# Wood-Concrete Composite Beams under Low-to-High Cycle Loading

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## Summary

The wood-concrete composite beams investigated in this paper consist of a wood layer overlapped by a concrete layer and interconnected by notched shear-key connections to prevent the relative slip. When this type of structural system is applied to bridges with high traffic it is essential to know their fatigue behavior. This paper presents the result of a joint research at Colorado State University and Metropolitan State University of Denver, attempting to establish the S-N curve for fatigue conditions of notched wood-concrete connections based on low/high-cycle, repeated loading tests. Experimental results are reported on fourteen 1524 mm span composite beam specimens of 191 mm width, with a 89 mm thick wood layer consisting of five “2x4” boards and a 63 mm concrete layer interconnected by embedded anchor screws at the notch locations. Five specimens were only statically loaded while the others were cycled to failure with a maximum to minimum pulsating load ratio of 10. Points on the S-N curve were determined for three levels of the maximum load as a function of the average static failure load. Typical observed failure modes were block-shear of the wood at the notch and tension failure of the wood at mid-span. The obtained S-N curve is compared to the respective provisions of Eurocode 5 for timber beams and with the results of other fatigue tests performed in Germany.

**Keywords:** Wood-concrete composites, Fatigue, Design codes.

# 1. Introduction

Wood-concrete composite systems are constructed by interconnecting a wood layer with a concrete layer placed atop. In this way it is possible to exploit both materials at the best since the wood is subjected to tension coupled with bending, and the concrete slab is mainly compressed. The composite system, in fact, exhibits larger stiffness and strength, no problem of vibration, better seismic performance, reduced dead load, better appearance, and the possibility to use the wood layer as a permanent formwork for the concrete slab [1]. A notched interlayer connection detail [2] was adopted in this study, with a vertical bearing surface [3]. The interconnection between wood and concrete is achieved by direct bearing of the concrete in the notch on the wood surface. Advantages of the notch detail include the higher composite action (i.e. stiffness of the composite system) and larger achievable load capacity. The stiffness of the interlayer connection determines the degree of the composite behavior achieved [4, 5, 6].

Wood-concrete composite structural members are usually applied in building structures. There are a relatively small number (in the low 100s) of known bridge applications involving wood-concrete composites. A problem with using these novel composite members in bridges with high traffic is that the fatigue behavior of such members under high-cycle repeated loading is not yet well known due to the small number of test data available [7, 8, 9]. Knowing the fatigue performance of these members is essential in bridge applications. Nevertheless, a number of bridges have been built [10, 11], showing the adequacy of the wood-concrete composite system to bridge applications.

# 2. Experimental Setup

The research was performed at Colorado State University and the testing was conducted in the laboratory of the Metropolitan State College of Denver, in 2011 and 2012 [12]. The research program was conceived in coordination with work at University of Stuttgart.

## 2.1 Geometry

Fourteen 1626 mm (64 in) long wood-concrete composite beam specimens were built for this test program. The width of the specimens was 191 mm (7.5 in) and each had a 89 mm (3.5 in) thick wood layer consisting of five “2x4” boards with nominal size of 38 mm x 89 mm (1.5 in x 3.5 in), and a 63 mm (2.5 in) concrete layer, as shown in Fig. 1.

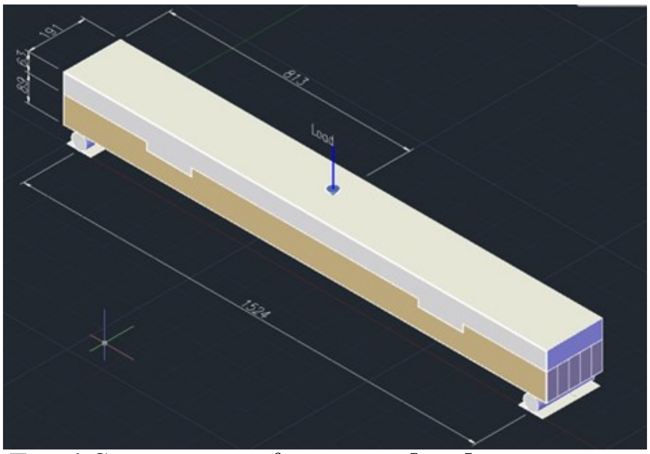

*Fig. 1 Specimen configuration [mm]*

The wood and concrete layers were interconnected by embedded anchor screws, of 12.5 mm (0.5 in) diameter and 102 mm (4 in) long with an embedding depth of 50 mm (2 in), at the notch locations. The notches were cut into the wood 25 mm deep (1 in) and were 150 mm (6 in) long over the entire width of the specimen. The wood boards were attached to each-other by 4 in deck screws 150 mm (6 in) apart. The wood layer and the end of the wood boards were coated with a sealer paint (shown as white in the picture) to reduce the moisture entering the wood during the casting of the concrete layer.

## 2.2 Material Properties

The wood material was premium-grade No.2 or better kiln dried Hem-Fir. The MOE value was determined by testing 28 wood samples according to ASTM D143 using an Instron 5569 device [12]. The moisture content of the wood was determined with a Delmhorst 11212 moisture mapping meter. The dry conditions are typical to the Colorado climate (the tests were conducted between the months of September and March). The concrete material contained glass fibers [12].

### 2.3 Test Setup

Simply supported specimens were configured with a span of 1524 mm (60 in). Mid-span (three-point loading) loading was applied using an MTS hydraulic loading and digital data acquisition system. Roller supports were configured at each end to avoid horizontal forces straining the actuator, resulting in a symmetric configuration, see *Fig. 2*. Some of the specimens were subject to static loading while others to cyclic pulsating loading.

All loading was displacement controlled. The controlled displacement component was the deflection of the member at the point of the load application (mid-span) [13].

*Fig. 2 Typical test setup*

## 3. Results

### 3.1 Static Test Results

In order to determine the average static failure load ($P_{max}$) a total of five specimens were loaded statically. The load-deflection characteristics recorded are shown in *Fig. 3*. It was observed that a drop in the resisted load occurs when block-shear failure develops first and that the member is usually able to take additional load. More severe and irrecoverable drops in the resisted load are caused by the failure of a wood board in tension at the mid-span . The average total failure load was $P_{s,max}$=56.4 kN (12.7 kip). Initial failures loads were recorded and stiffness data was derived [12].

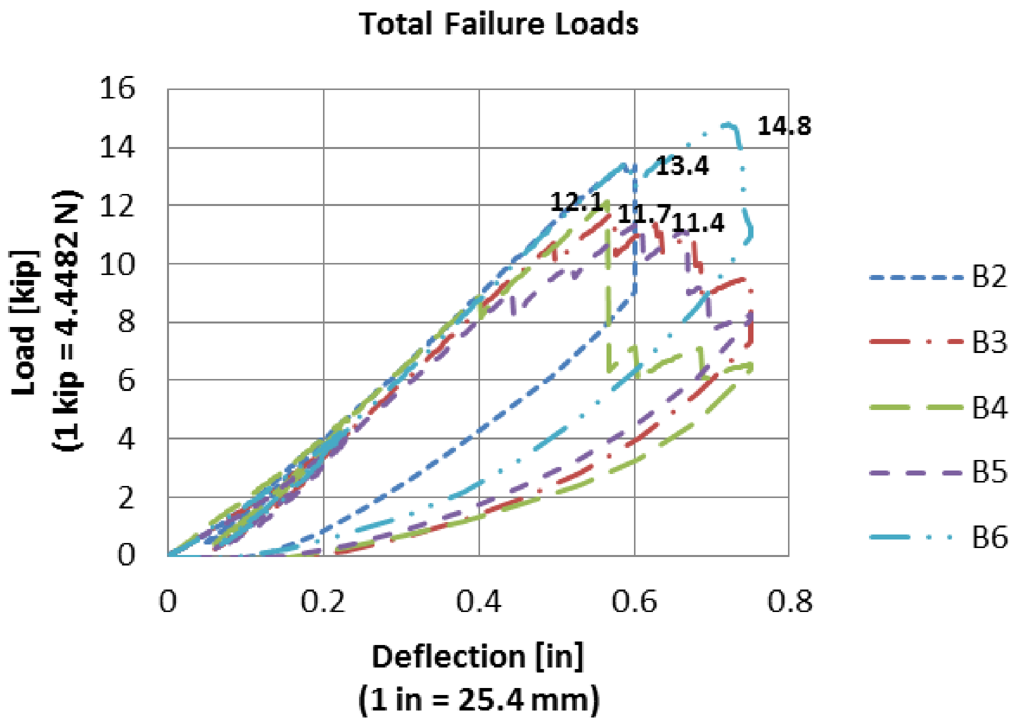


*Fig. 3 Typical test setup*

## 3.2 Fatigue Test Results

The load was cycled sinusoidally, at a frequency of 1 Hz, maintaining a maximum load, $P_{max}$, to minimum load, $P_{min}$, ratio of $R=P_{min}/P_{max}=0.1$.

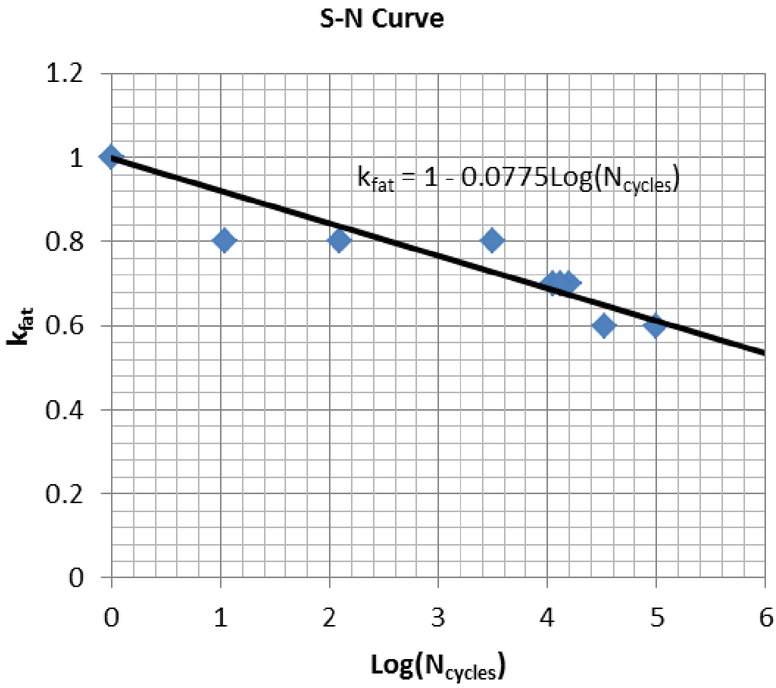


*Fig. 4 Mean S-N line approximation*

Points on the S-N curve are determined for three levels of the maximum load as a function of the average static failure load, $P_{max}/P_{s,max}$ of 0.8, 0.7, and 0.6. The results [12] are summarized in *Fig. 4*, showing the fatigue test results (blue bullets) and an approximation of S-N line on a logarithmic scale.

In addition, specimen F10 was investigated at a load level $P_{max}\approx 0.5P_{s,max}$, of 29.4 kN (6.6 kip) and no signs of failure were detected in the first $10^5$ cycles.

Typical observed failure mode was by initial block-shear, shown in *Fig. 5*, followed by a tension failure of the wood in bending, see *Fig. 6*.

*Fig. 5 Typical block-shear failure*


*Fig. 6 Typical tension failure*

## 4. Conclusions

This paper presents the result of a research at Colorado State University and Metropolitan State University of Denver, performed in coordination with work at University of Stuttgart, attempting to establish the S-N curve for fatigue loading of notched wood-concrete connections based on low-to-high-cycle, repeated loading tests. Experimental results are obtained on fourteen composite beam specimens. Five specimens were statically loaded to failure, while the others were cycled to failure.

Points on the S-N curve were determined for three levels of the maximum load as a function of the average static failure load. Typical observed failure modes were block-shear of the wood at the notch in some cases followed by tension failure of the wood at mid-span. The obtained S-N mean line was determined. This allows for comparison with the EC-5 EN 1995-2:2004 [14], Annex A which addresses the fatigue verification [12]. The results tentatively indicate that the provisions of EC5 EN 1995-2:2004 for fatigue verification could be used for the type of composite member studied herein provided the expected failure mode is by block shear of the wood at the notches. This conclusion is tentative only, due to the small number of tests it is based on, and is consistent with findings by Kuhlmann and Aldi [15].

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