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Rehabilitated reinforced concrete culvert performance under surface loading

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ABSTRACT

Reinforced concrete pipes require rehabilitation to mitigate the effects of deterioration and to increase their capacity when surface loading above the pipes is increased. Sliplining is one such method of rehabilitating reinforced concrete pipes. However, though design procedures exist for estimating the capacity of these rehabilitated pipes, there is no experimental evidence regarding how the load is shared between the pipe, the grout, and the liner, or the ultimate capacity of the rehabilitated pipe. Two damaged reinforced concrete pipes were buried and tested under surface loading before and after sliplining. Post-rehabilitation, the stiffness of the pipes was increased significantly, and the vertical diameter deformations were decreased by between 87% and 93%. The existing pipe was found to carry most of the load, partially due to the pre-existing cracks in the pipe being filled with grout during the sliplining process. Composite action was developed between the grout and the concrete pipe but not between the grout and the liner. The ultimate load carrying capacity of the pipes was governed by the bearing capacity of the unpaved ground surface rather than the pipes in these experiments.

1. Introduction

The United States and Canada are now undertaking very substantial reconstruction programs for structures built during the infrastructure booms of the 1950s and 1960s. With estimated investments in the billions of dollars to maintain or replace existing structures required in North America, infrastructure maintenance and rehabilitation represents a significant economic challenge for both Civil Engineers and governments (CIRC, 2012; ASCE 2013). In terms of buried infrastructure, circular reinforced concrete pipe (RCP) has been in use as highway culverts and sewers for over a century. Because of their age, many of these pipes are in a state of deterioration which requires prohibitively expensive infrastructure replacement, or alternatively rehabilitation. In some cases, the highways where these concrete culverts exist have been upgraded and the pipes are now required to carry higher surface loads than those they were originally designed for. In many situations, rehabilitation of the existing infrastructure is an attractive solution as it reduces the economic impact due to transportation network disruption and user delays.

A number of techniques have been developed for rehabilitating reinforced concrete culverts including sliplining as well as spirally wound (e.g. McAlpine and Anderson, 2005), cured in place (e.g. El Sawy and Moore, 1997), fold and form (e.g. Bennett et al., 1995), spray-on (e.g. Becerril García and Moore, 2015), and segmental liners (e.g. ASTM, 2013). Syachrani et al. (2008) surveyed 20 Departments of Transportation (DOTs) in the United States to identify the rehabilitation techniques being employed in industry. Sliplining was identified as the prevailing rehabilitation method with a popularity index of 93.2%, followed by cured in place lining at 75% (Syachrani et al., 2008). As such, the current research will explore the impact of sliplining on the structural capacity of deteriorated RCP as it is the most widely used rehabilitation method. Sliplining is the process of inserting a new pipe of smaller diameter into an existing deteriorated culvert by either pulling or pushing the new pipe followed in most cases by grouting of the annulus. In this study, segmental sliplining with a smooth walled HDPE pipe was chosen for investigation.

Current design methods for the rehabilitation of rigid culverts using grouted slipliners, such as the Water Research Centre (WRc) Sewerage Rehabilitation Manual (WRc, 2001), depend on classification of rigid pipes into deterioration categories. The WRc (2001) design approach classifies the repairs into two categories based on the interaction between the liner and the grouted annulus:

- Type 1: systems where the liner, grouted annulus and the existing culvert structure are fully bonded (no slip condition) such that composite action develops in the structure
- Type 2: systems where the liner does not bond to the grout or the structure and therefore acts as an independent structure (full slip condition)

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WRc (2001) Type 1 design depends on the development of a rigid composite structure to carry both earth and live loads. WRc (2001) Type 2 design depends on the existing deteriorated rigid structure and surrounding soil support having sufficient stability under earth loads. The liner in a Type 2 design acts only to restore the hydraulic performance and to resist external fluid pressure. Currently, the WRc (2001) design approach for culverts that fall between the two design classifications, i.e. partially bonded, is not clear. There is a lack of experimental data on the performance of sliplined reinforced concrete pipes to guide designers to the appropriate approach. Thus the current experimental study was undertaken to better understand the behaviour of these rehabilitated pipes.

The objectives of this research program are to investigate (i) the enhancement provided by a grouted slipliner rehabilitation, (ii) the role the liner plays in the structural system, (iii) the role of the grout in the system, and (iv) whether the controlling response of the system is across the barrel or joint locations. The first section of this paper presents the experimental background, including the test descriptions, the test configurations, the experimental specimens, the rehabilitation procedure, the instrumentation, and the applied loading schedule. The results of the service load experiments will then be presented and discussed, followed by the results of an ultimate limit state test on the rehabilitated system. Finally, salient conclusions from the experimental program will be presented.

2. Experimental background

2.1. Test descriptions

Three tests were undertaken during the experimental program: (i) T1 – a live loading test performed on the unlined deteriorated RCP specimens, followed by the rehabilitation of the RCP specimens, (ii) T2 – a live loading test on the rehabilitated structure and finally (iii) T3 – an ultimate limit state test on the rehabilitated RCP specimens. The deteriorated RCP specimens, referred to as RCP1 and RCP2, were damaged due to overloading prior to testing. RCP1 was damaged through the direct application of load during a D-load test while RCP2 was damaged during a separate buried pipe test not discussed in detail here (see MacDougall et al., 2016). For reference, a D-load test is a three point loading test conducted on reinforced concrete pipes that are not buried in soil. A line load is applied along the crown of the pipe through an actuator while the invert is supported along two parallel longitudinal lines. The test is used in industry to measure the critical cracking load of the pipe but in this instance was used to pre-damage the pipe. Surface loading to simulate vehicle loading was applied in several cycles for tests T1, T2, and T3 in order to capture the response due to initial loading as well as the repeated loading that is expected with vehicle loading.

2.2. Test configuration

Tests T1, T2, and T3 were performed within an 8 m long, 8 m wide, and 3 m deep reinforced concrete test pit. The RCP specimens were placed, prior to backfilling, within an excavated East-West oriented trench such that the invert of the culverts rested on the base of the trench. The reinforced concrete floor and sidewalls of the pit were located at a distance of 0.6 m and 1.5 m (shortest distance), respectively, from the outer wall of the concrete pipes as shown in Fig. 1. Two undamaged RCP extension segments were placed at the West and East ends of the assembled pipeline as shown in Fig. 1 to ensure that the soil cover extended past the ends of the deteriorated specimens to minimize the end effects of the embankment walls on the test specimens. The extension segments also served to eliminate boundary effects by providing joints at the ends of the test specimens. The joint between RCP1 and RCP2 was wrapped with geotextile prior to burial to prevent soil from entering the joint and so that the migration of grout into the joint

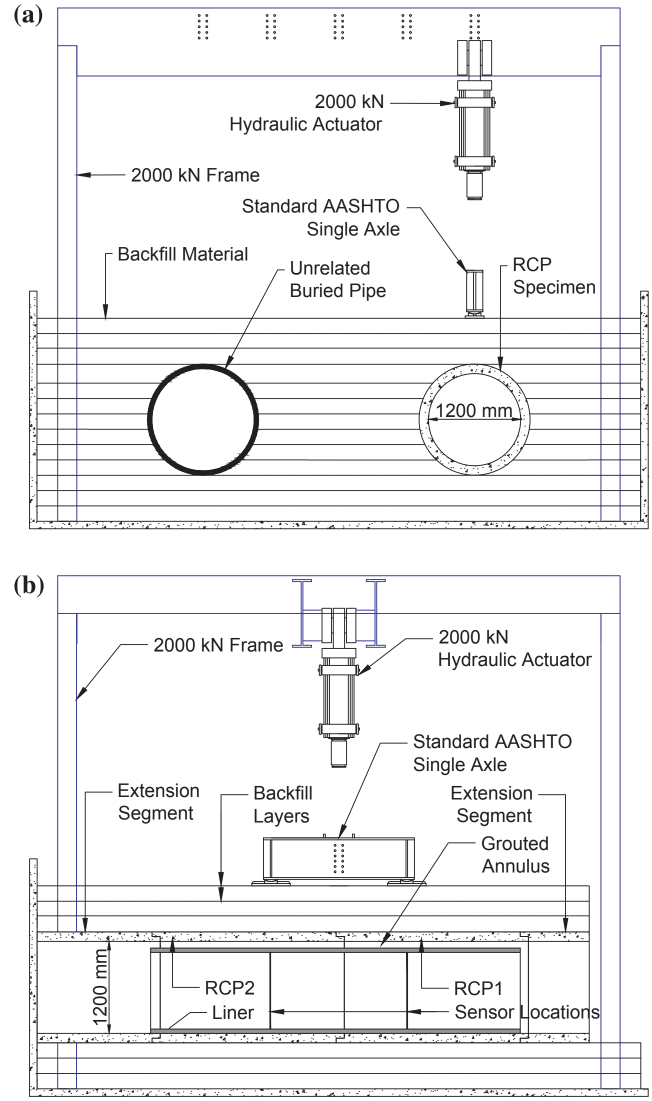

Fig. 1. Front (a) and Side (b) views of the test layout for tests T1, T2 and T3.

during grouting could be observed upon excavation after testing. Load was applied to the soil using a 2000 kN hydraulic actuator attached to a reaction frame as seen in Fig. 1 (a) and (b). The system was used with both a single wheel pair loading plate and a single axle frame with two single wheel pair loading plates to apply simulated vehicle loads to the soil. The single wheel pair load frame consisted of a steel column connected to a single steel pad measuring 250 mm by 600 mm (the standard dimensions specified in Canada for a wheel pair, CSA, 2006). The single axle frame consisted of two identical 250 mm by 600 mm steel plates spaced 1.8 m centre to centre (the axle dimensions specified by CSA, 2006) which were attached to the single axle frame (shown in Fig. 1(b)) that was placed on the surface of the soil.

2.3. Experimental specimens

RCP1 and RCP2 were CSA class 65D pipes with an internal diameter of 1200 mm and a type B wall type with a thickness of 125 mm (CSA, 2009). Both specimens were circumferentially reinforced with two steel D4 size wire mesh cages manufactured in accordance with ASTM A496M (2007). The steel used in the fabrication of the RCP specimens had a yield strength (f_y) of 485 MPa, an ultimate strength (f_u) of 550 MPa and a modulus of elasticity of 200 GPa. The measured inner and outer circumferential steel areas were 421 mm^2/m. The concrete strength (f'_c), based on concrete cylinder compression tests performed