Kaunas University of Technology
Faculty of Mechanical Engineering and Design

Design and Optimization of Anti-Roll Bar

Master's Final Degree Project

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Kaunas, 2018

Kaunas University of Technology
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Master's Final Degree Project
Vehicle Engineering (621E20001)

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Kaunas, 2018

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Design and Optimization of Anti-roll Bar

Declaration of Academic Integrity

I confirm that the final project of mine, Amalraj Palraj, Palraj Mariappa, on the topic „Design and Optimization of Anti-roll Bar "is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis has been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this project.

I fully and completely understand that any discovery of any manifestations/case/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology.

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KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Study programme VEHICLE ENGINEERING (621E20001)

TASK ASSIGNMENT FOR FINAL DEGREE PROJECT OF MASTER STUDIES

Given to the student: Amalraj Palraj Palraj Mariappa

1. Title of the Project:

Design and Optimization of Anti-roll Bar

Stabilizatoriaus Projektavimas Ir Optimizavimas

2. Aim and Tasks of the Project

To examine which measure the durability of the Anti-roll Bar on rotation and vertical displacement

Tasks:

1. To perform the literature review
2. Compare the stiffness of the various dimensions of the anti-roll bar, which will be made of spring steel
3. Perform an anti-roll bar analysis ANSYS Workbench and ANSYS parametric design language program
4. Assess how the displacement depends on the size of the forces and the dimensions of the anti-roll bar
5. Check the stresses and vertical displacements of the designed composite anti-roll bar

2. Initial Data:

Specification	Values
Type of cross-section	Hollow circular cross-section
Full length of the bar	1100mm
Location of bushing	±400
Internal diameter	22
External diameter	18

4.Main Requirements and Conditions

Spring Design Manual for desging Anti-roll bar

CAD- SolidWorks

CAE-ANSYS

5. Structure of the Text Part

- Detailed about the severity of the anti-roll bar with the help of the literature review depending the researches made by former authors.
- Selecting a proper Anti-roll bar model to carry out rolling stiffness and total deformation test
- Chosen model is designed using the CAD software's (SOLIDWORKS)
- The parameter in Anti-roll Bar are calculated which is mentioned in the Spring Design Manual
- Analytical calculation on the designed model using CAE software's (ANSYS Workbench and ANSYS APDL)
- Discussion about the result

6. Structure of the Graphical Part

- Correlation Matrix Parameter
- Sensitivity of the Parameter
- Response Graph of the Bar

7. Consultants of the Project

Student: ....

(Name, Surname, Signature, data)

Supervisor...

(Name, Surname, Signature, data)

Programme Director of the Study field *Janina Jablonskytė*

(Name, Surname, Signature, data)

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Amalraj Palraj,Palraj Mariappa. Design and Optimization of Anti-roll Bar. Master's Final Degree Project/supervisor Assoc. Prof. dr. Lukoševičius Vaidas; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.
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Keywords: *Anti-roll bar, Rollover, Ansys, Rolling Stiffness, SAE*
Kaunas, 2018. 64 pages.

Summary

In the final master's thesis is the construction of anti-roll bar stabilizer, principle of operation, types and stiffness. Anti-roll bar can be: disconnecting, swirling, or various different geometric shapes. The research project was designed to analyse the standard form stabilizers. The stabilizer calculations were performed in three different ways: analytical and integral finite element types. The stabilizer is designed by Ansys parametric design language and SolidWorks based on the mechanical properties of the material. Also, its geometric characteristics, which affect the stiffness of the stabilizer, are also evaluated. The results of different calculations are compared with each other and the percent differences in results are estimated. Also, in the final master's work, the correlation of parameters and Response surface was made, from which it is seen that the stabilizer mass has a direct relation to the external dimensions of the stabilizer, and the indirect - stiffness.

Amalraj Palraj Palraj Mariappa. Stabilizatoriaus projektavimas ir optimizavimas. Magistro baigiamasis projektas / vadovas doc. dr. Lukoševičius Vaidas; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Mokslo kryptis ir sritis: Technologijos mokslai: Transporto inžinerija (E12), Inžinerijos mokslai.

Reikšminiai žodžiai: *skersinis stabilizatorius, apsivertimas, Ansys, šoninis pakibimo tvirtumas, SAE*

Kaunas, 2018.64. p.

Santrauka

Baigiamajame magistro darbe yra nagrinėjama aktyvaus stovumo stabilizatoriaus konstrukcija, veikimo principas, jo tipai bei standumas. Stabilizatoriai gali būti: atjungiamieji, susukamieji, iš anglies pluošto-aliuminio ar įvairių skirtingų geometrinių formų. Tiriamajame projekte buvo pasirinkta analizuoti standartinių formų stabilizatorių. Stabilizatoriaus skaičiavimai buvo atliekami trimis skirtingais būdais: analitiniu, strypiniu bei vientiso kūno baigtinių elementų tipais. Stabilizatorius suprojektuotas „Ansys paramatric design language“ bei „SolidWorks“ programomis pagal gautas medžiagos mechanines savybes iš tempimo bandymo, jog gauti skaičiavimų rezultatai būtų realūs. Tempimo bandymas buvo atliekamas iš stabilizatoriaus medžiagos, kuris yra gaminamas iš spyruoklinio plieno. Taip pat įvertinamos jo geometrinės charakteristikos, kurios įtakoja stabilizatoriaus standumą. Skirtingų skaičiavimų gauti rezultatai palyginami tarpusavyje ir įvertinami rezultatų skirtumai procentais. Taip pat baigiamajame magistro darbe buvo atlikta parametrų koreliacija, iš kurios yra matyti, jog stabilizatoriaus masė turi tiesioginį ryšį su išoriniais stabilizatoriaus matmenimis, o netiesioginį – standumas.

Chapter 1
Introduction

1.1 Introduction to Anti-roll Bar

When designing cars, attention is given to the comfort and safety of the passenger, therefore, when designing car racks, the aim is to maximize comfort for passengers on uneven roads, improve wheel alignment with the road surface, increase vehicle stability, reduce or completely remove the potential impacts of moving suspension elements in the body of the car. A lot of attention is given to reducing the weight of the suspension elements, but the suspension elements cannot lose their characteristics. Also, a lot of attention is paid to the car suspension system, which is responsible for the stability of the car, it needs to balance the car when it rotates, stops and accelerates.

One of the suspension elements is the anti-roll bar or sway bar that improves the comfort, stability or fixing of the car with the road and control the rollover of the car. The anti-roll bar usually connects the one-axle wheel with the other side of the wheel. The anti-roll bar holds one wheel against another wheel, i.e. when riding on an uneven road surface, and one-wheel rides on unevenness - the other wheel stays on a level road surface, inhibits the movement of the opposite wheel. Designing the anti-roll bar is very important for its geometric parameters, which determine its rigidity, and from the stiffness - the comfort or stability of the car. The stabilizer is usually made of spring steel, but in order to reduce its mass, the development of the stabilizer production from carbon fibre and aluminium has begun.

While the vehicle wheel movie with respect to each other, the anti-roll bar is applied to torsion and forced to roll, the anti-roll bar is a torsion spring that protects them from vehicle body roll motions. The anti-roll bar end is attached to join in turn to a spot near a wheel or axle, transferring forces from a maximum load axle to opposite side

In the final master's thesis, the withstand and displacements of a simple structure anti-roll bar are calculated. Anti-roll bar dimensions are also gauged which affect the stiffness of the anti-roll bar. The simple anti-roll bar Figure.1.1 is shown below

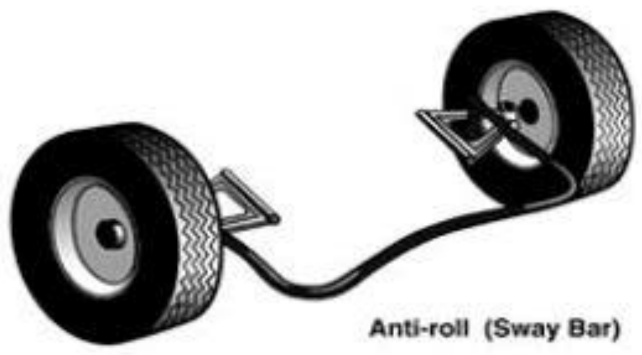


Figure 1.1 Anti-roll Bar [6]

1.2 Postulate of Anti-roll Bar

Anti-roll is a torsion spring which opposes the vehicle body against the roll motion. When the wheel translates together, the anti-roll bar rotates from at it is fixed support. When the wheel moves equally to each other, anti-roll bar is acted to torsion and force to roll vehicle body, both ends of the bar are at least connected to a link along a movable joint. The forces are transferred to high loaded axles to opposite side.

The force transferred to the anti-roll bar

- From the massively loaded axle.
- The end of the link is connected via Rubber bushing.
- To connect the end link for anti-roll bar at the opposite side of the body.
- To the anti-roll bar via flexible joint.

1.3 Basic geometry of Anti-Roll Bar

1.3.1 Geometry

The stuffing(packing) restriction obligatory by chassis elements outlines the trail that the anti-roll bar follows across the suspension. Anti-roll bar could have an uneven shape to induce around chassis element or is also a lot less complicated reckoning on the car. Anti-roll bar essentially has three varieties of the cross-section, there are: Solid Tapered, Solid Circular and Hollow Circular, in the current years the use of hollow circular anti-roll bar has become more widespread owing to the actual fact that is the mass of the hollow circular is less when compared to the Solid Circular Anti-roll bar. So, the use of the Hollow Circular anti-roll bar is more nowadays. [2] The two-sample part anti-roll bar geometrics is shown in Fig.1.2

Figure.1.2 Two-Sample Part Anti-Roll Bar [2]

1.3.2 Materials

The material used in manufacture the anti-roll bar are SAE Class 550 and Class 700 sheets of steel. The working stress of the bar should exceed 700Mpa for the bar which is made of these materials. In recent year materials like Titanium alloy are used in manufacturing bar because for it is a high strength to density ratio. Some car manufacture like Audi are using Carbon-fibre aluminium for manufacture the anti-roll bar it reduces weight for the anti-roll upon 35%. [6]

1.3.3 Connection

The Anti-roll Bar is connected to the opposite chassis element via four important attachment. The first two connecting elements are the rubber bush thought that anti-roll bar is hooked up to the mainframe of the chassis. The other two elements are the fixtures in the middle of the suspension element and also the anti-roll bar ends, either through the fulfilment of the short link or directly. [2]

1.3.4 Bushing

There are two major varieties of anti-roll bar bushing classified consistent with axial movement of the anti-roll bar within the bushing. In each sort, the bar is liberal to rotate at the interval the bushing, within the first bushing kind, the bar is additionally liberal to move on bushing axis, whereas the axial movement is prevented within the second kind.

Material for bushing plays an important parameter. The common material like rubber, Nylon or polyurethane, but even metal bushing is used in some race car [6]. The bushing is shown in Fig.

Figure.1.3 Bushing (rubber bushings and metal mounting blocks) [6]

1.3.5 Fixtures used to Suspension Members

The connections used between suspension member and the anti-roll is the pin joint is shown in Fig. 1.4. The connection used to provide is the spherical joint is used as the connection. The good issue concerning anti-roll bars is that they're terribly turnable by ever-changing bar diameters, commixture and matching bushing materials or adjusting the instant arm length [6].

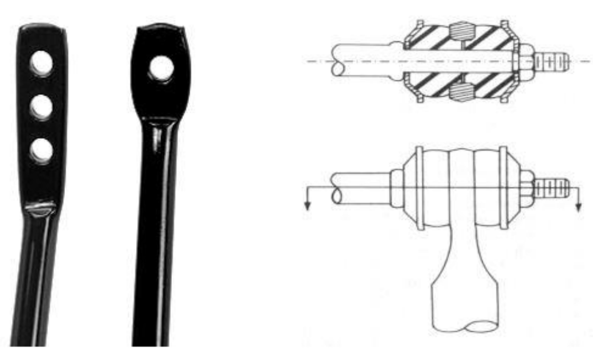


Figure.1.4 Pin Joint [6]

1.4 Detachable stabilizers

Modern SUVs of the fixed detachable active anti-roll bar. In the middle of the anti-roll bar, there is a cam sleeve whose connection and disconnection are controlled automatically - electrically hydraulically. When driving on good roads and high speed says at an average speed of 70km/h, the electronic control unit connects the sleeve. Then the anti-roll bar does not veer bodywork. When driving on rough roads or fields that the wheels can copy the road surface, the cam clutch disconnects the right side of the left anti-roll bar.

Stabilizer coupling is activated and quickly drifting bodywork. Body movement transverse acceleration sequence of sensors, such as a car VW Touareg "running at a speed exceeding 35 km / h, the clutch to be engaged at the anti-roll bar in excess the lateral acceleration. This prevents the vehicle from overturning.

The purpose is to investigate the dependence of the active stability anti-roll bar on rotation and vertical displacement.

Tasks:

1. To perform the literature review
2. Compare the stiffness of the various dimensions of the anti-roll bar, which will be made of spring steel
3. Perform an anti-roll bar analysis ANSYS Workbench and ANSYS parametric design language program
4. Assess how the displacement depends on the size of the forces and the dimensions of the anti-roll bar
5. Check the stresses and vertical displacements of the designed composite anti-roll bar

Chapter-2

Literature Review

The study was done by Mr Pravin Bharane, Mr Kshitijit Tanpure, Mr Ganesh Kerkal "Optimization of Anti-Roll bar using Ansys Parametric Design Language (APDL) [2] say that the main goal use for the anti-roll bar is to reduce the body roll. The objective of the researcher analyses the main geometric parameter which involves affecting the rolling stiffness. All the analyses are carried out using Ansys Parametric Design language. The Judgement of this paper is that by locating the bushing near to the bar centre can in increase the stress, the rolling stiffness of bar is decreased. Anti-roll bar stiffness increases by increasing the bushing stiffness, it also increases the stress induced in the bar.

The research study was done by Amol Bhanage and Padmanabhan "Static and fatigue Simulation of Automotive Anti-Roll Bar Before DBTT [4], show that the fatigue life of the anti-roll bar is compared with four materials. The fatigue life in setting up by using ANSYS Software, Fatigue model were calculated using ANSYS n code Design life software. shows higher fatigue life for SAE 5160 with a comparison to AISI 1020, SAE 4340 and SAE 9262. By using the same load condition above ductile to brittle transition temperature is found out.

The Conclusion is that the fatigue life of SAE 5160 is high compared with AISI 1020. The AISI 1020 is best to use in Anti-Roll Bar

The research study was done by J. Marzbanrad, A. Yadollah "Fatigue life of a passenger car [9], says that as the principal organizer, a few adjustments are proposed to some current weariness disappointment models. Numerous clues that might be considered to create general weakness disappointment models for three-dimensional pressure fields with arbitrary, nonproportional loadings are specified. At that point, exhaustion life of an against move bar segment of a traveller vehicle is explored by the numerical strategy lastly, the examination is made among the aftereffects of the FEM investigation, consequences of the current speculations, aftereffects of the altered adaptations of the hypotheses, and additionally the trial comes about. The introduced comes about affirm the exactness of numerical weakness investigation.

The research study was done by Kemal caliskan," Automated Design Analysis of Anti-Roll Bar" [6], say that Expanding the cross-sectional width of a hostile to move bar will build its move solidness. Be that as it may, bigger burdens happen on the bar for a similar bar end diversion.

The size factor utilized for perseverance constrain adjustment is additionally influenced by the distance across of the bar. Finding the bushings nearer to the focal point of the bar expands the worries at the bushing areas while move firmness of the bar diminishes. Required move solidness can be acquired with a lower weighting bar by changing the bar material

The research study was done by Bankar Harshal, Kharade Rushikesh, P. Baskar "Finite Element Analysis of Anti-Roll Bar to Optimize the Stiffness of the Anti-Roll Bar" [17] say that the main geometric of the body with affecting the stiffness of anti-roll bar is first analysed. Further, these parameters are additionally influencing the body move edge. By the enhancement of these geometric parameters, we can ready to build the solidness of bar and which will decrease the body move point. To compute the solidness of hostile to move bar Finite Element programming ANSYS is utilized.

The Conclusion, we have got the satisfactory result of anti-roll bar in terms of reducing the roll of the body that rolls angle of the vehicle by using the simple geometry of anti-roll bar. we can reduce body roll up to 67.68 % than the vehicle without anti-roll bar so finally, we can conclude that if the implementation of our modified bar is used then finally stability of the vehicle will be improved.

The research was done by Hubert, K. and Kumar, A., "Anti-Roll Stability Suspension Technology," [8] Studied and explained anti-roll bars are usually manufactured from SAE Class 550 and Class 700 Sheets of steel. The steels included in this class have SAE codes from G5160 to G6150 and G1065 to G1090, respectively. Operating stresses should exceed 700 MPa for the bars produced from these materials.

The research was done by Mohammad Durali and Ali Reza Kassaiezadeh "Design and Software Base Modeling of Anti- Roll System" [10] say that, examined and proposed the primary objective of utilizing hostile to move bar is to lessen the body roll. Body roll happens when a vehicle goes amiss during straight-line movement. The line interfacing the move focuses on the front and back suspensions shape the move pivot move hub of a vehicle. The focus of gravity of a vehicle is regularly over this move pivot. In this way, while cornering the radiating power makes a moving minute about the move hub, which is equivalent to the result of divergent power with the separation between the move hub and the focal point of gravity.

The study done by Birudala Raga Harshits Reddy "A Review on Anti-Roll Bar used in Locomotives and Vehicles" [5] has studied about all research paper done by the different researcher on Anti-roll bar. By reading the different paper the researcher gave the details review about the anti-roll bar like Material, Manufacturing, Function and Development. The reviewer concluded that the anti-roll bar has a direct effect on car performances, then the reviewer says that by changing the parameter of the bar, the properties can have improved.

The research done by P.M.Bora, Dr.P.K.sharma "Vehicle Anti-Roll Bar Analyzed Using FEA tool Ansys" [7] in this researcher changes different parameter and varying the applied load and find out the deflection, stress and rolling stiffness. He says that when the load on the bar is gradually increased, the deflection, stress and strain increases corresponding to the bar. He also concludes that by increasing the cross-sectional diameter it leads to increase in rolling stiffness and also decreases in deflection and stress. He also says that hollow bar weight ratio is less compared to a solid bar. When the thickness of hollow bar increases, stress, strain and deflection decreases, while the weight of the bar increases.

The research was done by Mr.Khartode Ankush.N, Prof. Gaikwad Mahendrals. U "Design and Analysis of Antiroll Bars for Automotive Application" [8] say that by an increase in efficiency of a parameter of anti-roll bar reduces the stress at the end of the bar. Increase in diameter of the bar, which lead an increase of the stiffness and shear stress. The target weight of the bar is reducing in greater than 60% to 70% of the weight of solid anti-roll bar

The research was done by M.Mohammad Taha, S.M. Sapuan, M.R. Mansor and N. Abdul Aziz "Development of an Automotive Anti-Roll Bar: A Review" [11] In this the researcher has done with all the review of the previous research paper about the anti-roll bar. The opinion of the researcher is that to develop the automotive anti-roll bar should be in the material reinforced composite material as it has a great potential in the automotive industry. The researcher also recommended the research should be done with a composite material in order tackle the challenges and shortcoming in the developing the composite materials.

The research was done by P.Senapathi, S.Shamasundar, G. Venugopala Rao and B.M.Sachin "Endurance testing and FE analysis of four wheeler automobile stabilizer bar"[13] The toughness of vehicle stabilizer bar is classed inside the present investigate. Limited detail examination of the stabilizer bar is done based absolutely at the test perceptions. Weariness assessment is finished under cyclic stacking. effect of shot peening has been considered. Exhaustion cycles are portrayed for the maximum loading circumstances. custom constructed exhaustion testing gear is utilized to re-enact the weariness ways of life of stabilizer bar. business programming program ABAQUS is utilized for numerical recreation. Computational exhaustion reproduction programming, fe-secure is utilized for the weariness examination to foresee the weakness presence (an assortment of cycles for break start) and split-site area. Mimicked impacts have been as contrasted and that of the physical check results for approval.

The research was done by M. T. Mastura, S. M. Sapuan, M. R. Mansor, A. A. Nuraini "Conceptual design of a natural fibre-reinforced composite automotive anti-roll bar using a hybrid approach" [14] In this paper the researcher has done the anti-roll bar with the conceptual design approach and it all use the material of nature fibre-reinforced composite. A new conceptual anti-roll bar is created with the material nature fibre-reinforced it was created to restrictions from nature fibre properties. The anti-roll bar needs various design value that also including strength stiffness and weight the performance was found to the most important as it gained a score of 63.7%. The anti-roll bar is compared with three different type based on VOC and VOE it should that the natural fibre-based composite or biocomposite can be used as the material for manufacturing anti-roll bar.

The research was done by H. Bayrakceken, S. Tasgetiren, K. Aslantas "Fracture of an automobile anti-roll bar" [15] In this study, fracture analysis of an anti-roll bar of the car is carried out. The analysed type of the anti-roll bar is especially important as many cases are reported about the fracture after a 100,000 km of travel. Mechanical characteristics of the material are obtained first. Then, the microstructure and chemical compositions are determined. Some fractographic studies are carried out to assess the fatigue and fracture conditions. A stress analysis is also carried out by the finite element technique for the determination of highly stressed regions on the bar.

The research done by Noraishikin Zulkarnain, Fitrian Imaduddin, Hairi Zamzuri, Saiful Amri Mazlan "Application of an Active Anti-roll Bar System for Enhancing Vehicle Ride and Handling" [16] This paper analyses the execution of various kinds of the suspension which is the framework without anti-roll bar, with inactive anti-roll bar and with a dynamic anti-roll bar. A four DOF vehicle show has been utilized to show the vehicle suspension framework. The MATLAB/SIMULINK condition of the re-enactment show on the Anti-move plans for four DOF vehicle dynamic models is utilized to mimic the proposed control arrangement of a dynamic anti-roll bar and its partners. As per the re-enactment comes about, the execution of the proposed framework is proficient to accomplish preferable execution over its partners as far as for move point furthermore, move rate decrease amid roll incited move.

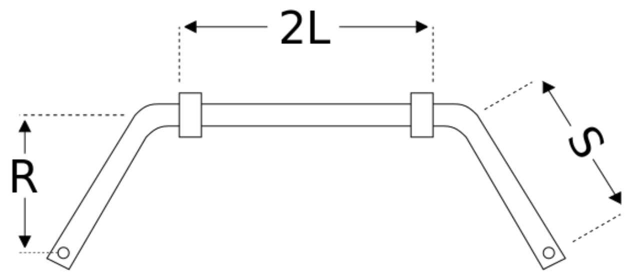
Chapter-3

Theoretical Background

Anti-roll bar, considered as one of the most parts of the automotive because it helps to prevent the vehicle from rollover which causes great damage to the vehicle. It also saves severe injuries to both passengers and crew members. It also helps vehicle from manoeuvres. One more benefit of that, it improves traction by controlling the camber angle change caused by body roll. The anti-roll bar may not have the exact model to get around chassis components or may be much simpler depending on the car. There are two available specifics to be examined about the anti-roll bars within the presented and second, the geometry of the bar is under the shape of else chassis components. The major purpose of anti-roll bar is to cut back the vehicle roll. Body roll seems once a vehicle moves away from in the direction of motion. The road connection the roll centres of wheels suspensions forms the roll axis of a body. Centre of gravity of a vehicle is mostly higher than this roll axis. Thus, whereas turning the centrifugal force creates a roll moment connecting roll axis, that is adequate to the develop a force with the space between the roll axis and therefore the CG. Anti-roll bars serve 2 or additional key functions. First, they cut back the role of the body, as explained higher than, and the second offer some way to once more spreading cornering hundreds between each wheel, that in turns, given the aptitude of modifying handling characteristics of the vehicle.

3.1 Determination and Function

The anti-roll bar is subjected force on each side of the vehicle to lower or rise to a certain height to a minimum the sideways roll of the vehicle during sharp turning or large bounce. Vehicle wheel can be tilted to large distance when the bar is removed, they are varied in design. There is familiar use is to force the shock absorber suspension rod to lower or rise to the equal level as the other wheel. In a fast roll, a vehicle tends to drop nearer to the outer wheels, and therefore the sway bar before long forces the other wheels to typically meet up with to the vehicle. As an effect, the vehicle head to "lock" the road nearer in a fast turn, at the point all wheels are closer to the chassis (body). As soon as the fast turn, then the sliding pressure is cut down, and the dual wheels can rebind to their regular height against the vehicle, kept at similar levels by the connecting sway bar [1]. Fig.3.1 shows the SUV image.



$$Q = \frac{10^4 \times T^2 \times K^2 \times d^4}{R^2 \times L}$$

Figure.3.1 SUV [1]

The anti-roll bar stiffness is estimated by only one way

T=Vehicle track width (inches)

K=Fractional lever arm ratio (movement at rolls bar /movement at wheels)

d=Bar diameter (inches)

R=Effective arm length (inches)

L=Half-length of the bar (Inch)

S=Length of the arm(lever) (inches)

Q=Stiffness (lb*in per degree)

A negative side-effect of bringing together a couple of wheels is that a bump to one wheel tends to also jar the opposite wheel, causing a giant impact applied to the full dimension of the vehicle. alternative suspension techniques will delay or dampen this result of the connecting bar as if striking little holes that momentarily jolt one wheel, whereas larger holes or larger tilting then tugs the bar with the other wheel [1]

3.2 Principal Function of Anti-Roll Bar

The two main function of the anti-roll bar, eliminate the body lean is a major function. The total rolling stiffness of the vehicle is depending upon the reducing of the body lean. The rise of the entire rolling stiffness of a vehicle doesn't modification the steady state total load (weight, mass) transfer from the within to the surface wheels, it solely reduces body lean. the entire lateral load transfer is set by the Centre of Gravity height and track breadth. Another perform of anti-roll bars is to tune the driving balance of an automotive. Steering behaviour may be tuned out by ever-changing the proportion of the entire rolling stiffness that comes from the front and rear axles. Increasing the proportion of roll stiffness at the front will increase the proportion of the entire load (weight) transfer that the front shaft reacts to and reduces the proportion that the rear shaft reacts to. In general, this makes the outer front wheel run at a relatively higher slip angle, and also the outer rear wheel to run at a relatively low slip angle, that is an associate under-steer result. Increasing the proportion of roll stiffness at the rear shaft has the alternative result and reduces understeer. The perform of stabilizer bars in motorcars is to scale back the body roll throughout cornering. The body roll is influenced by the occurring wheel load (weight) shift and also the modification of camber angle.

3.3 Problem Statement

One of the most unrecognised part but yet important component hiding under the vehicles is the anti-roll bar bushings. Located on the chassis of the vehicle and used to reduce road noise, absorb bumps and cracks in the road and deliver a softer ride, the anti-roll bar is fixed with rubber bushings that keep the vehicle’s body from rolling as it manoeuvres turns.

When it is properly lubricated and maintained, the anti-roll bar bushings can bring excellent driving conditions for many years. At the point when the bar begins to weakness, the alert signs can go from subtle noises to significant problems with steering and handle this potentially leading to a vehicle accident and other safety concerns.

3.3.1Inactive in vehicle handling

Since when driving the car routinely. It’s likely that we can have an unmistakable comprehension of how the car handles the road. Simple way to identify problem with the anti-roll bar bushings are the point at which when the handling seems inactive or respond slowly, mainly when the vehicle makes a sudden turn and during take turn near the corner, the vehicle appears to be less steady than it has been beforehand, this is likewise a caution of bushings has been worn out and need to be restore to new bushings.

3.3.2 Rattling under the chassis of the car

The anti-roll bar is found specifically under the car. At the point when bushings are worn out, exhausted or totally breakout, the anti-roll bar itself will end up flexible and cause a rattling or thumping sound while we are driving. The turbulence will get continuously louder when you steer the car in either direction or when you are driving on the hard road. Mostly the noise will come from the front end of the vehicle, near the feet on the floor area and are very easily notable.

3.3.3Squeaking Sound from under the vehicle

Not quite the same as a shake or thumping sound, the squeaking commotion originating from under the car is a potential cautioning sign that the bushings are beginning to wear. This sound is detectable while you are rolling over knocks, making forceful swings to one side or right, or an event that you crash into the garage. This noise is normally caused by an anti-roll bar bushing that isn’t appropriately greased up because of metal-on-metal contact.

3.4 Type of Suspension System

Vehicle suspension - is a system that needs to maintain the body at a certain height above a road and transmit forces generated by driving over bumps or when braking when cornering. No less important is the ride comfort, which is ensured by vibration and shock damping. The suspension comprises rigid and flexible elements connecting the vehicle wheels with the bodywork. Constructor to align the many, often conflicting functions were developed different solutions

3.4.1 McPherson's Suspension

McPherson strut suspension is used in the methodology of depreciation on vehicles with front-wheel drive. This decision deserves special attention because in many cases, the front suspension is used McPherson suspension. The lower-class cars, it is almost the only applicable solution. McPherson suspension column significantly simplified, as cushioning, supporting and steering functions of the elements have been merged into a single system. In addition, it takes up little space, which is particularly important in front wheel drive case at the transverse drive system layout. The main elements of the column are a shock absorber and helical spring. The upper shock absorber fastening element bearing column gives the possibility to rotate around its axis turn the wheels. The column is rigidly connected to the swing bracket (bracket) and swing arm ball joints (joints) is connected to the lever.

3.4.2 The double hinge suspensions

New production cars are often having a double hinge with Chassis. This decision every single axle wheel moves and the amortization independently of the other wheel. Used in the end, and sometimes the front of the vehicle suspension and ensure a high level of ride comfort.

At the same time preserves the excellent driving characteristics. Each design has its own decision, but the general principle is the same. The double Structures based on the longitudinal, transverse and diagonal levers and a rod connected to the system to ensure the driving comfort. A common solution is lower longitudinal arm system with two transverse rods (top, which is attached with a spring shock absorber and bottom). This prevents the rear suspension wheel angle changes with increasing vehicle load

3.4.3 Dependent suspension

Transverse suspension guides, that is four fixing points of two arms of aluminium, creates a support side and longitudinal forces. All four levers are connected to the wheel supports ball-joints. The upper parts are arms attached to the bracket and the bottom - to the section rails. Validating rubber and metal sleeves.

According to the relationship between the wheels, the suspension can be dependent and independent. Addict sits on both wheels are mounted to a continuous axle beam. Then, one of the slipping wheels vertical direction, and other necessary moves. That the majority of commercial vehicles of all bridges and some of the car’s rear axle suspension.

3.4.4 Independent suspension

When times are an independent suspension, a drive axle is attached to one bar connected to the chassis. Drive wheels two levers connected to the crossbar Levers to respectively jet and braking moments bodywork. Steered axles time the front of the car, gives the shoe resulting from the longitudinal and lateral forces. They drive a car. Steered bridges are continuous and composite.

3.5 Anti-roll bar Position

The anti-roll is usually found in car suspensions system. The type anti-roll bar is shown in Fig. The anti-roll bar is usually made upon spring steel. The anti-roll bar is made of a solid, round, spring steel pole with a breadth of 10-60mm or an empty tube. The stabilizer can likewise be made of composites on the grounds that the composite materials are light and strong and are reasonable for use in the making of a stabilizer. Because of the properties of composite materials, a stabilizer made of composites is light and strong [20]

Figure.3.2 various type anti-roll bar connection [20]

Stabilizers typically connect one side of the same axle with the other side wheel. They are connected by a metallic rod, and at its end, depending on the type, is fixed connections, hinges. Stabilizers typically connect one side of the same axle with the other side wheel. They are connected by a metal rod, and at the rear, depending on the structure, the connections, hinges. It is secured to the lower forks or shock absorber according to the vehicle brand or model of the structure

The middle part of the stabilizer is fastened transversely to the body rubber bushings (1). The stabilizer elbows 3 are attached to the wheel suspension on the left and right axles. There are also cars with 2 stabilizers. The Fig.3. The stabilizer can be both front and rear, but usually only in front of the car. Some cars do not have a stabilizer because they were not intended for their construction.

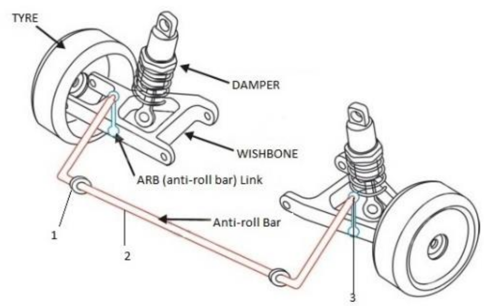


Figure.3.3 Anti-roll Bar [16]

3.6 The effect of the anti-roll bar on comfort

The three important aspects that check the safety of the cars when driving at high speed or in turn of the vehicle are driving comfort, driving and maintaining vehicle stability. To ensure driving comfort, the chassis of the car must abolish the vibrations caused due to unevenness's road. The vehicle must be smoothly controlled by the rotating manoeuvres. The tire contact with the road surface must be good in order to maintain the vehicle stability and braking capabilities.

In the car, the anti-roll bar is a very essential element for a vehicle with independent suspension system, which helps to improve vehicle stability. The performance of the anti-roll bar is directly proportional to safety, because if there is no anti-roll bar, then there would be a high turning point during the corner of the vehicle. According to statistics, the chance of the rollover is reduced about 60% to 80% when the vehicle is installed with an anti-roll bar.

The anti-roll bar also less the vibration angle in the small car. The anti-roll bar usually places in the front end of the vehicle. This is of steel rod. The bar middle part is fixed to the body by means of rubber bushings. The folded ends are connected to the brackets of the lower link arms. Hanging over the body of the car, on one side the spring deforms more, and the body approaches the wheel. Turning the stabilizer bar makes the wheel on the other side approach the body. This prevents the body from turning to the sides.

3.7 Audi R8 Anti-roll Bar

The dynamic stability anti-roll bar is made by carbon fibre, which comprises a carbon fibre tube and an aluminium elbow. This design is lighter than 35% of the standard steel squeezed steel anti-roll bar. [19] This shown in Fig.3.4

Figure.3.4 Anti-roll bar Audi R8 [19]

Chapter 4
Methodology

The stress field at the bar will be investigation utilizing a three-dimensional finite element solid model. There are two different vital certainties to be considered about the anti-roll bar that in the first place, the counter moving firmness of the bar has the immediate impact on the turning attributes of a car. What is more, second the geometry of anti-roll bar is reliant on the geometry of the different body segments. The main objective of the master's thesis

- To check the anti-roll bar are designed according to the spring design manual.
- To ensure the bar is designed to withstand the rolling stiffness and the deflection at end of the bar.
- To execute that the stress of the bar is less than the desired stress.

4.1 Investigation Method

This research study is to optimization for the anti-roll bar. An explicit research method as recommended by the manual is used in the work for successful authorizing. This thesis is mould into four unique type of mode which is catalogued below figure.4.1

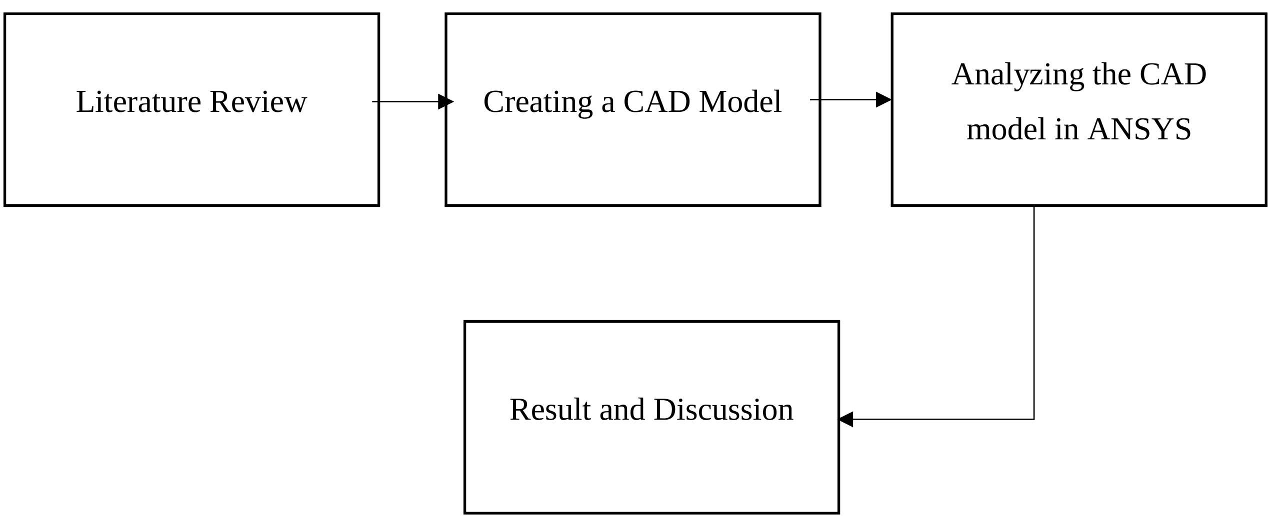


Figure.4.1 Investigation Method

In the previously mentioned the research methodology, the initial step or process is the writing the literature review depends on the past research work done by different specialists in the field of the anti-roll bar.

The next procedure is picking a substantial model for the research to convey forward. An appropriate model is an outline utilizing CAD software. In this work, SOLIDWORKS is utilized as a CAD programming for the planning of a model. The four procedure is the imperative process in which the designed model is analysed with the help of the analysis software. The last advance is the discourses area in which the outcomes are talked about and some reasonable remedy controls are examined.

4.2 Materials

For the anti-roll bar analysis materials selected is structural steel

4.2.1 Introduction to structural steel

The structural steel is a low hardenability and low malleable carbon steel with Brinell hardness of 119-234 and elasticity of 410-790Mpa. It has high quality, high malleability and great weldability. It is typically utilized as part of turned and cleaned or icy drawn condition. Because of it is low carbon content, it is impervious to enlistment solidifying or fire solidifying. Because of the absence of an alloying component, it won't react to nitriding. In any case, carburization is conceivable keeping in mind the end goal to get case hardness more than RC65 for littler segments that decrease with an expansion in area measure. Centre quality will stay as it has been provided for every one of the segments. Then again, carbon nitriding can be performed, offering certain advantages over standard carburizing.

Steel can be great extent used in every modern division with a specific end goal to upgrade weldability or machinability properties. It is utilized as a part an assortment of utilization because it is cool drew or turned and cleaned complete property. The mechanical properties of Steel is shown in the table 4.1.

Table.4.1 Physical Properties

Property	**Values**
Density	7850 kgm^{-3}
Tensile Yield Strength	2.5E+08
Compressive Yield Strength	2.5E+08
Tensile Ultimate Strength	4.6E+08
Poisson Ratio	0.3

4.3 CAE Tools

CAE tool is broadly utilized as apart of vehicle industry. Accordingly, the car manufacturer has lessened item advancement cost and time while enhancing security, solace, and sturdiness of the vehicle they deliver. The prescient capacity of CAE apparatuses has advanced to the point where a great part of the plan confirmation is presently done utilizing computer re-enactments as opposed to physical model testing. Tools utilize as a part of this investigation are quickly clarified beneath

4.3.1 System Analysis

The computer and data innovation are a necessary piece of the advanced enlightened world. The computer has turned into a vital apparatus and architect. Be that as it may, until further notice, he cannot supplant what is called designing reasoning. Looked with another issue, the designer must finish the assignment, utilizing the notable standards of material science, arithmetic and different sciences. The computer can just complete human-customized directions. He does this rapidly and precisely. The human concern is to furnish the computer with revised information. A computer can perform estimations productively, however, it cannot autonomously, without human mediation, details an undertaking, assemble a count plot, check presumptions, select the fitting strategies for choosing and condition, check whether the outcome is sensible, reach determinations and make suggestions. Up until this point, there is just a single step in building investigation methodology, which is in a perfect world suited for the computer for the calculation.

As has just been said, different computer programming can be utilized for computer analysis. Notwithstanding, such fundamental project is utilized that depend on finite element method. The market offers various bundles of this compose, so the inquiry is which one to look over. On the planet, a standout amongst the most famous and most adaptable computer project of this write is Ansys. Understanding crafted by this program can without much of a stretch be connected to an arrangement of analysis tasks.

4.3.2Ansys Simulation

For finite element analysis, ANSYS Workbench programming is utilized. ANSYS is a computer-aided engineering software which is utilized to decide finite element, structural analysis, Computational Fluid Dynamics analysis, Explicit and Implicit method. For our case, static structural is done to decide the disfigurement of the structure and different parameters, for example, the pressure and vitality consumed by the structures. These figurines are then checked with the hypothetical computations to decide the quality of the superstructures. Infinite element investigation, the entire anti-roll is discretized into smaller element called as finite element and the analysis is done. The precision of the components relies upon the meshing. Ansys software is used as simulation program.

4.4 Model Description

The standard model of the anti-roll is chosen the model is drawn as per the spring design manual. The danti-roll bar with a hollow circular section for geometrical has been considered important parameter that is used to draw the model in SOLIDWORKS software is listed in the below table

Table.4.2 parameter of the Anti-roll bar

Specification	Values
Type of cross-section	Hollow circular cross-section
Full length of the bar	1100mm
Location of bushing	±400
Internal diameter	22
External diameter	18

4.5 SOLIDWORKS Model

SOLIDWORKS is used as a design software to model the chosen anti-roll bar. The SolidWorks is a designing software was created by the French company Dassault System. It is one of widely-used software in aerospace and automotive industries. Only the anti-roll is designed as per the specifications. The designed CAD model of the anti-roll bar is shown below Fig.4.2

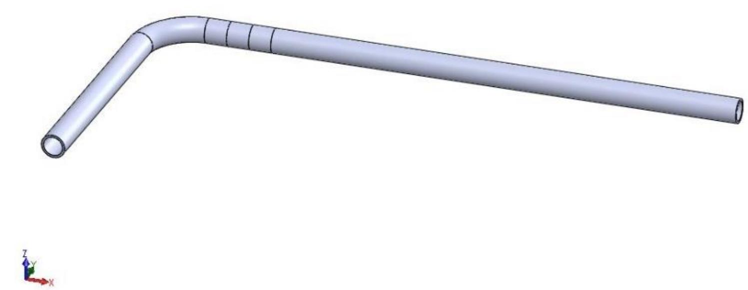


Figure. 4.2 Anti-roll Bar in CAD Model

4.6 Response Surface optimization

The response surface optimization is an accumulation of numerical and measurable system for the experimental model building. By watchful the design of experiments, the objective is to optimize the output variable. which have an effect on the input parameter? An analysis is a progression of tests, called the runs, in which changes are made in the information factors keeping in mind the end goal to distinguish the explanations behind changes in the output response.

The response surface optimization is also known as the combination of three model, namely surrogate model, metamodel and the approximation model. The function of the response surface is different nature where the output values are taken in the term of the input values. The approximated values of the output values everywhere it is analysed in the design space.

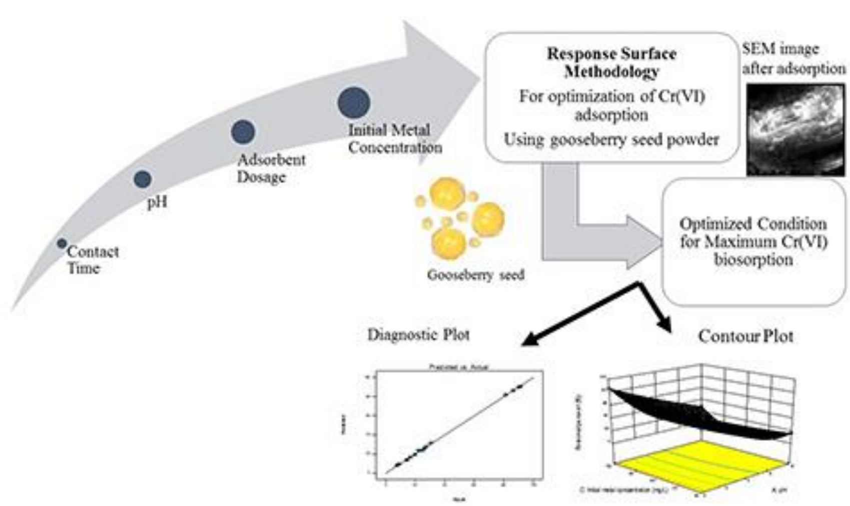


Figure.4.3 Response Surface Optimization [21

Chapter 5

Calculation of Anti-roll bar

The outline of the anti-roll bar and the unbending nature of the material must be picked so as too hard to coordinate the mechanical properties and guarantee an adequate level of solidness and driving steadiness while driving. Since it is difficult to examine the properties of a dynamic anti-roll bar, keeping in mind the end goal to choose the right one, it is important to make certain computations that are hard to discover in the logical writing.

Anti-roll bar utilized as a part of the creation of organization are produced by their own particular breaks down and are not freely accessible. Dissimilar to the attributes of the sleeves or the pressure of the anti-roll materials, which can be found in the writing. Every so often, the state of the anti-roll bar is likewise reported

The Society of Automotive of Engineering presents general information on the Anti-roll bar, its generation and determination in the book (spring Design Manual) see Appendixes 1. The dynamic strength anti-roll bar is appointed to the spring gathering. There are a few recipes in the manual that can utilize to ascertain the solidness of the anti-roll bar, the diversions at the anchorage point under certain heap powers. Be that as it may, these equations must be connected to standard frame anti-roll bar. The accompanying demonstrates frame anti-roll bar (shown in Fig.5.1), which will be utilized for logical estimations

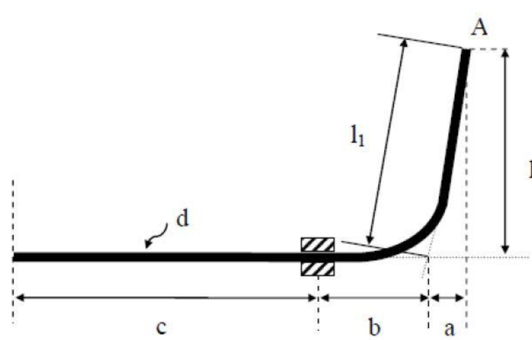


Figure.5.1 Anti-roll bar geometric form used from Spring Design Manual [18]

According to the image point A and the stabilizer is subjected to a force. The formulas to calculate the stiffness of the stabilizer [18].

The formula used to find this halfway track Length [L]

$$L = a + b + c \qquad (5.1)$$

Where,

L = Halfway Track length, mm

$$f_A = \frac{P}{3EI}[l_1^3 + a^3 + \frac{L}{2}(a+b)^2 + 4l_2^2(b+c) \qquad (5.2)$$

f_A = Deflection At 'A' (mm)

E= Young's Module's (GPa)

I = Moment of Inertia (mm), I=$\frac{\pi d^4}{64}$

The rolling stiffness of the bar is calculated as [18]

$$k_R = \frac{PL^2}{2f_A} \qquad (5.3)$$

Where,

k_R = Rolling stiffness (Nmm/rad)

P = Load Applied on the Anti-roll Bar (N)

Expecting that the force F caused by misshapenness (f_A) at the closures of the anti-roll bar solidness can be Compute by the accompanying picture. Wherein the anti-roll bar elbow are fixed and connection focuses concur with the longitudinal pivot of the anti-roll bar [18].

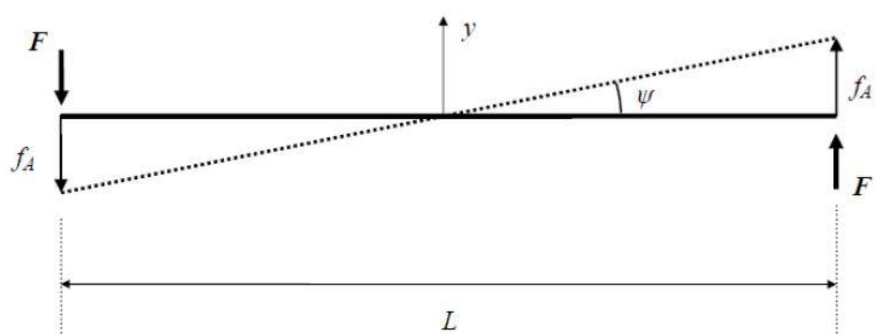


Figure.5.2 Anti-roll bar before and afterload [18]

On the off chance that the suspensions are of a free sort, at the point, the wheel relocation concurs with the stabilizer move. In like manner, we can compute the angle φ

The Rolling stiffness of the bar is calculated by three different methods

$$k_R = \frac{PL^2}{f_A} \,\text{Nm}/\text{mm} \tag{5.4}$$

$$k_R = \frac{P}{f_A} \,\text{N}/\text{mm} \tag{5.5}$$

$$k_R = \frac{PL}{\tan^{-1}\frac{f_A}{\frac{L}{2}}} \,\text{Nm}/\text{deg} \tag{5.6}$$

Where,

P= Load applied on the bar N

L = halfway track length mm

5.1 Diameter calculations

The design of the anti-roll bar is very important to choose the correct diameter. The anti-roll bar can be neither too small in diameter than the larger diameter, and the diameter is counted. According to the preceding chapters the calculating the anti-roll bar stiffness (k_R) and rotating bending determine the appropriate beam diameter according to the formula

$$\text{d} = \frac{\sqrt[4]{\left[\frac{128}{3*\pi} * \frac{k_R}{L^2 * E}\right]}}{[l_1^3 + a^3 + \frac{L}{2}(a+b)^2 + 4l_2^2(b+c)}$$

5.2 Analytical method

$$\text{f}_\text{A} = \frac{\text{P}}{3\text{EI}}[\text{l}_1^3 + \text{a}^3 + \frac{\text{L}}{2}(\text{a}+\text{b})^2 + 4\text{l}_2^2(\text{b}+\text{c}) \ \text{mm}$$

$$\text{f}_\text{A} = \frac{1000}{200000 * 3 * 63460.01716}[250^3 + 70^3 + \frac{550}{2}(70+60)^2 + 4230^2(420+60)$$

$$\text{f}_\text{A} = 34.509 \text{ mm}$$

$$k_R = \frac{PL}{\tan^{-1}\frac{f_A}{\frac{L}{2}}} \, {}^{Nm}/_{deg}$$

$$k_R = \frac{1000 * 1100}{\tan^{-1}\frac{34.509}{\frac{1100}{2}}} \, {}^{Nm}/_{deg}$$

$$k_R = 306.38 \, {}^{Nm}/_{deg}$$

5.3 Numerical Analysis in ANSYS

For our case, another technique for computer simulation is proposed in which ANSYS is utilized to decide the quality of the anti-roll bar. Statics structural analysis is looked at the changed kind of analysis. In the Numerical analysis, the ANSYS workbench program was additionally used to calculate the displacement and stress of the anti-roll bar by finite element method, however utilizing the integral body. The following figure demonstrates the geometric model of the anti-roll bar which was simulated by the SOLIDWORKS programming package. The created model of the anti-roll bar is imported into ANSYS for the analysis reason. Once the model is imported the engineering data is set for the model. The engineering data include the material data in that the material used for the model and it is properties are selected. For the anti-roll material selected from the engineering data is structural steel. The imported model is shown in Fig.5.3. The step involved in ANSYS Workbench is illustrated in the below Fig.5.3

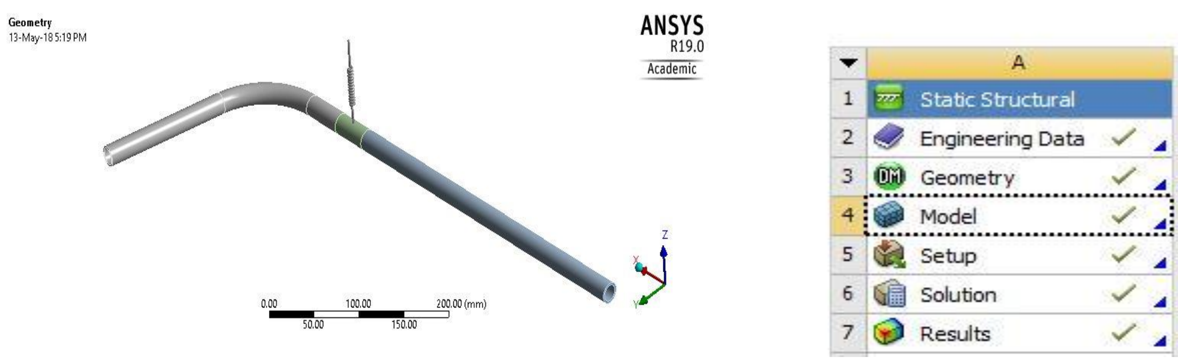


Figure.5.3 Imported Geometry and ANSYS Workbench analysis steps

5.4 Model setup

After the model is imported in ANSYS. The next step in workbench is to analysis the model in model setup. In this step, the data regarding static structural analysis is given. The data's like fixtures, load and other related data to the model are given which are needed for running the static analysis

5.4.1 Remote Displacement: The anti-roll bar is given with the remote displacement constraint to fix the end to arrest the motion in the particular direction and rotations. The table.5.1 below is listed at what the point the component is to fixed and free. The 'zero' indicate that component are arrested for all DOF, the "FREE' indicated the component is free in all DOF. The below figure.5.4. showing the remote displacement (shown in the black circular).

Table.5.1 Remote Displacement

Type	**Remote Displacement**
X component	0 mm
Y component	0 mm
Z component	Free
X rotation	Free
Y rotation	0
Z rotation	0

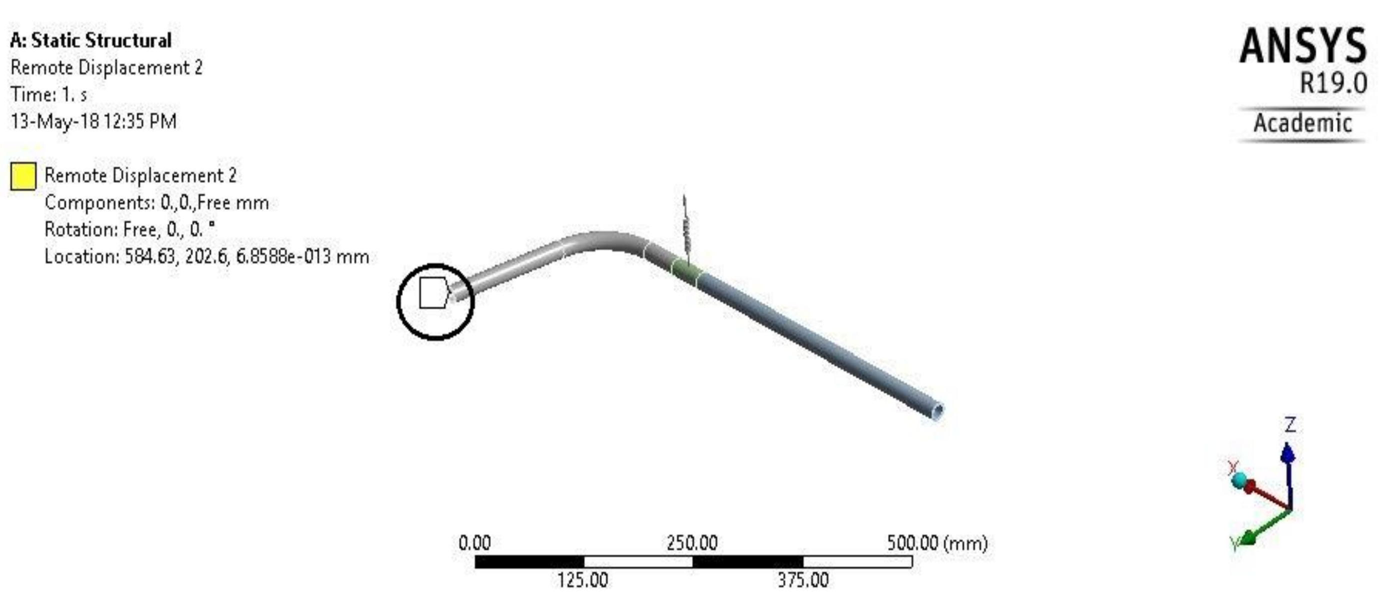


Figure.5.4 Remote Displacement

5.4.2 Connections: For this model connect is used. The spring connect is used, it is connected to the body-ground connections. The spring is connected to a length (400mm) from the x-axis. The type of spring is selected is longitudinal, the spring has both behaviour (tension and compression). The longitudinal stiffness value of the spring is 1500 N/mm. The behaviour of the spring is rigid. The Figure.5.5 Shown the connections (shown in black Circle).

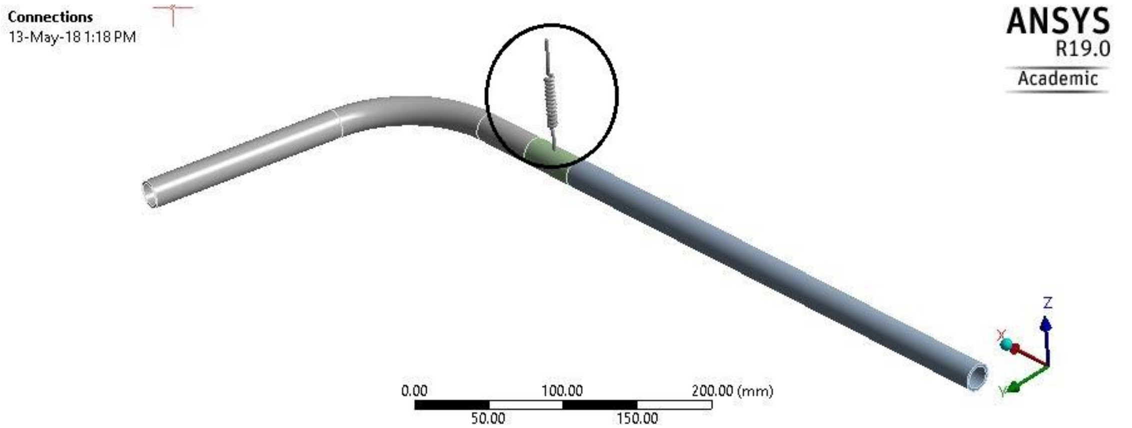


Figure.5.5 Spring Connections

5.4.3 Load: The load is applied at the end of the bar applied load is in the z-axis coordinates 1000 N is applied to the bar. The below figure.5.6 shows the applied load

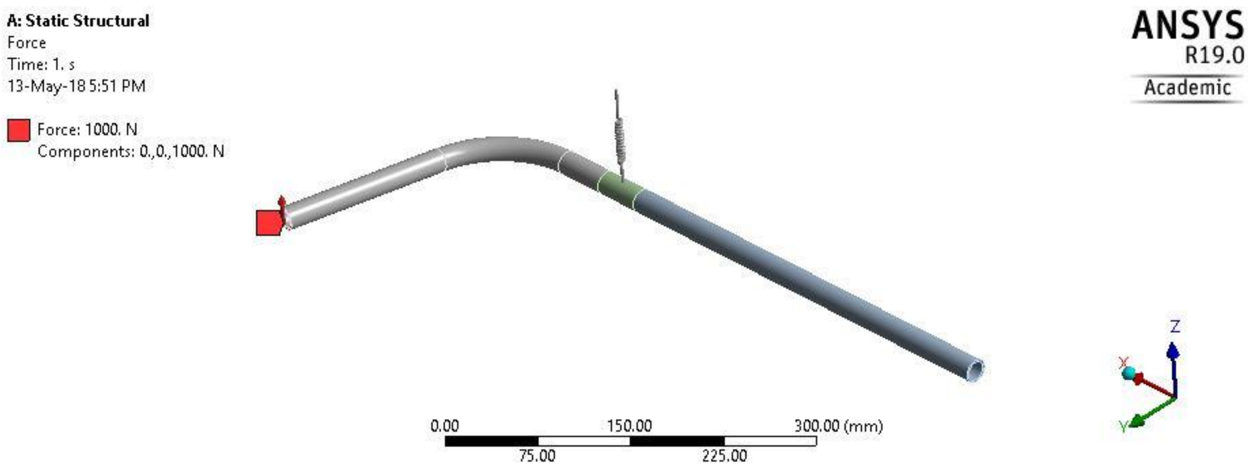


Figure.5.6 Load

5.5 Meshing

The exactness of the finite element analysis relies on the precision of meshing. A Fine mesh is chosen and whole structure has meshed. The accompanying table 5.2 is shown the mesh information in detail:

Table.5.2 Meshing details

Size function	Adaptive
Relevance centre	Fine
Element size	50.00mm
Number of nodes	5752
Number of element	816
Transition	Fast
Minimum edge length	50.2650 mm

The below figure.5.7 showing the Meshing of the bar

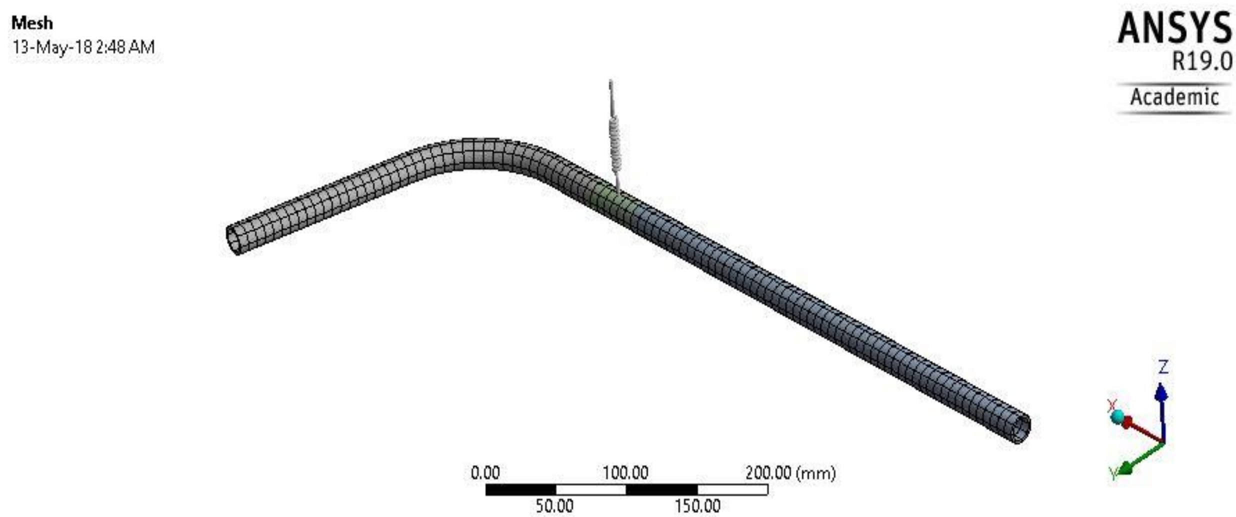


Figure.5.7 Meshing

Chapter 6

Result and Discussion

After the calculation are done for the bar and the model is imported in the ANSYS workbench, the investigation is done to find the total deformation of the bar and the results are obtained. In this section discusses those outcomes and it impacts on the rolling stiffness is also analysed

6.1 Analysis of Anti-roll in finite element analysis result

The anti-roll bar of the car is analysed in ANSYS with the given load as shown in section 5.4.3. Two solutions are required for anti-roll bar are obtained from the finite element analysis are shown below

- Total Deformation
- Equivalent Stress

6.1.1 Total deformation

Deformation is one most critical analysis the anti-roll bar deformation is obtained is shown in the Fig. The maximum displacement occurs in the workbench program is 34.577 mm by using the load 1000 N

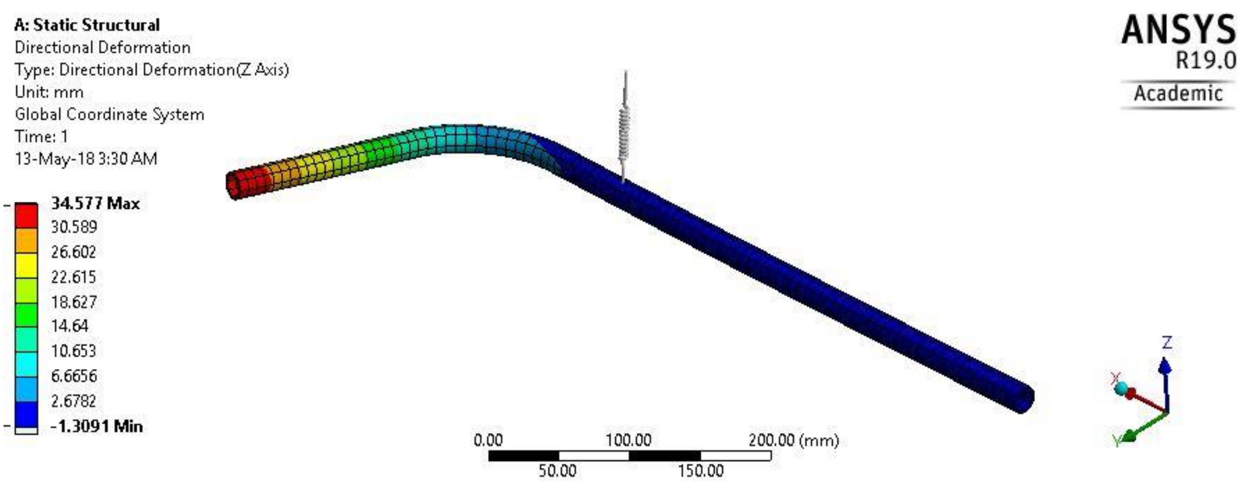


Figure. 6.1 Anti-roll bar Total displacement in ANSYS Workbench

6.1.2 Equivalent Stress

The Figure.6.2 shown the equivalent stress that is analysed the maximum stress obtained is 600MPa, for the applied load 1000 N. Which is less than the working stress 700MPa has per the spring design manual (Appendix 1)

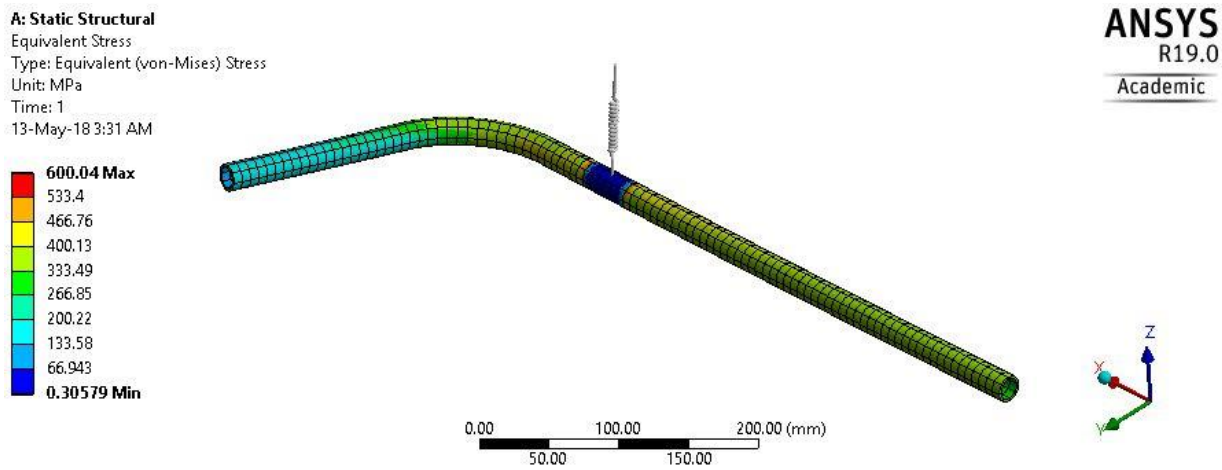


Figure.6.2 Equivalent Stress

6.2 Analyser Numerical analysis with APDL

Anti-roll bar was selected to examine the software package APDL. Creating a conceptual model selected the appropriate finite element type properly expressing the structural behaviour. Using APDL program to calculate the stresses and displacement anti-roll bar was used bolt element. The code written in the APDL program for calculating the anti-roll bar characteristics is given in the (Appendix 2). The below figure.6.3 illustrates the geometric model of the anti-roll bar which is created by the APDL program

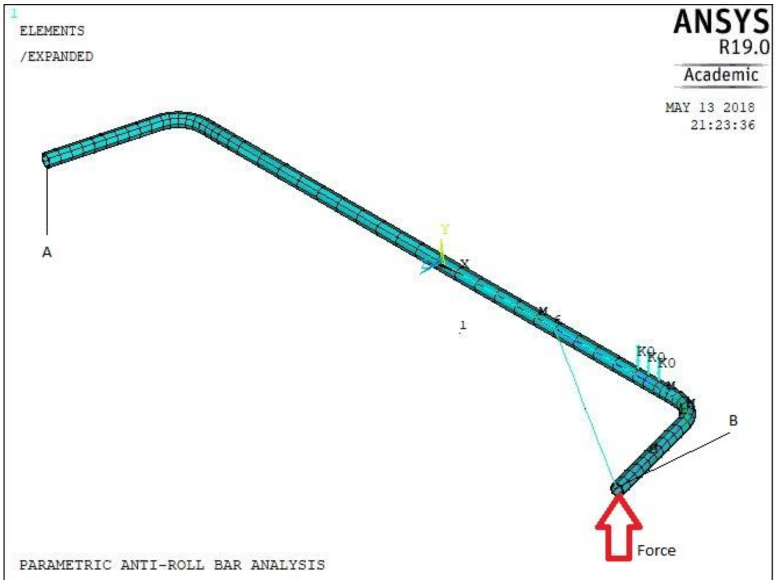


Figure.6.3 Geometric of Anti-roll bar in ANSYS APDL

The above figure shows that the anti-roll bar the point A is constrained in some direction. At the point A, the anti-roll bar cannot move in the z-axis, but it can move smoothly in y-axis and x-axis. In addition, to that, the point A the anti-roll bar cannot rotate about y-axis and z-axis, but it can smoothly rotate in the x-axis. The upward force is also applied at the point A.

At the point B, the anti-roll bar can translate in the y-axis, but it cannot move in x-axis and z-axis. Similar to that the Point B can rotate around the x-axis and z-axis. The downward force is also applied at the point B

when the modelling the anti-roll bar, it was necessary to take into account the fact that the anti-roll bar is fastened with bushings. Spring with a rigidity of 1500 N/mm was used to simulate locally space bushings. Such spring stiffness is closest to the rigidity of rubber bushing.

The results of the equivalent stresses and total displacement obtained by linear analysis are shown in figure 6.4 and 6.5 respectively

The highest displacement values are 28.7267mm of the anti-roll bar is shown in Figure.6.4, When the anti-roll bar is applied with 1000 N.

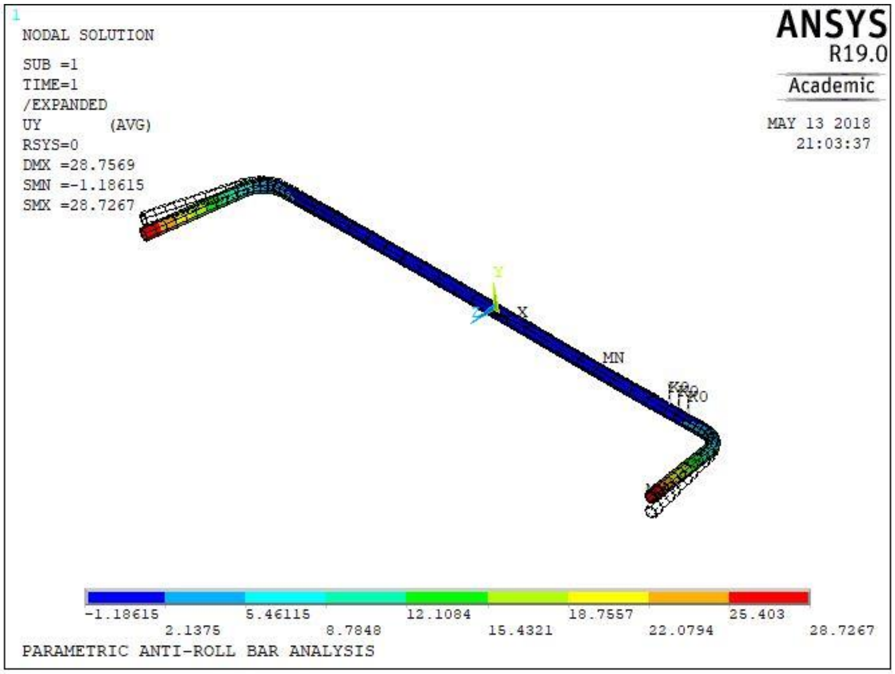


Figure.6.4 Anti-roll Bar Displacement in ANSYS APDL

The shows the maximum equivalent stresses values are 395.134 MPa of the anti-roll bar is shown in Figure.6.5 when the bar is applied with a load of 1000N

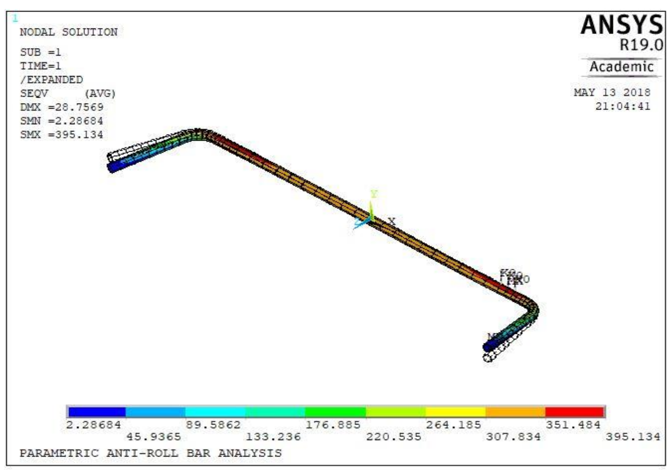


Figure.6.5 Anti-roll Bar Equivalent stress in ANSYS APDL

Table.6.1 Result obtained for optimization

Parameter	*I*	*II*	*III*	*IV*	*V*
External diameter	20	20.7	20	21	22
Internal diameter	16	16.7	16.5	17	18
L	1100	1100	1100	1100	1100
c	400	390	330	365	440
b	65	70	100	85	60
a	85	90	120	100	70
l_1	230	230	230	230	230
l_2	250	250	250	250	250
E	200000	200000	200000	200000	200000
P	1000 N	1000 N	1000 N	1000 N	1000 N
f_a	35.85	36.02	46.72	36.49	34.51
Ansys workbench	34.57	33.15	44.54	32.94	25.97
Percentage%	1.03	1.09	1.05	1.1	1.33
Ansys APDL	28.73	34.76	42.5	28.76	28.73
Percentage%	1.25	1.04	1.01	1.27	1.20

All three methods of calculating the results of the change in displacement changing the anti-roll bar parameter are shown in table 6.1. we can say that the displacement of the anti-roll bar is found correctly because using two different analytical and numerical calculation method because the result is closer to each other. The different ranges from 1.01 % to 1.27 %. The calculation was carried out with five different dimensions of the anti-roll bar. Changing the outside or inner diameter, length or the anti-roll bar sleeve position. The anti-roll bar to different displacement. According to the result, it can prove that the change of anti-roll bar depends mainly on the outside diameter.

6.3 Parameter c6orrelations for the Anti-roll bar

During the anti-roll bar calculations, the person correlations were also performed. The rule for the calculating the person correlation coefficient is extremely straightforward. The computation of this correlations coefficient is contrasted with the rank of two successions. For this reason, contrasts between the rankings are discovered, they are put in a square and put together. At that point, extra coefficients are added to the count so the coefficient esteems change form -1 (which show very strong negative associates) to +1 to an exceptionally solid positive correlation. In the event that the coefficient is zero, this shows there are no statistical connections

$$r = \frac{\sum((X-\bar{X})(Y-\bar{Y}))}{\sqrt{\sum(X-\bar{X})^2\sum(Y-\bar{Y})^2}}$$

where,

X- parameter1 values

Y- parameter2 values

$\bar{X}$-Mean of parameter1 values

$\bar{Y}$-Mean of parameter2 values

In the today case, the person correlation is made with the ANSYS Design Xplorer (shown is

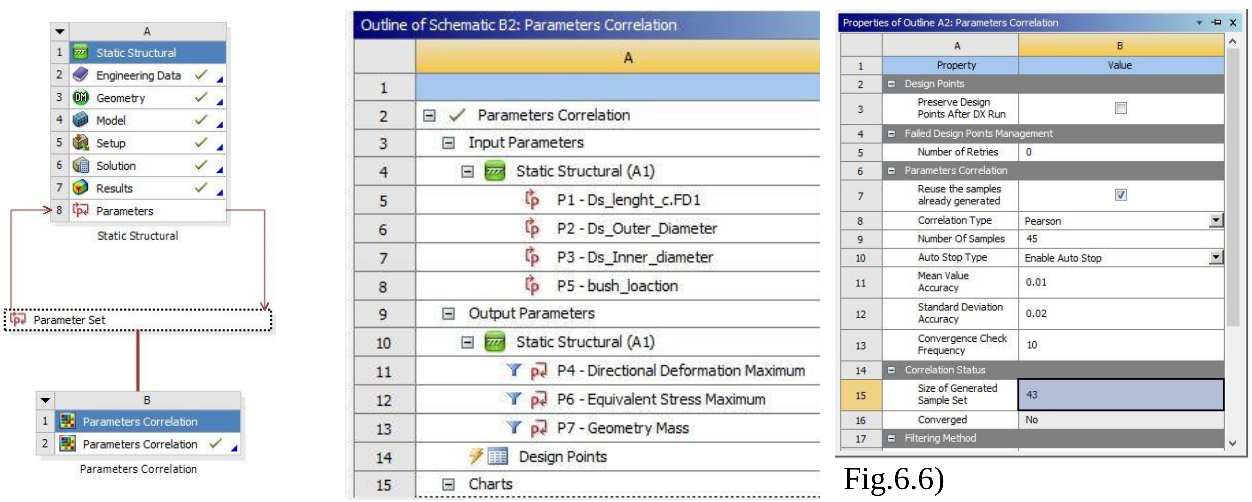


Fig.6.6)

Figure.6.6 Design Xplorer with correlation

The correlation matrix was carried out after the completion of Analysis, which is shown in Fig.6.7

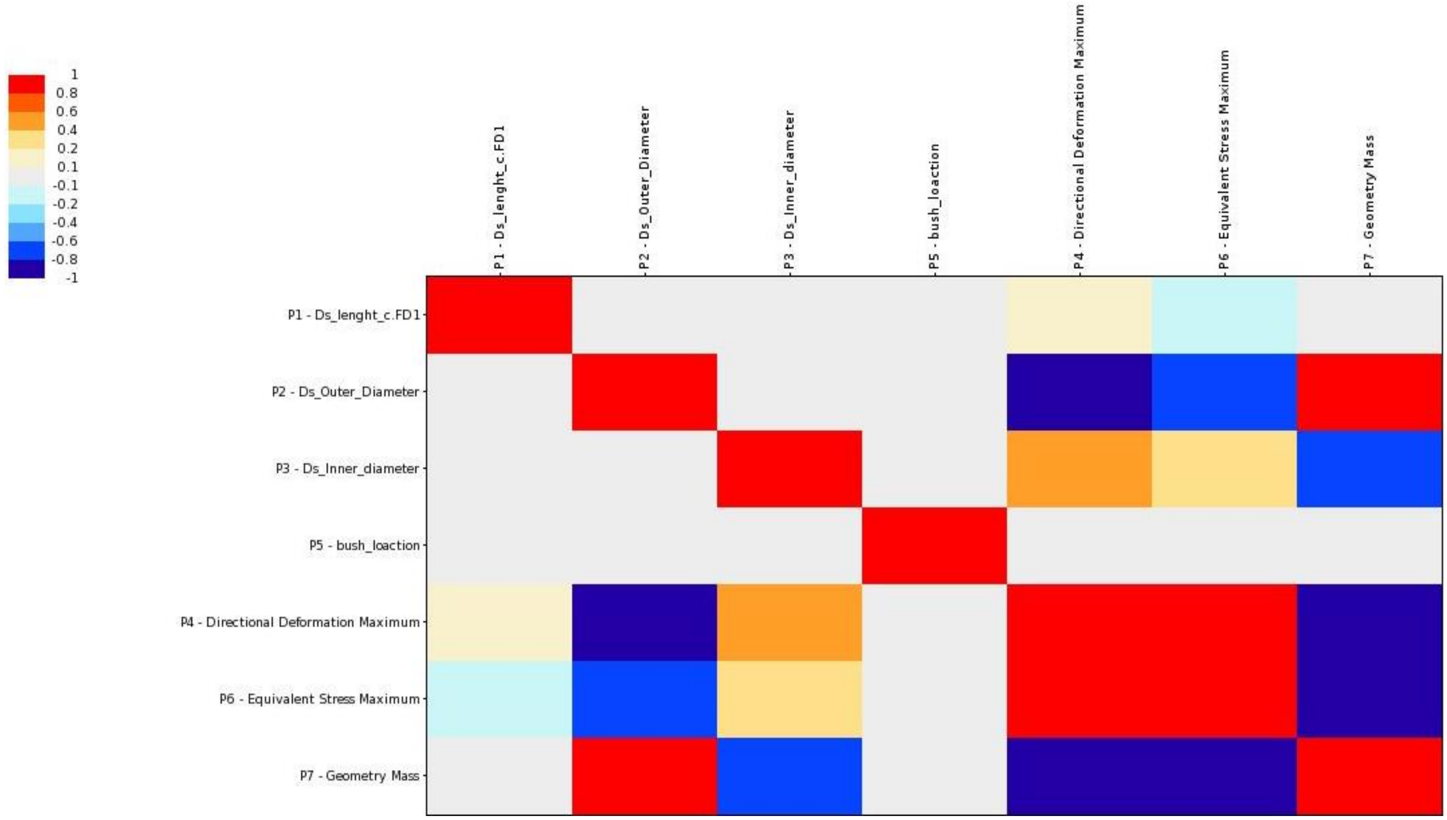


Figure.6.7 Correlation Matrix Parameter

As stated by the correlation matrix, it is seen that the external diameter of the anti-roll bar has the highest effect. It is seen from the correlation matrix that the external diameter is indirectly proportional to the displacement of the anti-roll bar, the greater the external diameter, the smaller the displacement. Be that as it may, the anti-roll bar mass is specifically corresponding to the external diameter of the anti-roll bar. For the instance, the bigger the external diameter, the bigger the anti-roll bar mass will be.

The anti-roll bar stress has a weak opposite correlation with the external diameter of the anti-roll bar. The anti-roll bar moves additionally depend directly on the internal diameter of the anti-roll bar, however, it is frail.

In the below Fig.6.8 illustrate the sensitivity of the parameter, which epitomises these day parameter correlation matrix is shown in Fig.6.7. How strongly the displacement, the mass, the stresses from the anti-roll bar dimensions depend

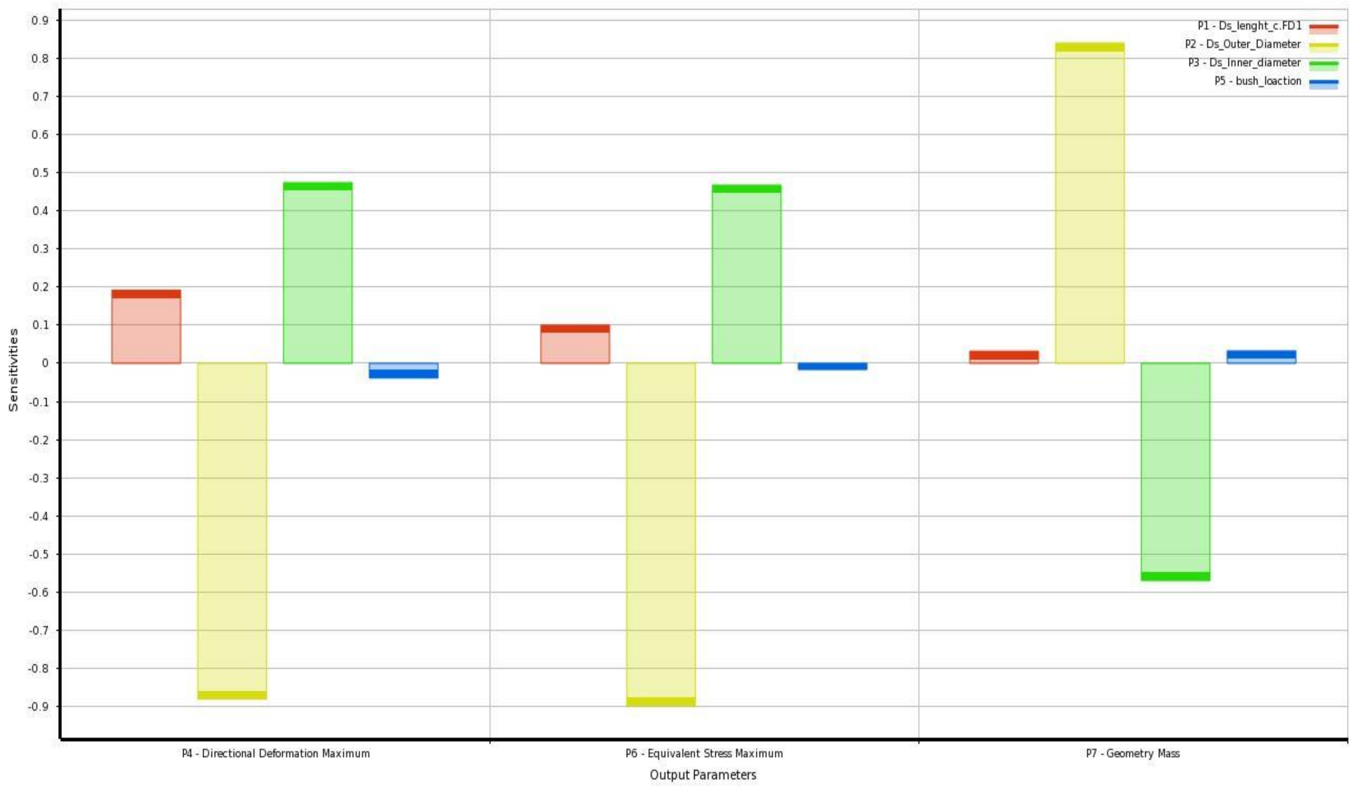


Figure.6.8 Sensitivity of the parameter

6.4 Response Surface Optimization

Response Surface optimization utilizes a grouping of outlined analyses to acquire an ideal reaction. The effective approach for the outline of computationally costly models, for example, those found in aviation frameworks, including optimal design, structures and so on. Offers both subjective plan appraisal. The response surface method is not in itself a streaming agent, but instead an instrument for expanding the speed of enhancement. It predicts the reaction of a framework for a working point without really performing a re-enacted investigation by then.

In the today case, the Response Surface Optimization is made with the ANSYS Design Xplorer (shown in Figure.6.9)

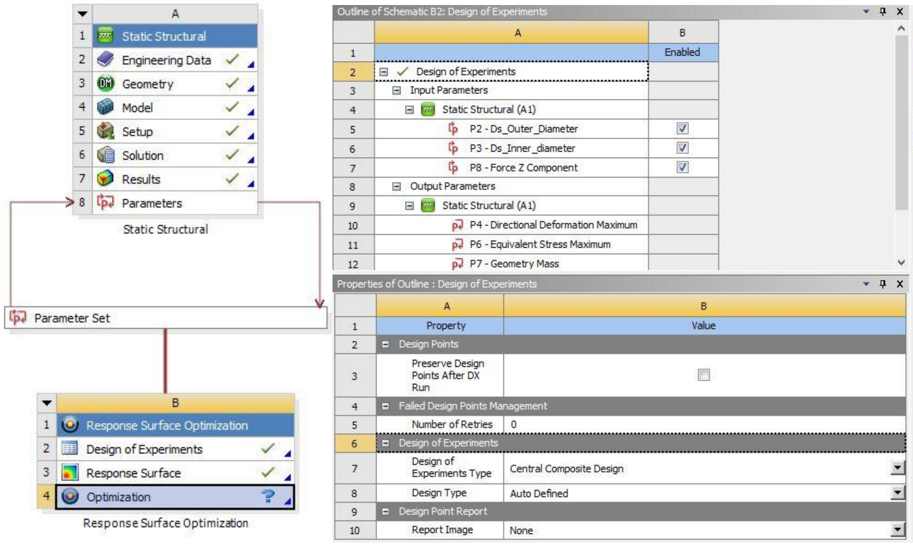
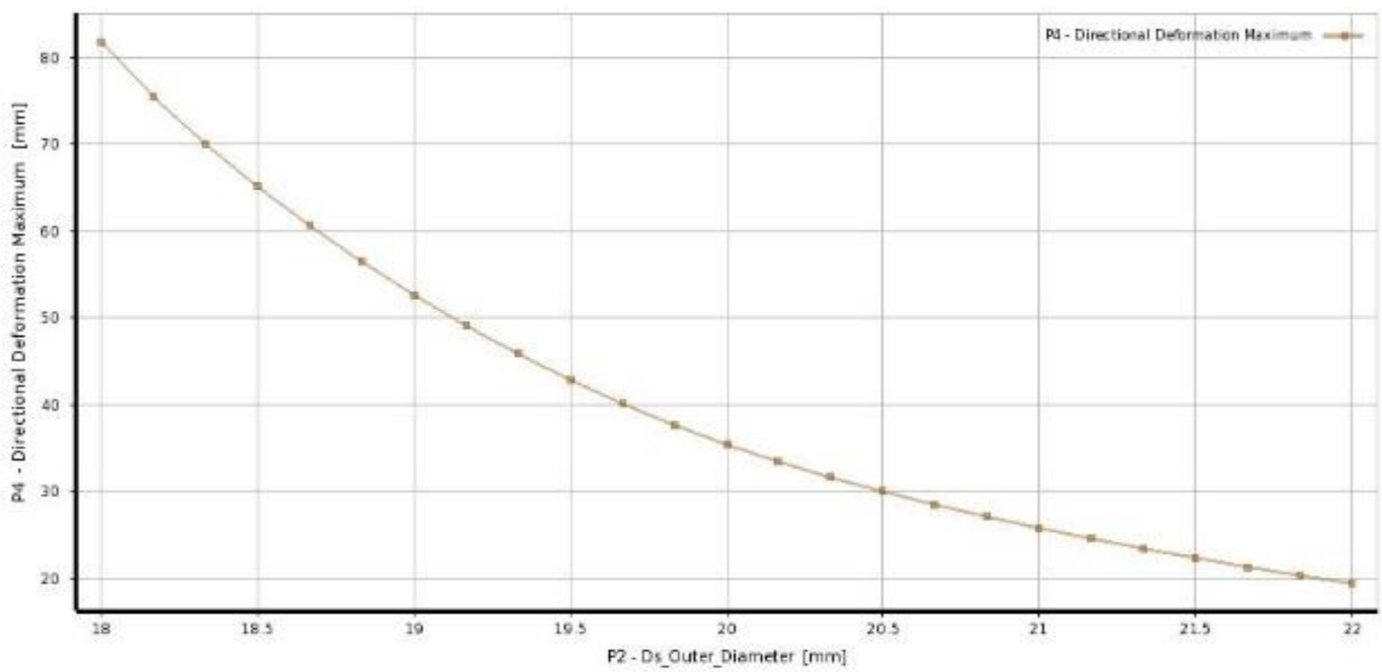


Figure.6.9 Design Xplorer with correlation

In the below figure.6.10 it shows clearly that when there is an increase in the diameter of the bar, there is a gradual decrease in the total deformation. There is gradually response in the graph. This response surface is the powerful tool in the field of optimization.



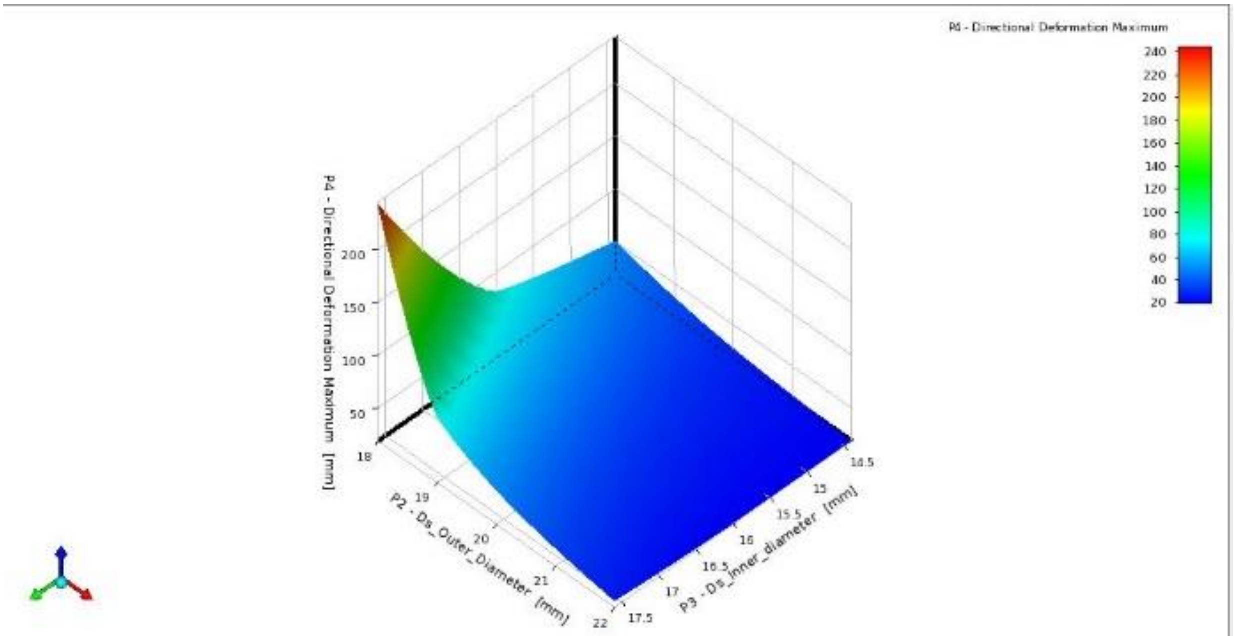


Figure.6.10 Response Graph of the bar

Conclusion

The design of the anti-roll bar is carried with help of SOLIDWORKS. Then the analysis is carried in ANSYS Workbench. An ANSYS APDL program also created for the particular model. The dynamic strength of the anti-roll bar is a program. Perform computation using different sort of finite element strategies and the total displacement, equivalent stress is estimated. The Numerical computation was carried out in ANSYS program. The result is shown is in table.6.1. The comparison showed that the difference between the percentage various between 1.01 % up to 1.27 By chance, the parameter of the anti-roll bar there strongly effects on the vehicle performance. Most of the vehicle uses hollow type circular anti-roll bar. By locating the bushing closer to centre this may increase the stress and this resultant in decrease rolling stiffness.

The value obtained in ANSYS workbench and ANSYS APDL program are displacement value is 34.577 and 28.73 mm particular to load of 1000 N. The stress value for the both is 600 MPa and 395.134 Mpa corresponding for the load of 1000 N. The value for stress is comparatively less than allowable stress which is mentioned in the Spring Design Manual.

A linear status, Pearson correlation also found between the parameter and it was found that the external parameter of the diameter increases as the displacement parameter decrease gradually. When the external diameter increase, the mass of the bar increases gradually. It found that there is an interlink statistical relationship between the values.

When performing the response surface optimization, it shows that external parameter of the diameter increases as the displacement parameter decrease gradually. When the external diameter increase, the mass of the bar increases gradually. It found that there is an interlink statistical relationship between the values.

Reference

Design and Analysis of Antiroll Bars for Automotive Application, Mr Khartode Ank Prof. Gaikwad. Mahendra. Uush.N, International Journal on Recent and Innovation Trends in Computing and Communication, Volume:4 Issue:6, 340 – 345

Optimization of Anti-Roll bar using Ansys Parametric Design Language (APDL), Mr Pravin Bharane, Mr Kshitijit Tanpure, Mr Ganesh Kerkal, International Journal of Engineering Research and General Science Volume 2, Issue 5, August-September, 2014, 699-706

Product Development Support with Integral Simulation Modeling, Somnay, R.Shih, SAE Technical Paper Series, paper No: 1999-01-2812, 1999.

Static and Fatigue Simulation of Automotive Anti Roll Bar before DBTT, Amol Bhanage, Padmanabhan Krishnan, International Journal of Applied Engineering Research · August 2015, 472-476

A Review on Anti-Roll Bar used in Locomotives and Vehicles, Birudala Raga Harshits Reddy, International Journal of Current Engineering and Technology, Vol.7, No.3 (June 2017), 838-841

Automated Design Analysis of Anti-Roll Bars, Kemal Caliskan, September 2003

Vehicle Anti-Roll Bar Analyzed Using FEA Tool Ansys, P.M.Bora, Dr.P.K.sharma, International Journal of Advanced Technology in Engineering and Science, Volume No.02, Issue No. 07, July 2014, 130-136

"Design and Analysis of Antiroll Bars for Automotive Application", Mr.Khartode Ankush.N, Prof. Gaikwad Mahendrals.U, International Journal on Recent and Innovation Trends in Computing and Communication Volume: 4 Issue: 6, June 2016, 340 – 345

"Fatigue life of a passenger car", J. Marzbanrad, A. Yadollah, International Journal of Mechanical and Mechatronics Engineering Vol:6, No:2, 2012, 407-413

"Design and Software Base Modeling of Anti- Roll System", Mohammad Durali, Ali Reza Kassaiezadeh, SAE Technical Paper 2002-01-2217, 2002,

M.Mohammad Taha, S.M. Sapuan, M.R. Mansor and N. Abdul Aziz "Development of an Automotive Anti-Roll Bar: A Review" Journal of the Society of Automotive Engineers MalaysiaVol. 1, Issue 1, January 2017, pp 63-81

Hubert, K. and Kumar, A., "Anti-Roll Stability Suspension Technology, SAE SAE Technical Paper 2005-01-3522, 2005,

P.Senapathi, S.Shamasundar, G. Venugopala Rao and B.M.Sachin "Endurance testing and FE analysis of four wheeler automobile stabilizer bar" TopTECH SAE and ARAI, Feb 2009.

M. T. Mastura, S. M. Sapuan, M. R. Mansor, A. A. Nuraini "Conceptual design of a natural fibre-reinforced composite automotive anti-roll bar using a hybrid approach" Springer-Verlag London 2016, 2031-2048

H. Bayrakceken, S. Tasgetiren, K. Aslantas "Fracture of an automobile anti-roll bar" ELSEVIER, 6 September 2005, 732–738

Noraishikin Zulkarnain, Fitrian Imaduddin, Hairi Zamzuri, Saiful Amri Mazlan "Application of an Active Anti-roll Bar System for Enhancing Vehicle Ride and Handling" IEEE Colloquium on Humanities, Science & Engineering Research (CHUSER 2012), December 3-4, 2012, 260-265

Bankar Harshal, Kharade Rushikesh, P. Baskar "Finite Element Analysis of Anti-Roll Bar to Optimize the Stiffness of the Anti-Roll Bar" International Journal of Modern Engineering Research, May 2014, 11-23

Society of Automotive Engineers, Spring community, Spring Design Manual,1999,3.47-3.59

Audi developed carbon-fibre aluminium anti-roll bar, viewed in internet access: http://ae-plus.com/technology/audi-develops-carbon-fibre-aluminium-anti-roll-bar

Various anti-roll shafts, with and without hinges viewed in internet access: https://www.automobiliuremontas.lt/stabilizatoriaus-remontas

J. Aravind, P. Kanmani, G.sudha, R. Balan," Optimization of chromium(VI) biosorption using gooseberry seeds by response surface methodology" Global Journal of Environment Science and Management, 2016, 61-68

APPENDICES

Appendix 1

Spring Design Manual

AE-11

Spring Design Manual

STANDARDS™
SEARCH

Prepared under the auspices
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Warrendale, PA 15096-0001

Chapter 8

Stabilizer Bars

1. Applications

Many vehicles utilize stabilizer (anti-roll) bars to increase roll rate for satisfactory handling characteristics. Stabilizer bars are laterally mounted torsional springs which resist vertical displacement of the wheels relative to one another. Vertical suspension rates are not increased when both wheels are deflected simultaneously, however, stiffness is increased for one wheel bump. Passenger car suspensions, tuned to give a soft ride with low rate springs, use stabilizer bars to reduce vehicle roll with only a minor deterioration of ride. Motor homes and pick-up trucks with slide in campers employ stabilizer bars to control body roll caused by a high center of gravity.[1] Stabilizer bars are generally installed in both front and rear suspensions or in front suspension only. Use of a stabilizer bar on the rear suspension only can sometimes have an adverse effect on vehicle handling. Such installations should be tested under severe cornering conditions to ensure the desired handling characteristics.

2. Design Elements

Stabilizer bars are generally one piece with bends to provide arms and meet package constraints. Stabilizer bars consisting of a torsion bar and separate arms are used on race cars and experimental vehicles. Bar diameter is easily changed to determine optimum roll rates.

Material and processing requirements of stabilizer bars are identical to regular torsion bar springs with the exception that stabilizer bars are not preset. Refer to Chapter 2 Table 2.2 and Chapter 5 for details.

Attachments to frame and suspension components are usually rubber insulated. Care must be taken in locating attachment points to avoid interference with suspension motion unless a specific constraint is required. Typical attachments are:

- Bar and bayonet type link (Fig. 8.1)—Rubber insulators and washers are generally common with shock absorbers
- Bar with rubber insulated eye (Fig. 8.2)
- Bar with eye type link (Fig. 8.3)
- Bar with trapped rubber and washers (Fig. 8.4)—Provides lateral in addition to vertical resistance. May be used as a drag strut on SLA and MacPherson suspensions or a torque arm on live axle suspensions
- Bar with rubber insulator block (Fig. 8.5)
- Bar with silent block bush eye (Fig. 8.6)—Similar to Fig. 8.2—Used to improve durability life

3. Roll Rate Calculations

The total suspension roll rate is due in part to the suspension springs and in part to the stabilizer. When connected to a rigid axle suspension, the roll rate of the stabilizer bar equals its effective roll rate at the wheels. When applied to an independent suspension, however, the bar roll rate is greater than its effective roll rate at the wheels. The required bar roll rate can be obtained by multiplying the desired effective roll rate at the wheels by the square of the ratio of wheel travel to bar travel at the bar end, and by the square of the ratio of bar length to wheel tread:

$$k_R = k_{RW} \times \left(\frac{f_W}{f_A}\right)^2 \times \left(\frac{L}{T}\right)^2$$

where:

k_R = Bar roll rate, N · mm/rad
k_{RW} = Effective roll rate at wheels, N · mm/rad
f_w = Wheel travel
f_A = Deflection at bar end "A"
L = Bar length
T = Wheel tread

When rubber supports are used, as is usually the case, they will add considerable deflection and thereby reduce the calculated roll rate of the bar. The effect of rubber supports, when the rubber rates are known, can be determined from the loads at the points of support C and bar end A. Any connecting links with rubber joints will add to the reduction of roll resistance in the critical stages of initial roll motion. Usually the roll rate of the steel bar is reduced 15–30% by rubber deflections.

The overall configuration of the stabilizer bar, and the points of attachment to the suspension and vehicle struc-

STABILIZER BAR ATTACHMENTS

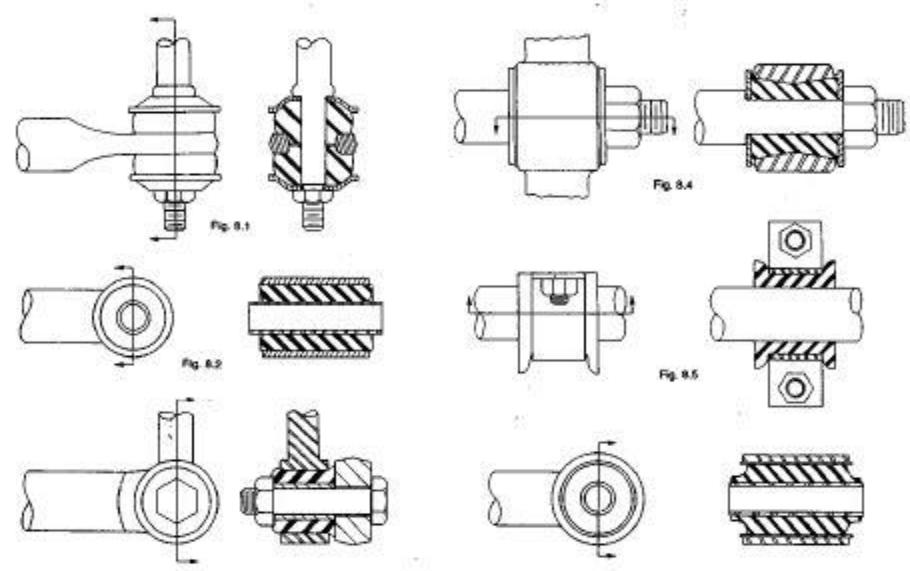

Fig. 8.1

Fig. 8.2

Fig. 8.3

Fig. 8.4

Fig. 8.5

Fig. 8.6

ture are usually determined by layout from available space in the vehicle. With the configuration defined, a bar diameter can be found which will provide the desired roll rate.

Deflection of the bar ends "A" may be determined by the method of unit loads:

$$f_A = \int \frac{M\,m}{E\,I}\,ds + \int \frac{T\,t}{G\,J}\,ds$$

Where M and T represent the bending and torsional moment equations respectively in terms of the distance s from the end of the bar to any section, and m and t are the bending and torsional moment equations due to a force of one Newton acting at the bar end "A" where the deflection is to be found. The integration indicated must be performed over each portion of the beam for which either M, m, T, or t are expressed by a different equation.

The following formulae were derived by this method and may be used to determine the diameter or rate of bars approximating the configuration shown in Fig. 8.7. Rates calculated below are reduced for bars having bends between point C and the centerline of the vehicle.

DEFLECTION OF "A"

$$f_A = \frac{P}{3EI}\left[\ell_1^3 - a^3 + \frac{L}{2}(a + b)^2 + 4\ell_2^2(b + c)\right]$$

BAR ROLL RATE

$$k_R = \frac{PL^2}{2f_A}$$

$$= \frac{3EIL^2}{2\left[\ell_1^3 - a^3 + \frac{L}{2}(a + b)^2 + 4\ell_2^2(b + c)\right]}$$

BAR DIAMETER

$$d = \sqrt[4]{\left[\frac{128}{3\pi} \cdot \frac{k_R}{L^2E}\right] \cdot \left[\ell_1^3 - a^3 + \frac{L}{2}(a + b)^2 + 4\ell_2^2(b + c)\right]}$$

where:

f_A = Deflection at bar end "A", mm
P = Applied load at bar end, N
E = 200 000 MPa
$I = \frac{\pi d^4}{64}$ mm^4
k_R = Bar roll rate, N · mm/rad

4. Stress

The maximum stress normally occurs at a point on the inside surface of the curved section B. Its magnitude depends upon the inside radius of curvature R_i and the Wahl factor K used in calculating the maximum stress in coil springs.

Since the allowable stress should not exceed 700 MPa (Table 2.2) for a fully hardened bar, R_i is determined as follows:

$$S_s \leq \frac{16\,P\,\ell_2\,K}{\pi\,d^3} \leq 700 \text{ MPa}$$

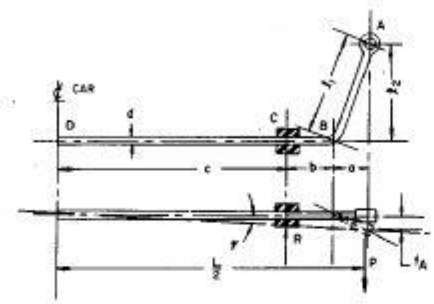

Fig. 8.7—Stabilizer bar

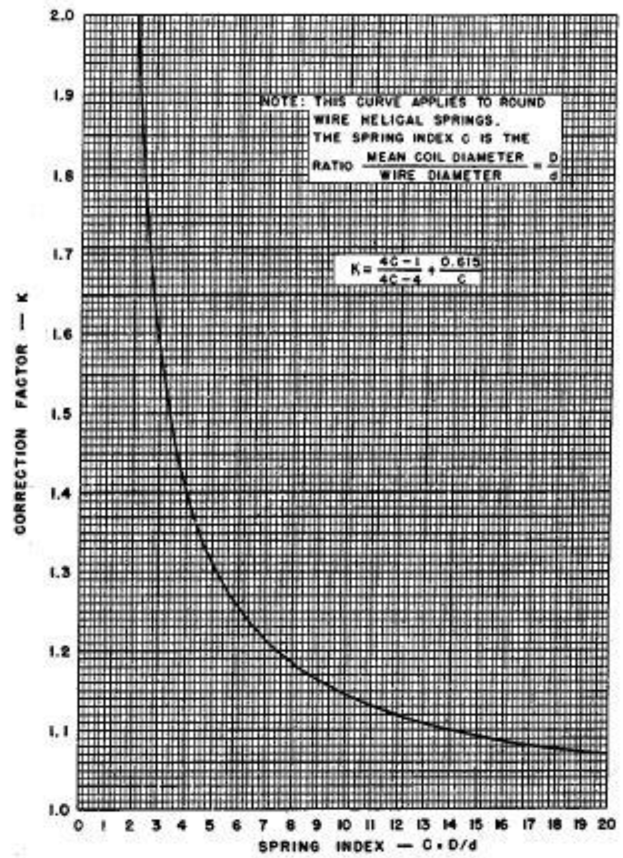

Fig. 8.8—Wahl stress correction factor

3.50

Therefore $K \leq \frac{137\, d^3}{P\, l_2}$ = Wahl factor (Fig. 8.8)

from which D/d may be determined, and

$$R_i = \frac{D - d}{2}$$

since $D = 2\, R_i + d$

It is recommended that R_i should at least equal and preferably exceed 1.25d.

The principal shear stress at section B produced by torsion and bending is less than the maximum torsional shear stress on the inside surface of the bend due to the stress concentration factor. On bars with length a + b approaching 2 l_2, check principal stress (bending and torsion) at attachment point C for critical stress.

Maximum bending stress $S_b = 32\, P\, l_1/\pi d^3$ is usually not critical in a well designed stabilizer bar but should never exceed the maximum yield point in tension (1250 MPa).

5. Design Example

Specifications

Stabilizer bar connected to solid axle.

Required effective roll rate at the wheels 280 000 N · mm/deg

Roll rate loss due to rubber = 30%

L = 1100 mm	l_1 = 250 mm	a = 90 mm
f_A = 75 mm	l_2 = 230 mm	b = 70 mm
		c = 390 mm

Calculation:

$$k_B \text{ (bar roll rate)} = \frac{280\,000}{0.7} = 400\,000 \text{ N} \cdot \text{mm/deg}$$

$$= 400\,000 \times 57.3$$

$$= 22.9 \times 10^6 \text{ N} \cdot \text{mm/rad}$$

$$\text{maximum } P = \frac{2\, k_B\, f_A}{L^2} = \frac{2 \times 22.9 \times 10^6 \times 75}{1100^2}$$

$$= 2840 \text{ N}$$

$$d = \sqrt[4]{\left[\frac{13.58 \times 22.9 \times 10^6}{1100^2 \times 200\,000}\right] \cdot \left[250^3 - 90^3 + (160^2 \times 550) + (4 \times 230^2 \times 460)\right]}$$

$$= \sqrt[4]{\frac{3.113 \times 10^8 \times 1.263 \times 10^8}{2.42 \times 10^{11}}}$$

$$= \sqrt[4]{1.63 \times 10^5} = 20 \text{ mm}$$

For S_t = 700 MPa

$$\text{Wahl factor } K = \frac{137\, d^3}{P\, l_2} = \frac{137 \times 20^3}{2840 \times 230} = 1.68$$

D/d (from Fig. 8.8) = 2.6

Then D = 2.6 × 20 = 52 and

$$R_i = \frac{D - d}{2} = \frac{52 - 20}{2} = 16 \text{ mm}$$

In line with the recommendation that R_i should at least equal 1.25d, it is apparent that R_i should be increased and thus S_t be decreased.

$$\text{maximum bending stress } S_b = \frac{32\, P\, l_1}{\pi d^3}$$

$$= \frac{32 \times 2840 \times 250}{\pi \times 20^3}$$

$$= 904 \text{ MPa}$$

Appendix
Conversion Table

To Convert from SI Unit to U.S. Customary Unit, Divide by the Factor
To Convert from U.S. Customary Unit to SI Unit, Multiply by the Factor

Quantity	SI Unit		Factor (§ = Exact)	U.S. Customary Unit	
Length	kilometer	km	1.609 344§	mile	
	meter	m	0.304 8§	foot	ft
	millimeter	mm	25.4§	inch	in
Area	square millimeter	mm^2	645.16§	square inch	in^2
Volume	cubic millimeter	mm^3	16 387.064§	cubic inch	in^3
	cubic millimeter	mm^3	3 785 412.0	gallon	gal (U.S.)
	liter	L	3.785 412	gallon	gal (U.S.)
Area Moment of Inertia	millimeter to the fourth power	mm^4	416 231.425 6§	inch to the fourth power	in^4
Mass	kilogram	kg	0.453 592 37	pound-mass	lb_m
Force (or Load)	newton	N	4.448 221 6[a]	pound-force	lb_f
Elastic Energy, Work	joule	J(N · m) (= kN · mm)	0.112 984 8	pound inch	$lb_f \cdot in$
Bending Moment, Torque	newton millimeter	N · mm (= mN · m)	112.984 8	pound inch	$lb_f \cdot in$
Spring Rate (Linear)	newton per mm	N/mm (= kN/m)	0.175 126 8	pound per inch	lb_f/in
Torsional Spring Rate	newton millimeter per radian	N · mm/rad	112.984 8	pound inch per radian	$lb_f \cdot in/rad$
Plane Angle	degree		57.295 780[b]	radian	rad
Stress, Modulus of Elasticity	pascal	Pa (N/m^2)	6894.757 3[c]	pound per square inch	
	kilopascal	kPa	6.894 757 3		
	megapascal	MPa	0.006 894 757 3	lb_f/in^2	(= psi)
Density of Material	kilogram per cubic meter	kg/m^3	27 679.90	pound per cubic inch	lb_m/in^3
e.g. for Steel		7850 kg/m^3		~0.283	lb_m/in^3
Acceleration "g" due to Gravity (by International Agreement)		9.806 650 m/s^2	0.3048§	32.174	ft/s^2
		9.806 650 m/s^2	0.0254§	386.09	in/s^2
Natural Frequency (Hz = cycles/s) $\frac{1}{2\pi}\sqrt{\frac{g}{\delta}}$ where δ = static deflection = load/spring rate	$f = \sqrt{0.248/\delta\,(m)}$ $= \sqrt{248/\delta\,(mm)}$			$f = \sqrt{9.78/\delta\,(in)}$	

[a] 4.448 221 6 = 0.453 592 37 · 9.806 650

[b] 57.295 780 = $180/\pi$

[c] 6894.757 3 = $\frac{4.448\ 221\ 6}{0.000\ 645\ 16}$

ANSYS APDL Program

```
/filname, ANTI-ROLL BAR
/title, PARAMETRIC ANTI-ROLL BAR ANALYSIS
!ENTER VARIABLE DATA
*afun,deg
*ask,ISR,'EXTERNAL ANTI-ROLL BAR RADIUS',10
*ask,VR,'INTERNAL ANTI-ROLL BAR RADIUS',8
*ask,L,'ANTI-ROLL BAR LENGHT',1100
*ask,B,'ANTI-ROLL BAR WIDTH',210
*ask,R,'ANTI-ROLL BAR RADIUS',50
*ask,C,'BUSH LOCATION',400
*ask,L1,'BUSH WIDTH',40
*ask,ALFA,'LINK ANGLE',75
*ask,F,'LOAD',1000
*ask,EX,'E-MODULIS',200000
*ask,PRXY,'POISSON'S RATIO',0.3
/prep7
!POINTS COORDINATES
k,1,(L/4),0,100
k,2,0,0,0
k,3,(C-L1/2),0,0
k,4,C,0,0
k,5,(C+L1/2),0,0
k,6,(L/2-(B/tan(ALFA))),0,0
k,7,(L/2),0,B
k,8,(C-L1/2),50,0
k,9,C,50,0
k,10,(C+L1/2),50,0
!LINES
l,2,3
l,3,4
l,4,5
l,5,6
l,6,7
lfilt,4,5,R
!ELEMENT TYPES
et,1,beam189
et,2,combin14
keyopt,2,1,0
```

```
keyopt,2,2,0
keyopt,2,3,0
!REAL CONSTANTS
sectype,1,beam,ctube,,0
secoffset,cent
secdata,VR,ISR,
r,2,500,,,
!MATERIAL PROPERTIES
mp,ex,1,EX
mp,prxy,1,PRXY
!ELEMENT PROPERTIES
latt,1,,1,,1,,1
lesize,1,,,10,
lesize,2,,,1,
lesize,3,,,1,
lesize,4,,,3,
lesize,5,,,10,
lesize,6,,,5,
!MESH
lmesh,ALL
!bush
l,3,8
l,4,9
l,5,10
latt,1,2,2, , , ,1
lesize,7,,,1,
lmesh,7
lesize,8,,,1,
lmesh,8
lesize,9,,,1,
lmesh,9
/eshape,1
/replot
finish
/solu
antype,0
!CONSTRAINTS
dk,2,,,,0,,uy,uz,rotx,,,
```

```
dk,7,,,,0,ux,,uz,,roty,,
dk,8,all
dk,9,all
dk,10,all
!FORCES
fk,7,fy,F
/status,solu
antype,0
nlgeom,1
solve
finish
/post1
!*
/view,1,1,1,1
/ang,1
/EXPAND,2,POLAR,FULL,,180
/replot
PLNSOL,U,SUM,1,1.0
finish
```