Study on Static Structural Analysis of Parabolic Leaf Spring Used In Heavy Commercial Vehicle: A Review

1. Pushpendra Shekhawat ,2. Gaurav Saxena, 3. Janmit Raj
1.Research Scholar, Department of Automobile Engineering, Rustam Ji Institute of Technology, Tekanpur, Gwalior (M. P.)- 475005, India
2.Associate Professor, Department of Automobile Engineering, Rustam Ji Institute of Technology, Tekanpur, Gwalior (M. P.)- 475005, India
3.Research Scholar, Department of Automobile Engineering, Rustam Ji Institute of Technology, Tekanpur, Gwalior (M. P.)- 475005, India

Abstract - In view of the significant increase in the demand of parabolic leaf spring due the light weight and more life cycle than the conventional leaf spring, the present article is an attempt to identify and highlight the various researches that are most relevant to the design and development of the parabolic leaf spring. This review includes the study on FEA(finite element analysis) ,stress distribution and experimental testing of leaf spring. Literature is intended to give a brief knowledge about the researches carried out for the analysis of parabolic leaf spring.

Key words- Parabolic leaf spring, stress distribution, FEA

Introduction-

Parabolic leaf spring are the one having tapered leaves having parabolically varying thickness illustrated in Fig. 1.1. The thickness is maximum at the center and varies towards the end. Top leaf is regarded as main leaf in parabolic leaf springs also and other leaves as supporting leaves. These are having certain advantages in terms of ride height, comfort conditions, uniform bending stresses which enables them to be used increasingly in the modem automobile applications.

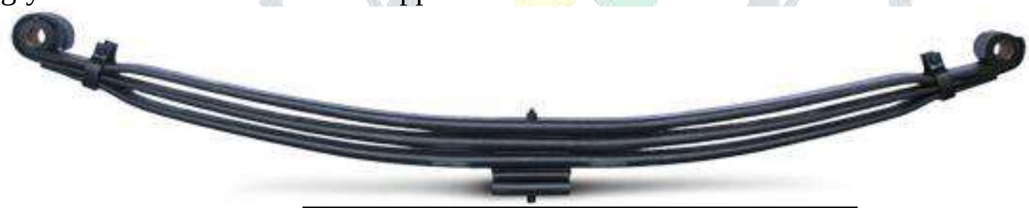


Fig. 1.1 Parabolic Leaf Spring

The mathematical equation between the thickness and the length of the spring is that of a parabola & hence it has been named as parabolic leaf spring. This results in less inter leaf friction, because of which the only contact point between the springs in vehicle is at the end and the center where the axle is connected. Besides being less in weight the main advantage of parabolic leaf springs is their greater flexibility, which is translated as a high ride quality of the vehicle.

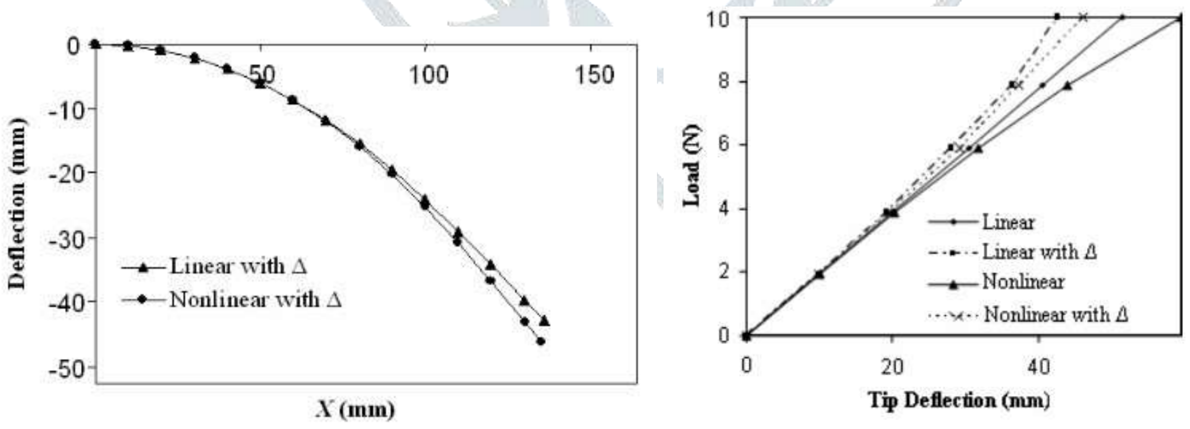
Previous Researches –

Kim S. et al. [1] developed the analytic method to calculate the nonlinear mechanical characteristics of a progressive multi-leaf spring based on Euler beam theory. This method utilizes the interaction between the main and help springs that induces the nonlinearity. The main and the help springs are modelled as multi-leaf cantilever beams, and are then integrated as one by connecting the models for each side of the progressive multi-leaf spring at the centre-bolt. The results from the developed model are evaluated by comparison with those from the commercial FEA programme, ABAQUS. Finally, comparison of the model results with those from an experiment measuring the stiffness of a progressive multi-leaf spring show that the model captures the mechanical characteristics of the spring to accuracy acceptable for design use.

Omar M. A. et al. [2] demonstrated deformations and vibrations of the leaf springs by nonlinear finite-element procedures, which account for the dynamic coupling between different modes of displacement. Two finite-element methods that take into account the effect of the distributed inertia and elasticity are discussed in this investigation to model the dynamics of leaf springs. The study revealed that the overall stiffness of the leaf spring depends on the magnitude of the dynamic load that affects the contact between the leaves of the spring. Furthermore, the numerical results obtained in this study show that the mode shapes selected to model the leaf spring must be able to describe all possible significant deformation modes of the spring in order to obtain accurate results.

Rahman M. A et al. [3] carried out numerical simulation using both the small and large deflection theories to calculate the stress and the deflection in parabolic leaf spring. Non-linear analysis is found to have significant effect on the beam's response under a tip load. It is seen

that the actual bending stress at the fixed end, calculated by nonlinear theory, is 2.30-3.39 % less in comparison to a traditional leaf spring having the same volume of material as illustrated below in Fig. 2.1. Interestingly, the maximum stress occurs at a region far away from the fixed end of the designed parabolic leaf spring.



(a) (b)

Fig. 2.1 (a): Deflected shape of parabolic leaf spring & (b) Tip deflection of parabolic leaf spring.

Abdullah S. et al. [4] presented fatigue life prediction based on finite element analysis and variable amplitude loading (VAL). The experiment is done on parabolic leaf spring of heavy commercial vehicle.

Service loading of parabolic spring has been collected using data acquisition system. Finite element analysis (FEA) was performed on the spring model to determine the stress distribution and damage. The experimental result of variable amplitude loading correlated with that of simulation results.

Refngah F. N et al. [5] predicated fatigue life based on finite element analysis and variable amplitude loading. Service loading of parabolic spring has been collected using data acquisition system. The finite element method (FEM) was performed on the spring model to observe the distribution stress and damage. The main finding can be obtained when the VAL as the input, and it was combines with the FE model. From the results, the fatigue damage using VAL was been predicted and the result was correlated with FEM.

Refngah F. N et al. [6] evaluated the capability of parabolic spring to replace the multi leaf in suspension system. The researcher conducted the finite element analysis for stress distribution for both type of springs. Then, time histories service loading data was analyze and damage area was simulated to predict the fatigue life of the components. The study revealed that for multi- leaf, the stress was concentrated at the center part, while for parabolic, stress was distributed well at the both side of the part. For both springs, the eye itself didn't show significant or no damage at all. The eye only experiencing rotational movement, where the magnitude deflection was relatively small compared to the critical area. Moreover, there are center hole at the high damage area that increase the potential of failure.

Kanbolat A. et al. [7] presented a new approach for non-linear finite element solutions of parabolic leaf spring by evaluating the effects of the production parameters, the geometrical tolerances and the variations in the characteristics of the material**.** The geomartric modal on which the analysis is performed is shown below in Fig. 2.2. The author conducted the experimental and simulation analysis. The analysis concluded that when tolerances changes the stress distribution and spring rate changes rapidly under loaded condition.

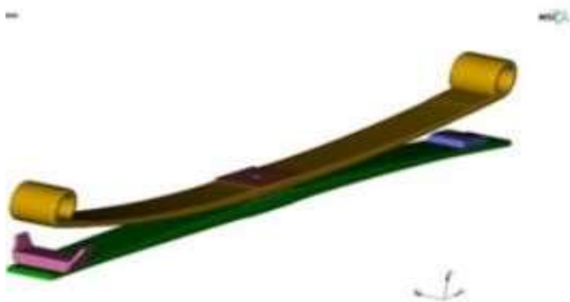


Fig. 2.2: Geometric Model of Leaf Spring.

Soner M. et al. [8] studied non-linear finite element modal of a five layer parabolic lea spring using Abaqus 6.10 and results of analysis were verified with the theoretical load deflection diagram. The same spring was then optimized to reduce weight by converting a five layer parabolic spring to a four leaf spring. This was achieved by increasing thickness of main leaf Difference of only 13 MPa was found between the design iterations with appreciable reduction in weight of the spring.

Refngah F. N et al. [9] test was carried out full scale fatigue test was carried out until that parabolic spring meet failure. To determine the fatigue life**,** CA signal was generated based on an actual fatigue test on the parabolic spring, and it was then analysed using the FEA-based fatigue simulation. A microstructure study was then performed for both fracture and non- fracture area. From the FEA-based simulation, it gave the prediction on damage that occurred at the critical area and also the prediction on the lowest cycle with respect to the FEA model. In the actual fatigue test, the failure was occurred at the centre part of the spring, which is at bolt join of assembly hole. The microstructure analysis showed that the grain at the fracture area indicated some different from the non-fracture area in term of size, phase and precipitation of carbon.

Patnaik M. et al. [10] studied the mono parabolic leaf spring using FEA and DOE (Design of Experiments) approach. CAD modeling and analysis was carried out using CATIA. Effect of camber and eye diameter were selected for study from design of experiments approach. FE results in terms of Von-Mises stresses and displacement were evaluated from static structure analysis and were plotted. With the increase in camber there was decrease in displacement and increase in the stresses. With the increase in eye distance there was increase in displacement, however, the stresses were found to decrease.

Karthik J. P. et al. [11] in their work presented fatigue life prediction of parabolic spring under non-constant amplitude proportional loading using finite element analysis. The researcher analysed the stress distribution and damage for SAE1045-450-QT, SAE1045-595-QT, and SAE5160-825-QT materials. The study concluded that SAE 1045-595-QT gives constantly higher life than material SAE5160-825-QT and SAE1045-450-QT for all loading conditions under both methods. Further, that when the loading is predominantly tensile in nature, the life of the component in Morrow approach is 176.41×10^5 sec which is more sensitive and is therefore recommended for crack initiation approach.

Kong Y. S. et al. [12] designed the parabolic leaf spring based on the input of vertical deflection and stress. The explicit nonlinear dynamic finite element (FE) analysis is done on the designed parabolic leaf spring. A series of load cases; viz. vertical push, wind-up, and suspension roll were applied during the simulation. The vertical stiffness of the parabolic leaf springs is related to the vehicle load-carrying capability, whereas the wind-up stiffness is associated with vehicle braking. The result of the study indicated that the newly designed high vertical stiffness parabolic spring provides the bus a greater roll stability and a lower stress value compared with the original design.

Kumar K. et al. [13] worked on CAE analysis of a symmetrical EN45 parabolic leaf spring consisting of three leaves. CAD model was generated using CATIA V5 and analysis was carried out using ANSYS 11.

The spring in study was a three-layer parabolic spring and meshing was carried out by using relevance, sizing controls and refinements. Appropriate boundary conditions in terms of joint rotation and vertically applied force at seat length were applied. A stress deflection curve was plotted for the rated and maximum loading and comparison made with the experimental results. The curve was linear and CAE results were found to be in accordance with the experimental results.

Kong Y.S. et al. [14] simulated fatigue life predictions of parabolic leaf spring on smooth highway, curve mountain road and rough rural area road under variable amplitude loading (VAL). FE model together with VAL was used as the input to the fatigue life and damage simulation. FE method has provided the critical region of the parabolic leaf spring where the strain gauge was attached. The strain signal represented the parabolic leaf spring loading history when the bus travels on the particular road. In the fatigue life prediction both Morrow and SWT model was adopted to estimate the fatigue life in more conservative way. The fatigue life of parabolic spring during rough road operations is lowest, and the second is mountain road condition. Smooth highway consists of highest life compared to others. The equivalent maximum principal stress observed by the author is shown below in Fig. 2.3.

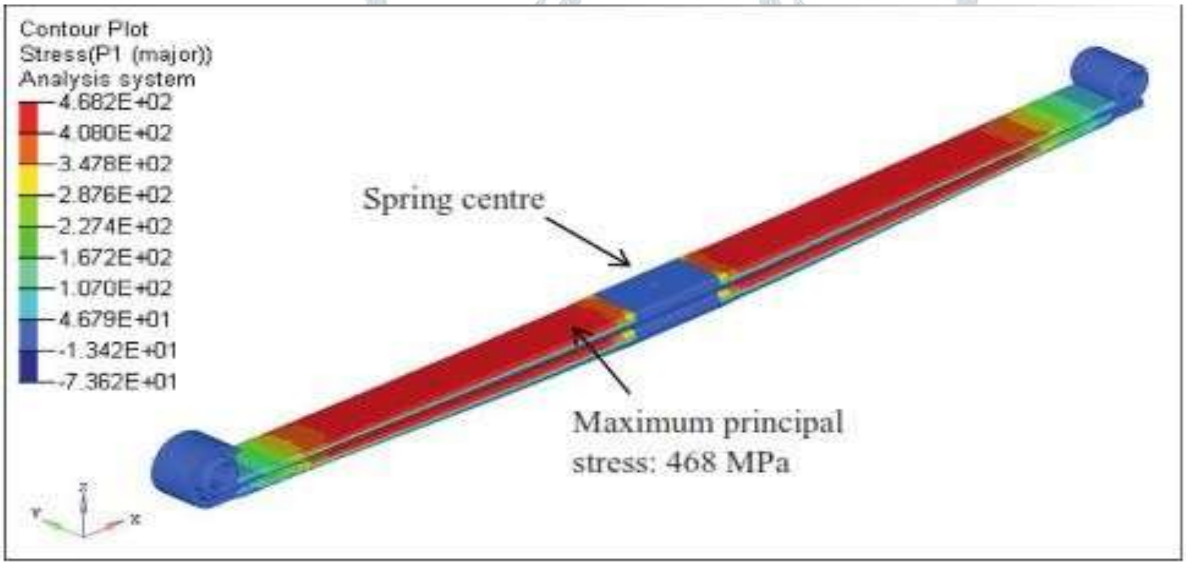


Fig. 2.3: Equivalent maximum principal stress of parabolic leaf spring.

Karlus E. N et al. [15] in their work optimized the parabolic mono leaf spring. The geometric modelling of the leaf spring was done in 3-D modelling software Creo 2.0. While the simulation of the same was done in Ansys Workbench. The analysis was done on conventional spring steel material 55Si2Mn90 and E-Glass/Epoxy composite under the same boundary conditions. The study concluded that epoxy composites can be used for leaf springs for light weight vehicles and convene the necessities, along with considerable weight reductions. Further, by reduction of weight and the less stresses generation, the fatigue life of Epoxy composite leaf spring is higher than that of steel leaf spring.

Karditsas S. et al. [16] designed parabolic 2-leaf-spring for front axles of heavy duty vehicles was designed using the FE method simulating the on-vehicle operating conditions. Vertical loads from straight ahead driving and biaxial loads from full braking of the vehicle are

considered as design criteria. The stress limitations were exceeded and approximately uniform stress distribution was achieved along the length of the two leaves. The stress limitations were exceeded and approximately uniform stress distribution was achieved along the length of the two leaves.

Palaskar M. P. et al. [17} conducted stress analysis on mono leaf spring by finite element method. The variation of thickness considered initially is linear. Further the thickness is varied parabolically along the length of the leaf spring. The analysis revealed that Material saving up to 25% can be achieved by parabolic variation in thickness along the length of the leaf spring. Moreover, distribution of stress of leaf spring can be improved, it becomes more uniform after optimization.

Kumar K. et. al. [18] performed fatigue analysis of parabolic leaf spring by three different methods. The CAE analysis is performed to observe the distribution of stress fatigue life and damage using Goodman approach. The S-N curve obtained from simulation analysis is shown below in Fig. 2.4. The fatigue life of the parabolic leaf spring is determined as per SAE spring design manual and experimentally by testing on full scale fatigue testing machine. The study concluded that fatigue life obtained through experimental testing & CAE analysis shows a 6.54

% variation which is acceptable range.

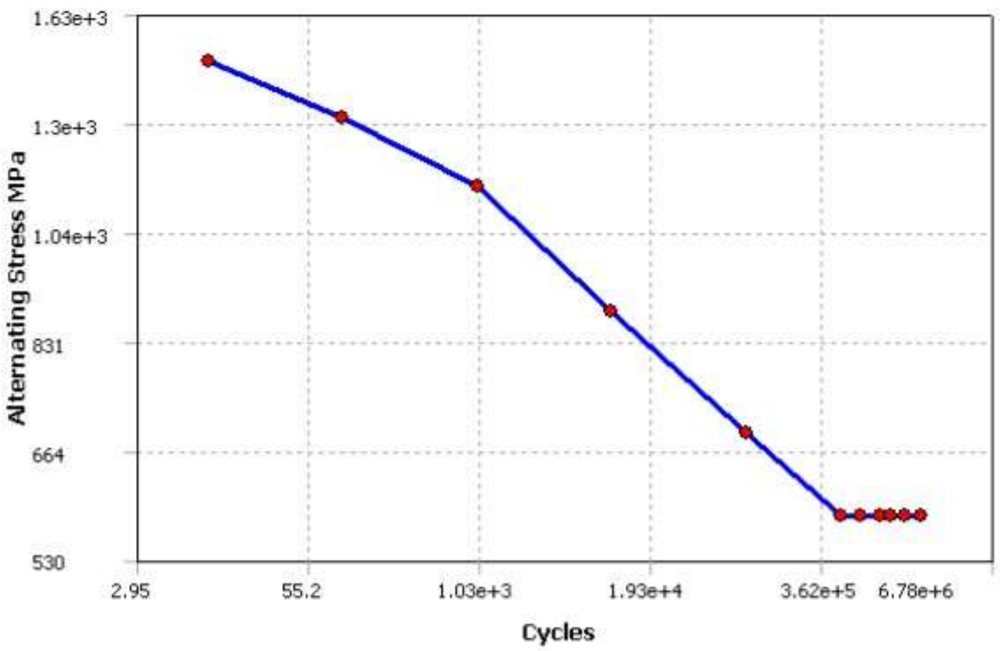


Fig. 2.4: S-N Curve from CAE Analysis.

Duruş M et al. [19] determined fatigue life prediction and the correlation of Z Type leaf springs. The FE model of leaf spring is presented below in Fig. 2.5. Leaf springs are tested with different loads until failure and component S-N curve is constructed to take account of process effects.

Rate measurement on test rig is completed for first FE correlation. Comparison of FE and test tip displacement results showed that finite element model get enough convergency, so it means that model does not behave over stiff because of the FE model. However, vehicle test includes two parts only and because of the low sample rate, the deviation of the results will increase.

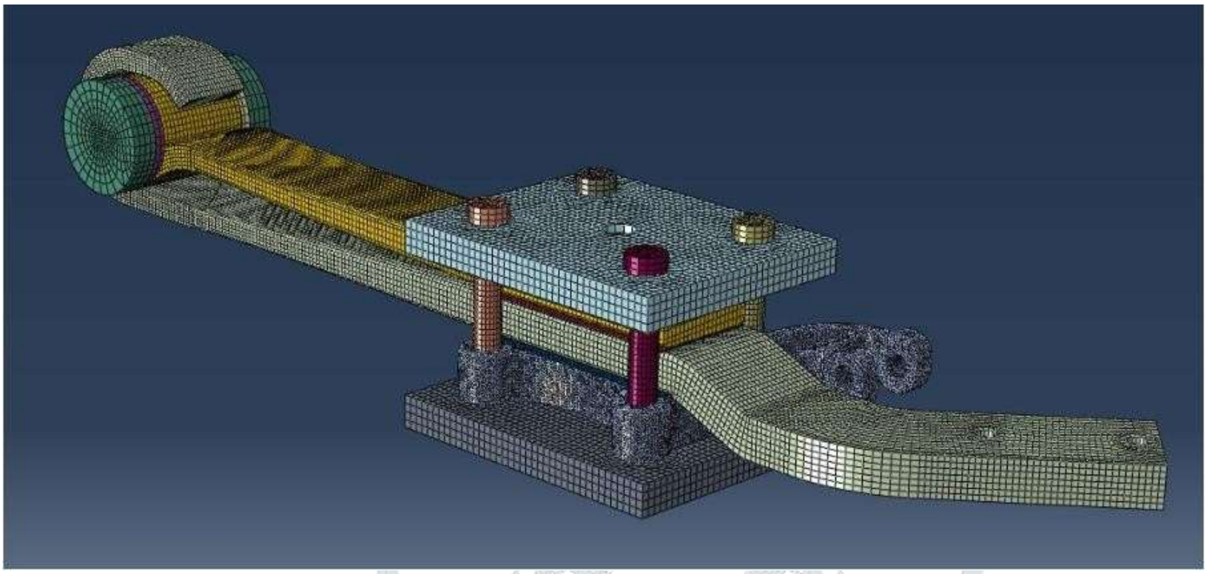


Fig. 2.5: Finite element model of leaf spring & test setup.

Karditsas S. et al. [20] performed the finite element analysis of mono leaf spring of serial heavy truck. The various parameter like eye type, eye lever, spring rate and arm rate difference have been examined. Eye lever and eye type affect significantly the wheel joint kinematics and there with the steering behavior of the vehicle. Both the eye lever and eye type do not affect the magnitude of the stresses and the stress distribution in the effective (parabolic) length of the leaf spring. Spring rate and arm rate difference affect solely the stress performance of the leaf spring.

Kurna S. et al. [21] presented study on finite element analysis (FEA) simulation result of Multi- stage Suspension Leaf Spring done at done in Volvo-Eicher Commercial Vehicles to correlate rig result. The leaf spring is modeled and Quasi-static analysis is carried out by using Radioss software and it is concluded that for the given specifications of the leaf spring FEM gives quite accurate prediction of critical area stresses from the viewpoint of Quasi-static loading. The results of Quasi- static analysis of the leaf spring using the commercial solver and analytical results shows better correlation at all measured locations at all the measured displacements. Correlations have been achieved in both Stiffness and Stress at strain gauge locations between the Rig test and Computer Aided Engineering (CAE) results.

Sunar Ö et al. [22] determined a new method to minimize the number of prototypes and the testing period required to start mass production of parabolic leaf springs. The stress analysis has been performed using Ansys Workbench 14.5 and fatigue life analysis has been performed using Ansys nCode Design Life 14.5. The results of the finite element analysis have been validated by experimental results and a reasonably good correspondence has been obtained. Further, it is possible to predict the fatigue life of single leaf springs used in heavy and light commercial vehicles by the finite element method without long test periods.

Shi W. K et al. [23] developed an efficient method for calculating the composite stiffness of parabolic leaf springs with variable stiffness. The researcher built the simplified model for double-leaf springs with variable stiffness. The composite stiffness calculation method for the model is derived using displacement superposition and material deformation continuity. The accuracy of the calculation method is verified by the rig test and FEA analysis. The rig test and FEA analytical results indicate that the calculated results are acceptable. The proposed method can provide guidance for the design and production of parabolic leaf springs with variable stiffness. The composite stiffness of the leaf spring can be calculated quickly and accurately when the basic parameters of the leaf spring are known.

Giannakis E et al. [24] in their work investigated the effect of the manufacturing process (heat treatment and stress peening) on their performance under fatigue loading. The results of these investigations have been used as input for analytical fatigue life calculations and the theoretical assessment of every individual life-influencing factor such as material, heat treatment, surface treatment, loading. The comparison between the theoretical and experimental curves (for constant amplitude) and fatigue lives (for variable amplitude – operational loading) seems to produce a satisfactory agreement.

Belli M. et al. [25] demonstrated methodology development of a parabolic leaf spring for the rear suspension of a commercial truck. The approach mainly considers the parabolic profiles and stress distribution. The finite element analysis using Ansys was done to determine the stress distribution in the leaf spring followed by experimental testing to calculate the actual stress. The study concluded that mathematical model was robust and the stress values on specific points on the spring were close enough to assume that the model was representative. Further, during durability tests the leaf springs showed no issues and the expected calculated life was achieved.

Atig A. et al. [26] demonstrated probabilistic design approach to predict the high cycle fatigue behavior of a single asymmetric parabolic leaf spring. The geometric model is presented below in Fig. 2.6. The suggested approach is based on the Gerber fatigue criterion, response surface method, and finite element model of the single asymmetric parabolic leaf spring. The researcher compared the fatigue reliability values, calculated by the application of Monte Carlo simulation method on the finite element and response surface models. The study revealed that there is a good correlation between different method results.

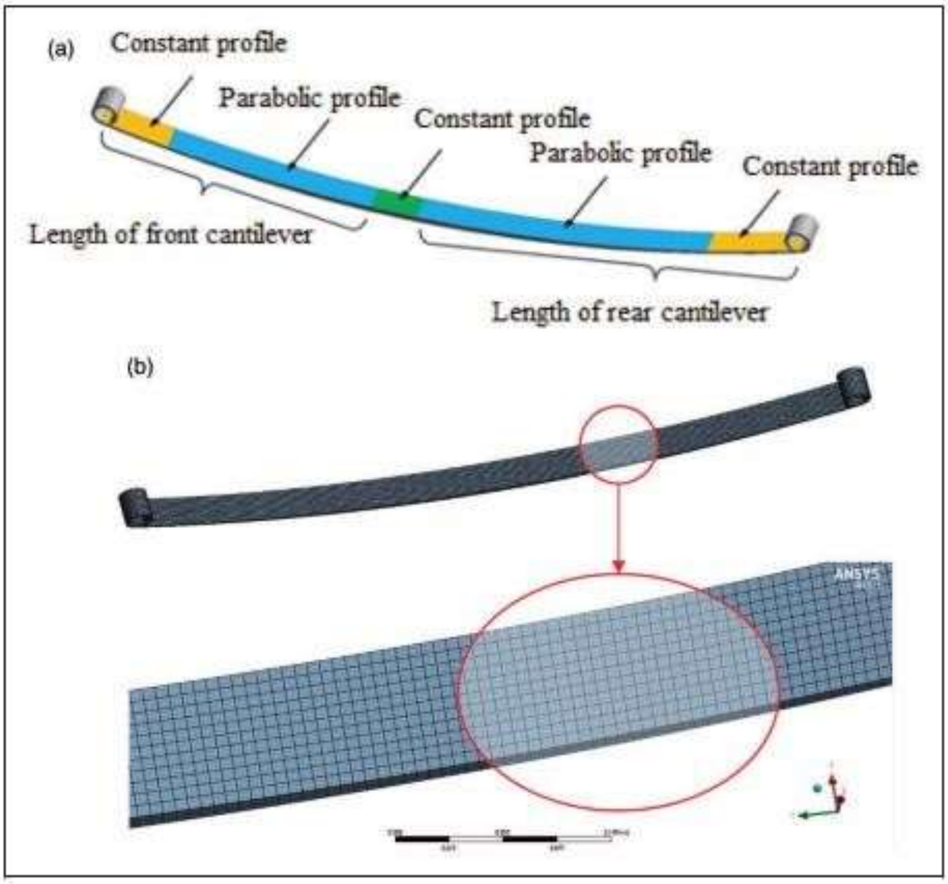


Fig. 2.6: (a) Geometrical and (b) FE model of SAPLS.

Ishtiaque M. T. et al.[27] designed the parabolic leaf spring consisting of 1 Master leaf and 3 graduated leaves. The parabolic design was derived from flat profile design. The finite element analysis of the designed parabolic leaf spring was done in simulation software Ansys Workbench. The boundary condition imposed by the researcher is presented below in Fig. 2.7. The analysis is performed on for two different material EN45A Steel and SAE 5160 Steel. The study concluded that both static performance and fatigue life has been improved with the implication of SAE 5160 steel for parabolic leaf spring with 5 leaves including standard camber profile.

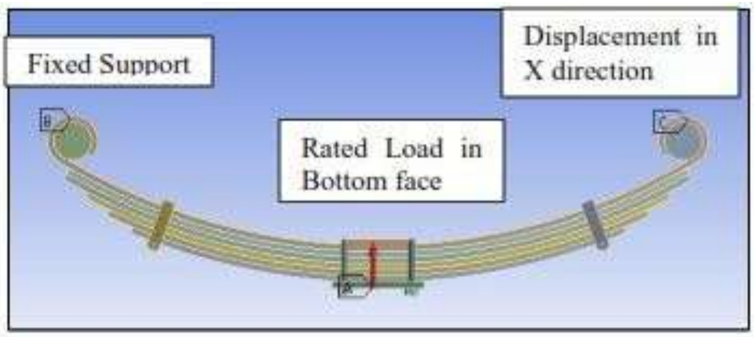


Fig. 2.7: Boundary Conditions.

Sivanandam S. et al.[28] designed the parabolic leaf spring using composite material. The composite material selected for analysis were glass fiber reinforced polymer (E-glass/epoxy), carbon epoxy and graphite epoxy. The geometric modelling of the leaf spring was done in 3-D cad modelling software Pro-E while the simulation was performed in Ansys Workbench. The study concluded that composite parabolic leaf spring reduces the weight by 81.22% for E- Glass/Epoxy, and 90.51 % for Carbon/Epoxy over conventional leaf spring.

Atig A. et al. [29] proposed three analytical models for determining the bending stress distribution of a simply supported single asymmetric parabolic leaf spring: (i) an initially curved single asymmetric parabolic leaf spring, subjected to a concentrated load; (ii) a straight single asymmetric parabolic leaf spring, subjected to a uniform load and (iii) an initially curved single asymmetric parabolic leaf spring, subjected to a uniform load. In comparison with classical model assumptions, the recommended model takes into account both the uniform distribution of the vertical load on the parabolic leaf spring seat part and the initial curvature. Further the, results of suggested model are in a good agreement with those of the FEA.

Marappan K. et al.[30] in their work compared the semi-elliptic steel leaf spring and the parabolic leaf spring on load carrying capacity and weight basis and evaluated the stresses and deflection. For analysis the dimensions of the HM trekker Jeep semi-elliptic leaf springs are taken. The 3-dimensional model is created and the static structural analysis is performed. The semi-elliptic leaf spring tests on Universal Testing Machine and the experimental result is compared with the analytical result for the validation. The comparative graph is presented below in Fig. 2.8. After validation, stress analysis of parabolic leaf spring is carried out and compared with the semi-elliptic leaf spring. The study concluded that parabolic leaf spring have lesser stresses and better load carrying capacity than the conventional leaf spring.

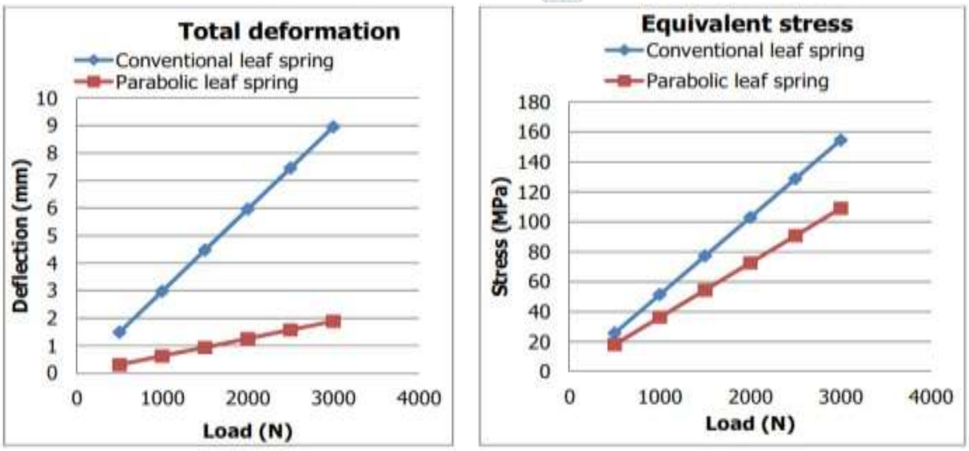


Fig. 2.8: Deformation and Equivalent stress plot, semi-elliptic vs. parabolic spring.

Conclusion –

The extrusion of the literature is defined in the following points.

1. Parabolic leaf spring has lesser stresses and better load carrying capacity than the conventional leaf spring. It can obviously improve the ride quality and ride comfort for the passengers.
2. Finite element predictions of stiffness, strain, and dynamic responses of the spring agree well with the experimental results. This gives confidence in the use of finite element method for the design of parabolic spring.
3. In comparison to the conventional spring, a parabolic leaf spring improves ride and handling, reducing the weight, increasing the strength to weight ratio, extending fatigue life, reducing the noise, improving corrosion resistance, and etc.

References-

[1] Kim S., Moon W. & Yoo Y. (2002). An efficient method for calculating the nonlinear stiffness of progressive multi-leaf springs. *International journal of vehicle design*, *29*(4), 403-422.

[2] Omar, M. A., Shabana, A. A., Mikkola, A., Loh, W. Y., & Basch, R. (2004). Multibody system modeling of leaf springs. *Modal Analysis*, *10*(11), 1601-1638.

[3] Rahman M. A., Siddiqui, M. T., & Kowser, M. A. (2007). Design and non-linear analysis of a parabolic leaf spring. *Journal of Mechanical Engineering*, *37*, 47-51.

[4] Abdullah, S., Refngah, F. N., Jalar, A., Chua, I. B., Ariffin, A. K., & Zaharim, A. (2008, November). FEA-based durability assessment: A case study using a parabolic leaf spring. In *Proceedings of the 7th WSEAS international conference on System science and simulation in engineering* (pp. 67-72). World Scientific and Engineering Academy and Society (WSEAS).

[5] Refngah F. N., Abdullah, S., Jalar, A., & Chua, L. B. (2009). Life assessment of a parabolic spring under cyclic strain loading. *European Journal of Scientific Research*, *28*(3), 351-363.

[6] Refngah F. N., Abdullah, S., Jalar, A., & Chua, L. B. (2009). Fatigue life evaluation of two types of steel leaf springs. *International Journal of Mechanical and Materials Engineering*, *4*(2), 136-140.

[7] Kanbolat A., Soner, M., Erdogus, T., & Karaagac, M. (2011). Parabolic leaf spring optimization and fatigue strength evaluation on the base of road load data, endurance rig tests and non linear finite element analysis *SAE Technical Paper (No. 2011-01-0438).*

[8] Soner, M., Guven, N., Kanbolat, A., Erdogus, T., & Karaagac, M. (2011). *Parabolic leaf spring design optimization considering FEA & rig test correlation* (No. 2011-01-2167). SAE Technical Paper.

[9] Refngah, F. N. A., Abdullah, S., Jalar, A., & Chua, L. B. (2011). Microstructural behaviour study and FEA-based fatigue simulation on parabolic leaf spring. In *Key Engineering Materials* (Vol. 462, pp. 419-424). Trans Tech Publications.

[10] Patnaik M., Yadav, N., & Dewangan, R. (2012). Study of a parabolic leaf spring by finite element method & design of experiments. *International Journal of Modern Engineering Research*, *2*(4), 1920-1922.

[11] Karthik J.P., Chaitanya K.L. and Sasanka C.T., (2012). "Fatigue life prediction of a parabolic spring under non-constant amplitude proportional loading using finite element method." *International Journal of Advanced Science and Technology*, *46*, pp.143-156.

[12] Kong, Y. S., Omar, M. Z., Chua, L. B., & Abdullah, S. (2013). Explicit nonlinear finite element geometric analysis of parabolic leaf springs under various loads. *The Scientific World Journal*, *2013*.

[13] Kumar K., & Aggarwal, M. L. (2013). Computer aided FEA simulation of EN45A parabolic leaf spring. *International Journal of Industrial Engineering Computations*, *4*(2), 297-304.

[14] Kong, Y.S., Omar M.Z., Chua L.B. and Abdullah S., (2014). "Fatigue life prediction of parabolic leaf spring under various road conditions." *Engineering Failure Analysis*, *46*, pp.92-103.

[15] Karlus E. N., Himte, R. L., & Rathore, R. K. (2014). Optimization Of Mono Parabolic Leaf Spring. *International Journal of Advances in Engineering & Technology*, *7*(1), 283.

[16] Karditsas S., Savaidis G., Mihailidis A., Savaidis A., & Fragoudakis, R., (June 5-11, 2014). "Leaf springs–Design, calculation and testing requirements." *35th Int. Symposium on Mechanics and Materials*, Greece.

[17] Palaskar M. P. (2014). Optimization of Mono Leaf Spring by Parabolic Variation of Thickness along the Length. *International Journal of Scientific and Research Publications*, *4*(5), 1.

[18] Kumar K. and Aggarwal, M., 2015. Fatigue life prediction: A comparative study for a three layer EN45A parabolic leaf spring. *Engineering Solid Mechanics*, *3*(3), pp.157-166.

[19] Duruş M., Kırkaya L., Ceyhan A. and Kozan K., 2015. Fatigue life prediction of Z type leaf spring and new approach to verification method. *Procedia Engineering*, *101*, pp.143-150.

[20] Karditsas S., Savaidis, G., & Malikoutsakis, M. (2015). Advanced leaf spring design and analysis with respect to vehicle kinematics and durability. *International Journal of Structural Integrity*, *6*(2), 243-258.

[21] Kurna S., Mathur, A., & Sharma, S. (2015). Investigation of Stresses and Deflection in Multi Stage Leaf Spring of Heavy Duty Vehicle by FEM and Its Experimental Verification (No. 2015-01-1345). SAE Technical Paper.

[22] Sunar Ö., and M. Çevik, (2015). "Finite Element Modeling of Leaf Springs for the Prediction of Fatigue Life. "*International Conference on Advances in Applied and Computational Mechanics*.

[23] Shi W. K., Liu, C., Chen, Z. Y., He, W., & Zu, Q. H. (2016). Efficient Method for Calculating the Composite Stiffness of Parabolic Leaf Springs with Variable Stiffness for Vehicle Rear Suspension. *Mathematical Problems in Engineering, 2016*.

[24] Giannakis E., M. Malikoutsakis, and G. Savaidis. "Fatigue design of leaf springs for new generation trucks." In *IOP conference series: materials science and engineering*, vol. 161, no. 1, p. 012065. IOP Publishing, 2016.

[25] Belli M., & Daldegan, R. (2017). Development of a Commercial Truck Parabolic Leaf Spring Using CAE Simulation with Correlated Experimental Stress Analysis Results (No. 2017-36-0126). SAE Technical Paper

[26] Atig A., Ben Sghaier R., Seddik R. and Fathallah R., (2017). "Reliability-based high cycle fatigue design approach of parabolic leaf spring." *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, p.1464420716680499.

[27] Ishtiaque M. T., & Joo, S. H. (2017, November). Optimized Modelling and Fabrication of a Parabolic Leaf Spring With Finite Element Analysis. In *ASME 2017 International Mechanical Engineering Congress and Exposition* (pp. V009T12A052-V009T12A052). American Society of Mechanical Engineers.

[28] Sivanandam S., Shankar M. and Vivekanandhan M. (2018). Design and Analysis of Composite Parabolic Leaf Spring for Light Vehicles. *IOSR Journal of Engineering*, 23-28.

[29] Atig A., Ben Sghaier, R., Seddik, R., & Fathallah, R. (2018). A simple analytical bending stress model of parabolic leaf spring. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *232*(10), 1838-1850.

[30] Marappan, K., Jenarthanan M.P. and Krishna B.S. (2018). Design of Parabolic Leaf Spring for light duty automobile. *World Journal of Engineering*.

-