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Optimum design of stiffened square plates for longitudinal and square ribs

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Abstract

For a given loading, the stiffness of a plate or shell structure can be increased significantly by the addition of ribs or stiffeners. Hitherto, the optimization techniques are mainly on the sizing of the ribs. The more important issue of identifying the optimum location of the ribs has received little attention. In this investigation, finite element analysis has been achieved for the determination of the optimum locations of the ribs for a given set of design constraints. In the conclusion, the author underlines the optimum positions of the ribs or stiffeners which give the best results.

Keywords: Optimum, Stiffeners, Plate, Stress, FEA.

Introduction

The wide use of stiffened structural elements in engineering began in the nineteenth century, mainly with the application of steel plates for the hulls of ships and with development of steel bridges and aircraft structures. Stiffened plates now find applications in modern industry. Stiffeners in a stiffened plate make it possible to resist highly directional loads, and introduce multiple load paths that may provide protection against damage and crack growth under both compressive and tensile loads. The biggest advantage of the stiffeners, though, is the increased bending stiffness of the panel with a minimum of additional material, which makes these structures highly desirable for out-of-plane loads and destabilizing compressive loads.

In addition to the advantages already found in using them, there should be no doubt that stiffened plates designed with optimization techniques will be bring many benefits like swings in material usage, cost, better performance, etc.

Several researches have recently been published regarding the stiffened plates and there applications in ships, bridges, bunkers, tank roofs, offshore structures, vehicles, etc. [1-7].

In general, analytical and exact variational solutions for plate or shell behavior are desirable because of their ease of use and the insight they provide to the designer. Specific geometric effects can be ascertained from these solutions. However, these solutions are generally only applicable for small deflections. Numerical techniques, such as finite element analysis, boundary element analysis, and finite difference analysis, can be more accurate in predicting stresses and deflections, especially for large deflections. Unfortunately, these techniques generally require more effort to use and may not supply the same insight as analytical or exact variational solutions. The use of plate theory is appropriate for the analysis of plates or shells; therefore, this work has been achieved by using the finite element software package *MSC/NASTRAN* with plate bending and shell elements.

Finite element analysis

During the last three decades considerable advances have been made in the applications of numerical techniques to analyze basic structural elements as well as highly sophisticated structures in various fields of engineering. Among these numerical procedures, the finite element methods are the most frequently used today [8].

Finite element procedures have become an important and frequently indispensable part of engineering analysis and design. Finite element computer programs are now widely used in practically all branches of engineering [9].

Applications range from deformation and stress analysis of automotive, aircraft, building, and bridge structures to field analysis of heat flux, fluid flow, magnetic flux, seepage, and other flow problems. With the advances in computer technology and *CAD* systems, complex problems can be modeled with relative ease. Several alternative configurations can be tried out on a computer before the first prototype is built [10].

The development of finite element methods for the solution of practical engineering problems began with the advent of the digital computer. That is, the essence of a finite element solution of an engineering problem is that a set of governing algebraic equations is established and solved, and it was only through the use of the digital computer that this process could be rendered effective and given general applicability. These two properties- effectiveness and general applicability in engineering analysis are inherent in the theory used and have been developed to a high degree for practical computations, so that finite element methods have found wide appeal in engineering practice.

Design constraints

Three cases of design constraints are used in this work. Figure (1-a) shows the first case where all of the edges of the square plate are fixed. Figure (1-b) represents the second case where two edges are fixed and the other two edges are free. In the third case, figure (1-c) three edges of the square plate are fixed and one is free.

Types of ribs or stiffeners

Several types and shapes of ribs or stiffeners may be used to strength plates or shells to increase the stiffness of these structures like flat, L, trapezoidal or other shape [3].

This paper deals with flat ribs or stiffeners for longitudinal and square shapes. For all of the design constraints cases used in this work, one or two longitudinal flat ribs or stiffeners are used; whereas square flat ribs or stiffeners are used to strength the wholly clamped edges plate only, as shown in figures (2 – 5).

Theory and simulation

In many of the available references on the analysis of stiffened plates, the approximate method proposed by Huber is used. Based on the orthotropic plate theory, this method analyzes the plate stiffener system as a plate of equivalent uniform thickness. It neglects the in-plane displacement of the middle plane of the plate. In an improved method presented by Clifton et al., the eccentricity and torsional rigidity of the stiffeners are taken into account, the effect of the stiffeners is smeared out. The governing equations are solved for a simply supported plate and a plate with bridge-type boundary conditions [11].

Large numbers of researches which deal with the analysis of stiffened plates use the finite element computer programs such *MARC*, *ANSYS*, *CARES*/*Life*, *PATRAN*, and *NASTRAN* which is used in this work.

Structural analysis consists of static analysis, normal modes analysis, and buckling analysis. The static analysis equation is:

$$[\mathbf{K}]\{\mathbf{u}\} = \{\mathbf{f}\}$$

Where **K** is the system stiffness matrix (generated automatically by *MSC/NASTRAN*, based on the geometry and properties), **f** is the vector of applied forces, and **u** is the vector of displacements that the program computes. Once the displacements are computed, the finite element software package uses these to compute element forces, stresses, reaction forces, and strains. The applied forces may be used independently or combined with each other. The loads can also be applied in multiple loading subcases, in which each subcase represents a particular loading or boundary condition. Multiple loading subcases provide a means of solution efficiency, whereby the solution time for subsequent subcases is a small fraction of the solution time for the first.

The accuracy of numerical results depends on the number of the Elements used in the descritization scheme. The resolution increases when the number of Elements increases. In order to investigate the optimum locations of the ribs or stiffeners, fine meshes with the maximum permissible number of elements have been used in order to easily change the positions of the ribs and to freely control it.

All of the models used are of the same dimensions (1m × 1m × 2mm) and same material (stainless steel) with the following properties:

Modulus of elasticity, **E** = 196.5 GPa
Modulus of rigidity, **G** = 77.221 GPa
Poisson's ratio, $\boldsymbol{\nu}$ = 0.27
Mass density, $\boldsymbol{\rho}$ = 7834.6 kg/m^3

Every model consists of quadrilateral plate bending and shell elements. All of these elements are subjected to uniform hydrostatic pressure of (P = 2.5 kPa) to work safely within elastic limit.

It is found by experiments that initiation of yielding in most materials is predicted fairly well by either the maximum shearing stress criterion or the octahedral shearing stress criterion which gives the same results as does the energy of distortion criterion [12]. So, in this work, Von-Mises stresses have been proposed.

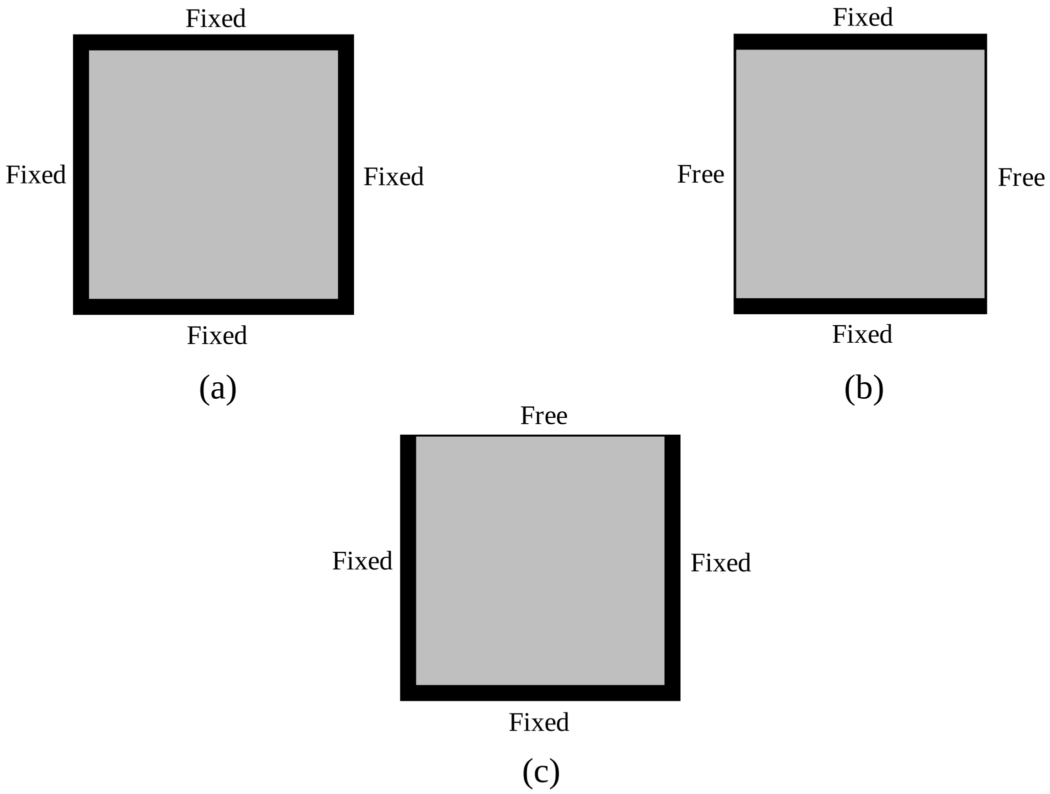
To achieve this study, first, one longitudinal flat rib is used to strength the plate for the three cases of design constraints that discussed previously, as shown in figure (2). The width of the stiffener (w) is used to be (5 cm) and the thickness of it (t) varies from (2 to 6 mm) and located at the middle of the plate, on one or two of the plate sides as shown in figure (6). Depending upon the results of these cases, two longitudinal and parallel ribs are used with the same dimensions to stiffen the plate for the same design constraints. This time, the positions of stiffeners are varied from the center line of the plate to the edges, as shown in figure (3). As an individual situation, one longitudinal rib parallel to the free edge of the third case of the design constraints is used for the same purpose. As shown in figure (4), this time, location of the rib varies from one edge to the free one on one and two of the plat sides. Finally, one square stiffener is used to strength the clamped square plate, as shown in figure (5-a). Position of this stiffener varies from the center of the plate to the fixed edges on one and two of the plate sides. Width and thicknesses of the rib are the same of those used previously.

Results and discussions

To strength a plate, stiffeners may be used on one or two of its sides. To show the best way, one longitudinal rib with different thicknesses is used to stiffen the plate. Figures (8 & 9) show the effect of using the rib on one side and two sides respectively on the maximum stress for the three design constraints (a, b, and c) which discussed in article (3). It is obvious that the use of the rib on two sides is the best for all cases and the use of it on one side gives bad results for small thicknesses. Maximum deflection is the same when using the stiffener on one or two sides, as shown in figure (10). The second step is using two longitudinal and parallel ribs on the two sides. Figures (11 – 16) show the variation of maximum stress and deflection with the change of distance between the two ribs for the three cases of the design constraints. For the first case of the design constraints, it is clear that the use of ribs with thickness more than the plate thickness give good results when the two stiffeners are located together on the center line of the plate, as shown in figure (11). So, the stiffness of the plate may be increased by increasing the width of the one longitudinal stiffener that used before. For the second and third cases of the design constraints, two stiffeners may be used with a certain thickness and in between displacement to reduce the maximum stress induced, as shown in figures (13 – 16). As shown in figure (9), there is no importance of using one longitudinal rib perpendicular to the free edge of the third case of the design constraints; therefore, this rib may be used parallel to the free edge. For different locations, figures (17 & 18) show that the use of the rib on two sides is better than using it on one side. Also, there is an optimum location for the rib depending on its thickness. Similarly, when a square rib is used to strength the wholly clamped square plate, there is an optimal position depending upon thickness of the stiffener and the use of this stiffener on two sides is the best, as shown in figures (20 & 21). Significantly, a good location is appeared at the edges of the plate when using a small thickness for the rib. This may enable us to use two square ribs, one clamped with the edges and the other at a certain position depending upon its thickness, as shown in figure (5-b). For the first case of the design constraints used in this work where the plate is fixed from all its edges, it is noted that the use of a longitudinal rib may gives better results than using a square stiffener. Two perpendicular ribs at the center lines of the plate, as shown in figure (7) may also give good results. As a comparison between some cases of strengthening the wholly clamped plate, results of using some longitudinal and square stiffeners are shown in table (1).

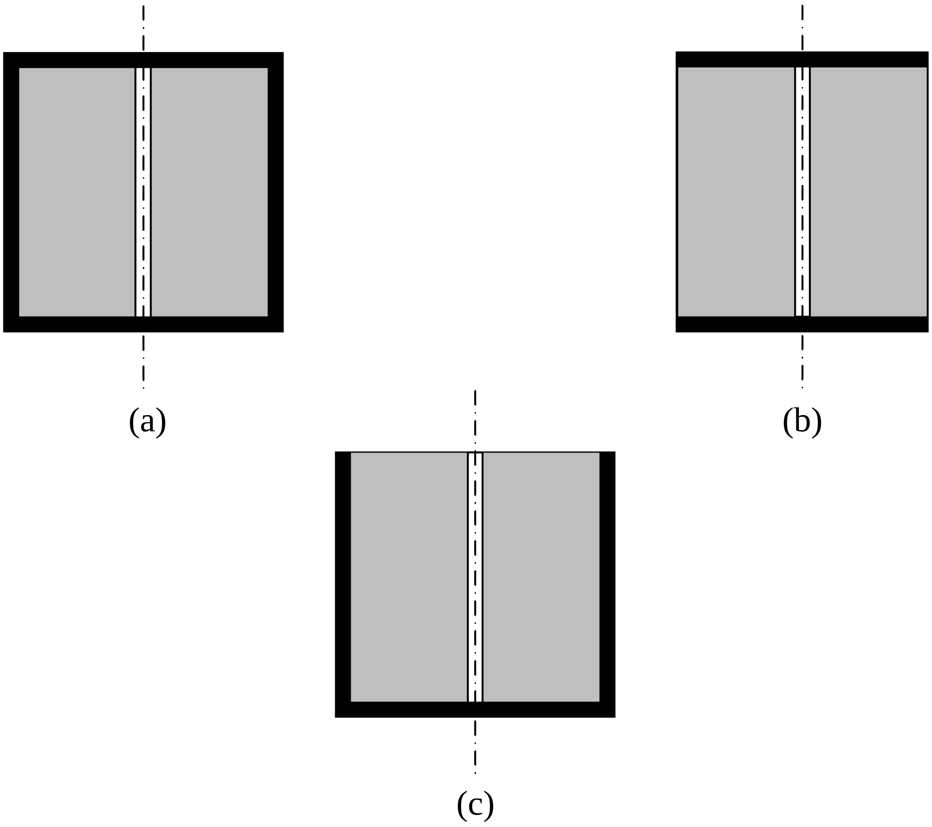
Conclusions:

From the results of this work, it is obvious that using stiffeners on both of the two sides of a square plate gives better results than using the same size of these ribs on one side. This is the primary choice to increase the stiffness of the plate for all of the design constraints used. The choice does not affect the maximum deflection. For the first case of the design constraints, the use of one longitudinal stiffener with certain dimensions at the center line of the plate may be better than using one longitudinal or square stiffener. To use square stiffeners, one may locate a thin rib on the edges and another at a position depends upon the dimensions of this stiffener. For the second case of the design constraints, two parallel stiffeners at certain locations give better results than using one rib. Finally, in the third case, one longitudinal stiffener may be located parallel to the free edge of the plate as an optimal choice, in order to get good results.



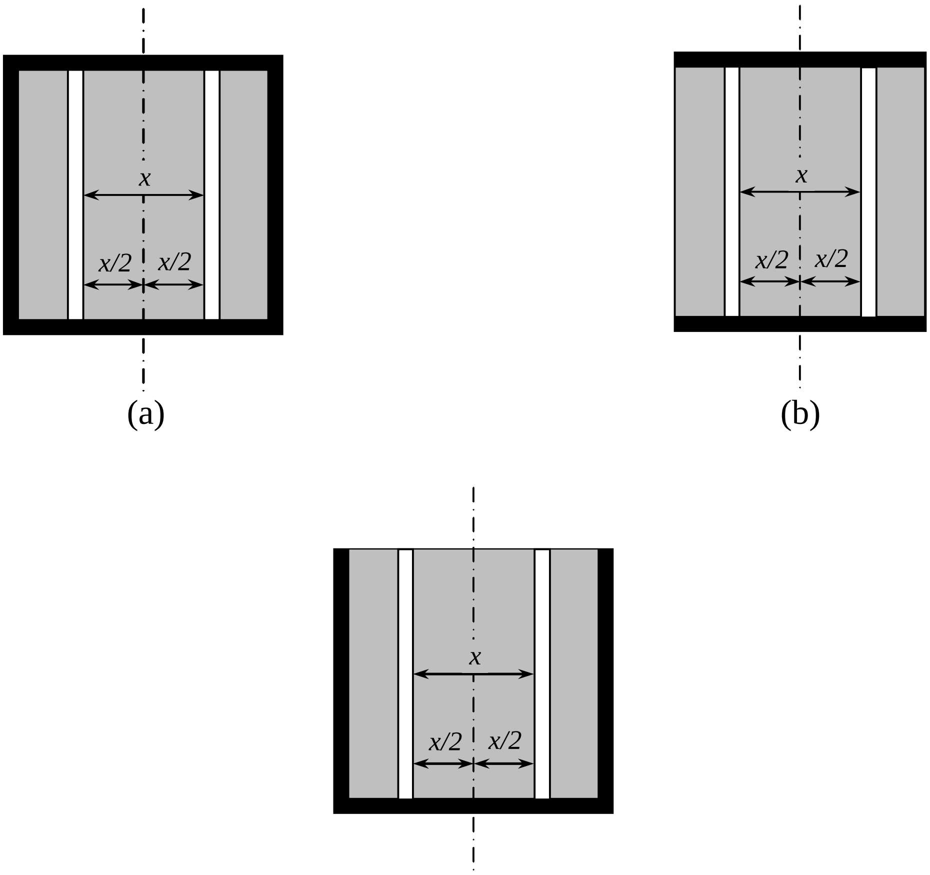
(a) (b) (c)

Fig.(1) The three design constraints used



(a) (b) (c)

Fig.(2) One longitudinal rib



(a) (b)

(c)

Fig.(3) Two parallel longitudinal ribs

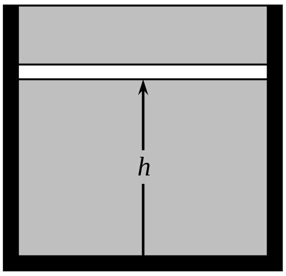
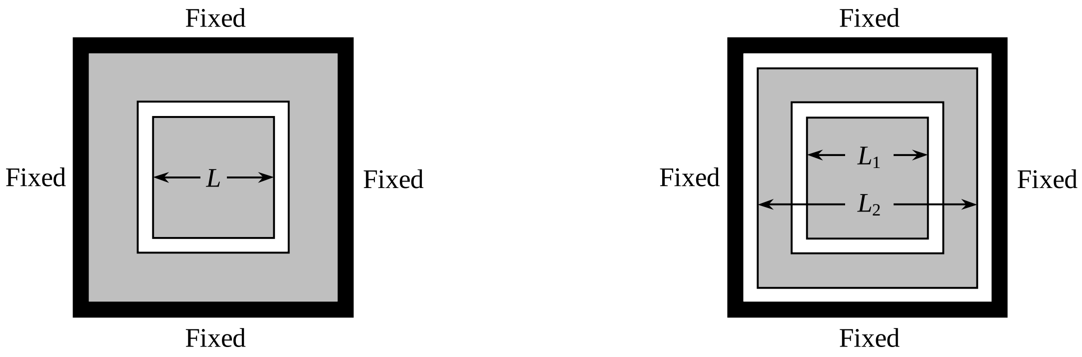


Fig.(4) One longitudinal rib parallel to the free edge



(a) (b)

Fig.(5) One and two square ribs

(a) (b)

Fig.(6) Side view of the stiffened plate

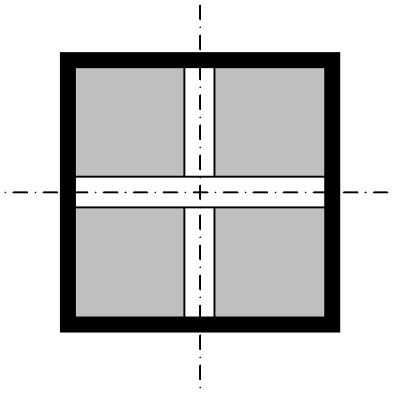


Fig.(7) Two perpendicular longitudinal ribs

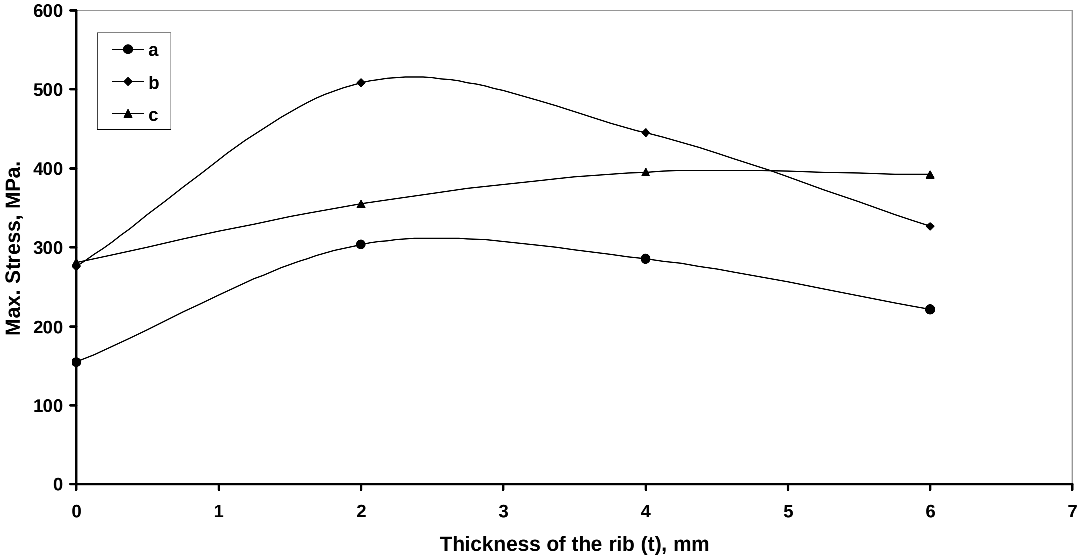


Fig (8) Effect of using one longitudinal rib on one side on the maximum stress

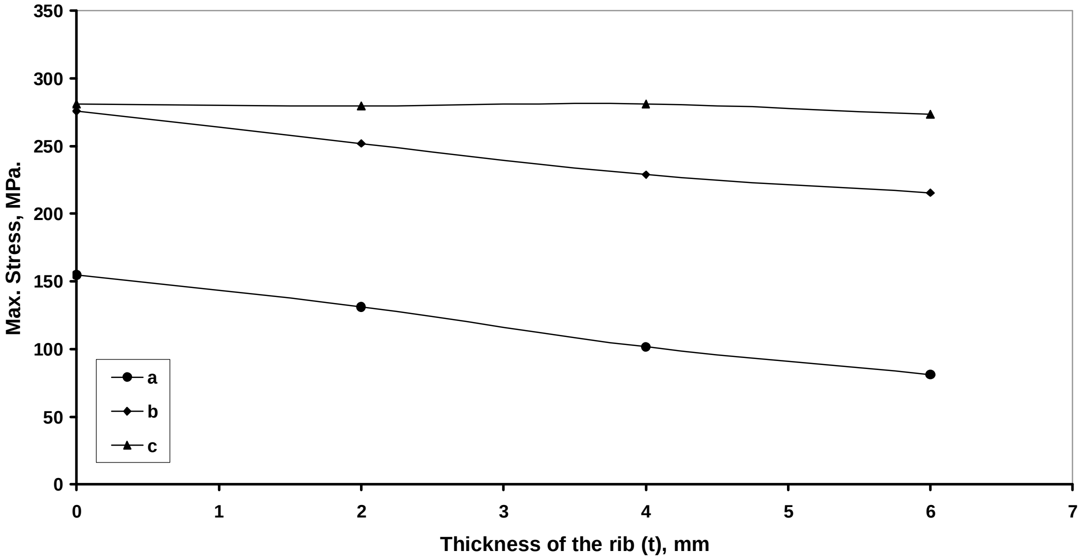


Fig (9) Effect of using one longitudinal rib on two sides on the maximum stress

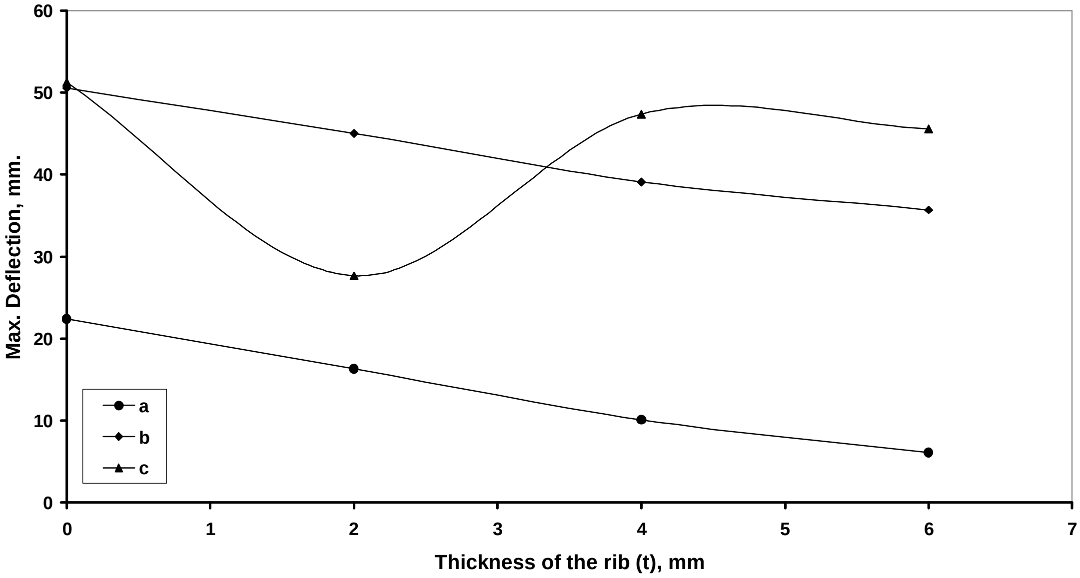


Fig (10) Effect of using one longitudinal rib on one or two sides on the maximum deflection

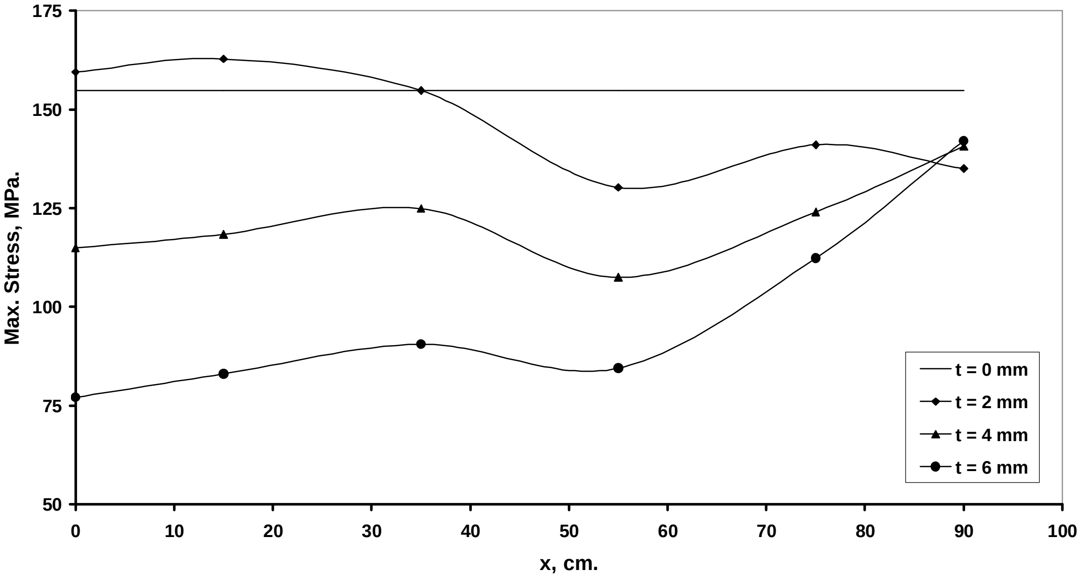


Fig (11) Effect of using two parallel ribs on the maximum stress for the first case of the design constraints

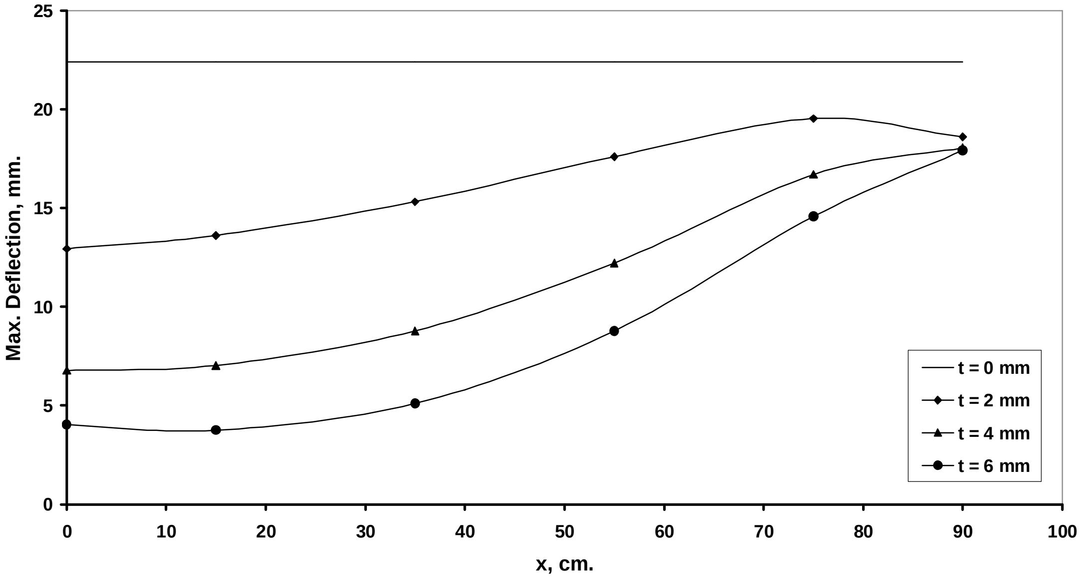


Fig (12) Effect of using two parallel ribs on the maximum deflection for the first case of the design constraints

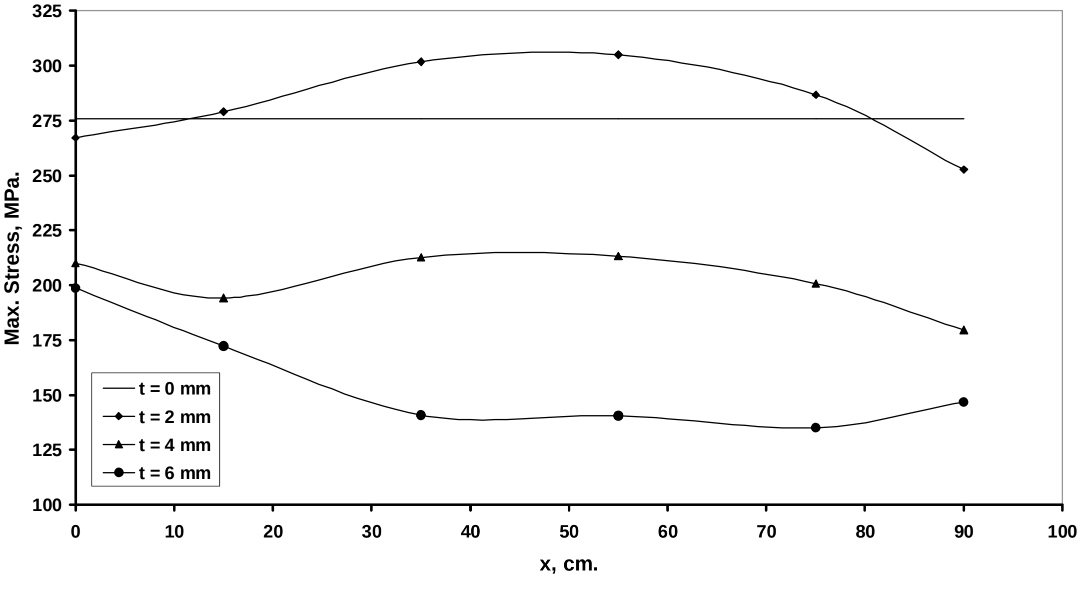


Fig (13) Effect of using two parallel ribs on the maximum stress for the second case of the design constraints

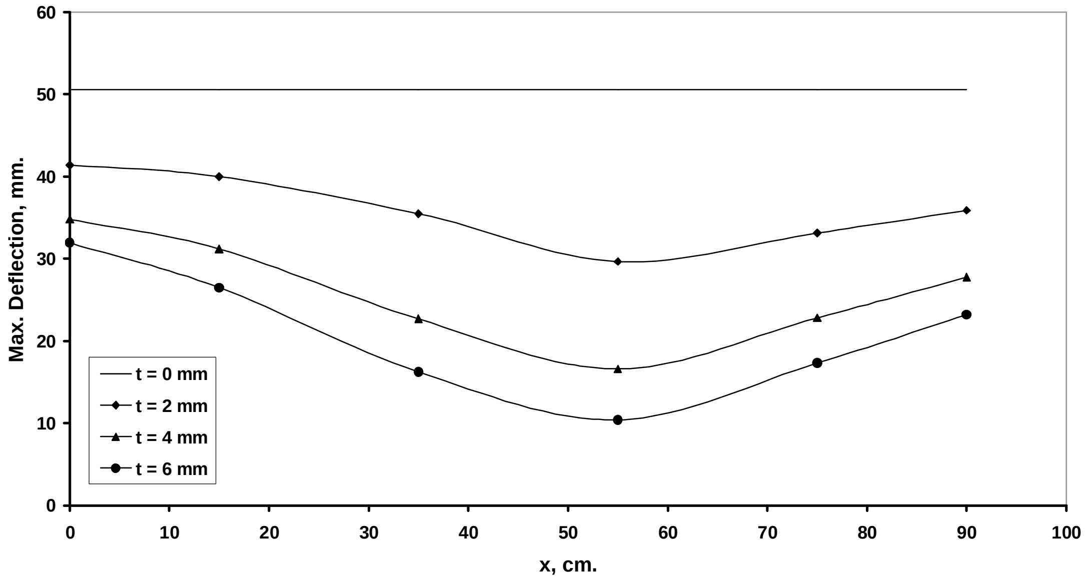


Fig (14) Effect of using two parallel ribs on the maximum deflection for the second case of the design constraints

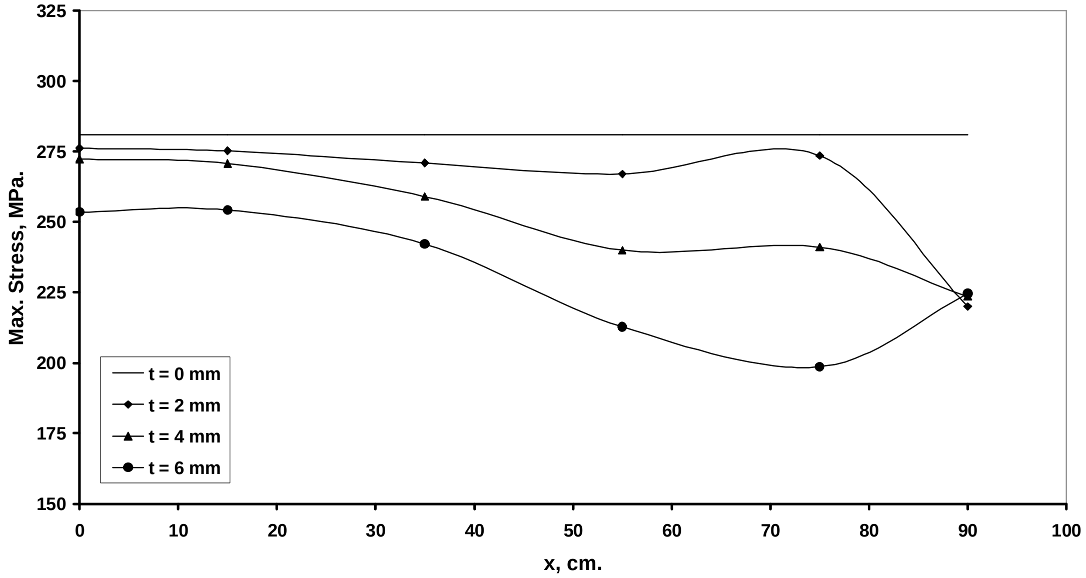


Fig (15) Effect of using two parallel ribs on the maximum stress for the third case of the design constraints

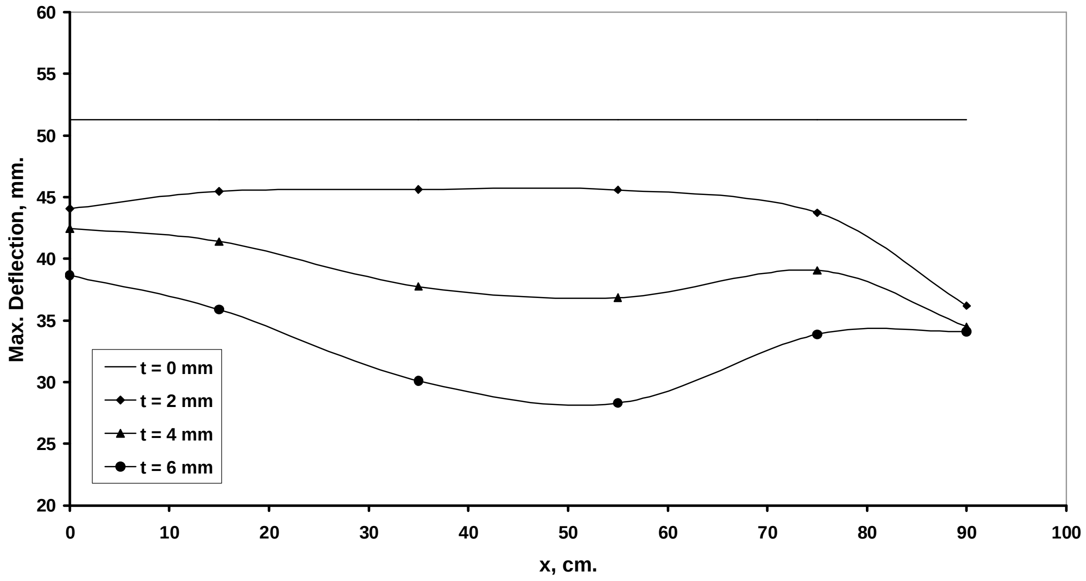


Fig (16) Effect of using two parallel ribs on the maximum deflection for the third case of the design constraints

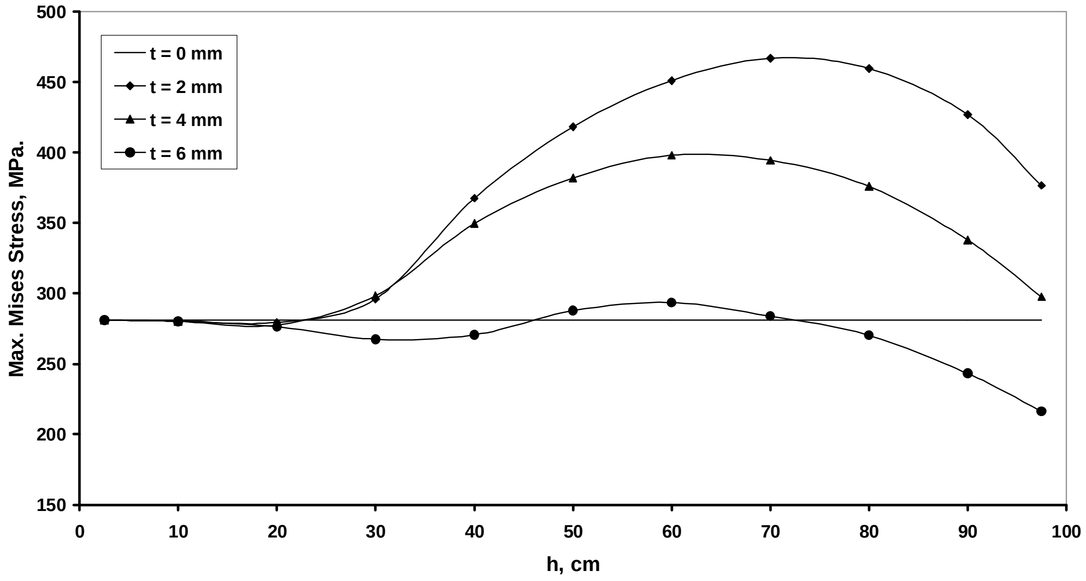


Fig (17) Effect of using one longitudinal rib on one side parallel to the free edge for the third case of the design constraints on the maximum stress

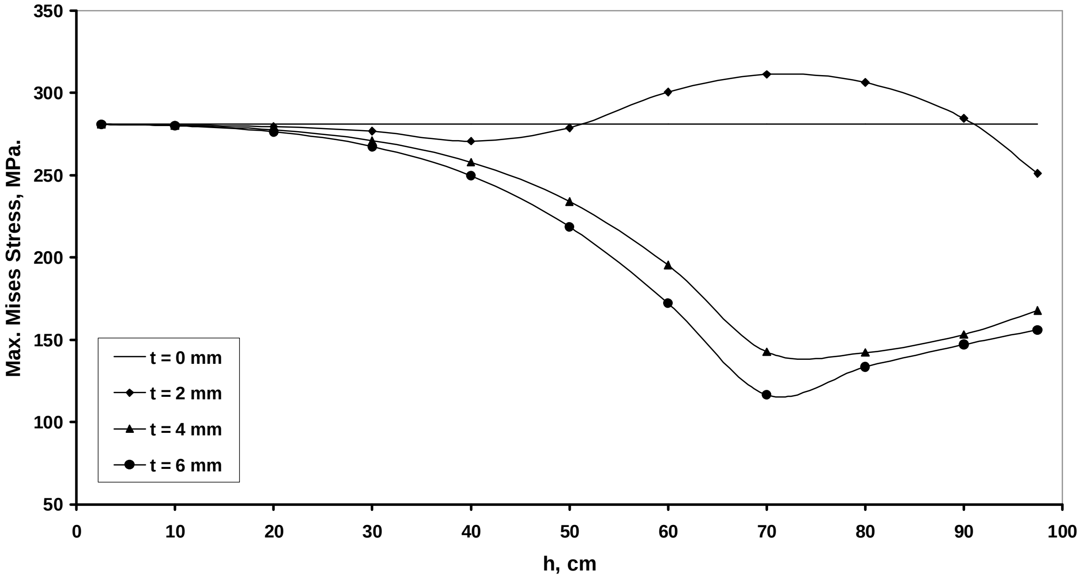


Fig (18) Effect of using one longitudinal rib on two sides parallel to the free edge for the third case of the design constraints on the maximum stress

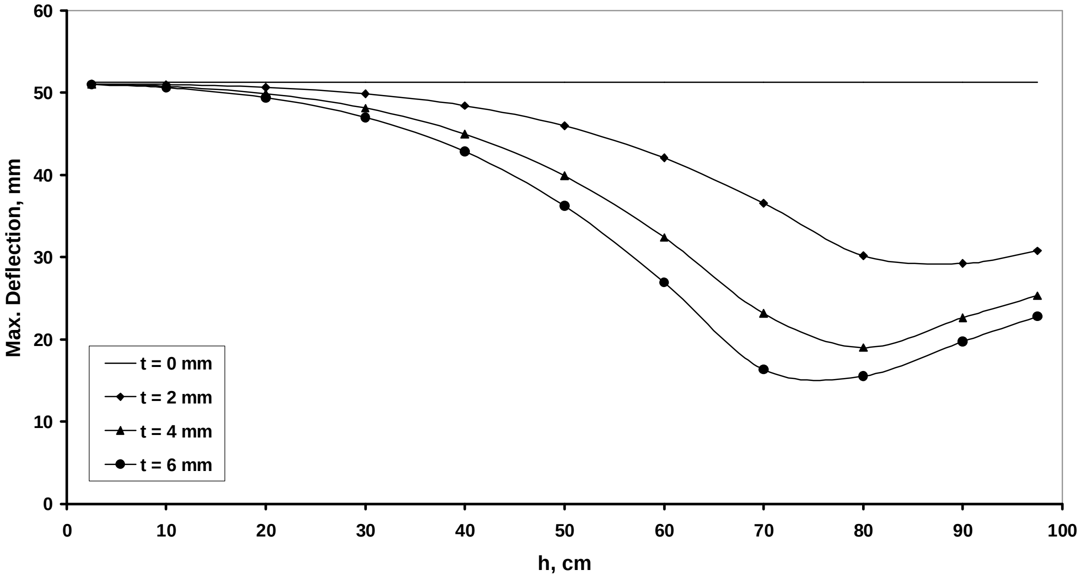


Fig (19) Effect of using one longitudinal rib on one side parallel to the free edge for the third case of the design constraints on the maximum deflection

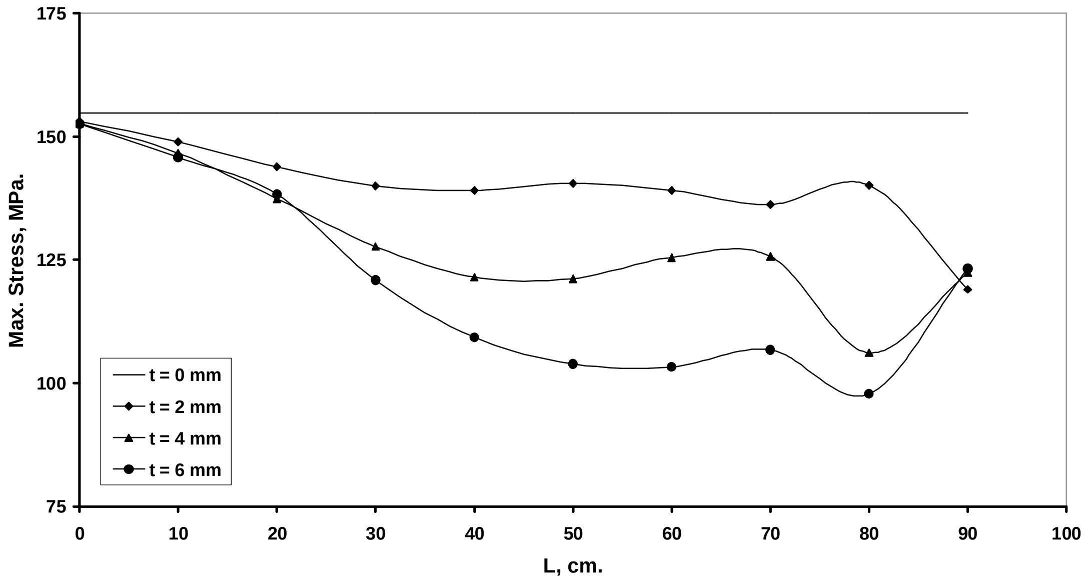


Fig (20) Effect of using one square rib on one side on the maximum stress for the first case of the design constraints

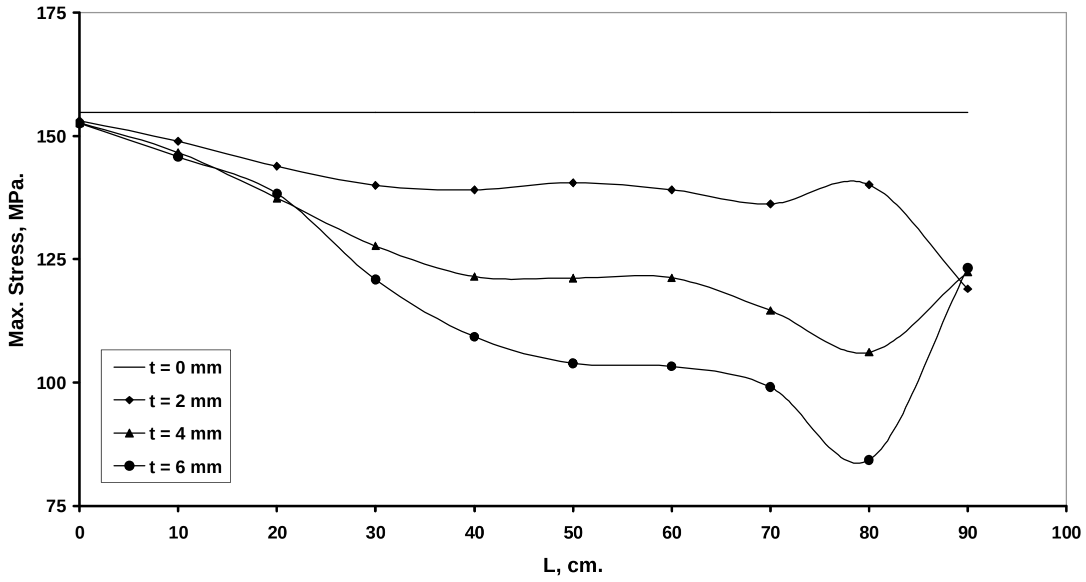


Fig (21) Effect of using one square rib on two sides on the maximum stress for the first case of the design constraints

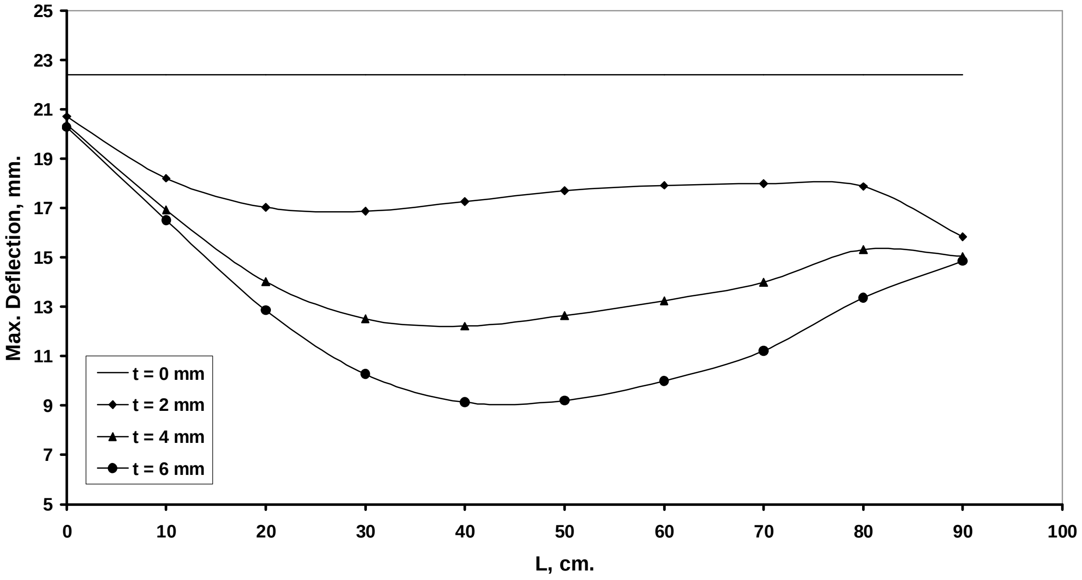


Fig (22) Effect of using one square rib on one or two sides on the maximum stress for the first case of the design constraints

TYPE OF STIFFENER	DIMENTION OF STIFFENER	LOCATION OF STIFFENER	PERCENTAGE INCREASING IN WEIGHT	PERCENTAGE REDUCTION IN MAXIMUM STRESS
One longitudinal rib	w = 5 cm, t = 6 mm	At the center line of the plate	15 %	47.55 %
One longitudinal rib	w = 10 cm, t = 6 mm	At the center line of the plate	30 %	50.2 %
Two perpendicular ribs	w = 10 cm, t = 6 mm for each one	At the center line of the plate (fig. 7)	57 %	70.14 %
Square stiffener	w = 5 cm, t = 6 mm	At the best position (L = 80 cm)	51 %	45.56 %

Table (1) Comparison between some cases of strengthening the wholly clamped edges plate

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التصميم الأمثل للصفائح المربعة المقواة بأضلاع طولية ومربعة

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الخلاصـــــــة :

إن التراكيب المؤلفة من الصفائح أو الأغشية المعدنية والمعرضة لحالة تحميل معينة من الممكن زيادة صلابتها بشكل ملحوظ عن طريق إضافة أضلاع مقوية. لحد الآن فإن تقنيات الأمثلية تتناول في الدرجة الأولى والى حد بعيد حجم الأضلاع المقوية. إن المسألة الأكثر أهمية هي تحديد الموقع الأمثل للأضلاع المقوية والتي لم تولى إلا اهتماما قليلا. لقد تم استخدام طريقة التحليل بالعناصر المحددة لإيجاد المواقع المثلى للأضلاع المقوية ولحالات تثبيت تصميمية محددة. يحدد الباحث في الاستنتاجات المواقع المثلى للأضلاع المقوية والتي تعطي أفضل النتائج.