Journal of Engg. Research **Vol. 3 No. (2) June 2015** pp. 129-140

تحليل حمل التواء الحرج في شاسيه الشاحنة بطريقة طول القوس

إحسان هدايتي، **عارفة هدايتي ومحمد واحدي**

*منتدى الباحثين الشباب والنخب، فرع ساوة، جامعة آزاد، ساوة، إيران

**قسم الهندسة الصناعية، جامعة آزاد، فرع ساوة، ساوة، إيران

***قسم الهندسة الميكانيكية، جامعة آزاد، فرع ساوة، ساوة، إيران

الخلاصـة

إحدى العوامل التي تسبّب التصدع بسبب الإجهاد في شاسيه الشاحنة هي النقاط الحرجة. وفي هذه الدراسة، تم تحليل حمل التواء الحرج في شاسيه شاحنة بطريقة طول القوس وكذلك تأثير تبديل الفولاذ العادي باثنين من الفولاذ الصلب في النقاط الحرجة. وتم استخدام برمجيات العناصر المحدودة مثل (ABAQUS) لأجل تحليل النقاط الحرجة والأحمال التي يمكن أن تؤدي إلى التصدع بسبب الإجهاد. أظهرت النتائج من تحليل الخطي للتواء بأن التغيير في مادة الشاسيه لا يؤدي إلى تغييرات كثيرة في كميات الأحمال الحرجة. وإن النتائج بعد التواء أظهرت بأن العيوب الصغيرة جدّاً تُسبّب في انخفاض كبير لأحمال التواء الحرجة وهذه الإنخفاضات تسبّبت في ايجاد نقاط الإجهاد في الشاسيه. وكشف البحث كذلك بأنه عندما يستخدم الفولاذ العادي في الشاسيه، تتكون عدد من الإزاحات والأحمال في نقاط الإجهاد حرجة وكمية هذه الإزاحات والأحمال يمكن أن تُسبّب تصدع بسبب الإجهاد في الشاسيه وتُقلّل من عمرها.

Critical Buckling load Analysis of Truck Chassis Using Arc-length Method

Ehsan Hedayati*, Arefeh Hedayati** and Mohammad Vahedi***

**Young Researchers and Elite Club, Saveh Branch, Islamic Azad University, Saveh, Iran.*

***Department of Industry Engineering, Islamic Azad University, Saveh Branch, Saveh, Iran.*

**** Department of Mechanical Engineering, Islamic Azad University, Saveh Branch, Saveh, Iran.*

**Corresponding Author: hedayati.uast.ac@gmail.com*

ABSTRACT

Critical point is a factor that causes chassis fatigue failure. In this study, critical buckling load analysis of truck chassis with arc-length method and the effect of replacing conventional steel with two stainless steels in critical point of truck chassis have been investigated. critical point analysis of stress that may cause the fatigue failure, the FE software, ABAQUS, is employed. The obtained results from the linear analysis of buckling showed that changing of the chassis materials did not bring about considerable changes in the values of critical loads. Post buckling response showed that the imperfection of very small values causes a significant decrease of the critical buckling loads. These reductions make stressful points in chassis. Investigation showed that when conventional steel is used in chassis, the amount of displacement and stress is critical in Stressful points. This amount of displacement and stress can cause fatigue failure in chassis and reduce the longevity of chassis.

Keywords: ABAQUS; critical loads; critical point; fatigue failure; post buckling; truck Chassis

INTRODUCTION

Chassis is usually defined as the frame (backbone) of an automobile and is the most important part, which is exposed to buckling. Therefore, a crucial part of chassis designing is analysis of its buckling. Buckling occur in two elastic and plastic regions. A factor that cause buckling phenomenon is the structural defect. These defects are problematic when they are in critical points. Thus by a small change in static applied load, a large displacement will occur in critical point. This displacement can cause to fatigue failure in chassis from that point. Since fatigue failure start from the highest stress point, whatever displacement is less in critical and buckling point, the probability of fatigue failure will be less in that point. This cause to increase the longevity of chassis and the accuracy and correctness of selected material for chassis will be closer to fact. Therefore, it is better to choose materials with higher strength and reforming ability so that they exhibit an acceptable resistance to dynamic and static loads (Corolla, 2009; Higley & Mischke, 1989; Khalkhali, 2012).

Nowadays, conventional steels which are used in chassis, cannot give an appropriate performance in comparison with other steels because of their lower strength, energy-absorption level, and lifetime. It is years since stainless steels have been used to make exhaust pipe, maintenance systems, brake, motor frame, gas tank, cylinder-head gasket, suspension system, wheels, and so on. They have recently been used in automobiles frames and chassis because of their higher strength to weight ratio, in comparison with aluminum, better ductility compared to HSLA steels and their economy. The great tensile properties of two austenitic stainless steels, C850, C1000, give them great advantages in hydro-forming processes, which are carried out to improve the performance of chassis. In addition, these two steels have a higher strength than conventional steel used in chassis (Bachman, 2005; Hosford & Caddell; 2007; Juvinall & Marshek, 2006).

Many designers and researchers carried out study on the chassis . Conle & Chu did a research about fatigue analysis and the local stress-strain approach in complex truck structures (Conle & Chu, 1997; Filho *et al*.,2003) have investigated and optimized a chassis design for a truck with the appropriate dynamic and static behaviour, taking into account the aspects relative to the economical viability of an initial small-scale production for reduction of the production cost (Filho, *et al*., 2003). Recently Karaoglu & Kuralay (2002) investigated stress analysis of an off-road vehicle chassis with riveted joints using FEM. Results showed that stresses on the lateral parts can be reduced by increasing the lateral parts thickness locally. If thickness change is not possible, length of the connection plate may be increased (Karaoglu & Kuralay, 2002).

Non-linear Buckling Mode Analysis

Nonlinear buckling analysis with effect of plastification will be used to investigate the post buckling behaviour. Since the post buckling behaviour may become unstable when the elasto-plastic deformations take place, it is very important to investigate the influence of defects on the loading capacity of structure (Novoselac *et al*., 2012). This makes the selection of appropriate analysis method and technique more important. It is very difficult to determine the structural strength with ordered static analysis using Newton-Raphson method. Furthermore, this technique fails near the limit point. To overcome on difficulties with limit points, displacement control techniques were introduced. The Riks's technique is generally used to post buckling analysis; predict unstable, geometrically nonlinear collapse of a structure (Ahmed & Zu, 2004;

Życzkowsky, 2005; Bochenek, 2003). In this kind of buckling analysis the applied load on structure starts from zero and graduatlly increases at given increments. Abaqus uses the arc length method for determining the length of increments. The maximum and minimum length of an increment is determined by user. After finishing each increment, all stresses and strains are calculated based on material behavior. Thus loading is increased step by step until it reaches to a point that in it the structure is unstable. The nonlinear responses of buckling are very good and they are used for complex models (Khalkhali, 2012; Novoselac *et al* , 2012)

Arc-length method

In arc-length method, the load proportionality factor (i. e. LPF) at each iteration is modified so that the solution follows some specified path until convergence is achieved. Since the method treats the LPF as a variable, it becomes an additional unknown in equilibrium equations resulting from finite element procedure, and gives N + 1 unknown, where N is the number of elements in the displacement vector. The solution of N + 1 unknown requires an additional constraint equation expressed in terms of current displacement, load-factor and arc-length. Two approaches, fixed arc-length and varying arc-length are generally used. In the former the arc-length is kept fixed for current increment, whereas in the latter case, new arc-length is evaluated at the beginning of each load step to ensure the achievement of the solution procedure. Simplification of the constraint equation leads to a quadratic equation, whose roots are used for determining the load-factor. The equilibrium equation of nonlinear system can be written as:

$$g_i\,(\lambda_i) = f_i - \lambda_i q, \qquad (1)$$

Where f_i is vector of internal equivalent nodal forces, q is the external applied load vector, λ_i is the load-level parameter, and g_i is out-of-balance force vector. The arc-length method is aimed to find the intersection of Equation 1. with constant s termed as the arc-length, and can be written in differential form as: (Novoselac *et al*, 2012):

$$S = (dp^T\,dp + d\lambda^2\,\Psi^2\,q^T q\,)^{1/2} \qquad (2)$$

FE modeling

Ladder chassis and perimeter chassis are used in most of the heavy vehicles to provide a larger space between beams and also to mount the main part of the structure. (Corolla, 2009; Hhigley & Mischke, 1989). In this work, the ladder chassis was chosen as in the truck Benz model. The model is shown in Figure 1.

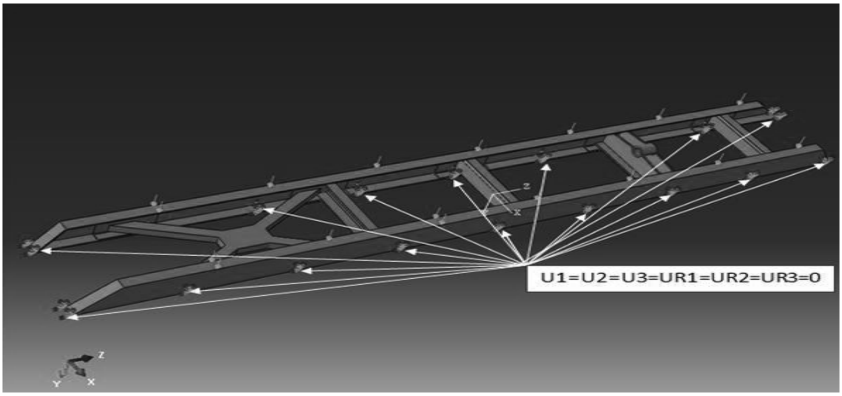


Fig. 1. A schematic presentation of ladder chassis and its loading method

The Selected chassis was analyzed using the finite element software, ABAQUS 6.10.1, with a better meshing compared to other softwares. In addition, the chassis made up of C1000, C850, and conventional steels were compared with each other. Table 1 lists the mechanical properties of two stainless steels and conventional steel (Juvinall & Marshek 2006; Chiaberge, 2011). For analysis, continuum tetrahedron elements with 10 nodes (C3D10) were used. This element has each nod three degrees of freedom along the X, Y, Z directions. It is used for non-linear elasto-plastic analyses and plastic deformations (Abaqus Documentation, 2010).The number of elements existing in meshing of this structure is, 160076 while that of its nods is 50451.

Table 1. Physical and mechanical properties of materials

Steel	Density (gr/cm^3)	Elastic modulus (GPa)	0.2% yield strength (MPa)	Ultimate tensile strength(MPa)	(Poisson's Ratio) ν	Specific strength (σ/ρ)
Conventional	7.80	207	520	620	0.300	66.666
C1000	7.80	200	900	1150	0.303	115.385
F2229	7.63	200	1280	1610	0. 301	167.759

RESULTS

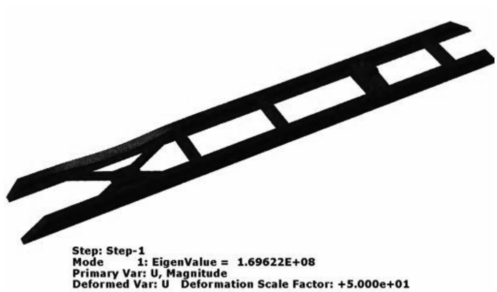
Stress analysis using finite element method can be used to locate the critical point, which has the highest stress and the magnitude of the stress can used to predict the Safety Factor (SF) of the truck chassis (Higley & Mischke, 1989; Brady, 1997). The first analysis done was Eigen value linear analysis for determination of critical buckling load and buckling mode. Then the nonlinear Riks static analysis was done for critical point analysis, stress that may cause the fatigue failure and to predict the Safety Factor (SF) of the truck chassis.

Eigen Value Linear Buckling Analysis

In this section, linear Eigen value analysis is applied to calculate the amount of critical loads. Results are shown in Figure 2. Results showed that, no noticeable change in buckling shape is observed with a change in chassis material and just a slight variation in critical loads is yielded. Thus, from the viewpoint of buckling mode and critical load, it is possible to use these two stainless steels in chassis structure. Linear Eigen value analysis result usually involves very little deformation prior to buckling. From the detailed structural view point, it is more precise to use nonlinear analysis, which includes post buckling behaviour with elasto-plastic behaviour of material.

Conventional Steel

Stainless steel C850



Stainless steel C1000

Fig. 2. The deformation resulted from linear buckling analysis of different steels.

Loading

The truck chassis model is loaded by static loads from the cargo and truck body (Higley & Mischke, 1989). For this model, the maximum loaded weight of truck plus cargo is 10000 kg. The magnitude of static load on the upper side of chassis is estimated by:

$$P = \frac{mg}{A} = \frac{10000 \times 9.81}{10.876} = 9019.86 \text{ N/m}^2 \tag{3}$$

Results of nonlinear elasto-plastic FEM model with the Riks method

As observed before, it is possible from the viewpoint of buckling mode to replace conventional steel with these two stainless steels. Now, the effect of this replacement on post-buckling behavior of chassis can be investigated. In the section, the non-linear buckling analysis of chassis is employed to calculate the stress that may cause the fatigue failure and the Safety Factor (SF) of the truck chassis. In all models, for analyzing the post buckling response of chassis in a more accurate manner; the very small defects are made in part structure by command "Imperfection". Then deformation in first mode of Linear Eigen value analysis multiplied at 10^{-5}, deformation of second mode multiplied in 10^{-6} and deformation of third mode multiplied in 10^{-6} and finally all of them summed with each other by command Imperfection and result was used as initial deformation of structure in non linear buckling analysis (Khalkhali, 2012).The static load was employed by 50 increments and the buckling load is estimated. Figure 3 shows that, the first of the critical load is at arc length 11433. The value of this load is less than critical load in linear analysis and thus it is probable that the maximum stress that applied on chassis is critical.

The location of maximum stress is at node 487. The level of stress is 490.8 MPa. From formula SF = $\frac{S_{ut}}{S_{max}}$ (Beer & Johnston, 2006) the magnitude of safety factor for this chassis is 1.263. Vidosic (1957) recommends the value of 1.5 to 2 for well known materials under reasonable environmental condition, subjected to loads and stresses that can be determined readily.

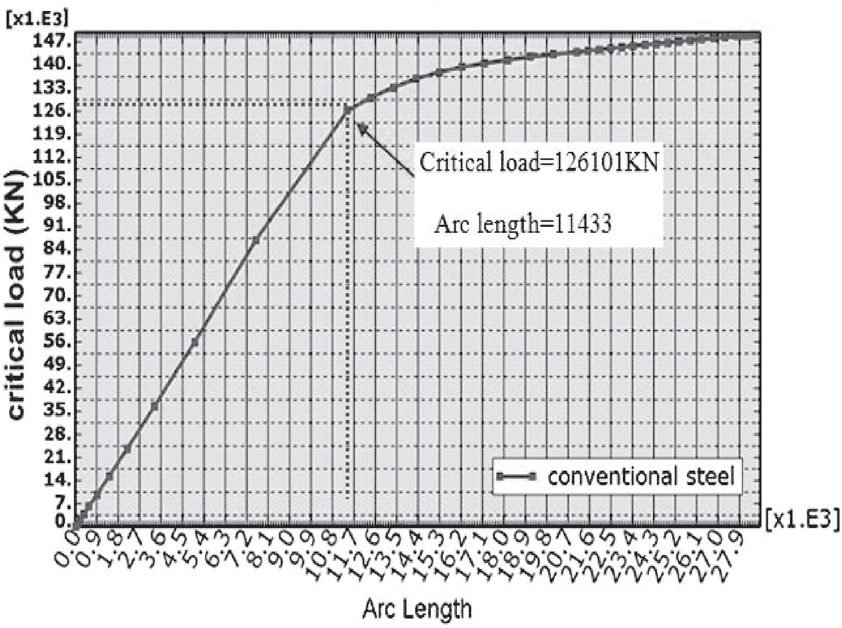


Fig. 3. Critical load - arc length diagram.

Therefore, displacement and stress in this point is critical because the value of SF is below the recommended value and by a small increase in applied load value, the fatigue failure will occur from this point. Results of critical displacement and location of critical stress are shown in Figure 4 (a) and (b). Accordingly the resistance, which chassis has in post buckling loading and critical point, is low. Given this reason, it is necessary to increase the safety factor in critical point of chassis.

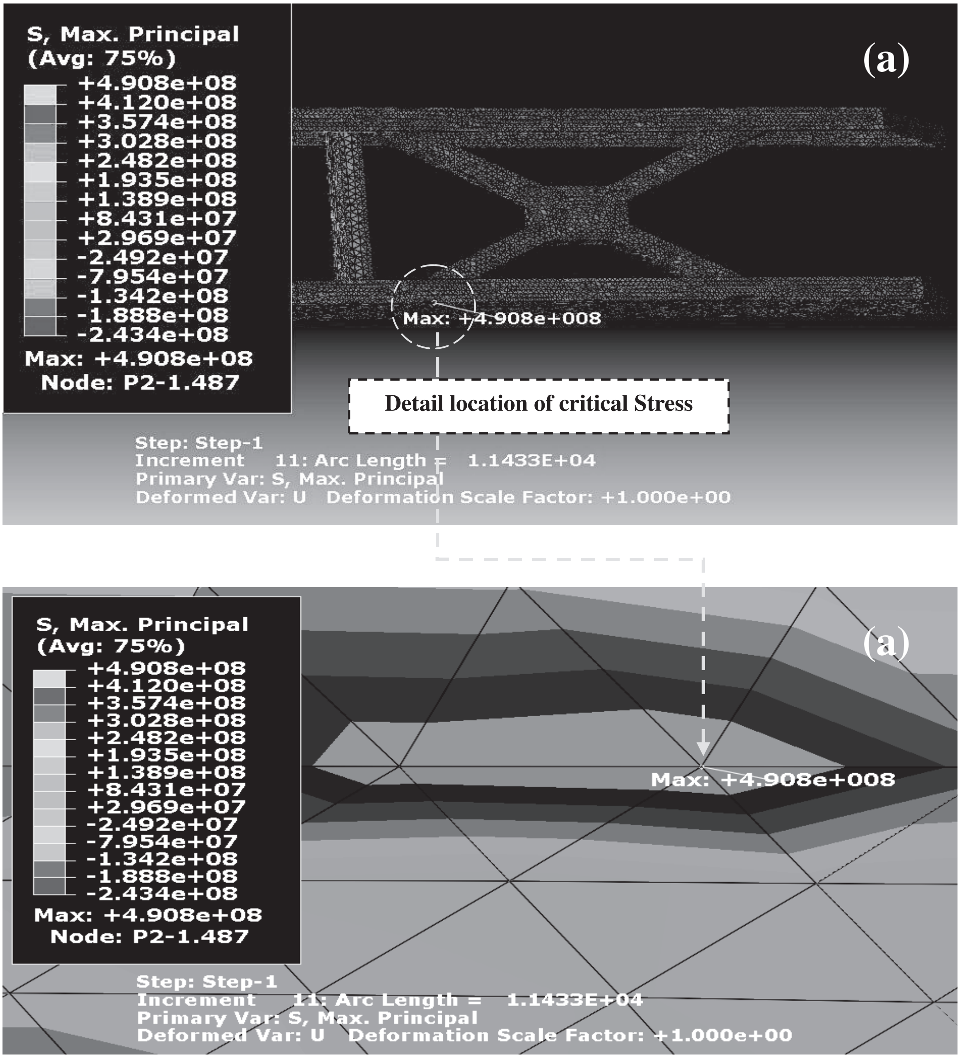


Fig. 4. (a) Illustration of Critical stress distribution and critical point location at arc length 11433

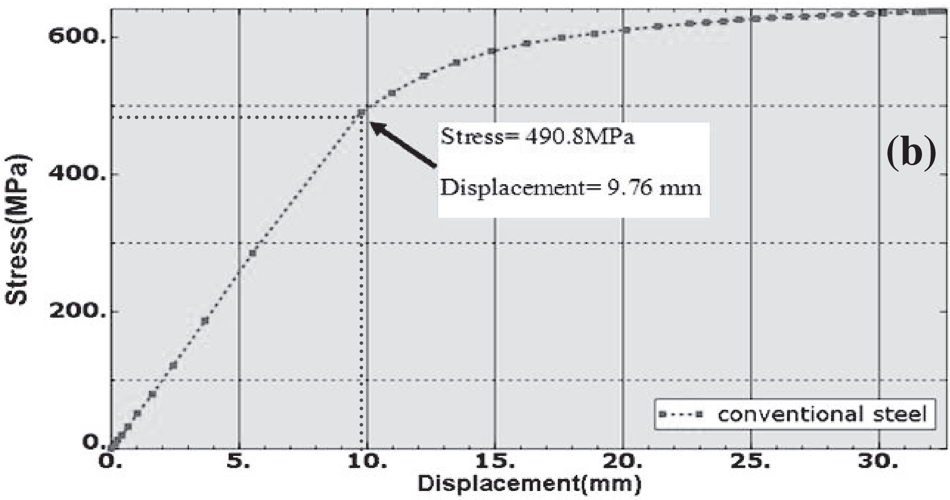


Fig. 4. (b). Illustration of stress - Displacement diagram at arc length 11433.

For increasing the safety factor in critical point of structure and for preventing the fatigue failure in stressful points of chassis, two steels as C1000 and C850 are used. The results of Figure 5 (a) and (b) show the critical load - arc length diagram and the stress - displacement diagram at arc length 1433, respectively. Figure 6 (a) and (b) shows the maximum stress distribution and stress location in steel C850 and steel C1000 respectively. The obtained results proved that the occurred stress and displacement is not critical because the magnitude of safety factors for this chassis is 1.81 and 2.28 respectively. Thus there is increase in the safety in stressful point of chassis, for avoiding from critical point and using these two steels in chassis due to having less displacement cause to Increase the chassis longevity against fatigue failure.

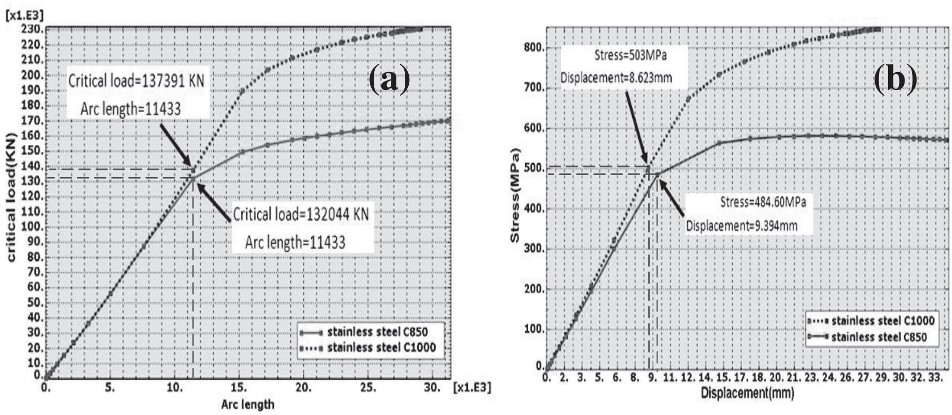


Fig. 5. (a) Illustration of Critical load - arc length diagram,(b) stress-Displacement diagram at arc length 1433

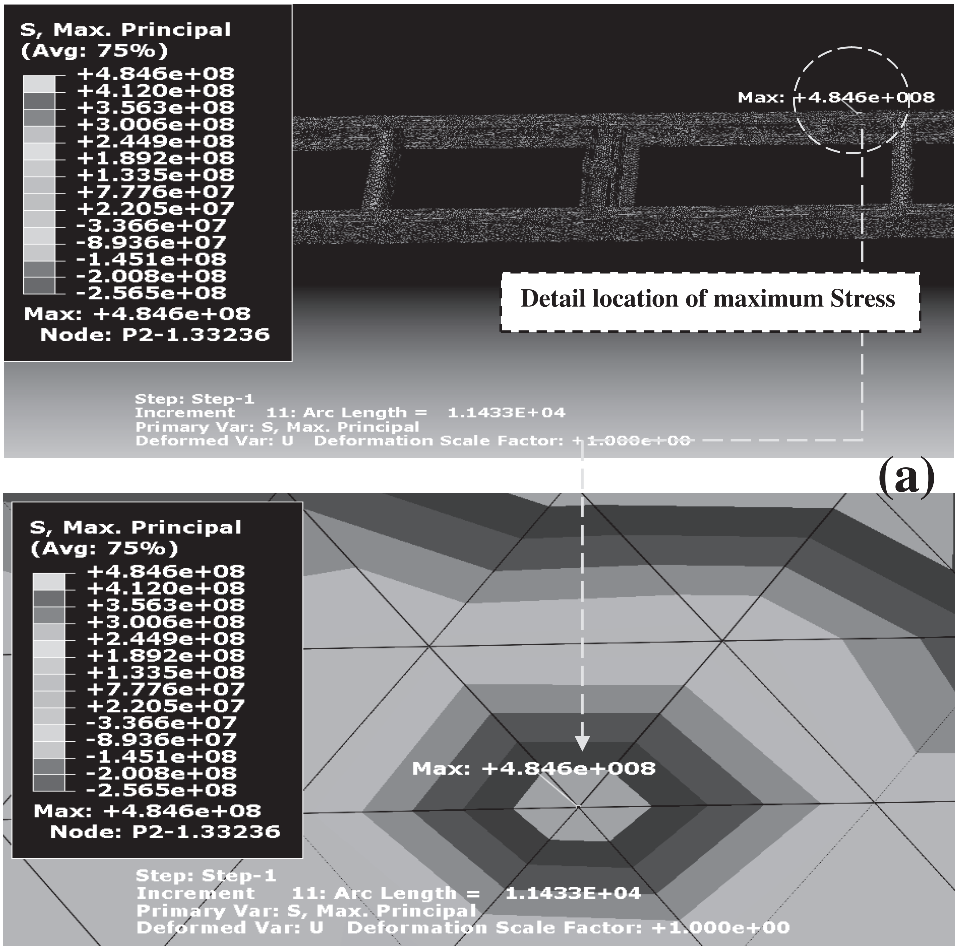


Fig. 6 (a). Maximum stress distribution and stress location in steel C850

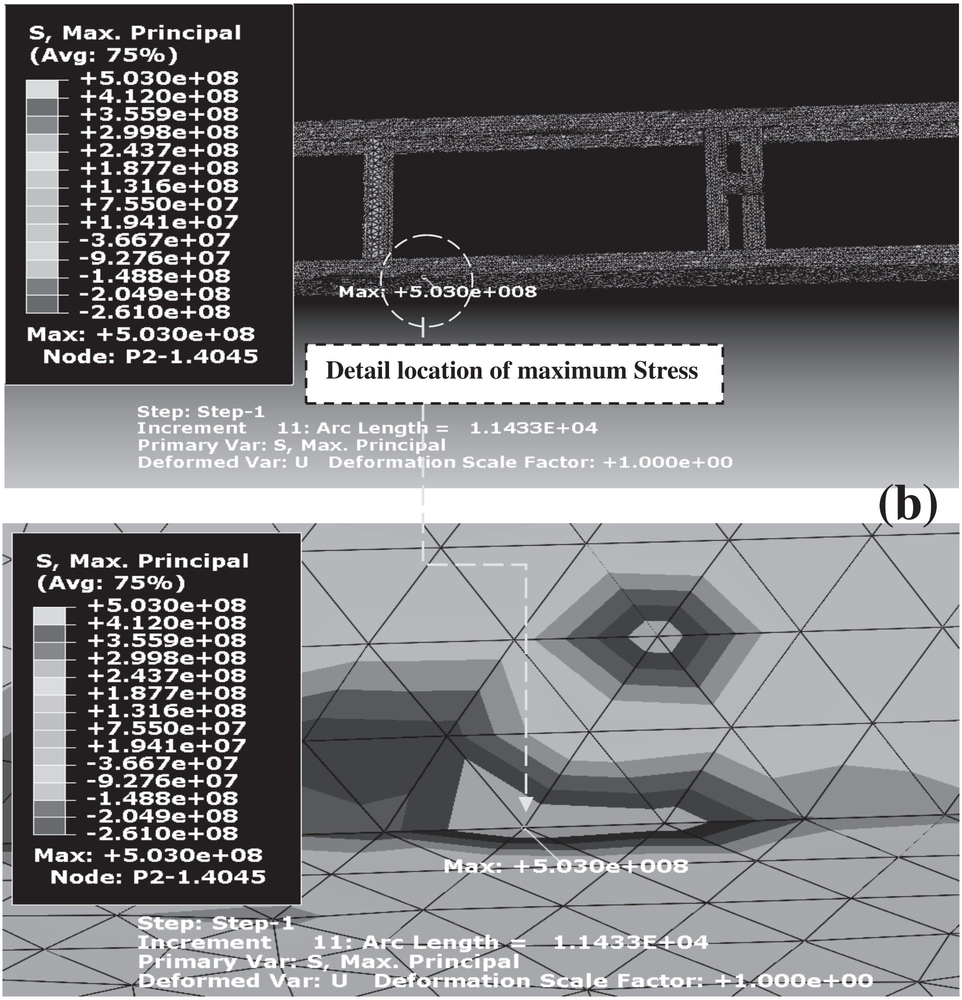


Fig. 6 (b). Maximum stress distribution and stress location in steel C1000.

CONCLUSION

- Since a change in chassis material imposes just a little variation on the amount of critical buckling loads, the effect of conventional steel replacement with these two stainless steels on buckling mode is trivial and hence the replacement is practical.
- Linear Eigen value analysis result usually involves very little deformation prior to buckling and Eigen value analysis is used just for evaluation of structure critical buckling load.
- Post buckling response shows that the imperfection of very small values causes a significant decrease of the critical buckling load and that post buckling response

show that the arc length method is a good way to predict the life span of the truck chassis.

- Displacement and stresses that occurred in critical point are good evidence for proximity of accuracy and correctness of selected material to fact in structure.

REFERENCES

Abaqus Version 6.10 Documentation. **2010**. Dassault Systemes Simulia Corporation.

Ahmed, M. B. & Su xiao, zu. 2004. Arc-length technique for nonlinear finite element analysis. Journal of Zhejiang university Science **5**: 618-628.

Bachman, k . 2005. Trends for stainless steel tube in automotive applications. The Tube & Pipe Journal **16**: 28–31.

Beer, FP. & Johnston, ER. **2006**. Dewolf JT, Mechanics of Materials. McGraw Hill, New York, USA.

Bochenek, B. **2003**. Problems of structural optimization for post-buckling behaviour. Structural and Multidisciplinary Optimization **25**: 423-435.

Brady, R.N. 1997. Heavy Duty Trucks: Power train, In Prentice Hall, New Jersey, USA.

Chiaberge, M. 2011. New Trends and Developments in Automotive Industry, first Ed. In Tech, UK.

Conle, F. A. & Chu, C . 1997. Fatigue Analysis and the Local Stress-strain Approach in Complex Vehicular Structures. International Journal of fatigue **19**: 317-323.

Corolla, A. D. 2009. In Automotive Engineering, first Ed. Jordan Hill, Oxford, UK.

Filho, R. R. P., Rezende, J. C. C. & Borges, J. A. F. 2003. Automotive Frame optimization. 2th International Mobility Technology Congress and Exhibition, Brail.

Higley, J.E. & Mischke, C.R. **1989.** Mechanical Engineering Design. McGraw Hill, New York, USA.

Hosford, W.F. & Caddell, R M. 2007. Metal forming mechanics and Metallurgy. Cambridge University Press, Cambridge, UK.

Juvinall, R. & Marshek, K. M . 2006. Fundamental Machine Component design. John Willey & Son, Inc, USA**.**

Karaoglu, C. & Kuralay, N. S. 2002. Stress analysis of a Truck Chassis with Riveted Joints. Finite Elements in analysis and Design **8**: 1115 – 1130.

Khalkhali, A. 2012. Finite element analysis with abaqus. Dibagarn, Tehran, Iran

Novoselac, S., Ergić, T. & Baličević, P. 2012. Linear and non linear buckling and post-buckling analysis of a bar with the influence of imperfections. Technical Gazette **19**: 695-701.

Vidosi J, P. C. **1957**. Machine Design Project. Ronald Press, New York.

Życzkowsky, M .**2005**. Post-buckling analysis of non-prismatic columns under general behaviour of loading. International Journal of Non-Linear Mechanics **40**: 445-463.

Submitted: 20-7-2014
Revised: 27-1-2015
Accepted: 10-2-2015