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Long Wheelbase Flat Wagons: Structural Strength

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Abstract
The article considers the issues of the strength test for long wheelbase flat wagons and the usage of the theoretical and the experimental methods for this kind of researches. The calculation of frame elements in terms of fatigue has been performed by means of the computing system, which implements the finite element method. They have showed a good convergence with the tests. We have also analyzed the experimental studies for the strength qualities of long wheelbase flat wagons.
Key words: LONG WHEELBASE FLAT WAGONS, STRENGTH OF ELEMENTS, FATIGUE SAFETY FACTOR, CALCULATED STRESSED AND EXPERIMENTAL STRESSES.

Introduction. The situation with an insufficient strength of the long wheelbase flat wagons requires further elaboration of the construction elements with special methods of both theoretical and experimental type. This, in its turn, requires us to determine the research methods for the dynamic processes in the construction of long wheelbase flat wagons.

Actual scientific researches. The problems of the rolling stock dynamics and strength were considered in works by V. A. Lazaryan, Ye. P. Blokhin, M. B. Kelrikh, A. V. Donchenko, S. V. Myamlin, V. M. Bubnov and other famous scientists [1-5, 7-11]. However, even today, there are many problems related to the studies on the strength of elements within long wheelbase flat wagons when development of new models.

The Article Purpose. The current publication aims at determining the optimal practices [1, 3, 6] of construction improvement for long wheelbase flat wagon with the purpose to increase the strength of the elements of their construction. In order to study the strength of the bearing elements for the long wheelbase flat wagons, we use both the theoretical and the experimental special methods. One of such methods is mathematical simulation, which properly reflects the construction and the loads influencing it.

Background. Meeting the needs of transporters, the product differentiation and the issues of the reduction in transportation prime cost, many wagon manufacturers of Ukraine, Russia and other CIS countries developed and put into production lots of long wheelbase flat wagons of different design. However, during the operation of such kind of wagons, there appeared the problems with the strength of the main bearing elements of many constructions and revealed themselves as the cracks of fatigue type (see Figure 1).

The Crack in the Backframe of the Long Wheelbase Flat Wagon

The Crack in the Drawbar of the Long Wheelbase Flat Wagon

Figure 1. Cracks of Fatigue Type in the Main Bearing Elements of the Construction

Such situation was caused by low strength of the mentioned units within the rolling stock. The analysis of the failures on long wheelbase flat wagon frames says that the reason of it is the dynamic loads [2, 4, 5, 7], conditioned by both the irregularities of the rail track and the design peculiarities of the wagons.

Research Methods. In this publication we used the improved method on the conventional one to evaluate the metal fatigue. The existing engineering solutions were incorporated for enhancing the construction challenging places, chosen with application of the criterion of unallowably low coefficient to resist the fatigue. The fatigue calculation for the frame elements were performed over the time when the maximum permissible loads for the sections with high level stresses were acting on the long wheelbase flat wagons (hereinafter referred as flat wagons), illustrated in Figure 2.

The calculation has been performed with the computational system, which implements finite elements method (FEM) by standard IBM-PC, upon that the laminose finite-element model and finite elements of SHELL 63 type were used. The finite elements have quadratic functions of shape and six degrees of freedom in every unit: moving along the axes x, y, z and turns around these axes. For the development of the calculation model, the right Cartesian coordinate system with the center on the wagon longitudinal axis within the plane surface of neutral axis of the frontal beam is chosen as global coordinates system.

Axis X of the coordinate system is directed along the longitudinal axis of the wagon while axis Y goes upward vertically. The load with its own weight has been performed by the virtue of setting the material densities applicable for the model and further applying the calculation model with acceleration of up to 9.81 m/s^2 along vertical axis Y to its every unit. The calculation model is in Figure 3.

The evaluation of the fatigue has been conducted by fatigue safety factor with the formula written under [2]:

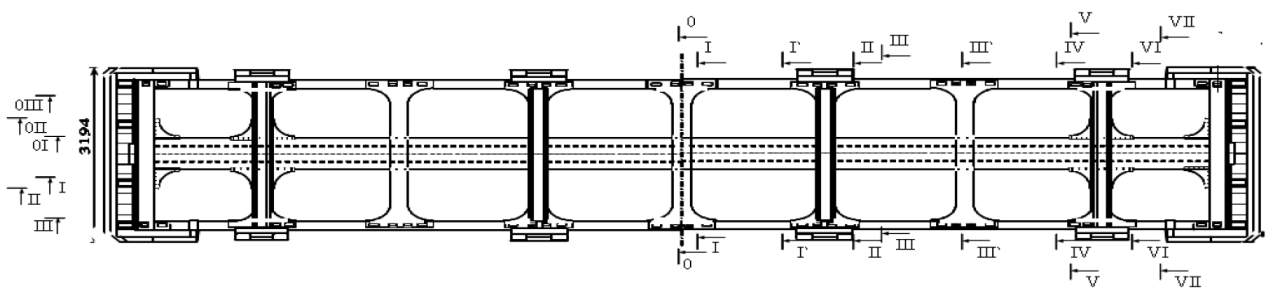

Figure 2. Diagram of Sections Location with Maximum Stresses on Universal Long Wheelbase Flat Wagon

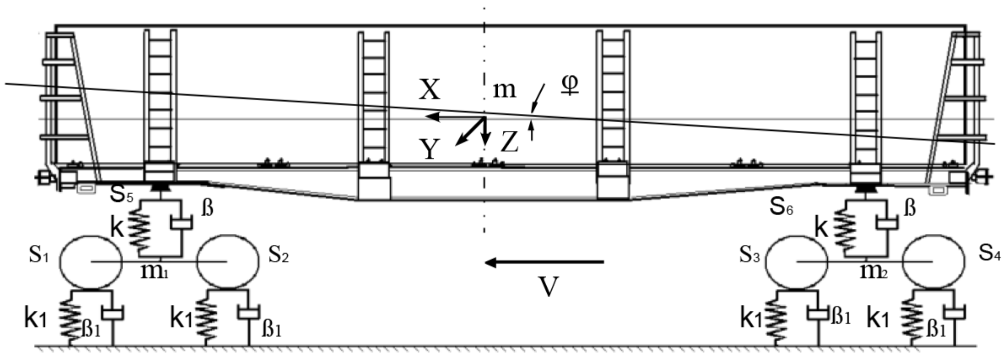

Figure 3. The Calculation Model of the Flat Wagon

$$n = \frac{\sigma_{a,N}}{\sigma_{a,э}} \geq [n], \quad (1)$$

where $\sigma_{a,N}$ - endurance limit (by amplitude) for the area under monitoring: the symmetric cycle and the steady mode of loading at the base number of cycles $N_0 = 10^7$;

$\sigma_{a,э}$ - the amplitude value of the dynamic stress of the conditional symmetric cycle, carried into the base number of cycles N_0. It is equivalent to the damaging effect of the real operational mode for designed service life;

$[n]$ – the minimum permissible fatigue safety factor during the chosen service life duration.

The wagon gross tonnage created the static stresses which also have been determined with finite elements method.

Two versions of loading have been anticipated (two 40-feet containers and four 20-feet containers), at which by the virtue of calculation analysis we have determined the greatest bending moments (refer to figures 4 and 5).

The stress-strain state of the wagon under the effect of static vertical load (gross) is illustrated in figure 6.

Results. The calculation results for the fatigue safety factor when loading the flat wagon with two 40-feet containers are presented in Table 1.

As we can see in Table 1, the fatigue factor [7-11] for flat wagon frame loaded by two 40-feet containers is below the permissible value [n] = 1.5.

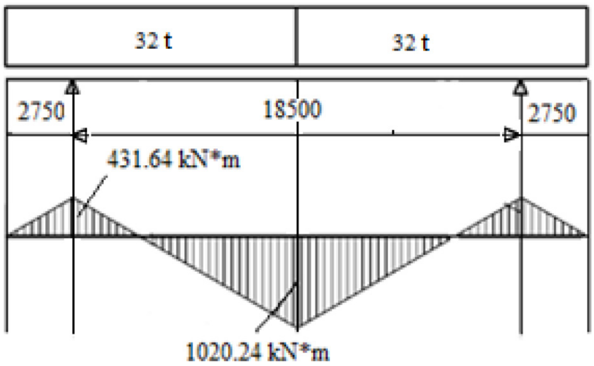

Figure 4. Two 40-Feet Containers

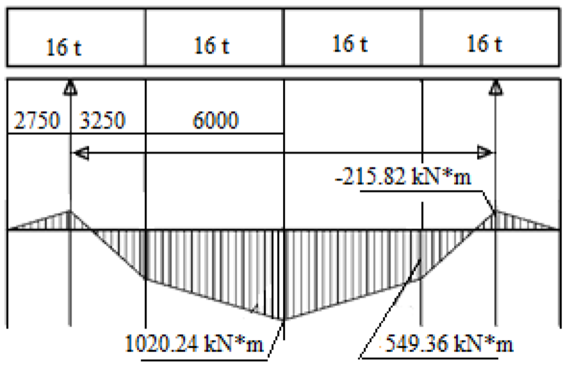

Figure 5. Four 20-Feet Containers

This is confirmed by the results of bench tests where the destruction was detected in two zones, namely in section I-I, in the zone of the overlay end, and in section III-III of the backframe on the gaps for the

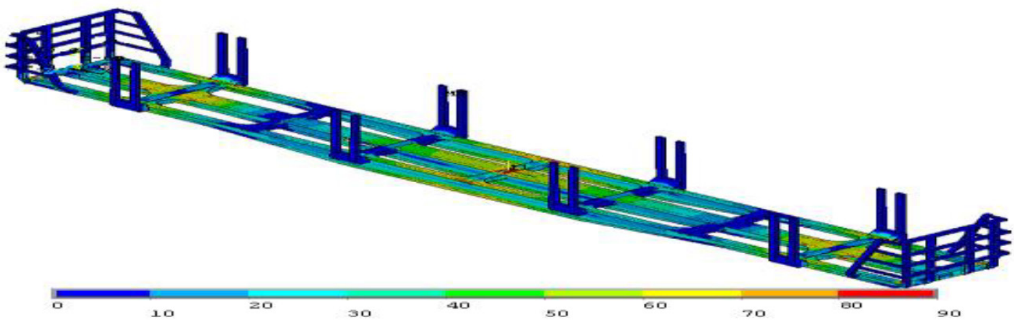

Figure 6. Stress due to the Action of Static Vertical Load of Two 40-Feet Containers

Table 1. Fatigue Safety Factor when Loading the Flat Wagon with Two 40-Feet Containers

Element	Section	Point	Unit Number	Results of calculations				
				σ_{static}	$\sigma_{a\ni}$	$(\overline{k_\sigma})_k$	σ_{aN}	n
Backframe	I-I	p.1	6948	83.2	46.38	4.5	41.293	0.89
Backframe	I-I	p.3	43015	93.4	52.06	4.0	46.455	0.89
Backframe	I-I	p.4	40158	83.4	46.49	4.5	41.293	0.89
Backframe	III-III	p.5	39428	86.8	48.39	4.5	41.293	0.85
Backframe	III-III	p.6	6179	87.4	48.72	4.5	41.293	0.85
Backframe	V-V	p.7	39523	65.4	36.45	3.0	61.940	1.70
Backframe	V-V	p.8	6274	65.8	36.68	3.0	61.940	1.69
Backframe	VI-VI	p.9	48292	10.1	5.631	3.0	61.940	11.00
Backframe	VI-VI	p.10	15179	10	5.575	3.0	61.940	11.11
Drawbar	I-I	p.21	22937	58.9	32.83	4.0	46.455	1.41
Drawbar	I-I	p.17	10504	29.5	16.44	4.5	41.293	2.51
Drawbar	I-I	p.19	22893	28.4	15.83	4.5	41.293	2.61
Drawbar	0I-0I	p.22	56272	58.9	32.83	4.5	41.293	1.26
Drawbar	0I-0I	p.18	43684	29.5	16.44	4.5	41.293	2.51
Drawbar	0I-0I	p.20	56228	28.5	15.88	4.5	41.293	2.60
Side beam	0-0	p.23	23455	98.8	55.07	4.0	46.455	0.84
Side beam	0-0	p.24	504	68.8	38.35	4.0	46.455	1.21
Side beam	I′-I′	p.27	90821	93.3	52.01	4.5	41.293	0.79
Side beam	I′-I′	p.28	94116	91.1	50.78	4.5	41.293	0.81
Side beam	I′-I′	p.30	126001	91.1	50.78	4.5	41.293	0.81
Side beam	I′-I′	p.29	122580	93.3	52.01	4.5	41.293	0.79
Side beam	II-II	p.31	59382	111.2	61.99	4.0	46.455	0.75
Side beam	II-II	p.32	26006	111.4	62.10	4.0	46.455	0.75
Side beam	III′-III′	p.33	66644	76.3	42.53	4.5	41.293	0.97
Side beam	III′-III′	p.35	52273	2.9	1.617	4.5	41.293	25.54
Side beam	III′-III′	p.34	33092	76.1	42.42	4.5	41.293	0.97
Side beam	III′-III′	p.36	23918	93.1	51.90	4.5	41.293	0.80
Side beam	IV-IV	p.34	410	69.6	38.80	4.0	46.455	1.20
Side beam	V-V	p.35	66121	56.6	31.55	4.0	46.455	1.47
Side beam	V-V	p.36	32578	56.5	31.49	4.0	46.455	1.47
Side beam	VI-VI	p.37	60111	6.9	3.847	4.0	46.455	12.08
Side beam	VI-VI	p.38	26732	6.9	3.847	4.0	46.455	12.08
Side beam	VII-VII	p.39	58800	0.9	0.502	4.0	46.455	92.59
Side beam	VII-VII	p.40	1661	3.5	1.951	4.0	46.455	23.81

horizontal lever of the mechanical brake. The stress-strain state of these zones when loaded with two 40-feet containers is shown in Figures 7 and 8.

The results of the calculations for the fatigue safety factor in these zones are presented in Table 2.

As follows from Table 2, the fatigue safety factor is below the permissible [n] = 1.5. Consequently, all these zones need to be strengthened. For the zone of destruction in I-I section, we propose to remove the overlay on the lower belt, which allows eliminating the concentrator near the seam and reducing in the concentration factor $(\overline{k_\sigma})_k$ from 5.0 to 2.5.

For the zone of the destruction in the gap, in section III-III, we propose to transfer the joints of the belt rail stiffener to the zone with lower stresses, which allows us to reduce the level of stress from 66.1 MPa to 5.1 MPa. The stress-strain states of these zones to occur after the changes in the design are shown in Figures 9 and 10 and the results of the calculation are reported in Table 3.

Table 2. Fatigue Safety Factor in Destruction Areas at Loading by Two 40-Feet Containers.

Element	Section	Model Node No	Calculation Results				
			σ_{static}	$\sigma_{a\ni}$	$(\overline{k_\sigma})_k$	σ_{aN}	n
Side beam	I-I	34553	66.1	27.3	5.0	37.2	1.36
Backframe	III-III	64578	78.3	32.3	5.0	37.2	1.15

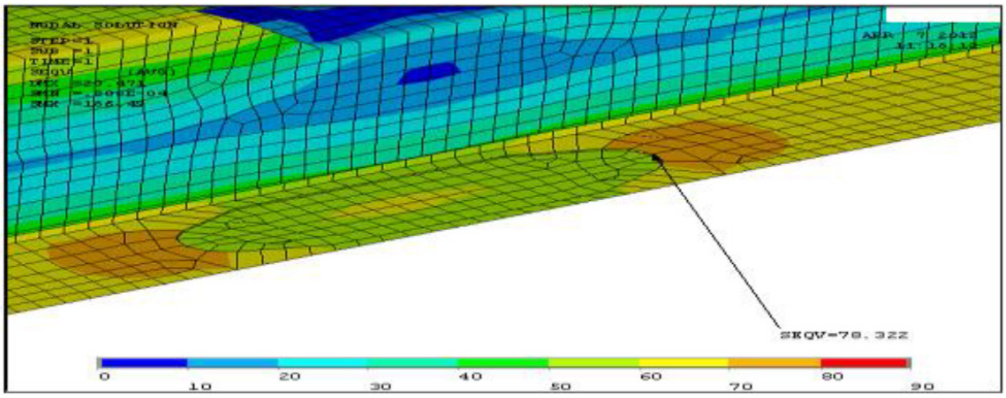

Figure 7. Stress-Strain State in the Overlay Seam Area (in the Center of the Side Beam before the Modification Proposed)

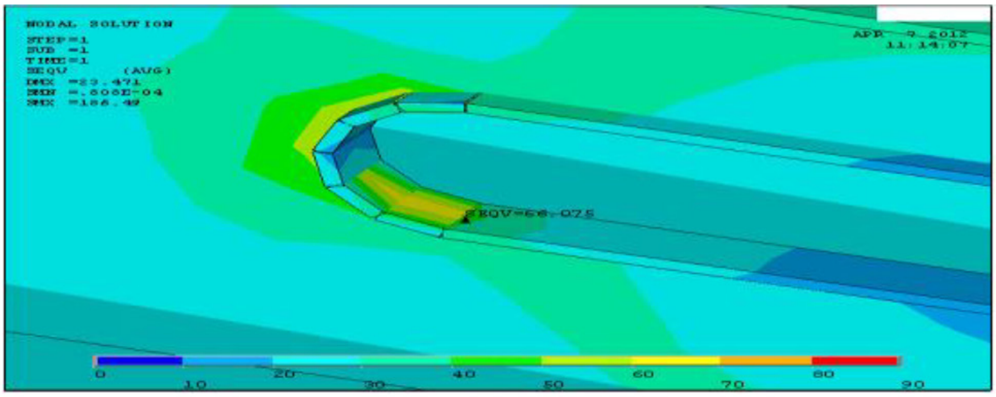

Figure 8. Stress-Strain State in the Zone of the Horizontal Lever Gap of the Backframe before the Modification Proposed

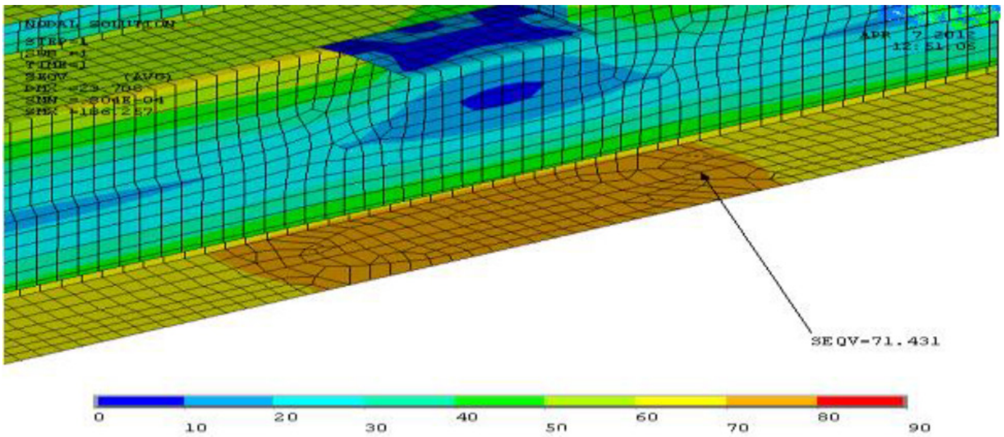

Figure 9. Stress-Strain State in the Seam Area of the Overlay in the Center of the Side Beam after the Proposed Modifications

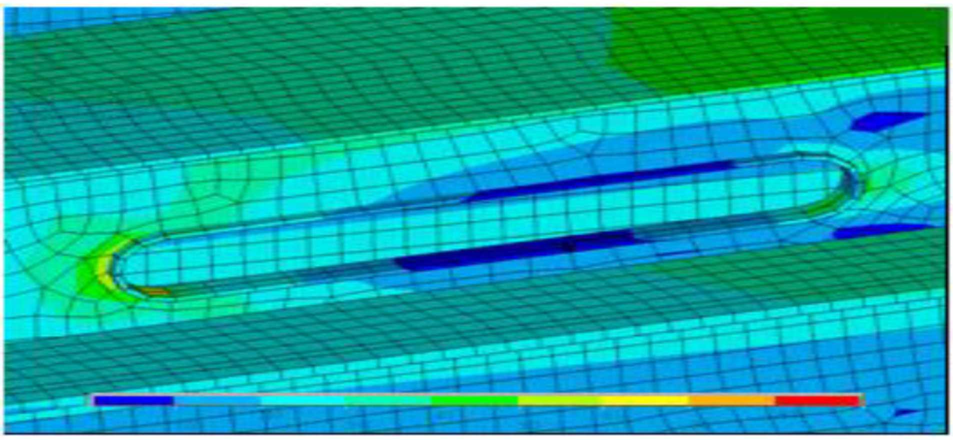

Figure 10. Stress-Strain State in the Area of the Gap of the Horizontal Lever of the Backframe after the Proposed Modifications

Table 3. Fatigue Safety Factor in Destructione Zones after Modifications, Loaded with 40-Feet Containers

Element	Section	Model Node No	Calculation results					
			σ_{static}	$\sigma_{aЭ}$	$(\overline{k_\sigma})_k$	σ_{aN}	n
Side beam	I-I	34553	71.4	2.1	2.5	37.2	17.67
Backframe	III-III	64578	5.1	29.5	1.6	116.1	3.94

As it can be seen from Table 3, the fatigue of the frame is provided for the entire lifecycle of the load schemes with four 20 feet containers and two 40-feet containers.

Outcomes. After improving the design of the frame, the calculation was made to check the long wheelbase flat wagons compliance with the requirements for I, III and the repair load modes as well as those for impacting between each other.

The calculated and the experimental stresses in all elements of the long wheelbase flat wagon in all operating loads do not exceed the permissible values. The convergence of the calculations and the tests is satisfactory, which testifies to the correctness of the calculations performed.

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