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Interaction of Prestressed Concrete Beams and Steel Beams in Same Span

Interaction de poutres en béton précontraint et de poutres métalliques dans une même travée

Zusammenwirkung von vorgespannten Stahlbetonträgern und Stahlträgern im gleichen Feld

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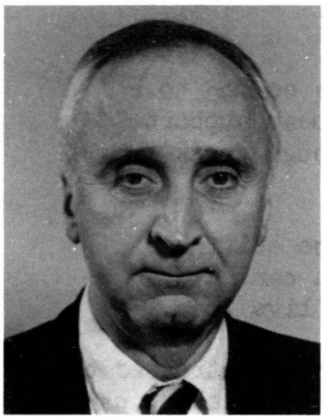

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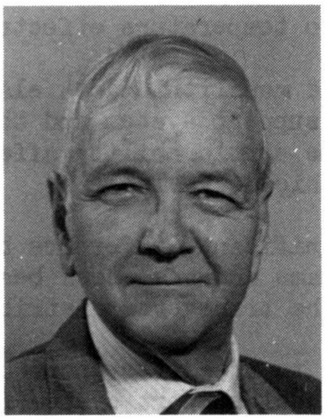
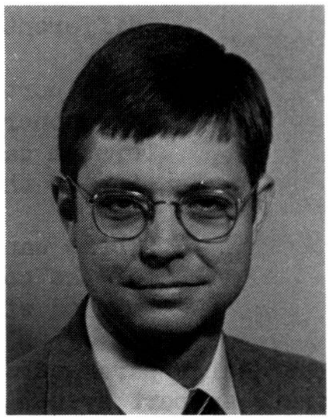


James O'Hara, born in 1928, earned the Ph. D. at the Ohio State University, and is now researching the computer modelling of structural systems.



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SUMMARY

When prestressed concrete beams are used in parallel with steel beams in the same span, certain design parameters caused by basic differences in prestressed concrete and steel should be considered; including time dependent as well as thermal and other effects. The modelling and prediction of the relevant design parameters by a three dimensional finite element computer program is presented.

RÉSUMÉ

Lorsque des poutres en béton précontraint sont utilisées en même temps que des poutres métalliques dans la même travée, certains paramètres de calcul doivent être pris en compte, à cause des différences de comportement du béton précontraint et de l'acier, tels les effets thermiques et dans le temps. La représentation et la prédiction de ces paramètres dans un programme de calcul tridimensionnel à l'aide de la méthode des éléments finis est présentée.

ZUSAMMENFASSUNG

Wenn vorgespannte Stahlbetonträger neben Stahlträgern im gleichen Feld verwendet werden, sind die grundlegenden Unterschiede des Verhaltens von vorgespanntem Beton und Stahl zu berücksichtigen. Dazu gehören auch zeitabhängige Effekte und Temperatureinflüsse. Die Modellierung der entsprechenden Parameter in einem dreidimensionalen «Finite Element» Programm sowie die damit gewonnenen Ergebnisse werden vorgestellt.

1. INTRODUCTION

It may be desirable at times to use prestressed concrete beams in parallel with steel beams in the same span. This situation can occur when the width of a prestressed concrete span is increased by use of steel beams, or when a steel span is widened by use of prestressed concrete beams. When prestressed concrete beams are used in parallel with steel beams to support the same monolithic deck slab, certain design parameters should be taken into account. These design parameters are three - dimensional and nonlinear, and are caused by basic differences between the prestressed concrete beam support system and the steel beam support system. The differences between the two support systems are attributable to the following.

1. The prestressed concrete beams are subject to creep effects and to increasing upward deflections with time, whereas the steel beams are not.

2. Prestressed concrete beams and steel beams can respond in a different manner to temperature effects.

3. That portion of the monolithic deck slab that is common to the concrete beam support system and the steel beam support system can have the serviceability affected through cracking of the monolithic deck slab.

4. There can be a significant difference between the stiffness of the concrete beams and the steel beams, which can have a marked effect on the transverse distribution of live load.

The design parameters, related to the differences between the prestressed concrete support system and the steel support system functioning together, can be modeled and predicted by a three - dimensional finite element computational procedure.

In order to investigate the design parameters involved in a bridge span incorporating a combination of prestressed concrete beams and steel beams in the same span, it is desirable to model the span in a three - dimensional finite element computational model, and to validate the model. The computational model chosen for the research reported in this paper was the three-dimensional finite element computer program as provided by the MacNeal Schwendler Corporation, the MSC/NASTRAN program. It was necessary to adapt the MSC/NASTRAN program to a span having a mixed beam (concrete beams and steel beams) support system subject to time-dependent effects. Since the computer program required modification, it was desirable to validate and to verify the accuracy of the computer program when applied to spans with mixed beam support systems.

2. COMPUTATIONAL MODEL AND VALIDATION

The research investigation as reported herein is divided into three major parts. The first part involves the adaptation of the MSC/NASTRAN computer program to an existing simple span bridge incorporating a mixed beam support system. The second part involves field measurements of the same existing simple span bridge in order to validate and verify the accuracy of the MSC/NASTRAN computer program when applied to spans having a mixed beam support system. The third part of the investigation, following the validation of the computer program, involved the use of the MSC/NASTRAN computational program in the identification of any potential problems inherent in the use of prestressed concrete beams and steel beams used in the same span.

The research investigation was able to use an existing span with a mixed beam support system, in order to test and to verify the MSC/NASTRAN computer program. The existing span is located in a multi-span bridge forming the Bonnabel Overpass near the city of New Orleans. The span used in the research investigation was the 13.72 m span shown in Fig. 1.

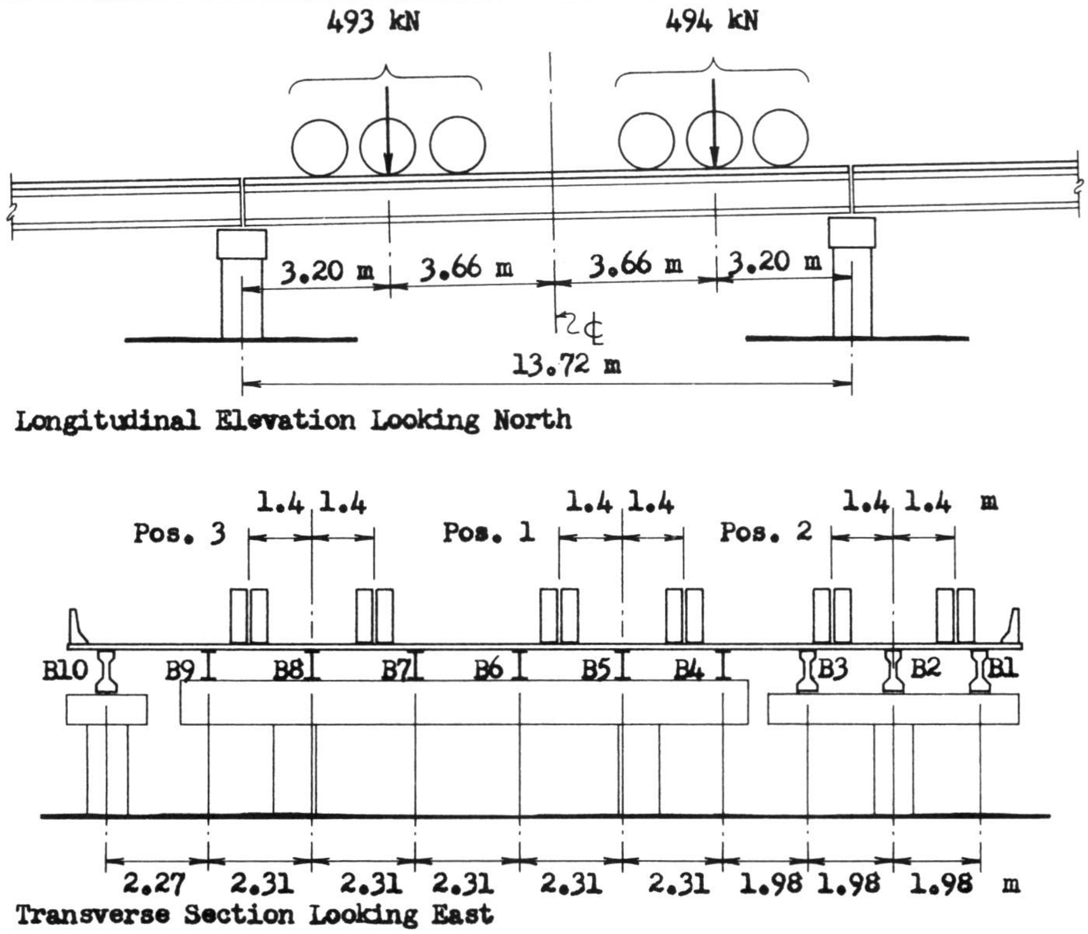

Fig. 1 Overload Truck Crane Loading Positions No. 1, No. 2, and No. 3

The original span consisted of six longitudinal simply supported steel beams as shown in the figure. The width of the span was increased at a later time by the addition of three prestressed concrete beams on one side (South) of the roadway and one prestressed concrete beam on the other side (North) of the roadway. For reference purposes, the ten support beams as shown in Fig. 1 are designated as B-1 through B-10 from South to North. The roadway slab was built continuous in the transverse direction across all ten beams. The slab, however, is not continuous from span to span in the longitudinal direction.

Transverse spacing of the longitudinal support beams is also shown in Fig. 1. Prestressed concrete beams are standard AASHTO Type II girders; steel beams are of plate girder design. All beams are made composite with the deck slab. Thickness of the deck slab is shown in Fig. 1. The steel beams are supported on steel rocker plates, while the prestressed concrete beams are supported on neoprene elastomeric bearing pads. The MSC/NASTRAN computer procedure was adapted to the mixed beam support system shown in Fig. 1, and verified by field testing. Field tests involved loading of the span with service load trucks in various positions and also loading the span with an overload truck crane in various positions. Since the overload truck crane provided better definition, the results presented in this paper are those for the overload truck crane whose weight is indicated in Fig. 1. Three positions of load are shown in the figure, with loading position no. 1 being the one most closely related to the interaction between the adjacent prestressed concrete beams and the steel beams.

Deflections under the overload truck crane in loading position no. 1 are indicated in Fig. 2. Deflections indicated were measured at midspan for each of the ten beams. The deflection values as measured in the field are indicated by a circle.

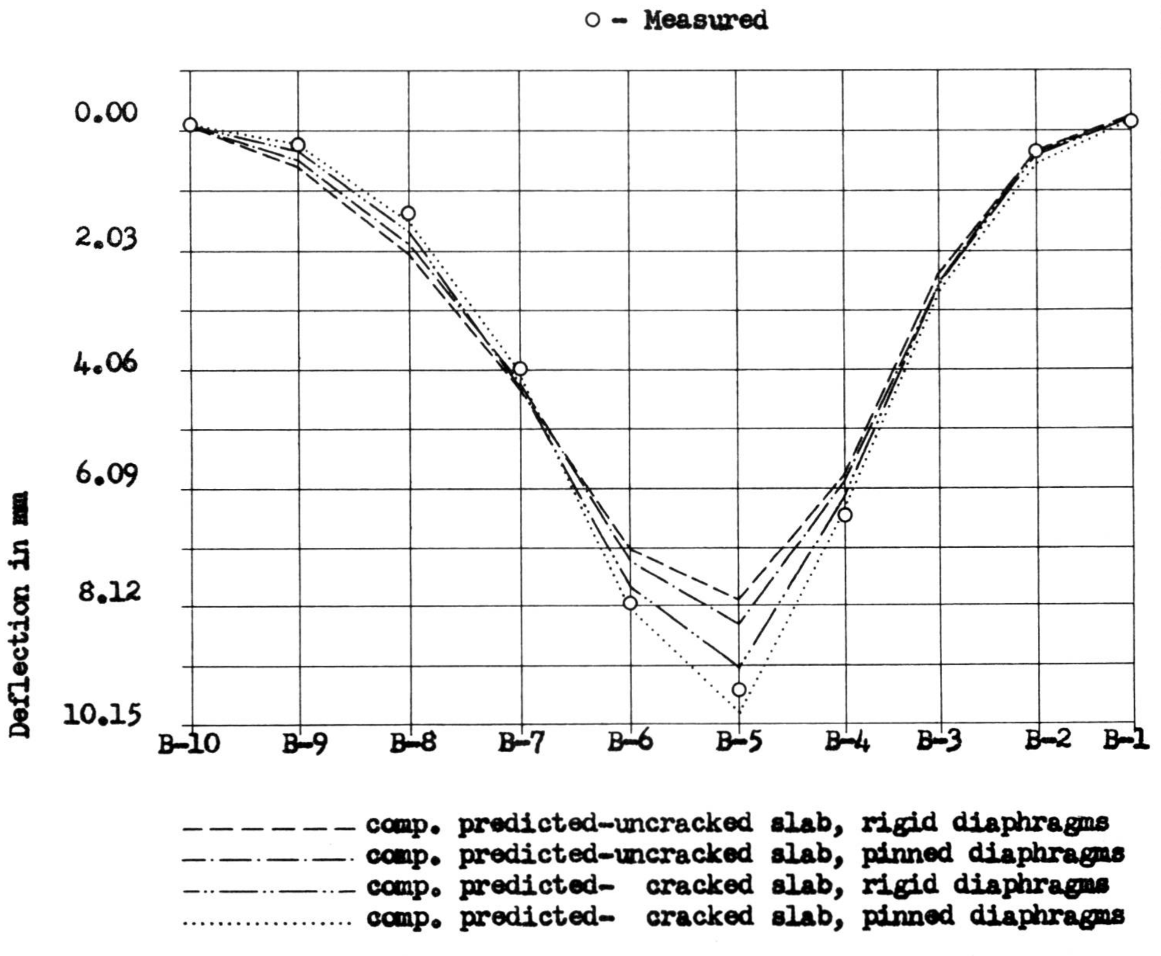

Fig. 2 Span Transverse Centerline Computer-Predicted Versus Measured Deflections for Overload Position No. 1

The computer - predicted deflections are superimposed on the same plot of the field measurements in Fig. 2. The computer-predicted plots include combinations of cracked versus uncracked deck slab, and rigidly connected versus pin connected transverse diaphragms. It can be seen from Fig. 2 that the case of cracked slab pinned-end diaphragms most closely agrees with the field measurements. The field observations of the actual deck slab indicated that it was cracked in the region between beams B-3 (concrete) and B-4 (steel). The transverse diaphragms were observed to be bolted, providing the flexibility of a pinned-end connection. The computer predictions when compared to the field observations led to the conclusion that the MSC/NASTRAN computer program could be used effectively to predict the behavior of a span having a mixed beam support system.

3. DESIGN PARAMETERS PREDICTED BY COMPUTATIONAL MODEL

Once the computer model was validated in terms of its ability to accurately predict live-load deflections, other design parameters were modeled. Parameters that were modeled include the effect of the camber growth of the prestressed concrete beams due to creep effects, the effect of temperature, the effect of beam stiffness, the effect of transverse diaphragms, and the effect of support conditions. In addition, combinations of these effects were considered. In addition to distribution of live load, those effects emphasized in this paper include the camber growth due to the creep effects, and response of the mixed beam support system to variations in temperature.

As upward deflections of the prestressed concrete beams increase with time due to creep effects, there is a tendency of the prestressed concrete beams to lift the monolithic slab off of adjacent steel beams not subject to camber growth. If the monolithic slab is composite with the adjacent steel beams, camber growth of the concrete beams also tends to lift the adjacent steel beams with the slab. As the slab is lifted through increased camber, the load supported by the prestressed concrete beam is increased, with a corresponding decrease in the load that is supported by the adjacent steel beam.

Fig. 3 indicates the effect of camber growth on the midspan moment for adjacent prestressed concrete and steel beams. Both beams are composite with the deck slab. It can be seen from Fig. 3 that with an increasing amount of camber growth, the moment in the prestressed concrete beam B-3 is increasing while the moment in the steel beam B-4 is decreasing at the same time. The investigation assumed an amount of the camber growth equal to 6.4 mm, which is based on the fabrication history of the prestressed beams and the PCI method for computation of the stress losses. For a camber increase of 6.4 mm, the resulting moment increase in prestressed concrete beam B-3 is significant and on the same order of magnitude as the design moment for service loads. It is noted that Fig. 3 simplifies a complex situation.

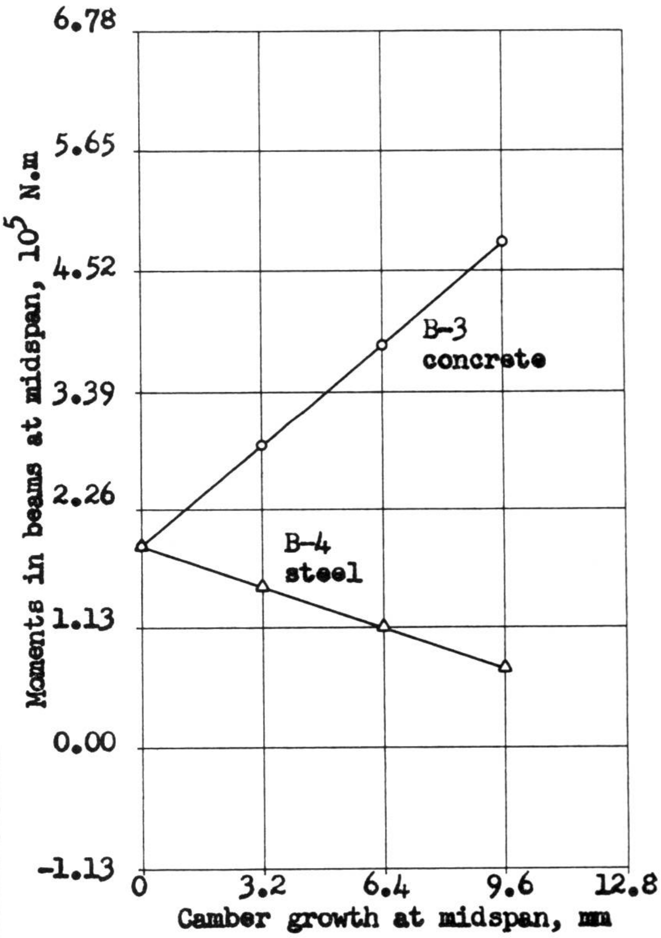

Fig. 3 Effect of Camber Growth on Moment at Midspan for Beams B-3 and B-4

In addition to live load distribution and effects of camber growth, this paper also presents the effects of temperature variations on a mixed beam support system. Of particular interest is the effect of changes in ambient temperature upon stresses in that section of monolithic deck slab that is jointly supported on one side by a prestressed concrete beam and on the other side by a steel beam. The research investigated three conditions: a sudden increase in ambient temperature, a sudden decrease in ambient temperature, and a period of bright sunshine on the deck slab.

When a span is subjected to a period of constant ambient temperature and no sunshine, as might occur in the early morning hours, the slab and supporting components tend to reach a uniform temperature. If bright sunshine then impinges upon the slab, the slab will experience a radiant heat input which will start to heat the top layer of the slab. With time the heat will be conducted through the slab. After approximately three hours of sunshine on a 165 mm thick slab, the thermal profile from top to bottom will be linear, and the temperature difference between the top of the slab and the bottom of the slab will be a maximum.

The MSC/NASTRAN computer program was modeled in order to predict vertical deflections of prestressed concrete beams and steel beams as a function of temperature. However, the response of the structural system was not so much a function of temperature as it was a function of the hours of sunshine on the deck slab. Computer predictions of vertical deflections as a function of the hour of the day are shown in Fig. 4. Vertical deflections are indicated for two prestressed concrete beams, B-2 and B-3, and two steel beams, B-4 and B-5. The indicated computer predictions may be compared to the field measurements of vertical deflections made during a 24 hour period. Field measurements are shown as circles, and the computer predictions are shown as dashed lines. Of greatest interest is the period when the deck slab is being heated by the morning sun, the period from 0700 hours to 1400 hours. It can be seen from Fig. 4 that there is good agreement between the computer predictions and the field measurements for this seven hour period of time. It can also be noted that there is no significant difference between the temperature-related deflections for the prestressed concrete beams and the steel beams. Even though the difference in deflection is not

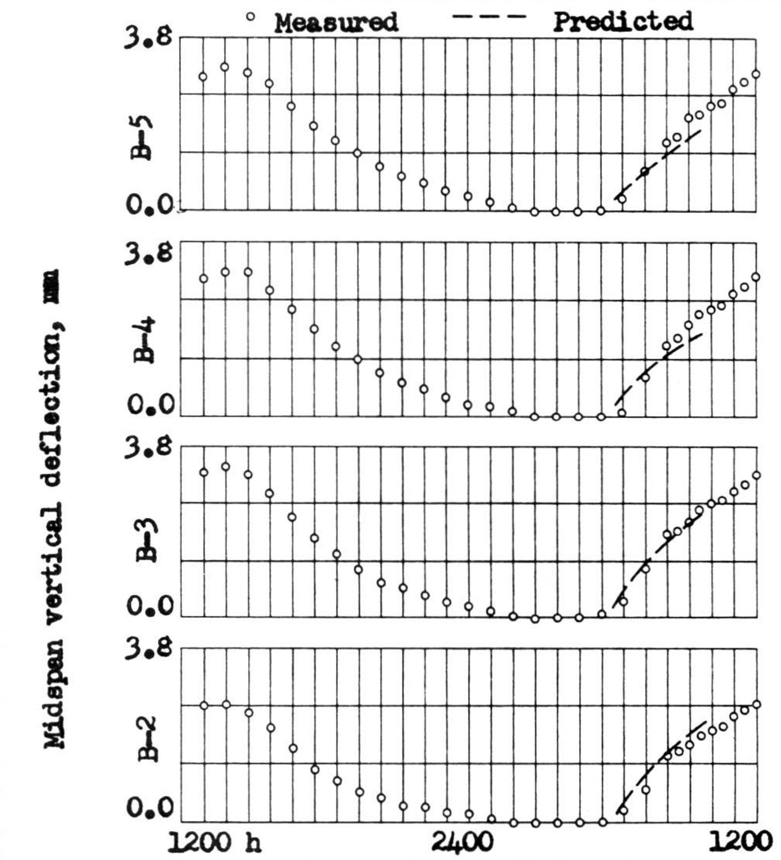

Fig. 4 Predicted vs. Measured Thermally Induced Deflections as a Function of Time of Day

significant, slab stresses related to the deflections are significant. In both the lateral and longitudinal direction, slab tensile stresses caused by temperature-related deflections are approximately 22 percent of the modulus of rupture. This level of tensile stress assumes greater significance when combined with the other effects.

The scope of the research investigation did not permit the detailed study of all possible combinations of the various effects described at the beginning of this section. Rather, representative combinations of effects were investigated in order to determine potential problems inherent in the use of prestressed concrete beams and steel beams in the same span.

The loading situations which the computer solutions indicate as having significant effects on beam moments include the combination of live load effects and camber growth effects. The computer analysis indicates that a combination of the effects due to live loads and the effects caused by camber growth could cause significant overloading of the prestressed concrete beam adjacent to the steel beam in a mixed beam span.

The loading situation which the computer solutions indicate as having a marked effect on the tensile stresses in the monolithic concrete slab consists of a combination of live load effects and the added effect of sunshine on the deck slab. This combination can result in tensile stresses in excess of the modulus of rupture, and can cause cracking of the monolithic slab. Furthermore, tensile stresses exceeding the modulus of rupture can occur in both the transverse and longitudinal directiens, with reference to the direction of the span.

Thus, computer predictions indicated that the concrete beam adjacent to the steel beam, in a mixed girder span, may be overloaded by a combination of live load and camber growth. The monolithic deck slab, supported on one side by a prestressed concrete beam and on the other side by a steel beam, may be overstressed by a combination of live load and temperature effects.

4. CONCLUSIONS

The results of this research investigation indicate that a three dimensional finite element computational procedure, such as the MSC/NASTRAN computer program, can be used successfully and accurately to predict the behavior of a bridge span supported by a combination of prestressed concrete beams and steel beams in parallel. Once the computer model was validated in terms of its ability to accurately predict live load deflections, other design parameters were then modeled and predicted; including the time-dependent effect of camber growth due to creep, the effect of beam stiffness, the effect of temperature, the effect of variable support conditions, and the effect of transverse diaphragms. Combinations of these various effects were also modeled and predicted by the computational procedure.

It was concluded that the combination of live load effects and effects of camber growth could have a marked effect on the moment in the prestressed concrete beam located adjacent to the steel beam in the same span, significantly increasing the moment in the prestressed concrete beam. It was also concluded that the combination of live load effects and temperature effects could have a significant influence on tensile stresses in the concrete slab, increasing the tensile stresses to a value exceeding the modulus of rupture.

It is intended that the future direction of the research will address live load distribution in more detail, the optimum location of the prestressed concrete beam adjacent to a steel beam, and the effects of fatigue on mixed beam spans.

It is noted that the use of concrete and steel beams in parallel is a rather unique solution which is not very frequently used except for the temporary enlargement of bridges. There are cases, however, when existing steel bridges must be widened. In some locations, the availability and cost benefits of prestressed concrete indicate that this material should be considered for the permanent enlargement or widening of existing steel bridges. The research reported in this paper indicates the presence of problem areas that should be addressed when using prestressed concrete beams and steel beams in parallel.

5. ACKNOWLEDGEMENTS

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