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A Software for Optimum Design of Laterally Loaded Bolted Joints

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Tasarım ve Optimizasyon
Analiz
Yanal Yük
C#

Graphical/Tabular Abstract (Grafik Özet)

For the design and optimization of laterally loaded bolted joints, a software with a graphical user interface was developed with C# programming language in Visual Studio environment. / Yanal yüklemeli cıvatalı bağlantıların tasarımı ve optimizasyonu için Visual Studio ortamında C# programlama dili ile grafik kullanıcı arayüzüne sahip bir yazılım geliştirilmiştir.

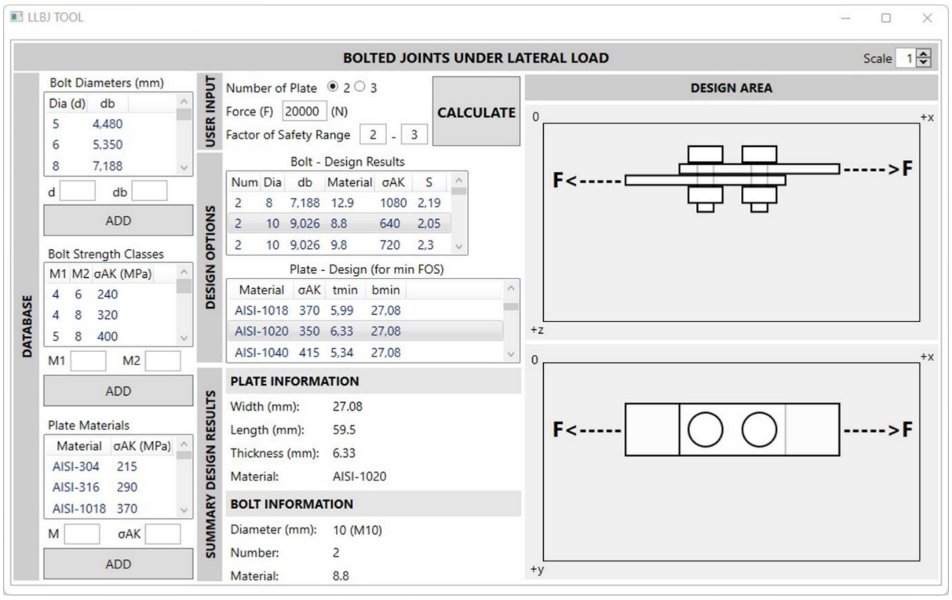

***Figure A:** Developed sowftware / **Şekil A:** Geliştirilen yazılım*

Highlights (Önemli noktalar)

- *Laterally loaded bolted joints. / Yanal yüklü cıvatalı bağlantılar.*
- *Design, analysis and optimization. / Tasarım, analiz ve optimizasyon.*
- *Software and graphical user interface (GUI). / Yazılım ve grafik kullanıcı arayüzü.*

Aim (Amaç): *Optimal designs of bolted joints for minimum user input were determined to save workload, time and cost. / Minimum kullanıcı girdisi için cıvatalı bağlantıların optimum tasarımları belirlenerek iş yükü, zaman ve maliyet tasarrufu amaçlanmıştır.*

Originality (Özgünlük): *Compared to the literature, different joint designs and optimizations were performed for the target conditions in one go. Graphical user interface (GUI) was designed for visualization and usability. / Literatüre kıyasla hedef şartlar için tek seferde farklı bağlantı tasarımları ve optimizasyonlar gerçekleştirilmiştir. Az rastlanan grafik kullanıcı arayüzü tasarlanarak görsellik ve kullanışlılık sağlanmıştır.*

Results (Bulgular): *Optimal bolted joint designs were output for minimal user input and the process was automated. The software results were validated by comparing them with theoretical solutions. / Minimum kullanıcı girdisi için optimum cıvatalı bağlantı tasarımları çıktı alınmıştır ve süreç otomatikleştirilmiştir. Yazılım sonuçları, teorik çözümler ile karşılaştırılarak doğrulanmıştır.*

Conclusion (Sonuç): *With the developed software, the design-analysis cycle was avoided by automatically reaching the optimum bolted joint designs instantly in one go for the targeted conditions according to the minimum user input. Thanks to the graphical user interface (GUI), a visual, easy and interactive use was provided. Efficiency and productivity were increased by reducing workload and time. / Geliştirilen yazılım ile minimum kullanıcı girdisine göre hedef şartlar için otomatik olarak tek seferde anında optimum cıvatalı bağlantı tasarımlarına ulaşılarak tasarım-analiz döngüsü önlenmiştir. Grafik kullanıcı arayüzü sayesinde görsel, kolay ve etkileşimli bir kullanım sağlanmıştır. İş yükü ve zaman azaltılarak etkinlik ve verim yükseltilmiştir.*

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A Software for Optimum Design of Laterally Loaded Bolted Joints

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Abstract

Bolted joints, which are one of the detachable joining methods, are used extensively. The reliability of bolted joints is extremely important for the strength and life of the system. The determination of the number of bolts to be used in a system, the position and other data of the bolt requires very serious design and engineering studies. In this study, the design and optimization of bolted joints subjected to lateral forces are performed. For this purpose, a software has been developed in C# programming language. The software visually guides the user and asks a minimum number of questions to the designer and all other parameters are calculated by the program. The visual design of the program was done in Visual Studio environment. The graphic designs used in the software help the user to enter correct data. When the program is run for bolted joint under lateral loading, the user only enters the number of plates and force as input. Although the program performs its calculations between 1.5-2 factor of safety, it is possible to change it according to the characteristics of the design. The program developed in the light of these inputs calculates the appropriate bolt diameter, number, material and dimensions of the plates for the designed joint according to the optimum design options. The design options determined by the program are also presented to the designer visually. With the developed software, the user workload is minimized by determining the optimum options of bolted joints according to the minimum amount of user input. This resulted in significant savings in the time spent in design and engineering calculations. The user-friendly interface provides an easy and visual use. The results obtained by the program were also solved manually to check the reliability of the program.

Yanal Yüklemeli Cıvatalı Bağlantıların Optimum Tasarımı için Bir Yazılım

Makale Bilgisi

Araştırma makalesi
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Öz

Sökülebilen birleştirme yöntemlerinden olan cıvatalı bağlantılar çok yoğun bir şekilde kullanılmaktadır. Cıvatalı bağlantıların güvenirliği, sistemin dayanımı ve ömrü açısından son derece önemlidir. Bir sistemde kullanılacak cıvata sayısı, konumu ve cıvataya ait diğer verilerin belirlenmesi çok ciddi tasarım ve mühendislik çalışmalarını gerektirmektedir. Bu çalışmada, yanal kuvvete maruz kalan cıvatalı birleştirmelerin, tasarımı ve optimizasyonu gerçekleştirilmiştir. Bu amaçla C# programlama dilinde bir yazılım geliştirilmiştir. Yazılım görsel olarak kullanıcıyı yönlendirmekle birlikte tasarımcıya minimum miktarda soru sormakta ve diğer bütün parametreler program tarafından hesaplanmaktadır. Programın görsel tasarımı Visual Studio ortamında yapılmıştır. Gerçekleştirilen yazılımda kullanılan grafik tasarımlar kullanıcının doğru veriler girmesine yardımcı olmaktadır. Yanal yükleme altında cıvatalı birleştirme yapılması amacıyla program çalıştırıldığında, kullanıcı, sadece plaka sayısını ve kuvveti girdi olarak programa yazmaktadır. Program 1,5-2 emniyet katsayısı arasında hesaplamalarını yapmasına rağmen bunu yine tasarımın özelliğine göre değiştirebilme imkânı sunulmuştur. Bu girdiler ışığında geliştirilen program tasarlanan birleştirme için, uygun cıvata çapı, sayısı, malzemesi ve plakaların ebatlarını optimum tasarım seçeneklerine göre hesaplamaktadır. Program tarafından belirlenen tasarım seçenekleri yine tasarımcıya görsel olarak sunulmaktadır. Geliştirilen yazılım ile minimum miktarda kullanıcı girdisine göre cıvatalı bağlantıların optimum seçenekleri belirlenerek kullanıcı iş yükü en aza indirilmiştir. Bu sonuç tasarımda ve mühendislik hesaplamalarda harcanan zamanda çok ciddi tasarruf sağlamıştır. Kullanıcı dostu arayüz kolay ve görsel bir kullanım sağlamıştır. Program tarafından elde edilen sonuçlar manuel olarak da çözdürülerek programın güvenirliği kontrol edilmiştir.

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1. INTRODUCTION (GİRİŞ)

Today, there are many joining methods for fixing parts to each other. One of these joining methods is bolted joints. Bolted joints are one of the commonly used joining methods in engineering applications. However, the design and optimization of these joints has a very complex process and requires the consideration of many factors. These factors include material properties, geometrical parameters, joint loads and assembly methods. Incorrect design of bolted joints can cause serious problems and even jeopardize life safety. Therefore, the correct design and optimization of bolted joints is an important issue for engineers.

Bolts are removable fasteners widely used in machinery, aviation, construction, etc. They are usually used together with additional components such as nuts or washers. Bolted joints are systems formed by joining two or more parts with bolts and additional components. These joints with soluble structure provide easy assembly and disassembly.

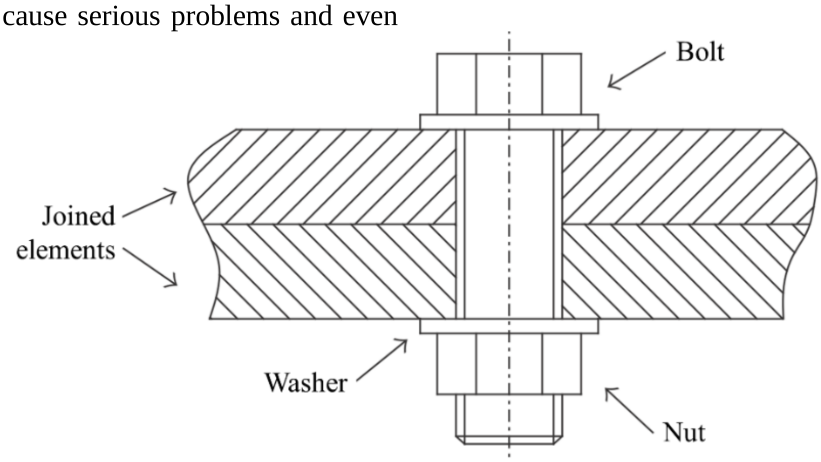

Figure 1. Bolted joint (Cıvatalı bağlantı) [1]

Optimization is the act of obtaining the best result under given conditions. In the design, construction and maintenance of any engineering system, many decisions are made at various stages. The ultimate goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. Since the required effort or the desired benefit in any practical situation can be expressed as a function of certain decision variables, optimization can be defined as the process of finding conditions that give the maximum or minimum value of a function [2].

A literature survey on the design and optimization of bolted joints was carried out and the researches and methods in this field were examined. In the design process of bolted joints, equations were derived by calculating the compliance and load factors for the strength cases [3]. In order to facilitate the modelling of composite bolted joints, a tool called BOLJAT was developed using the finite element analysis method and integrated into the MSC.Patran analysis program [4]. In order to quickly calculate the strength of the joined elements in bolted joints, a software with a user interface in Visual Basic based on finite element analysis (ANSYS) and artificial neural network was developed [5]. A software was developed for the design and analysis of riveted and bolted joints under compound load [6]. A model was developed for the analysis of the effects of load distributions on bolts and laminates in composite bolted joints by finite element method [7]. The behavior of the distance between bolt holes and hole diameter under tensile load in a bolted and nutted joint made of MIL-A-46100 high alloy armor steel plates was investigated [8]. A multi-objective optimization method for bolted joints under multiple loads was developed and integrated into the Nastran finite element program in order to obtain uniform load distribution on the bolts in multiple load cases [9]. An analysis tool was developed using ANN technique for the design of bolted flange joints under axial, shear and moment loading. [10]. A study was carried out to predict the loosening rate of bolted joints under vibration using MATLAB and ANN [11]. A program was developed for strength calculation and design of connecting rod bolts in internal combustion engines using MS Excel program [12]. The behavior of bolted sandwich composites under tensile loading was investigated [13]. A compound topology optimization approach was developed for simultaneous optimization of the shape, topology, bolt location and number of bolted joints [14]. An accurate and reliable damage prediction approach for the design of high-strength steel bolted joints based on machine learning was presented [15]. The bearing capacity of critical joints in single lap and single bolted shear conditions was investigated numerically [16]. An expert system was developed for the selection of bolt head shape type in the design of bolted joints [17].

Previous studies include theoretical, computational and experimental work on the design and optimization of bolted joints. The joints were studied on limited types as a design. There are very few studies on the automatic optimization of the design in one go according to the targeted conditions. Graphical user interface feature was not encountered much.

In this study, the focus is on the design and optimization of laterally loaded bolted joints. For this purpose, a software was developed in Visual Studio environment with C# programming language and a graphical user interface was created for visuality and convenience. The software developed was named "LLBJ TOOL". With the software, optimum designs are produced instantaneously with a minimum amount of input. In this way, it is aimed to facilitate the process by minimizing the workforce and time spent.

2. BOLTED JOINTS UNDER LATERAL LOAD (YANAL YÜK ALTINDAKİ CIVATALI BAĞLANTILAR)

In laterally loaded joints, the applied load is perpendicular to the direction of the bolt axis and passes through the center of gravity of the bolt group. Under the influence of the lateral force, shear stresses occur in the bolts and bearing and tensile stresses occur in the plates. An example visualization for this type of joint and the formulation for the calculation of the resulting stresses are given below [18].

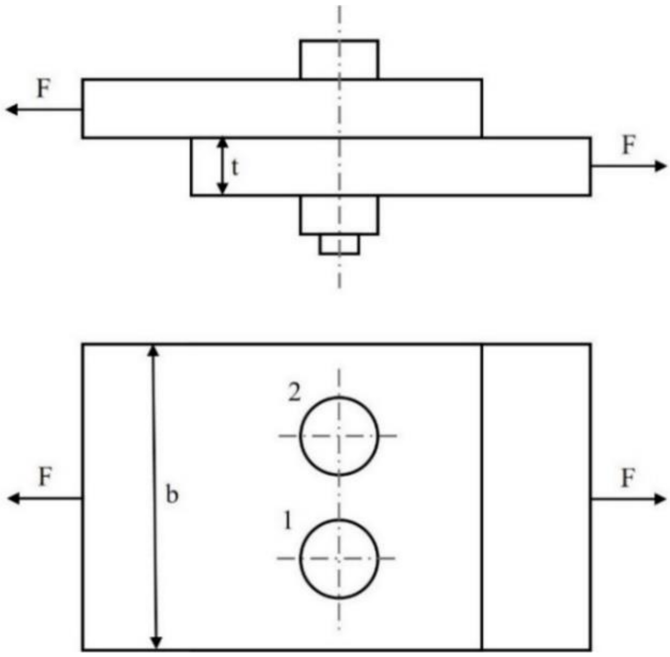

Figure 2. Bolted joint under lateral load (Yanal yük altında cıvatalı bağlantı)

Shear stress (τ) and safety situation

$$\tau = F/A \quad (1)$$
$$\tau = F/\sum A_b \quad (2)$$
$$\tau = F/(n * A_b * z) \quad (3)$$
$$\tau = F/(n * ((\pi * {d_b}^2)/4) * z) \quad (4)$$
$$S_\tau = \sigma_{yield} * 0{,}5/\tau \quad (5)$$

Where:
τ: Shear stress (N/mm^2)
F: Force (N), A: Area (mm^2)
$\sum A_b$: Total bolt area (mm^2)
n: Number of bolts
A_b: Bolt area (mm^2)
z: Number of shear plane
π: pi
d_b: Bolt pitch circle diameter (mm)
S_τ: Factor of safety for shear
σ_{yield}: Material yield strength (MPa)

Real time status

As a result of the lateral load, the bolts are subjected to shearing by the plates through the cross-sections on the mating surface of the plates and shear stress occurs. If the shear stress exceeds the stress that the material can bear, a failure mode occurs in the bolt. Below is a shear failure event that occurred in real time showing this situation.

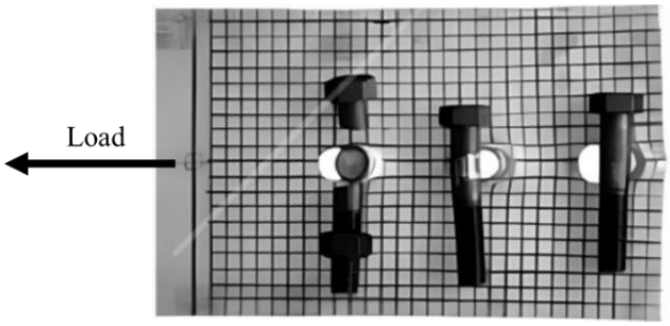

Figure 3. Shear failure of the bolts (Cıvatada kesme hasarı) [19]

Bearing stress (σ_c) and safety situation

$$\sigma_c = F/A \quad (6)$$
$$\sigma_c = F/(n * A_c) \quad (7)$$
$$\sigma_c = F/(n * (d_b * t)) \quad (8)$$
$$S_c = \sigma_{yield}/\sigma_c \quad (9)$$

Where:
σ_c: Bearing stress (N/mm^2)
F: Force (N)
A: Area (mm^2)
A_c: Bearing area (mm^2)
n: Number of bolts
d_b: Bolt pitch circle diameter (mm)
t: Plate thickness (mm)
S_c: Factor of safety for bearing
σ_{yield}: Material yield strength (MPa)

Real time status

The plates are subjected to compression by the body of the bolts as a result of the lateral load and bearing stress is generated. If the bearing stress exceeds the stress that the material can bear, a failure mode occurs in the plate. The following figure shows a bearing failure event that occurred in real time.

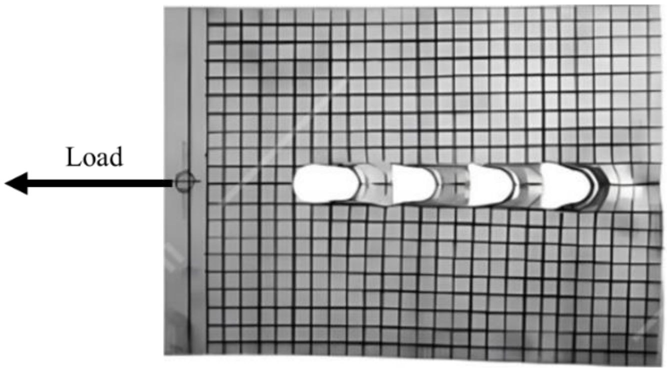

Figure 4. Bearing failure of the plate (Plakada basma hasarı) [19]

Tensile stress (σ_t) and safety situation

$$\sigma_t = F/A \quad (10)$$
$$\sigma_t = F/A_t \quad (11)$$
$$\sigma_t = F/((b - n * d_b) * t) \quad (12)$$
$$S_t = \sigma_{yield}/\sigma_t \quad (13)$$

Where:
σ_t: Tensile stress (N/mm^2)
F: Force (N)
A: Area (mm^2)
A_t: Tensile area (mm^2)
b: Plate width (mm)
n: Number of bolts in cross section
d_b: Bolt pitch circle diameter (mm)
t: Plate thickness (mm)
S_t: Factor of safety for tensile
σ_{yield}: Material yield strength (MPa)

Real time status

As a result of the lateral load, the plates are subjected to pulling from the sections of the bolts perpendicular to the force and parallel to the upper surface of the plate and tensile stress occurs. If the tensile stress exceeds the stress that the material can bear, a failure mode occurs in the plate. The image below shows a tensile failure event that occurred in real time.

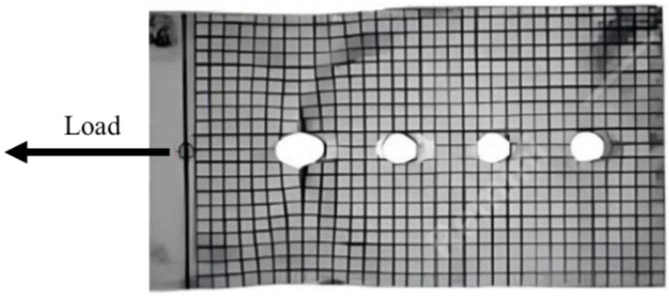

Figure 5. Tensile failure of the plates (Plakada çekme hasarı) [19]

Safety situation

The factor with the lowest value among the factors of safety calculated for each stress state is the factor of safety of the system (Eq. 14).

$$S_{sys} = S_{min} \quad (14)$$

3. PLACEMENT OF BOLTS (CIVATALARIN YERLEŞİMİ)

In bolted joints, the distances between bolts are determined according to the intervals specified in the standards. In the following, a sample arrangement for the placement of bolt holes is given in Figure 6 and the equations (Eqs. 15 – 20) for the relevant parameters on the figure are given in accordance with the TS648 standard [20].

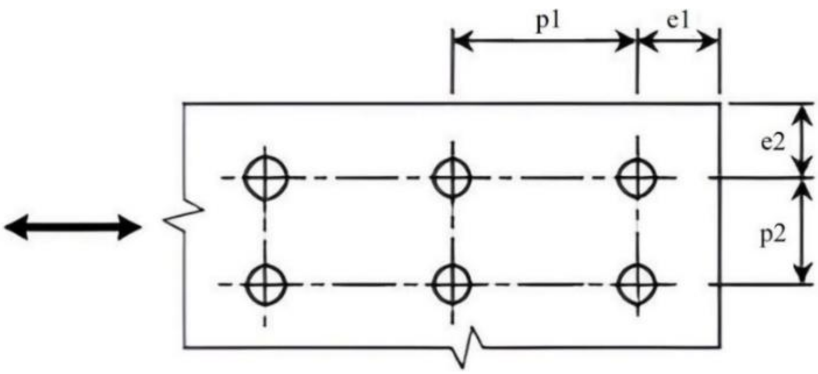

Figure 6. Placement of bolt holes (Cıvata deliklerinin yerleşimi) [21]

$$p1_{min} = p2_{min} = 3 * D \quad (15)$$
$$p1_{max} = p2_{max} = 8 * D \quad (16)$$
$$e1_{min} = 2 * D \quad (17)$$
$$e1_{max} = 3 * D \quad (18)$$
$$e2_{min} = 1{,}5 * D \quad (19)$$
$$e2_{max} = 3 * D \quad (20)$$

Where,
D: Hole diameter (mm)
p1, *p2*: Distance between two bolt holes (mm)
e1: Distance from edges in the direction of force (mm)
e2: Distance from edges perpendicular to the force (mm)

Real time status

When the bolts are not correctly positioned, the plates may not be able to carry the applied lateral load and as a result, tearing and splitting failure modes may occur in the plates. A real time splitting failure event is given below.

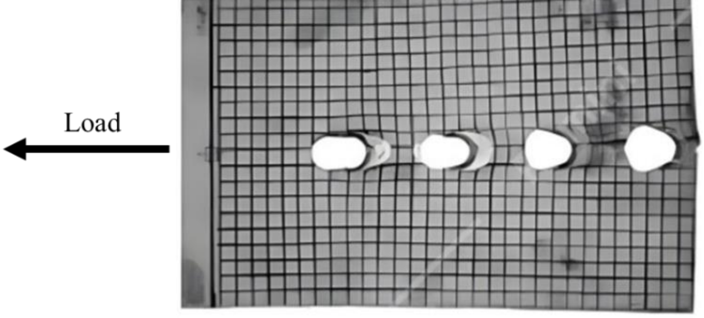

Figure 7. Splitting failure of the plate (Plakada yarılma hasarı) [19]

4. DEVELOPED SOFTWARE (GELİŞTİRİLEN YAZILIM)

A software named "LLBJ TOOL" was developed in Visual Studio environment with C# programming language for the design and optimization of bolted joints under lateral load. C# programming language was preferred because it has a structure suitable for graphical operations and is widely used. A user interface was created for visual and easy use.

Users can easily give their inputs through the interface and see the results. In the developed software, shear (for bolts), bearing (for plates) and tensile (for plates) stresses in the joint are calculated based on user inputs. For bolted joint, parameter properties such as dimensions, material properties, load information, etc. are taken into account. By taking into account the mechanical properties of different materials in the database, the design options that provide the most suitable situation according to user preferences are given as drawings and tables.

With this software, it is aimed to facilitate the design and optimization work of technical staff for bolted joints. Users can quickly and accurately determine the dimensions, materials and other properties of bolted joints. Optional design results are listed and the most accurate design is preferred.

The flowchart of the developed software is given below.

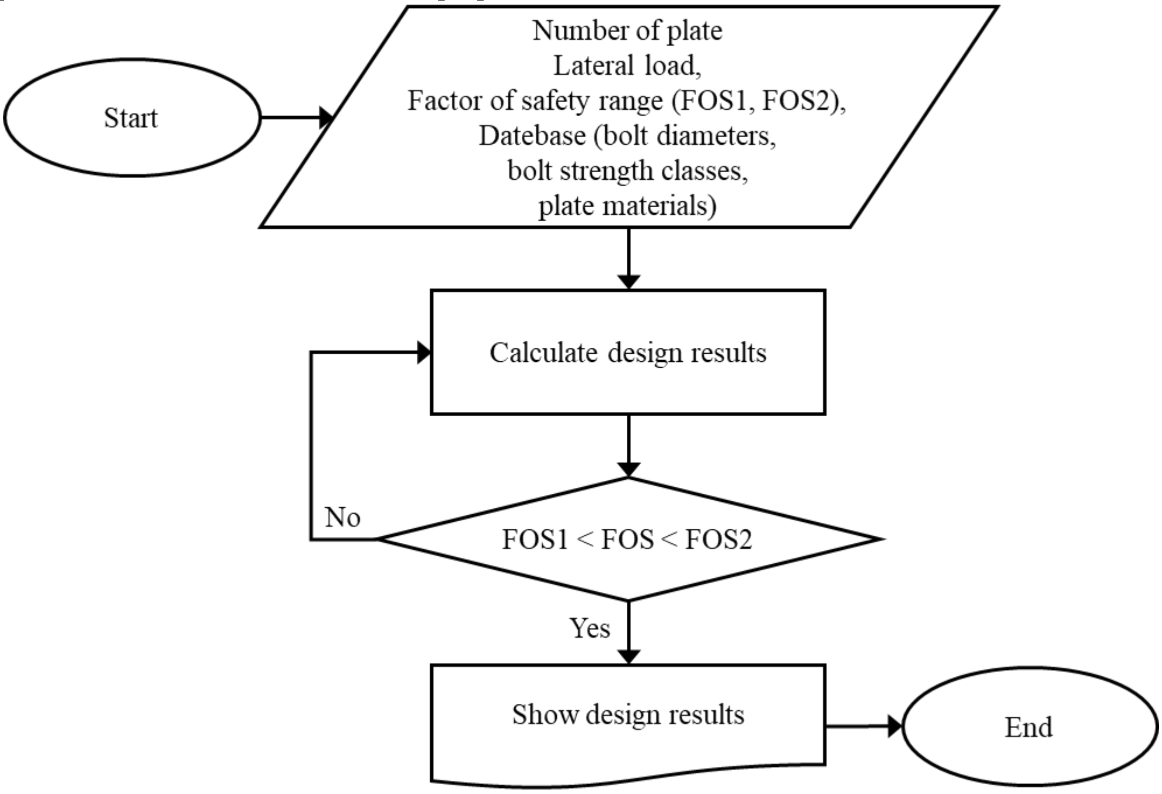

Figure 8. Software flowchart (Yazılım akış şeması)

4.1. Database (Veri Tabanı)

The database used in the developed software contains bolt information, bolt strength classes and plate material information. The database was integrated into the software interface and the user can interact with the database. The user can also add his own information and data to this database.

The information and data used in the database in the following tables include bolt diameter information, bolt strength classes and plate material information and are given in tables below.

For bolt diameter information, catalogues were examined and commonly available bolts were taken as basis. These data are covered by the ISO 724 standard titled "ISO general-purpose metric screw threads - Basic dimensions".

Table 1. Diameter information for bolts (Cıvatalar için çap bilgileri)

Nominal Diameter (mm)	Pitch Circle Diameter (mm)
5	4,480
6	5,350
8	7,188
10	9,026
12	10,863
14	12,701
16	14,701
18	16,376
20	18,376

Bolt strength classes and properties were based on the data specified in the standard with the name and subject "ISO 898-1: Mechanical properties of fasteners". It is given in the table below [22].

Table 2. Bolt strength classes (Cıvata dayanım sınıfları)

Bolt Strength Class	Yield Strength (MPa)
4.6	240
4.8	320
5.8	400
8.8	640
9.8	720
10.9	900
12.9	1080

Material properties for the plates were prepared in accordance with catalogues and materials commonly used in the industry. ASTM A240, ASTM A108, ASTM A519, ASTM A29 and ASTM B209 standards were used for these materials.

Table 3. Material properties for plates (Plakalar için malzeme özellikleri)

Material	Yield Strength (MPa)	Standard
AISI-304	215	ASTM A240
AISI-316	290	ASTM A240
AISI-1018	370	ASTM A108
AISI-1020	350	ASTM A519
AISI-1040	415	ASTM A29
AISI-1045	310	ASTM A29
AISI-4140	415	ASTM A29
AISI-4340	470	ASTM A29
Al-2024	324	ASTM B209
Al-5083	228	ASTM B209
Al-6061	276	ASTM B209
Al-6063	214	ASTM B209
Al-7075	503	ASTM B209

4.2. Presentation and Use (Tanıtım ve Kullanım)

The interface designed for the developed software consists of design area, user input, result and database sections. The section where the design for bolted joints is made is the design area. The parameters related to the bolted joint and its design are entered by the user in the user input section. The section where optional design results are given in line with user inputs is the result area. After the user's choice among the optimum design results, the bolted joint is drawn in the design area and the final design parameters are given in the summary design results section.

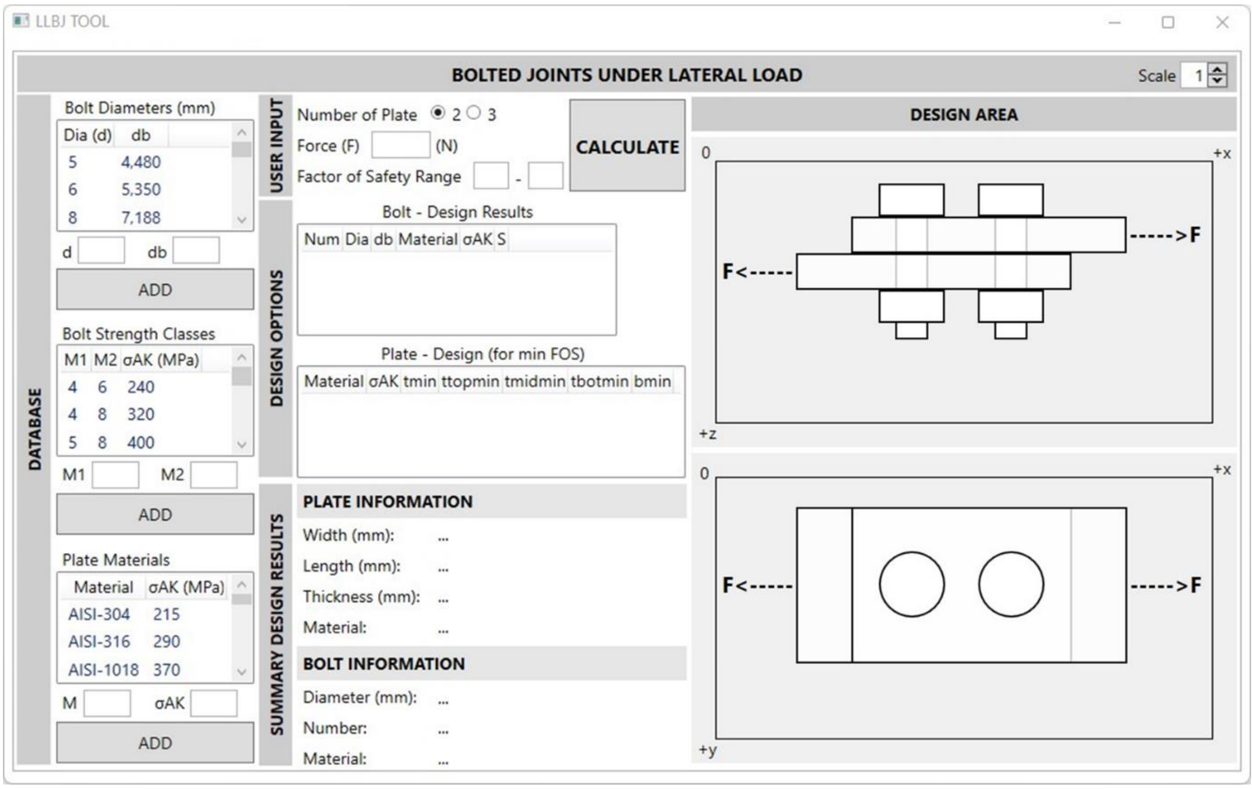

Figure 9. Interface (Arayüz)

The database section contains bolt information, strength classes and plate material information. This data is reflected in the interface with the listing tool. Text boxes and buttons are placed at the bottom of the database lists. Users can enter their own data in these text boxes and expand the database by using the add button.

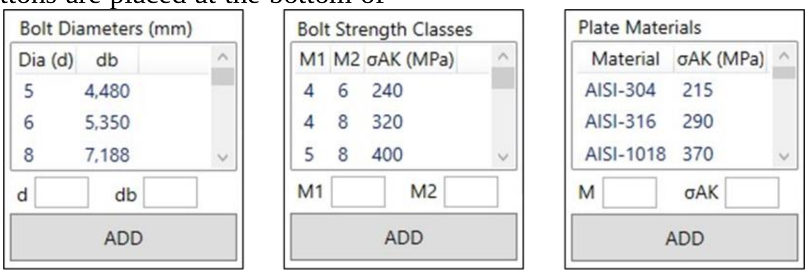

Figure 10. Database (Veri tabanı)

In the user input section, the number of plates, load and safety factor range information for bolted joint are entered by the user in the relevant fields. The number of plates that can be used in bolted joint can be selected as 2 or 3. The amount of lateral load that the joint is subjected to is entered in the form of N units. This lateral load is perpendicular to the bolt axis and passes through the center of gravity of the bolt group. Forces of the magnitude desired by the user can be applied by entering this field. In order to create a range for the factor of safety, two values as minimum and maximum are taken from the user. In line with these inputs, the "CALCULATE" button is pressed and automatic calculations are made for the bolted joint.

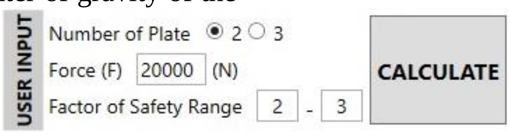

Figure 11. User input area (Kullanıcı girişi alanı)

In this calculation process, shear stress was taken as basis and the related formulation was used. Based on user inputs, calculations are run for bolt numbers between 1 and 20 according to the diameter and strength classes of the bolts in the database. Different design results are calculated for these data and the results within the safety factor range are filtered and sorted in the listing tool on the interface. Accordingly, the user is given design options in the result section. Design options consist of two sections and these are bolt design results and plate design results. The process was structured with the objective of finding the minimum feasible outcomes. The aim is to design bolted joints that are feasible for minimum workload, time and cost.

Primary design options include bolt results and these are number of bolts, nominal diameter, strength class, yield strength and safety factor parameters for these data. The user makes a choice among these options and according to this choice, secondary design options for plates are calculated. Secondary design results include the results for the plates and include minimum thickness, width and material data that can be used. Design options are given as results in the listing tools.

Figure 12. Primary and secondary design options (Birincil ve ikincil tasarım seçenekleri)

The user chooses between primary and secondary design options and the optimum bolted joint for the data in their preferences is automatically drawn in the design area. The design area where the design of bolted joints is realized consists of 2 sections as front view and top view. In this way, the bolted joint design was reflected from different angles in the form of two views, providing visuality and comprehensibility. As an example, for the layout of the bolts, balanced and symmetrical arrangements are given on the design as a suggestion. In addition, there is also the minimum length of the plates in line with the recommended arrangement using the formulations found in the bolt placement standards given in section 3.

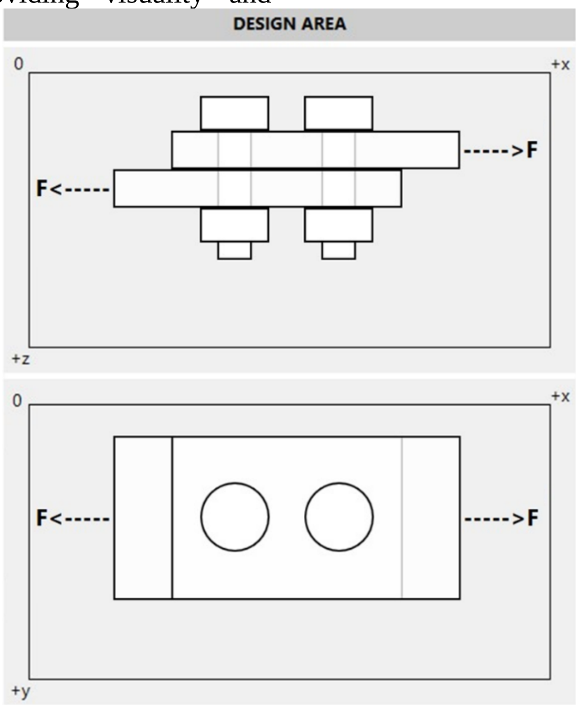

Figure 13. Design area (Tasarım alanı)

In the "Summary Design Results" section of the interface, the relevant parameters for the designed bolted joint are transferred as the final result. Summary design results consists of two sub-headings as plate information and bolt information. Under the plate information heading, there are width, length, thickness and material parameters, and under the bolt information heading, there are nominal diameter, number and strength class parameters. Thus, the user sees the final design results for the bolted joint together in a single area.

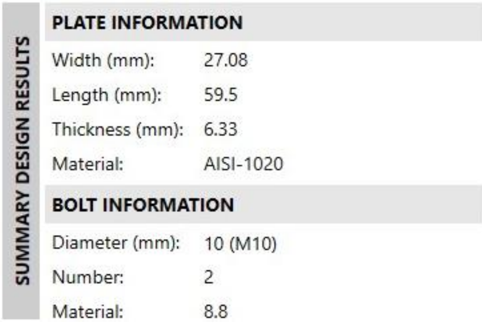

Figure 14. Summary design results (Özet tasarım sonuçları)

4.3. Example Study (Örnek Çalışma)

In this section, a sample study was carried out on the developed software. Comparisons were made with the theoretical solutions for the software outputs and the accuracy of the developed software was ensured.

In the verification process, the bolted joint problem was used as an example. The number of bolts used in the bolted joint under lateral load is 2 and the number of plates is 2. Since the number of plates is 2, it has a single shear plane. The material of the plates is AISI 1020 with a yield strength of 350 MPa. The plates were joined using 2 M10 bolts with strength class 8.8 and yield strength 640 MPa. The pitch circle diameter of the M10 bolt is 9,026 mm. The joint is subjected to a lateral force of 20 000 N. The acting lateral load creates shear stress in the bolts. Accordingly, the resulting shear stress and the safety case were calculated and given below (Eqs. 21 – 25).

Shear stress (τ)

$$\tau = F/(n * ((\pi * {d_b}^2)/4) * z) \quad (21)$$

$$\tau = 20\,000/(2 * ((\pi * 9{,}026^2)/4) * 1) \quad (22)$$

$$\tau = 156{,}286 \quad (23)$$

Factor of safety (S)

$$S = \sigma_{yield} * 0{,}5/\tau \quad (24)$$

$$S = 640 * 0{,}5/156{,}286 = 2{,}05 \quad (25)$$

As a result of the calculations, the shear stress in each bolt was found to be 156,286 N/mm^2. The yield strength of the bolt material is 640 MPa. Bolt safety factor was calculated as 2,05 for the shear stress and yield strength.

As a result of the applied lateral loading, bearing and tensile stresses occur in the plates. In this direction, it was requested to calculate the width (*b*) and thickness (*t*) values of the plates in the bolted joint according to the safety factor value of 2 in the plates.

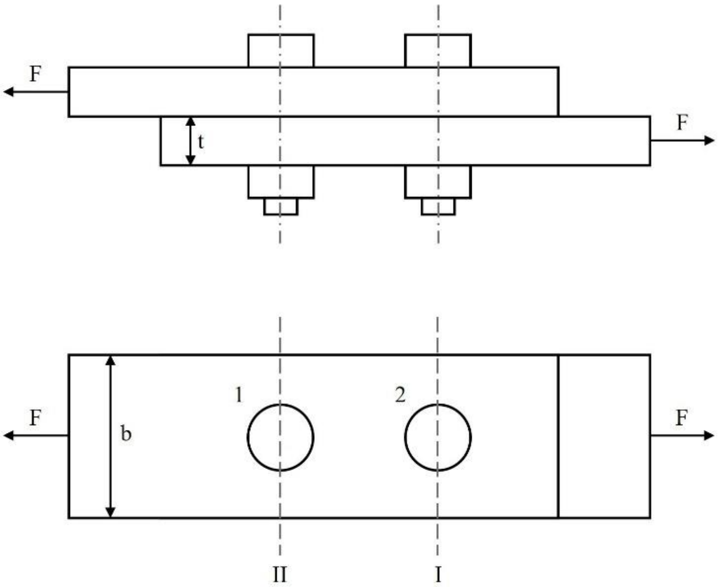

Figure 15. Example of bolted joints problem under lateral load (Örnek yanal yük altında cıvatalı bağlantı problemi)

According to these data, the plate thickness (*t*) value was calculated using the bearing stress formulation (Eqs. 26 – 29). The plate width (*b*) value was found using the formulation used for tensile stress (Eqs. 30

– 33). The t and b values were calculated by writing the values given in the sample problem in their respective places in the formulas.

In the bearing stress formulation, the plate thickness (t) is drawn.

$$\sigma_c = F/(n * (d_b * t)) \quad (26)$$
$$t = F/(n * d_b * \sigma_c) \quad (27)$$

The yield strength of the material was divided by the factor of safety and the bearing stress was calculated.

$$\sigma_c = \sigma_{yield}/S = 350/2 = 175\ MPa \quad (28)$$

Plate thickness (t) was found for all these data.

$$t = 20000/(2 * 9{,}026 * 175) = 6{,}33\ mm \quad (29)$$

Then the plate width (b) is drawn in the tensile stress formulation.

$$\sigma_t = F/((b - n * d_b) * t) \quad (30)$$
$$b = (F/(t * \sigma_t)) + (n * d_b) \quad (31)$$

n: Number of bolts in section I

The maximum tensile stress (σ_t) was calculated.

$$\sigma_t = \sigma_{yield}/S = 350/2 = 175\ MPa \quad (32)$$

According to the values found, the plate width parameter (b) was found.

$$b = (20000/(6{,}33 * 175)) + (1 * 9{,}026)$$
$$b = 27{,}08\ mm \quad (33)$$

Then the plate length (l) was calculated based on the placement of the bolts. Firstly, the hole diameter was found.

$$D = d * 0{,}85 = 10 * 0{,}85 = 8{,}5\ mm \quad (34)$$
$$l = (2 * (2 * 8{,}5)) + (1 * (3 * 8{,}5))$$
$$l = 59{,}5\ mm \quad (35)$$

As a result of the processes, the minimum plate thickness (t) was found to be 6,33 mm, the plate width (b) 27,08 mm and the plate length (l) 59,5 mm.

The sample problem was also applied to the developed software and verified by comparison. In the user input field in the software interface, the number of plates was entered as 2 and the lateral force was entered as 20 000 N. In the example problem solution, the safety factor value for the bolts was calculated as 2.05. For this reason, the safety factor range was written as 2 and 3 to cover the safety factor of 2.05 so that the software can output the sample solution as a result. Since the minimum dimensioning of the plates is carried out in line with the minimum value of the factor of safety range entered, it also meets the condition that the factor of safety value for the plates is 2. The calculation process was carried out automatically by pressing the "CALCULATE" button.

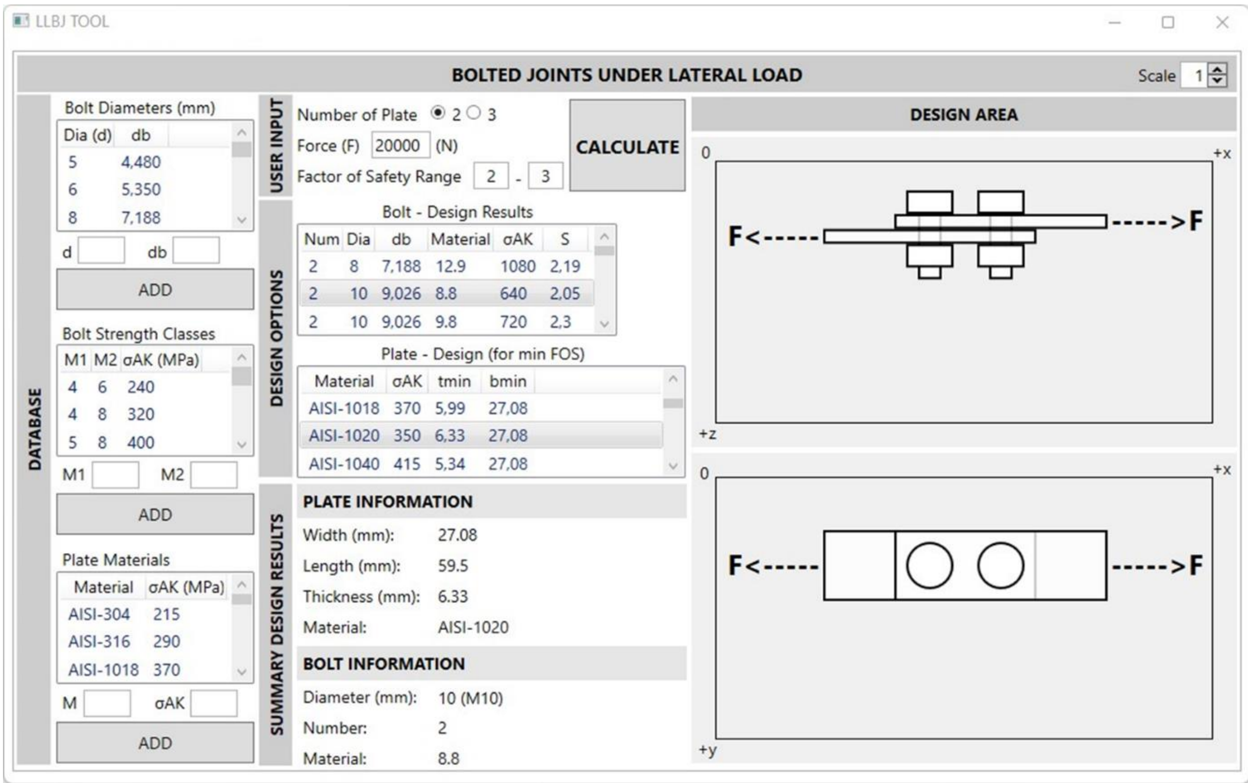

Figure 16. Sample application on software (Yazılım üzerinde örnek uygulama)

In the result section, the joint option with 2 M10 bolts and 8.8 strength class was selected among the primary design options. According to this selection, the design option containing AISI 1020 material feature was found and selected among the secondary design options. In this option, the plate thickness value (t) was calculated as 6,33 mm and the plate width value (b) as 27,08 mm. The plate length was found to be 59.5. The developed software outputs and the theoretical solutions were compared and found to be compatible with each other.

Table 4. Comparison of design parameters (Tasarım parametrelerinin karşılaştırılması)

	Design Parameters		
	Parameter	**Analytics**	**Software**
Plate	Width (mm)	27,08	27,08
	Length (mm)	90	90
	Thickness (mm)	6,33	6,33
	Material	AISI-1020	AISI-1020
Bolt	Diameter (mm)	10 (M10)	10 (M10)
	Number	2	2
	Material	8.8	8.8

5. CONCLUSIONS AND SUGGESTIONS (SONUÇ VE ÖNERİLER)

In this study, the design and optimization process of bolted joints under lateral loading is automated with the developed software. Optimum bolted joint design options are given as output based on minimum user inputs. The results obtained with the software were compared with the theoretical solutions and the results were found to be compatible.

Today, the existing design and analysis processes cause a high amount of labor and time losses. With the software developed, the design-analysis cycle was prevented by automatically reaching the optimum bolted joint designs in one go according to the targeted conditions. Designs and analyses were performed and immediate results were produced and implemented. Less user input was received. A wide range of designs was offered to users by producing different design results at once, without being tied to one type of design. The software focusing on bolted joints was a more targeted study. A graphical user interface, which is not very common in the literature, was created and a visual and easy use was provided to the user. Users were given the opportunity to add their own data by interacting with the database system. According to these results, the workload was saved and the results were reached more quickly and time was saved. The developed software effectively performs the design and optimization of various types of bolted joints under different loading types and increases productivity.

Based on this study, the scope of the study can be expanded in various subjects in the future. Different loading types can be included. Friction can be taken into account. Pre-tensioned and non-pretensioned joints can be studied. In addition to bolted joints, riveted, welded, etc. different joint methods can be applied.

DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS’ CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Kadir SARI*:** He created the idea, developed the software, carried out the design, literature review, analysis of the results and writing of the article.

Fikri oluşturmuş, yazılımı geliştirmiş, tasarımı, literatür taramasını, sonuçların analizini ve makalenin yazım işlemini gerçekleştirmiştir.

***Hakan DİLİPAK*:** He contributed to the process management, evaluation of the results obtained and content control of the article.

Süreç yönetimine, elde edilen sonuçların değerlendirilmesine ve makalenin içerik açısından kontrolüne katkıda bulunmuştur.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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