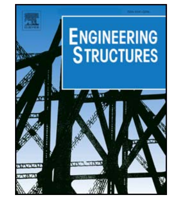
Engineering Structures 161 (2018) 134–145

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct



Investigation of residual fatigue life in shear studs of existing composite bridge girders following decades of traffic loading

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A R T I C L E I N F O

Keywords:
Shear studs
Fatigue
Existing bridges
Experimental testing

A B S T R A C T

Adequate design of composite bridge girders requires accurate determination of stud capacities and demands that develop during force transfer at the steel–concrete interface. This paper focusses on residual stud fatigue capacities and accumulated stud damage in existing bridge girders, following decades of high traffic loading. The paper includes discussion from non-destructive magnetic-particle inspection (MPI) and dye-penetrant testing (DPT) crack investigations on the studs of two existing bridge girders following deck removal. In addition, three destructive fatigue push-out tests are performed on the flanges of an existing high-traffic bridge girder to help understand stud residual fatigue capacity. Historic traffic count data are combined with these destructive and non-destructive tests to provide insight into accumulated bridge damage during many years of traffic loading, and to provide insight into potential conservancies in the current AASHTO stud design provisions. Results from the non-destructive MPI and DPT investigations indicated no detectable fatigue cracks within the studs of the two bridge girders (which were estimated to have seen over 25,000,000 and 38,000,000 truck cycles respectively). Results from all three fatigue tests exceeded the AASHTO design life expectancy of approximately 850,000 cycles (at 11.6 ksi (80 MPa)) by over 2.5 million cycles. This residual fatigue life is over 400% of the expected shear stud fatigue life, even after over 38,000,000 truck cycles estimated during the in-service life of the bridge. The excellent shear stud fatigue performance observed is likely due to additional shear transfer through adhesion and or friction between the concrete deck and steel flange during service loading, which are not considered in the current AASHTO design calculations.

1. Introduction and background

Aging of existing bridge infrastructure is a significant issue that requires attention as over half of the steel bridges within the United States have met or exceeded their initial design life. Current specifications provided by the American Association of State Highway Transportation Officials (AASHTO) require bridge designs to achieve a 75 year fatigue design life [1]; however, previous versions of the specifications prior to 1998 considered a 50-year fatigue design life. This is significant as approximately 158,600 of the estimated 181,000 steel bridges in the United States were designed and constructed prior to the 1998 code change from a 50 to 75 year design life [2]. Additionally, nearly 51% of these pre-1998 bridges are currently 50 years of age or older [3] (see Fig. 1). Note in Fig. 1 that bridges aged between 0 and 19 years are designed to the currently required 75-year design life [3].

With many bridges close to their design fatigue life, opportunities exist to examine residual fatigue capacities within the shear studs of composite bridge girders, providing insight into potential over-conservancies in composite design. Unfortunately, existing management and maintenance inspections are largely visual and can only detect deterioration of the exposed bridge superstructure [4]. Shear stud fatigue damage is not easily examined prior to demolition of the concrete bridge deck, and it is often unclear what existing fatigue damage has occurred within the studs of these bridges having more than 50 years of service. Forensic analysis of decommissioned bridges having removed concrete decks would allow determination of internal deterioration and residual fatigue life within the studs, creating a better understanding of stud fatigue processes that occur during the service life of actual bridges [5].

Limited research exists on the residual composite strength of decommissioned high-traffic bridges having more than 50 years of service, and following an extensive literature search, no studies were found to have investigated the residual fatigue capacity of shear studs within a 50-year-plus decommissioned bridge. One study by [6] examined the residual shear strength of a decommissioned bridge with static loading tests; however, stud failure is often governed by fatigue processes

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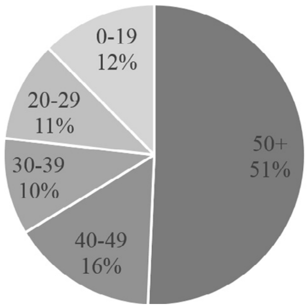
https://doi.org/10.1016/j.engstruct.2018.02.018
Received 22 August 2017; Received in revised form 25 January 2018; Accepted 2 February 2018
Available online 20 February 2018
0141-0296/



Age (years)	Quantity
0-19	22,484
20-29	19,568
30-39	18,865
40-49	28,401
50+	91,776

Fig. 1. Age distribution for steel bridges within the United States.

[7–11] and strength testing provides little insight into residual fatigue life. The lack of research on residual shear fatigue capacity is likely due to the focus of published research on bridge collapse mechanisms, rather than forensic analysis of bridges removed in non-catastrophic ways.

This paper experimentally investigates the residual fatigue life of existing high-traffic bridges using non-destructive and destructive techniques. Two bridges are chosen for the study, (1) an airport-road interstate overpass bridge undergoing a scheduled lane expansion (referred to as Bridge 'A'), and (2) a decommissioned bridge along Interstate 40 (I-40) in Arkansas (hereafter referred to as Bridge 'B'). Both bridges provide unique opportunities for stud fatigue investigation as the concrete bridge decks were carefully removed prior to decommissioning or expansion.

The paper begins by discussing the experimental program, including detailed descriptions of the bridges investigated. Following, a traffic count study is presented to help estimate existing fatigue damage and an overview of the non-destructive and destructive testing methods are described. Next, an experimental fatigue test setup is discussed along with the specimen fabrication, geometry, and loading. Finally, results from the non-destructive and fatigue testing are presented and conclusions are summarized.

2. Experimental program

The experimental study consists of two parts: (1) non-destructive testing and (2) destructive fatigue testing. The non-destructive testing methods used in this experimental program are magnetic particle inspection and dye penetrant testing. As will be described in following sections, these non-destructive methods allow identification of existing fatigue cracks within non-failed components. The additional destructive testing involves fatigue testing of pushout specimens having been fabricated from portions of the decommissioned bridge along I-40 (Bridge 'B').

2.1. Bridge descriptions and traffic loading

Bridge 'A' is located in Lowell, Arkansas on Highway 264 at the point Highway 264 crosses Interstate 49. Fig. 2 shows the location of Bridge 'A' within Northwest Arkansas. Access to shear studs on the bridge for non-destructive testing became available as the bridge was being widened. The original bridge was built in 1982 as a multi-girder continuous composite bridge spanning 266 ft (81 m) with three piers along the span at the center-line and 84 ft (25.6 m) off of the centerline. Bridge 'A' contains eight girders laterally spaced at 7 ft (2.1 m) which are comprised of five beams connected by bolted splice plates. All beams are A572 Gr50 steel with beam sizes varying across the span. Original plans for Bridge 'A' obtained from the Arkansas Department of Transportation (ARDOT) indicate a design using ¾ in. (19 mm) diameter headed shear studs with rows containing three studs at a 2 in. (50.8 mm) lateral spacing. The plans indicate a design pitch varying from approximately 8 to 17 in. (203 to 432 mm) longitudinally along the girder; however, when the shear studs were uncovered it was discovered that existing shear stud pitch ranged from 12 to 20 in. (305 to 508 mm). This larger spacing indicates that the shear studs were exposed to higher stresses for each in-service fatigue cycle than was accounted for in design. During the bridge widening, additional shear studs were welded to exposed girder flange to correct for the increased stud demands.

Bridge 'B' was decommissioned and removed from I-40 Just west of Russellville, Arkansas, one of the most heavily traveled interstate

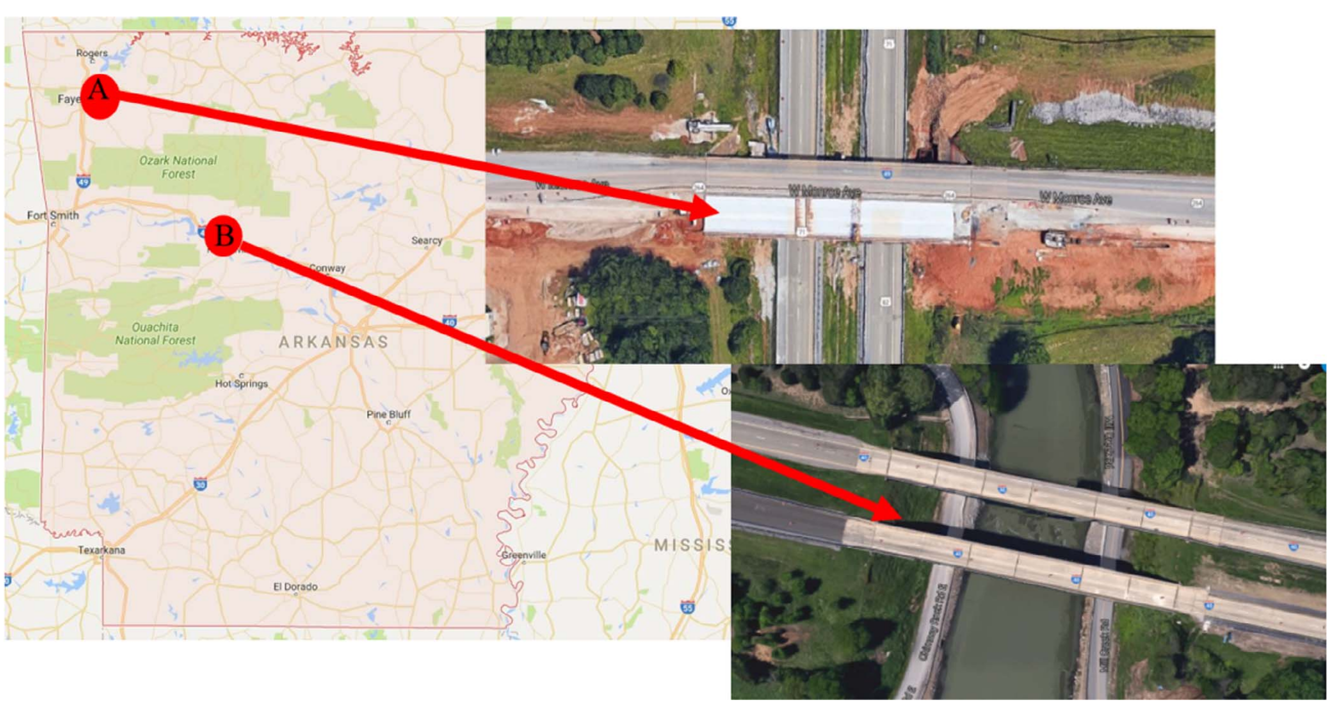


Fig. 2. Location of Bridge 'A' and Bridge 'B' in Lowell and Russellville, Arkansas.