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The longitudinal response of buried large-diameter reinforced concrete pipeline with gasketed bell-and-spigot joints subjected to traffic loading

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ABSTRACT

The longitudinal response of a buried 1400 mm diameter reinforced concrete pipeline with gasketed bell-and-spigot joints subjected to traffic loading is investigated through three-dimensional numerical simulation. The soil is represented by a non-linear elastic perfectly plastic constitutive model that accounts for the reduction of soil stiffness with strain. Reasonable agreement is found between the computed results and the centrifuge test results.

The simulation reveals that four pipe segments and three joints are influenced significantly under the surface load. Variation in gasket stiffness has only minor influence on the longitudinal response of the buried pipeline. In contrast, variation in soil stiffness has a dominant influence. Due to the asymmetric geometry of the bell-and-spigot joint, the pipeline movement is not symmetrical, whether the load is applied above a joint or above the mid of a pipe segment. The longitudinal deformation of jointed pipeline is highly discontinuous, with concentration of rotation and shear displacement at the joints. The maximum joint rotation always occurs when the surface load is directly above the joint, while the maximum joint shear displacement is generated when the load is applied above the adjacent pipe contributing the spigot. The most unfavorable load position to generate the maximum joint shear displacement depends on the burial depth and can be estimated by a simplified method.

1. Introduction

Reinforced concrete (RC) pipes have been widely used in underground infrastructure construction. Traditionally the circumferential response of pipe barrels has received significant amount of research (e.g., Rakitin and Xu, 2014; Clayton et al., 2010; Lay and Brachman, 2014). However, the longitudinal response of pipelines is also important, with joints as potential weak points. Buco et al. (2006) found that 26.7% of concrete pipe defects were related to joint displacements or openings, based on the inspection of an 1800 km long sewer network. Failure in joints can lead to leakage, resulting in erosion of soil support and eventually collapse of the pipes. Even so, there is only limited research related to the longitudinal response of pipelines and the behavior of joints.

The structural performance of joints connecting two unburied pipes has been evaluated by full-scale laboratory tests (Vipulanandan and Liu, 2005; Buco et al., 2008; Wang, 2013), with the purpose of understanding the leakage response, joint stiffness and the structural capacity of bell-and-spigot joints. Several standards of American Society for Testing and Materials (ASTM) are related to joints in reinforced concrete pipes. ASTM (2014) standard C361 defines the manufacturing and performance requirements of joints in reinforced concrete low-head pressure pipe. ASTM (2005) standard C443, ASTM (1998) standard C497, and ASTM (2002) standard C1214 describe methods and procedures for testing joint leakage, joint structural capacity, and integrity of installed pipelines, respectively. However, none of these standards specifies the behavior of joints connecting pipes that are buried in soils. In practice, jointed pipelines are usually buried in the ground and subjected to various loading, including the soil weight and the surface loading. The condition would become more unfavorable if the bedding soil is non-uniform, or if there are localized load on the ground surface, e.g., traffic load (Davies et al., 2001).

Sheldon et al. (2013) investigated the field performance of joints in existing pipelines subjected to static loading (by parking a heavily loaded truck) and dynamic loading (by driving the truck over the pipeline with different speeds) at various load conditions. Only displacements of one joint in each pipeline were monitored; and no observation was made about the joint rotation and the longitudinal deformation of the pipeline.

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Becerril García and Moore (2015a) performed full-scale tests to investigate the behavior of buried reinforced concrete pipelines with bell-and-spigot joints when subjected to a surface load. The pipeline consisted of two complete pipes and two half-segments, and three load positions (offset = 0, 0.9 m and −0.9 m) combined with two burial depths (0.6 m and 1.2 m) were investigated. It was observed that the joint experienced the maximum rotation when the load was applied directly above the joint, while a larger shear displacement was measured when the surface load was located with an offset to the joint. However the exact load position that could induce the largest shear displacement could not be determined.

Buco et al. (2006) studied the effect of the gasketed bell-and-spigot joint on the longitudinal pipeline behavior subjected to a traffic load through a 3D numerical modeling. Shell elements were adopted to simulate the pipes, and a ring with rectangular cross section formed by solid elements was used to model the gasket. The total length of the pipeline was 27.2 m. However, only two

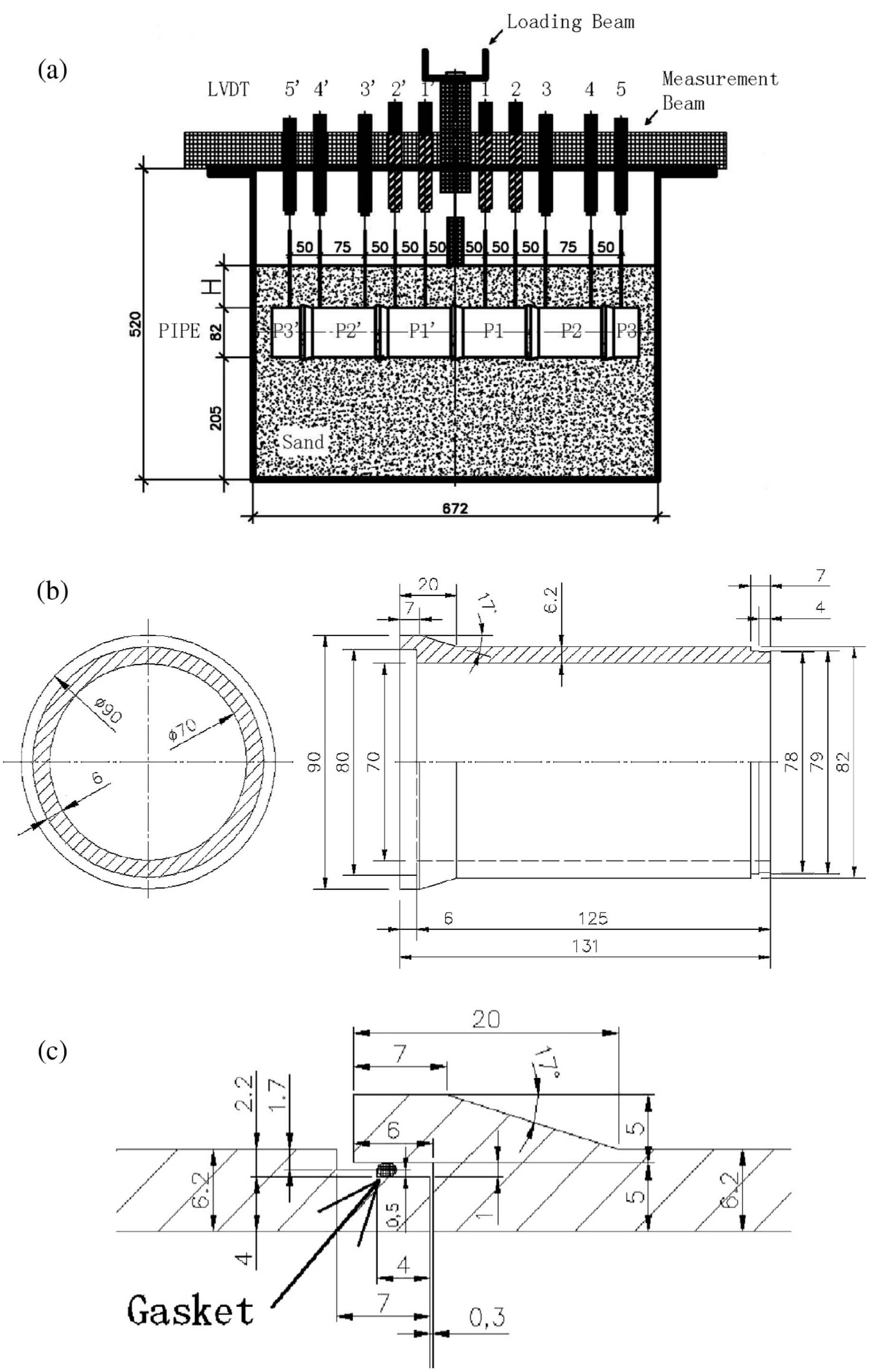

Fig. 1. (a) Details of centrifuge strongbox on model scale. H = 35 mm or 70 mm – soil cover depth; (b) details of pipe segment model; (c) gasketed bell-and-spigot joint on model scale. (All dimensions in millimeters.) (Rakitin and Xu, 2015).