SHORT SPAN STEEL STRUCTURES

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SUMMARY

The *Modular Span Multi-Cell Box Girder System* developed for short span steel bridge structures is described in terms of its structural solution and detailed static analysis. The paper presents the structural solution, manufacture and erection of the system, redistribution of stresses resulting from creep and shrinkage of concrete, the connection of the corrugated plates, transverse connection of individual modules and distribution of load into these modules. Static assumptions and quality of design are being verified by static and fatigue loading tests.

Keywords: Multi-Cell Box Girder, distribution of load, influence lines, connection

1. INTRODUCTION

The *Modular Span Multi-Cell Box Girder System* was developed for small span bridges of spans from 6 to 30 m. The bridge deck is assembled of steel modules and a composite concrete deck slab - see Fig.1. The number of modules depends on the width of the bridge. The modules are assembled of corrugated shape plates which are mutually connected by a continuous fillet welds into a multi-cell box girder. The top and bottom slabs and webs are formed by steel plates with a minimum thickness of 8 mm. The girder webs are not stiffened by any longitudinal or transverse intermediate stiffeners.

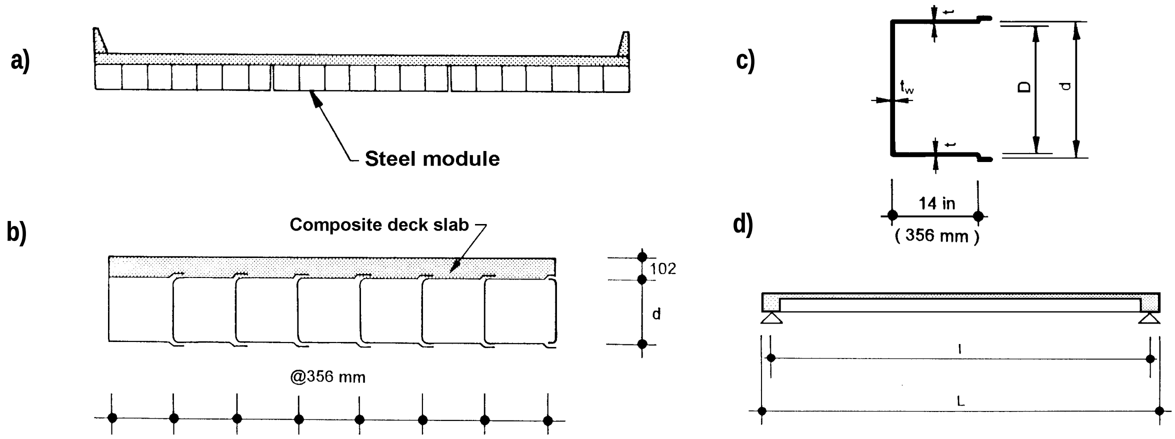

Fig.1

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The width of modules is 2.540 m, the depth *D* and number of cells depends on the span length and loading. Spans from 6.00 to 17.00 m are formed by a seven cell box girder, spans from 18.00 to 23.00 m are formed by six cell box girder, and spans from 24.00 to 30.00 m are formed by seven cell box girder.

The composite deck slab stiffens the deck, distributes a wheel load and resists longitudinal and transverse compression stresses caused both by global and a local bending. The top plate of the steel modules resists tension stresses that are created by longitudinal and transverse local bending. Tension stresses in the composite slab which are caused by local bending are resisted by reinforcing bars situated both in the longitudinal and transverse direction of the bridge. A composite action of the steel modules with a concrete deck is guaranteed by shear studs (M10x51). - see Fig.2.

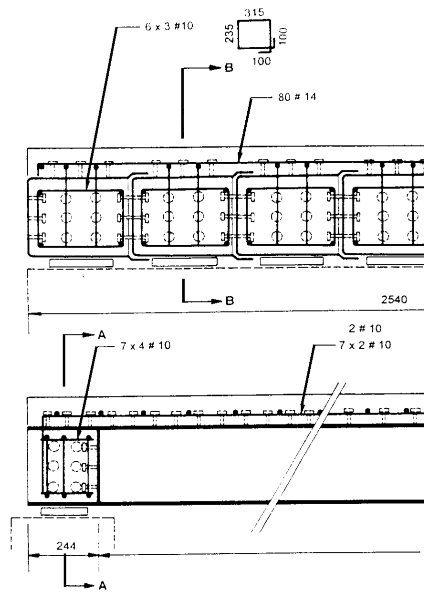

Fig.2

Steel stiffeners and concrete diaphragms have been designed at the end of the deck. The deck is supported by neoprene pads, or it is integrated with the abutments - see Fig.3a,b. Multi-span continuos structures assembled of simple spans, joined by concrete cast-in-place diaphragms are also studied - see Fig.3c. The reactions are transferred from the bearings into the webs by the concrete diaphragms. The webs have shear studs and the diaphragms are reinforced by reinforcing bars, which resist splitting forces.

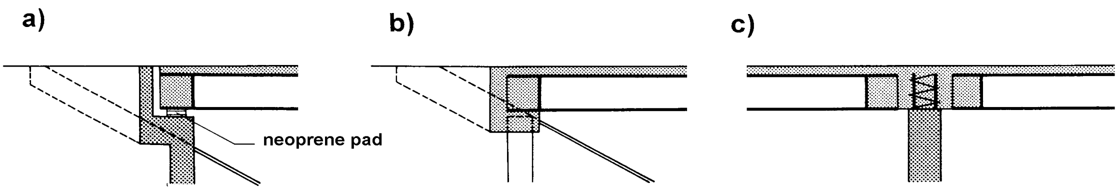

Fig.3

2. STRUCTURAL TYPE DEVELOPMENT

The arrangement of the structure was developed on the basis of a very detailed finite element analysis that considered the influence of warping and distortion of the cross section. Also, the stresses in the top slab and webs due to local bending caused by wheel loads were carefully determined. The structure was modeled by a space structure that corresponds with the designed shape. The composite slab and the end diaphragms were modeled of solid (brick) elements, the steel structure was modeled of *shell* elements which are able to express both the plate bending and membrane loading of the members. Between the shell and solid elements, the compatibility of deformations was secured. The neoprene pads were modeled of solid elements with corresponding physical and geometric properties.

The development of the system was done in several steps. At first, individual modules were analyzed, a redistribution of stresses resulting from creep and shrinkage of concrete was calculated, the connection of the corrugated plates were checked, static and fatigue loading tests were prepared for a structure with a nominal span of 12.192 m and finally, a transverse connection of individual modules and distribution of load into these modules was determined. At present, static and fatigue loading tests are being done and longitudinal connection of simple spans into continuous structures is being studied.

3. ANALYSIS OF THE INDIVIDUAL MODULE

In the beginning designers supposed that the structures would have an asphalt overlay. It was evident that the top plate would require additional transverse stiffening and the webs would require transverse stiffeners, which would eliminate the distortion of the cross section. To identify these effects a comparison study of the proposed structure (see Fig. 4a) and of a structure stiffened by a composite concrete slab and end diaphragms (see Fig. 4b) was performed. While the first structure was supported directly under the webs, the second structure was supported by neoprene pads situated under the diaphragms between the webs.

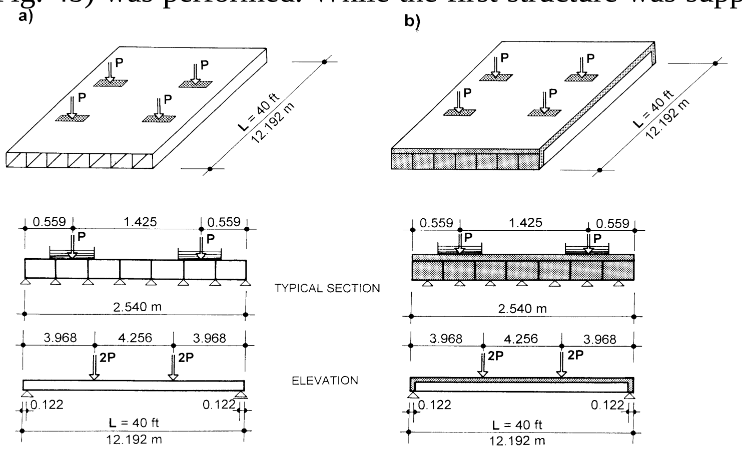

Fig.4

The local bending of the top plate was studied on a structure loaded by HS20 Truck. The stresses in the top steel plate of the structure according to Fig.4a were app.100 times higher than in the structure according to Fig.4b. The results confirm that the top steel plate is not able to resist these stresses without additional stiffening.

The deformations of the cross section of these structures were studied for a point load situated at mid-span, and for a linear uniform load. Both loads were situated above the webs of the box girder. Fig.5 shows a deformation of the cross section at mid-span and above supports due to the linear uniform load situated above the second and fourth web. It is evident from the Fig.5 that the composite concrete slab together with end diaphragms significantly eliminate deformation of the cross section of the box girder. Corresponding

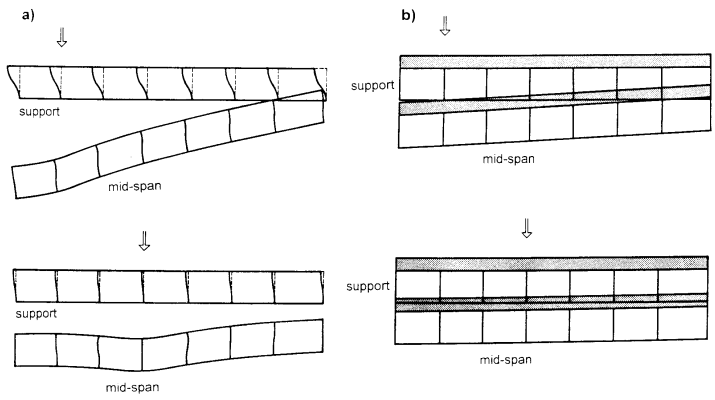

Fig.5

bending and shear stresses due to the distortion of the cross section were also significantly reduced.

The analysis also proved that it is not necessary to design intermediate transverse or longitudinal stiffeners. The composite concrete slab guarantees a uniform distribution of the wheel load into all webs of the box girder. Also, the shear lag is very small and therefore the flanges (chords) of the deck are stressed by uniformly distributed normal stresses.

3.1 Connection of Corrugated Plates

In traditional plate or box girders the top and bottom plates are directly connected with webs. In the proposed structure the modules are assembled of corrugated shape plates that are joined by continuous welds that connects the plates. The shear stresses are transferred from the top and bottom plates into the webs by curved parts of the pates. To understand the function of the structure a very detailed study of the connection was done. The structure formed by two cell box girder was assembled of shell elements that exactly correspond to the shape of the structure – see Fig.6. The structure was loaded by linear uniform load situated above the webs. Results of the analysis did not show any discontinuity in the courses of normal or shear stresses.

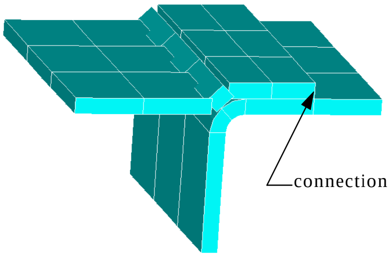

Fig.6

3.2 Time-Dependent Analysis of Creep and Shrinkage of Concrete

To check the stresses in the structure due to the creep and shrinkage of concrete a detailed time-dependent analysis of the structure by the TDA program was done [1]. For creep and shrinkage the CEB-FIP Model Code 90 was used. The analysis was performed for two options of erection - Option 1 and Option 2. In Option 1 the steel module is erected without temporary support, in Option 2 the steel module is supported by temporary towers situated at mid-span during the casting of the deck slab.

The analysis proved that the level of stresses are within limits given by AASHTO and that supporting of deck during the casting of the concrete deck slab does not improve the function of the bridge. The compression stresses in concrete created by the temporary support dismissed in time.

3.3 Static and Fatigue Loading Tests

Although the arrangement of the structure was based on a detailed static analysis that proved the effectiveness of the system, *Advanced Bridge Systems, Inc.* has decided to demonstrate the static function and safety of the proposed system by static and fatigue loading tests. At present these tests are being done at the University of California, San Diego.

The tested structure is formed by one modules of width of 2.540 m and a span length of 12.192 m. Since the module is part of the bridge, the loading situated on the width of 3.04 m is reduced in the portion 2.54/3.04 = 0.8356.

The design of the Modular Girder System is not controlled by stress limits of steel or concrete members but by the requirements on minimum thickness of metal and on the deflection of the structure. From economic point of view, it was decided to test the structure that fulfills the requirements on the minimum thickness, but which did not fulfill the recommended requirements on the maximum deflection. This approach corresponds to the paragraph 10.6.7 of the AASHTO.

The structure was designed for loads given in Section 3 of the AASHTO Standard Specifications. For lane loading and HS20-44 loading Service Load Design Method (Allowable Stress Design) was used, for P loads (permit loads) the Load Factor Design Method (Strength Design) was used. Live load stresses were increased by impact allowances given in 3.8.2. The composite deck slab was designed for an axle load of 32 k. A wheel load of F= 16 k was situated on the contact area A = 0.01 P. The structure was designed in accordance with Section 10 of the AASHTO Standard Specifications - as a plate girder that is composite with a concrete deck.

Maximum bending stresses in the deck were created by the H 20-44 truck (see Fig.7). The bending moment at mid-span is nearly the same for two positions (positions *a* and *b*). Maximum shear stresses in the webs are caused by the H 20-44 truck situated close to the supports since there is no distribution of stresses into neighboring webs. The shear stresses are low and do not influence the dimensions of the structure. For fatigue load testing, the structure is loaded by the concentrated load situated at mid-span. The value of the concentrated load was chosen in such a way that the corresponding bending stresses are equal to the design stresses which were created by load *a*.

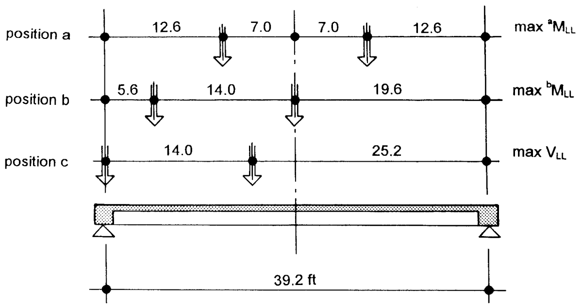

Fig.7

At present, the structure is being tested for fatigue load that creates maximum bending at mid-span. After that, the structure will be tested for a static load that creates both maximum bending and shear - position *b*. Then, the ultimate capacity of the structure will be verified. The loading will be increased by increments of 20% of the design load until failure.

4. DISTRIBUTION OF LOAD - TRANSVERSE CONNECTION OF MODULES

The connection of the individual modules in the bridge structure is formed only by a composite concrete slab and by the end diaphragms. A gap of width of 0.050 m is designed between the individual modules. This arrangement was developed on the basis of a very detailed analysis of two structures assembled of four modules. The calculations were performed for two spans, namely 12.192 m and 30.236 m. These spans represents reasonable span limits of the bridge system.

The 12.192 m long structure was assembled from four modules which correspond exactly to the module of the tested structure - see Fig.8a. The structure is formed by a seven cell box girder of the depth of 0.274 m. The concrete slab has a thickness of 0.106 m, the steel corrugated shape plates have a thickness of 8 mm. The 30.236 m long structure is assembled from four modules, that are formed by a five cell box girder of the depth of 0.965 m - see Fig.8b. The concrete slab has a thickness of 0.127 m, the steel corrugated shape plates have thickness of 8 mm.

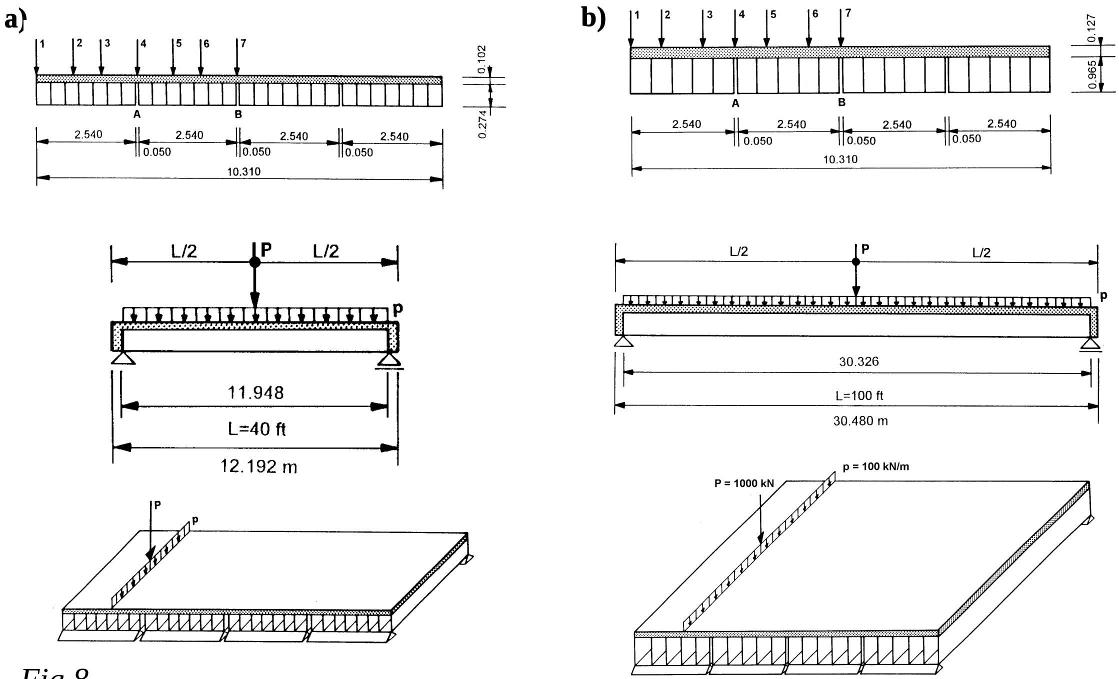

Fig.8

The stresses in the 12.192 m long structure are governed mainly by HS-Truck. In the 30.236 m long structure the stresses created by the HS-Truck are similar as the stresses created by the lane load. To determine influence lines of the deflection and stresses the structures were analyzed for two loading - a uniform linear load p=100 kN/m situated along the whole length of the structure and for a point load P=1000 kN situated at the mid-span. Both loads were applied in seven different positions uniformly distributed along the cross section.

For each loading the deflections and stresses both in the concrete deck and the steel modules were plotted. Since the outputs of the analysis are deflections and stresses, the internal forces were not additionally calculated. Rather, the stresses at the top and bottom fibers of the concrete composite deck and steel module were studied. To determine critical positions of the uniform load and HS-Truck, which create maximum longitudinal and transverse stresses in the structure, influence lines of stresses were determined.

4.1 Influence Lines of the Transverse Stresses

To determine the positions of the uniform load and HS-truck, which cause the maximum stresses at the connection between the individual modules, the influence lines of the normal stresses f_c were determined. The influence lines were calculated for the connection between the first and second module - point **A**, and for the connection between the second and third module - point **B**. The influence lines were determined for both spans and for both loads - for the uniform linear load and for the point load. The influence lines of the stresses in the top f_c^t and bottom f_c^b fibers of the connecting concrete slab have a similar shape and therefore only influence lines of stresses f_c^t both for point and uniform loads are plotted in Figs.9a,b.

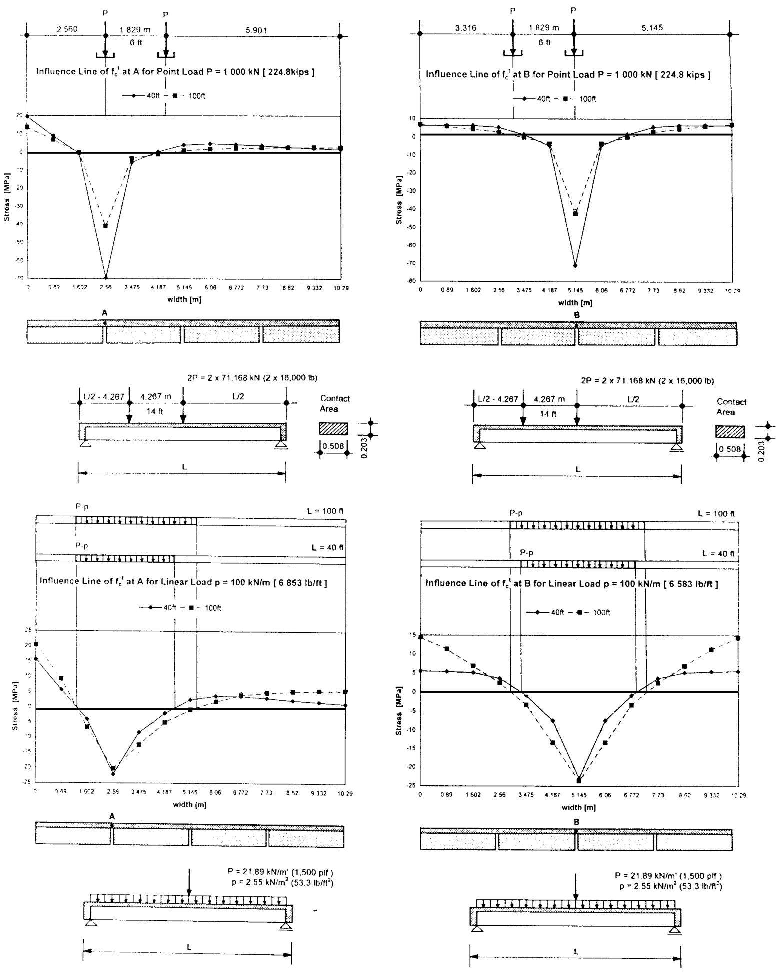

Fig.10

The influence lines served for determining positions of HS-Truck and lane load for which the structure was again analyzed and reinforcement of the connection was determined - see Fig.10a,b. The results of the analysis confirmed that the modules can be joined only by a composite concrete deck.

4.2 Distribution of Load

Since the individual modules have a large stiffness in torsion and they are eccentrically connected by the composite slab, the system distributes well the point load. To understand the function of the structure, the influence lines of longitudinal stresses created both in top and bottom fibers of the concrete slab and in the steel module were plotted. Since the lines have a similar character, Figs. 10a show only the longitudinal stresses in top fibers of the concrete slab f_c^t at seven points (1 to 7) of the deck slab. The influence lines of stresses which are resisted by the individual modules were obtained by integration of the influence lines of points 1 to 7 - Figs. 10b.These figures also show the portion of the load (the distribution factors), that is resisted by the modules.

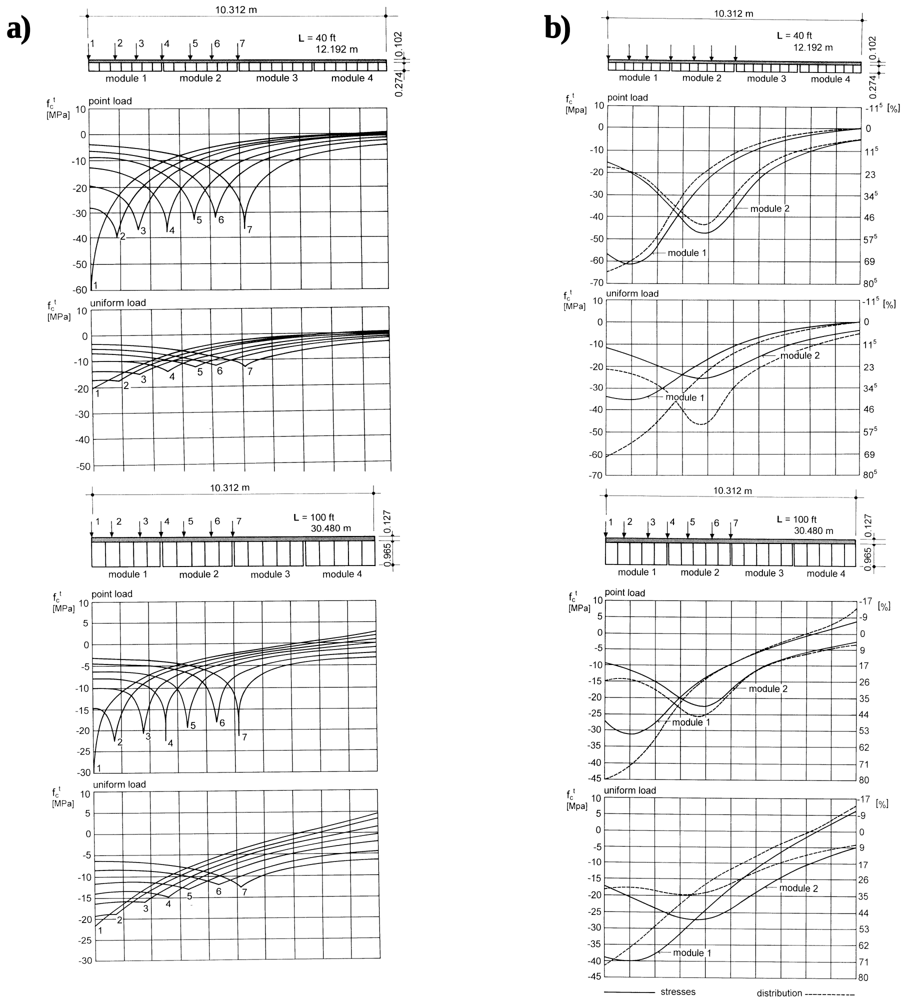

Fig. 10

5. CONCLUSIONS

The results presented in the paper have confirmed that the proposed bridge system complies with all requirements of the AASHTO Standard Specification. The simple production, speed of erection and nearly no maintenance, give the system large possibilities. Therefore the authors believe that *Modular Span Multi-Cell Box Girder System* will find wide application in the bridge industry.

6. ACKNOWLEDGEMENTS

The Modular Bridge System was developed by *Advanced Bridge Systems, Inc., Redding, California* and engineered by *Prof. Jiri Strasky.*

7. REFERENCES

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