

Optimization of Material Handling Trolley using Finite Element Analysis

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Abstract: The purpose of this work is to optimize the design using finite element analysis method and to validate the design. The main intention is to reduce the weight of the structural design of the base welded structure which is the only component that bears the whole load plus the weight of the trolley and then it transfer to the wheel. This paper presents finite element analysis of a methodology to model and simulate trolley used in automotive industry, especially in car manufacturing company for shifting the car body and panel. In this study, the design is carried out using CREO software and analysis of the trolley is performed using finite element commercial code ANSYS Workbench. The Von-mises yield principle has been used to determine the distribution of stress intensity. The proposed model has better results compared to the existing model of the trolley.

Keywords: Ansys, Ergonomics, Material handling system, Trolley, Von-mises stress

I. Introduction

Trolley is a type of vehicle that runs along the street on tracks. The trolley is used in a wide area of application like home, office, railways, airport, hospital, resort, and construction industries and in manufacturing industries. Thus usage of trolley plays a vital role, utmost in all construction industries and manufacturing industries. Trolley are manufactured according to various features like load capacity, materials and mainly of ergonomic design. The main intention of the trolley is to provide a hassle-free mode of transporting from one loading station to other loading station. The existing designs of trolleys are enormous due to the reality that they require to carry loads of different sizes. In the global competition, it is very essential for the manufacturer to develop new product designs to market at a more rapidly rate and also at cheaper cost. Optimization of trolley is required to improve strength to weight ratio for a certain factor of safety without varying any assembly parameters. Trolley is the large base which is used to transfer the heavy parts from one place to another place. The Trolley designed here is used to carry the car body and panel from loading station to the Coordinate Measuring Machine (CMM) inspection station. The Trolley is moved manually over the tracks mounted on the floor. Four castor wheels of 2 types are used to move the Trolley, one is V-groove type to guide the trolley and another is flat type to have less friction over tracks.

The tracks are made up of structural steel flats and structural angles for V-groove tracks. The tracks are laid for a distance of 50 metres, and it covers 3 CMM stations. Theodolite / water level tubes are used to check the level of tracks and shims are used to adjust level throughout the total distance of 50 metres. Anchor bolts are used to anchor the tracks on the floor for rigid mountings. The 2D drawings are converted into 3D model using CREO software and final manufacturing and assembly drawings are generated from the 3D models. In the present market scenario, weight reduction, cost reduction technique and simplicity in design are playing a significant role to meet the competition in the industrial market [1]. Various components or products such as farming machinery, thrashers, tractor trolleys etc used in rural areas are mostly manufactured by small scale industries. These rural products are not properly designed. Accordingly, industries have tried to use the computer's vast memory facility, fast meting out speed, and user-friendly interactive graphics capability to automate and tie together otherwise cumbersome and separate engineering or production tasks, thus reducing the cost and time of product development and manufacture. The following three technologies such as Computer Aided Engineering (CAE) Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) are the used for this purpose during the product cycle. Welded base frame is a structural assembly consisting of beams with various cross sections and size. The sections used may be of the same dimensions and cross sections, or a combination of both may be used for optimum weight and strength. The sections can be of IS standard dimension or custom made. Placement of beams is done in such a way that all the footprints of the components are covered. Different arrangements for assembly lifting (for e.g. handle, roller, I bolt, pin etc.) are provided in the structural frame. The frame was designed and analyzed for eight ton load under both car body holding fixture and car body. For sufficiently lower values of deflection (< 2.5 mm), and higher value of factor of safety(> 1.5), the structure was redesigned using thinner and smaller IS standard sections. The final optimum solution was achieved by repetitive iterations with smaller sections. The base frame is subjected to gravitational

loading of all the components mounted. Depending on the type of loading, the optimum design is made considering material properties and type of welding.

II. Various model of Trolley

Some of the non powered (manually) handling trolleys are illustrated which may not be used for carrying heavy loads. Hand trolley shown in Fig.1 is manufactured with innovative design and good outlook features. This Platform hand truck trolleys are designed under the direction of capable professionals by complicated technology and quality tested raw material in line with the international quality standards. To understand some basic model of manually handling trolleys, the source of all images is taken from Lokpal Industries, India, Noida, Uttar Pradesh [2] & [3].



Fig. 1 Platform hand trolley



Fig. 2 Tilting forklift trolley

Source: Lokpal Industries

To meet the requirements of the customer, Tilting forklift trolley shown in Fig. 2 is quietly made at highly developed production unit by means of making use of superior quality material and advanced equipment in fulfillment with the industrial eminence norms. This type of trolley is used for load capacity 50-75 kg. The features include; Good finish and made up of high grade material.

Folding trolley shown in Fig. 3 is manufactured with exactitude-design with features like easy installation and high durability, the given range is widely demanded in quite a lot of industries. It also has optimum strength and anti corrosive. Canvas wheel barrow shown in Fig. 4 is a type of trolley made with big pneumatic wheel, powdered coated and light weight with greater strength with load capacity of 25-110 kg, used in many applications as per the requirements.



Fig. 3 Folding trolley



Fig. 4 Canvas wheel barrow trolley

Gas cylinder trolley shown in Fig. 5 is manufactured with ergonomics design which allows any worker, however sturdy, to move cylinders around the workplace within manual handling regulations. Platform hand trolley shown in Fig. 6 is made up of strong powder coated chequered plate with anti skid platform with wheel brake with removable handle. It can withstand load capacity of 500 kg. These wheels are made with rubber coated type. Single wheeled wheelbarrow trolley shown in Fig. 7 is manufactured with supreme grade of stainless steel which imparts maximum load bearing capacity and optimum tensile strength in the wheel shown. Mostly this type of trolley is widely used in construction Industries for the purposes movement of material.



Fig. 5 Gas cylinder trolley



Fig. 6 Platform hand trolley

Sack trolley shown in Fig. 8 is a type of trolley made up of 10" pneumatic tyres and tubular steel frame has an extendable loading platform feature. Sack trolley is suitable for office, factory, and warehouse etc, which can withstand load capacity of 250-350 kg



Fig. 7 Single wheeled wheelbarrow trolley



Fig. 8 Sack trolley

III. Importance of Ergonomics design approach

According to the United State, Department of Labor, handling is defined as Seizing, holding, grasping, turning, or otherwise working with the hand or hands. Hand fingers are involved only to the extent that they are an extension of the hand, such as to turn, twist and lift etc. The workplace may be improved by manual handling procedures [4]. The manual handling of containers may cause workers to physical conditions (e.g., load, awkward postures, and repetitive motions) that may lead to injuries, wasted time, and wasted energy. To avoid these problems, every industry is directly benefited from *improving the fit* between the demands of work tasks and the capabilities of your workers. The abilities of the workers may vary because of differences in gender, age, physical fitness, stature, strength, and other factors to perform work tasks [4] & [5].

3.1 By changing the workplace by improving the fit may benefit to:

- ✓ Preventing or reducing injuries of workers
- ✓ By decreasing forces in lifting, handling, pushing, and pulling materials will leads to reduce worker efforts
- ✓ Reducing risk factors for musculoskeletal disorders. This further reduces or eliminate workers' compensation claims, excessive worker turnover, absenteeism, and retraining
- ✓ Increasing productivity, product & service and quality concepts

Engineering improvements and Administrative improvements are two types of ergonomic improvements. Engineering improvements include modifying, remodeling the design, providing or replacing equipment, tools, workstations, packaging, products, or materials, parts and processes. Administrative improvements include altering from heavy tasks to light tasks, adjusting the work schedules and work practices, providing revival time, providing variety in jobs to eliminate or reduce repetition (i.e., allotting same nature of work to same muscle groups), Modifying work practices so that workers perform work within their control zone (i.e., below the shoulders, above the knees, and close to the body) and Rotate workers through jobs that use different muscles, body parts, or postures

3.2 Four steps to a proactive action plan:

- ✓ Look for clues by reviewing written records, observing work activities and using assessment tools
- ✓ Prioritize jobs for improvements by considering frequency and severity of the risk factors, frequency and severity of complaints, and ideas of workers for making improvements
- ✓ Make improvements by following ways;
 - Discuss with various employees
 - Contact others in your industry
 - Studying the equipment catalogs
 - Interacting with equipment vendors
 - Consult with ergonomics experts
- ✓ Follow up

The below figures Fig. 9 and Fig. 10 show, how to lift a box manually from the ground floor? This technique may be effective only if the loads are small, light weight and can be easily fit between the knees. Always avoid lifting from the floor whenever possible. While lifting from the floor, do not bend at the waist. The below technique shown in the figure helps the worker to keep the spine in safer position, while lifting from the floor



Source: California Department of Industrial Relations, 2007
Fig. 9 Worker lifting a packed box safely from the ground floor

To alternate the manually handling system, later industries used powered and non-powered equipment. Non-powered equipment such as drum dolly, cart or platform truck, portable scissors lift, conveyers or slide, pallet truck, crane, etc. Powered equipment includes such as stacker, powered hand truck, forklift, power crane, tilter, etc.



Source: California Department of Industrial Relations, 2007
Fig. 10 Worker lifting a packed box safely from the ground floor

Nowadays Robotic Material Handling Systems designed by various feature like small footprint, variable speeds, simple programming [6]. Robotic Material Handling Systems are mainly useful while dealing with harmful and likely injury-causing materials, including recurring motion exposure. Robotic Material Handling Systems are adaptable to odd sizes, small scales, and randomly oriented pieces. The systems also exceed standards for purity, product integrity and cleanliness.

IV. Designing Procedures and Parameters

Two types of optimization involved;

- ✓ Weight optimization: To reduce the weight of the structure
- ✓ Shape optimization: To replace rectangular beam into I-beam

Drawback of existing model

- ✓ In an existing model it consumes more weight, so it increases the initial cost of the trolley.
- ✓ In existing model rectangular channel is used which is difficult to carry the heavy load.

Design of base structural frame

- ✓ The base frame required to support various components has been designed by conventional design procedure. The weights of the components mounted on the frame were considered as loads for designing. Some simplifying assumptions were made at the initial stages in order to decide the cross sections of various beams.
- ✓ There are different new techniques which enable the production of a wide range of structures and shapes, the procedures being the following;
 - High-precision stress analysis
 - Computerized stress analysis
 - Innovative jointing

The structural steel all over the world pre-dominates the construction scenario. This material has been exhaustively used in various constructions all over the world because of its various specific characteristics that are very much ideally suited for construction. Structural steel is durable and can be well molded to give the desired shape to give an ultimate look to the structure that has been constructed. Connections are normally made either by bolting or welding. Bolting is common in field connections, since it is simple and economical to make. Bolting is also regarded as being more appropriate in field connections from considerations of safety. However, welding connections, which are easier to make and are more efficient, are usually resorted in shop fabrications. Welded connections are direct and efficient means of transferring forces from one member to the adjacent member. Welded connections are generally made by melting base metal from parts to be joined with weld metal, which upon cooling form the connection. The welded connections in a majority of the cases may be categorized as fillet weld or butt (or groove) welds.

- ✓ Fillet welds are made against two surfaces of adjacent plates to join them together
 - Merits:
 - Simple, fast and economical to make, and
 - Does not require very skilled labour
 - Demerits:
 - Not appropriate to transfer forces large in magnitude,
 - Poorer performance under fatigue loading
- ✓ Butt welds are made by butting plate surfaces against one another and filling the gap between contact surfaces with weld metal, in the process fusing the base metal also together.
 - Merits:
 - Easily designed and fabricated to be as strong as the member,
 - Better fatigue characteristics, compared to fillet welds.
 - Demerits:
 - Easily designed and fabricated to be as strong as the member,
 - Better fatigue characteristics, compared to fillet welds.
- ✓ Thermal stress relief: Residual stresses resulting from welding are reduced by a post weld thermal stress relief heat treatment. The residual stress remaining in a material after stress relief treatment will depend on rate of cooling;
 - To improve the dimensional stability
 - To decrease the heat affected zone (HAZ) hardness by decomposition of marten site and other supersaturated structures.
 - To increase the resistance to corrosion and to remove cold cracking

V. Optimization

The designed frame was analyzed with Finite Element Method. The analysis was required to check the values of induced stresses and deflections caused due to the weights of components. The STEP file structure was meshed and analyzed using ANSYS Workbench for stresses and displacements during various loading conditions. In today's modern construction the beams are generally made up of materials like: Steel, Wood, Reinforced concrete. Trolley model is designed with various design parameters for the casting industries and CAD model is constructed using CREO- software. It is seen that the design is safe and can be implemented in casting industries for small and medium scale castings [7]. Material handling techniques become necessary to reduce the manufacturing cost, manufacturing cycle time, smooth material flow and remain competitive on various issues usually faced by small and medium enterprises in handling parts during different stages of processing in a machine shop that houses a variety of machine tools [8]. They have identified the wasteful activities regarding the material handling, and to streamline the activities to reach a minimum of material handling in Ginning machine manufacturing company and suggested to create more space and that fits the transportation devices better in their case study [9]. Material properties of Mild Steel are shown in Table. 1

Table. 1 Material Properties of Mild Steel

Properties	Values
Density	7.5×10^{-6} Kg/mm ³
Young's modulus	2×10^5 N/mm ²
Poisson Ratio	0.29
Ultimate Strength	1400 N/mm ²
Yield Strength	750 N/mm ²

5.1 Static Analysis

The static analysis is applied when the value of any load acting on frame does not change with time. Generally linear behaving materials are used for manufacturing of frames. Thus the structural welded base frame structure was subjected to linear static analysis. The material used is structural steel cold-formed welded, structural sections. The literature regarding base frames being rare, their hypothetical similarity with automotive chassis gives aid in referring the chassis analysis methods. Meshing for Iteration I structure was done and later remote forces and respective constrains were applied. Weight of the body is always assumed to be acting from its Centre of Gravity, hence applied as a remote force. The forces behave rigidly, i.e. as if the whole body is mounted on the frame. For analysis, some of the parts to be an idealized like roller CAM, Eye bolt, handle holder, handle lock pin rest of the parts to be included .The rectangular section up to length 1500 mm was loaded and pad to be constrained in vertical direction. Dummy constrains (along horizontal axes) were also given in both cases. They help in solving Finite Element Method equations correctly without affecting stress distribution.

5.2 Finite Element Modeling

Finite element modeling of any solid component consists of geometry generation, applying material properties, meshing the component, defining the boundary constraints, and applying the proper load type. These steps will lead to the stresses and displacements in the component. In this study, similar analysis procedure is performed for structural steel beams. Fig. 11 shows the isometric view of trolley. The drawing specification of the trolley is shown in Table. 2

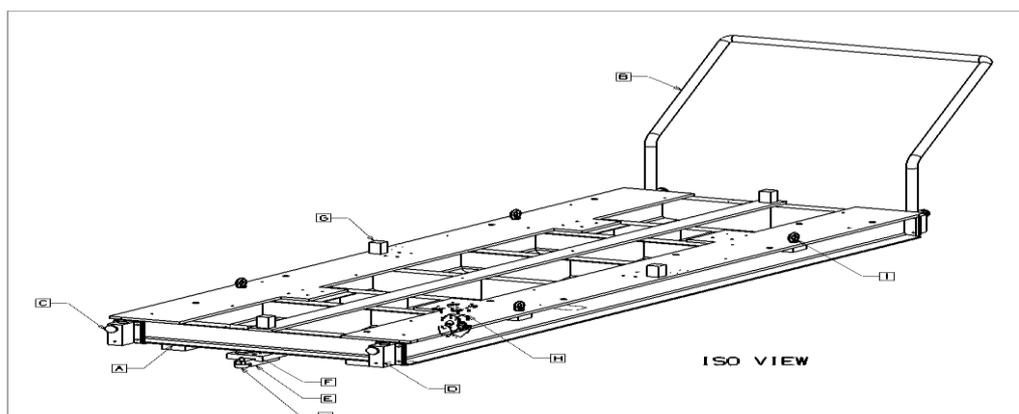


Fig. 11 Isometric view of existing trolley

Table. 2 Trolley Drawing specifications

J	CAM ROLLER	2	PURCHASE	(IKO MAKE-MODEL:CF 20J)	N/A
I	EYE BOLT	4	PURCHASE	M20 EYE BOLT	N/A
H	CASTER WHEEL - (MUVTON MAKE)	4	PURCHASE	DIA 150 (MODEL:GRDE 62R MCNYJ)	N/A
G	REFERENCE BLOCK	4	MS	64 X 64 X 80MM	N/A
F	TROLLEY LOCK PIN	2	MS	DIA 50 X 80 LENGTH	N/A
E	CAM Z-BRACKET	2	MS	50 X 50 X 280MM	N/A
D	HANDLE HOLDER	4	MS	100 X 100 X 150MM	N/A
C	HANDLE LOCK PIN	4	MS	DIA 50 X 85MM	N/A
B	OPERATOR HANDLE	1	STL. TUBE	DIA 42 X 4 W/T X 4000 DEV. LENGTH	N/A
A	BASE WELDED STRUCTURE	1	STD.	N/A	N/A
PC NO	PART NAME	QTY	MATERIAL	DIMENSION	REMARK

5.3 Mesh Generation

FEA analysis is performed on trolley for the dynamic load analysis. In this section, meshing for dynamic FEA is presented for the steel. Quadratic tetrahedral elements are used to mesh the trolley finite element geometry. Tetrahedral elements (element size is 7) are used for meshing the imported complex geometries to the ANSYS Workbench software are shown in Fig. 12, Fig. 13, Fig. 14 and Fig. 15.

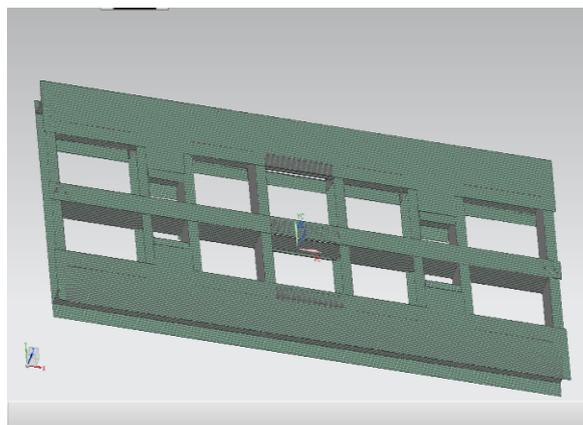


Fig. 12 Mesh generation

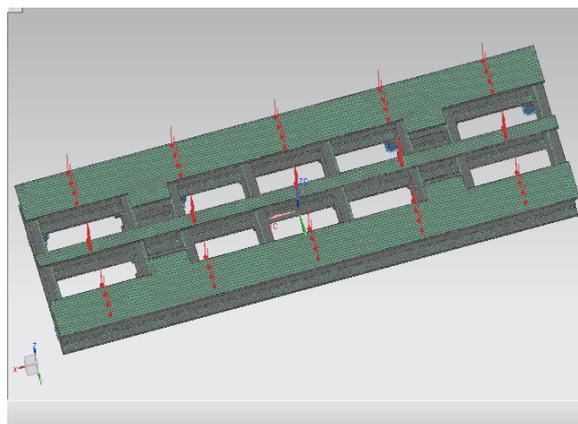


Fig. 13 Load applies at downwards direction using solver and post-processor

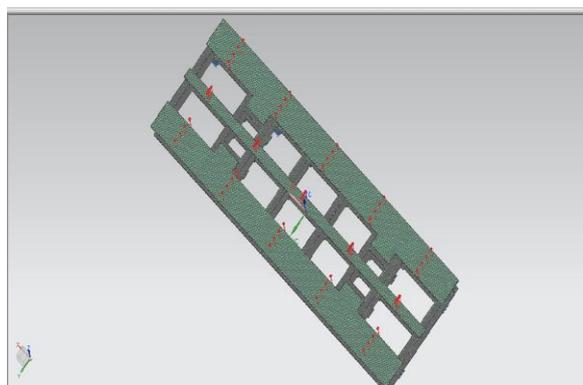


Fig. 14 Load applies at upwards direction using solver and post-processor

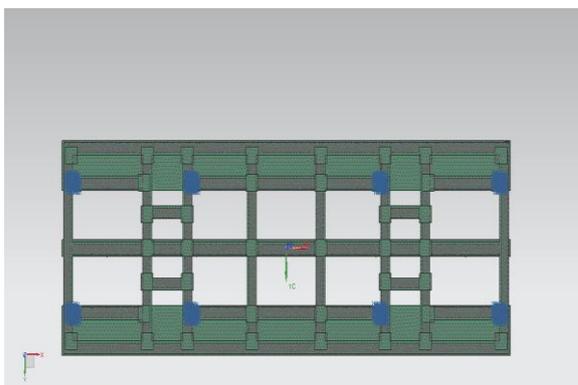


Fig. 15 Fixed supports

5.4 Finite Element Analysis of Existing Trolley

For the FE Analysis, it is necessary to create a solid model of trolley and also to create a FEA model. In the present work, static analysis has been carried out for the trolley considering sudden load effects. The structural base frame of trolley integrates the main components of system such as structural plate, channels, and

section beams. It is considered that structural plate is integral with of section beams which carries the weight of plate and pay load acting on top plate. The total weight of trolley excluding roller wheel, handle, and lock pin and car body weight is 9957 kg. External weight acting on the trolley is car body weight of 3000Kg and car body holding fixture weight of 1000kg .Totally 4000kg and factor of safety 1.5.This load is considered to be distributed over the top plate area of 1270 x 3750 mm² .Thus this distributed load considered for analysis is 6000N. The deformation, maximum and minimum stress is shown in Fig. 16, Fig. 17, and Fig. 18. The model is discretized using solid 187 elements with 52443 elements and 106801 nodes.

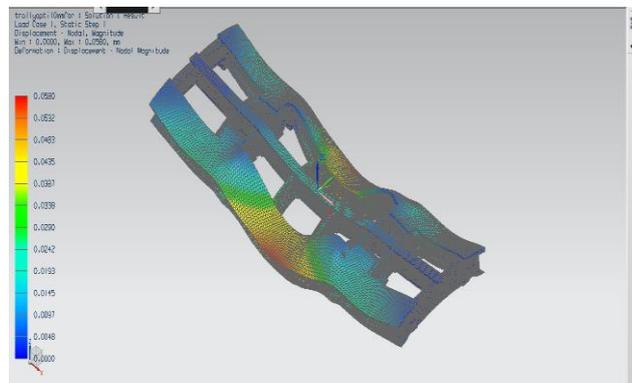


Fig. 16 Total Deformation - Distribution of Von -Mises stresses (MPa) at trolley models. Maximum displacement 0.0580 mm and Minimum displacement 0.0000 mm .Blue to red colors represents stress values from lower to higher respectively

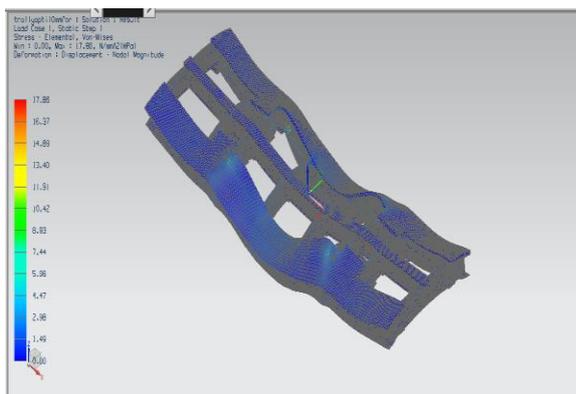


Fig. 17 Equivalent Stress: Von-Mises: Maximum stress 17.86 MPa. Blue to red colors represents stress values from lower to higher respectively

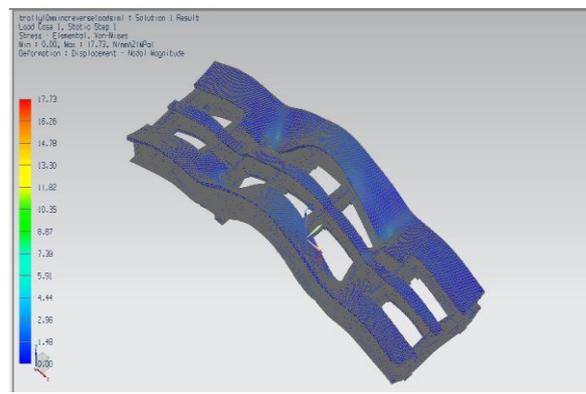


Fig. 18 Equivalent Strain: Maximum stress 17.73 MPa and Minimum stress 0.00 MPa. Blue to red colors represents stress values from lower to higher respectively

5.5 Redesigning of the Trolley

Redesigning the trolley and removing material from this section was the next optimization case under consideration while keeping the feasibility of the manufacturing process in mind. This does not requires negative slopes. The Structural steel plate thickness was modified then supporting pads are introduced. There is not much changes would be implemented in structural beam sections. In this, three cases have been analyzed.

CASE 1: 5mm plate thickness with pad. The 2D view, load applied, deformation, maximum and minimum stress is shown in Fig. 19, Fig. 20, Fig. 21, Fig. 22, Fig. 23, and Fig. 24

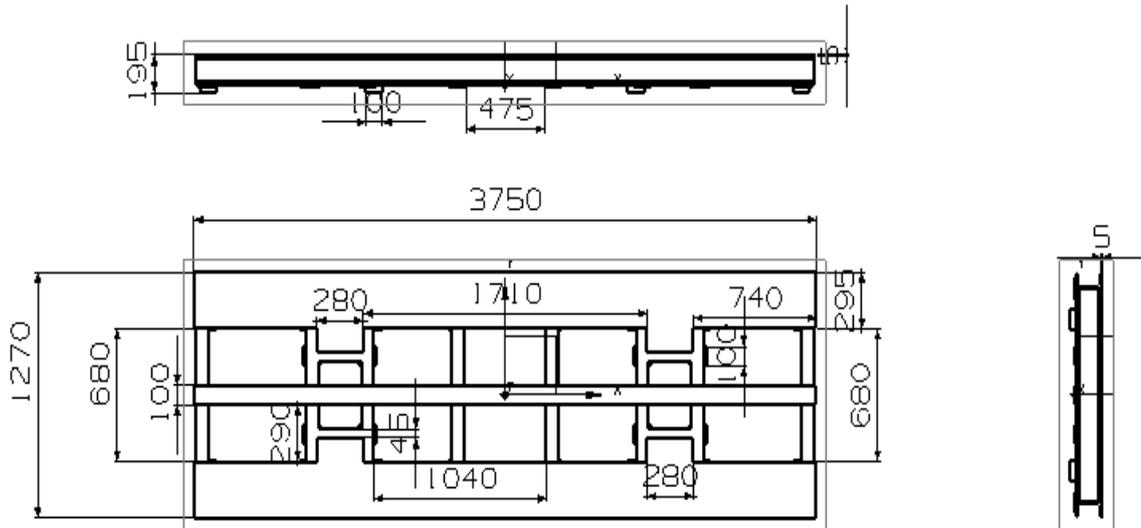


Fig. 19 2D view of Trolley for Case 1

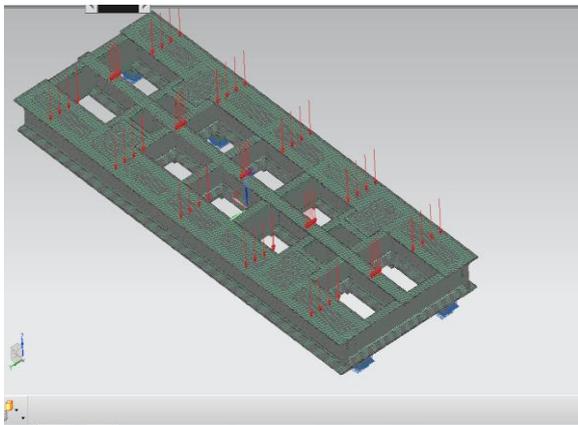


Fig. 20 Load applied downwards

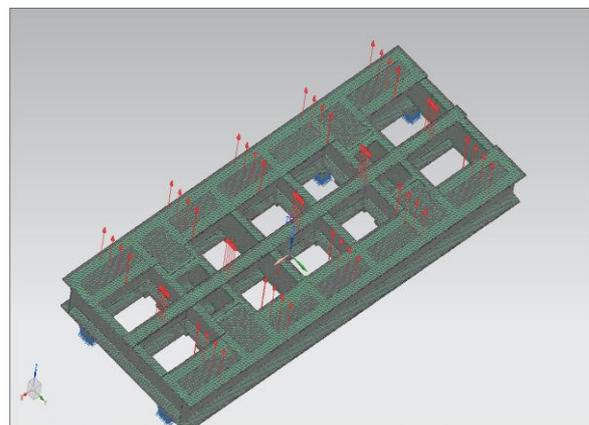


Fig. 21 Load applied upwards

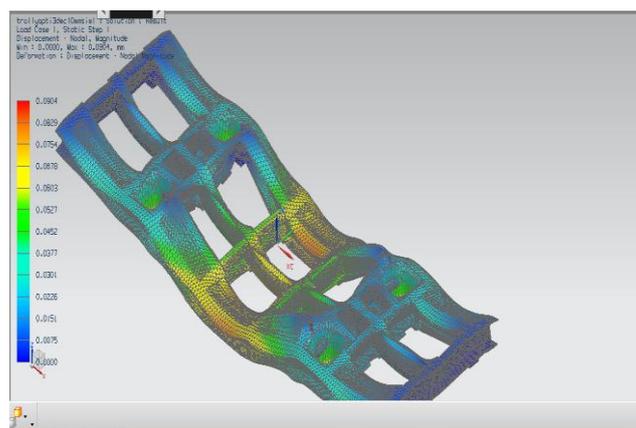


Fig. 22 Total Deformation - Distribution of Von- Mises stresses (MPa) at trolley models. Maximum displacement 0.0904 mm and Minimum displacement 0.0000 mm Blue to red colors represents stress values from lower to higher respectively

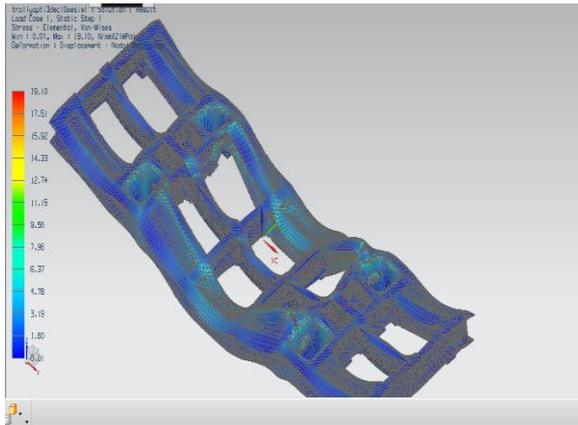


Fig. 23 Equivalent Stress: Von-Mises: Maximum stress 19.10 MPa and Minimum stress 0.01 MPa . Blue to red colors represents stress values from lower to higher respectively

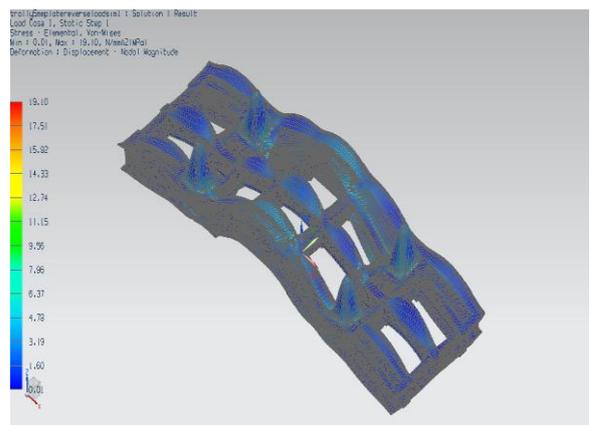


Fig. 24 Equivalent Strain: Von-Mises: Maximum stress 19.10 MPa and Minimum stress 0.01 MPa . Blue to red colors represents stress values from lower to higher respectively

CASE 2: 15mm plate thickness with pad. The deformation, maximum and minimum stress is shown in Fig. 25, Fig. 26, and Fig. 27

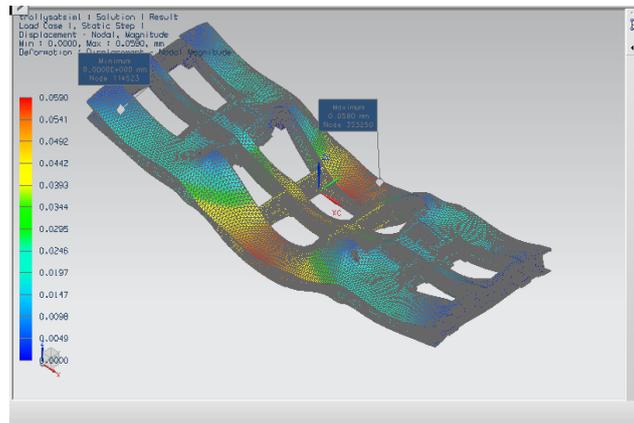


Fig. 25 Total Deformation - Distribution of von Mises stresses (MPa) at trolley models Maximum displacement 0.0590 mm and Minimum displacement 0.0000 mm Blue to red colors represents stress values from lower to higher respectively

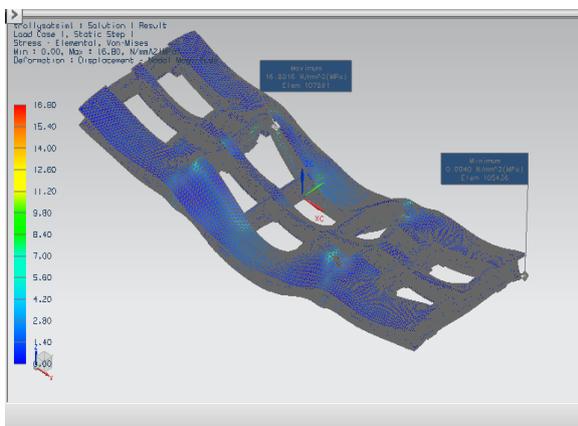


Fig. 26 Equivalent Stress: Von-Mises: Maximum stress 16.80 MPa and Minimum stress 0.0040 MPa . Blue to red colors represents stress values from lower to higher respectively

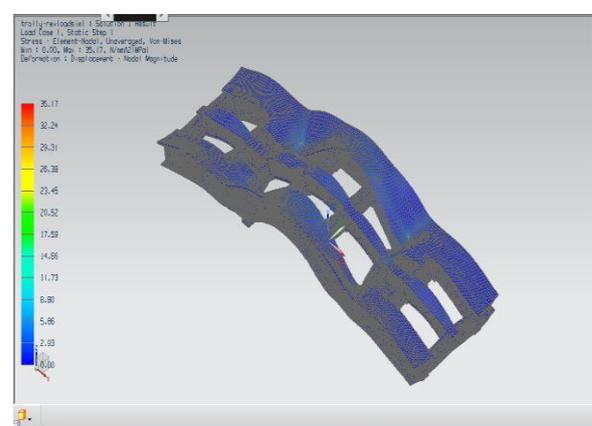


Fig. 27 Equivalent Strain: Von-Mises: Maximum stress 35.17 MPa and Minimum stress 0.00 MPa. Blue to red colors represents stress values from lower to higher respectively

CASE 3: Without pad and 25mm plate. The deformation, maximum and minimum stress is shown in Fig. 28, Fig. 29, and Fig. 30

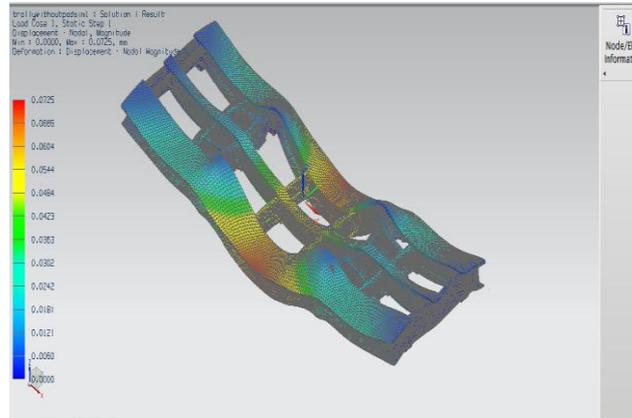


Fig. 28 Total Deformation - Distribution of Von- Mises stresses (MPa) at trolley models. Maximum displacement 0.0725 mm and Minimum displacement 0.0000 mm Blue to red colors represents stress values from lower to higher respectively

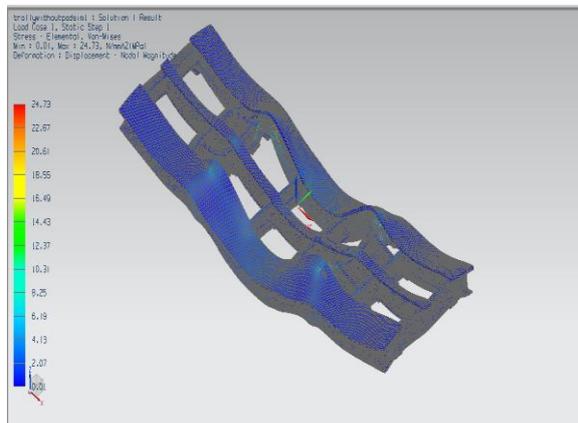


Fig. 29 Equivalent Stress: Von-Mises: Maximum stress 24.73 MPa and Minimum stress 0.01 MPa . Blue to red colors represents stress values from lower to higher respectively

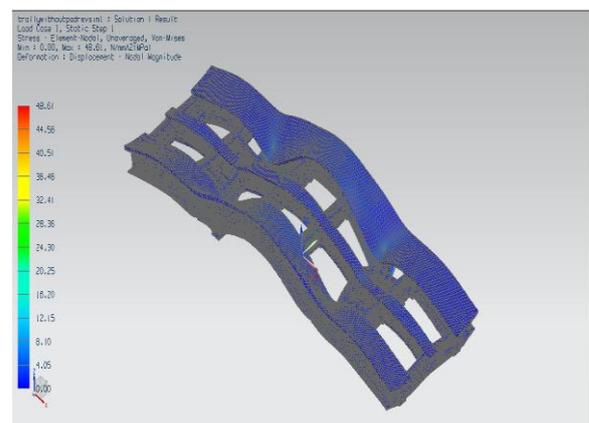


Fig. 30 Equivalent Strain: Von-Mises: Maximum stress 48.61 MPa and Minimum stress 0.00 MPa . Blue to red colors represents stress values from lower to higher respectively

Table. 3 Consolidated shape optimization

Design Stress	Existing Case	Case 1	Case 2	Case 3
Max. stress(N/mm ²)	17.86	19.16	35.17	48.61
Min. stress(N/mm ²)	17.73	19.10	16.80	24.73
Mean stress(N/mm ²)	35.59	38.26	51.97	73.34
Amp. stress(N/mm ²)	0.13	0.06	18.37	23.88
Deflection	0.06	0.1	0.05	0.07
Weight	9957	5776	7866	9699
Weight reduction %	Existing	42	20	2.6
Inference	Not Ok	Not Ok	<i>Ok</i>	Not Ok

Table. 3 shows the consolidated shape optimization of the trolley, from this table it is clear that that Case 2 has proposed better results compared to the existing model of the trolley.

VI. Conclusion

Finite element analysis of trolley was carried out to optimize and validate the design. To design a trolley, a design procedure is proposed. The design procedure leads to fine results in a shorter time. In this study, the design is carried out using CREO software and analysis of the trolley is performed using finite element commercial code ANSYS Workbench. The Von-mises yield principle has been used to determine the

distribution of stress intensity. The proposed model has better results compared to the existing model of the trolley by means of reducing the weight of the structural design of the base welded structure which is directly transferred to the wheel.

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