ROCKER PIPE SOLUTION TO ALLEVIATE SETTLEMENT INDUCED DISTRESS IN FLEXIBLE PIPES

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Abstract: Soil-pipe interaction studies generally recognise the significance of deformations in the pipe due to soil loading, but not differential ground and structure movements, which can induce excessive stress concentrations in the pipeline. Plastics pipes can suffer failure due to such movements, though their flexibility makes them less vulnerable than rigid pipes. This paper examines the settlements and how the redistribution of the soil sub grade reactions caused by the installation of a pipeline within a soil mass, can then be estimated by treating the pipeline as a beam on elastic foundation. Various case histories are summarised, demonstrating these effects, and pointing the way to possible solutions, which could be incorporated at the project design stage.

1. Introduction

Lines of rigid pipes are the most vulnerable to movement within the soil mass because of the redistribution of pressure they cause. The response of rigid and flexible pipelines to differential movements can be used to establish maximum levels of bending moment that can be accommodated by a variety of pipelines.

This paper concentrates on the response of buried pipelines to displacement caused by structure settlement /differential settlement. A model for representing soil-pipeline interaction in response to differential settlement is described in section 3.

2. Case Studies of Pipe Failures due to Settlement

2.1. Failure of Asbestos Cement Pipe – Need for sound bedding conditions

As part of a post 2000 new city development, a 600mm diameter sewer was being installed adjacent to an existing 300mm AC water main, which was laid across a busy highway (see figure 1). The AC water main pipe failed within 3days after the installation of the same at the site. The constructional specification required pea gravel bedding. The extent of excavation of the trench access the highway is seen in figure 1 and also evident is the conspicuous transverse subsidence cracking (figure 1) of the highway pavement that indicated traffic induced settlement of the backfilled trench walls.

Figure 1. Subsidence cracks, parallel to trench walls on the surface

Figure 2 below shows the approximate dimensional details of pipe location and note that the AC water main was above and perpendicular to the sewer line being installed. It was also noted that the heavy traffic passing over the irregular road surface caused noticeable vibration of the road surface above the pipe.

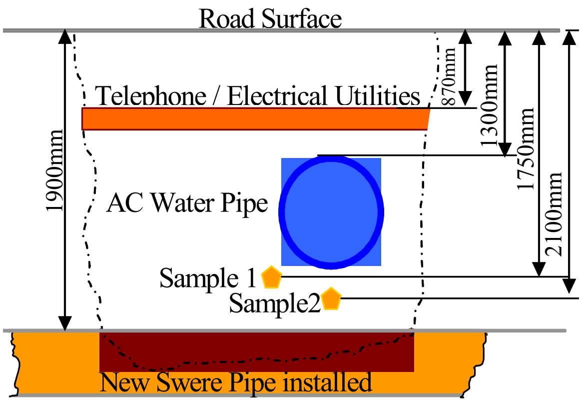


Figure 2. Sectional detail of the pipe trench

Figure 3 shows the failure surface observed on AC pipe. The geometry of the failure surface shows a vertical feature at the end of the zone with fine secure unexcavated pipe bedding. The fracture surface shows the propagation of the failure resulting from the repeated vertical movements of the pipe with poor bedding.

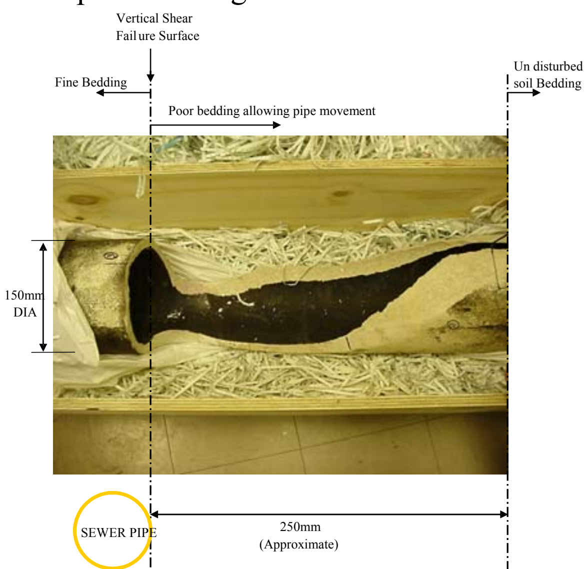


Figure 3. View of the fractured section of the150mm AC pipe

Figure 3 also indicates the additional support given by the sewer, which resulted in the peculiar vertical failure surface. The site investigation indicated ground water level was near the spring line and above the pipe invert of the 300 mm water main. This indicated high water table conditions and the soil to be of high permeability that could cause rapid flooding into the trench.

2.1.1. Pipeline settlement evaluation

However the elements of this evaluation are based on BS EN 1295-1, Pipe materials selection manual and the paper by Olliff (2001). In this analysis, the 150 mm AC pipe with a soil cover of 0.5m and in a trench of 1.1m was considered. The two specific cases of the pipe being in a lean mix embedment and in a pea gravel embedment were also considered. However, it is recognised that only a length (probably 2m) was exposed at the time of the sewer construction. This length of pipe will be subjected to an increased settlement over and above that of the settlement of the rest of the 150mm AC pipe on either side of this section.

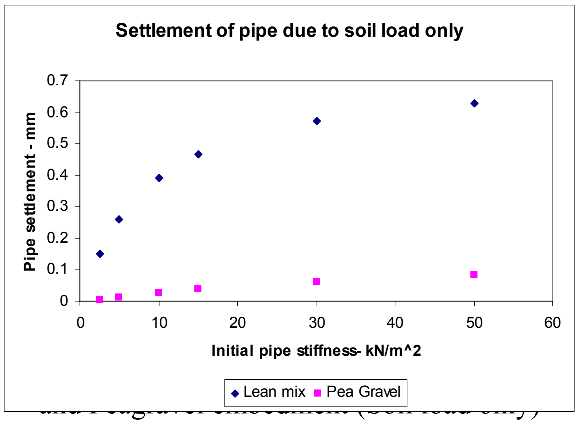
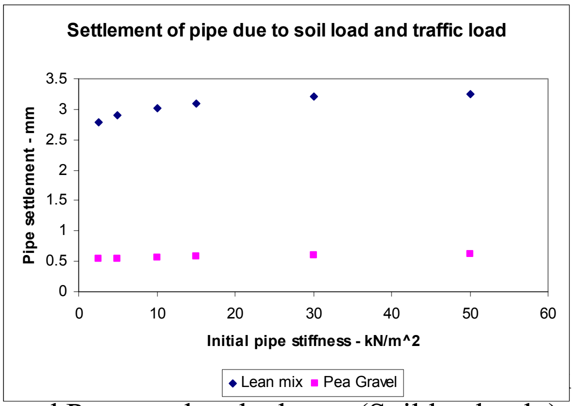


Figure 4 shows the amount of settlement that can occur for a pipe when embedded in lean mix or pea gravel. This depends on the stiffness of the pipe. Nevertheless the settlements are very small and that with pea gravel embedment is about 10th of the settlement anticipated with lean mix surround. Figure 5 below illustrates the corresponding effects when traffic loading is also considered. Settlements of the order of 3.25 mm can be anticipated for pipes with a stiffness of 50 kN/m^2.



and Peagravel embedment (Soil load only)

2.2. Failure in 100mm Domestic Sewer at new installations – Need for structural design solution

This section describes of an investigation into the failure of several sections of sewer pipe placed in 2004. The pipes were 100mm diameter PVC plastic pipes, placed at depth ranging from about 1-2m.The CCTV inspection of the pipes revealed that the settlement of manhole of as much as 28mm had caused failure in connected pipeline. The CCTV investigation revealed about 30 m of pipeline installed did not meet alignment specification.

2.2.1. Site location and construction

The author investigated a typical building construction with seven numbers of manholes. This site is at the south east of London, the failures were noticed on a regular run down check carried out by the consultants of the design and build project prior to completion.

Figure 6.Two length of pipe connecting manhole without construction Joint at the interface

The figure 6 shows a typical layout of manhole with two length of plastic pipe. No bedding is used. Pipes are laid 2-3m away from the structure and hence influence of surcharge and loading is minimum.

2.2.2. Typical failures

Since clear observation was made on the total manhole runs of gravity flow pipelines. Inspections for gravity flow rundown checks are not made such failures go unnoticed.

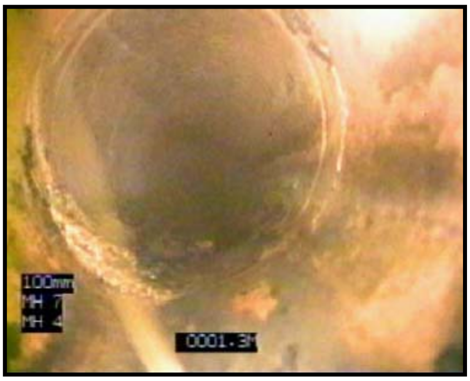


Figure 7. CCTV Monitoring circumferential crack [Failure location from manhole: 15xDia]

Failures of such (figure 7) sewer pipelines cause an environmental problems and the effect of the fracture and pipes remains un noticed. One of the typical investigations are presented in this section to support the hypothesis of this research study.

2.3. Failure of 2700mm diameter GRP pipe – Need for Rocker Pipes

This case study presents the failure, at the point of commissioning, of a network of offshore GRP pipelines, serving as intake pipelines installed in a powerhouse project. Information was gathered by one of the authors, who was employed by the contractors on the project, but the exact location details of the case study are not disclosed.

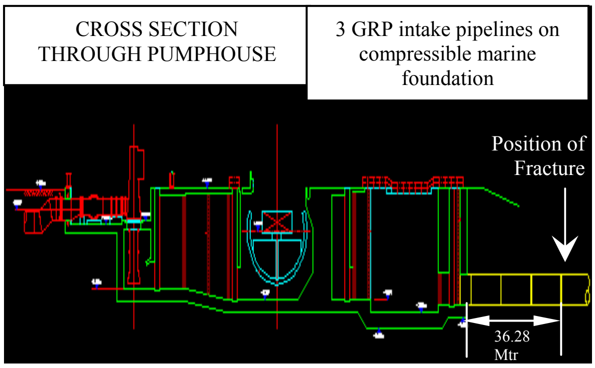


Figure 8. Cross section through Cooling water Pumphouse [Failure location 13xDia]

2.3.1. Geotechnical properties

Along the transition zone in the vicinity of the pumphouse, the trench for the pipeline was excavated to the marly bedrock. The minimum depth of the trench was 200mm below the elevation of the pipeline invert. Ground investigations suggested that the required excavation to reach the bedrock level would not exceed 300mm below the base of the pipeline, and in most cases, some excavation of the marl was required in order to satisfy the minimum bedding thickness requirement of 200mm.

2.3.2. Pipe properties

The Filament wound GRP pipes of stiffness 2500 N/m^2 were installed in 12m lengths. These were of 2.7m internal diameter with a wall thickness of 30mm, and utilised GRP sleeve joints. The pipe laying was started from the point of the intake structures and progressed towards the inlet area of the pumphouse.

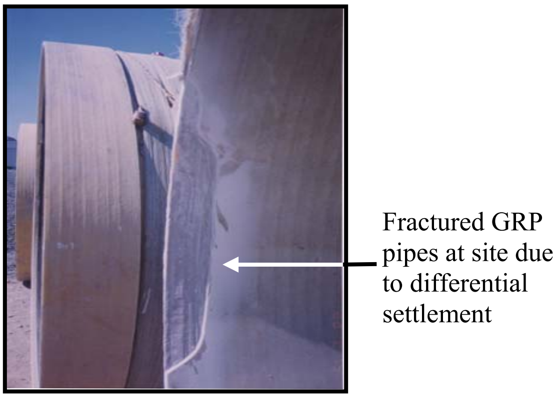


Figure 9. Photographic evidence of the fractured pipes and couplings

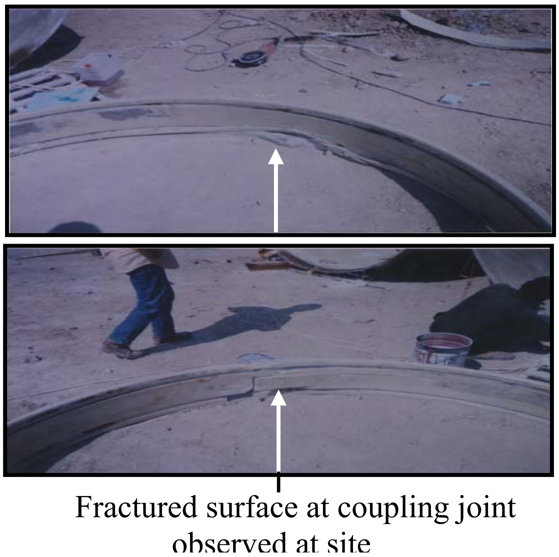


Figure 10. Photographic evidence of the fractured pipes and couplings

The design did not accommodate flexible joints or rocker pipe connections at the interface of the pipe with the structure in the transition zone. The three 2.7m diameter GRP pipes failed at the forebay inlet area as a consequence of the flooding of the cooling water pumphouse. The failure took place at a distance of 36.28m from the inlet wall of the pumphouse, and was consistently at the crown of the joints fracturing both the pipe and the coupling, see figures 8, 9 and 10.

3. Pipeline Flexibility near Settling Structure

When differential settlements occur between a structure and the connected buried pipeline the pipes will be subjected to longitudinal bending, and the joints to shear and angular rotation. The length of the pipe section immediately adjacent to the structure must be designed to keep all of these considerations within allowable limits. A method of determining this appropriate length of pipe section is described. The method can be applied to pipes of differing materials with different types of joints.

3.1. Analytical Study

Failure to design pipelines to accommodate, or avoid differential settlements is one of the more common causes of structural failure, and design should therefore be carried out, based On an analysis which permits verification against criteria established.
A prismatic beam (figure 11) connected to a structure and supported continuously along its length by a foundation, itself assumed to experience elastic deformation. Sub grade reaction to be linearly proportional to the beam deflection at any point. Under such conditions the reaction per unit length of the beam can be represented by the expression ky, in which y is the deflection and k is a constant usually called the modulus of the soil foundation. This constant denotes the reaction per unit length when deflection is equal to unity. This assumption not only leads to equations amenable to solution, but represents an idealization closely approximating many real situations.
Beam behaviour of pipeline is analysed according to the theory of beams on elastic foundations, a theory validated by the results of many field studies and experiments (Olliff ,2003).

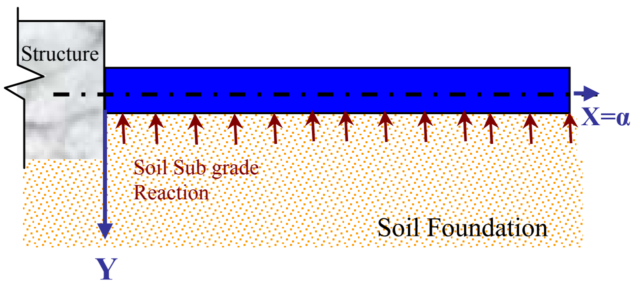


Figure 11. Semi-infinite beam on elastic foundation

$$y = e^{\beta x}\left(A\cos\beta x + B\sin\beta x\right) +$$
$$e^{-\beta x}\left(C\cos\beta x + D\sin\beta x\right)$$
$$At \rightarrow x = \infty; y = 0$$
$$Atx = 0.... \Rightarrow y = \Delta(deflection)$$
$$Atx = 0.... \Rightarrow y' = \alpha(slope)$$
$$\Delta = C$$
$$\alpha = y' = e^{-\beta x}(-C\beta Sin\beta x + D\beta\cos\beta x)$$
$$+ (C\cos\beta x + D\sin\beta x)(-\beta)e^{-\beta x}$$

Substituting x=0; α=β(D-C) ; α=(D-Δ)β

Hence

$$D = \frac{\alpha}{\beta} + \Delta; and\beta = \left(\frac{k}{4EI}\right)^{1/4}$$

$$y' = e^{-\beta x}[-\Delta\beta\sin\beta x + \beta(\frac{\alpha}{\beta} + \Delta)\cos\beta x]$$

$$-\beta e^{-\beta x}[\Delta\cos\beta x + (\frac{\alpha}{\beta} + \Delta)\sin\beta x]$$

$$y''' = \beta^3 e^{-\beta x}\left\{\frac{2\alpha}{\beta}\sin\beta x + 4\Delta\cos\beta x + \frac{2\alpha}{\beta}\cos\beta x\right\}$$

$$x = \frac{1}{\beta}\tan^{-1}\left[\frac{-[2\Delta + \frac{\alpha}{\beta}]}{\frac{\alpha}{\beta}}\right]$$

X represents the location of maximum bending movement measured from the settling structure position. The analysis described above will establish the minimum length required to ensure that the allowable joint rotation is not exceeded, and knowing this length, the bending moments in the rocker pipe, and the shear forces at its ends, can be calculated. If these are excessive, they must be reduced to below the allowable limits, but this cannot of course, be done by reducing the length of the 'rocker pipe', otherwise the joint rotation criteria would not be met.

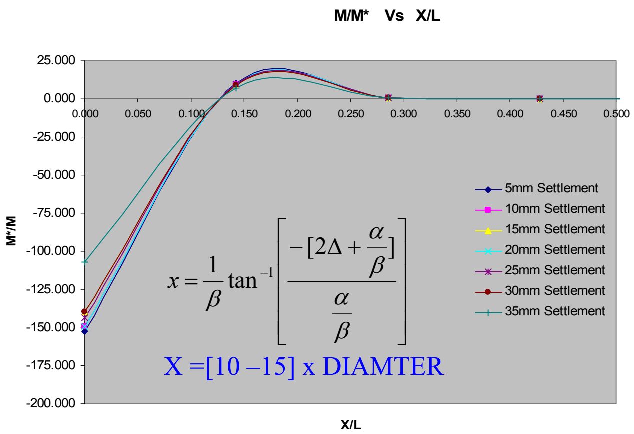


Figure 12: Design graph for Rocker pipe location

3. Conclusions

- Established pipeline design procedures frequently ignore or underestimate the settlements of soil masses, pipelines and structures.
- Analysis of pipelines as strip foundations can provide a useful estimate of likely settlements.
- Pipeline design should include analysis of settlements, and the provision of measures to limit them and/or enable the pipelines to accommodate their effects.
- The ability to accommodate settlements should be taken account of during the pipe material selection process.
- The effective modulus of a pipeline foundation will vary from place to place, reflecting inconsistencies in the placing and compaction of bedding material, variations in bedding thickness, and in sub-grade properties.

5. References

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