenth Beach near Barwon Heads, Victoria. The sand grading is shown in Figure 4 and sand particle shape can be seen in photograph Figure 5. The "characteristic" sand grain size adopted was 0.33 mm, that is, the diameter at 50% finer by weight.

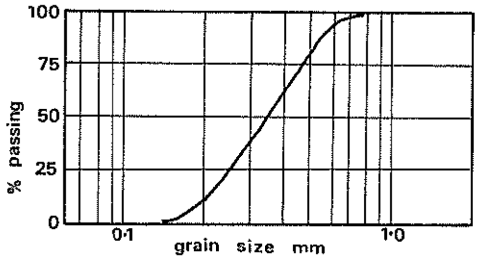

Figure 4 Sand grading

Figure 5 Sand particle shape

2.2 Model Pipeline Laying Procedure

The procedure used to lay the model pipeline was chosen to be approximately similar to a full scale pipeline construction. The sand in the tank, Figure 2, was first flooded by raising the water level in the tank from below and the sand was left flooded for several days. The sand was then "de-watered" by lowering the water in the tank to below the level of the pipeline. A parallel sided trench about 125 mm wide, was then excavated in the damp sand, the pipe placed in the trench and backfilled. The water table was then raised to the level of the sand surface and a further rest period of one or two days allowed. The above procedure was used primarily for reproducibility of the tests than for a simulation of an actual pipe laying operation.

2.3 Pressure Fluctuations

The pressure in the pipeline was fluctuated between zero and maximum pressures of 100 KPa, 200 KPa and 260 KPa. The pressure pulsing circuit is shown in Figure 2 and the resulting pressure pulse in the pipe is shown in Figure 6. The free diametric expansion of the pipe produced by the aforementioned pressures, was 0.28 mm, 0.41 mm and 0.57 mm respectively. The position of the pipe was monitored with dial gauges.

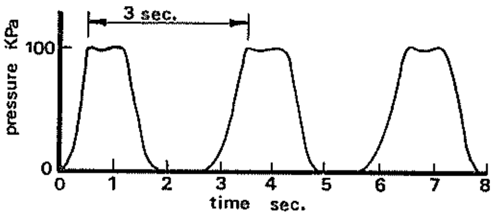

Figure 6 Pressure pulse forms

3 EXPERIMENTAL RESULTS

3.1 Pipe Jacking For Different Pressure Fluctuations

The rise, or jacking, of the model pipeline above its original position is shown in Figure 7, for the pipe buried to a depth of 1.5 pipe diameters. The trend in Figure 7 was also observed for depths of burial equal to 1 and 2 pipe diameters. However, for a depth of burial of 0.5 pipe diameters, the pipe jacking rate was continually accelerating, probably towards a floatation type failure.

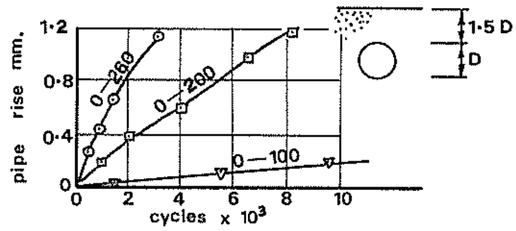

Figure 7 Pipe jacking at different pressure fluctuations

For several tests, the pipe was observed to settle before commencing to jack upwards as shown in Figure 8. The settlement of the experimental pipe used by Inckel, 1972, during the seven cycles of raising and lowering of the ground water table, may be only a transient response to be followed by pipe jacking.

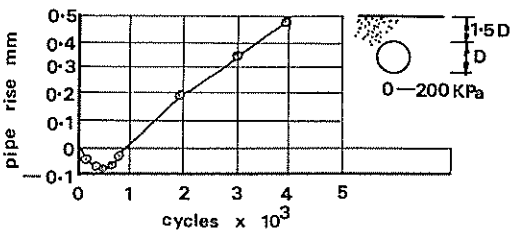

Figure 8 Pipe jacking with initial settlement

As the depth of burial of the pipe increased, the jacking rate decreased. The jacking rate of the pipe is shown in Figure 9 for different depths of burial but for the same pressure fluctuations.

The experimental results shown in Figure 9 are replotted in Figure 10. The vertical scale is free pipe diametric deformation divided by characteristic sand grain size, and the horizontal scale is jacking "rate" in cycles of pressure fluctuations required to cause the pipe to rise by 1 mm.

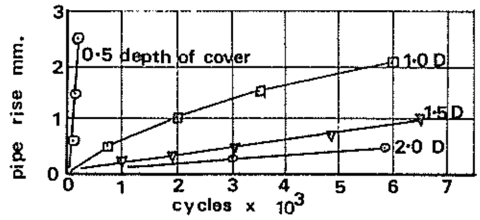

Figure 9 Pipe jacking at various depths

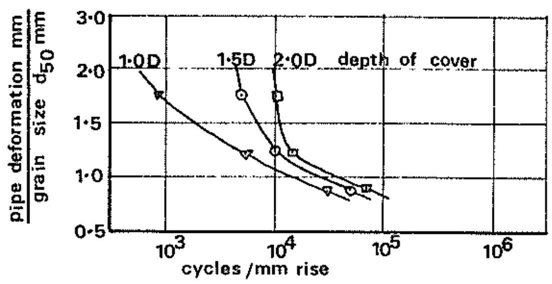

Figure 10 Pipe jacking results related to sand particle size

3.3 Influence of Pipe Surface Roughness on Jacking Rates

If the mechanism leading to pipe jacking is migration of sand particles at the surface of the pipe, then a smooth pipe could be expected to enhance jacking. Conversely, a pipe with a rough surface would retard jacking. The results in Figure 11 were obtained using the same pipe, the rough results for the pipe after coating with sand particles glued to the pipe.

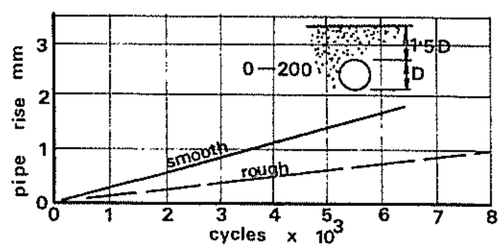

Figure 11 Pipe jacking rate for a rough pipe

4. Discussion Of The Results And Their Implication

From the model pipeline results it appears that internal pressure fluctuations can produce pipe jacking. The relevance of the model results to prototype pipelines is not known and will be studied in the future. However, for typical pressure fluctuations in actual pipelines, the rate of jacking would probably be very slow and of no consequence to the stability of the pipeline.

The jacking mechanism, that is, migration of soil particles in response to small deformations of the pipe, could modify the pipe-soil interaction.

For pipelines with discrete anchors, either swamp weights or helical anchors, the pipe jacking effect could lead to longitudinal bending stresses additional to those currently recognised by designers.

5 CONCLUSIONS

From the experimental results for the model pipeline the following conclusions can be drawn.

(i) Pipe jacking due to internal pressure fluctuations can occur for gas pipelines buried in sand and below the water table.

(ii) The pipe jacking rate is directly related to the magnitude of the pressure fluctuations within the pipe.

(iii) The pipe jacking rate decreases as the depth of burial of the pipeline increases.

6 ACKNOWLEDGMENTS

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7 REFERENCES

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