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Cross-Sectional Shape Comparison In Corrugated Plates

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ABSTRACT

Corrugated sheets are sheet parts used in various applications. The shapes of parts are dominators in mechanical behavior. Structural reliability is related to the ability of the structure to remain within the desired range of stress and deformation values according to the load type. The use of corrugated plates on platforms for load-bearing both prevents the use of thick materials for strength and ensures that the structure created is light.

In this study, corrugated plate samples that have 100 mm width and 2 mm thickness were comthepared by the finite element method. Corrugated plate models such as pentagon, circle, supported rectangle, rectangle, square, saw, and trapeze were designed and evaluated under 20 kg load that was t applied on the surface of 50 mm width. Results showed that the trapeze model is the most rigid and circle has the least stress value model. The study revealed the effect of the corrugate model on the structural strength for plates, which are frequently used in industrial applications.

Keywords

Corrugated plates, Strength, Cross-section, Shape comparison, Finite element method.

Introductıon

Corrugated plates are used in several applications as buildings, load carrying, and volume covering. Out of buildings, this creation is used in the packaging sector to obtain more strength and light cover cases for transportation. Corrugated plates on the platforms [1] provide more strength and stiffness. Also, vowed walls [2] are alternative examples to corrugated plates and they have the same mechanical behavior.

Shape and material affect the mechanical response under a specific load. Structural Steel, Aluminum, and Stainless Steel are preferred materials in corrugated plates [3]. Since the material preference depends on expectations from construction, several material types can be used in corrugated plates. Mechanical loads target the cross-sectional shape of the part to which it is applied. Cross-sectional shape creates the part-based properties as inertia or center of gravity. Parts of construction will have more stability with the technical knowledge of the nature of engineering. Stiffness is basically the ability to maintain its current state under load. It is a mechanical property that depends on the elasticity of the material. Apart from the material, this feature also has an effect on what the part will be used for. While stiffness is important in a bracket to be used for vibration damping, if there is no special condition, it is relatively less important for an element to be used for containment. Corrugated plates are formations with geometric modifications applied to increase stiffness and reduce deformation under load due to their structural use. Deformation under surface load can be expected to be less in corrugated plates as compared to a flat plate. Therefore, corrugated plates are often used on roofs, enclosures and, platforms.

There are many studies indicating that shaping is effective on parts. Beytüt, Karagöz, and Özel [4] accomplished a numerical study to obtain the effect of aluminum alloy bumper beam cross-sectional shape on mechanical strength. 5 different profiles with the same weight were modeled in HyperMesh and exposed to the pole and wall impact scenarios. Cross-section variation can be seen in figure 1. In the pole impact scenario, model 5 is the most energy-absorbed one while model 5 has the most energy absorber in the wall impact scenario. This study highlighted that cross-section shape is dominated on the strength of the longitudinally long parts. Doori and Noori [5] studied on beams with 6 different web openings to see the effect of beam cross-section on the bending response. 6 different beam illustration was shared in figure 2. For this evaluation, the finite element method was used on modeled beams with different web openings in Abaqus. Fixed support was applied on side surfaces and a uniform pressure was defined on the top surfaces of the beams. Results of the study revealed that cross-section has an effect on the mechanical behavior of parts and beams with hexagon web openings are fragile while beams with circle web openings are the most stable. Also, the web openings edge should be parallel with the beam edge. Park et. Al. [6] accomplished numerical and experimental study on corrugated paperboard to obtain the strength and optimum shape for packaging. 3 different corrugated paperboard models can be seen in figure 3. On the numerical side, benefited from finite element method. In order to reflect the real time conditions, clamp contact surfaces were restricted on each axis. Loading was limited up to 50 N for process control. 12,5 mm/min Velocity was defined on top surfaces of the model. Result of the study showed that refraining from sharp edges in design process brings about more stable products, parts with long edge are prone to be damaged, cross-sectional surfaces with circles have more strength than triangles. Yang et. al. [7] have accomplished a shape comparison study on corrugated plates both numerical and experimental. 3 different corrugate shapes are in figure 4. Collapse behaviors of different cross-section shapes were obtained by biomimetic aspect. Finite element model was used for non-linear analysis in Ls-Dyna. Aluminum alloy (1060) is the preferred material for this study. Simulation includes boundary conditions as 2 mm/min velocity on the top surfaces of models and model was mounted between 2 rigit plates. Study that aimed the effect of corrugate number, height, thickness on the energy absorption of model resulted with corrugate shape is dominator on the strength and thickness plays energy absorption increaser role on the models. Zhang, Liu, and Tang [8] conducted a study on cross-sectional design optimization on a beam in view of bumper. Optimization targets are energy absorption increase and peak force reduce. 3 different cross-sectional as empty, foam-filled, and internal surface supported model was taken into account. 3 different cross-section models are in figure 5. Finite element study was accomplished by ANSYS. During analyzing process, in order to see the bending collapse response, a cylinder with 25 mm diameter was used as load applicator on the mid-section of the model. Vertical 10 m/s velocity was defined to load cylinder. The friction coefficient between the model–load applicator cylinder and the model–fixed supporter is 0,3 and 0 respectively. Preferred material is high strength steel. After the optimization stages, internal surface supported cross-section model showed most energy absoption at same weight. This model has been redesigned according to bending deformation and energy absorption has been increased. Mehetre and Talikoti [9] accomplished a study on beams with four different web opening to see the shape effect on strength. Beams with four different web openings were compared with a full beam. Finite element method was used in ANSYS. Obtained numerical results validated in experimental study. During numerical analyzing study, each model was restricted on displacement and 78200 N was applied on the top surface o model. In the results of this study, model 2 showed the least deflection on both numerically and experimentally.

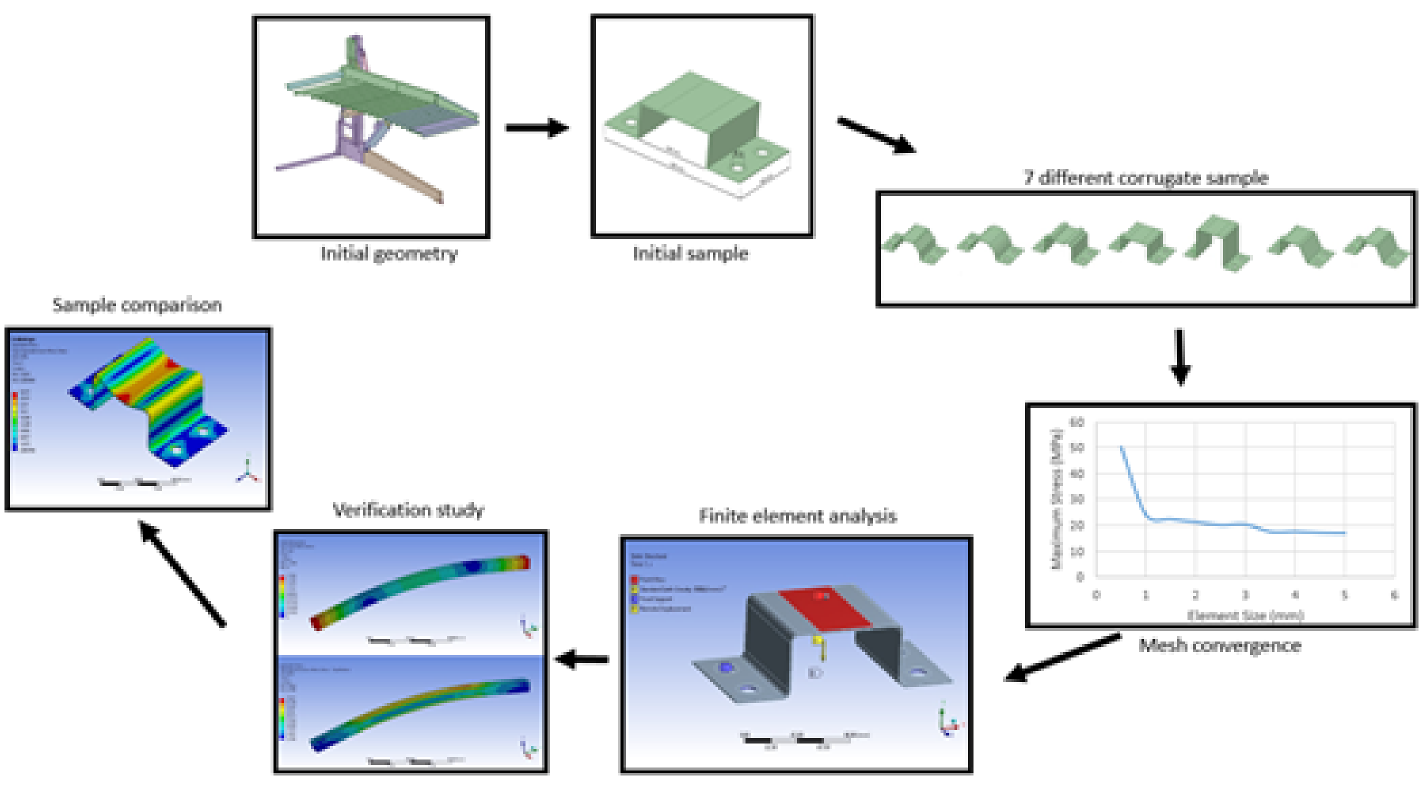


Figure 1: Flow chart of the study

In this study, 7 different cross-sectional corrugated plates were evaluated on the mechanical strength under the same load. Corrugated plate models as pentagon, circle, supported rectangle, rectangle, square, saw, and trapeze have 2 mm thickness were modelled and compared in finite element analyzes. 20 kg load was used on the surface that has 50 mm width and 100 mm long. Results include that trapeze is the most rigid model among 7 different corrugated sheet models. On the other side, circle model showed the least stress value.

Materıal and Method

In this study, 7 different corrugate model was compared in view of mechanical strength and deformation. Modelled plates samples were static structural analyzed by finite element method. Since finite element method uses unit elements size of element definition is mandatory. Therefore, mesh convergence study was accomplished. Total 7 different model analysed under the 20 kg mass load and observed the distribution of stress and deformation on the samples. A flowchart of this study was shared in figure 1.

Model Definition

Initial corrugate geometry obtained from an automated vehicle lift system that used rectangle type corrugated plate. An illustration of lift system was given in figure 2. 7 different corrugated plate models has 2 mm thickness, 200 mm total length, 100 mm internal gap, 100 mm width, 4 fixing holes of 14 mm diameter. General dimensions on the sample shared in figure 3.

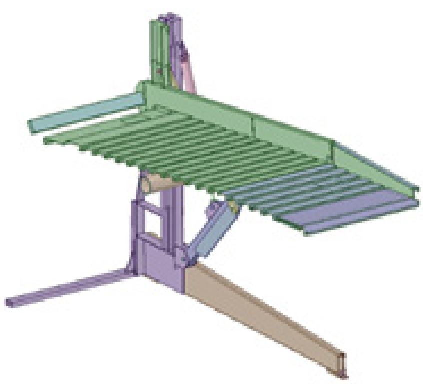


Figure 2: Corrugated plate used platform example [1].

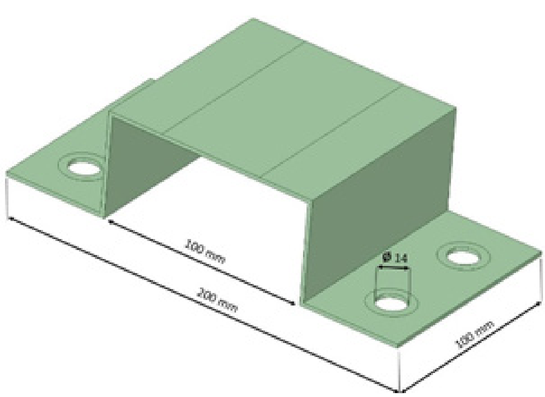


Figure 3: General dimensions of samples.

For the cross-section shape comparison, 7 different shape as pentagon, circle, supported rectangle, rectangle, square, saw, and trapeze. All specimens were illustrated in figure 4.

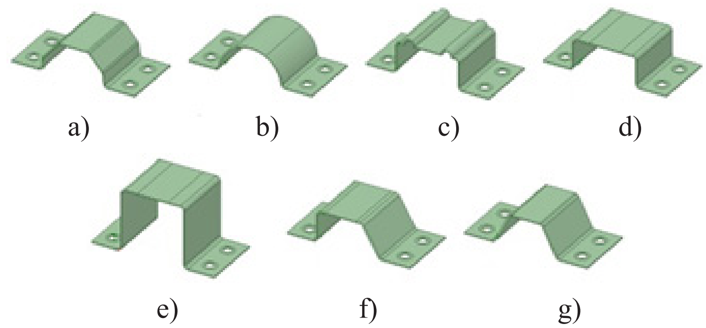


Figure 4: corrugate shapes; a)pentagon b)circle c)supported rectangle d)rectangle e)square f)saw g)trapeze.

Material

In several engineering processes, material preference depends on what the construction need. For instance, when it comes to automotive sector, general parts in construction made by high strength steel, aluminum, and polymer-based materials. The preferred material on a construction should provide strength, lightness, and rigidity sufficiently. Since this study focused on the shape effect on strength, St37 was preferred as the basic material for all analyzes. Mechanical properties of St37 shared in table 1 below.

Table 1: Mechanical properties of St-37 [1,10].

Density (kg/m^3)	Young's Modulus (MPa)	Poisson's Ratio	Yield Strength (MPa)	Ultimate Strength (MPa)
7850	210	0,3	240	360

Finite Element Method

Finite element method is a numerical method as boundary element method and statistical energy analysis [11]. This method basically includes stages of seperation the model into small and computable unit elements and mathematical solution with the help of determinants. In the nature, each material or shaped part treats as a mechanical spring and each of them has a rigidity coefficient. Basic spring mechanism stated in equation 1. Mechanical reaction (deformation etc.) is created according to the rigidity of the structure. In linear analysis, rigidity values of unit parts are constant in the stiffness matrix while in non-linear analysis is vice versa. Therefore, the result values depend on the change in the stiffness matrix. In equation 2, finite element matematical model was showed for one element. The number of columns and rows depend on number of elements and loading types. Therefore, small size mesh element using increase the column and row number and increase the solution time in processor. During the solution stage of any analysis, the inverse of the stiffness matrix is multiplied by the column with the loading types, and the resulting values are the response value of the unit element to the loading type.

$$\{F\} = \{k\} * \{\Delta x\} \quad (1)$$

$$\begin{bmatrix} F_1 \\ Q_1 \\ M_1 \\ T_1 \end{bmatrix} = \begin{bmatrix} \frac{AE}{L} & 0 & 0 & 0 \\ 0 & \frac{12EI}{L^3} & \frac{6EI}{L^2} & 0 \\ 0 & \frac{6EI}{L^2} & \frac{4EI}{L} & 0 \\ 0 & 0 & 0 & \frac{GJ}{L} \end{bmatrix} * \begin{bmatrix} u_1 \\ v_1 \\ \theta_1 \\ \emptyset_1 \end{bmatrix} \quad (2)$$

Mesh Convergence

In this study, cross-sectional shape comparison on corrugated plates was accomplised by finite element analysis. Aforementitwod unit element size is dominator on the solution time and has variable property on shape of samples. Therfore proper element size definition is mandatory. This stage is actually an optimization process of unit size between rough distribution of stress and very high stress value far from reality. Mesh convergence study was accomplished sepeately for 7 different samples and it was found that 1 mm tetrahedron element is proper for all samples. Graphics of mesh convergence study can be seen in figure 5.

Boundary Conditions

A comparison study requires at least 1 variable parameter and rest of all factors must remain constant to ensure the accuracy of the study. In this study, since the aim is obtaining effect of shape variation on the mechanical strength, variable parameter is cross-sectional shape. During the static structural analyzes, 20 kg mass was applied on the top surface of each sample and the load applied each surface has 50 mm width. The inner surfaces of 4 holes were defined as fixed support. In order to simulate the real conditions, a displacement limitation that vertical movement and rotation was defined on the bottom surface of sample. General view of boundary conditions on a sample can be seen in figure 6.

Verification Study

Numerical studies require reliability and must demonstrate accuracy. This demonstartion can be made in experimentally or comparison with another numerical study. For this study, a comparison was accomplished with a study that aimed the

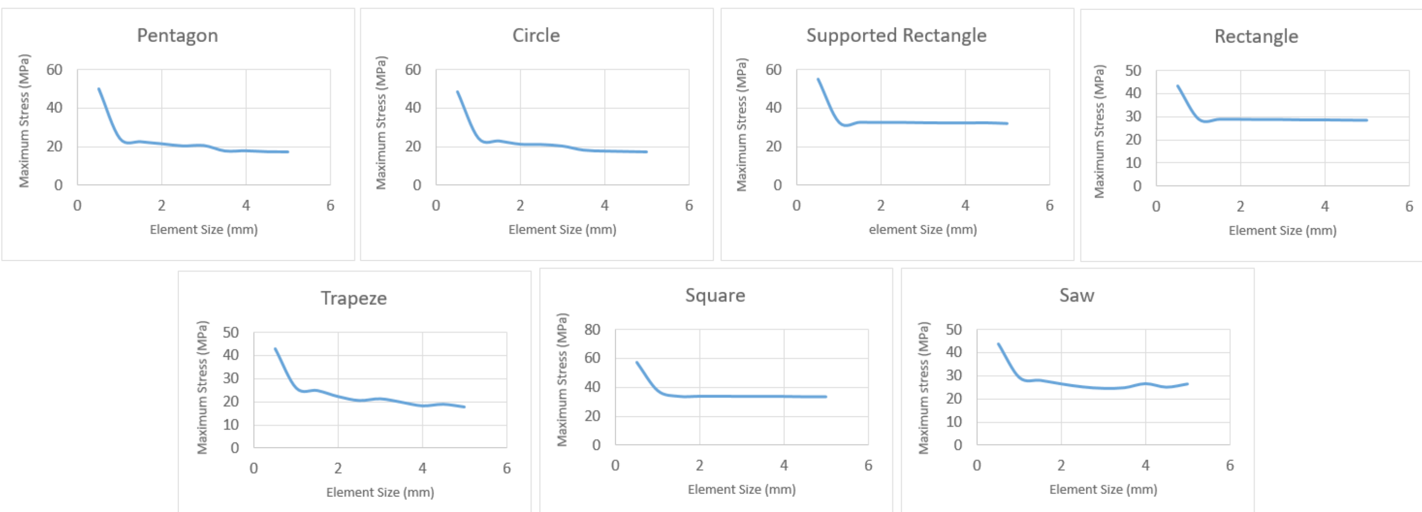


Figure 5: Mesh convergence study on 7 different corrugated plates.

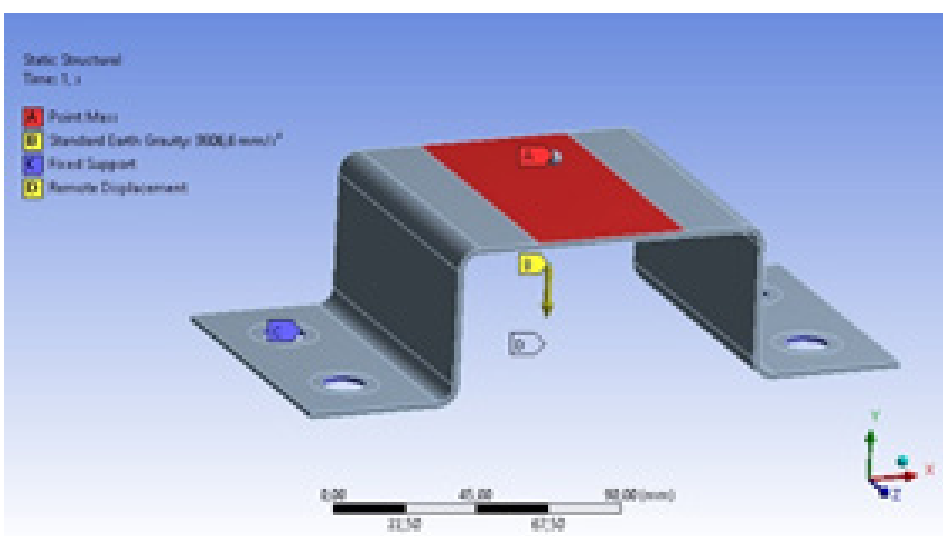


Figure 6: Boundary conditions on a sample.

difference between solid and Shell model in finite element analysis. Irsel [12], created a beam model that has 2000 mm long, and 6 mm thickness square profile with fixed and roller support. 15000 N was applied on the top surfaces of 2 sides of beam separately. Support points are 500 mm far from side surfaces. In order to reduce the solution time, deformation verification was accomplished with shell model. Result of verification study showed that there is 4,4% difference in deformation and 2% difference in maximum stress. Deformation and stress comparison were illustrated in figure 7.

Results

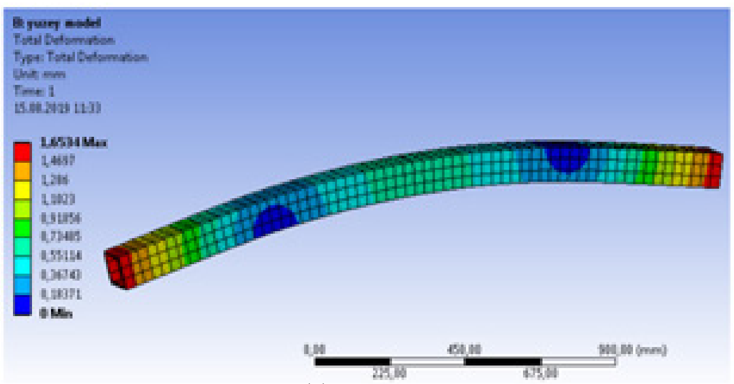
Corrugated plates with 7 different cross-sections were analyzed by finite element method under the same boundary conditions. Results of static structural analysis studies include deformation and stress response under 20 kg loading. In this section obtained results were shared under the subsections.

Pentagon

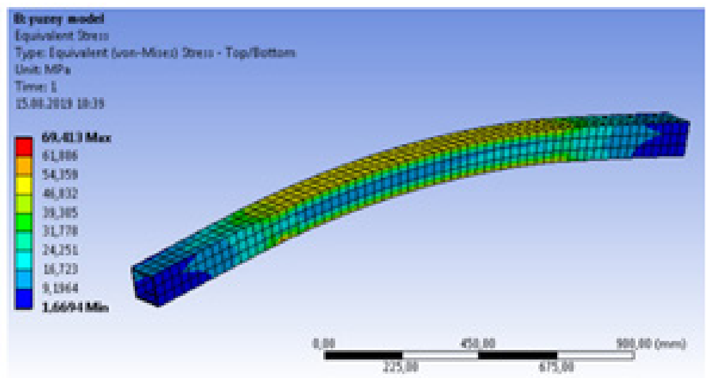
Pentagon model has 4 side walls according to geometry that is relatively parallel to load application axis. These parallel side walls brought about increased inertia and decreased deformation. According to static structural analysis results, pentagon model showed maximum stress as 24 MPa and maximum deformation as 0,025577 mm. Analysis results were illustrated in figure 8.

Circle

Circle model has specified diameter and thickness value that create the inertia value of this cross-section shape. When a vertical load is applied on the top surface of a circle, thanks to geometry, most of unit elements exposed compression load. This phenomenon has been used in bridges, water channels and structures in the past. Static analysis study revealed 24,16 MPa maximum stress and 0,017755 mm maximum deformation on circle model. Analysis results were shared in figure 9.



(a)



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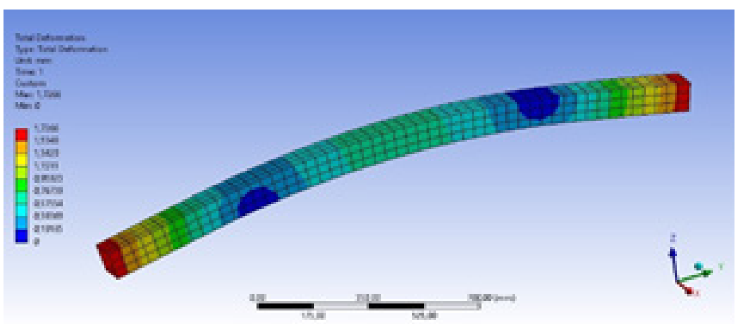

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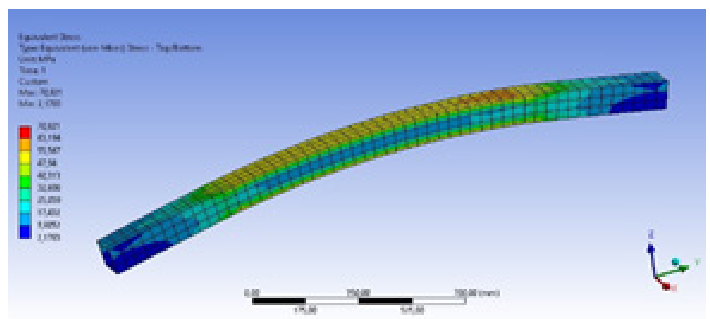

(d)

Figure 7: Finite element analysis verification in shell model;

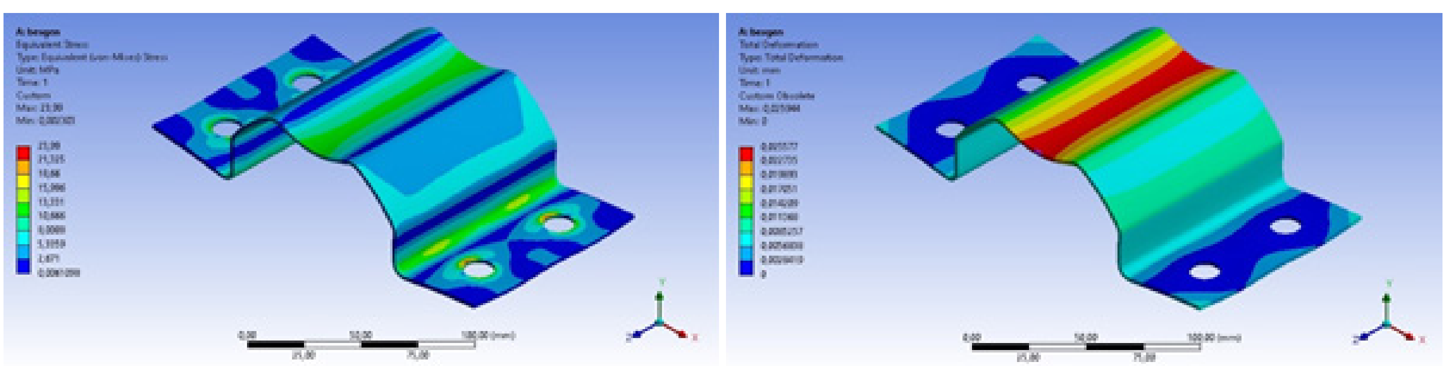

Figure 8: Stress (left) and deformation (right) distribution of pentagon model.

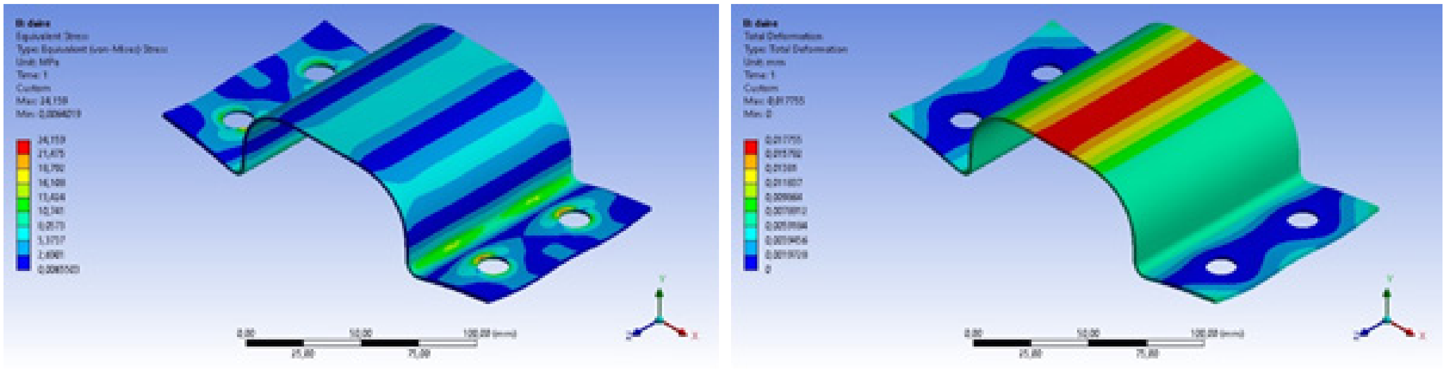

Figure 9: Stress (left) and deformation (right) distribution of circle model.

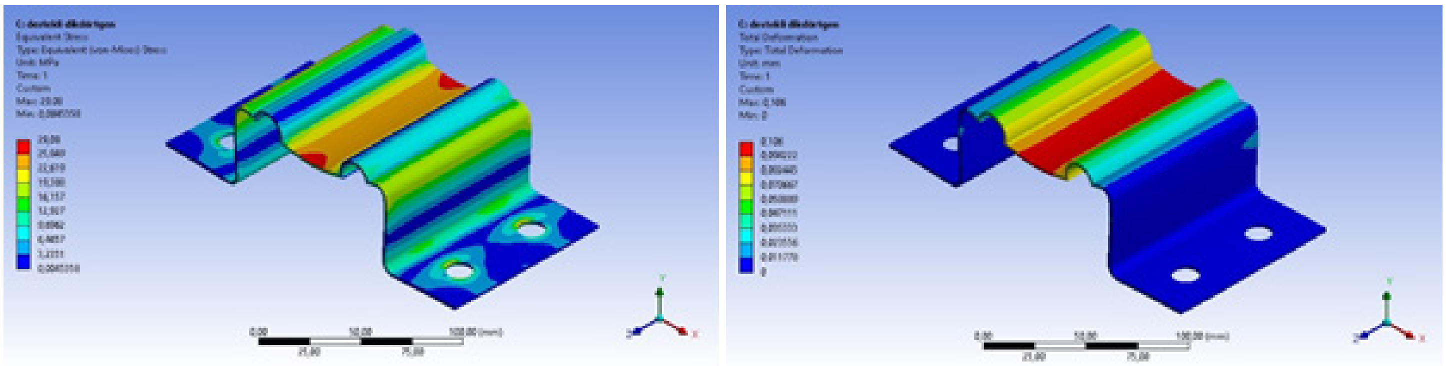

Figure 10: Stress (left) and deformation (right) distribution of supported rectangle model.

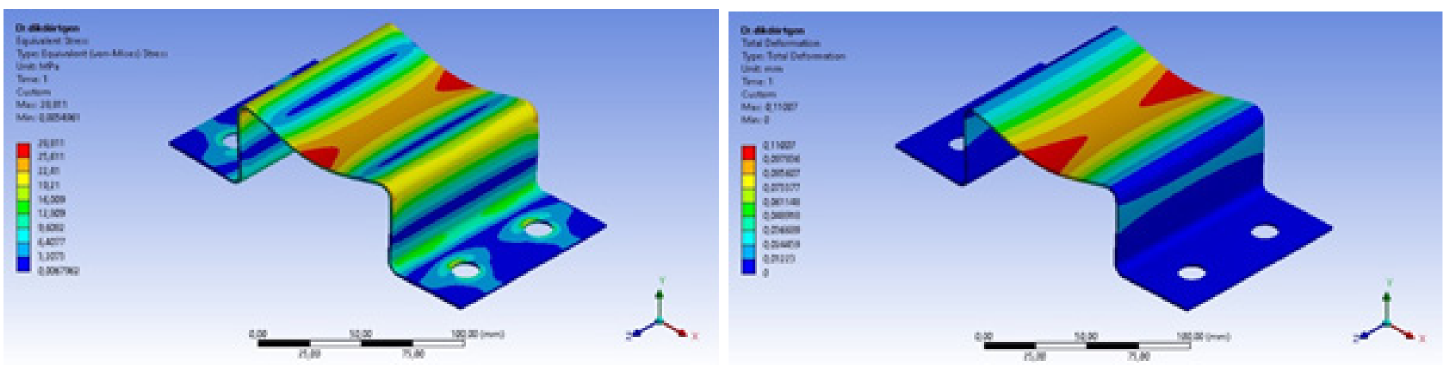

Figure 11: Stress (left) and deformation (right) distribution of rectangle model

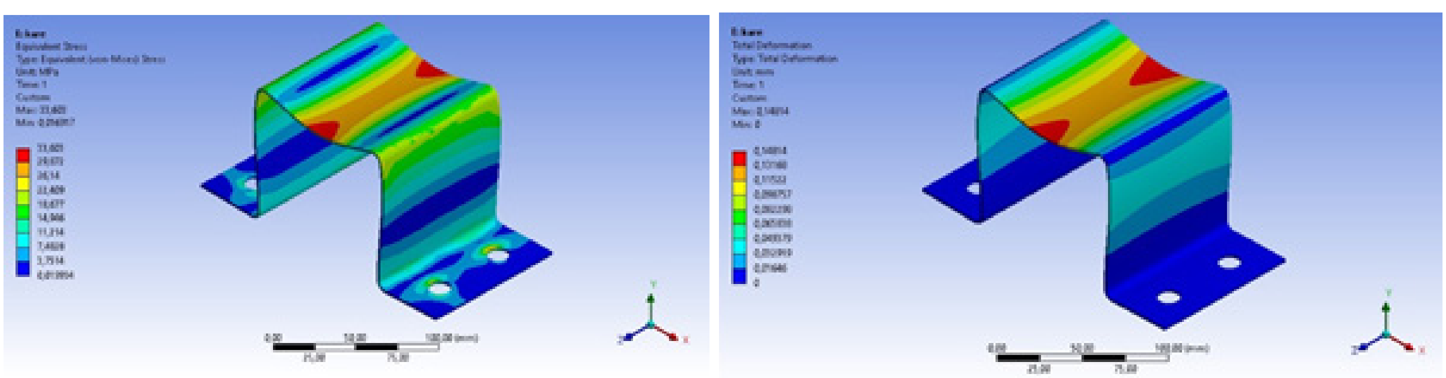

Figure 12: Stress (left) and deformation (right) distribution of square model.

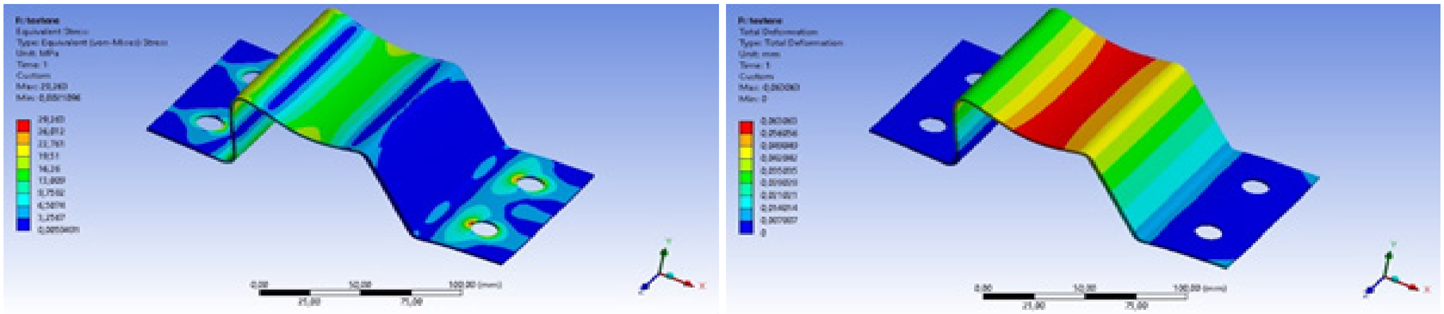

Figure 13: Stress (left) and deformation (right) distribution of saw model.

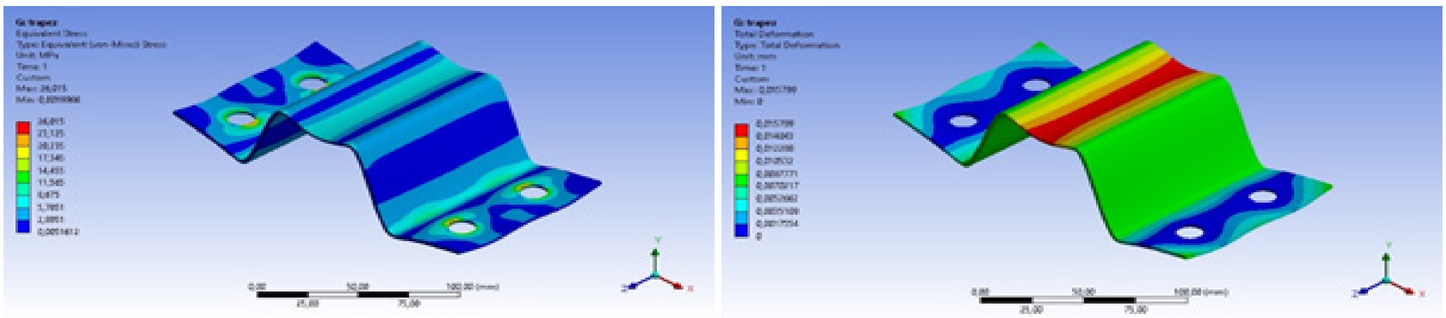

Figure 14: Stress (left) and deformation (right) distribution of trapeze model.

Supported Rectangle

External geometry modifications on the cross-section of any model gives good results in deformation and stress distribution. If this model one of most preferred, revealed difference will affect the part. Supported rentangle model has 29 MPa maximum stress and 0,106 mm maximum deformation value under the 20 kg load. Figure 10 shows the result distribution of supported rectangle model.

Rectangle

Rectangle model has relatively easy to produce, simple, strength, and preferred shape on corrugated plates. However, this model has a wide surface that exposes it to bending loading. The large surface subject to bending makes the part vulnerable to high stress and deformation. This model has 28,8 MPa maximum stress and 0,11 mm maximum deformation value in the static structural analysis. Result distribution can be seen figure 11.

Square

Square model ha ssimilar shape with rectangle model. It has longer side walls and this difference makes it vulnerable to buckling problem. Also longer side walls increase the deformation and tilt value. Beside these negative properties, square cross-section has isotropic interia. Therefore loading direction is not important for this model and energy absorption comparison can be added for the study. According to results square model showed 33,6 MPa maximum stress and 0,148 mm maximum deformation under 20 kg loading. Result distribution was illustrated in figure 12.

Saw

Saw model can be seen in bolt groove. It is useful for unidirectional loading or load with eccentricity relative to the axis of symmetry of the part. One side of this model is has acute angle (0^o – 3^o), another side has obtuse angle (120^o – 135^o) on base surface. Saw model has variable response that depends on loading direction and type. In this study since the loading is relatively on symmetry axis, mechanical response can be interpreted according to the different loading types to be applied. Static structural analysis showed 29,26 MPa maximum stress and 0,063 mm maximum deformation on saw model. Results can be seen in figure 13.

Trapeze

Trapeze model is symmetrical version of saw model. This model is isotropic for the loading type. However, it can not response isotropical as square model. In this study trapeze model showed 26 MPa maximum stress and 0,0158 mm maximum deformation value. Figure 14 states the stress and deformation distribution for trapeze model.

Conclusıon

Corrugated plates are used in building or any structures for cover a volume or to carry the load. The cross-sectional shape in corrugated plates affects the mechanical behavior. The fact that the stress and deformation values stay in the desired range according to the load type reveals the reliability of the constructed structure. The use of corrugated plates on platforms for load-bearing both prevents the use of thick materials for strength and ensures that the structure created is light.

In this study 7 different cross-section corrugated plate were compared in view of strength. For mechanical comparison, finite element method was benefited. Stress and deformation distributions were obtained under the same boundary conditions. According to results, circle model showed the least stress and trapeze model has the least deformation under the 20 kg loading. If the stress values are though as similar, trapeze model will be good preference for structural stiffness. This result is related to geometrical properties of specific model. Trapeze model has ability to seperate the excitation force to base surface homogeneously and side walls has more strength when compared to other models for bending scenario. These results can be These results can be used in platforms to be used in the structural field. For future studies, different loading types and fixing methods can be added this study. Fatigue life of the model can be defined. Stiffness increaser geometrical modifications can be made on trapeze model and results can be validated experimentally.

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