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Research Article / Araştırma Makalesi

ASSESSMENT ON WEB SLOPE OF TRAPEZOIDAL RIB IN ORTHOTROPIC DECKS USING FEM

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ABSTRACT

Thanks to their light weights, orthotropic deck structure is commonly used in industry to span long distances. An orthotropic deck is composed of deck plate, ribs and cross- beams. The deck is referred to as "orthotropic", because it is generally assumed as a simple plate having two different stiffnesses in longitudinal and transverse directions. Ribs provide the longitudinal stiffness of the bridge, whereas cross- beams provide transverse stiffness. Cross- beams are broadly of the similar shapes; nevertheless ribs can possess several different shapes like strip, bulb, angle, V- shaped, U- shaped, sektkelch or trapezoidal. This study is focused on trapezoidal ribs, since they are dominantly used in industry. Three different slopes of trapezoidal rib web are assessed using FEM, while rib width, height, span and thickness are kept constant. Results show that stresses especially of cross- beam and deflections of deck plate change depending on slope of trapezoidal stiffener webs.
Keywords: Orthotropic deck, stress analysis, longitudinal stiffener, trapezoidal rib, FEM.

ORTOTROP PLAKLARDAKİ TRAPEZ NERVÜRLERİN GÖVDE EĞİMLERİNİN SEM KULLANILARAK İNCELENMESİ

ÖZET

Ortotrop plaklar hafif olmalarından dolayı uzun açıklıkları geçmede endüstride yaygın bir kullanım alanına sahiptirler. Ortotrop plak çelik tabliye laması, nervürler ve enine kirişlerden oluşur. Bu plak genelde boyuna ve enine doğrultularda farklı rijitlikleri olan basit plak olarak farz edilebildiği için ortotrop ismiyle anılır. Boyuna nervürler boyuna doğrultudaki rijitliği, enine kirişlerde enine doğrultudaki rijitliği sağlarlar. Enine kirişler genellikle hep benzer kesitlere sahipken, boyuna nervürler şerit, ampul, köşebent, V- şeklinde, U- şeklinde, sektkelch veya trapez formunda olabilirler. Trapez nervürler endüstride uygulamada sıklıkla kullanıldıklarından bu çalışmada onlar üzerine yoğunlaşılmıştır. Trapez nervürün gövdesinin üç farklı eğimde olması durumu için SEM analizleri yapılmıştır. Gövde eğimleri değiştirilirken nervürlerin genişlikleri, boyları, aralıkları ve et kalınlıkları sabit tutulmuştur. Sonuçlar göstermiştirki, özellikle enine kirişte ortaya çıkanlar olmak üzere tüm gerilmeler ve tabliyede gerçekleşen deplasmanlar trapez nervür kesitinin gövde eğimine gore değişmektedirler.
Anahtar Sözcükler: Ortotrop plak, gerilme analizi, boyuna nervür, trapez nervür, SEM.

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1. INTRODUCTION

Construction of orthotropic decks with deck plate, cross- beams and trapezoidal ribs going through the cut- outs in cross beam webs started approximately in 1965 and is still widely used in industry [1]. Orthotropic deck structure is a common design, which is used worldwide in fixed, movable, suspension, cable- stayed, girder, etc. bridge types. In Japan, Akashi Kaikyo suspension bridge, Tatara cable stayed bridge [2], Trans-Tokyo Bay Crossing steel box-girder bridge [3], which are among the longest bridges in the world, have orthotropic deck structure. In France Millau viaduct has a box girder with an orthotropic deck using trapezoidal stiffeners [4]. In England, Germany and Netherlands there are a lot of steel highway bridges having orthotropic decks [1]. The traditional orthotropic deck is composed of deck plate, longitudinal stringer and cross beams. Spacing of longitudinal stringers and cross beams are in general 300 mm and 3 m to 5 m respectively. In addition to deck structure, wearing course lying on deck plate and main girders transmitting load to supports are two important components of orthotropic bridges. While wearing course might be of asphalt or concrete, main girder might be of a girder, a truss, a cable stayed or a tied arch system. Wheel loads are first dispersed by wearing course and introduced in deck plate. Then longitudinal stringers transmit wheel loads to cross beams. Finally wheel loads are transferred from cross beams over main girders to the bridge's supports [5,6]. Ribs are the longitudinal stiffeners, which are welded continuously to deck plate from bottom and to cross beams intermittently at cross beam locations. In this manner deck plate forms flanges of ribs and cross beams and also a supporting base to its wearing course, while spreading the load on all structural components. Rips are referred to as longitudinal stiffener, stiffener or through in some sources and mainly grouped in classes as open and closed ribs. In the progress of orthotropic steel bridges, closed ribs proved their superiority due to their high torsional and buckling stiffness, less material and welding needs. Nowadays, trapezoidal form of closed ribs is preferred broadly in industry. In the scope of this study trapezoidal ribs having three different web slopes shown in Figure 1 are compared with each other for the assessment of their efficiency with respect to stresses developed in deck plate, rib and cross beam and deformations of deck plate.

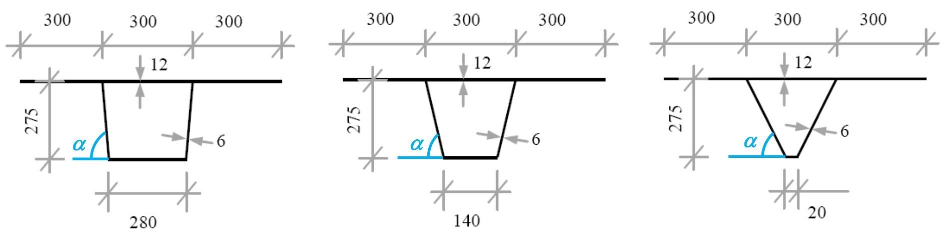

Figure 1. Dimensions (in mm) of different rib shapes used in this study. The slopes of the rib shapes from left to right are 87.92°, 73.78° and 63.02° respectively.

Design rules and recommendations are given in DIN FB 103 [7], US Department of Transportation Federal Highway Administration Report No: IF-12-027 [8], Mangus and Sun [9], Wolchuk [10] and Wolchuk [11] for dimensions of orthotropic steel bridges. In this research the cross section of bridge is chosen as per DIN FB 103 [7], since it is the most updated information source in comparison with Mangus and Sun [9], Wolchuk [10] and Wolchuk [11] and a frequently used reference in Europe. In addition, US Department of Transportation Federal Highway Administration Report No: IF-12-027 [8] also sets similar rules and recommendations as DIN FB 103 [7] does.

2. FE- MODEL OF BRIDGE

In order to achive to perform a parametric study, all dimensions of FE- model of the bridge are defined as variables by means of an algorithm, which is written employing APDL (Ansys Parametric Design Language). The FE- model of the bridge is generated using SHELL 181 already defined in ANSYS [12]. The FE model of orthotropic steel bridge used by Huurman et al. [13] inspired the researcher to create the FE- model of bridge, which is used in this research, in Fettahoglu and Bekiroglu [14] and in Fettahoglu [15]. However, in the FE- model utilized in this study, stiffened main girder and pedestrian road are also generated, which are not included in the FE- model used by Huurman et al. [13]. Because of the number of nodal unknowns the dimensions of the bridge used in this research are chosen as short as possible. The number of elements and nodes in the FE- model of the bridge are 284 010 and 293 491 respectively, in case slope of rib web is 73.78°. As a result the bridge spans 6 m and has stiffened main girders at supports, normal main girders at field (outside support areas), 2 exterior- 5 interior ribs, 1 rib in main girder and 1 rib in pedestrian road. The height, width and spacing of the ribs used in orthotropic deck are 275 mm, 300 mm and 300 mm respectively. To decrease the number of nodal unknowns further, only the quarter of the bridge shown in Figure 2 is modeled by means of FEM.

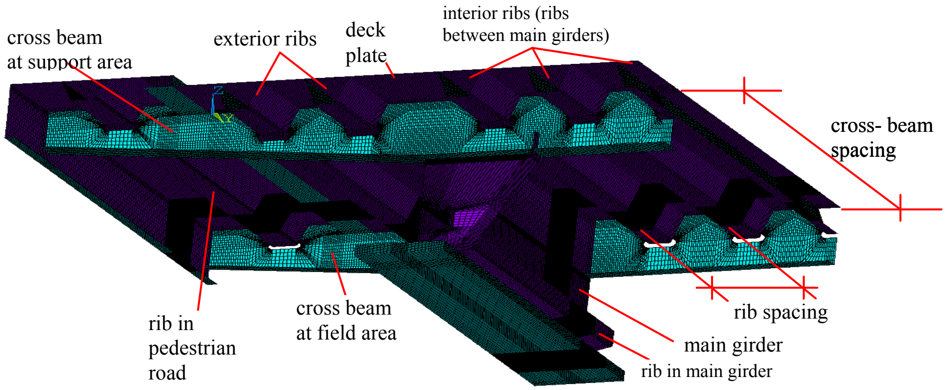

Figure 2. FE- model of orthotropic steel bridge.

The material of steel parts of bridge is selected as S 355 according to Capital II of DIN FB 103 [7], which is the standard used throughout this study. Table 1 shows the yield stress, strength, material constants and density of S 355. The conservatively selected wheel loads on the bridge are given in Figure 3. The deformed shape of bridge is scaled up for a better illustration of results given in Figure 4 to Figure 9. In the FE- analyses geometric non- linearity is taken into account during the solution process.

Table 1. Material Properties

Yield stress (f_y)	355 MPa	Shear Module(G)	81000 MPa
Ultimate strength (f_u)	510 MPa	Poisson ratio (υ)	0.3
Elasticity module (E)	210000 MPa	Density (ρ)	78.5 kN/ m^3

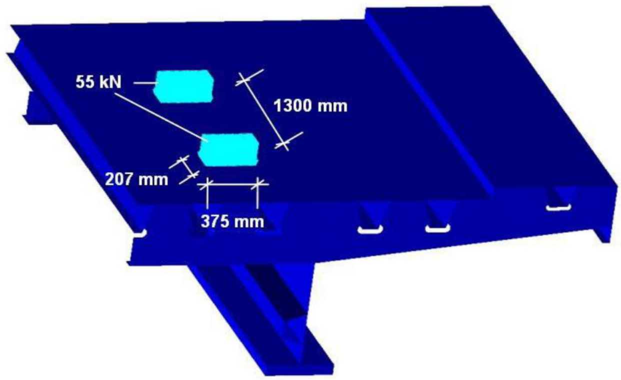

Figure 3. Wheel loads on quarter of bridge' s FE- model.

3. RESULTS & DISCUSSION

FE- analyses of steel orthotropic bridge are performed for trapezoidal rib web slopes of 87.92°, 73.78° and 63.02° respectively. First, deformation vectors of whole structure are given in Figure 4, Figure 5 and Figure 6 to identify which rib web slope results in the best load dispersing of wheel loads on deck plate. It is seen from Figure 7 that, rib web slope of 73.78° leads to best load dispersing of deck plate with the lowest deformations. According to shape of curve given in Figure 7 a moderate rib web slope between two limit situations satisfies the best rib shape so as to obtain min. deformations of wearing surface lying on deck plate. Max. deformation vector values under wheel loads are 1.898 mm ,1.729 mm and 1.966 mm for trapezoidal rib web slopes of 87.92°, 73.78° and 63.02° respectively.

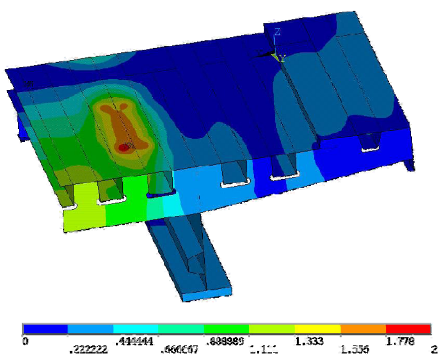

Figure 4. Distribution of deformation vector sum for rib web slope of 87.92°. Max. value is 1.898 mm.

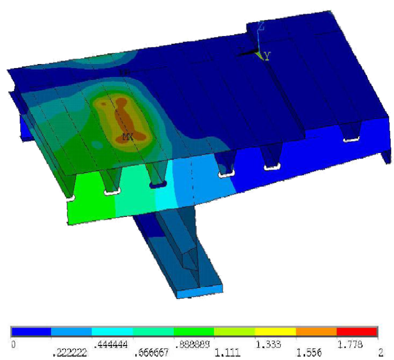

Figure 5. Distribution of deformation vector sum for rib web slope of 73.78°. Max. value is 1.729 mm.

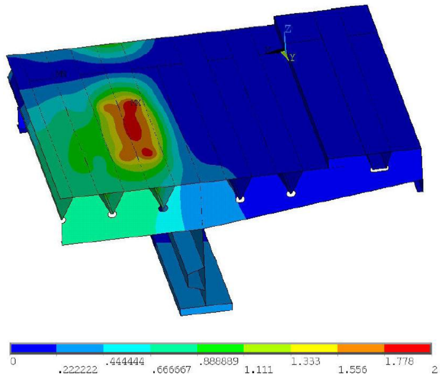

Figure 6. Distribution of deformation vector sum for rib web slope of 63.02°. Max. value is 1.966 mm.

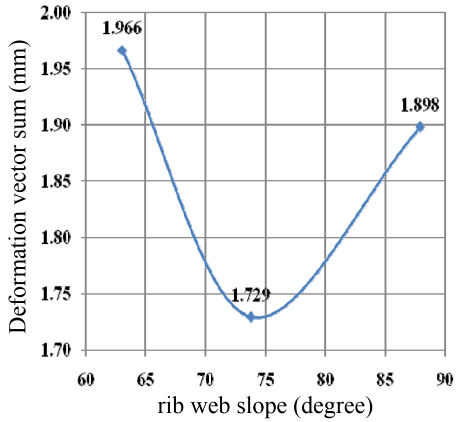

Figure 7. Variation of deformation vector sum depending on rib web slope.

Second, von Mises stress distribution of rib web slopes of 87.92°, 73.78° and 63.02° are given in Figure 8, Figure 9 and Figure 10 respectively. In all these figures von Mises stress distribution of the whole structure is given at the top and close- up view of max. von Mises stress distributions as per averaged and non- averaged nodal values are given at the bottom. If the max. values of von Mises stresses appear in deck plate, ribs and cross- beams for rib web slope of 73.78° are taken as 100 percentage, Figure 8 indicates that using rib web slope of 87.92° leads to % 4.04 stress decrease in deck plate, % 2.77 stress increase in ribs and % 30.79 stress increase in cross beams. Likewise, Figure 10. indicates that using rib web slope of 63.02° yields to % 5.61 stress increase in deck plate, % 1.98 stress decrease in ribs and % 8.55 stress decrease in cross beams. As a result using rib web slope of 63.02° is the best according to yielding of steel parts of the bridge. Variation of stresses in steel parts is shown in Figure 11 for illustration. Third, the extreme values of normal and shear stresses developed in deck plate, ribs and cross beams are examined as to Table 2. Max. absolute normal stress value in bridge's transverse direction appears in cross beam as 173.086 MPa, when rib web slope is 87.92°. Using other slopes of rib web concludes in lesser transverse normal stress values. According to normal stresses in bridge' s longitudinal direction max. tension and compression stresses occur always in rib steel parts, whatever rib web slope is used. Min. tensional longitudinal normal stress and max. compressive longitudinal normal stress develop as 89.998 MPa and 200.105 MPa respectively, when rib web slope is 63.02°. From the close examination of longitudinal normal stresses it is concluded that, using lower rib web slope values leads to slight increase of compressive longitudinal normal stresses, but also ~% 50- % 90 decrease of tensional longitudinal normal stresses in rib steel parts. Vertical normal stresses in global Z axis rise in cross beams and ribs, when rib web slope is 87.92°, but lessen in cross beams and ribs, when rib web slope is 63.02°. Values of shear stresses appear in steel structural parts are very much smaller than normal stresses and are of no importance for the assessment of slope of rib web in orthotropic steel bridges.

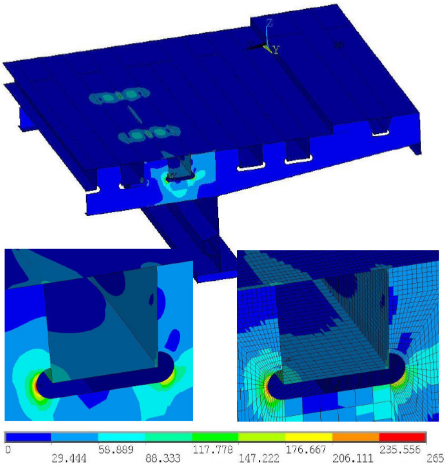

Figure 8. Distribution of von Mises stress with averaged nodal values (top and bottom left) and non- averaged elemet results (bottom right) for rib web slope of 87.92°. Max. values developed in deck plate, ribs and cross beams are 121.538 MPa, 262.34 MPa and 263.612 MPa respectively.

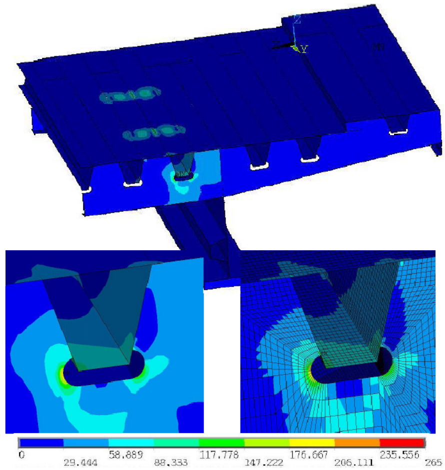

Figure 9. Distribution of von Mises stress with averaged nodal values (top and bottom left) and non- averaged elemet results (bottom right) for rib web slopeof 73.78°. Max. values developed in deck plate, ribs and cross beams are 126.652 MPa, 255.259 MPa and 201.549 MPa respectively.

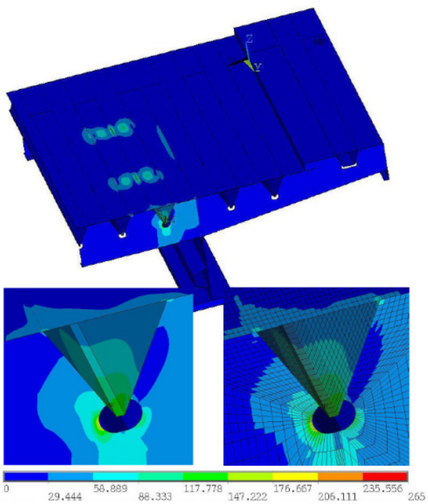

Figure 10. Distribution of von Mises stress with averaged nodal values (top and bottom left) and non- averaged elemet results (bottom right) for rib web slope of 63.02°. Max. values developed in deck plate, ribs and cross beams are 132.997 MPa, 250.202 MPa and 184.319 MPa respectively.

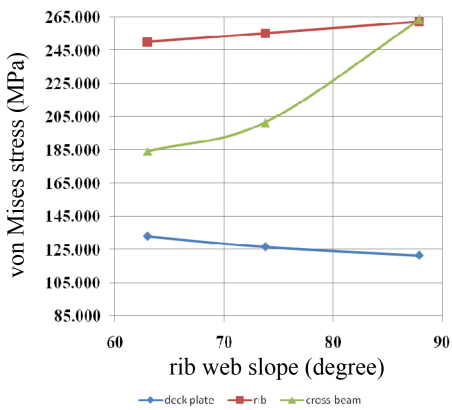

Figure 11. Variation of max.von Mises stress depending on slope of rib web.

Table 2. Comparison of stresses for different slopes of rib webs

Type of stress (Mpa)		Slopes of rib webs					
		87.92°		73.78°		63.02°	
		value & place		value & place		value & place	
σ_X	Min	-125.281	deck plate	-136.048	deck plate	-137.314	deck plate
	Max	173.086	cross beam	143.551	cross beam	142.694	deck plate
σ_Y	Min	-180.902	rib	-180.979	rib	-200.105	rib
	Max	188.973	rib	145.481	rib	89.998	rib
σ_Z	Min	-274.543	cross beam	-212.199	cross beam	-192.876	cross
	Max	289.724	rib	244.216	rib	189.821	rib
σ_{XY}	Min	-23.904	rib	-21.289	rib	-22.569	deck plate
	Max	22.223	deck plate	21.782	deck plate	24.892	Rib
σ_{YZ}	Min	-51.88	Rib	-46.702	Rib	-37.716	Rib
	Max	39.141	Rib	54.273	Rib	48.926	Rib
σ_{XZ}	Min	-94.819	cross beam	-69.481	cross beam	-62.108	cross
	Max	78.239	cross beam	71.628	rib	97.041	Rib

Variation of max.stressesin steel parts depending on slope of rib web is given below in Figure 12.

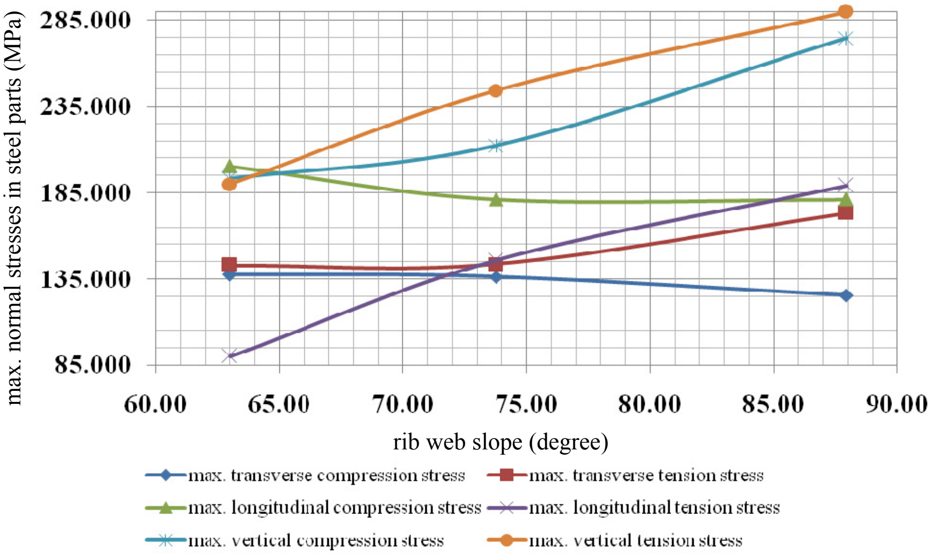

Figure 12. Variation of max. stresses in steel parts depending on slope of rib web.

4. CONCLUSION

Briefly, using limit situations and a moderate value of slope of trapezoidal rib web in orthotropic deck is compared with each other using FEM in this study. A detailed FE- model is used to assess the effect of slope of rib web on the stresses of steel parts of orthotropic bridge and on the deformations occur at the deck plate. Results of the FE- analysis show that using the lowest slope of rib web is the best, while using highest slope of rib web is the worst as per stresses revealed in rib and cross- beam steel parts of the bridge. This result is especially true for cross- beam stresses. On the other hand max. deck plate deformation and hence max. deformation in bridge' s wearing surface is obtained, when the lowest slope of rib web is used. Consequently, the lower slope of trapezoidal rib web is used, the lower stresses are obtained in steel parts. However, this slope degree shall be determined according to the permissible deformation value of wearing course laid on deck plate.

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