ASSESSMENT METHODOLOGY FOR DIAGONALLY CRACKED REINFORCED CONCRETE DECK GIRDERS

1.0 INTRODUCTION

There are over 500 conventionally reinforced concrete (CRC) cast-in-place bridges in the Oregon Department of Transportation inventory that are identified as exhibiting diagonal cracking. Of these cracked bridges, 220 are along the I-5 and I-84 corridors. The majority of these bridges was built between the years 1947 and 1962 and classified structurally as reinforced concrete deck-girder (RCDG) bridges. Uncertainties regarding the capacity and remaining life of these bridges has resulted in unplanned bridge replacements, weight restrictions resulting in significant detours, as well as costly emergency repairs, additional inspections, and monitoring. The problem has further impacted local municipal and county agencies, which own and have responsibility for a large number of RCDG bridges in the State. In response to the uncertainties and the scope of the problem, a research program was undertaken to assess the capacity and predict the remaining life of RCDG bridges.

1.1 BACKGROUND

Large numbers of conventionally reinforced concrete (CRC) bridges remain in the national bridge inventory that are lightly reinforced for shear. One of the most common types is the slab-girder bridge used widely during the highway expansion of the late 1940’s through the early 1960’s. Bridges of this type have girders cast integrally with the slab and may be single span or continuous over multiple supports.

Early AASHTO (American Association of State Highway and Transportation Officials) provisions (*AASHO 1944, 1949, 1953, 1957, 1961, 1965*) for shear design of CRC bridges used allowable stress design and relied on the concrete to carry a prescribed working stress at service load levels. Reinforcing steel was used to provide supplemental shear resistance when required, and the permissible stirrup stress increased from 16 ksi in 1949 (*AASHO 1949*) to 20 ksi in 1953 (*AASHO 1953*). The magnitude of working stress permitted for the concrete in shear was $0.02f'_c$ for unanchored longitudinal bars and $0.03f'_c$ for anchored longitudinal bars (*AASHO 1941, 1944, 1953, 1957, 1961, 1965, and 1969*).

During the late 1940’s, research on bond strength for deformed reinforcing bars resulted in increased allowable bond stress in the 1953 AASHO Specification thereby reducing requirements for anchorages. The new deformed bars meeting ASTM A305-50T were used to provide anchorage (and therefore permit use of higher allowable concrete shear stress in design) in locations that would previously have required flexural bars to be bent across the web or terminated by a hook in a compression region (*Siess 1960*).

The combined effects of higher allowable concrete shear stress (permitted with less well anchored flexural bars terminated in tension regions) and the increased allowable stirrup stress changes made in the Specifications in the late 1940’s and early 1950’s may help to explain the diagonal cracking observed in 1950’s vintage RCDG bridges.

Shear design provisions in the AASHTO specifications for CRC bridges have evolved over time to reflect the latest experimental research, behavior theories, analysis methods, and service performance. Following the collapse of two separate warehouses at Air Force bases in Ohio and Georgia in 1955 and 1956, significant experimental research work was undertaken to improve the understanding of shear behavior. This research indicated that previous design provisions overestimated the concrete contribution to shear capacity and the permissible concrete stresses were reduced in the early 1960's to $1.1\sqrt{f'_c}$ (*ACI 1963*). As a consequence, designers in the 1950's relied on a larger allowable concrete stress than would be permitted today; and these early designs would have smaller cross-sectional dimensions, smaller sized stirrups or more widely spaced shear reinforcement, and reduced requirements for flexural bond stresses. It is interesting to note that the service level truck load model H20-S16-44 has not changed and remains the current HS20-44 truck used in the 17^{th} Edition of the Standard Specification (*AASHTO 2002*). While the load model has not changed, it is clear that actual truck load magnitudes and the volume of truck traffic have increased over time.

Many CRC slab-girder bridges are reaching the end of their originally intended design lives and the combined effects of over-estimation of allowable stresses for shear at design, increasing service load magnitudes and volume, as well as shrinkage and temperature effects, may contribute to diagonal tension cracking in these bridges. Due to the relatively light shear reinforcement, diagonal cracks may not be well constrained and therefore become quite wide.

Inspections of approximately 1800 vintage CRC slab-girder bridges in Oregon by Oregon Department of Transportation personnel revealed over 500 with varying levels of diagonal cracking. Crack widths over 0.1 in. were observed. These findings resulted in load postings, monitoring, emergency shoring, repairs, and unscheduled bridge replacements. The large numbers of bridges and their widespread distribution across the state prompted a research study to investigate the remaining capacity and life of diagonally cracked RCDC bridges.

1.2 OBJECTIVES

The objectives of this research were to: (1) assess field performance of typical RCDG bridges with diagonal cracks under in-service load and controlled loading conditions; (2) develop models that will enable ODOT engineers to estimate the life of RCDG bridge girders with diagonal cracks; and (3) develop new or modify existing analysis methods to predict remaining capacity of shear-cracked RC girders.

1.3 RESEARCH APPROACH

To address the research objectives, an integrated approach was taken to develop a reliability-based assessment technique. Research components included the following:

- collection of data describing vehicle loads in the State and prediction of the corresponding load effects;

- inspection, instrumentation, and controlled testing of in-service RCDG bridges;

- tests of large-scale laboratory specimens were conducted to evaluate strength and fatigue performance for a variety of loading conditions and specimen parameters;
- analyses for capacity using a range of available methods; and
- development of techniques to estimate service-level prediction for fatigue evaluation.

Employing all of these elements, an assessment methodology that makes use of reliability concepts was developed. The research tasks and findings are described and the assessment methodology is applied to a bridge in the ODOT inventory as detailed below.