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MULTIDISCIPLINARY ANALYSIS OF STEEL PLATE OF VARIABLE THICKNESS IN VIEW OF OPTIMAL DESIGN

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The paper shows the indentification of deformational-stress state of partially loaded plates composed of two elements of different thicknesses. We analyzed metallurgical processes that characterize the technology of welding steel structures. The mathematical interpretation of the local stress state, through the developed software, enables an optimal design of geometric parameters of plate or supporting elements of construction according to the stress criteria. Comparative analysis of deflection and equivalent stress obtained by the analytical method and Finite elements method (FEM), using ANSYS 12 software package, the high agreement of results in terms of values and distribution trends is noticed. The application of the results of this paper is particularly important for the optimal design of steel girders.

Key words: steel plate, stress, multidisciplinary analysis, microstructure, optimal design

INTRODUCTION

One of the biggest demands that was set for metallurgy by engineering industry is develo-pment of constructive steel, in order to meet the complex requirements of exploitation, and to be technologically reasonable. Strength, hardness and ductility (toughness) are the basic mechanical properties of the steel, directly dependent on the carbon content. Adding Mn and Si influence favorably the relationship between strength and hardness, proeutectoid steel of which are designed bearing structures. The paper presents unconventional approach to the optimal design of welded structures. Installation of steel plates of different thickness is suitable for exploitation stress state, but such actions can be counterproductive, if adequate measures to reduce the residual stress were not taken. The application of steel plate elements is significantly represented in the various constru-ction purposes. Classical calculations are mainly based on the theory of line girders. Models of line girders does not provide the ability to identify structural behavior in the areas of active or reactive loads, which is characterized by significant changes. Such changes were first established during the operation, and later appropriate experimental researches have been carried out.

These researches have shown that stresses are several times larger than those obtained by the calculation using the model of global stress.

Detailed research conducted on the girder of constant geometric structures has confirmed that the actual stresses may be higher for an order of magnitude than the calculated one by using the classical model of line girder. In addition, it is important to emphasize the accuracy of the resu-lts obtained that do not exceed 5 %, while in the areas of extreme stress deviation is about 1 % [1]. Models of local stress are based on the assumptions of the theory of plates [2], while research [3] treats this problem through the principle of decomposition of box girders.

Classical optimization of cross-section of girder [4-6] is based on a global carrying capa-city, where the aim function is mass of girder that should be minimized with the fulfillment of carrying capacity conditions according to the model of global stress. However, such an appro-ach is justified on the part of girder where the global stress state is dominant. Part of the girder around the effect of load represents the zone of intense local stress, and the optimization process in this section must be supplemented by the condition of local capacity.

MICROSTRUCTURE AND CHARCTERISTICS OF CONSTRUCTIVE STEEL

Capacity of steel structures is largely dependent on the type and quality of used material. This paper presents a multidisci-plinary approach in the analysis of mechanical properties of materials and structural steel supports measures that contribute to the improvement in exploitation characteristics of carriers. In the first part, it is already emphasi-zed the influence of the individual alloying elements on the mechanical properties of the steel. Properties of structural steels include: physical, chemical, mechanical and technolo-gical properties [7, 8].

Table 1 shows the general constructive steels in addition to Mn and Si and related items are in limited quantities (P, S, N_2, O_2), and are consi-dered undesirable in the structure of steel. By reducing the content of impurities and increa-sing the percent of Mn and Si are

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obtained higher strength steels, class QS (Quality Steel). Steels under serial No. 1 and 2 are classified BS (basic steel) for a greater share of its relevant elements.

The microstructure of steel with a minimum content of the ferrite composition C (Figure 1a), which is characterized by a poly-gonal shape metal beads. The welding of steel are formed lamellar structure of ferrite, known as Widman-nstätten. Steel with 0,025 % C makes pearlite which is eutectoid with 0,8 % C and consists of ferrite and cementite grains (Figure 1b).

Table 1 **Review of structural steel [7]**

N_o	Standard	Alloying elements		Tensile strength
	EN 10027-1	Mn / %	Si / %	R_m / N/mm^2
1	S 235 JR	1,50	-	340
2	S 235 JRG1	1,50	-	340
3	S 235 JRG2	1,50	-	340
4	S 235 J0	1,50	-	340
5	S 235 J2G3	1,50	-	340
6	S 275 JR	1,60	-	410
7	S 275 J0	1,60	-	410
8	S 275 J2G3	1,60	-	410
9	S 355 JR	1,70	0,60	490
10	S 355 J0	1,70	0,60	490
11	S 355 J2G3	1,70	0,60	490

Cooling of low carbon steel (0,08 ÷ 0,25 % C), with a substantial amount of retained austenite, martensite is obtained. The steel structure is the result of an unbalanced process and a typical structure of welded structures. Slowing down the cooling process is obtained bainite, which represents the dispersion of supe-rsaturated ferrite and carbides. Such a structure is acceptable because it provides significantly better mechanical properties of the bracket.

Welding is the dominant technology in the process of making steel structures accompanied by a large amount of heat input. This may lead to a change in the composition of the base material in the heat affected zone (HAZ). Experimental tests of box welded rails (Figure 2) showed that the stress in the steel plates is greater than calculated, as a consequence of residual stresses from welding.

Figure 3 shows the microstructure of the base material and HAZ. Controlled heat input in the welding process provides a gradual transition between the coarse bainitic structure HAZ bainitic structure and toughness.

Uncontrolled heat input in the welding process is manifested considerable changes HAZ characterized by martensitic structure (Figure 4a). Coarse grain structure badly affect the carrying capacity of steel plates under the action of load, which may be significantly less than the exploitation, which is initiated by the appearance of cracks (Figure 4b).

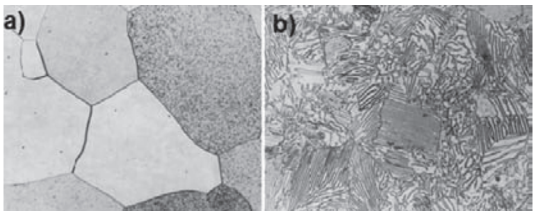

Figure 1 a) ferrite and b) pearlite structure of steel

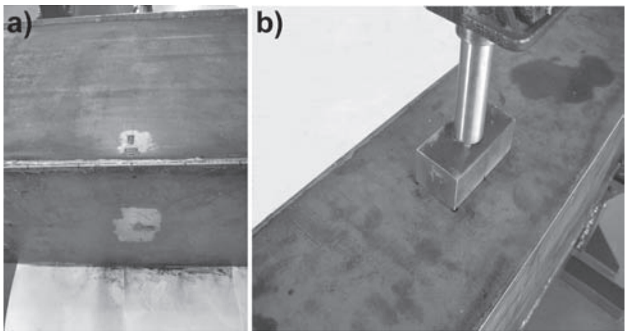

Figure 2 Welded construction of box girder: a) strain gauges and b) simulation load [1]

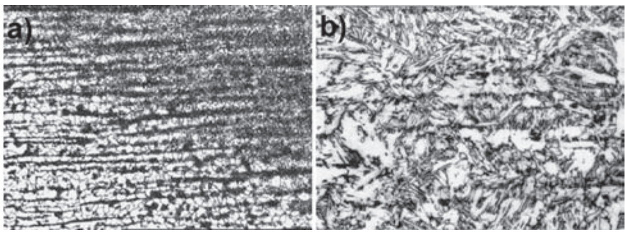

Figure 3 Structure of a) basic material and b) HAZ

It can affect the characteristics of steel, by adding alloying elements, but must be taken of the value of carbon equivalent. Empirical formula for determining the weldable of steel is:

$$C_{ekv} = C + \frac{M_n}{6} + \frac{C_r + M_o + V}{5} + \frac{N_i + C_u}{15} \ /\% \qquad (1)$$

Steel is weldable if $C_{ekv} < 0{,}45$.

Based on the above analysis it can be concluded that the optimization of welded steel construction makes sense only as part of a multidisciplinary approach that takes into account metallurgical processes followed during the welding process. Below, attention will be focused on the modeling of welded steel plates of different thickness.

MATHEMATICAL MODELLING

The subject of research is a rectangular plate composed of two elements of different thickness. The need for research of plates made up of several elements of different thickness derives from the requirements for optimal design of supporting structures. In order to analytical identification of strain and stress state of plates as a constructive elements of the whole, exhibited by partial load, we use a physical model given in Figure 5.

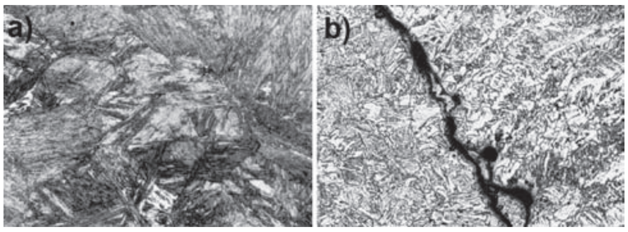

Figure 4 a) martensitic structure and b) initial cracks in HAZ [8]

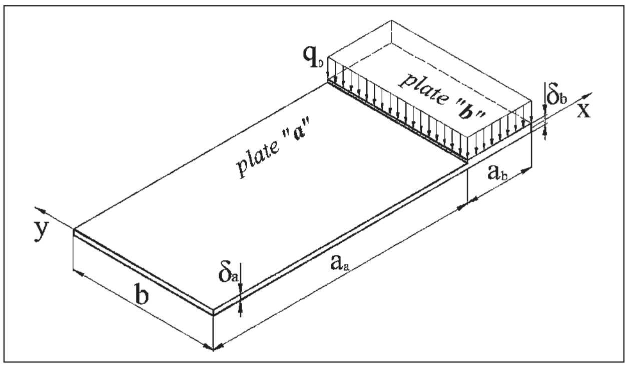

Figure 5 A rectangular plate of variable thickness subjected to partial load

The differential equation of the elastic surfaces of transversely loaded plate (Figure 5), according to [2] has the form:

$$\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{q}{D} \tag{2}$$

Equivalent (von Mises) stress of plate is:

$$\sigma_{e,i} = \sigma_{e,i}(A_{m,i}, B_{m,i} C_{m,i}, D_{m,i}) \tag{3}$$

Determination of moment of elastic anchoring of box girders with constant geome-tric structure is given through research [1, 3].

The required coeficients (Table 2), for practical reasons, are not given in the explicit form (because very long and vast mathematical records). They are presented in the table using the parameter "m".

Table 2 **The values of unknown coeficients**

Plate-a	$A_{m,a}$	$B_{m,a}$	$C_{m,a}$	$D_{m,a}$
m=1	0,079	0	0	-0,010
m=3	0	0	0	0
Plate-b	$A_{m,b}$	$B_{m,b}$	$C_{m,b}$	$D_{m,b}$
m=1	0,352	8,307	-0,353	-8,307
m=3	-30 926,61	2 750,15	30 926,61	-2 750,15

APPLICATION OF ANALYTICAL PROCEDURE TO THE OPTIMAL DESIGN ACCORDING TO THE STRESS CRITERION

In this chapter attention will be focused on non conventional procedure of optimization of thickness of the plate of element of carrying structure by using a mathematical model for defining the local stress. Objective function for optimization in terms of local stress to the stress criterion is:

$$\min \{m(\delta_1, \delta_2, b, a_1)\} \tag{4}$$

$$\sigma_e < \sigma_{doz} \tag{5}$$

Since software is developed for determining the deflection and the stress of the plate, its use to define the optimal geometric size is consider- ably more convenient than using the objective function. By varying the desired geometrical parameters (in this case the thickness), with constant mass of the plate the stress distribution is obtained (as shown in the diagram).

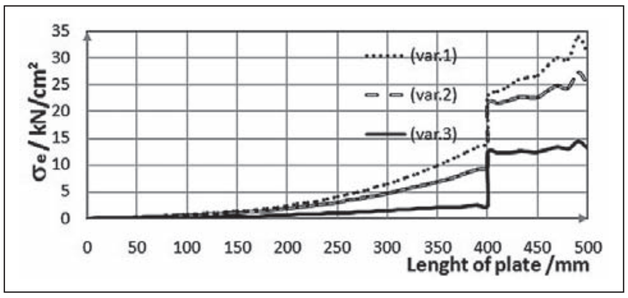

Figure 6 Diagram of von Misess stress

According to Table 3 and the diagram in Figure 6 it is concluded that the geometry of plate No. 3 is exposed to less stress by 90 % compared to variant 1, with the same mass.

Table 3 **Optimal determination of thickness of the considered plate**

Variant	Geometrical parameters of the plate / mm					von Mises stress / kN/cm²
	δ_1	a_1	δ_2	a_2	b	σ_e
1	8	400	12	100	220	25,00
2	7	400	14	100	220	20,02
3	5	400	20	100	220	13,15

ANALYSIS BY USING FEM METHOD

Finite element method is used for verification of the results obtained by analytical procedure. Analysis of finite elements is obtained by using the software package ANSYS 12 (Figure 7).

Conditions of models in terms of loads, geometry, and connections are identical with the theoretical model. To generate FEM model finite elements square plate were applied. The values of the FEM model are presented in comparative diagrams.

COMPARATIVE ANALYSIS OF THE RESULTS OBTAINED BY ANALYTICAL AND FEM PROCEDURE

According to the defined terms for the determination of deflections and stresses of the considered plate (Figure 5) the corresponding diagrams of the distribution are forms (Figure 8 and 9).

On the same diagrams the values obtained by the FEM are shown. By analyzing the diagrams, it can be concluded that the analytical function of deflection fol-

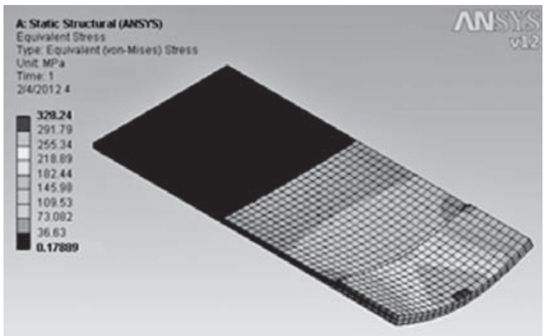

Figure 7 Equivalent srtess of plate model

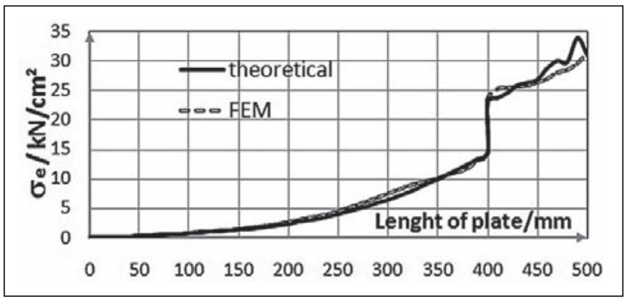

Figure 8 Diagram of the equivalent stress – longitudinal direction

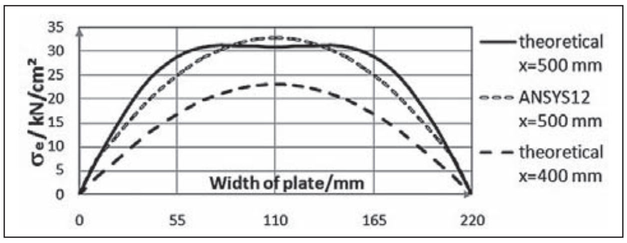

Figure 9 Diagram of the equivalent stress – transverse direction

lows the trend of changes of this magnitude with the values established by the FEM model. As for the distribution of equivalent or von Mises's stress is concerned, small oscillations may be seen on the element "2", which are the result of a slower convergence of the stress functions, but the trend of change completely follows the distribution which is formed by values of the FEM model.

Deviation of values of the equivalent stress and deflection at characteristic points are given in Table 4.

Table 4 **Comparative values of deflection and von Misess stress**

Value	Coordinate		Value		Deviation / %
	x=	y=	theory	ANSYS12	
von Mises stress σ_e / kN/ cm^2	400^-	110	14,352	14,134	1,5
	400^+	110	23,117	23,385	1,1
	450	110	26,725	26,473	0,9
	500	110	31,000	31,591	1,8

CONCLUSIONS

On the basis of the research treated in this paper, we presented the identification of stress strain state of rectangular plate made up of two elements of different thicknesses. Verification of the calculated sizes is performed by the FEM using ANSYS 12 software package. Compara-tive analysis of the obtained results shows that the maximum deviation of values of deflections and stresses do not exceed 5 %, while in extreme zones the deviation is around 2 %. The formed mathematical model of the local stress (stability) gives a realistic stress picture on the part of the girder in the zone of action of external loads [9]. Results given in [10, 11] can be implemented at the research [12].

This aspect is particularly important applica-tion of the means of transport and storage of equipment in the process of servicing distribu-tion centers, where the aforementioned structu-ral elements occur, which rationalization of the mass has a significant financial effect.

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NOMENCLATURE

w	deflection of plate,
D	plate stiffness,
q	continuous load intensity,
$i = (a,b)$	number of plate element,
$A_{m, a}...D_{m, a}$	coeficient of plate "a",
$A_{m, b}...D_{m, b}$	coeficient of plate "b",
a_a	length of plate "a",
a_b	length of plate "b",
B	width of plate,
$m(\delta_1, \delta_2)$	mass function,
d_a	thickness of plate "a",
d_b	thickness of plate "b",
s_e	equivalent stress and
s_{doz}	stress permitted.

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