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Post-Tension Strengthening of Composite Bridges

Renforcement de ponts mixtes par post-contrainte

Verstärkung von Verbundbrücken durch nachträgliche Vorspannung

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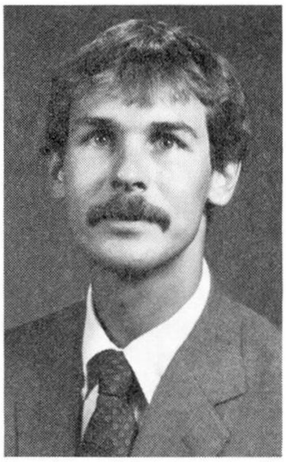

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SUMMARY
Because of changes in design specifications and increases in legal loads, a number of simple-span steel-beam, composite-concrete deck bridges in Iowa need the live load carrying capacity of the exterior stringers increased to meet current legal load limits. The feasibility of strengthening such bridges by post-tensioning was determined from laboratory tests. Reported herein are the results of strengthening by post-tensioning of two existing bridges.

RESUME
Faisant suite au changement des normes de projet et de l'augmentation des charges admises légalement, un certain nombre de ponts mixtes à une travée, en Iowa, USA, doivent être renforcés pour satisfaire aux règlements en vigueur. Des essais en laboratoire ont montré la possibilité de renforcer de tels ponts, par post-contrainte. L'article présente deux cas d'application de la post-contrainte à de tels ponts.

ZUSAMMENFASSUNG
Aufgrund von Änderungen in den Konstruktionsnormen und der Erhöhung der zulässigen Lasten müssen die Randträger einer Anzahl als einfache Balken ausgebildete Verbundbrücken im Staate Iowa, USA, verstärkt werden. Laborversuche haben die Möglichkeit aufgezeigt, solche Brücken durch nachträgliche Vorspannung zu verstärken. Der Beitrag bespricht die Verstärkung zweier Brücken die mit vier Längsträgern ausgebildet sind.

1. INTRODUCTION

Many simple-span, steel-beam, composite-concrete slab bridges built between 1930 and 1960 are not in complete compliance with today's bridge standards. In Iowa alone over 70 bridges of this type require "strengthening" to meet current standards. More specifically, the live load carrying capacity of their steel stringers must be increased. The simple-span steel-beam composite-concrete slab bridges (henceforth simply referred to as bridges) requiring such strengthening fall into two categories:

- those that should be posted because they do not satisfy allowable live load stress limits.
- those that presently are structurally and geometrically adequate but require additional load capacity to acccommodate resurfacing for extended life.

At present, no acceptable procedures for such strengthening have been developed. Thus, the purpose of this research program was to determine a technique for increasing the capacity of the steel stringers of these bridges, thereby increasing both their live load and dead load carrying capacity.

After an extensive literature review of the various methods for strengthening bridges, post-tensioning was viewed as the most economical and promising. Phase I of this study was, therefore, directed to determining the desirability of post-tensioning the stringers in the bridges. The objective of Phase I was fulfilled by testing a model bridge and applying known analytical procedures to determine the bridge's behavior under post-tensioning. Phase II of the study, which is reported herein, involved the strengthening of two existing bridges utilizing the post-tensioning schemes designed in Phase I.

The concept of prestressing steel structures is well over a century old. However, prestressed composite structures are a much more recent development. In the 1960s several USA researchers tested prestressed composite structures and developed methods for their analysis [1,2]. A few U.S. bridges have been built utilizing prestressed composite structures since 1960. Reference 3 is recommended for a more complete review of post-tensioning steel structures.

2. GENERAL RESEARCH PROGRAM

On the basis of the literature review, field inspection of several bridges, and the results of Phase I, a second testing program was planned which involved the strengthening and testing of two existing bridges.

One of the bridges selected for strengthening, henceforth referred to as Bridge #1, was a four stringer 15.24m × 9.14m I-beam right angle bridge which is similar to the model bridge of Phase I but twice as large. The other bridge, henceforth referred to as Bridge #2, was a four stringer 21.34m × 9.14m I-beam 45° skewed bridge.

As noted later, only the exterior stringers of each bridge were post-tensioned as they were the only ones significantly overstressed. In addition to the post-tensioning forces which were applied to the bridges, each bridge was subjected to an overloaded truck weighing slightly over 267 kN. The response of the bridges to the truck loading was determined before and after post-tensioning so that the effectiveness of the post-tensioning could be ascertained.
Although a variety of bridge deck analysis methods are available, such as grillage analysis, finite difference analysis, and finite element analysis, orthotropic plate theory was utilized for correlation of experimental results [4]. Although good agreement was obtained between experimental and theorectical re-

sults, post-tensioning forces can only be approximated with orthotropic plate theory. A finite element program is presently being developed for a more exact analysis; however, in the authors' opinion, the analysis developed to date may be used in design with little difficulty.

3. DESCRIPTION OF BRIDGES STRENTHENED

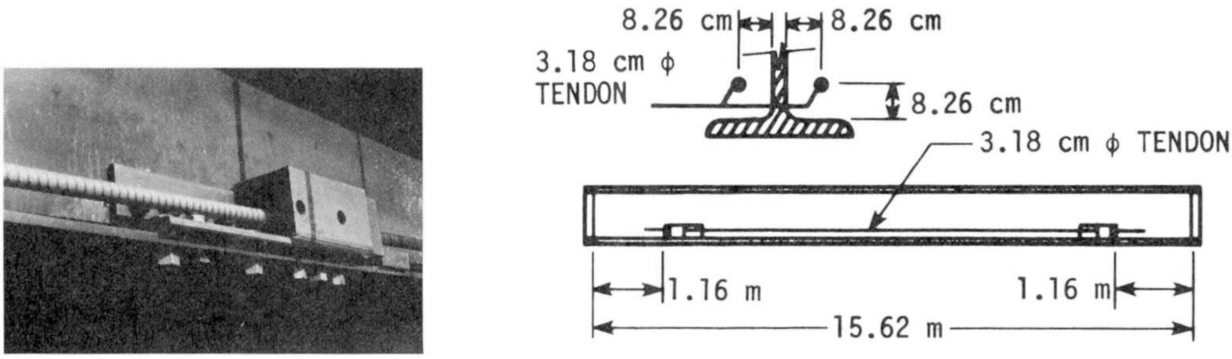
Bridge #1, built in 1948, is located 3.54 km north of Terril, Iowa, U.S.A. For composite action, all stringers had angle-plus-bar type shear connectors. Analysis indicated that for the bridge to carry additional live load, the exterior stringers needed additional shear connectors. Assuming the type of steel may be unknown in bridges requiring strengthening, it was decided to add shear connectors by bolting rather than welding. High strength bolts were tested as shear connectors in the laboratory and found to be more than adequate. Cores (10.16 cm to diameter) were drilled in the bridge deck above the exterior stringers and a total of 52 (26 per stringer) high strength bolts were double-nutted to the stringers; later the core holes were grouted. Member sizes, span lengths, etc. for Bridge #1 as well as Bridge #2 are presented in Table 1.

	Bridge #1		Bridge #2	
Span (Center line to Center line of Bearing)	15.62 m		21.72 m	
Deck Slab Width	9.72 m		9.72 m	
Deck Slab Thickness	23.50 cm		20.96 cm	
	Exterior Stringer	Interior Stringer	Exterior Stringer	Interior Stringer
Steel Beam	W27 × 94	W30 × 116	W33 × 130	W36 × 194
Beam Depth	68.38 cm	76.23 cm	84.05 cm	92.68 cm
Cover Plate	22.86 cm × 1.11 cm	22.86 cm × 3.18 cm	25.40 cm × 2.22 cm	27.94 cm × 3.49 cm

Table 1 Properties of Strengthened Bridges

Details of the post-tensioning system employed are shown in Figure 1. Due to uncertainty about the type of steel in some of the bridges to be strengthened, the connections were bolted. Figure 1a illustrates one of the 8 brackets, fabricated from 1.91 cm thick structural angle, bolted in position. The position of the 3.18 cm ϕ post-tensioning tendons is shown in Figure 1b.

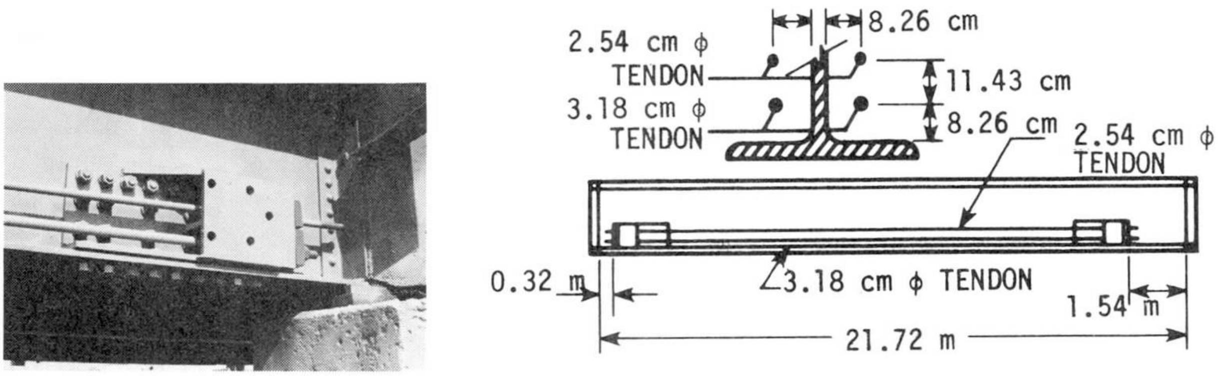
Bridge #2, built in 1947, is located on State Highway 144 approximately 24.14 km north of Grand Junction, Iowa, U.S.A. This bridge, like Bridge #1, has angle-plus-bar shear connectors and needed additional shear connectors on both the interior and exterior stringers to be able to carry additional live load. As on Bridge #1, cores were cut in the deck and 28 high strength bolts were added to each exterior stringer and 26 to each interior stringer for a total of 108 on the bridge.



(a) POST-TENSIONING BRACKET AND TENDON IN POSITION

(b) TENDON LOCATION

Fig. 1. Post-tensioning details - Bridge 1.



(a) POST-TENSIONING BRACKET AND TENDONS IN POSITION

(b) TENDON LOCATION

Fig. 2. Post-tensioning details - Bridge 2.

Details of the post-tensioning system employed are shown in Figure 2. Figure 2a illustrates one of the brackets bolted into place with high strength bolts; each bracket was fabricated from 1.91 cm thick plate. The position of the 3.18 cm ϕ and 2.54 cm ϕ post-tensioning tendons is shown in Figure 2b; note that the bracket is located at a great distance from the center line of bearing on the jacking end of the stringer.

4. FIELD TESTING PROGRAM

The testing program on each bridge included three parts: Part 1 was the response of the bridge to an overloaded truck (weight = 267 kN). Part 2 was the response of the bridge to post-tensioning, and Part 3 was the response of the bridge to the same truck after post-tensioning.

Parts 1 and 3 were essentially identical for both bridges. The truck was placed at a number of positions on the bridge, and the response of the bridge was recorded. Part 2 was different for each bridge and is noted below.

4.1 Bridge #1

For data collection, four electrical-resistance strain gages (two on the top flange and two on the bottom flange) were placed at the center line of each stringer. Additional instrumentation was used to measure deflections at the midspan of all stringers and the quarter points of one interior and one exterior stringer, and to measure the force in each tendon.

Hollow core hydraulic cylinders were used in post-tensioning the bridges. Since only two cylinders were available, it was necessary to post-tension the bridge in steps, post-tensioning one exterior stringer to approximately 1/3 of the desired force and then the other until slightly less than the desired force of 818.5 kN per stringer was obtained.

4.2 Bridge #2

As a result of the strengthening of Bridge #1, the instrumentation of Bridge #2 was increased. Electrical-resistance strain gages (two on the top flange and two on the bottom flange) were placed at the center line of each stringer, the quarter point of one interior and one exterior stringer, and close to one support of the same interior and exterior stringer. Strain gages were placed close to the ends of the stringers to measure the end restraint which was observed in the testing of Bridge #1. A step by step post-tension sequence similar to that utilized on Bridge #1 was employed except that twice as many steps were required because the exterior stringers had four tendons to post-tension. On the average, the desired force of 1361.2 kN per stringer was achieved.

5. TEST RESULTS

Space limitations allow only a portion of the results of the study to be presented in this paper. Details of the results of Phase I are presented in Reference [3]; those of Phase II will be presented in the final report which is currently being prepared.

5.1. Bridge #1

The desired post-tensioning force for each bridge was based upon the results of Phase I of the study. Thus, subjecting each exterior stringer to a force of 818.5 kN was supposed to cause a strain reduction in the lower flange of 218 $\mu\varepsilon$. This was based upon the assumption that the bridge was simply supported. However when the 818.5 kN force was applied in the field, a strain reduction of only 147 $\mu\varepsilon$ was obtained due to restraint of the ends of the stringers. Figure 3 compares the midspan strains measured with theoretical strains assuming the stringer to be completely restrained against rotation and completely free to rotate. Note that the measured strains are essentially midway between the fixed and the free condition. Thus, although the desired strain reduction was not obtained, it should be noted that the end restraint also reduces the effect live load has on the bridge.

5.2 Bridge #2

As in Bridge #1, the force applied to each exterior stringer (1361.2 kN) was determined assuming the stringers to be simply supported. The 1361.2 kN force was to cause a strain reduction in the lower flange of 212 $\mu\varepsilon$. When the desired force was applied in the field, a reduction of only 102 $\mu\varepsilon$ was obtained because of end restraint. Figure 4 compares the midspan strains measured with the theoretical strains assuming the stringers to be first completely restrained against rotation and second completely free to rotate. As may be seen, the strains in the exterior stringers approach the fixed end condition.

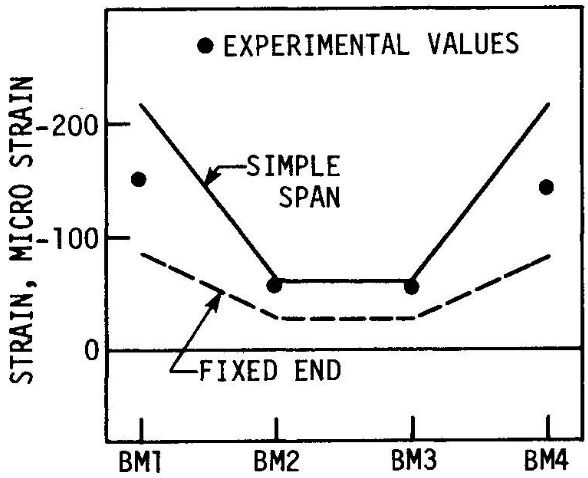


Fig. 3. Midspan, bottom flange strains resulting from post-tentioning: Bridge #1.

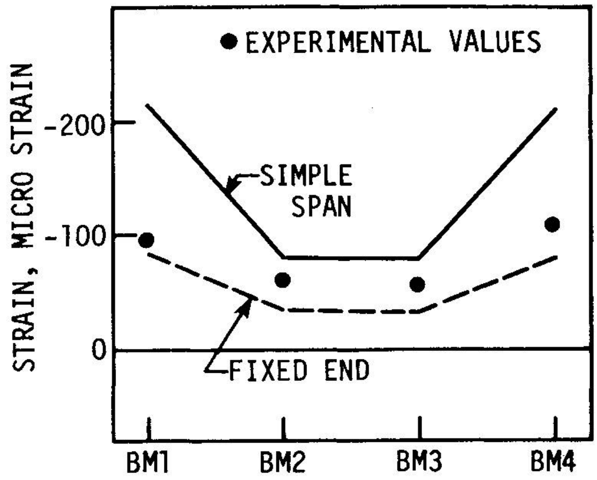


Fig. 4. Midspan, bottom flange strains resulting from post-tentioning: Bridge #2.

6. SUMMARY AND CONCLUSIONS

The results of the research outlined in this paper indicate that post-tensioning can be used for flexural strengthening of simple-span steel-stringer concrete-deck highway bridges. Each bridge to be strengthened should be reviewed to determine if additional shear connectors are required and what type and degree of end restraint exists as these variables are extremely significant in the strengthening procedure. Orthotropic plate theory, which has been established as a means to predict vertical load distribution in bridge decks, may be used to predict approximate distribution of post-tensioning axial forces.

7. ACKNOWLEDGMENTS

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