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Displacement-Induced Fatigue Cracking of a Box Girder Bridge

Fissures de fatigue dues aux déformations d'un pont-poutre

Durch Verformungen verursachte Ermüdungsrisse in einer Kastenträgerbrücke

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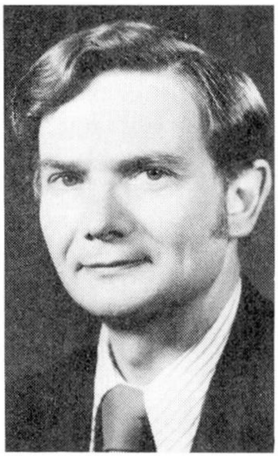

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SUMMARY
Unanticipated out-of-plane distortions as a result of the three dimensional behavior of structures have caused fatigue problems in welded bridge structures. This paper assesses the nature and causes of the distortion of the relatively small web gap of the web of curved box girders in the Ramp C Viaduct at the intersection of Interstate 695 and 83 near Baltimore, Maryland. The ultimate extent of cracking is evaluated, and a retrofit procedure is presented for the fatigue-damaged structure.

RESUME
Des déformations inattendues — hors de leur plan — résultant du comportement tridimensionnel de constructions ont causés des problèmes de fatigue dans des constructions soudées de ponts. Cet article traite de la nature et des causes du développement d'une étroite fissure dans l'âme d'une poutre en caisson courbe, d'un viaduc près de Baltimore, MD, USA. L'état final des fissures est évalué. Une technique de réparation est présentée pour la structure endommagée.

ZUSAMMENFASSUNG
Unerwartete, unebene Verzerrungen als Resultat von dreidimensionalem Verhalten von Bauwerken haben Ermüdungsprobleme an geschweissten Brückenbauten verursacht. Dieser Bericht behandelt die Art und Gründe der Verzerrung der relativ engen Stegspalte des Stegs an gebogenen Kastenträgern eines Viadukts in der Nähe von Baltimore, MD, USA. Die letzte Rissgrösse wird ermittelt und ein rückwirkendes Verfahren für ermüdungsgeschädigte Bauwerke wird beschrieben.

1. INTRODUCTION

Since the mid-1970's, fatigue problems with welded bridge structures have developed which are associated with out-of-plane displacements causing secondary web bending stresses in floor beam-girder bridges, and at cross frames and diaphragms in multiple girder bridges [1,2]. When such web bending stresses are sufficiently large and cyclical, fatigue cracking can result. Such displacement-induced cracking was recently observed at several internal diaphragm connection plates of a curved continuous box girder bridge in Baltimore, Maryland at the intersection of Interstates 695 and 83, in the Ramp C Viaduct. The characteristic cracking associated with out-of-plane movement of the web in a relatively small gap at the ends of transverse connection plates was detected after eight years of service, in the negative moment region where the transverse connection plates were not welded to the tension flanges.

Diaphragms and cross-framing are frequently used in curved box girders to prevent the cross-section from grossly distorting. It has been the practice to utilize transverse connection plates shop welded to the girder web and compression flange to connect the diaphragm members between the box girder webs. The end of the transverse connection plate is cut short or coped and fitted creating an unstiffened web gap adjacent to the tension flange. Figure 1 shows a cross-section of the curved box girder with the internal diaphragm in the negative moment region.

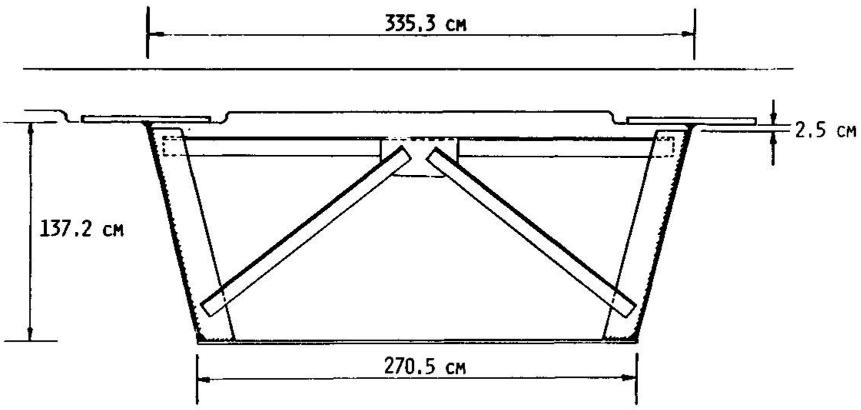

Fig. 1 Cross-Section of Curved Box Girder

2. CRACK DEVELOPMENT

The observed cracks all exhibited the characteristics that are associated with out-of-plane movement of the web in the relatively small gap at the end of the transverse connection plate. Figure 2 shows a photograph of a typical crack that was observed in the box on the outside web under the southbound lanes. Cracking has occurred in the web gap at the upper end of the transverse connection plate where no attachment was made to the tension flange in the negative moment region. This cracking is directly comparable to cracking that has been observed elsewhere in bridges with longitudinal girders and transverse floor beams.

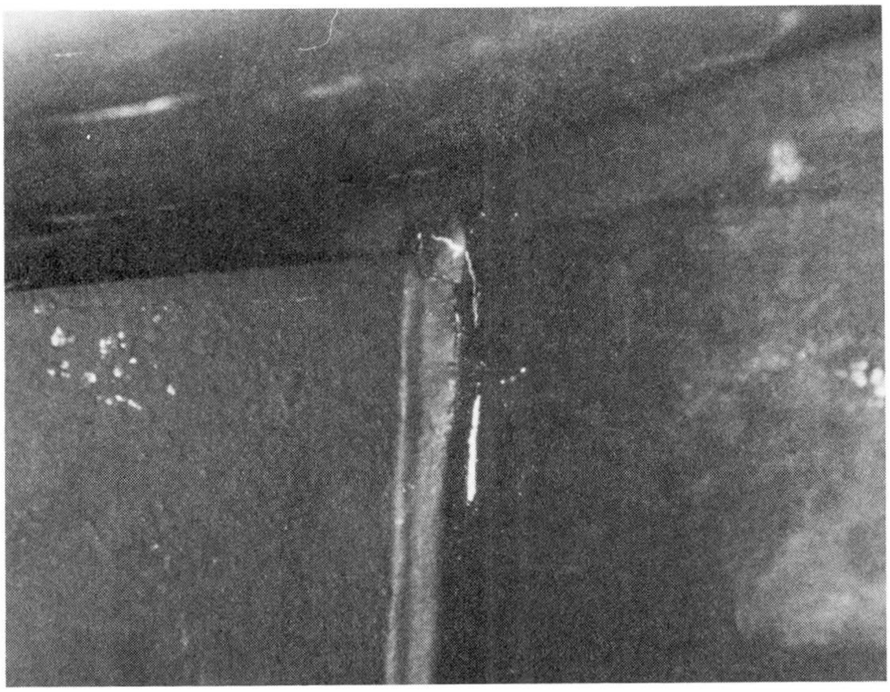

Fig. 2 Typical Crack in Transverse Connection Plate-Web Weld

When the web gap is relatively small, i.e. 2.5 cm, the movement of the diaphragm introduces large stresses on the upper end of the fillet weld connecting the diaphragm to the girder web and in the web gap. This results in cracking of the diaphragm-web weld connection at smaller welds, as illustrated in Fig. 3. If this cracking is not arrested through some retrofitting procedure, eventually between 2.5 cm and 5.0 cm of the weld will crack introducing enough additional flexibility into the girder such that the web gap is forced into greater double curvature. This distortion is shown schematically in Fig. 3. Cracking along the web-flange weld connection and longitudinal cracking in the girder web at the lower end of the diaphragm-web connection crack result from this cyclic distortion. At several locations, cracks formed in the web without significant weld cracking.

This observed cracking results from the distortion of the curved box section and subsequent loading of the diaphragms due to this distortion. This causes forces to be introduced into the girder web adjacent to the top flange, since the transverse connection plate is not welded to the flange. At the bottom end of the transverse connection plates, fillet welds positively attach the plate to the bottom flange which is acting in compression. Therefore, no cracks can develop at this welded end.

Most of the cracking was detected in the outside web of the curved box section and not in the inside web. This is a result of the direction of the out-of-plane movement. The transverse angle that is attached to the upper ends of the web connection plates is relatively stiff compared to the web gap. The outside web is pulled in on one side by the transverse angle producing cyclic tension stresses and subsequent cracking. On the other side, the web is pushed out resulting in cyclic compressive stresses. Since the effective stress range is less, severe cracking was not as extensive prior to retrofitting the structure.

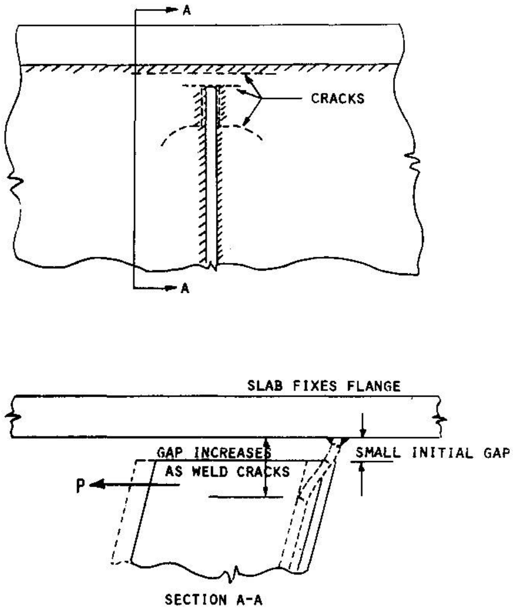

Fig. 3 Schematic of Crack Development

The cracking that has developed is a detail problem, not conceived of when this structure was designed and fabricated. Web gap cracking has only revealed itself during the past eight years. First observations of such cracking was made in floor beam-girder bridges. The cracking experienced in the Ramp C Viaduct is the first known case of displacement-induced fatigue cracking in a curved box girder structure. The development of these cracks is also related to the very high volume of truck traffic using the structure (estimated average daily truck traffic is 5100).

3. THEORETICAL ANALYSIS

One unit of the three unit Ramp C Viaduct structure was analyzed using the finite element method. SAP4 - A Structural Analysis Program for Static and Dynamic Response of Linear Systems [3] was used to perform the two phase analysis. The first phase consisted of analyzing the entire structure utilizing a gross discretization to model overall structural behavior. The resultant displacements from this and subsequent analyses were used to load the boundaries of substructure models of the region of the structure adjacent to the point of detected fatigue cracking. This second phase produced a better representation of the web gap behavior while conserving computer resources. One such substructure is shown in Fig. 4.

Using an HS 20-44 truck statically placed on the structure to represent live load, the uncracked web gap was distorted sufficiently to produce cyclic stresses varying from -7.13 MPa to +52.53 MPa. The maximum stress range exceeds the fatigue limit of the weld toes and crack propagation is unavoidable. An

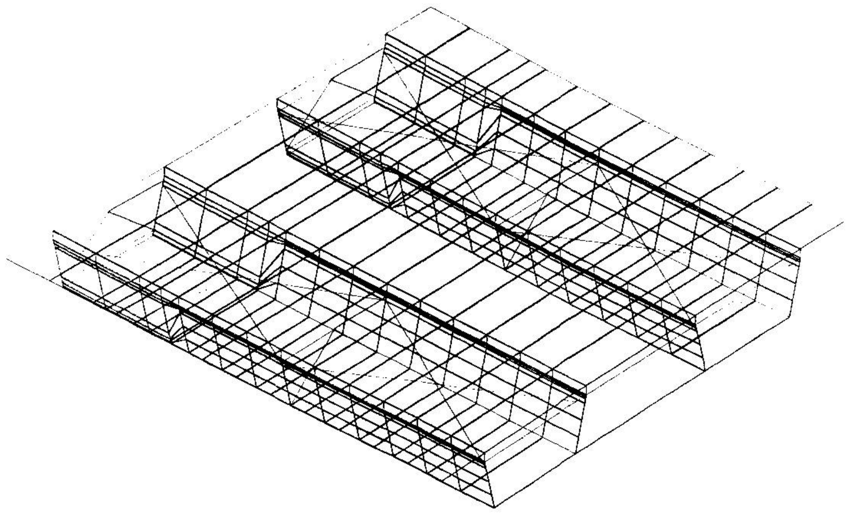

Fig. 4 Typical Finite Element Substructure Model

ongoing more extensive investigation suggests that the gap condition may be even more severe than this preliminary study indicates. The stress range in the gap, during passage of the HS 20-44 truck, may be as high as 90 MPa. Under random variable truck traffic, an effective stress range of 45 MPa ($0.35^{1/3}$ times stress range H20) would result in visible cracking from the estimated 15 million vehicles that have crossed the structure since it was placed in service. Hence, the observed behavior is in agreement with experiment test data and predicted crack propagation.

4. RETROFIT PROCEDURE TO IMPROVE FATIGUE LIFE

The only conceivable possibility for retrofitting this detail in the negative moment region is to provide a positive attachment between the transverse connection plate and the flange where web gaps now exist. This was accomplished by welding a shear tab to the transverse connection plate and flange, as shown in Fig. 5. This attachment provides a Category C fatigue condition for the flange plate which is not significantly different than the connection plate-web weld.

It is not feasible to cut back the connection plate, increasing the gap length to provide additional flexibility as an alternate solution to the out-of-plane movement problem. The diaphragms in the curved box section are carrying load while maintaining the cross-sectional shape. Cutting the connection plates back would alter the structural behavior and would likely result in more adverse behavior than is currently being experienced and continued fatigue cracking in the girder web.

The corrective action at the Ramp C Viaduct at the intersection of Interstates 695 and 83 has arrested continued crack propagation. Since the existing flange-web weld cracks are parallel to the normal cyclic stress, no further crack propagation is possible once the web gap distortion is prevented. This ensures that the desired life of the structure can be achieved without further adverse cracking.

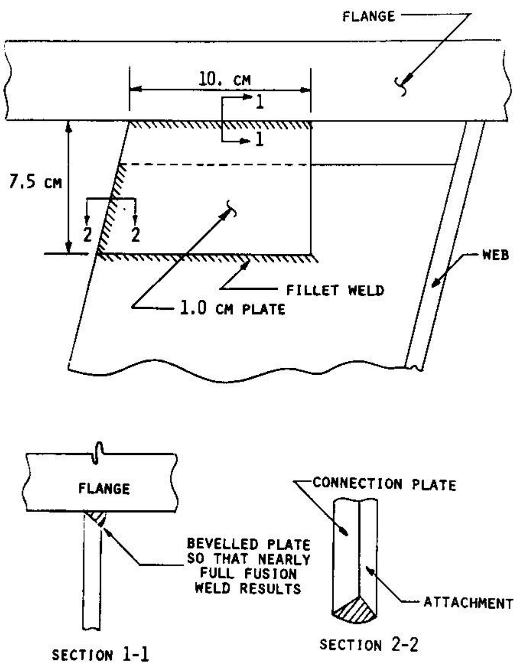

Fig. 5 Detail for Retrofit Procedure

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