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Intensity analysis and structural optimization on multi-shank dozer ripper: visualization of stress, strain and deformation through FEA

Tooth (ripper tip) and shank both are the important part of the ripper which is under huge stress and subject to deformation during operation. In order to improve force condition and to extend its service life, a crawler bulldozer ripper is studied. This paper presents the calculation of the stress, strain developed, and the deformation produced in dozer multi-shank ripper assembled with shank, tooth (also called as tip) and ripper frame. The Finite Element Analysis (FEA) approach was used to determine the stress, strain and deformation. A theoretical model of dozer multi-shank ripper (individual parts like tip, shank, frame) all were created in CATIA with standard dimensions and were assembled further to relate the geometry with practical models and the design was simulated in ANSYS 14 workbench. The properties of the materials used here for shank and tip are as per American Society of Testing and Materials ASTM A897M-90 standards. The materials which are to be tested here on ripper tip and shank are HARDOX-400 and SAILMA-450HI. The magnitude and position of pressure and force applied are described under further sections in detail. The calculation of strain on both the parts with different material is based on maximum distortion theory also equivalent von-misses stress and overall displacements are calculated. Subsequent to findings of the stress and strain suitable modifications and alteration in design and material used are recommended by this study for this particular application.

Keywords: *Ripper tip; shanks; FEA; HARDOX-400; SAILMA-450HI.*

I. Introduction

The rippers of the bulldozer is highly used in construction industry and harrowing the strata or the hard road [1]. Bulldozers use two types of rippers:

1. A giant ripper with one shank and tooth
2. Multi-shank ripper which have more than one shank [2].

According to adjustment provisions there are hinge type, parallelogram type and adjustable parallelogram type rippers.

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Here our study is based upon adjustable parallelogram type ripper. Generally dozers use 3 shank ripper only and the rippers with more than 3 shanks are used in agriculture for ploughing the field. A ripper is generally an assembled unit consisting of shank with tooth bolted at bottom of it and few designs are also assembled with shank protector for more heavy duty work and this whole assembly is fitted through bolts on protecting frame which have the proper attachments position for hydraulic cylinders and drawbar attachment. As shank protector is not always given importance as other parts as frictional effect is more on teeth only so here we excluded it from our study. Also excavators use impact ripper as a demolish equipment. Here our study is fully based upon 3 shank ripper generally used with BEML and KOMATSU 320hp engine. During working most of the ripper's energy is used up in smashing the medium into pieces and removing it by tooth point and the shank. The shank suffers the various forces from the soil under the biggest force of the ripper. Under the action of complicated and external load, the shank often meets the bad and complicated conditions, and often breaks when force crosses the ultimate tensile strength of material used [2]. Hence in order to meet the strength requirement, the materials of tip and shank are chosen keeping in mind the cost factor. So here the aim is to study the effect of load during working on the whole ripper and to know the areas having more stress distribution i.e. to identify the weak zones.

The rippers are provided with the hydraulic attachments for operation. In our study this ripper has lifting and tilting adjustment hydraulic cylinders attached to it. In some models there is only one set of cylinders for both the operation lifting as well as tilting but when two separate sets for both tilting and lifting is provided as is our case then the lifting one is responsible for digging force and getting more penetration.

Magnitude and position of force

A proper study has been done for selecting the pressure at tooth tip of the ripper. The impact rippers and giant rippers are generally specified with maximum operating pressure and this data have been taken as a reference for deciding operating pressure for our analysis. As it is not mentioned clearly that what should be operating pressure for our particular application so the above study was highly useful also the relief valve setting of all the cylinders for ripper operation for different dozer models varies between 22MPa to 27MPa [3] for this particular application and the data of giant and impact ripper is also in accordance with expected limits hence we took a nearby value of 24 MPa to apply on the ripper tip. Since the tractor is classified by a maximum drawbar pull/drag force hence this force values have been assumed to be acting on the front side of the shank and tooth assembly. So there will be two types of load acting on the ripper: 1. Will be acting vertically due to action-reaction pair of lifting cylinder force and 2. Will be acting horizontally due to pulling force of the tractor. Fig.1 shows the position of loads and constraints an assembled model in CATIA which is then imported in ANSYS workbench 14.0

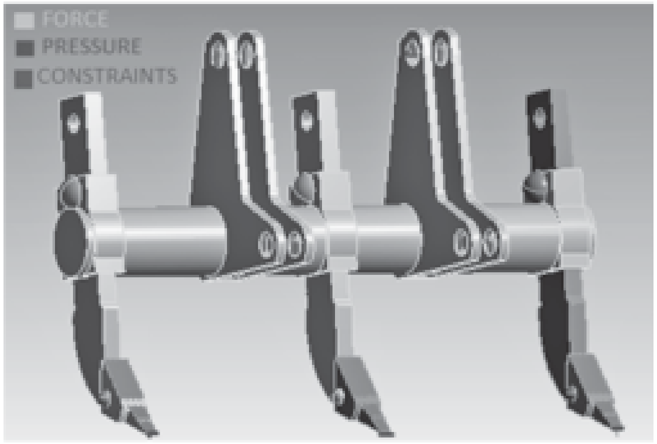

Fig.1 Depicting forces, pressure and constraints

The green coloured areas are showing the application of pulling force. The maximum drawbar force of 320hp and nearby engines is between 600 to 700 kN so a 640 kN force has been distributed equally among these green shaded areas. Also the tips of rippers are shown with blue colour and the 24MPa pressure is assumed to be equally distributed among the three teeth i.e. 8MPa on each tooth tip. The constraints applied parts are shown with red coloured areas. These force and pressure are applied keeping in view of the maximum possible force for that particular application for this particular design. And hence this is how the force is applied during analysis.

In present application the material HARDOX is used extensively in mining equipment because of its excellent high strength, toughness, good wear resistance and machinability and all that at low cost. Along with the type of job the cost is always a main deciding factor for the choice of material hence timely the variation have been done in approaching towards the best possible cost effective and strength wise suited material for the particular application and for present trend HARDOX have been the most preferable one [4]. Here we conducted study on HARDOX-400 on tooth and SAILMA 450HI on shank which are generally used and more preferable than any other material especially for this particular application. These materials have good property combination of strength, ductility and toughness and are used extensively in construction industry for ripper tooth, shank, dozer blades and cutting edges and are also used on other digging and cutting equipment. And hence it is most significant to study the development of stress, strain and deformation produced and their results.

Finite element analysis (FEA) is a very important tool to check the behaviour of component after practical application of stress on it. This powerful design tool has significantly improved both the standard of engineering designs and the methodology of the design process in many industrial applications. FEA allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements. FEM software provides a wide range of simulation options for controlling the complexity of both modelling and analysis of a system [4].

Similarly, the desired level of accuracy required and associated computational time requirements can be managed simultaneously to address most engineering applications. FEA allows entire designs to be constructed, refined, and optimized before the design is manufactured. Teeth and shanks are the main working part of dozer ripper. They have to sustain with the different kinds of stresses being applied continuously at them during operation. Therefore, teeth and shanks must be designed accurately and efficiently with proper choice of material to avoid the deformation and superfluous halts in the operations. Table 1 shows physical properties available for HARDOX-400, SAILMA-450HI, structural steel according to A897M-90 [5, 6, 7].

When normal stresses are applied to HARDOX in service a localized strain occurs which hardens the material. As a result, this material exhibit excellent abrasion resistance which holds enormous significance in digging operation.

II. Research aim

The primary purpose of conducting this research work on a multi-shank dozer ripper is to understand the distribution of stress, strain and deformation produced when the forces are

Table 1 Material Properties

Material	Tensile Strength (MPa)	Yield strength (MPa)	Elongation (%)	Impact Energy (J)	Typical hardness(HBW)
HARDOX-400	1250	1000	10	45	370-430
SAILMA-450HI	700	450	19	NA	366-477
Structural steel	460	250	23	27	157-190

applied at shanks and teeth and hence to identify the weak zones for further modification for increasing the safety limit during operation/digging.

The specific aims of the investigation are two-fold:

- To determine the maximum stress and strain areas so that modifications on design can be made for safer operation.
- To determine the level of stress and strain on SAILMA-450HI and HARDOX-400 and to derive conclusion whether they can be successfully used for teeth and shank manufacturing by relating their maximum stress developed to their ultimate tensile strength and determining the safety limits during operation.

III. Methodology

In the current work application of Finite Element Analysis (FEA) in whole dozer ripper (assembled with teeth, shank, and protector frame) is done. Stress and strain on whole ripper assembly is found out using maximum distortion energy theory. With the help of distortion theory it can be explained that If all structures where loaded in only one direction, it would be easy to predict failure. All that would be needed was a single uniaxial test to find the yield stress and ultimate stress levels. If it is a brittle material, then the ultimate stress will determine failure. For ductile material, failure is assumed to be when the material starts to yield and permanently deform.

The following steps have been adopted:

- A 3D model of main frame, tooth, shank and fasteners (rivets) is prepared in CATIA V5 R-19.
- The analysis part is carried out in ANSYS 14.0 workbench.
- The force is applied at tip of dozer blade cutting edge.
- The magnitude of stress, strain is noted down.
- For this particular application if more strain is there then the alteration in material quantity and design at targeted zones may be suggested. In Table 2 different isotropic (strain values) properties of all the three materials are shown [5, 6, 7].

TABLE 2 ISOTROPIC PROPERTIES

Material	Young's Modulus (GPa)	Poisson's ratio	Density (kg/m³)
HARDOX-400	210	.29	7473.57
SAILMA-450HI	210GPa	.3	7900
Structural steel	200GPa	.3	7850

IV. Analysis through finite element model and simulation

In this study, a three-dimensional elastic-plastic finite element model is used to simulate the strain in whole ripper caused by the drawbar force and the lifting cylinder pressure and simulations are performed using ANSYS 14.0 workbench. The region of interest is the tip of tooth and the middle region of shank (shown in figure further). Where maximum distortion is shown and geometry changes sharply and therefore maximum stress is observed. The deformation shown in picture are according to force and pressure application in this analysis however practical conditions may not be similar in terms of load position and magnitude in fact the load will be always less than what is applied in this analysis as this system is tested for maximum possible limit of pressure and force for this particular application and operating condition and this analysis was assumed for the simplest and most typical case which may arise but the numerical data is in accordance with the expected values hence the simulation results are fully reliable.

We are interested in 'static structural analyses' and 'solid' is used as an element type (by default in system). The ripper frame i.e. main body, teeth, shanks, rivets' (in assembled form) 3D model on CATIA V5 R-19 drafting is shown in Fig.2. The above ripper configurations are as follows [8, 9, and 10]:

i. Main frame length × breadth × height =2400 mm × 790 mm × 1050 mm
ii. Shank length × width × thickness = 1420 mm × 370 mm × 76 mm
iii. Teeth length × breadth × height = 340 mm × 116 mm × 233 mm (all data at the insert point)
iv. Fastener diameter of tooth and shank = 25 mm
v. Fastener diameter of shank and frame = 80 mm

The above ripper specifications are suitable for attachment to BEML model BD155 with additional specifications:

a. Maximum clearance raised = 590 mm
b. Maximum penetration = 780 mm
c. Maximum penetration force = 124.2 kN

Fig.2 shown below is a screenshot of assembled model in CATIA which was then imported in ANSYS workbench 14.0

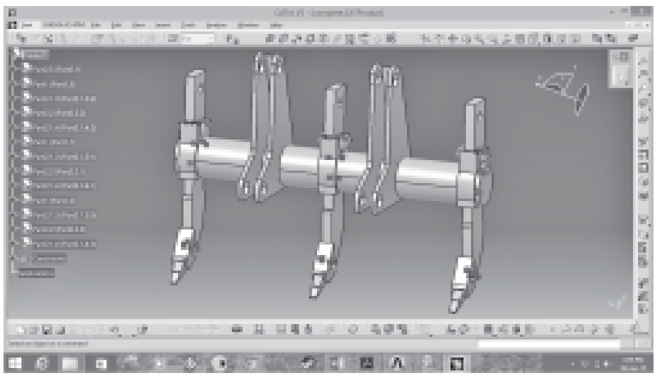

Fig.2 Assembled model in CATIA V5 R-19

As this model was an assembled model so after the import the proper connections (the feature of Ansys workbench platform) were to be established between different contact surfaces. The rest necessary inputs are used which are set by default. To explore the effect of all types of loads on the ripper body a pressure of 24 MPa with 8 MPa on the each tooth cutting tip and 670kN force is equally distributed among three shank-tooth assembly.

V. Results and discussions

A static elastic-plastic finite element model is employed to study the distribution of stress, strain and deformation produced due to loads applied on ripper geometry. The generated results after simulation are added here along with full pictures.

Figs.3 to 5b show the stress, strain and deformation produced on SAILMA-450HI and HARDOX-400 which are used for shank and tooth respectively and gives a clear picture of major and minor stress, strain induced and deformed areas. The stress, strain intensity and deformations increased from blue to red color as they appear in the color strip on left side with the magnitude in the pictures.

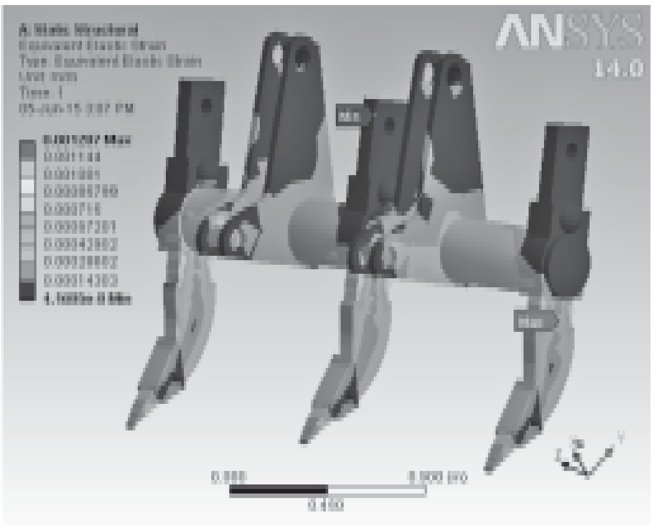

Fig.3(a) Strain induced areas, isometric view 1

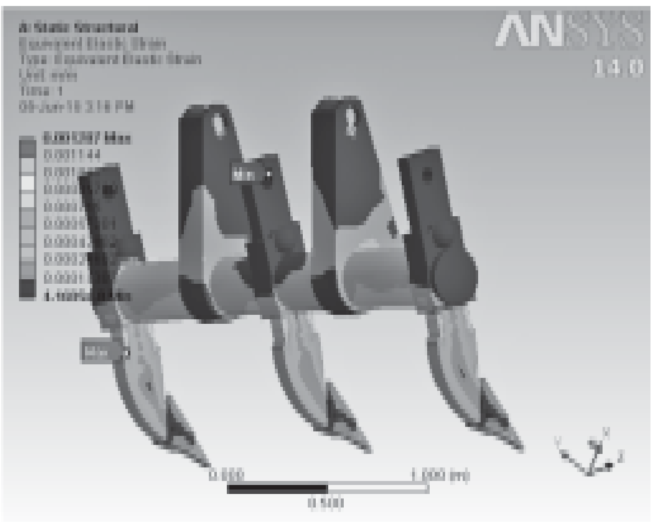

Fig.3(b) Strain induced areas, isometric view 2

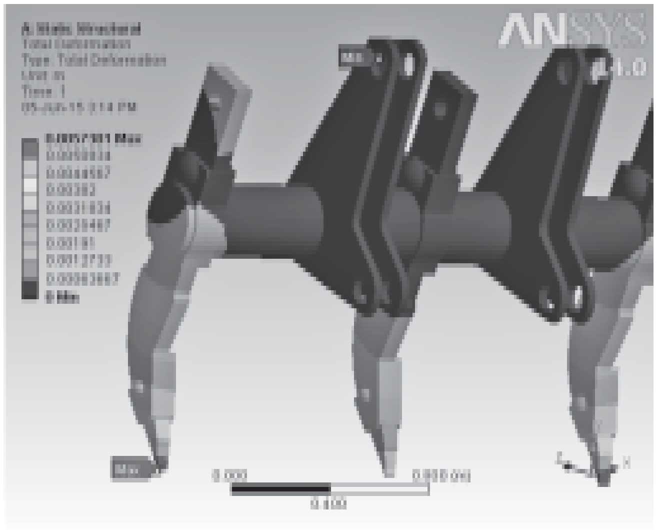

Fig.4(a) Total deformation produced, isometric view 1

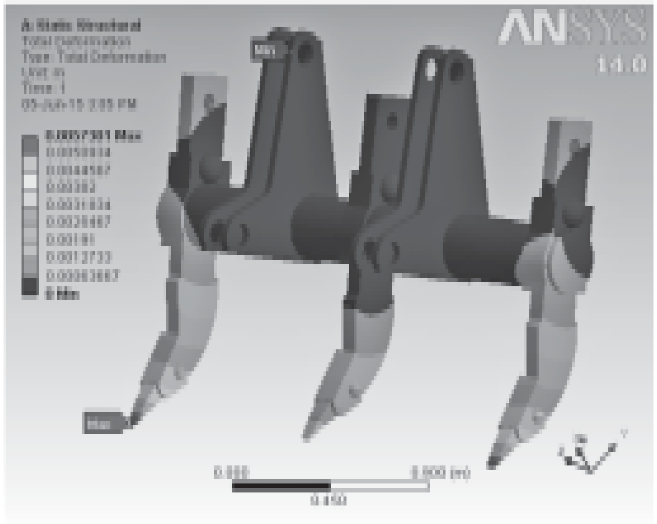

Fig.4(b) Total deformation produced, isometric view 2

The regions showing with red colour are major stress, strain induced and deformed areas and blue coloured regions are minors stress, strain induced and deformed regions. The main frame is a bulky part and is used with structural steel for analysis as through experience it was predicted that it will have least stress distribution due to more quantity of material.

Among all the figures described from 3(a) to 5(b), the Fig.3(a) and Fig. 3(b) depict strain induced areas, Fig.4(a) and Fig.4(b) are showing the deformation produced in the structure whereas Fig.5(a) and Fig.5(b) show the von-misses stress distribution on the whole structure. The two isometric views are presented for a more clear understanding.

VI. Inference

From all the above data depicted through pictures it is cleared that in a ripper tooth tip is most deformed part and whole

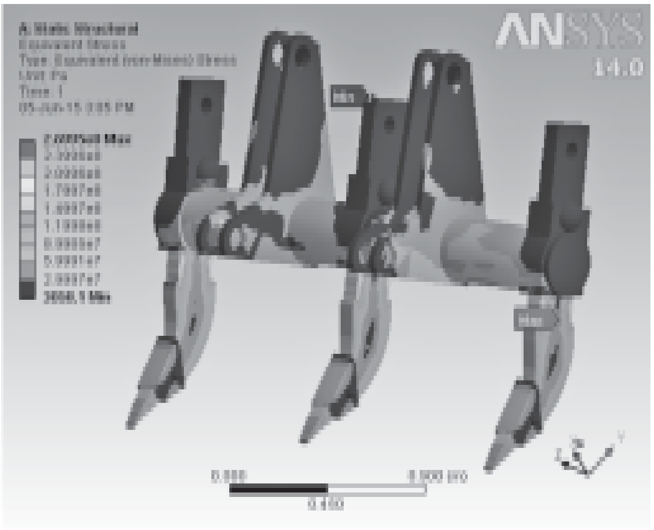

Fig.5(a) Von-misses stress distribution, isometric view 1

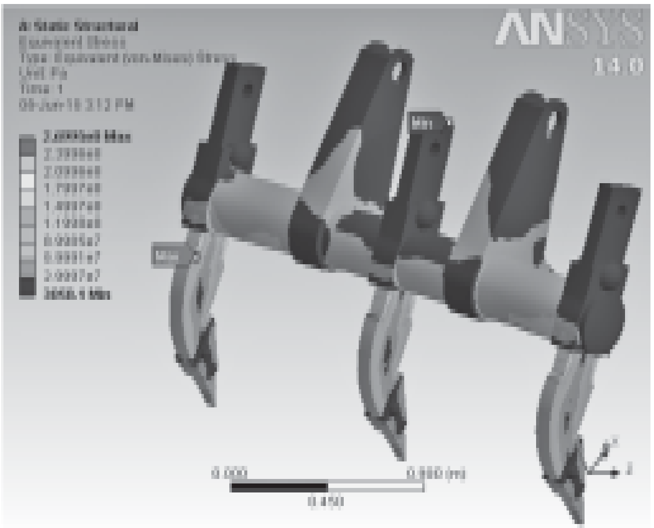

Fig.5(b) Von-misses stress distribution, isometric view 2

tooth is under deformation due to direct load application and it also matches with practical case as teeth are to be changed after a certain period of operation; e.g. 500 hrs – 600 hrs. The middle of the shank have more stressed zones and these are the regions from where breaking of shank takes place and hence these parts require more material by altering the geometry. The frame is least stressed, as we can see that maximum it is blue coloured as it accumulates the largest quantity metal and here we have used the structural steel but we could have gone for another material having better property but for tooth the material should be hard, brittle and should have work hardening property, there are strict limitation in choice of tooth material.

Below is the result as shown in Table 3 derived through study of above figures generated after simulation.

VII. Conclusions

The following conclusions have been drawn:

- The factor of safety at maximum stressed zones comes out to be 2.59 which are not acceptable. In this theoretical analysis we took the thickness of shank to be 76mm but for this particular application it seems to be less and needs to be altered after validation from the field.
- Though the teeth tips are not much stressed but they are under maximum deformation as they are always in contact with the material and hence metal loss takes place gradually from the tooth body and they are timely replaced when they are deformed up to permissible limit.
- The ripper frame is under least stress, strain and deformation effects so there can be appreciable difference in qualities of material used for those tooth and shanks and rest of the frame.
- A special attention and consciousness are needed for choice of material for tooth whereas a much freedom is there for choice of material for frame and can go for less strength material which may be more cost effective and saves unnecessary high material usage.
- Loading condition greatly influences the mechanical behaviour of the material. Therefore, in sensitive cases, material selections for the solid bodies are to be done with utmost care.
- Fracture and fatigue analysis on the components could be beneficial to examine the working life of the dozer ripper specially shank and tooth. Therefore, more sensitive performance calculations could be made.
- The findings and methodology adopted can be applied to other types of materials other than SAILMA/HARDOX/ structural steel with different mechanical properties.

VIII. Scope for future work

- A similar study can be conducted with different material which claims of better property and hence cost effectiveness can be determined.
- A very less effort has been put till now in deciding the right material and design for dozer ripper for different application.

TABLE 3. RESULT SHOWING THE MAXIMUM AND MINIMUM VALUE OF STRESS.

Max. Stress	Min. Stress	δ_1(m)	δ_2 (m)	ε_1	ε_2
270MPa	3.1kPa	5.7×10^{-3}	6.4×10^{-4}	1.3×10^{-3}	4.2×10^{-8}

Maximum Value with 1, Minimum Value with 2

- If designing of theoretical model would be done in same platform where analysis is to be made then more accurate results would be obtained.
- More extensive work can be done to replace the existing traditional materials and which are under use without any deep study.
- A dynamic study can be conducted in software like ADAMS if hydraulic interface is to be created between the ripper and hydraulic cylinders; also there are other platforms too for designing as well as simulation like use of Neural Network, Abaqus, and Matlab.
- Similar study can be conducted for a single shank giant ripper. A transient vibrational analysis can be done using ANSYS for impact ripper too.

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