The comparative analysis of different computations methods of strength of materials by the example of calculations of the axle beam

S I Evtushenko, I A Petrov, M N Shutova and A S Alekseeva

Platov State Polytechnic University (NPI), 132, Prosvescheniya str., Novocherkassk, 346428, Russia

E-mail: evtushenko_s@novoch.ru

Abstract. The paper presents data of calculation the main characteristics of resilience by different ways. The basic data for the article were the calculation of the guiding axle beam of the vehicle. The calculation was performed by the analytic method and it was necessary to re-check strength of materials by any other method for reliability of the carried-out work. The finite element method was chosen as the competing option.

1. Introduction
The main goal of research is evaluation of using a numerical method (finite element method) compared with the analytic method of stress strain analysis of the guiding axle beam.

As a rule, to produce new parts and to improve old parts, before starting batch production, their load capacity ratings are carried out. Mechanical parts' main characteristics, which identify the suitability or unsuitability of constructions, are yield factor and fatigue safety factor.

At first, the analytic method was calculated and then the finite element method was used for the comparative analysis.

It should be noted that the dual motion mode was produced for this construction:
1. Operating mode;
2. Transport mode.

Efforts and safety margin were determined for four cases:
1. Vehicle skidding (maximum transverse force, zero longitudinal force);
2. Motion on barriers (maximum vertical force, zero transverse and longitudinal forces);
3. Hitting on obstruction (maximum longitudinal force);
4. Motion excluding dynamics (vertical force is vehicle weight, longitudinal force is the rolling resistance).

Both motion modes were calculated for each case, i.e. there are 8 calculations.

There is a diagram of the axle in Figure 1. Gravity load is applied at points A and B depending on the mode and loading case. In general, the load is presented by concentrated force of X, Y and Z directions. The stress was calculated in main sections A-A, B-B, C-C and D-D. It was found in the course of the solution that the minimal yield factor was in section D-D, which is shown in Figure 2.
2. The analytical method

The analytical method means that point moment equations are recorded, moments in horizontal and vertical planes are calculated, horizontal and vertical forces and von Mises equivalent stress are estimated for each section, and relies on this data the yield factor can be found:

\[ n_y = \frac{\sigma_y}{\sigma} \geq [n], \]  \hspace{1cm} (1)

\( \sigma_y \) – yield stress of the material, which is 295 MPa for steel 20,

\([n]\) – minimal yield factor, which is 1.5.

As the Table shows, the factor of safety is lower than permissible values (which is 1.5) when the vehicle is running over barriers or insurmountable obstacle.

Fatigue safety factor is determined by the following formula:

\[ n = \frac{\sigma_{-1}}{k_\sigma \cdot \sigma_y + \psi_{\sigma} \cdot \sigma_m} \leq 2.0, \]  \hspace{1cm} (2)

where \( \sigma_{-1} \approx 0.4 \cdot \sigma_y = 168 \) MPa; \( \sigma_y = 420 \) MPa (steel 20); \( k_\sigma \) – fatigue notch factor;
\[ \sigma_a = \sigma(k_D - 1) \] – the amplitude of stress; \( \psi_\sigma \) – stress ratio, 0.1; \( k_D \) – dynamic factor, 1.2.

The results of calculations are shown in Table 1.

**Table 1.** The factor of safety against yielding of the axle beam.

| Beam sections | Motion mode | Load case | 1 | 2 | 3 | 4 |
|---------------|-------------|-----------|---|---|---|---|
| A-A           | Operating mode | 1.69 | 1.73 | 1.13 | 2.70 |
|               | Transport mode | 2.07 | 1.98 | 1.22 | 3.66 |
| B-B           | Operating mode | 2.16 | 1.34 | 0.82 | 2.06 |
|               | Transport mode | 2.78 | 1.53 | 0.88 | 2.82 |
| C-C           | Operating mode | 2.22 | 1.16 | 0.71 | 1.78 |
|               | Transport mode | 1.90 | 1.73 | 0.75 | 2.43 |
| D-D           | Operating mode | 2.12 | 1.10 | 0.60 | 1.97 |
|               | Transport mode | 2.70 | 1.65 | 0.64 | 2.27 |

The result of calculation for section C-C is:

\[ n = \frac{168}{1 \cdot 27.5 + 0.1 \cdot 149.5} = 4.07. \]

The result of calculation for section D-D is:

\[ n = \frac{168}{1.5 \cdot 29.85 + 0.1 \cdot 149.24} = 2.81. \]

3. **Finite element method**

The computation is also made by means of finite element analysis using appropriate software. The finite-element model consisting of 125400 is developed for the calculation. The model is shown in Figure 3. The actual loads are transmitted through the concentrated forces, bending moments and surface pressure.

![Figure 3. The finite-element model of the guiding axle beam.](image)

Workloads obtained from the analytic method are applied to the same points. The result of calculation is Von Mises equivalent stress pattern on the surface of the construction and inside it.

For example, the results of some modes are shown in Figures 4 and 5.
As we can see from figures, there are isolated local areas with stresses exceeding permissible values. The results of the finite element analysis are shown in Table 2. Furthermore, maximum values of the stresses are set for each section. For example, the stress for section C-C is 164.31 MPa, the stress for section D-D is 175.84 MPa.

**Table 2.** The factor of safety against yielding

| Beam sections | Motion mode       | Load case | Load case | Load case |
|---------------|-------------------|-----------|-----------|-----------|
|               |                   | 1         | 2         | 3         | 4         |
| A-A           | Operating mode    | 1.75      | 1.76      | **1.08**  | 2.75      |
|               | Transport mode    | 2.21      | 1.96      | 1.24      | 3.60      |
| B-B           | Operating mode    | 2.23      | 1.32      | **0.85**  | 2.12      |
|               | Transport mode    | 2.77      |           | 0.87      | 2.85      |
| C-C           | Operating mode    | 2.24      | 1.24      | **0.67**  | 1.85      |
|               | Transport mode    | 1.94      |           | 1.79      | 0.80      | 2.48      |
| D-D           | Operating mode    | 2.14      | 1.13      | **0.65**  | 2.02      |
|               | Transport mode    | 2.74      |           | **1.68**  | 0.68      | 2.32      |
As Table 2 shows, the difference in the magnitude of the factor of safety against yielding is slight. In general, miscalculation of $n$ by different ways can be written as:

$$\Delta n = \frac{\sum (n_{sek} - n_{f.e.})}{\sum n_{sek}}$$  \hspace{0.5cm} (3)

Where $n_{sek} -$ yield factor, calculated by the analytic method; $n_{f.e.} -$ yield factor, calculated by the finite element method; $\Delta n = 0.041$ or 4.1%, which is lower than permissible 5%.

Yield factor is calculated using the same formula (2), but using other way of finding the components.

The computation is made for the longest work mode, i.e. for the motion excluding dynamics. Meanwhile, the maximum principal stresses are measured in the operating mode and in the transport mode at the same point (at 12 mm from the section D-D).

The following components of the formula (2) are changed:

- $n = \frac{\sigma_{\alpha}}{k_{\sigma} \cdot \sigma_{\alpha} + \psi_{\sigma} \cdot \sigma_{\psi}} \leq 2.0$;
- $\sigma_{\alpha} = \frac{\sigma_{op} - \sigma_{tr}}{2}$ - the stress amplitude;
- $\sigma_{op} -$ stresses of the operating mode, Figure 6;
- $\sigma_{tr} -$ stresses of the transport mode, Figure 7.
- Mean values of stress amplitude, $\sigma_{m} = \frac{\sigma_{op} - \sigma_{tr}}{2}$.
- $\psi_{\sigma} -$ the stress ratio, which is 0.3 for FEA.

$$n = \frac{168}{1.11.7 + 0.3 \cdot 116.12} = 3.20.$$  

**Figure 6.** Maximum principal stresses in the operating mode with the motion excluding dynamics.
4. Conclusion

Consequently, the quintessence of researching is captured in the following key observations:

The difference between the values of the factors is insignificant, which indicates the correctness of calculations with the use of both methods.

Finite-element analysis is more vivid and it allows one:

– to perform a visual check of locations and sizes of the areas with critical stresses;
– to find stress raisers;
– to make a 3D model;
– to save time of calculations.

The finite element gives a close definition of the fatigue safety factor because this method uses the real loads for the design model instead of using the reference factor, which can be changed depending on the engineer’s decision.

References

[1] Evtushenko S I, Shutova M N, Shkurakov L V, Petrov I A and Fedorchuk V E 2008 The expertise of strength calculation of the guiding axle beam Int. Conf. on Engineering (Rostov-on-Don: Rostov State University of Civil Engineering) pp 56 – 58
[2] Perelmuter A V and Slivker V I 2011 Design models of structures and possibility of their analysis vol 4 (Moscow: SCAD SOFT)
[3] Perelmuter A V and Slivker V I 2010 Stability of equilibrium of structures and related problems vol 1 (Moscow: SCAD SOFT)
[4] John R Taylor 1982 An Introduction To Error Analysis vol 2 (California: Mill Valley/University Science Books)
[5] Gaydzhurov P P and Isakova E R 2011 News of Higher Educational Institutions of North Caucasus region 3 26-29
[6] Gaydzhurov P P and Isakova E R 2011 News of Higher Educational Institutions of North Caucasus region 4 7-13
[7] Kindmann R and Kraus M 2007 Finite element method in steel constructions