Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 25, Issue 3, 2025
PRINT ISSN 2284-7995, E-ISSN 2285-3952

USING FINITE ELEMENT ANALYSIS FOR DEVELOPMENT OF BOGIE SUSPENSION SYSTEM FOR AGRICULTURAL SEMI-TRAILER AND EVALUATION OF THE RELATED COSTS

Kareem ALHAMSHARY[1], Rashad HEGAZY[2], Tarek FOUDA[1]

[1]Tanta University, Faculty of Agriculture, Agricultural Engineering Department, Egypt; Emails: kareemalhamshary@gmail.com, tfouda628@gmail.com.
[2]Kafrelsheikh University, Faculty of Agriculture, Agricultural Engineering Department, Egypt; Email: rashad.hegazy@agr.kfs.edu.eg

Corresponding author: tfouda628@gmail.com

Abstract

Unite Finite Element Analysis- FEA model has been developed containing material properties, loads, fixtures, constraints and connections among all parts, faces and edges of the suspension system components. FEA analysis showed that U-bolt is a critical component of this suspension system. Simulation study analyzed both U-bolt diameter and doubling the Quantity of U-bolts from four to eight U-bolts. Von-Mises stresses, displacements and Shear stresses have been monitored and analyzed. U-bolt diameter has gradually increased with 2mm steps from 20mm to 22mm to 24mm for a first configuration with four U-bolts and second design configuration with eight U-bolts. Taking into consideration available materials, manufacturing methods and cost in Egyptian market showed that using the first design configuration with four U-bolts of 24mm diameter decreased the maximum von-Mises stress, displacement and shear stress on the U-bolts from 775 to 547 MPa, 4 to 2.4 mm and 335 to 222 MPa respectively instead of using the same configuration with 20mm diameter U-bolts. A more durable option is using the second design configuration with 24mm diameter U-bolts which decreased the maximum von-Mises stress, displacement and shear stress on the U-bolts from 775 to 321 MPa, 4 to 2.19 mm and 335 to 108 MPa respectively. The results showed the importance of CAD software for improving the design process of the suspension system with minimum cost and time. Also, the effects of using thicker U-bolts and doubling their quantity were noticeably observed. The allowable shear stress of the U-bolt material is 254 MPa, after running FEA analysis the maximum shear stress on U-bolts has been reduced to 222 MPa and 108 MPa for both design configurations and the shear stress ratio were 0.874 and 0.425 respectively which make both design configuration safe for operation. The total cost of imported bogie suspension system worthed 3,447 US dollars. while the total cost of the local manufactured bogie suspension system for the 1st consideration and 2nd consideration were 3,257.4 and 3,358.6 US dollars respectively. The local component percentage of the local manufactured bogie suspension system for the 1st consideration and 2nd consideration were 51.602% and 53.06% respectively.

Key words: *local development, trailers, SolidWorks software, stress analysis, suspension, Bogie and costs*

INTRODUCTION

Transportation is one of the most important operations of agricultural production system. Transportation is a game changer especially for mega agricultural projects, where transportation concept is simple: Less Time & Higher Speed. Agricultural Trailers manufacturers face a challenge to prove their design and products for such a “simple” concept.
Egypt imported 17.76 thousand unit of various Agricultural Machinery worth 193.99 million US dollars in 2022 0. Agricultural trailers and semi-trailers production in Egypt reached 824 units worth 53.826 million Egyptian pounds in 2020, Agricultural trailers and semi-trailers Exports reached 22 units worth 828 thousand Egyptian pounds, and Agricultural trailers and semi-trailers Imports reached 68 units worth 2.552 million Egyptian pounds 0. Total Area of field crops reached 12.3 million feds., total production of field crops was 110.6 million tons and Total Agricultural tractors was 133.5 thousand in 20210.
Transportation is one of the most important and energy consuming operations in Agricultural production before, within and after planting the crops. Transportation is the activity of moving something from one place to another 0. It can be said that agriculture is an industry of conveyance, because various types of vehicles

are required for transportation tasks ranging from carrying fertilizer and chemicals to getting the actual crops to market. It is not always evident that a high proportion of the work on farms consists of transporting. Off road conditions include uneven field surfaces and bumpy roads on which the trailer must operate. These irregularities lead to unexpected loads on the trailer components [1]. That is why task of moving this varied type and amount of material requires different and specialized vehicles. in western Europe, transportation tasks make up 30% to 40% of a tractor's operating time. In developing countries, a similar trend is emerging 0.

An agricultural trailer can be used with various tractor types, for multiple purposes, from light duty range (0.5-5tons), medium duty range (6-16tons), up to heavy duty range (18-30tons). In more details, Agricultural Trailers can be classified according to:

Hitching tractor: trailer working with two-wheels tractors and trailers for four-wheels tractors 0.

Axle(s) arrangement: one axle with two wheels, two axles each with two wheels, one axle with four wheels (dual tires), and a tandem axle with four wheels (dual tires) 0.

Mass transfer between trailer & tractor: trailer can be as simple as balanced trailer whose total load is supported by at least two axles with four or more wheels, or it can be a semi-trailer where a part of its load is transferred to the towing tractor and the rest of the load is carried on its axle 0.

Trailer usage: agricultural trailers are used for many purposes, here are the common uses of an agricultural trailer: flatbed trailer, tipping trailer, liquid transfer trailer (tanker), fuel dispensing trailer, low-bed trailer, grain cart, manure or slurry spreader, special purpose trailer.

The Main components of an agricultural trailer are chassis, drawbar, tow eye, platform, side boards and the suspension system. The suspension system consists of leaf spring, axle and wheel hub 0.

These components manufactured of different Materials and the design, material and terminology of these components are dependent on the functions and loading capacity of the trailer.

Chassis is a frame on which the body of a trailer is mounted [12]. It is the structural unit, and one of the main parts of a semi-trailer. Also, it is the most decisive element that gives stability and strength under different load conditions of the trailer. Many things are considered while designing a chassis such as weight, material selection, strength of the material, and other material properties. It is the main mounting part for all the components including the body, so it is also called the carrying unit [21].

Drawbar design of a balanced trailer differs from a semi-trailer, in balanced trailers drawbar has a separate steel frame which is connected to the chassis through a turntable frame which is free to rotate 360 degrees, whether in semi-trailers drawbar could be welded or bolted part of the chassis or it can be hinged to chassis and supplied with a shock absorber i.e. helical spring, leaf spring, solid rubber, or hydraulic spring.

Tow-eye is an important part of any trailer, which connects a trailer to a tractor. Tow-eye transfer draft forces from the tractor to the trailer, also it should handle the mass transferred from the trailer to the tractor especially in semi-trailer tow-eye, that is why tow-eye material selection and design should be done with both maximum draft force and the vertical loading calculated and tested for this component.

Suspension system is a system of springs, shock absorbers, and other devices supporting the upper part of a trailer, in simple words a suspension system is a set of springs and shock absorbers that connect the wheels to the vehicles body, A vehicle suspension system provides a smooth ride over rough roads while ensuring that the wheels remain in contact with the ground and vehicle roll is minimized 0.

The main function of the suspension is to connect the wheel to the vehicle with a degree of freedom. The degree of freedom is an essentially vertically directed possibility of movement of the wheel. The wheel, or more precisely the tire, should always make the maximum possible contact with the road surface 0.

A suspension connects a trailer's wheels to its chassis while supporting the trailer's weight. It allows for the relative motion between the wheel and trailer chassis; theoretically, a suspension system should reduce a wheel's degree of freedom (DOF) from 6 to 2 on the rear axle and 3 on the front axle even though the suspension system must support propulsion, steering, brakes, and their associated forces. The relative motions of a wheel are its vertical movement, rotational movement about the lateral axes, and rotational movement about the vertical axes due to steering angle 0.

The suspension system and frame must also position the wheels and tires properly to provide normal tire life and proper steering control. If the suspension system does not position each wheel and tire properly, wheel alignment angles are incorrect and usually cause excessive tire tread wear. Improper wheel and tire position can also cause the steering to pull to one side. When the suspension system positions the wheels and tires properly, the steering should remain in the straight-ahead position if the car is driven straight ahead on a reasonably straight, smooth road surface 0.

The suspension system contains three major parts: a structure that supports the vehicle's weight and determines suspension geometry, a spring that converts kinematic energy to potential energy or vice versa, and a shock absorber that is a mechanical device designed to dissipate kinetic energy 0.

A suspension system should satisfy certain requirements for use in vehicles. The main desired features like: Independency, camber control, structural efficiency, isolation, low weight, long life, low cost 0.

U-bolt is a structure element that bolts the leaf spring to the bogie-pin flange of the suspension system (Figure 1). The U-bolt does not constrain the displacement of the leaf spring against soil reactions while moving, but it supports the leaf spring and maintains it in position which a relatively small force is applied to the U-bolt compared to the leaf spring 0.

U-bolts can have various types of forces which can lead to failure. Horizontal forces cause bending in the bolting area. Axial forces generated in the U-bolts cross-section. Shear failure generated in the threads where the U-bolt is fixed by a nut for vertical load. U-bolt can handle much larger load-carrying capacity for vertical load than horizontal load. According to laboratory tests calibrated with FEM analysis the thread region is the most vulnerable location and that most of the failures start from that region 0. In addition, Fracture stress should be taken into consideration for the design of U-bolts. 90% of mechanical failures is caused mainly by fatigue. Fatigue arises from multiaxial forces on the U-bolt 0.

Finite Element Analysis, commonly referred to as FEA, is a numerical method used for analysis of structural and thermal problems encountered by mechanical engineers during Design is process. Design analysis can be conducted on a real object or on models that represent certain aspects of the real object. If models are used instead of a real object, the analysis can be conducted earlier in the design process before physical prototypes are built. The models can be physical models (scale-down models, mock-ups, photoelastic models, etc.) or mathematical models where a certain behavior of the design in progress is captured and described by a mathematical apparatus. Simple mathematical models can be solved analytically. More complex models require the use of numerical methods. FEA is one of those numerical methods used to solve complex mathematical models. The FEA is a powerful but demanding tool of engineering analysis. The expertise expected from FEA users depends on the complexity of analysis but always requires familiarity with Mechanics of Materials, Kinematics and Dynamics, Vibration, Heat Transfer, Engineering Design, and other topics 0.

SOLIDWORKS Simulation is a commercial implementation of FEA capable of solving problems commonly found in design engineering, such as the analysis of displacements, stresses, natural frequencies, vibration, buckling, heat flow, etc. It belongs to the family of engineering analysis software products originally developed by the Structural Research & Analysis Corporation (SRAC).

SRAC was established in 1982 and since its inception has contributed to innovations that have had a significant impact on the evolution of FEA.

The focus of the FE analysis is to accurately simulate the interactions between components using contact, friction, and elasto-plastic material definition **Error! Reference source not found.**. The starting point for any SOLIDWORKS Simulation project is a SOLIDWORKS model, which can be a part or an assembly. First, material properties, loads, and restraints are defined. Next, as is always the case with using any FEA-based analysis tool, the model geometry is split into relatively small and simply shaped entities called finite elements. The elements are called "finite" to emphasize the fact that they are not infinitesimally small, but relatively small in comparison to the overall model size. Creating finite elements is commonly called meshing. When working with finite elements, the SOLIDWORKS Simulation solver approximates the sought solution (for example stress) by assembling the solutions for individual elements 0. A FEA model is composed of several different components that together describe the physical problem to be analyzed and the results to be obtained. At a minimum the analysis model consists of the following information: discretized geometry, element properties, material data, loads and boundary conditions, analysis type, and output requests. Agricultural Machinery Industry in Egypt was and still depend on small farm workshops spreading over rural areas, however there were some efforts to develop the local manufacturing of agricultural machinery which produce "Society of Agricultural Machinery Manufacturers and Trading" in 1991 at that time it included 43 manufacturer companies in addition to 71 supplier's facilities under supervision of Agricultural Engineering Research Institute in Cairo 0. But it is unknow for now whether how active this society is or if it is still working.

Most of agricultural farms in Egypt used to have balanced trailer with load capacity ranges up to 25 tons, agricultural trailer used as flatbed or two ways or three ways tipper. In the last two decades having more agricultural projects mainly in the western desert region of Egypt, the need for an agricultural semi-trailer is increasing because of the soil conditions which full of rocks, holes, and bumps. Also, transportation is becoming more energy consuming because agricultural trailers will be operated for longer distances especially in mega agricultural projects. In addition, the design of semi-trailer transfers a portion of its mass to the tractor which will maintain the trailer more stable behind the tractor and the operator has more manoeuvrability control of the trailer especially while the trailer is loaded and passing over hard soil conditions.

Agricultural semi-trailers firstly used in Egypt were imported by agricultural companies, which inspire local manufacturers to copy that design, and the first trails to manufacture agricultural semi-trailer was in 2012 when the need for semi-trailer increasing and some local manufacturers proposed local manufacturing of semi-trailer, the first products of semi-trailers have loading capacity 16tons, supplied with two tandem axles rear suspension, the stub axles are welded to a rocker arm which is hinged to chassis and free to rotate up and down on both sides according to soil conditions.

The first local developed suspension system for agricultural semi-trailer has a recurrent problem the stub axles cannot maintain the loading capacity, the axles deformed until it breaks under loading, and suspension hinge pin wear rapidly and the wheels get an unacceptable camber angle. Many modifications have been made to this design; however, it becomes clear that the components of this design are not suitable for the loading capacity. Also, the suspension system did not have a basic component, i.e. the shock absorber, a spring should be added to the suspension system to help it have more impact resistance. That is why restructuring of the suspension system design will be done in this study.

The main objectives of the study are:

(i)Development of local manufactured suspension system for increasing suspension components efficiency and enhancing Semi-trailers' performance.

(ii)Reducing the cost of production requirements.

MATERIALS AND METHODS

The first prototype of the semi-trailer has been manufactured in Egypt by **Delta Agricultural Machinery** Company in 2021. The semi-trailer has been tested in field in different agricultural sites as shown in Photo 1.

Photo 1. Local developed semi-trailer field test
Source: Delta Agricultural Machinery at Tanta-Egypt.

Hardware and software used in creating the 3D assembly model and FEA analysis are shown in Table 1.

Table 1. computer hardware and software specifications

Hardware	
Computer	HP Z420 workstation
Processor	Intel(R) Xeon(R) CPU E5-1650 0 @ 3.20GHz
RAM	16.0 GB
Display	HP Compaq LA2205 Wide LCD Monitor
Graphics	NVIDIA Quadro M2000
Software	
Operating System	Windows 10 Pro 64-bit
CAD software	SOLIDWORKS® Premium 2020 SP 0.1

Source: Authors' determination.

Computer Aided Design (CAD) software SOLIDWORKS® is used to create a suspension system 3D model, every part of the suspension system has been created and assembled, both imported components and local developed ones are assembled in virtual reality before the actual manufacturing to reach the best possible terminology and dimensions and to provide more stability in future modifications or manufacturing.

A 3D model of the Agricultural Semi-trailer has been built in the virtual environment of SOLIDWORKS® software as shown in Photo 2. The suspension system and all of its components are shown in Photo 3.

Photo 2. Agricultural semi-trailer 3D-model
Source: Authors' drawing.

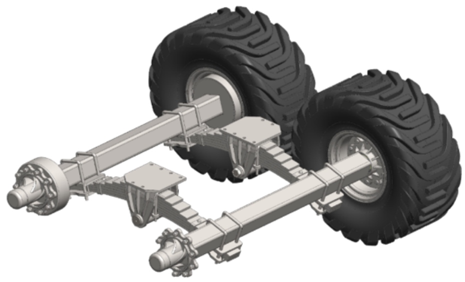

Photo 3. Suspension system 3D-model
Source: Authors' drawing.

Engineering Design of suspension components

There are some factors that should be considered in the suspension system design.

Load capacity calculation

First, the loads should be calculated to be considered for the suspension component loading capacity. This design will be designed to transport 16tone of agricultural material, this should be the payload of a semi-trailer, while there is another load that should be added to the payload which is the unladen mass of the semi-trailer, the unladen mass of a trailer is about 3.5tons. Then we add a loading factor of safety 25% of the total gross load as follows:

$$grossload = (16 + 3.5) \times 1.25 = 24.375 \cong 25tons$$

Semi-Trailer Component Selection

Not all the suspension system will be locally manufactured, some components will be imported like tires, rims, and axles. However these components should be selected with the gross load distributed equally on each component, that means for: gross load will be divided on the quantity number of each component to calculate the minimum requirement of loading capacity for each component. The suspension has 4 tires so every tire should have loading capacity= 25/4= 6.25tons per tire. The same way axles loading capacity= 25/2= 12.5tons per axle.

The rest of the suspension system component will be locally manufactured so stress calculation will be done after a 3D model is built to have the right terminology of each part.

After reviewing many suspension designs, a promising bogie suspension using two heavy duty leaf springs hinged to the chassis has been chosen to be locally developed.

Semi-trailer manufacturing materials

Material selection is a critical step in the design, for a suspension system there are many types of materials that will be used according to the function and the predicted stress of each component of the suspension system.

Figure 1 below shows the 3D CAD model and an exploded view of one side of the suspension system.

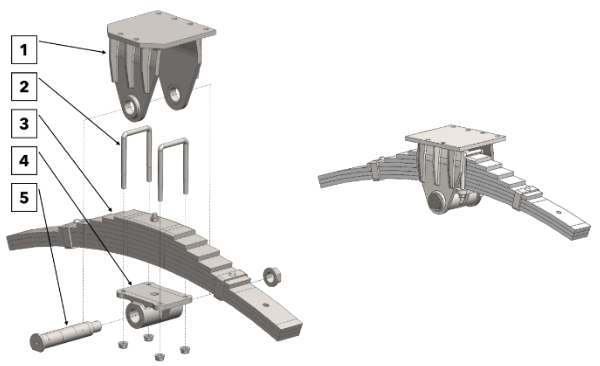

Fig. 1. CAD model and exploded view of bogie suspension system (1) Chassis bracket, (2) U-bolt, (3) Leaf Spring, (4) Bogie-pin flange, (5) Bogie pin
Source: Authors' drawing.

Component 1 is the chassis bracket which connects the suspension system to the main chassis of the semi-trailer. Component 4 is the bogie pin flange. This flange is the hinge of the bogie suspension; it connects most of the suspension components together. Both component 1 & 4 should have ductile feature with enough strength to deal with the exerted stresses. S235JR (1.0038) is the material selected for these components according to EN 10025:2004 0, this material has minimum yield strength Fy= 235MPa and tensile strength Fu= 360MPa this material is available in Egyptian local market mostly called steel 37.

Component 2 is the U-bolt which tightens the leaf spring to the bogie pin flange. This component is critical in its design and the material used should have higher tensile strength to endure shear stresses exerted on this component. Material selected for this U-bolt is A325 grade 8.8 according to ISO 898-1:2013 0 and ASTM A325-10 0, this material used to manufacture high tensile bolts and its minimum yield strength Fy= 635MPa and tensile strength Fu= 825MPa.

Component 3 is the articulate member of the bogie suspension and at the same time it is a leaf spring that can resist damping and impact loads coming from the soil. Spring Steel 38Si7 (1.5023) is the one of the suitable materials that have the properties and characteristics needed for the function of this component of the suspension system. According to EN 10089:2002 0, this material is used to manufacture leaf spring and its minimum yield strength Fy= 1,150MPa and tensile strength Fu= 1,300-1,600MPa.

Component 5 is the bogie pin. This is the articulation hinge point of the bogie suspension so the material used in this component should have good machining ability and enough strength to resist the exerted loads and stresses. C45 (1.0503) is a good choice for this application. This material can be found in the local market whether in hot or cold rolled bars. According to EN 10083-2:2006 0, its minimum yield strength Fy= 430MPa and tensile strength Fu= 650-800MPa.

Stress calculation of critical parts

In this section some design calculation will be run for the most critical components of the suspension assembly, in the calculation the maximum gross load is considered as and exerted on each part to have a safe design with higher factor of safety.

U-bolt (Figure 1, component 2)

This component should be designed for the allowable shear stress to be exerted on it. The allowable shear stress in pins and bolts is 0.4 Fy0 with a factor of safety 2.5. So, this allowable shear stress should be calculated for the U-bolt material and compared to the calculated shear stress on U-bolt. The average shear stress on U-bolt is calculated from this equation:

$$\tau_{ave} = \frac{V}{A_v} \quad (1)$$

where:

τ_{ave}: average shear stress on U-bolt (MPa)

V: shear force (N)

A_v: shear area (mm2)

Since we already know the minimum allowable shear stress for the selected material then τ_{ave} is considered to equal:

$\tau_{ave} = 0.4 \times 635 = 254MP_a$

The shear force is already known as the maximum gross load divided by 4 because the calculation is for each side of the suspension and each side has 2 U-bolts, so:

$$V = \frac{25}{4} = 6.25\ tons = 6{,}250kg$$

The shear area is the cross-section area of the bolt and is equal to:

$$A_v = \pi \frac{d^2}{4} \quad (2)$$

Then the only parameter that should be calculated is the U-bolt diameter and this calculated size is the minimum size for the U-bolt diameter:

$$\therefore d = \sqrt{\frac{4 \times 6{,}250 \times 9.81}{\pi \times 254}} \cong 17.5mm$$

The standard available round material according to the calculated U-bolt diameter is 18mm, however for more stiffness and durability for this component a 20mm U-bolt diameter is selected. Then the shear stress ratio for this component will be calculated to be sure about its safe design. The shear stress ratio should be less than one for accepted design, it will compare the calculated shear stress f_v for the selected U-bolt size to the allowable shear stress τ_{ave}:

$$\frac{f_v}{F_v} = \frac{\frac{V}{A_v}}{0.4F_y} = \frac{\frac{4 \times 6{,}250 \times 9.81}{3.14 \times 20^2}}{0.4 \times 635}$$

$$\therefore \frac{f_v}{F_v} = 0.768 < 1$$

Bogie pin flange (Figure 1, component 4)

The critical stress exerted on this flange is the bearing stress behind the U-bolts, the allowable bearing stress behind pin or bolts is 0.9 Fy with 1.11 factor of safety 0.

$\sigma_{br} = 0.9F_y = 211.5MP_a$

And the bearing stress equal to:

$$\sigma_{br} = \frac{P}{A_{br}} \quad (3)$$

where:

σ_{br}: bearing stress behind the U-bolt (MPa)

P: bearing force (N)

A_{br}: bearing area (mm^2)

The bearing force equals the total gross loading of the semi-trailer divided by 8 because the calculation is for each side of the suspension and each side has 2 U-bolts in addition each U-bolt has two bearing area, so:

$$P = \frac{25}{8} = 3.125\ tons = 3{,}125kg$$

The bearing area is the cross-section area of the bogie pin flange at the U-bolt hole center and is equal to:

$$A_{br} = t \times d_b \quad (4)$$

where:

t: flange thickness (mm)

d_b: bolt diameter (mm) = 20mm

Since the thickness of the flange is parameter to be determined:

$$\therefore t = \frac{3{,}125 \times 9.81}{20 \times 211.5} \cong 7.5mm$$

The standard sheet metal thickness available in the local market is 8mm, however 20mm thickness is used for this flange to handle more stresses and have high factor of safety. The bearing stress ration is calculated, and it should be less than one, it will compare the allowable bearing stress to the calculated bearing stress for the selected sheet metal thickness:

$$\frac{f_{br}}{F_{br}} = \frac{\frac{P}{t \times d_b}}{0.9F_y} = \frac{\frac{3{,}125 \times 9.81}{20 \times 20}}{0.9 \times 235}$$

$$\therefore \frac{f_{br}}{F_{br}} = 0.362 < 1$$

FEA simulation Analysis using SOLIDWORKS® software

SOLIDWORKS SIMULATION® software used to evaluate the design in more complicated situations, stress analysis will be run on the suspension assembly not on every part of the suspension system, this will help to understand the behavior of each part of the suspension assembly taken into consideration the combined forces, torques or displacements which may arise in the stress analysis. Figure 2 below shows the suspension assembly after applying the same material properties described in Figure 1. Loads are applied on the chassis bracket which is 12,500 kgf equally distributed on the chassis bracket flange and directed in the downward direction of the Y-plane that represents how the semi-trailer load would be transferred to the suspension assembly in the field. Gravity is taken into consideration with 9.81 N/m2 in the downward direction of the Y-plane. fixed fixtures are applied on both ends of the leaf spring which represents how the leaf spring is fixed on the axles.

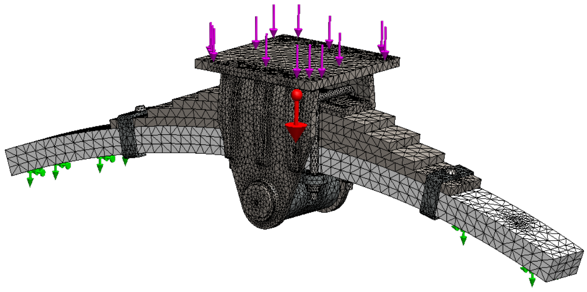

Fig. 2. Suspension assembly after meshing process on SOLIDOWRKS SIMULATION® software
Source: Authors' determination.

In Addition, other connections are used to represent how all of the suspension components interact with each other, No-Penetration contact sets are used to describe the interaction between inner faces on the suspension components especially for tangent faces on the leaf spring, between leaf spring and U-bolts, among bogie pin, bogie pin flange and chassis bracket, while Bonded global contact are applied to the rest of suspension components.

After analysis some parameters like stress, strain, displacement, reaction forces and shear forces will be monitored and discussed to evaluate the design of the suspension system.

RESULTS AND DISCUSSIONS

The analysis type was static analysis, with solid mesh type used along with curvature-based high quality mesher with maximum element size 30mm and minimum element size 6mm.

The total number of nodes was 168,977 nodes, and total elements number was 96,415 elements, number of degrees of freedom was 505,581, time of meshing was nine seconds, total solution time was one hours, nine minutes and 46 seconds.

The Analysis results after solving the calculations for the suspension system assembly showed that maximum von Mises stress value is 872 MPa on the inner rear U-bolts threading area which has diameter of 18mm, while maximum displacement was 4.19mm on the tangent area between the U-bolt and the leaf spring, maximum reaction force was 2,650 kgf acting on the fixture surface of the leaf springs where arrow pointing in Figure 6.3, and the maximum shear stress was 380 MPa in XY-plane acting on the outer front U-bolt threading area as shown in Figure 3.

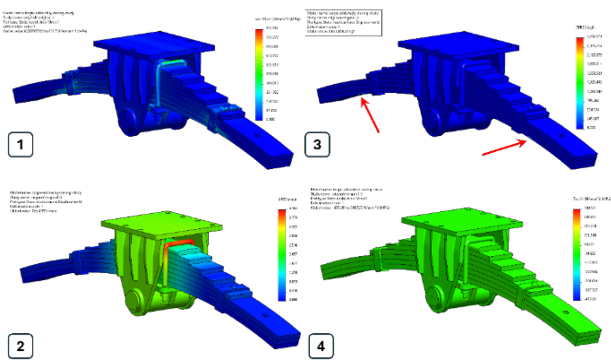

Fig. 3. Chassis bracket and Leaf Spring components: (1) von Mises stress, (2) displacement, (3) reaction force and (4) shear stress plots of suspension assembly.
Source: Authors' determination.

After reviewing the results of the whole suspension assembly, the same results will be viewed and analyzed for every component individually to make sure we are in the safe design limitations.

Chassis bracket, Figure 1, component number 1 had maximum stress of 65 MPa acting at the weld bead between chassis connecting flange and bogie pin bracket flange.

Chassis bracket has also maximum displacement was 2.75 mm in the middle of front edge of the connecting flange, there were not any reaction forces on this component and maximum shear stress was 31 MPa on the YZ-plane acting near the bogie pin hole as shown in Figure 3 and Figure 4.

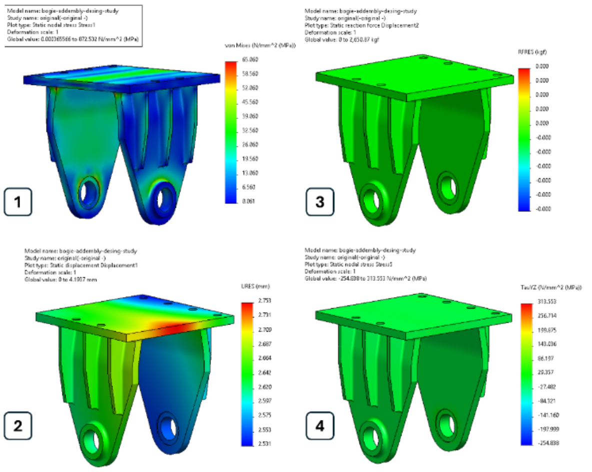

Fig. 4. Chassis bracket and its components: (1) von-Mises stress, (2) displacement, (3) reaction force and (4) shear stress plots of chassis bracket.
Source: Authors' determination.

U-bolt, Figure 1, component number 2, had maximum stress of 771 MPa acting near the bending radius area of the front U-bolt, maximum displacement was 4.19mm on the tangent area between the U-bolt and the leaf spring, no reaction forces on the U-bolts, and maximum shear stress on the YZ-plane was 313 MPa acting near the bending radius area of the U-bolt as shown in Figure 5.

Leaf spring, Figure 1, component number 3, had maximum stress 419 MPa acting in the contact area between U-bolt and the upper leaf of the spring, maximum displacement was 2.06 mm acting in both expecting position and direction in the middle of the leaf spring in the downward direction of the Y-Axis, maximum reaction forces was 2,650 kgf acting in the fixture area between leaf spring and axle and the maximum shear stress was 192 MPa in XY-plane acting in the tangent edge between spring collar and the leaves of the spring as shown in Figure 6.

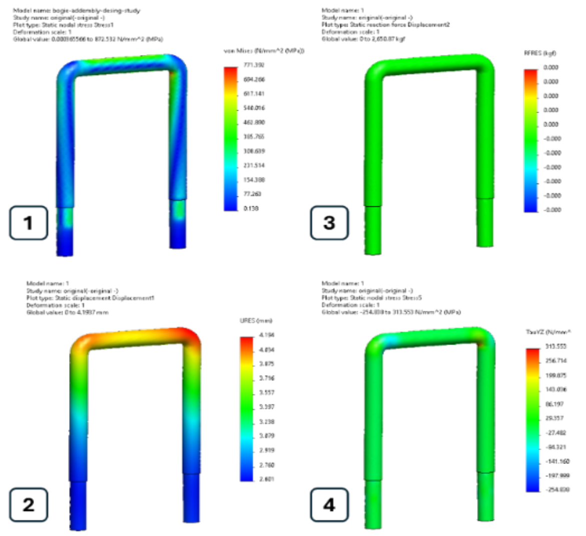

Fig. 5. U-bolt and its components: (1) von-Mises stress, (2) displacement, (3) reaction force and (4) shear stress plots of the U-bolt.
Source: Authors' determination.

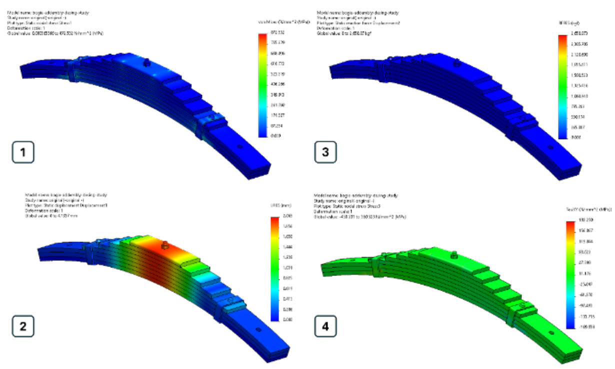

Fig. 6. Leaf spring and its components: (1) von-Mises stress, (2) displacement, (3) reaction force and (4) shear stress plots of suspension leaf spring
Source: Authors' determination.

Bogie pin flange, Figure 1, component number 4, had maximum stress of 325 MPa acting in the weld bead between bogie pin hinge and bogie pin flange, maximum displacement of 2.63mm on the outer section of the bogie pin hinge, there were not any reaction forces on this component and the maximum shear stress was 144 MPa in XY-plane acting in the weld bead between bogie pin hinge and bogie pin flange as shown in Figure 7.

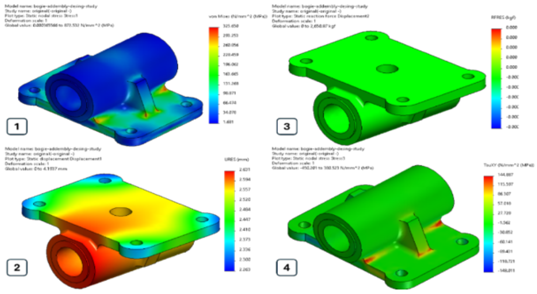

Fig. 7. Bogie pin flange and its components: (1) von-Mises stress, (2) displacement, (3) reaction force and (4) shear stress of bogie pin flange
Source: Authors' determination.

Bogie pin, Figure 1, component number 5 had a maximum stress of 39 MPa in an expected common area where bogie pin connect the chassis bracket with bogie pin flange, the maximum displacement was 2.65mm near the pin head, there were not ant reaction forces on this component and the maximum shear stress was 8.8 MPa in XZ-plane in the area where bogie pin connect the chassis bracket with bogie pin flange as shown in Figure 8.

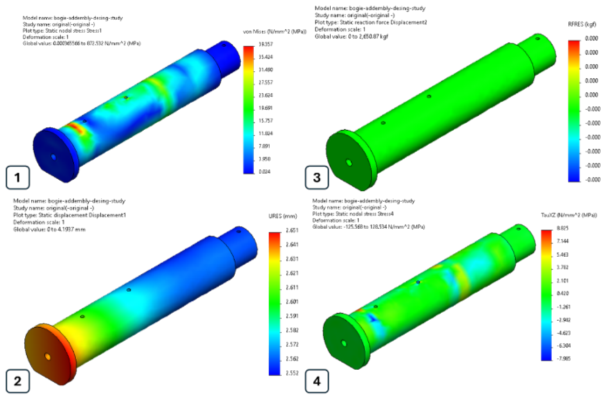

Fig. 8. *Bogie pin*: (1) von-Mises stress, (2) displacement, (3) reaction force and (4) shear stress of bogie pin
Source: Authors' determination.

The above results showed that some design modifications need to be done for critical component specially the U-bolts, there are two main factors that affect the performance of this critical component: 1st the clearance between U-bolt and leaf spring or the bogie pin flange, 2nd the possible movements of the U-bolts on the tangent face of the upper leaf spring which would arise during operation of the trailer and passing through rough terrain.

A new simulation design study has been done using SOLIDWORKS SIMULATION® software focused on the U-bolt diameter size to be the main factor under study and another design configuration has been added to the study which will have the same conditions of material, fixtures, loads and constraints however the design has been modified to have four U-bolts of every bogie hinge instead of two. Which means the suspension system will have eight U-bolts instead of four U-bolts in the whole suspension assembly to enhance the performance, safety and life of this critical component of the suspension system.

Also, another component has been added to the design, which is U-bolt lock plate. This part will reduce the amount of displacement and restrict any possible movements of the U-bolts, which is one of the important concerns from the previous simulation study Figure 9 showing the 2nd design configuration.

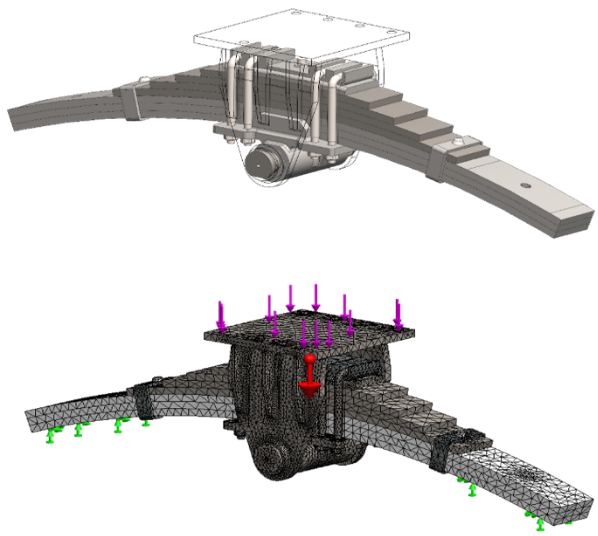
Fig. 9. 2nd design configuration with four U-bolts, (up) CAD model, (down) FEA model
Source: Authors' determination.

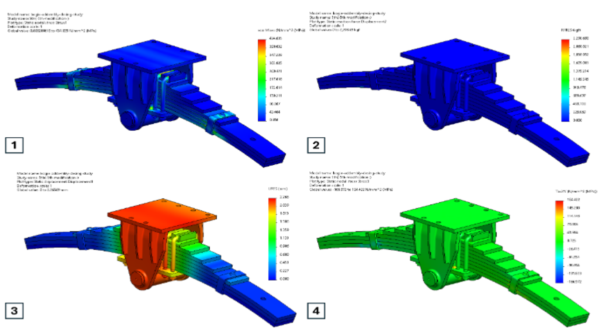

Fig. 10. The 2nd design configuration: (1) von Mises stress, (2) displacement, (3) reaction force and (4) shear stress of the 2nd design configuration
Source: Authors' determination.

Figure 10 showing the simulation analysis results plots of the 2nd design configuration.
Maximum stresses, displacements and shear stresses of the U-bolt are the measurement of this study. The U-bolt diameter has been modified by increasing it from 20mm, 22mm to 24mm. for every U-bolt diameter all calculations have been repeated.

Stress, displacement and shear stress have been monitored and plotted for both design considerations. Table 2 shows the maximum stresses, displacements and shear stresses on the U-bolts obtained for both design configurations and U-bolt diameter sizes.
Figures 11, 12, 13, show Maximum von-Mises stress, displacement and shear stress on U-bolt for both configurations respectively.

Table 2. maximum stresses, displacements and shear stress for different design configurations

Design Configuration	Two U-bolts			Four U-bolts		
U-bolt diameter (mm) / Study Parameter	20	22	24	20	22	24
Maximum Stress (MP_a)	775	596	547	412	320	321
Maximum Displacement (mm)	4	2.68	2.4	2.27	2	2.19
Maximum Shear Stress (MP_a)	335	230	222	181	114	108

Source: Authors' determination.

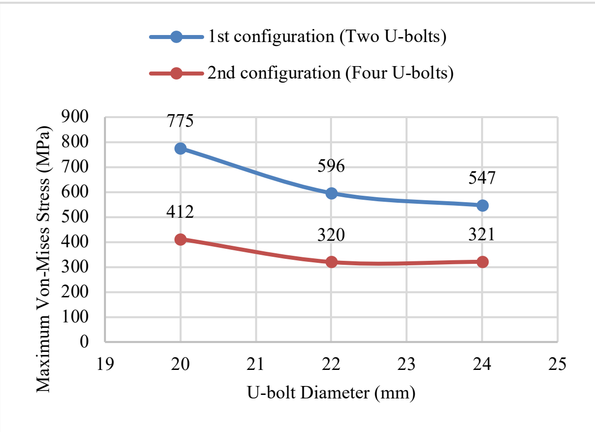

Fig. 11. Maximum Von-Mises stress on U-bolt for both design configurations
Source: Authors' determination.

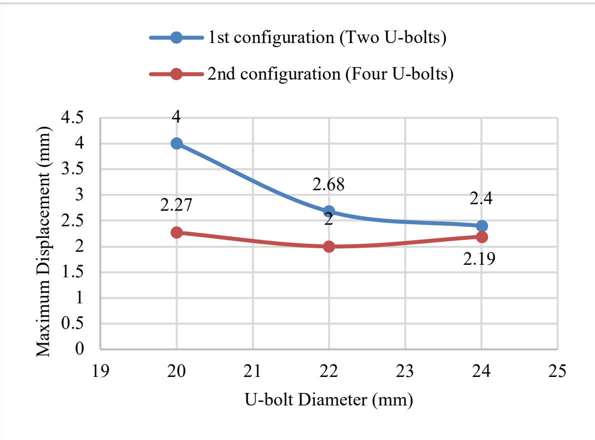

Fig. 12. Maximum Displacements on U-bolt for both design configurations
Source: Authors' determination.

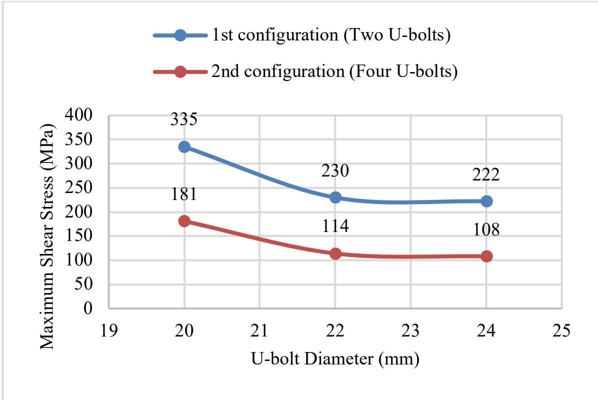

Fig. 13. Maximum Shear Stress on U-bolt for both design configurations
Source: Authors' determination.

Economic cost analysis

According to the manufacturer data, In 2025 the total cost of imported bogie suspension system worthed 3,447 US dollars. While the total cost of the local manufactured bogie suspension system for the 1st consideration and 2nd consideration were 3,257.4 and 3,358.6 US dollars respectively. Hence, the local component percentage of the local manufactured bogie suspension system for the 1st consideration and 2nd consideration were 51.602% and 53.06% respectively. Table 3 below show the total cost of local manufactured bogie suspension parts along with the local component percentage of each component with Quantities.

Table 3. local manufactured bogie suspension components cost, quantity and local component percentage

No.	Component	1st consideration			2nd consideration		
		Quantity	Price (US $)	Local component (%)	Quantity	Price (US $)	Local component (%)
1	Chassis Bracket	2	96.85	100	2	96.85	100
2	Bogie U-bolts	4	19.6	100	8	19.6	100
3	Leaf Spring	2	397	100	2	397	100
4	Bogie-Pin Flange	2	84.9	100	2	90.5	100
5	Bogie Pin	2	27.25	95	2	27.25	95
6	Axles	2	784.3	0	2	784.3	0
7	Axle-Spring U-bolts	8	23.5	100	8	23.5	100
8	Axle-Spring flanges	8	10.25	100	8	10.25	100
9	Miscellaneous components	---	51.9	90	---	51.9	90
10	Manufacturing, assembly and paint	---	76.5	100	---	76.5	100
11	Bogie U-bolt lock	---	---	---	2	5.8	100
12	Total price (US $)	3,257.4			3,358.6		

Source: Authors' determination.

CONCLUSIONS

The increasing agricultural production in Egypt requires more efficient and durable transportation trailers. Semi-trailers specially are required for the most rough and harsh conditions of agricultural roads and field operation. Bogie suspension system provides higher loading capacity with independent axle arrangement for each axle in addition it has a shock absorbing member which can maintain the semi-trailer performance and longer operating life.

CAD and FEA software are important tool which save time and effort consumed in complicated mathematical analysis.

Also, with a simple comparison between the maximum total cost of local manufactured bogie suspension system after the reviewed modification and enhancement was 3,358.6 US dollars, while the imported bogie suspension system worthed 3,447 US dollars with 2.56% saving of the imported bogie cost and 53.06% local component percentage. In addition to the higher loading capacity of the local developed suspension after applying the U-bolt modification and enhancement along with the after-sales support and the availability of any parts of the suspension components which are not available for the imported suspension. Then it can be clear that the local developed suspension system is a cost-effective solution for the local manufacturing of agricultural semi-trailers in Egypt.

ACKNOWLEDGEMENTS

A tribute to **Delta Agricultural Machinery** at Tanta-Egypt, which supported the researchers during the research with equipment and technical support.

REFERENCES

[1]Aloni, S., Khedkar, S., 2012, Comparative Evaluation of Tractor Trolley Axle by Using Finite Element Analysis Approach. Int. J. Eng. Sci. Technol., Vol. 4(4), 1351-1360.

[2]Annual Bulletin of Statistical Crop Area and Plant Production 2020/2021. Central Agency for Public Mobilization and Statistics, Issue: Jan 2023. Ref No. 71-22122-2021.

[3]Annual Bulletin of Mechanical Farm Machinery, 2022, Central Agency for Public Mobilization and Statistics, Issue: Nov. 2022. Ref No. 72-22129-2021.

[4]Arab Agricultural Statistics Yearbook, 2024, Volume (43), Arab Organization for Agricultural Development (AOAD).

[5]ASTM, 2013, A325-10 Standard Specification for Structural Bolts, Steel, Heat Treated, 120-105, Minimum Tensile Strength. ASTM International. DOI: 10.1520/A0325-10.

[6]Bateman, H., Curtis S., McAdam, K., 2006, Dictionary of Agriculture 3rd Edition-A & C Black Publishers.

[7]BSI, 2002, EN 10089-2002 Hot rolled steels for quenched and tempered springs. BSI Standards Publication, British Standard Institution, https://knowledge.bsigroup.com/products/hot-rolled-steels-for-quenched-and-tempered-springs-technical-delivery-conditions?version=standard, Accessed on December 5, 2024.

[8]BSI, 2019, EN 10025-2:2019 - TC Hot rolled products of structural steels - Technical delivery conditions for non-alloy structural steels. BSI Standards Publication. British Standard Institution, https://knowledge.bsigroup.com/products/hot-rolled-products-of-structural-steels-technical-delivery-conditions-for-non-alloy-structural-steels-1?version=tracked. Accessed on December 5, 2024.

[9]BSI, 2006, EN 10083-2-2006 Steels for quenching and tempering 2 Technical delivery conditions for non-alloy steels. BSI Standards Publication. British Standard Institution, https://knowledge.bsigroup.com/products/steels-for-quenching-and-tempering-technical-delivery-conditions-for-non-alloy-steels?version=standard, Accessed on December 5, 2024.

[10]Chun, M., Kim, J., Kim, K., Jeong, D., Lee, D., Wi, S., Kim, B., Kim, C., Shim, C.-S., 2024, A fundamental study on structural strength assessment of U-bolts for expanded application to shipbuilding and offshore piping systems, International Journal of Naval Architecture and Ocean Engineering, Vol. 16, 2024, 100561, https://doi.org/10.1016/j.ijnaoe.2023.100561.

[11]CIGR Handbook of Agricultural Engineering, 1999, Vol. III. Plant Production Engineering. Chapter 1 Machines for Crop Production, Part 1.7. Transportation, pp. 455-469. doi:10.13031/2013.36352.

[12]Dictionary of Engineering, 2003, McGraw-Hill, 2nd. edition, DOI: 10.1036/0071417990.

[13]Goodarzi, A., Lu, Y., Khajepour, A., 2023, Vehicle Suspension System Technology and Design, Synthesis Lectures on Advances in Automotive Technology. Springer. https://doi.org/10.1007/978-3-031-21804-0_1

[14]IS 8213:2000, Agricultural tractor trailer—specification, 3rd. Ed., Bureau of Indian Standards. https://www.services.bis.gov.in/php/BIS_2.0/bisconnect/standard_review/Standard_review/Isdetails?ID=MTUzMDI%3D. Accessed on December 5, 2024.

[15]ISO 898-1:2013, Mechanical properties of fasteners made of carbon steel and alloy steel, Part 1: Bolts, screws and studs with specified property classes — Coarse thread and fine pitch thread, (5th Ed., 2013). The International Organization for Standardization. https://www.iso.org/standard/60610.html, Accessed on December 5, 2024.

[16]Kirby, D., Charniga, R., 2005, A Finite Element and Experimental Analysis of a Light Truck Leaf Spring System Subjected to Pre-Tension and Twist Loads, SAE Technical Paper 2005-01-3568, 2005, https://doi.org/10.4271/2005-01-3568

[17]Knowles, D., 2011, Automotive Suspension & Steering Systems (Classroom Shop Manuals). 5th Edition. Delmar, Cengage Learning.

[18]Kurowski, M.P., 2023, Finite Element Analysis for Design Engineers, 3rd. Ed. SAE International.

[19]Kurowski, M.P., 2018, Engineering Analysis with SOLIDWORKS Simulation 2018. SDC publications.

[20]Liu, Z., Phares, M.B., 2020, Determination of U-bolt connection load capacities in overhead sign support structures, Journal of Constructional Steel Research, Vol. 170, 106096, https://doi.org/10.1016/j.jcsr.2020.106096.

[21]Math, S.N., Bhandari, I.P., Sanajay. S. J., 2016, Analysis and Optimization of Tractor Trolley Chassis. International Journal of Engineering Research & Technology (IJERT) Vol. 5(6), 557-561, June 2016, http://dx.doi.org/10.17577/IJERTV5IS060711

[22]PAES 136, 2004, Agricultural Machinery – Agricultural Trailer – Specifications. Philippine Agricultural Engineering Standard. Agricultural Machinery Testing and Evaluation Center (AMTEC) College of Engineering & Agro-Industrial Technology, University of the Philippines Los Baños. https://amtec.uplb.edu.ph/wp-content/uploads/2019/07/paes-136.pdf. Accessed on December 5, 2024.

[23]Reihanian, M., Sherafatnia, K., Sajjadnejad, M., 2011, Fatigue failure analysis of holding U-bolts of a cooling fan blade, Engineering Failure Analysis, Vol. 18(8),2019-2027, https://doi.org/10.1016/j.engfailanal.2011.06.004.

[24]Segerlind, L. J., 2010, Designing Structural Components for Machines. American Society of Agricultural and Biological Engineers. doi:10.13031/2013.29532

[25]Shriwas, A.K., Deepak, Keshari, M., Malvi, C. S. 2022, Design, Analysis and Fabrication of Agriculture Semi-Trailer. International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE), Vol.9(5), 28-33. (http://dx.doi.org/10.36647/IJERMCE/09.05.A005)

[26]Study of Tractor and Agricultural Machinery Manufacturing in Arabia Countries, Arab Organization for Agricultural Development, AOAD, 1995.

[27]Trzesniowski, M., 2023, Suspension System, Springer Vieweg, https://doi.org/10.1007/978-3-658-39847-7