Vertical Loading Tests for Buried Flexible Pipes with Equivalent Ring Stiffness

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ABSTRACT

In the current Japanese design standard for the irrigation pipeline, deflection and stresses of the pipe are calculated through structural analysis (closed-form analysis) based on bending ring stiffness EI/D (E: elastic modulus, I: geometrical moment of inertia, D: diameter of pipe).

The pipes with equivalent bending ring stiffness would have the same behavior in design. However, it is easily understandable that the behavior of pipe may be influenced not only by EI/D but also by the relationships between E and I.

In this paper, model tests for buried flexible pipe were conducted to evaluate the effects of pipe thickness on the behavior. The steel pipe of thickness 1.2mm and the low density polyethylene pipe (LDPE pipe) of thickness 11.5mm were used. These pipes had equivalent bending stiffness.

The test pit had a length of 1,830 mm, a width of 1,000 mm and a depth of 1,230 mm. The model pipe was backfilled with silica sand under an overburden depth of 400 mm. After backfilling, vertical pressure on the ground surface was applied to 120 kPa in 10 kPa increments using air bag.

In order to evaluate the deflection of the pipe more accurately, 240 strain gauges were attached circumferentially to the inner and outer surface of each pipe at intervals of 6 degrees. In addition, the deformation of the pipe was measured by rotating the displacement transducer.

In order to clarify the behavior of the buried flexible pipe, numerical analyses by two dimensional FEM were conducted. As a result, it was found that the vertical deflection and the radial strain of each pipe was approximately the same irrespective of the pipe thickness. On the other hand, the larger radial stress occurred in the pipe with the thinner wall. Therefore, the probability of buckling of the pipe may be higher on thinner pipes. It is considered that the current design standard for the pipeline should be revised to consider this fact.

KEY WORDS: Buried pipe; Model test; FEM analysis

INTRODUCTION

Main irrigation pipeline networks extend over 4,500km in Japan. 14% of those networks in length requires immediate repair works. The behavior of a buried pipeline or any underground structure is significantly influenced by the surrounding ground, the construction method employed, and various properties of the backfill material used. Particularly, an increased application of flexible pipes having a low stiffness is expected in the near future because of their good workability and economy reason. Such flexible pipes having a low stiffness with thin wall tend to be easily deformed and buckling may occur as a result of an external force applied as overburden pressure.

The pioneering principles of mechanics on the flexible pipe were reported to verify and determine its horizontal and vertical deflections, bending moments, and tangential thrusts by Marston (1930) and Spangler (1941). Full-scale experiments on flexible culverts were conducted and the design formula developed from the load hypothesis was verified by Spangler (1941). The hypothesis assumed the passive horizontal pressures to be distributed parabolically on the sides of a pipe. In Japan, Marston-Spangler theory is applied to the design standard of the pipeline by the Ministry of Agriculture, Forestry and Fisheries (1998).

The load-deflection characteristics of steel and plastic - base pipe buried in a special test container were investigated by Howard (1972(a), 1972(b), 1974). Howard (1973) proposed modulus of soil reaction $e'$ because $e'$ is a pipe - soil interaction modulus rather than a true soil modulus $e$ originally proposed by Spangler (1941). The special laboratory tests were conducted to examine some of the relationships expressed in the Marston-Spangler theory for flexible - pipe design by Howard (1974). As the result in the load tests examined by varying the ring stiffness and soil - modulus, when the soil is well compacted beside the pipe, the pipe strength had little effect on the deflection of the pipe, as predicted by the Marston-Spangler theory.

Field buried tests and finite element method were conducted by Allgood (1972) to determine the relative stiffness of the pipe with respect to the stiffness of the enveloping soil. The effect of both density of model sand ground and pipe installation type on the measured earth pressures were discussed by Tohda et al. (1995).

Ring compression theory was proposed by White (1961) as designing and building of the corrugated structure according to a theory that analyzes an embedded pipe of large diameter, and realized a considerable saving. The theory involved a method for determining gage thickness in relation to the size of the structure and the depth of cover. In Japan, Corrugate Metal Culvert Manual (1979) was also