STUDY OF MICHIGAN'S CONTINUOUS SPAN VARIABLE DEPTH T-BEAM BRIDGES

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MICHIGAN DEPARTMENT OF TRANSPORTATION
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STUDY OF MICHIGAN'S CONTINUOUS SPAN VARIABLE DEPTH T-BEAM BRIDGES

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Testing and Research Section
Construction and Technology Division
Research Project 94-TI-1706
Research Report No. R-1374

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Lansing June 2000

Technical Report Documentation Page

1. Report No.
Research Report R 1374

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle: Study of Michigan's Continuous Span Variable Depth T-Beam Bridges

5. Report Date
November, 1999

7. Author(s) David A. Juntunen, P.E.

6. Performing Organization Code
R - 1374

9. Performing Organization Name and Address
Michigan Department of Transportation
Construction and Technology Division
P.O. Box 30049
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8. Performing Org Report No.

12. Sponsoring Agency Name and Address
Michigan Department of Transportation
Construction and Technology Division
P.O. Box 30049
Lansing, MI 48909

10. Work Unit No. (TRAIS)

11. Contract/Grant No.

15. Supplementary Notes

13. Type of Report & Period Covered
Final Report

14. Sponsoring Agency Code

16. Abstract: This report reviews the condition of Michigan's reinforced concrete, continuous span, t-beam bridges. The report also shows the results of diagnostic load testing of this type of structure, and discusses what effects deterioration has on load carrying capacity. Findings in the report show the majority of Michigan's variable depth t-beam bridges are in good or better condition, and the superstructures deteriorate at a rate of approximately one rating level per 20 years of service. We found no correlation between ADTT and superstructure rating. The deterioration found on variable depth t-beams is common to all reinforced concrete structures, with the exception that a few variable depth t-beams were found with extensive shear and flexural cracking. The cracking found was the result of design details and material properties specific to that structure. Variable depth t-beams and t-beam structures, in general, have been found to have greater load carrying capacity than predicted by analysis. Load carrying capacity is not significantly affected by deteriorated or weak concrete strength, but there is a linear relationship between load carrying capacity and loss of flexural tension reinforcement. Our diagnostic load test of a variable depth t-beam structure in good condition showed that the actual response of the structure to load can be reasonably predicted using common analysis procedures.

17. Key Words : T-Beam, Bridge, Reinforced Concrete Load Testing.

18. Distribution Statement
No restrictions. This document is available to the public through the Michigan Department of Transportation.

19. Security Classification (report)
Unclassified

20. Security Classification (Page)
Unclassified

21. No of Pages

22. Price

Form DOT F 1700.7 (7-1999)

INTRODUCTION

In May of 1993, the Engineer of Bridge Design, Dr. Sudhakar Kulkarni, requested the above referenced research project. The bridge type in question, shown in Figure 1, is Michigan's reinforced concrete, continuous span, t-beam bridge with variable depth beam stems, referred to within this report as "variable depth t-beam." Dr. Kulkarni requested that we determine the following:

1. By load testing, compare the analytical load carrying capacity with the actual load carrying capacity.
2. Examine how deterioration affects the load carrying capacity of the structure.

The outcome of this project would be a better understanding and confidence regarding the strength of variable depth t-beams. This would be useful when developing deck removal procedures, when determining load carrying capacity of the beams, and when determining remaining life of the structure.

Figure 1- Variable Depth T-Beam Bridge

Since the initiation of this project, the department has made progress with respect to several of the issues mentioned above. Special procedures for deck removal are required because the deck of a variable depth t-beam structure contributes to the load carrying capacity of the beams; i.e. - negative moment reinforcing steel in the deck over the piers provides support for dead load and live load. A procedure to replace the deck was developed and a demonstration project using this procedure was successfully built as reported in Research Report R-1349[1]. The superstructure of several variable depth t-beam structures have been successfully removed, and a simple span reinforced concrete t-beam bridge in a highly deteriorated condition was load tested as reported in Research Report R-1336[2]. In general, we have gained experience and knowledge regarding the strength of t-beam structures.

During this project, we reviewed the Department's inventory of variable depth t-beam structures to learn how they are performing and to locate any problems associated with this type of bridge. We did a comprehensive literature review of load testing of t-beam structures. Finally, we investigated the feasibility and potential benefit of load testing this type of structure.

INVENTORY REVIEW

Michigan has approximately 500 reinforced concrete t-beam bridges, 230 of these structures have continuous spans and variable depth beam stems. From a review of the Department's inventory of variable depth t-beam bridges, the following graphs were produced. Figure 2 shows when Michigan's variable depth t-beam structures were built, and Figure 3 shows their superstructure rating. We noted that these bridges were built primarily in the 50's and 60's, and that the population of these structures for the most part is in good to very good condition.

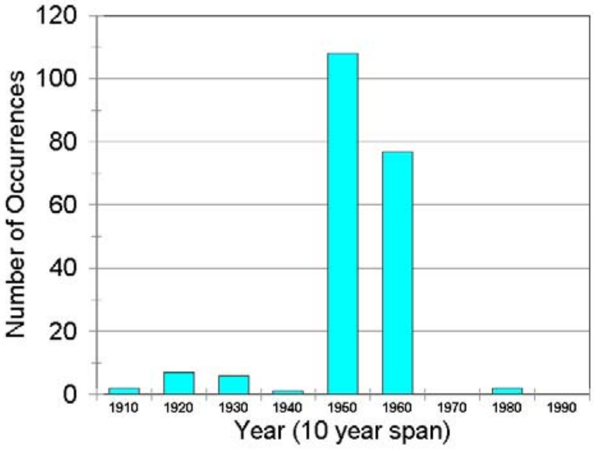

Figure 2 - Year Constructed

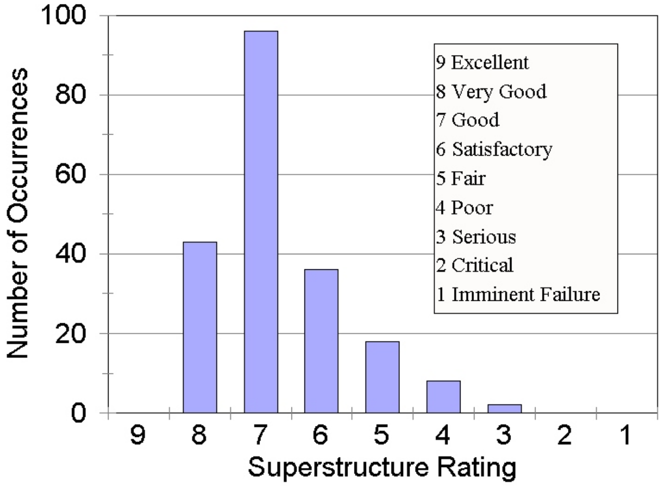

Figure 3 - Superstructure Rating

Figures 4 and 5 show graphs of the superstructure rating versus Average Daily Truck Traffic (ADTT) and year the structure was built, respectively. We can see that there is no correlation between ADTT and the condition of the superstructure. We can see from Figure 5, that the superstructure rating can be expected to drop one rating number every 20 years.

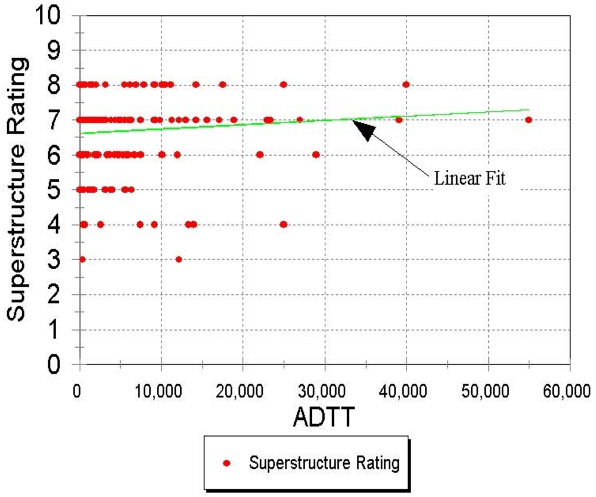

Figure 4 - Superstructure Rating vs. ADTT

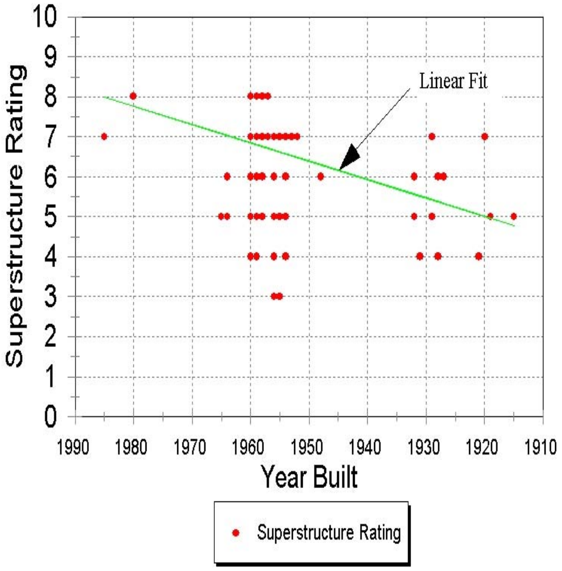

Figure 5 - Superstructure Rating vs. Year Built.

To complete our inventory review, we inspected ten variable depth t-beam bridges with superstructure ratings five or below. Types of deterioration we found are as follows:

Deteriorated Bridge Decks. Like most other bridges in Michigan, the reinforced concrete decks on variable depth t-beams are the first component of the structure to deteriorate. On the surface of the bridge decks, we observed longitudinal and transverse cracks, map cracking, delaminated areas, spalls and corroded reinforcing bars. On the bottom surface of the decks, we observed the same type of cracking and corroded reinforcement found on the top surface, as well as leachate and stalactite from moisture moving through the full depth cracks. In badly spalled areas, we could see repair patches where there had been full depth spalls in the deck. Figures 6, 7, and 8 show examples of typical deck deterioration.

Figure 6 - Repair patch of spalled bridge deck. Map cracking of the deck also shown in the foreground.

Figure 7 - Delaminated area on bottom surface of the deck. A sign panel was used as a bottom form to repair the hole in the deck.

Figure 8 - Transverse and longitudinal cracks and leachate shown on bottom surface of the bridge deck.

Deteriorated Beams. The types of deterioration observed on the beams were spalls accompanying corroded reinforcement (Figure 9), flexure cracks and map cracking (Figure 10), and shear cracks (Figure 11). We investigated the nature of extensive shear and flexure cracking found on the bridge carrying Sherman Road over US-31 (Structure Number - S03 of 61072). In Appendix A, an explanation of the cracks is presented in a memo dated August 20, 1996, from Mr. Roger Till, Supervising Engineer, Structural Research Unit to Mr. Sonny Jadun, Structures Engineer, Maintenance Division.


Figure 9 - Large spalls on the beam stem.


Figure 10 - Flexure cracks on beam stem (epoxy injected).


Figure 11 - Shear cracks on beam stem.

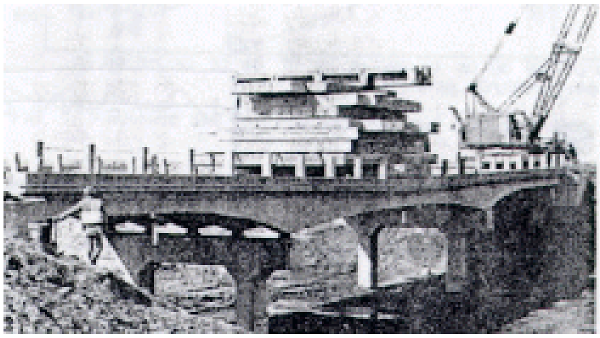
Figure 12 - Load test of Canadian t-beam bridge. (Picture Courtesy of NRC Research Press)

LITERATURE REVIEW

As part of this project, we did a literature review to find information about load tests on variable depth t-beams. Due to the problems and expense in performing full scale load tests of bridges Burdette and Goodpasture[3] found only a few full scale bridges tested to ultimate capacity. Fortunately, one of these was a variable depth t-beam structure very similar to what we have in Michigan. A full-scale, three-span continuous, variable depth t-beam bridge, located in Alberta, Canada, was load tested to failure by Scanlon and Mikhailovsk[4]. A picture of the load test is shown in Figure 12. They found that "the critical-moment section exhibited a high degree of ductility and appeared to have developed the ultimate tensile strength of the reinforcement before failure of the section by crushing of concrete at the compression face." The structure reached an ultimate capacity of 1895 kN with a maximum deflection at midspan equal to 158 mm. The load applied to the bridge was well above any load expected to cross a highway structure, and the maximum deflection demonstrated a high degree of ductility.

The literature review also showed that deterioration has little effect on the load capacity of t-beam reinforced concrete bridges. Beal[5] load tested to failure a highly deteriorated t-beam bridge in New York. The structure was a simple span concrete t-beam bridge with a clear span of 11 meters. From the load test, Beal found that a 50 percent reduction in concrete strength (from 20 to 10 MPa) resulted in only 8 percent reduction in ultimate bending resistance. Also a 50 percent loss of slab thickness decreased the flexural capacity of the beam by only 12 percent. Beal found the relation between flexural strength and tension reinforcement to be approximately linear, thus loss of reinforcing area can significantly reduce a bridge’s load carrying capacity. However, he felt large losses of reinforcement area is unlikely. Beal concluded that "deterioration sufficient for substantial reduction of the capacity of the structure would be manifested in a local collapse and that overall failure need not be a concern."

Our experience reinforces Beal’s findings. In the fall of 1994, the Structural Research Unit proof loaded the bridge carrying M-52 over the CSX railroad south of Bailey, Michigan (Structure Number - R01 of 61131). Although, the three span simply supported t-beam structure was visibly in serious condition with extensive deterioration, our testing showed that the structure still had adequate load carrying capacity. We found that load was dispersed more equally to the beams, and the loss of reinforcing steel was much less than inspection reports estimated.

Nowak and Saraf[6] proof load tested a single span reinforced concrete t-beam bridge in 1996. The structure carries M-66 over Mud Creek, southwest of Woodbury, Michigan. They found that, “for most cases, the experimental deflections were smaller than the analytically predicted values, which means that the structure is stiffer than the analytical model.” The bridge, which previously had load restrictions, successfully carried the target proof load without any signs of distress or non-linear response; therefore, the load restrictions for the structure were removed.

LOAD TESTING

Load testing a bridge can be a formidable task. The methods used and potential for success of a load test is dependent on the type of structure being tested, the size and length of the structure, the expected load carrying capacity of the structure, and site parameters such as traffic conditions or the depth and flow of a river. Load testing a variable depth t-beam structure is particularly challenging since its load carrying capacity is typically near or in excess of Michigan's maximum legal load, and these bridges primarily cross over freeways, which would mean expensive traffic control.

Diagnostic Test of Jones Road over I-96

We decided that for this study, a diagnostic test would be done on one or more of the Michigan's variable depth t-beam bridges. Prior to testing a bridge with questionable capacity, we wanted to become familiar with the response of this particular type of structure. Variable depth t-beams are relatively stiff structures requiring precise deflection measurements. Measuring strain on reinforced concrete requires special gages and an understanding of the nature of the material; i.e. - because of the composite nature of reinforced concrete, 76 mm long gages were used to average the strain reading across the aggregate and cement matrix, and across the cracks. Caution must be taken when interpreting strain data, because cracks in the tension zones of the beam greatly influence the strain readings.

The bridge selected for testing was Jones Road over I-96 west of Lansing (Structure Number S02 of 19022), shown in Figure 13. The structure has variable depth t-beams with four continuous spans, 15.0, 23.0, 23.0, and 15.0 m, respectively. The clear roadway width over the bridge is 7.92 m. This bridge was selected because it has a simple geometry, its location was convenient, and instrumentation of the structure would not greatly interfere with traffic. Our intent was to become familiar with load testing this type of structure, and results obtained could be used for comparison with future load tests; i.e. - of a badly deteriorated variable depth t-beam structure.

For the diagnostic test we mounted electrical resistance strain gages on the bottom of each beam at midspan of Span 3 and on the deck over the top of each beam at Pier 2. We also mounted elevation pins on the bottom of each beam at midspan of Span 3 for taking elevation readings.

Figure 13 - Jones Road over I-96.

Concrete cores were taken from the structure to determine the compressive strength and the modulus of elasticity of the concrete. Table 1 shows the location of each core, and Table 2 shows the measured compressive strength, the calculated modulus of elasticity (using the measured compressive strength), and the measured modulus of elasticity for each core. For the strain and deflection calculations, a modulus of elasticity of 33,000 MPa was used.

Table 1 - Location of Cores

Core #1 - West fascia beam, near the south abutment.
Core #2 - East fascia beam, near the north abutment.
Core #3 - Deck, north end, west side.
Core #4 - Deck, south end, west side.

Table 2 - Concrete Material Properties

	Core #1	Core #2	Core #3	Core #4	Average
Compressive Strength (MPa) measured	52.4	51.2	50.6	46.5	50.2
Modulus of Elasticity Calculated (MPa)	34,300	33,900	33,600	32,300	33,500
Modulus of Elasticity Measured (MPa)	N.A. *	31,000	36,900	31,100	33,000

*Incorrect placement of extensometer corrupted the results.

The structure was loaded separately with the two trucks as shown in Figures 14 and 15. The trucks were parked on the bridge to produce the maximum positive moment at midspan of Span 3 as shown in Figures 16 and 17. In the figures, “CW” is abbreviation for “control wheel”. The control wheel is the wheel or axle nearest to the truck’s centroid. Both trucks were positioned in the southbound lane of Jones Road and elevation and strain gage data were collected. Figure18 shows how the measured deflections compare with the analytical deflections based on the gross cross section of the t-beam. The calculated values are conservative since the gross section was used rather than the effective cross section. Likewise, Figures 19 and 20 compare the measured strain to the analytical strain at the bottom of the beam at midspan and on top of the deck over the pier, respectively. For the deflections, the measured values were always less than the calculated values, which indicates that the beams are stiffer than estimated. The measured strain at the bottom of the beam at midspan of Span 3 was very close to the calculated strain. For the weight scale truck with the control wheel positioned at midspan, the measured strain readings were 37 micro strain greater than the calculated values.

Strain data were not collected for the weight scale truck on the top of the deck over Pier 2 because of equipment failure. However, the measured strains for the gravel train were less than the calculated values.

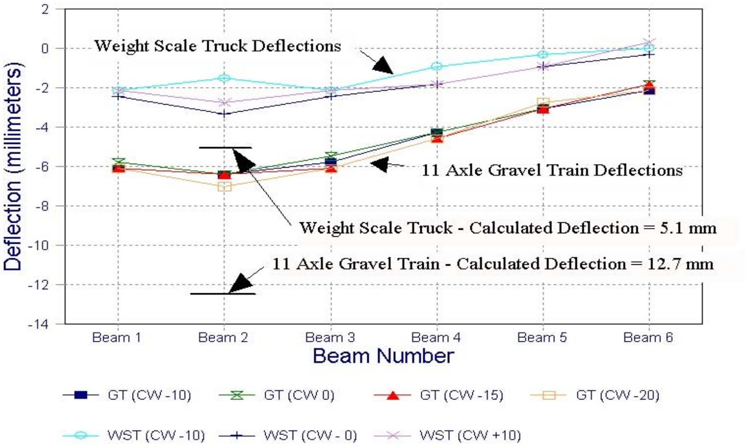

Figure 18 - Deflections at Midspan, Span 3

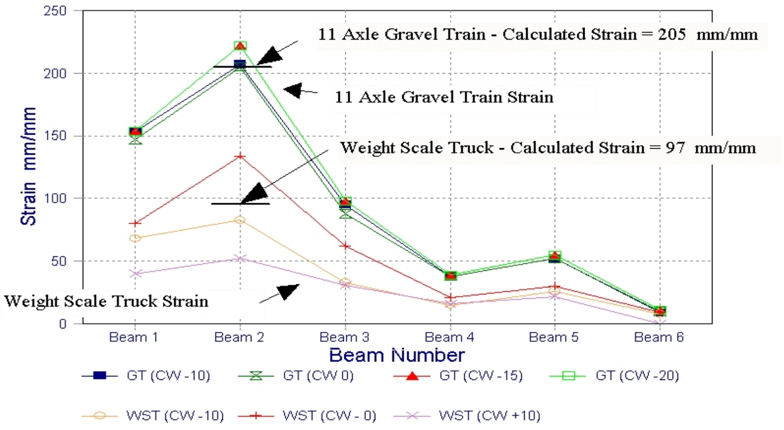

Figure 19 - Strain at Midspan, Span 3

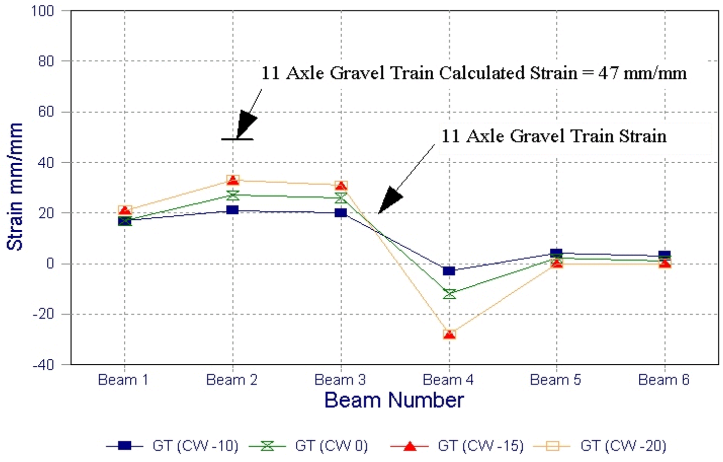

Figure 20 - Strain at Pier 2, Top of Deck

CONCLUSIONS

The majority of Michigan's variable depth t-beam bridges are in good or better condition. Their superstructures deteriorate at a rate of approximately one rating level per 20 years of service. We found no correlation between ADTT and superstructure rating. The deterioration found on variable depth t-beams is common to all reinforced concrete structures with the exception that a few variable depth t-beams were found with extensive shear and flexural cracking. The cracking was the result of design details and material properties specific to that structure. Variable depth t-beams and t-beam structures in general have been found to have greater load carrying capacity than predicted by analysis. Load carrying capacity is not significantly affected by deteriorated or weak concrete strength, but there is a linear relationship between load carrying capacity and loss of flexural tension reinforcement. Our diagnostic load test of a variable depth t-beam structure in good condition showed that the actual response of the structure to load can be reasonably well predicted using common analysis procedures.

Recommendations

The final phase of this project was to load test a variable depth t-beam bridge having a poor superstructure rating to determine if its load carry capacity was reduced because of the deterioration. After taking into consideration the findings of the literature review, and our own experience with deteriorated concrete t-beam structures, I believe that *little would be learned from another load test.*

When a variable depth t-beam structure has deteriorated to the point that the load rating is questionable, inspectors should measure the actual loss of tension reinforcement. Very often, load rating engineers must estimate the corrosion loss of the reinforcement from visual inspections or descriptions shown in an inspection report. The resulting estimate of section loss is most often very conservative. Michigan's variable depth t-beam bridges are durable and aesthetically appealing structures. We should continue our efforts to develop procedures to rehabilitate this type of bridge.

Future Work

There are still outstanding issues regarding variable depth t-beam structures. Can a deep overlay or a "complete" deck replacement be done without causing cracking of the beam stems in the negative moment zone over the piers? Although, a procedure was referenced in this report where a deck was replaced on a variable depth t-beam structure, the method involved extensive saw cutting of the deck and a portion of the existing deck was left in place to support negative moments. Simpler and less expensive deck replacement methods are needed. Following long standing and accepted engineering practice, the Department places an extensive amount of reinforcement in the deck over the piers to resist negative moment. Using more refined analysis, we may find that the amount of steel required is reduced, thus making it possible to do deep overlays. For deck replacements, we may be able to place carbon fiber strips on the beams to provide added structural strength during the deck replacement. With new developments regarding shear analysis of reinforced concrete and refined analysis procedures, we also may be able refine our analysis methods and better understand how shear is distributed in variable depth t-beams.

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APPENDIX A