THREE-DIMENSIONAL NONLINEAR ANALYSIS OF DEEP-CORRUGATED STEEL CULVERTS

by

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Dedication

To my parents who taught me how to work hard to achieve my goals

To my wife, Hala and my children, Omar and Nour, who were extremely patient with me during my study period

Abstract

Deep-corrugated steel culverts (with a corrugation wavelength of 400mm and amplitude of 150mm) can be used as an effective alternative for short-span bridges. Current design methods are typically based on two-dimensional finite element analysis. This thesis reports results from three-dimensional finite element analysis, with explicit modelling of the geometry of the corrugated plates (called corrugated analyses) and employing the orthotropic shell theory (called orthotropic analyses), for a specific box culvert having a 10 m span and 2.4 m rise. The results were compared to previously reported experimental data where a specific large span box culvert was tested under controlled laboratory conditions. The behaviour of the box culvert under small vertical displacement without any soil support was modelled to isolate the structure response. The box culvert was also modelled when subject to a fully loaded dump truck, and when loaded using a tandem axle frame to service and ultimate loads. Both corrugated and orthotropic analyses successfully captured the response of the box culvert when backfilled and loaded using dump truck and axle frame loading. It was found that the orthotropic model overestimated the culvert stiffness at the ultimate limit state, but provided effective estimates of response up to the factored design loads. The corrugated model with geometric nonlinearity was required to capture the real behaviour of the corrugated plates up to the ultimate limit state. New insights into the failure mechanisms of the box culvert were provided by the corrugated model analysis. A parametric study was then performed for 86 different long-span box and arch culverts, examining live load spreading in the axial direction, number of loaded lanes, design truck position, culvert geometry, plate thickness, and the existence of pavement. The results were then compared to the moment and thrust equations in the 2006 Canadian Highway Bridge Design Code (CHBDC) to check the performance of the current design equations. CHBDC equations overestimated the earth and live load bending moments, and did not give the correct trend for different spans. CHBDC thrust equations were found to underestimate the earth and live load thrust values for arch culverts.