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Dynamic Stress and Strain Analysis for 8x4 Truck Frame

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ABSTRACT. The truck chassis is subjected to lower stresses in rest than it is in movement where the stresses and strains are considerably increased. The current work contains the load cases and boundary conditions for stresses and strains analysis of chassis using finite element analysis. King pin inclination, camber, caster, and toe-in angles of a truck’s wheels affect its chassis’ longitudinal and transverse stresses and strains. This work concentrates on studying the chassis’ stresses and strains when the truck is in longitudinal acceleration motion on asphalted straight road and has adjustable wheel angels for the steerable axles’ wheels.

1. Introduction. Today wheel alignment is more sophisticated as there are several angles. Therefore, it is important to study the effect of wheel alignment as a factor on the truck chassis stresses and strains. Wheel alignment is often the cause of or at least a contributing factor in changes in the vehicle wheel forces, which is reflected on the values of chassis stresses and strains.

The stress analysis of chassis has been studied using finite element analysis over ANSYS in static and dynamic cases. Shell elements for the longitudinal and cross members, spring elements for suspension, and wheel stiffness have been used. In addition, impact loads have been measured experimentally. The road shocks and the vehicle moving situation have been studied with the adjacent corner of the frame. In addition, the determination of the natural frequencies of the chassis structure has been carried out by using Algor FEMPRO [1-4].

The previous studies investigated many kinds of classical and simple boundary conditions without considering wheel alignment as a factor of the chassis forces [1]. With the present approach, the study of the effect of the steerable wheels’ adjustable angles was covered using finite element approach with MATLAB package, which is more efficient and simple. Also, general boundary conditions for the road in addition to most real conditions have been considered in this comprehensive model for the investigation of chassis stresses and strains.

2. Basic Concepts

A Mitsubishi FUSO truck, model S52JS4RFAB has been studied in static case after calculated its wheels reaction forces. The truck chassis finite element models were checked in static case for stiffness, deflection, shear and bending stresses, and strain by using MALAB software [5, 6].

In dynamic case, the truck chassis forces are varied under the variation in operation condition. In this study, the structural, construction, and material of the truck tires, and the side air resistance are neglected. Also, the study has been considered the truck’s movement is a free rolling case and it moves on straight, hard, and dry road. This study is included the tire alignment as an effected parameter on the frame force.

2.1 Influence of Wheel Angles on the Location of Axle Loads [7-9]
The adjusting of the steered wheels’ angles is very important to keep the conditions for optimum steer of a vehicle. In addition, it makes the vehicle follows a path which is part of the circumference of its turning circle, which will have a center point somewhere along a line extending the axis of the fixed axle. It keeps the steered wheels at 90 degrees to a line drawn from the circle center through the center of the wheel as represents in Fig. 1 (a), (b).

To show the tire forces in three axes; longitudinal force \( F_x \) (x-axis), vertical load \( F_y \) (y-axis), and lateral force \( F_z \) (z-axis), which can be acting on the center of tire contact a zoomed in picture of a one tire, is shown in Fig. 2.

For static case, the positive kingpin inclination results a moment \( (M_{zk}=F_yw/2) \) around the wheel axis when the vertical wheel load \( (F_y) \) is shifted to the wheel axis and resolved into two components \( F_y \sin \beta \) (perpendicular on the king pin) and \( F_y \cos \beta \) (parallel to the king pin) as shown in Fig. 3.

A lateral force \( (F_z) \) will be created due to the vehicle wheel cambered at its top towards the outside by angle \( (\Phi) \). The reaction force \( (F_{zc}) \) of the lateral force \( (F_z) \) will be appeared at the wheel axis. The reaction force \( (F_{zc}) \) will be resolved into two components \( F_{zc} \cos \beta \) (perpendicular on the king pin) and \( F_{zc} \sin \beta \) (parallel to the king pin) as shown in Fig. 4.

The toe-in angle \( (\alpha) \) is that results from change the distance between the vehicle center plane in the longitudinal direction and the line intersecting the center plane of one wheel with the road plane and this angle \( (\alpha) \) corresponds to the tire slip angle. Fig. 5, 6 represent the plane view of the tire toe-in angle with the kingpin inclination and the tire toe-in, tire camber with the kingpin inclination. Equations 1, 2 describe the forces, which are shown at the center of wheel in Fig. 6.

Fig. 7 details the positive caster angle \( (\tau) \). It is the angle between the steering axis (EG) projected onto a xy-plane and a vertical drawn through the wheel center. Also, it clears that the kinematic caster trail \( (r_{zk}) \), the lateral force trail \( (r_{Tz}) \), dynamic radius \( (r_{dyn}) \), the force \( F_{yz} \), and its components \( F_{yzvk} \), \( F_{yzhk} \) which are in equations (3-5).

Fig. 8 shows the plane view of Fig 7. This figure shows how the center of the lateral forces \( (F_{zwA}) \) moves back by the value of the kinematic caster trail \( (r_{zk}) \). While the longitudinal forces \( (F_{xwA}) \) moves outside by the camber offset \( (r_{t}) \). Equations 6, 7 contain the values of the above forces.

\[
\begin{align*}
F_{csc} &= F_z \cos \beta - F_y \sin \beta & (1) \\
F_{ccs} &= F_y \cos \beta + F_z \sin \beta & (2) \\
F_{yz} &= F_{ccs} & (3) \\
F_{yzvk} &= F_{ccs} \sin \tau & (4) \\
F_{yzpk} &= F_{ccs} \cos \tau & (5) \\
F_{zwA} &= F_{csc} & (6) \\
F_{xwA} &= F_{yzvk} & (7)
\end{align*}
\]

![Fig.1. Steering geometry (a) with positive, (b) with zero tire rod angle](image)
Fig. 2. The tire forces in three axes

Fig. 3. Side view of the kingpin inclination

Fig. 4. Side view of camber with kingpin inclination

Fig. 5. Plan view of tire toe-in with kingpin inclination
2.2 Truck Chassis Dynamic Model [5, 10-13].

The truck used for the study is accelerating on the level ground by acceleration \(a\). The forces of inertia \(F_{\text{in}}\), air resistance \(F_{\text{air}}\), and rolling resistance \(F_r\) of the progressively moving masses directed oppositely to the acceleration. The truck chassis dimensions and forces in dynamic case are viewed in Fig. 9. The longitudinal forces at the wheels contact point with the ground \(A, B, C, D\) can be...
computed by sequence of steps. Firstly, the equation of motion along the longitudinal axis of the truck according the force balance method is expressed by equation 8 whereas the front axles’ tractive effort is zero because the truck is a rear wheel drive. The tractive effort for the rear axles is calculated as the equations group 9 and the dynamic wheel radius can be determined from equation 10. Secondly, the summation of air, rolling, coefficient of rolling resistance, and inertia resistance forces for the truck components mention in equations (11-14). Thirdly, the distribution of both the inertia and air resistance forces on the contact points of the truck’s wheels with the ground can be made by; a) Calculate the percentage of a vertical load of a truck wheel related to the summation the vertical loads of all wheels (equation 15). b) Multiply the percentage of the wheel load and the summation for both the inertia and air resistance forces (group of equations 16). C) Sum the resistance forces at the wheel contact point (group of equations 17).

\[
\frac{md^2x}{dt^2} = aW/g = F_{TC} + F_{TD} - \Sigma R_r - \Sigma R_{air}
\]

\[
F_{TC} + F_{TD} \geq \Sigma (R_{in} + R_r + R_{air})
\]  \hspace{1cm} (8)

\[
F_{TC} = M_{max} \beta_{t} \eta/w_1 \rho_{a}, \quad F_{TD} = F_{TC} \eta_2
\]  \hspace{1cm} (9)

\[
r_d = 0.5D_r + b(1-\lambda_t)
\]  \hspace{1cm} (10)

\[
\Sigma R_{air} = K_B \alpha H_a V^2
\]  \hspace{1cm} (11)

\[
\Sigma R_r = f(R_{YZA} + R_{YZB} + R_{YZC} + R_{YZD})
\]  \hspace{1cm} (12)

\[
f = f_0 \left(1 + \frac{V_2^{max}}{1500}ight) (V \text{ by m/s})
\]  \hspace{1cm} (13)

\[
\Sigma R_{in} = a/g(\Sigma w) = (\Sigma w) = F_{in1} + F_{in2} + F_{inc1} + F_{inc2} + F_{inc3} + F_{inc4} + F_{inc5} + F_{inc6} + F_{inc7} + F_{inc8}
\]  \hspace{1cm} (14)

\[
% R_{YZA} = R_{YZA} / \Sigma (R_{YZA} + R_{YZB} + R_{YZC} + R_{YZD})
\]  \hspace{1cm} (15)

\[
(R_{inA} + R_{airA}) = \Sigma (R_{in} + R_{air}) \cdot % R_{YZA},
\]

\[
(R_{inB} + R_{airB}) = \Sigma (R_{in} + R_{air}) \cdot R_{YZB},
\]

\[
(R_{inC} + R_{airC}) = \Sigma (R_{in} + R_{air}) \cdot % R_{YZC},
\]

\[
(R_{inD} + R_{airD}) = \Sigma (R_{in} + R_{air}) \cdot % R_{YZD}
\]  \hspace{1cm} (16)

\[
F_A = fR_A + R_{inA} + R_{airA}, \quad F_B = fR_B + R_{inB} + R_{airB}, \quad F_C = fR_C + R_{inC} + R_{airC}, \quad F_D = fR_D + R_{inD} + R_{airD}
\]  \hspace{1cm} (17)
2.3 Influence of Wheel Angles on the Value of Axle Loads [7, 8].

The truck chassis was modeled to study the effect of the wheel angles on the value of vertical reaction, longitudinal, and transverse (lateral) forces. From that point of view the vertical forces at the wheels contact points will be changed for the two front steered axles but didn’t change for the two rear drive axles to be become as in equations (18-21). From that and the above paragraph the longitudinal forces at points A, B, C, D will be as illustrated in equations (22-25). The average lateral force results from the wheel camber on the dry road $F_z$ is represented in equation 26. Therefore, the lateral force at points A, B, C, D are illustrated through equations (27-30).

\[
\begin{align*}
R_{YZA} &= R_A \cos \beta + F_{z,c} \sin \beta \\
R_{YZB} &= R_B \cos \beta + F_{z,c} \sin \beta \\
R_{YZC} &= R_C \\
R_{YZD} &= R_D \\
F_A &= F_{xwA} = f R_{YZA} + \cos \beta (R_{inA} + R_{airA}) \\
F_B &= F_{xwB} = f R_{YZB} + \cos \beta (R_{inB} + R_{airB}) \\
F_C &= F_{xwC} = f R_{YZC} + (R_{inC} + R_{airC}) \\
F_D &= F_{xwD} = f R_{YZD} + (R_{inD} + R_{airD}) \\
F_z &= F_{z,c} = F_{zw} = F_y \sin \phi \\
F_{zwA} &= R_{YZA} \sin \phi = R_A (\cos \beta + \sin \beta) \sin \phi \\
F_{zwB} &= R_{YZB} \sin \phi = R_B (\cos \beta + \sin \beta) \sin \phi \\
F_{zwC} &= R_C f_t \\
F_{zwD} &= R_D f_t
\end{align*}
\]

3. The Finite Element Model of the Truck Chassis [6, 14-15].

In this study the FEA has been used to analyse the truck chassis beams strength in dynamic case. The same procedure in reference [6] could be repeated. However the truck chassis’s beam model forces and supports reactions could be located at the same places but in three dimension axes. And also, the number of elements is five hundred; each element has nearly twenty mm (20.28 mm) length with two nodes at its edges.

3.1 Global Stiffness Matrix ($K_{NgNg}$) and The Deflection Vector ($\delta_{NgNg}$).
The shape of the element stiffness matrix in three dimensions is completely different rather than in one dimension. Each node in this case study has five degrees of freedom namely longitudinal ($u$), vertical ($y$), lateral ($l$) displacements respectively and $xy$-plane cross-section (slope) rotation ($\theta_x$), $xz$-plane cross-section (slope) rotation ($\theta_y$) respectively. The linear system for Euler-Bernoulli beam has been described in equation 31, 32 for one element ($L$) as a complete element stiffness matrix ($K_{ij}$), nodal variables (displacements and rotations) vector ($\delta e$), and nodal force vector ($F_e$). Matrix 32 is the element equilibrium equations for a two-plane bending element with axial stiffness in matrix form. The axial [$K_{ax}$], bending [$K_{bx}$], and bending [$K_{bx}$] stiffness matrices are detailed in appendix 1. The calculation steps of the assembled stiffness matrix ($K_{NgNg}$), and the assembled deflection vector ($\delta_{NgNg}$) is nearly as reference [6] with difference in the size of the global stiffness matrix.

$$[K_{ij}] \cdot [\delta e] = [F_e]$$

3.2 Stresses and Strains for the Truck Chassis in Three Axes.

In this article, Galerkin’s method is used in stress analysis of the truck chassis in three dimensions. The truck chassis elements have been loaded tensional-compression in the $x$ direction. From elementary strength of materials theory, the $E_x$ represents the strain resulting from applied load while the induced strain components are given by $E_x = E_z = -y/E_x$. Equations 33, 34 resulted from strength of materials’ laws for tension load and the substitution in the general stress-strain relations. This study has been assumed two planes of stress, that $xy$ and $xz$ planes. When $xy$ is the plane stress, $\sigma_{b(xy)}$, $\varepsilon_y$, and $\tau_{xy}$ can be calculated from equations (35-38). Again, by assuming that the $xz$ plane is the plane stress, $\sigma_{b(xz)}$, $\varepsilon_z$, and $\tau_{xz}$ can be calculated from equations (39-42).

$$\sigma_{t,c} = F(x)/A$$
$$E_x = \sigma_{t,c} / E$$
$$\sigma_{b(xy)} = M(xy)*D/2I_z$$
$$E_y = ((1+y)/(1-2y))G_b(xy) - y/\sigma_{t,c} / E(1-y)$$
$$\tau_{xy} = (F(y)BD^2) / (8I_b)$$
$$Y_{xy} = \tau_{xy}/E(2(1+y))= \tau_{xy}/G$$
$$\sigma_{b(xz)} = 6M(xz)/(D(D^2+(b/B)-1)-2b((b/B)-1))$$
$$E_z = ((1-2y)/E(1-y))((1+y)G_b(xz) - (y/(1-y))(1+y))G_b(xy) + \sigma_{t,c}$$
$$\tau_{xz} = (F_bB^2D) / (16I_yb)$$
$$Y_{xz} = \tau_{xz}/ G$$
4. Results and Discussions of Truck Chassis’s stresses and strains.

The vertical loads ($w_1$…………etc) and reaction forces on the wheels ($R_A$………) for one side of the chassis in static case have been written in Table 1. The wheel angles for the two front truck axles’ wheels have been taken equally while the two rear axles’ wheels haven’t adjustable angles. The values of the front wheels angles summarized in Appendix 2 Table 2. Appendix 2 also contains Tables 3, Table 4. Table 3 includes the variables’ values for the variables of paragraph (2.2). Table 4 has the longitudinal and lateral forces’ names and their values on one side of the truck chassis. All the Table in Appendix 2 has been used in drawing the stresses and strains graphs. Fig. 10, 11 represent the tension-compression stress and strain respectively. Fig. 12, 13 shows the vertical bending stress and strain respectively. Fig. 14, 15 have the vertical shear stress and strain respectively. The drawing in Fig. 16, 17 have the lateral bending stress and strain respectively. The lateral shear stress and strain have been represented through Fig. 18, 19 respectively. Each couple of the above figures has the same trend but with difference in their values. As example the maximum value of the lateral shear stress is about $36 \text{ N/mm}^2$ while the maximum of the lateral shear strain is about $44 \times 10^{-5}$ and so on for the others couples.

**Summary.** The noticed from this study is the wheel angles generate lateral force. Although the generated lateral force causes lateral stress on the frame chassis, it will help for smooth turning of the truck. Also, the noticed from the graphs 16, 17 that they have completely different trend in the shapes oppositely the others stresses and strains coupled graphs.

In this search, the description of the truck’s accelerating motion on flat, asphalted, and smooth road generate valuable longitudinal stress whenever the maximum value its maximum value is $24 \text{ N/mm}^2$.

This article considered a compromise of using the Finite Element Techniques (FET), MATLAB package; studying the effect of the steerable wheels’ angles on truck frame’s forces values and direction, analyze the forces, which result from the truck dynamic motion.

Finally, the article includes many drawings for the stresses and strains in $x$-axis, $xy$ plane stress and $xz$ plane stress.

**Nomenclature**

\[
\begin{align*}
F_l & \text{ – Wheel longitudinal force} \\
F_v & \text{ – Wheel vertical load or } R_s \text{ or } R_A \text{ or } R_C \text{ or } R_D \\
F_L & \text{ – Lateral force due to wheel cambered} \\
F_L & \text{ – Reaction force of the lateral force} \\
F_S & \text{ – Summation of the lateral forces} \\
F_S & \text{ – Summation of the longitudinal forces} \\
F_T & \text{ – Tractive effort of one wheel of the first rear axle} \\
F_T & \text{ – Tractive effort of one wheel of the second rear axle} \\
R_A, R_B, R_C, R_D & \text{ – Vertical truck wheels reaction forces before adding the effect of wheel angles} \\
R_{VZA}, R_{VZB}, R_{VZA}, R_{VID} & \text{ – Vertical truck wheels reaction forces after adding the effect of wheel angles} \\
R_{air} & \text{ – Air resistance} \\
R_w & \text{ – Inertia resistance} \\
d & \text{ – Linear acceleration of the truck} \\
g & \text{ – Acceleration due to gravity} \\
\mu & \text{ – Constant } (\mu/g) = 0.56 \\
M_{max} & \text{ – Engine maximum torque (1770 N m at 1100} \\
\text{rpm}) \\
i_{i1} & \text{ – The gearbox reduction ratio} \\
i_{i1} & \text{ – The first differential reduction ratio (2.15) } \\
i_{i2} & \text{ – The second differential reduction ratio (2.15) } \\
\eta & \text{ – The drive line efficiency (0.9) } \\
n_{w1} & \text{ – Number of wheels on the first rear axle (4) } \\
r_s & \text{ – Wheel static radius} \\
\% R_{VZA} & \text{ – Percentage vertical reaction force at point A} \\
R_{VZA}, R_{VZB} & \text{ – Inertia and air resistances at point A} \\
R_v & \text{ – Rolling resistance} \\
F_{in1} \ldots \ldots \ldots & \text{ – Inertia forces for the truck components} \\
w & \text{ – Tire width} \\
r_n & \text{ – Distance between the steering axis to the vertical wheel load at the wheel center} \\
r_\alpha & \text{ – Kingpin offset} \\
\beta & \text{ – Kingpin inclination angle} \\
\Phi & \text{ – Wheel camber angle} \\
r_\beta & \text{ – Longitudinal force lever depends on the kingpin offset} \\
r_r & \text{ – Camber offset} \\
\alpha & \text{ – Toe-in angle} \\
\tau & \text{ – Caster angle} \\
r_\lambda & \text{ – Caster trail} \\
r_\gamma & \text{ – Caster trail} \\
r_\gamma & \text{ – Dynamic radius} \\
m & \text{ – Truck mass (kg)} \\
M(x) & \text{ – Moment in xy plane} \\
M(xz) & \text{ – Moment in xz plane} \\
O(x) & \text{ – Bending moment in xy plane} \\
E & \text{ – Strain in xy plane}
\end{align*}
\]
Appendix 1

The axial $[K_{axial}]$, bending $[K_{bending}]$, and bending $[K_{bending}z]$ stiffness matrices are:

\[
[K_{axial}] = (AE/L) \begin{bmatrix}
1 & -1 \\
-1 & 1
\end{bmatrix}
\]

\[
[K_{bending}] = \begin{bmatrix}
12 & 6L & -12 & 6L \\
6L & 4L^2 & -6L & 2L^2 \\
-12 & -6L & 12 & -6L \\
6L & 2L^2 & -6L & 4L^2
\end{bmatrix}
\]

\[
[K_{bending}z] = \begin{bmatrix}
12 & -6L & -12 & -6L \\
-6L & 4L^2 & 6L & 2L^2 \\
-12 & 6L & 12 & 6L \\
-6L & 2L^2 & 6L & 4L^2
\end{bmatrix}
\]

Fig. (A-1). Channel Cross Section Area ($b=b_1=b_2$)

Appendix 2

Chassis components Loads, reactions, and resistances forces in static and dynamic cases for one side of the truck chassis:

Table 1. One Side Vertical Loads of Chassis’s Truck and wheels Angles
Table 2. Wheel Angles Symbols and Values

<table>
<thead>
<tr>
<th>$\beta$</th>
<th>9°</th>
<th>$\Phi$</th>
<th>1°</th>
<th>$\alpha$</th>
<th>0.1°</th>
<th>$\tau$</th>
<th>1°</th>
</tr>
</thead>
</table>

Table 3. Values for the Variables of Paragraph (2.2)

<table>
<thead>
<tr>
<th>Sy.</th>
<th>Value</th>
<th>Sy.</th>
<th>Value</th>
<th>Sy.</th>
<th>Value</th>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda$</td>
<td>0.2</td>
<td>$B_t$</td>
<td>0.236 m</td>
<td>$K_a$</td>
<td>0.7Ns$^2$/mm$^4$</td>
<td>$R_{inC}+R_{air}$</td>
<td>4539 N</td>
</tr>
<tr>
<td>$f_0$</td>
<td>0.018</td>
<td>$r_d$</td>
<td>0.47 m</td>
<td>$\Sigma R_{in}$</td>
<td>56121 N</td>
<td>$R_{inD}+R_{air}$</td>
<td>17341 N</td>
</tr>
<tr>
<td>$f$</td>
<td>0.024</td>
<td>$H_a$</td>
<td>3.24 m</td>
<td>$\Sigma R_{yz}$</td>
<td>99601 N</td>
<td>Without angles</td>
<td></td>
</tr>
<tr>
<td>$%R_{yzA}$</td>
<td>35</td>
<td>$B_a$</td>
<td>1.85 m</td>
<td>$\Sigma R_{air}$</td>
<td>2072 N</td>
<td>$F_A$</td>
<td>21212 N</td>
</tr>
<tr>
<td>$%R_{yzB}$</td>
<td>27.4</td>
<td>$r_s$</td>
<td>0.522 m</td>
<td>$\Sigma (R_{in}+R_{air})$</td>
<td>58193 N</td>
<td>$F_B$</td>
<td>16607 N</td>
</tr>
<tr>
<td>$%R_{yzC}$</td>
<td>7.8</td>
<td>$D_r$</td>
<td>0.572 m</td>
<td>$R_{inA}+R_{air}$</td>
<td>20367 N</td>
<td>$F_C$</td>
<td>4725.6 N</td>
</tr>
<tr>
<td>$%R_{yzD}$</td>
<td>29.8</td>
<td>$D_r$</td>
<td>0.572 m</td>
<td>$R_{inB}+R_{air}$</td>
<td>15945 N</td>
<td>$F_D$</td>
<td>18053 N</td>
</tr>
</tbody>
</table>

Values for the Variables of stresses and Strains Equations

<table>
<thead>
<tr>
<th>$\gamma$</th>
<th>0.3</th>
<th>$B$</th>
<th>90 mm</th>
<th>$A$</th>
<th>3262 mm$^2$</th>
<th>$I_z$</th>
<th>40.69*10$^6$ mm$^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D$</td>
<td>300 mm</td>
<td>$b$</td>
<td>7 mm</td>
<td>$E$</td>
<td>2.1*10$^3$ N/mm$^2$</td>
<td>$I_Y$</td>
<td>45.97*10$^3$ mm$^4$</td>
</tr>
</tbody>
</table>

Table 4. Longitudinal and Lateral Forces on One Side of Chassis’s Truck

<table>
<thead>
<tr>
<th>Longitudinal Force Value(N)</th>
<th>Longitudinal Force Value(N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_A = F_{swA}$ 20953</td>
<td>$F_C = F_{swC}$ 4726</td>
</tr>
<tr>
<td>$F_1 = w_1 \mu$ 21957</td>
<td>$F_{TC}$ 26236</td>
</tr>
<tr>
<td>$F_2 = w_2 \mu$ 1415</td>
<td>$F_5 = w_2 \mu$ 137</td>
</tr>
<tr>
<td>$F_{c1} = w_{c1} \mu$ 3614</td>
<td>$F_{c3} = w_{c3} \mu$ 5022</td>
</tr>
<tr>
<td>$F_B = F_{swB}$ 16404</td>
<td>$F_D = F_{swD}$ 18053</td>
</tr>
<tr>
<td>$F_3 = w_3 \mu$ 549</td>
<td>$F_{TD}$ 56407</td>
</tr>
<tr>
<td>$F_{c2} = w_{c2} \mu$ 12744</td>
<td>$F_7 = w_7 \mu$ 137</td>
</tr>
<tr>
<td>$F_4 = w_4 \mu$ 824</td>
<td>$F_{c4} = w_{c4} \mu$ 8522</td>
</tr>
<tr>
<td>$F_5 = w_5 \mu$ 1061</td>
<td>$F_8 = w_8 \mu$ 137</td>
</tr>
</tbody>
</table>

Lateral Force Value(N)

<table>
<thead>
<tr>
<th>Lateral Force Value(N)</th>
<th>Lateral Force Value(N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{swA}$ 610</td>
<td>$F_{swC}$ 187</td>
</tr>
<tr>
<td>$F_{swB}$ 478</td>
<td>$F_{swD}$ 712</td>
</tr>
</tbody>
</table>

Appendix 3

The longitudinal, vertical, lateral stresses and strains.
Fig. 10. Tension-Compression Stress versus Chassis Beam Length

Fig. 11. Longitudinal Strain versus Chassis Beam Length

Fig. 12. Vertical Bending Stress versus Chassis Beam Length

Fig. 13. Vertical Strain versus Chassis Beam Length

Fig. 14. Vertical Shear Stress versus Chassis Beam Length
Fig. 15. Vertical Shear Strain versus Chassis Beam Length

Fig. 16. Lateral Bending Stress versus Chassis Beam Length

Fig. 17. Lateral Bending Strain versus Chassis Beam Length

Fig. 18. Lateral Shear Stress versus Chassis Beam Length
Fig. 19. Lateral Shear Strain versus Chassis Beam Length

References


