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DYNAMICS AND DURABILITY OF FREIGHT WAGONS WITH NOMINAL (DRAWING) DIMENSIONS AND TAKING INTO ACCOUNT ABRADING ACTION

Monograph

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The purpose of the book is to highlight the results and features of the authors' research on the dynamics and durability of the main types of freight wagons under operating conditions in order to substantiate the restoration of their operation. The constructive substantiation of freight wagons of modern domestic park by types is analyzed. Theoretical provisions and methodological foundation for determining the specified indicators of dynamics and durability of load-bearing structures of freight wagons with nominal (drawing) and actual dimensions are given.

The monograph is intended for scientific and technical specialists in the fields of constructional design and study of the mechanics of load-bearing structures of freight wagons, including scientists, design engineers, designers, doctoral students, and graduate students.

The monograph can be used as a textbook for undergraduates and bachelors in relevant specialities.

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INTRODUCTION

Global trends in resource saving and energy saving point to the extremely important role of research projects in the development and implementation of the latest renewable technologies.

Today the general fleet of freight wagons of Ukraine includes 199590 units, and it consists of wagons of state (105655 wagons) and private (93935 wagons) property, which can be divided into the following types: open, covered and tank wagons. At the same time, railway transport is constantly in a competitive environment with other modes of transport. Particularly sharply competitive influence from other modes of transport has been felt recently when there has been a significant reduction in fuel prices. The above mentioned justifies the need to constantly ensure the efficient operation of freight wagons as the main component of rail freight traffic. However, the modern Ukrainian freight wagon fleet consists of 74.6 % of morally (models of the 1970s) and physically (operate on the verge of the assigned service life) obsolete models. Accordingly, only from 30 % to 60 % of the freight wagon fleet is operated on average at different intervals due to unsatisfactory efficiency, which has a negative impact on the profitability of railways. The rest of the park is in forced downtime and, thus, generates significant losses. At the same time, the reduction of the total number of freight wagons will lead to a shortage of their particular types in peak loads (e.g. seasonal grain transportation) and as a result it will increase the cost of railway services and cause the corresponding losses of customers. The key factors that reduce the efficiency of freight wagons are: unsatisfactory average (taking into account the bearable speed of empty and loaded freight wagons) speed of freight wagons by domestic railways; significant fault rate of obsolete components of their structures (for example, as a result of long-term operation container (own weight) of the wagon is reduced by 10-15 %) and as a consequence a dangerous reduction in stability on the tracks, or the emergence and development of fatigue cracks in wagonts and wagon bodies); load capacity of wagons insufficient to ensure a competitive level due to excess durability reserves in the structures; limited opportunities for the use of freight wagons in military defense activities (for example, the impossibility of conducting fire operations directly from the wagon), etc.

There are two main ways to increase the efficiency of the freight wagon fleet: to update the fleet with new generation models or to restore the existing obsolete wagons having improved their technical and economic characteristics to the appropriate competitive level. The price of a new freight wagon is on average UAH 1,400,000, and the volume of repairs (such as overhaul) is sufficient for restoration from 20 % to 30 % of the specified cost. At present, the assigned service life of domestic freight wagons is around 23 years. However, technologies have been created and used in Ukraine which double this period (this period reaches 50 years in countries with a developed freight system). Therefore, it is important to develop conceptual frameworks for the restoration of obsolete freight wagons which will allow to overcome the above factors that reduce the efficiency of their operation.

The purpose of the monograph is to solve a topical and important scientific and applied problem of compiling theoretical provisions, as well as methodological foundations for restoring the effective functioning of morally (models of 1970s) and / or physically (operated on the verge of service life) obsolete freight wagons of which more than 70 % constitute the domestic freight fleet.

To achieve this goal, the following tasks are set:

1. To analyze the design of a modern domestic fleet of freight wagons.

2. To investigate the dynamic load of the structures of freight wagons of the domestic park with nominal parameters.

3. To investigate the durability of the load-bearing structures of freight wagons of the domestic fleet with nominal parameters.

4. To investigate the load of the structures of freight wagons of the domestic park with the actual parameters.

5. To investigate the durability of the load-bearing structures of freight wagons of the domestic fleet with the actual parameters.

The object of the research is the load of load-bearing structures of the main types of freight wagons with nominal and actual parameters.

The subject of the research – load-bearing structures of freight wagons with nominal and actual parameters.

The monograph is intended for scientific and technical specialists whose activities are related to the design and study of the mechanics of load-bearing structures of freight wagons, including scientists, design engineers, designers, doctoral students, and graduate students.

The monograph can be used as a textbook for undergraduates and bachelors in relevant specialities.

Key words: transport mechanics; railway transport; dynamics and durability of wagons; service life; restoration of wagons functioning; bearing structures of wagons.

1. ANALYSIS OF FRIEGHT WAGONS CONSTRUCTIVE PERFECTION OF MODERN DOMESTIC PARK BY TYPES

1.1. Design features of gondolas

Gondola wagons are designed for transportation of flowable, bulk and piece goods that do not require shelter and protection from precipitation [1 – 3]. This provides the convenience of loading and unloading with the help of effective means of mechanization (bridge cranes, tippers, etc.). In addition, many gondola bodies have unloading hatches in the floor or side walls that allow unloading of bulk cargo by gravity.

We will consider the body design of a universal eight-axle gondola model 12-124 on the example of a wagon with a capacity of up to 125 tons. It is equipped with unloading hatches in the floor. The body is equipped with a door at the ends. The door that opens inside the wagon.

The frame of a body has the backbone consisting of two Z-shaped profiles welded together by a longitudinal seam, blocked in a place of connection by an I-beam. Brackets of hinges for hinged hanging of covers of unloading hatches are fixed on I-beams.

The front and rear stops of the autocoupling are installed in the cantilever part of the spine beam. The front stop is cast in one piece with the shock socket. Pin beams of the closed box section have blocks and slides. Sills welded on top of the frame beams limit the opening of the door to the outside of the body. On the end surfaces of the end beam the lever of the coupling drive of the autocoupling and handrails of the assembler are fixed. Transverse beams of the frame – I-intersection, their upper shelves have corrugations. Such protruding parts have pivot beams. Hatch covers are corrugated, they have special locks. The lids are also equipped with torsion devices that facilitate lifting while closing. On the lower binging there are brackets to provide tight pressing by means of the lever of covers.

The side walls of the body have a metal cladding with trough-shaped embossing, supported by a frame consisting of upper and lower straps, as well as corner, pivot and intermediate struts.

Pin and intermediate struts are of closed Ω -shaped profile. Angular racks (the closed cross-section profile) are welded from the two Z-shaped elements fixed to the top binding by overlays. The top binding between racks is strengthened by overlays. The cladding is fixed to the frame by spot welding.

The door is hinged to the corner posts of the body with hinges. Each door leaf consists of the metal corrugated covering strengthened by a framework consisting of the top and bottom binding, and also the vertical elements of the closed cross section welded from Ω– and Z-shaped profiles. In the closed position, the door is held by the lower and upper locks consisting of a wedge and a guide with stops for the wedge. In the open position, the door is placed along the side walls and held by special rotating brackets that are installed in the holes on the upper straps of the body. The body is equipped with external and internal pellets, footrests and handrails at the ends.

The bodies of universal four-axle gondola wagons have a similar design of individual elements and are built in different versions.

The bodies of universal four-axle gondola wagons of 12-119 and 12-753 models are all-metal, made of standard profiles and differ in some constructive properties. Thus, the 12-753 model gondola is equipped with end doors, and 12-119 models have dumb end walls.

The body of the universal four-axle gondola of 12-119 model is executed with deaf face walls, is durable as the lateral walls are strongly connected. In addition, it allowed to increase the internal useful length without changing the longitudinal dimensions of the frame and increase the volume of the body by 2 m³.

End beams of box section, angular racks are made in the form of plates from rolled metal 8 mm thick. Knots of racks seals in a frame are strengthened by laths of 160 × 100 × 12 mm.

The body of the gondola wagon of 12-757 model with a loading capacity of 75 t has the strengthened design. The ridge beam of the body frame is made of two reinforced zets № 31 (U) and an I-beam 190 mm high, welded together. Increased technical level of the wagon fleet of the CIS railways is obtained by increasing the share of specialized gondola wagons, as well as the wagons with bodies such as hoppers.

The specialized four-axle gondola wagon with a deaf body of the 12-1505 model is developed on the basis of the universal gondola wagon in which unloading hatches are replaced by a continuous flooring, end doors are tightly welded. There are two hatches in the floor for draining water and cleaning the body when preparing the wagon for loading. The frame of a body differs from the frame of a universal gondola wagon because to support boarding of a floor between a backbone beam and the lower bindings of lateral walls additional longitudinal beams from an I-beam № 19 are established. The difference of a gondola of model 12-1580 is that there is no I-beam of the spinal beam. It allowed to increase internal height and volume of a body to 83 m³, and loading capacity – to 71 t.

The body of a specialized four-axle gondola wagon with a deaf body of 71 tons capacity of 12-1592 model is all-metal with a welded construction. Its frame includes a spine beam of two typical № 31 zets, two pivot beams of box section, two end beams, four transverse intermediate I-beam type beams and two intermediate support beams.

The body of the specialized four-axle gondola wagon of 12-4004 model is intended for transportation of pulp and chipable chips and short timber (up to 2 m long) from places of production to the enterprises of the pulp and paper industry. The body frame includes a spine beam welded from two typical zets № 31, an I-beam № 19 and a crotch, pivot beams of box section from sheets 10 mm and 12 mm thick (lower), average intermediate cross beams made of vertical (7 mm), top (8 mm) and bottom (10 mm) sheets. End beams of the box section are made of two channels № 27. At present, the leading wagon-building plants of Ukraine produce new generation gondola wagons with high technical and economic performance. We will consider the design features of the latest models of gondola wagons developed by the plant.

A universal 12-7039 model gondola wagon (Figure 1.1) is made of high-strength steel and has an axial load of 25 t / axle. It is intended for transportation of piece, flowable including small and packed, freights which do not need protection against atmospheric precipitation on the railways of Ukraine, the CIS countries and the Baltics with a track width of 1520 mm with a possibility of unloading through the unloading hatches located in a wagon floor, and also on wagon tippers. The main technical characteristics of the wagon are given in table 1.1 [4].

Fidure 1.1. A universal 12-7039 model gondola wagon

The gondola wagon of 12-7023 model (figure 1.2) and its modifications are a universal four-axle wagon with a welded body, increased volume and made of low-alloy 09G2S steel. It is intended for transportation of flowable, piece, and packaged freights. The open top body has fourteen unloading hatches, the covers of which form the floor. Unloading of the wagon is wagonried out through unloading hatches or on the wagon tipper. The main technical characteristics of the wagon are given in table 1.2.

Table 1.1

The main technical features of 12-7039 model gondola wagon

The name of the parameter	*Value*
Load capacity, t	75,5
Wagon weight, t	24,5
Estimated load from the wheelset on the rail, kN	245,25
Length of the wagon on axes of coupling of autocouplings, mm	13920

The name of the parameter	*Value*
Base, mm	8650
Internal dimensions of the body – length, mm – width, mm – height, mm	 12790 2990 2362
Dimensions	1-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120
Service life, years	32

Figure 1.2. A universal 12-7023 model gondola wagon

Table 1.2

Main technical features of 12-7023 model gondola wagon

The name of the parameter	*Value*
Load capacity, t	70,3
Wagon weight, t	23,7

The name of the parameter	*Value*
Estimated load from the wheelset on the rail, kN	230,5
Length of the wagon on axes of coupling of autocouplings, mm	13920
Base, mm	8650
Internal dimensions of the body – length, mm – width, mm – height, mm	 12790 2990 2362
Dimensions	1-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120
Service life, years	22

Universal four-axle 12-783 model gondola (Figure 1.3) is all-metal, with a welded body, designed for the transportation of flowable, packaged, piece freihgt.

Figure 1.3. A universal 12-783 model gondola wagon

The floor of the wagon is formed by fourteen hatch covers. The wagon is equipped with automatic pneumatic, emergency contracting and parking brakes, and a T1 class absorber.

The main technical characteristics are listed in Table 1.3.

Table 1.3

Main Technical Features of 12-783 Model Gondola Wagon

The name of the parameter	*Value*
Load capacity, t	70,0
Wagon weight, t	24,0
Estimated load from the wheelset on the rail, kN	230,5
Length of the wagon on axes of coupling of autocouplings, mm	13920
Base, mm	8650
Internal dimensions of the body – length, mm – width, mm – height, mm	 12790 2990 2045
Dimensions	1-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120
Service life, years	22

Four-axle, all-metal EAOS model gondola wagon has a welded body and solid floor (Figure 1.4).

Figure 1.4. A universal EAOS model gondola wagon

The gondola wagon is designed for transportation of flowable, packaged and piece freight. The running gear of the wagon is represented by trolleys of Y25 type. The main technical characteristics of the wagon are listed in Table 1.4.

Table 1.4

Main technical features of EAOS model gondola wagon

The name of the parameter	*Value*
Load capacity, t	58,0
Wagon weight, t	20,8
Estimated load from the wheelset on the rail, kN	200,5
Length of the wagon on axes of coupling of autocouplings, mm	14400
Base, mm	9000
Internal dimensions of the body – length, mm – width, mm	 12792 2792

The name of the parameter	*Value*
– height, mm	1999
Dimensions	UIC 505
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	120
Construction design speed, km/h	22

Specialized gondola wagon with a removable roof and unloading bunkers (Figure 1.5) is designed for transportation of alumina in bulk by the railways of Ukraine, CIS and Baltic countries with 1520 mm tracks in one direction, with loading through the upper hatches and unloading into the interrail space through the lower hatches on special emptying devices, and in the other direction for transporting aluminum billets and other packaged non-bulk cargo that require protection from precipitation. The main technical characteristics of the wagon are listed in Table 1.5.

Figure 1.5. 12-9765 model gondola wagon

A universal four-axle, all-metal wagon of 12-757 EI-2 model with a welded body of the increased volume is made of low-alloy 09G2S or 09G2D steel. It is intended for transportation of flowable, piece, packaged freights which do not need protection against atmospheric precipitation (Figure 1.6).

Table 1.5

Main technical features of 12-9765 model gondola wagon

The name of the parameter	*Value*
Load capacity, t	65,0
Wagon weight, t	29,0
Estimated load from the wheelset on the rail, kN	230,5
Length of the wagon on axes of coupling of autocouplings, mm	17040
Base, mm	12800
Internal dimensions of the body – length, mm – width, mm – height, mm	 12400 2872 1965
Dimensions	1-T
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120
Service life, years	22

Figure 1.6. A 12-757 EI-2 model gondola wagon

The main technical characteristics are listed in Table 1.6.

Table 1.6

Main technical characteristics of 12-757 EI-2 model gondola wagon

The name of the parameter	*Value*
Load capacity, t	67,5
Wagon weight, t	22,5
Estimated load from the wheelset on the rail, kN	220,5
Length of the wagon on axes of coupling of autocouplings, mm	13720
Base, mm	8700
Internal dimensions of the body – length, mm – width, mm	 12490 2660

The name of the parameter	*Value*
– height, mm	2050
Dimensions	IIRR (RAI) 02-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Construction design speed, km/h	120
Service life, years	22

The four-axle, all-metal wagon with a welded body and a semi-cylindrical bottom of 12-791 model (figure 1.7) is intended for transportation of flowable and small-piece freights which do not need protection against atmospheric precipitation. The body of the wagon without unloading hatches with rounded surfaces at the junction of the frame with the side and end walls provides unloading of the wagon using the tipper with the minimum possible remnants of the load. The main technical characteristics of the wagon are listeв in Table 1.7.

Figure 1.7. A12-791 model gondola wagon

Table 1.7

Main technical characteristics of 12-791 model gondola wagon

The name of the parameter	*Value*
Load capacity, t	71,0
Wagon weight, t	22,9
Estimated load from the wheelset on the rail, kN	231,5
Length of the wagon on axes of coupling of autocouplings, mm	13920
Base, mm	8650
Internal dimensions of the body – length, mm – width, mm – height, mm	 12460 3070 2235
Dimensions	1-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Construction design speed, km/h	120
Service life, years	22

The universal four-axle, all-metal wagon with a welded body of the increased volume of 12-7019 model is made of low-alloy 09G2S or 09G2D steel. The wagon is designed to transport flowable, packaged and piece freights that do not require protection against precipitation (Figure 1.8). The main technical characteristics of the wagon are listed in Table 1.8.

Figure 1.8. A 12-7019 gondola wagon

Table 1.8

The main technical characteristics of 12-7019 model gondola wagon

The name of the parameter	*Value*
Load capacity, t	72,0
Wagon weight, t	22,0
Estimated load from the wheelset on the rail, kN	230,5
Length of the wagon on axes of coupling of autocouplings, mm	13920
Base, mm	8650
Internal dimensions of the body – length, mm – width, mm – height, mm	 12690 2950 2050
Dimensions	1-BM

The name of the parameter	*Value*
Height to the pulling face from the level of the rail heads, mm	1060±20
Construction design speed, km/h	120
Service life, years	22

The four-axle, all-metal wagon with a welded body, a solid bottom and two hatches in the side walls of 12-764 model is intended for transportation of flowable, packed and piece freights which do not need protection against atmospheric precipitation (Figure 1.9).

Figure 1.9. A 12-764 gondola wagon

The main technical characteristics of the wagon are listed in Table 1.9.

Table 1.9

The main technical characteristics of a 12-764 gondola wagon

The name of the parameter	*Value*
Load capacity, t	70,0
Wagon weight, t	23,5
Estimated load from the wheelset on the rail, kN	229,3
Length of the wagon on axes of coupling of autocouplings, mm	13720
Base, mm	8700
Internal dimensions of the body – length, mm – width, mm – height, mm	 12490 2660 2050
Dimensions	1-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Construction design speed, km/h	120
Service life, years	22

The four-axle, all-metal wagon of 12-1704-03 model is intended for transportation of flowable, packed and piece freights which do not need protection against atmospheric precipitation (Figure 1.10). The wagon has a welded body, the floor of which is formed by hatch covers. The main technical characteristics of the wagon are listed in Table 1.10.

Figure 1.10. A 12-1704-03 gondola wagon

Table 1.10

The main technical characteristics of 12-1704-03 model gondola wagon

The name of the parameter	*Value*
Load capacity, t	70,5
Wagon weight, t	23,0±0,5
Estimated load from the wheelset on the rail, kN	229,3
Length of the wagon on axes of coupling of autocouplings, mm	13720
Base, mm	8650
Internal dimensions of the body – length, mm – width, mm – height, mm	 12490 2660 2050
Dimensions	0-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Construction design speed, km/h	120
Service life, years	22

1.2. Design features of covered wagons

Covered wagons are used for transporting freights which need protection against precipitation. At present there is a great variety in the design features of covered wagons. We will consider the main models of covered wagons, which are produced by leading wagon manufacturing companies in Ukraine [1–3].

The covered 11-7094 model wagon is intended for transportation on the railway network with a track of 1520 mm of piece, unitized and packaged freights of wide assortment requiring protection against atmospheric precipitation (Figure 1.11). It is possible to equip the wagon with uppe loading hatches and ventilation hatches in the side walls. The wagon has automatic pneumatic, hand-operated and parking brakes. The undercarriage consists of two two-axle carriages of 18-7055 model of type 2 GOST (State Standard) 9246 or other interchangeable carriages of type 2 GOST (State Standard) 9246. Automatic coupling is CA-3 type. The shock-absorbing device is of class T1. The main technical characteristics of the wagon are listed in Table 1.1 [4].

Table 1.11. The covered 11-7094 model wagon

Table 1.11

The main technical characteristics of the covered 11-7094 model wagon

The name of the parameter	*Value*
Load capacity, t	68,0
Wagon weight, t	26,0
Estimated load from the wheelset on the rail, kN	230,3 (23,5)
Length of the wagon on axes of coupling of autocouplings, mm	18720
Base, mm	13500
Internal dimensions of the body – length, mm – width, mm – height, mm	 17492 2794 3106
Dimensions	1-BM
Height to the pulling face from the level of the rail heads, mm	1040 – 1080
Railway track gauge, mm	1520
Construction design speed, km/h	120
Service life, years	32

The covered wagon of 11-7045 model constructed by Kriukivskyi Rail Wagon Manufacturing Plant public joint-stock company is presented in Figure 1.12.

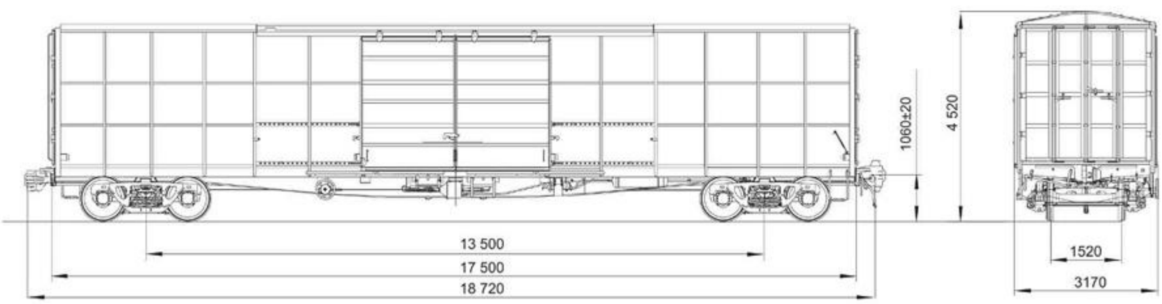


Figure 1.12. The covered wagon of 11-7045 model

The main technical characteristics of the wagon are listed in Table 1.12.

Table 1.12

The main technical characteristics of the covered wagon of 11-7045 model

The name of the parameter	*Value*
Load capacity, t	67,5
Wagon weight, t	26,5
Estimated load from the wheelset on the rail, kN	230,3 (23,5)
Length of the wagon over pulling faces of couplers, mm	18720
Base, mm	13500
Internal dimensions of the body – length, mm – width, mm – height, mm	 17492 2794 3106
Dimensions	1-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120
Service life, years	32

In 2014, large-scale manufacturing of covered wagons of 11-7038 model began at Kriukivskyi Rail Wagon Manufacturing Plant public joint-stock company (Figure 1.13). The load-bearing structure of the wagon provides the possibility of equipping it with the upper loading hatches.

The main technical characteristics of the wagon are listed in Table 1.13.

Figure 1.13. The covered wagon of 11-7045 model

Table 1.13

The main technical characteristics of the covered wagon of 11-7038 model

The name of the parameter	*Value*
Load capacity, t	68,0
Wagon weight, t	26,0
Estimated load from the wheelset on the rail, kN	230,5
Length of the wagon over pulling faces of couplers, mm	18720
Base, mm	13500
Internal dimensions of the body – length, mm – width, mm – height, mm	 17492 2790 3106
Dimensions	1-BM
Height to the pulling face from the level of the rail heads,	1060±20

The name of the parameter	*Value*
mm	
Railway track gauge, mm	1520
Construction design speed, km/h	120
Service life, years	32

The load-bearing structure of the covered wagon of 11-7139 model is rather interesting (Figure 1.4). The wagon has:

– six unloading hatches in the floor with opening and closing devices, designed for partial unloading and cleaning of the wagon body from the remnants of transported goods;

– the doors inside the body to prevent the loading of the side sliding doors of the wagon;

– upper loading hatches, stairs and ladders on the roof;

– ventilation hatches in the side walls of the wagon body if agreed with the customer.

Figure 1.14. The covered wagon of 11-7139 model

The main technical characteristics of the wagon are listed in Table 1.14.

Table 1.14

The main technical characteristics of the covered wagon of 11-7139 model

The name of the parameter	*Value*
Load capacity, t	65,7
Wagon weight, t	28,3
Estimated load from the wheelset on the rail, kN	230,5 (23,5)
Length of the wagon over pulling faces of couplers, mm	18720
Base, mm	13500
Internal dimensions of the body – length, mm – width, mm – height, mm	 17492 2794 3106
Dimensions	1-BM
Height to the pulling face from the level of the rail heads, mm	1040 – 1080
Railway track gauge, mm	1520
Construction design speed, km/h	120
Service life, years	32

Stakhaniv Rail Wagon manufacturing Plant public joint stock company was the first in Ukraine to costruct a universal covered four-axle wagon (model 11-950) in the size of 03-VM of the «east-west» type (Figure 1.15).

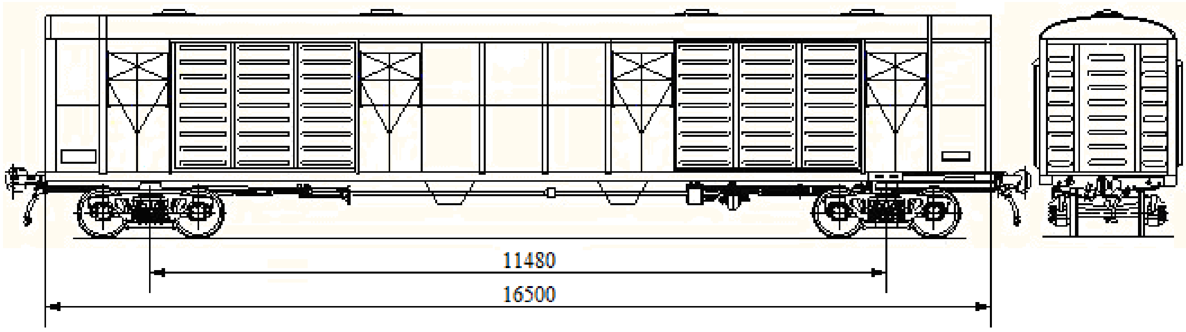


Figure 1.15. A covered wagon of 11-950 model

The design of the wagon allows to transport international freight from Ukraine to Western Europe and back or in transit through the territory of Ukraine as part of trains running on the railway network with a track 1520 mm in width and 1435 mm with a change from one track to another [1-11].

In early 2000 Kriukivskyi Rail Wagon manufacturing Plant public joint stock company also developed the design of a covered wagon for operation in the direction of «east-west» (Figure 1.16), which is remarkable for unloading bins in the middle part of the body, which allows it to transport flowable cargo, and the space of the body between the corner posts and the vertical walls of the central section has a sliding door for loading unitized cargo [35].

Figure 1.16. A covered wagon of section type

The peculiarity of the developed wagoncase is the use at the stage of their design of modern methods of optimization theory, which significantly reduced the material consumption of the body, as well as the use of new materials in load-bearing structures.

One of the most widely used models of covered wagons on the CIS railways is the model 11-217 (Figure 1.17).

Figure 1.17. A covered 11-217 model wagon

The universal covered wagon of 11-217 model (figure 1.8) manufactured by the Altai Rail Wagon Manufacturing plant is designed on dimension 1-VM (0-T) of GOST (State Standard) 9238-83 and is intended for operation on the railways of the CIS and Baltic countries of a track of 1520 mm in width[5]. It can also be operated on the reconstructed railways lines of the countries-participants of CMEA (Council of Mutual Economic Assistance) on a track of 1435 mm in width after corresponding replacement of running gears. The body of such wagons has a metal external covering and a wooden internal facing, and it is also equipped with double-leaf doors with an increased width of a doorway (3825 mm instead of 2000 mm of 11-066 model wagons). The use of a metal covering of a body increases its reliability in operation. Increased width of the doorway provides a faster loading and unloading process, and therefore reduces demurrage due to freight operations and speeds up the turnover of the wagon.

The wagon is loaded through door 3 and hatches in the roof 2 and side walls. The widened doorway is reinforced, the body floor is strengthened according to the calculations on the basis of the operation of automatic loaders with axial load up to 43 kN. The 11-217 model wagon has the characteristics shown in Table 1.15.

Table 1.15

The technical characteristics of 11-217 model covered wagon

Parameter	*Value*
Load capacity, t	68
Dead weight, t	24
Cubic capacity, m^3	120
Length, m	
By the axles of automatic couplings	14,73
By the end beams of the frame	13,87
Height to the level of the floor, m	1,286
Maximum height of the wagon, m	4,692
Width, m	3,249
Internal dimensions, m	
Width	2,77
Length	2,737
Base, m	10
The width of the doorway, м	3,825

Parameter	*Value*
Empty-weight-to-wagonrying-capacity ratio	0,35
Axle loading, kN/axle	228
Linear load, t/m	6,2
Design speed, km/h	120
Limiting dimensions	1-BM

All supporting elements of the frame, walls 1 and 4 and roof 2 are made of low-alloy steel 09G2D, and the cladding of the end 4 walls and roof are made of low-alloy steel 10HNDP.

The frame (Figure 1.19) consists of a spine beam 2, two side 3, two end 1, two pivot 4, two main 7 and seven intermediate 5 transverse beams, four bracing pieces 10, six longitudinal beams 6 to support the floor, one beam to attach the brake cylinder and two stepboards. Spinal beam 2 is welded from two Z-shaped profiles №31. In its end parts, the rear stops of the automatic couplings are installed, combined with overcenter plate box of the pivot unit, as well as the sockets, which are cast together with the front stops of the automatic couplings. The side beams 3 are made of channel beams № 20. The stepboards from special Z-shaped profiles are welded to the beams 3 in the area of the doorway. The end beams 1 are welded U-shaped section and made of sheets 6 mm thick. In the place of installation of the socket the beam has a 180 mm deep niche which allowed to deepen the socket and to reduce the length of bracket of an automatic coupling from 610 to 430 mm. This solution allowed to increase the internal length and the volume of the body without changing the size of the wagon on the axles of the automatic couplings.

Handrails are installed on the end beam to make the work of yardmasters safe. Pin beams 4 are welded box members. Each of them consists of two vertical 6 mm thick, upper (8 mm) and lower (10 mm) horizontal sheets. Steel overhead boxes are installed at the intersection of the pivot beams with the center sill, which connect the vertical walls of the center sill, as well as strengthen center plate arrangement of the frame. Pedestals 12 and side bearings 13 are riveted to the lower sheets of pivot beams. The main cross beams 7 are welded I-beams, made of sheets 6 mm thick. To ensure the uniformity of the frame structure, the end, pivot and main transverse beams have a variable height along their length. The braces 10 of the frame are made of channel № 14, and the transverse 5 and longitudinal 6 auxiliary beams to support the floor are made of bent channels of 100x80x5 mm. Special brackets are welded on each end of the side beams of the frame to move the wagons with a winch.

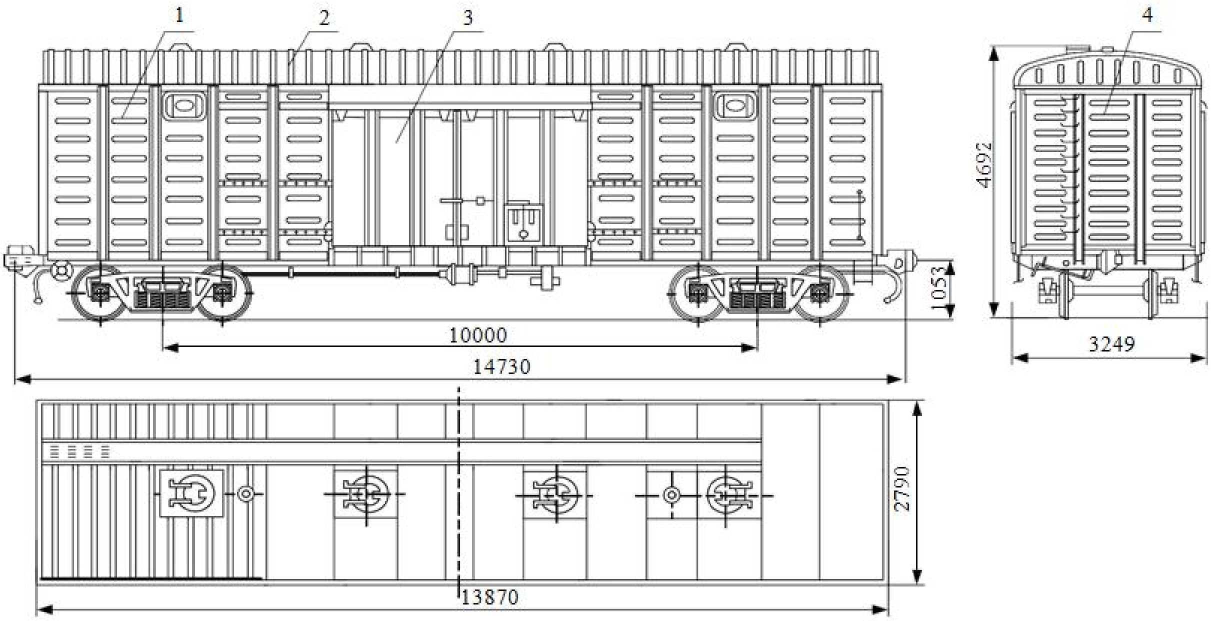


Figure 1.18. A covered wagon of 11-217 model

The frame is covered with a floor 9 of rabbeted boards 55 mm thick. The perimeter of the floor is reinforced with an angle bar 8. The wooden floor is covered with metal sheets 4 mm thick in the doorway, where the automatic loaders work intensively.

The side wall (Figure 1.20) of diagonal construction. The wall has a framework and a covering: metal 11 external covering and wooden 10 internal covering. Self-tightening door 6 and 7 and two hatches 4 provided with ventilating lattices are located in the middle part of a wall for loading and unloading of the wagon. The frame of the wall includes strapping 1, two pivot 3, six intermediate 2 and two door 5 racks. The upper strapping 1 (section AA) is made of a 90x56x8 mm angle bar, the pivot and intermediate struts are made of a bent Ω-shaped profile 6 mm thick, and the door racks13 (section DD) are made of a Z-shaped profile of 100x75x6.5 mm and a piloting angle 15 size 75x50x6 mm. The wall is welded to the longitudinal side beam of the frame 19 and to the end walls – to the corner posts 12 (section B-B). The outer covering 11 of walls is made of corrugated sheets 3 mm thick at the bottom and 2.5 mm at the top, and the inner 10 is made of moisture-resistant plywood of the FSF brand 10 mm thick. The inner covering is attached to the frame with screw bolts and framed at the joints with an angle bar 9. Each doorway 3825 mm wide has two door leaves 6 and 7 installed. One of the door leaves has a lowering hatch at the bottom, 8. The opening mechanism of this hatch is locked with the mechanism of opening and closing the door leaves and prevents its accidental opening. Sealing and self-tightening of door leaves on racks are provided by pressure of flowable cargo and rubber elements 14, and among themselves in a line it is done by tying 16 left doors of a special configuration in which groove 17 tying of the right door enters. The sealing of the door from the bottom is provided for by the load pressing the floor and the lower strapping 21 pressing the threshold 20 of the doorway. Each of the door leaves 6 and 7 consists of a frame lined on the outside with metal sheets 23 1.4 mm thick, and on the inside, it is lined with plywood 22 8 mm thick. The door leaves move behind the rail 26 attached on the doorway on rollers 25 with ball bearings.

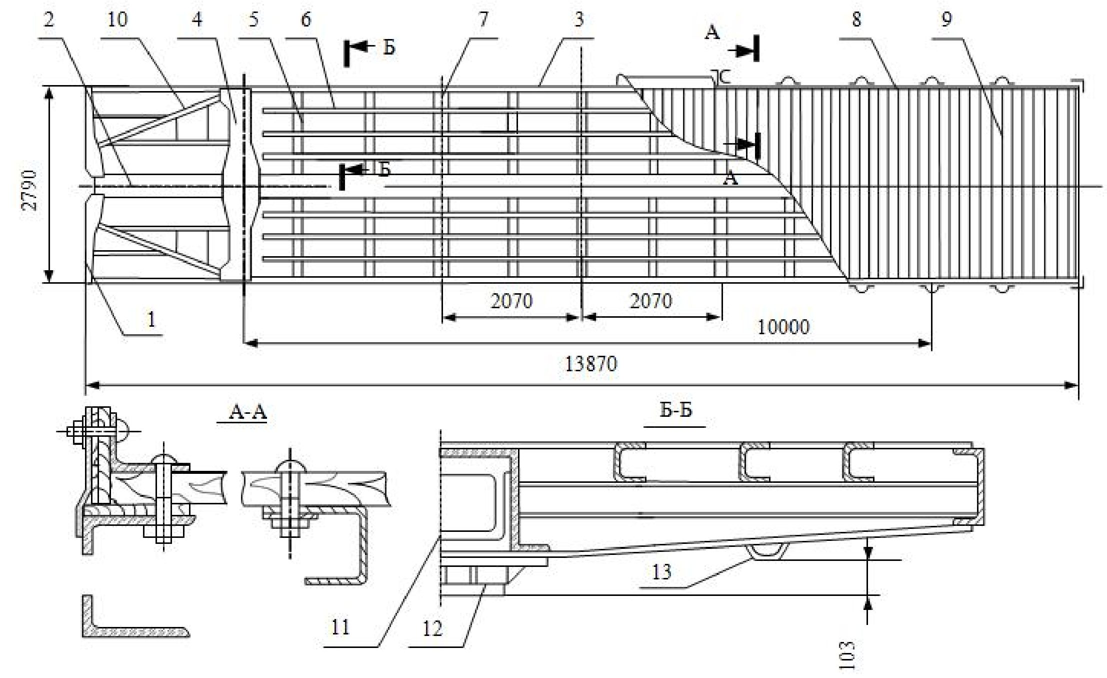


Figure 1.19. The frame of 11-217 model covered wagon

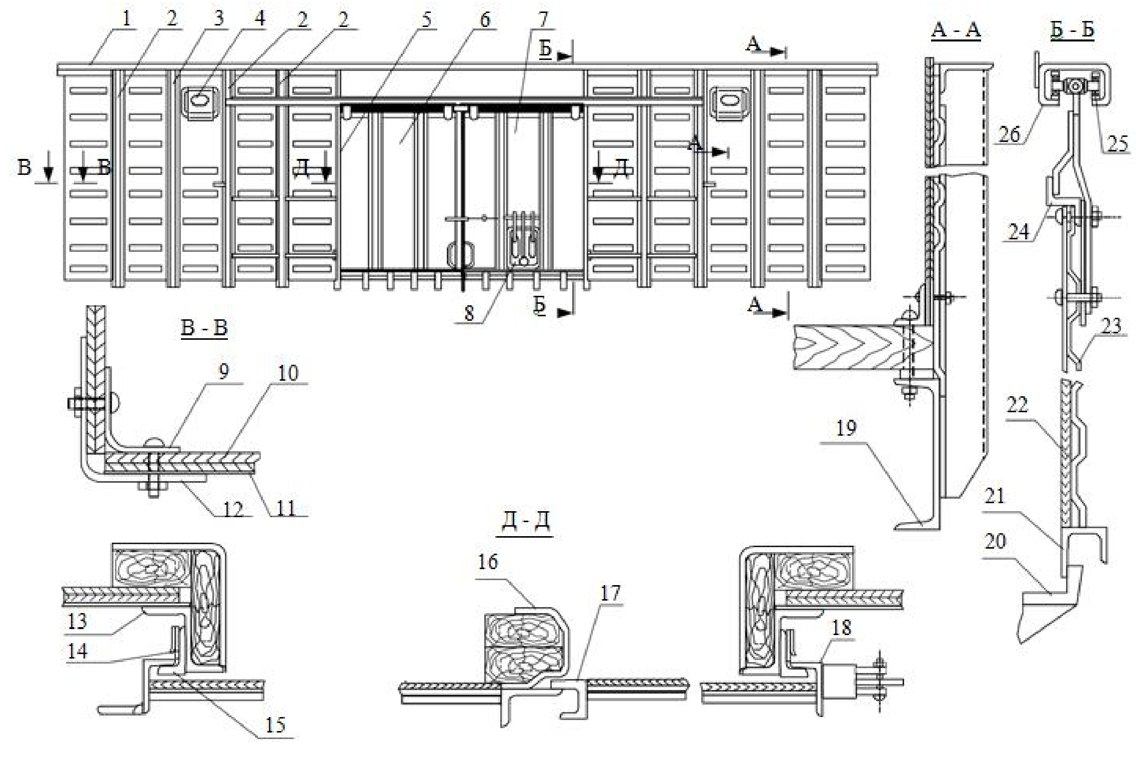


Figure 1.20. A side wall of covered wagon

The door frames consist of top, bottom and side strapping. The upper strapping 24 has a Z-shaped profile, the lower one 21 – U-shaped, the side end 18 – angle bars.

The middle strapping, respectively, on the left door leaf has a special profile welded from the angle bar and a bent element 16, inside which bars are inserted to provide rigidity, and the right door leaf is strengthened with a U-shaped profile. To protect the right door leaf from damage in case it suddenly opens a shock absorber is installed on the second from the doorway of the body rack. The shock absorber consists (Figure 1.21) of a body frame 1, a spring 3, a washer plate 4 and a rod 2. Side hatch covers with ventilation mesh made of stamped steel sheets 2 mm thick and locks that keep the lids closed. The locks open only from inside the wagon.

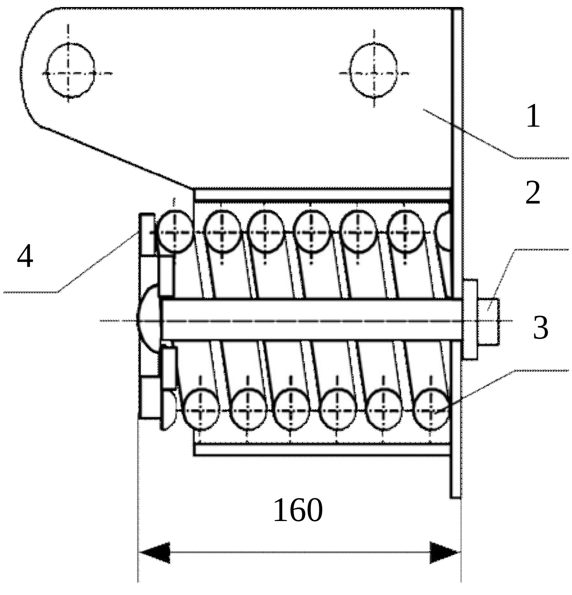


Figure 1.21. A shock absorber of door

The front wall (figure 1.22) is made of a framework, external metal 4 and internal wooden 5 coverings framed by an angle bar 6 on the floor, and on the corners – by an angle bar 8. The framework consists of two angular 2 and two intermediate vertical stays

3 connected by the top strapping 1. The outer metal strapping 4 is made of corrugated sheets with 3 mm thick below and 2.5 mm thick above, and the inner metal strapping 5 is made of moisture-resistant plywood 10 mm thick. The corner vertical stays 2 are made of a bent angle bar of 80x80x6 mm, the intermediate vertical stays 3 are made of a Ω-shaped element of 230x135x6 mm, and the upper strapping 7 is made of a special profile 6 mm thick. The lower beam 7 of the frame is the lower wall strapping.

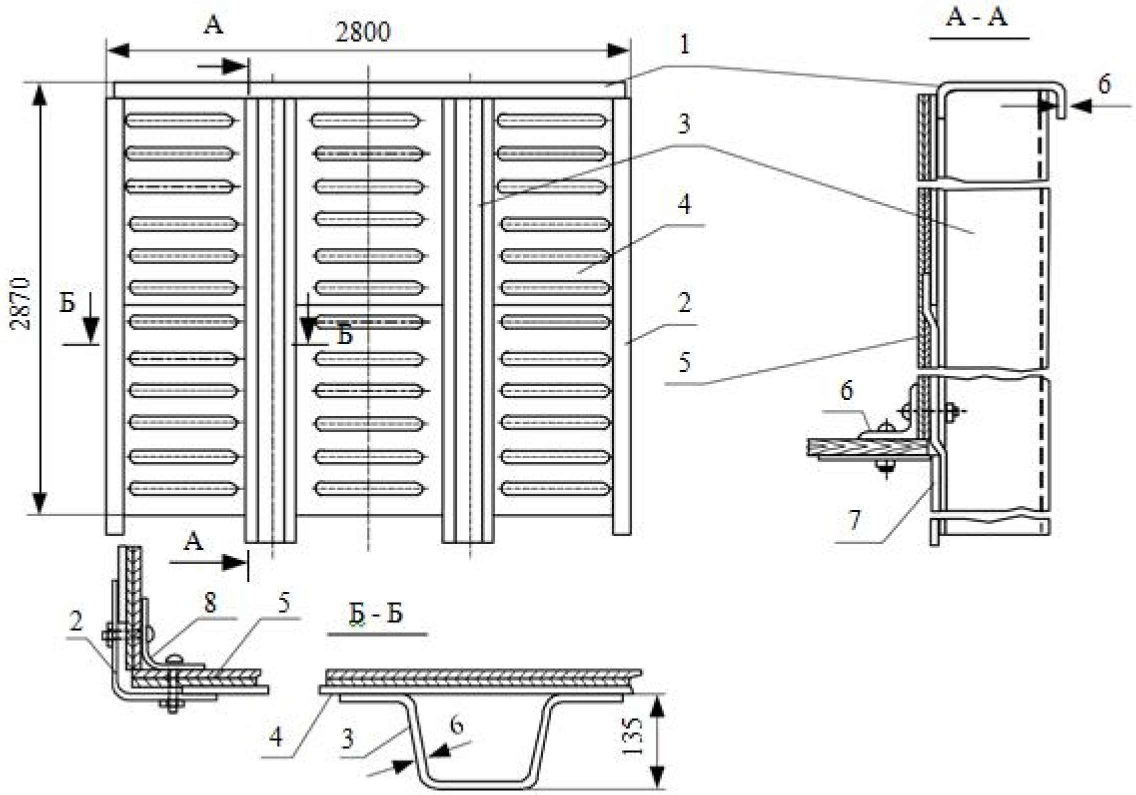


Figure 1.22. A side wall of covered wagon

The deck of the body (Figure 1.23) is all-welded with four loading hatches 6 400 mm in diameter and two standard pipe sections 4. The deck is attached to the side and front walls of the body with rivets with a diameter of 10 mm and it can be dismantled from the body with less complexity compared to the 11-066 model wagon, in which it is attached to the walls with the help of welding. Furnace places are provided for installation of pipes of heating furnaces in case of transportation of people. It is possible to climb the front ladder and scaffolding 5 to the loading hatches 6 and the furnace places 4 on the deck. The roof has a metal frame lined with corrugated sheets 3 1.5 mm thick, and two transoms 11, through which the roof is attached to the front walls. The transoms are made of metal sheets 2 mm thick with embossing for rigidity and filing. The deck frame is formed by a set of arches 1, longitudinal elements 2 located in the middle part, and two side longitudinal strappings.

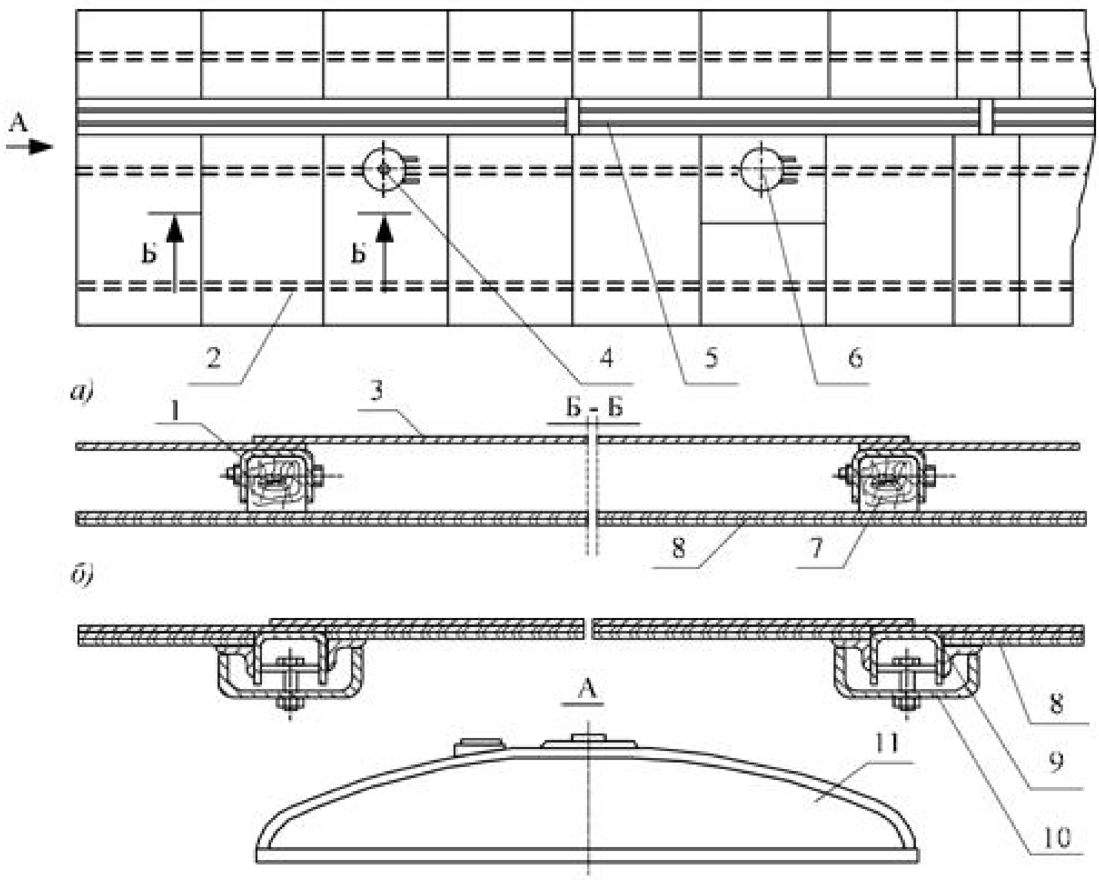


Figure 1.23. A deck of covered wagon

The arches 1 are made of bent channels 60x50x3 mm, middle longitudinal elements 2 are made of a bent angle bar 32x32x3 mm, and side strappings are made from two angle bars 56x56x5 mm. Sheets of the outer covering are welded to the arches of the longitudinal elements and the upper strapping of the side walls. The roof sheets are welded with overlap and to make them more rigid it is made with transverse corrugations 22 mm high. Inside (Figure 1.13, a) the deck is lined with moisture-resistant plywood 4 mm thick in two layers. The plywood fits tightly to the deck roof sheets from below, forming a ceiling. Plywood is attached to the covering with the help of angle bars 9 and brackets 10. This attachment of the covering prevents it from being damaged while loading and unloading of the wagon. In the previous versions (Figure 1.13, b) the covering 8 was attached to wooden bars 7 with an air layer, which led to frequent damage of the cover.

The covers of the deck hatches 4 (Figure 1.24) are fastened to the sheet 6 by two loops 5 and fixed in the closed position by special locks 1, which are opened from inside the wagon.

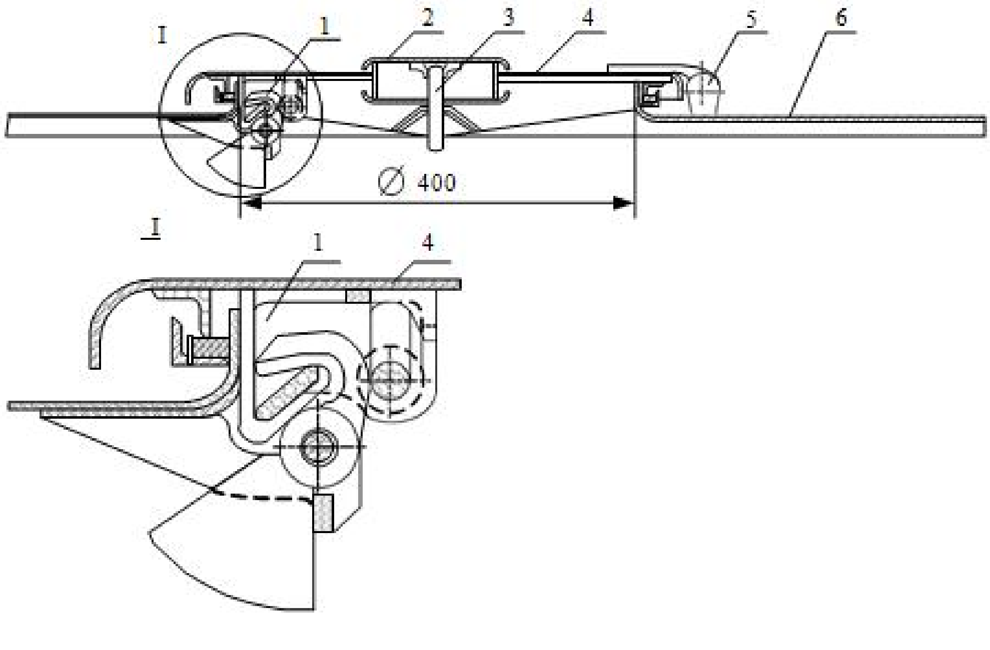


Figure 1.24. The covering plate of covered cat hatch

The lids 2 of the furnace sections, which are installed in the lids of the hatches 4, are held in the closed position by the screws 3.

Specialized covered hopper wagon for grain of 19-752 model is produced by Kriukivskyi Rail Wagon Manufacturing Plant. The wagon is designed according to 1-VM size. Its characteristics are shown in Table 1.2. The wagon has a metal frame (Figure 1.25), it is of self-unloading, hopper type.

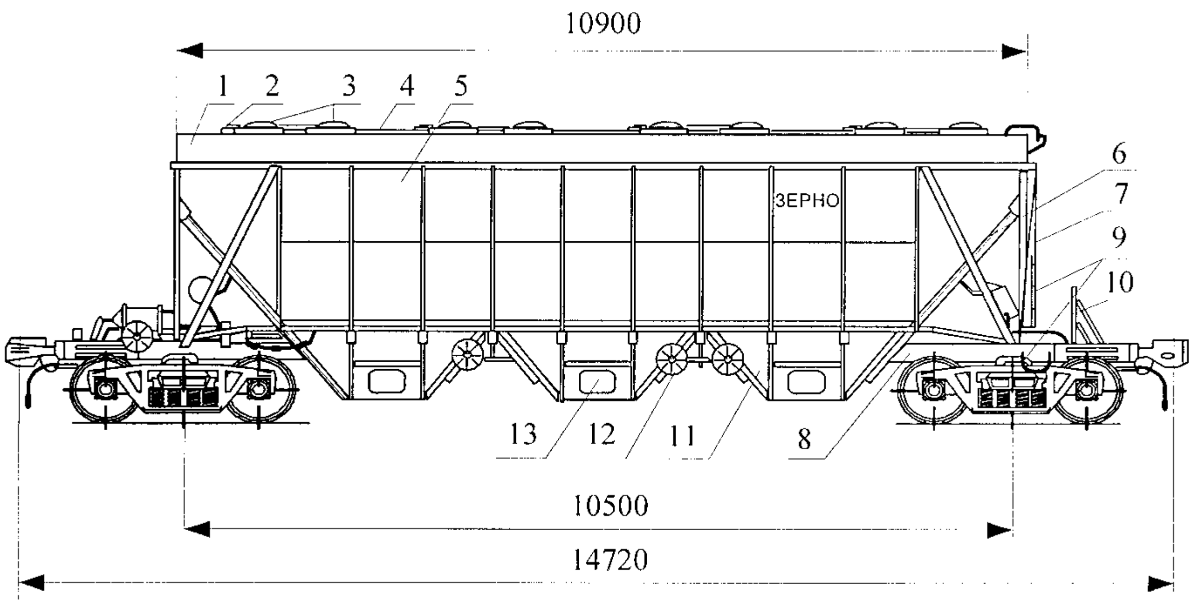


Figure 1.25. A hopper wagon for grain transportation

Frame 8, side 5 and front 6 walls, as well as the deck 1 form the body of the wagon. The wagon has six hoppers 11, three on each side with mechanisms 12 for opening and closing the unloading hatches. Devices 13 for placing vibrators are provided for on the hoppers to facilitate the emptying of cargo.

The wagon is loaded through four slatted loading hatches 2 located in the deck of the body. The hatches are closed with lids (1690x660 mm) with rubber thickeners.

Each cover is closed by two elastic flaps 3, which in the closed position go behind the gripping brackets, welded to the deck, and press the cover to the neck of the hatch. To prevent sudden release of latch hooks from the gripping brackets, the lids are equipped with a locking mechanism. It is a shaft 4, placed along the covers of the hatches along the entire length of the deck, with brackets welded to it. The shaft drive 7 is located on the frontal wall of the wagon. When turning the shaft clockwise, its sectors close the open space of the gripping brackets and prevent the flaps 3 go out from under them. When turning the shaft counterclockwise, the sectors come out from under the gripping brackets, remove the flaps from them and open the lids. Stairs 9 are installed on the frontal side of the body and on the frame to climb the deck of the wagon. The hoarding fence 10 is installed on the transition platform of the wagon. All bearing elements of a body are made of low-alloy steel 09G2D, and the covering of the wagon is made of steel 10KHNDP-2.

The frame (Figure 1.26) consists of a spine beam 3, two side 2, two end 5, two pivot 1 and two middle 4 beams. The spine beaml is made of Z-shaped profiles № 31, covered in the middle part with a ridge 8 (4 mm) for better unloading of the freight. In its cantilever part the spine beam is reinforced with a socket 7 and stops of automatic couplings. The side beams are made of an angle bar of 125x80x10 mm. The end L-shaped beams of cross section are welded from 4 mm thick sheets. Handrails 6 are installed on the end beam to make the work of assemblers safe. Pin beams of box section consist of two vertical 12 (6 mm) and two horizontal 12 sheets (10 mm). Flat spots 10 and a central plate 11 are installed on the the lower horizontal sheet. An overcenter plate box 9 is installed between the pivot and spine beams to ensure the durability of the support node and the rigidity of the connection of the pivot and spine beams. The middle transverse beams consist of vertical 14 (6 mm) and lower sloping 15 (8 mm) sheets. The side walls (Figure 1.27) are made of corrugated metal 3 mm thick sheets 6, supported by ten racks 5, upper 4 and lower 7 straps to make them more rigid.

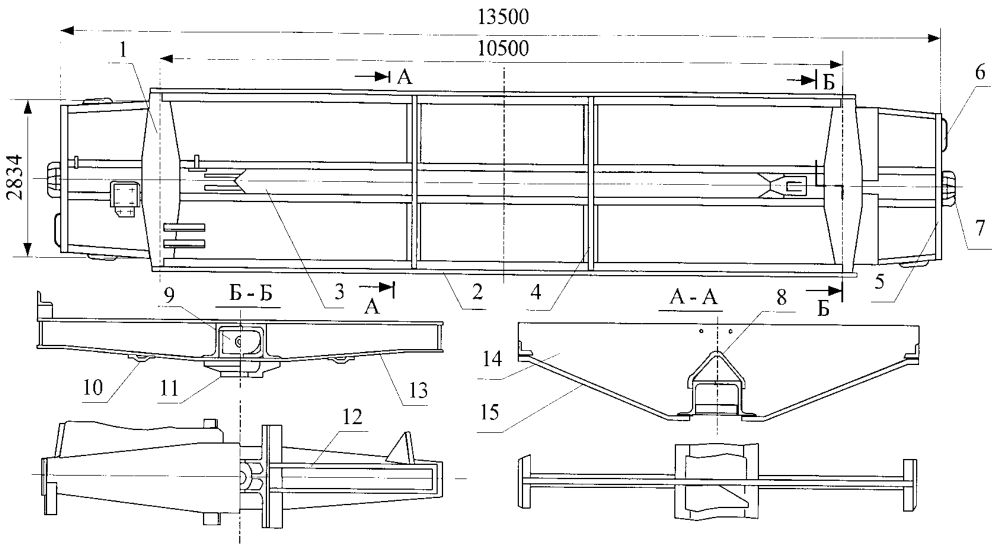


Figure 1.26. The frame of hopper wagon for transporting grain

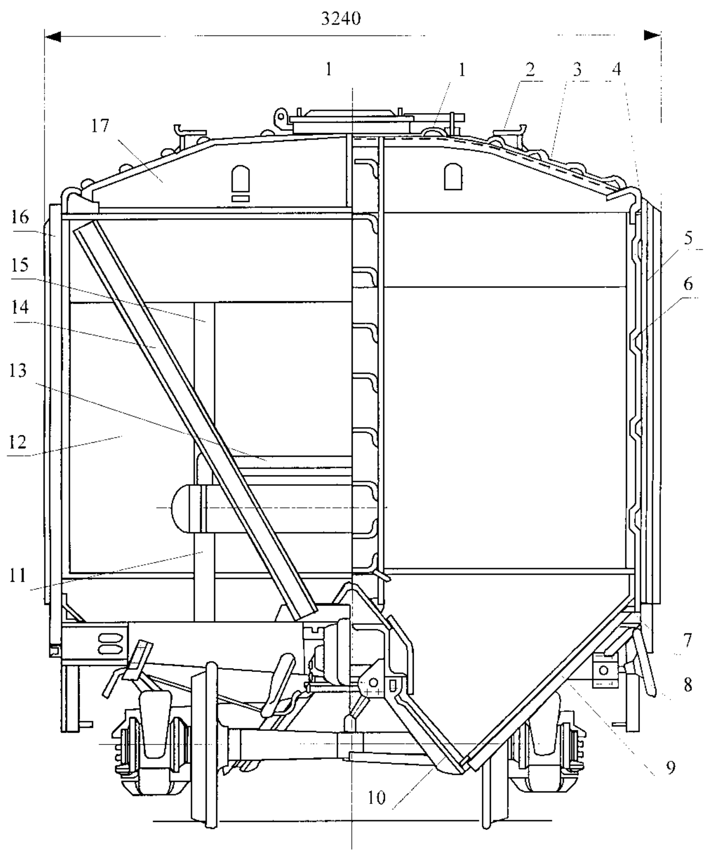


Figure 1.27. Cross section of the body of a hopper wagon for transporting grain

The vertical stays are made of I-beam № 10, the upper strapping 4 is made of a special bent 6 mm thick profile, and the lower one is made of a rolled angle bar 125 x 80 x 10 mm in size. For greater rigidity, each wall is connected to the frame by two inclined channels №14. The bunkers 9 are welded from 5 mm thick sheets in the form of a truncated pyramid and have hatches of unloading covers 10 with rubber thickeners. Every two opposite hopper boxes are equipped with one lever unloading mechanism with the driving steering wheel 8. The unloading mechanism provides pairwise opening and closing of the hatch covers of the hoppers. It consists of a screw drive with a steering wheel mounted on a draft attachment, and a system of articulated levers and rods with struts connected in pairs with the covers of the unloading hatches. When the axes of the struts transit the «dead» point, the lids are closed; it prevents sudden opening of the lids. For the wagons to undergo more complete unloading it is possible to install the vibrators on the hopper boxes. The inclined end walls of the body 12 are located at an angle of 55 ° to the plane of the frame. They are welded from the upper and lower 4 mm thick sheets and two side straps of angular bar profile with a cross section of 60 x 60 x 6 mm.

The top sheet has a flanging which acts as a top strapping. There is a figured stamping in the lower part, it is connected to the inclined sheet of a wall and it forms a cross beam of box section. The lower sheet of the covering is reinforced with two longitudinal 15 and one transverse 13 mouldings and struts 11. Each end wall is reinforced with two struts 14 and 16 of channel № 14 to make the cantilever parts of the body strong and rigid enough. The deck of the body is welded, it consists of a sheet corrugated covering 1 3 mm thick in the middle and 1.8 mm thick on the sides, which is supported by twelve arches 3, made of an angle bar of 75x50x5 mm in size. There are four slot-type loading hatches on the deck. The deck is connected to the end walls by transoms 17, and to the side walls by welding directly to the upper strapping 4 of the wall. There are stairs to climb the deck and inside the wagon, and a ladder 2 along the entire length of the deck.

A specialized covered hopper wagon for cement of 19-715 model has the characteristics listed in Table 1.2. The hopper type wagon is intended for non-packaged transportation of cement to places of mass consumption where there are receiving devices located between the rails.

The body of a cement tank wagon differs from the body of a grain tank wagon only in its size and the number of hoppers, of which there are four instead of six in the wagon. The end walls are inclined at an angle of 50 ° to the plane of the frame.

The wagon differs from the previously considered wagons because its loading hatches (1630 x 480 mm) in its deck open, as in all other wagons, in manual way, and unloading ones (2382 x 840 mm) open from pneumatic circuit from the locomotive or from a stationary air supply source. In addition, the unloading hatches of the hoppers are not for bottom, but for side unloading.

1.3. Design features of flat wagons

According to the classification, railway wagons refer to freight wagons of open type. This is a very popular type of transport for long-distance transportation [1–3].

A flat wagon for transportation of containers does not have a floor topping and planking, it is equipped with the stops necessary for fastening of containers. Railway flat wagons intended for timber transportation are provided with flooring and end planking. It is impossible to transport such cargo in other conditions. Flat wagons for transportation of wheeled vehicles are similarly equipped.

Flat wagons for long-distance transportation of automobiles have their specific features. Their body consists of specially fixed frames and metal flooring. This wagon platform has folding platforms-ramps at the ends, designed for racing wagons. The automobiles are fastened with the help of special stops.

We will consider the design features of the universal flat wagon (Figure 1.28).

The body of the platform consists of a frame 2 with a combined floor topping 10, eight side (four on one side) and two end 7 sides.

The side panels are hinged to the side beams of the frame and each of them is held in the closed position by three wedge locks 3 while the end sides are hinged by two wedge locks 6.

Four support brackets 8 are installed on the end beams of the frame to keep the end boards in a horizontal position while loading wheeled vehicles self-propelled.

Brackets 9 and connecting rings 5 are provided for tying the load inside the body. Brackets 4 for installing wooden racks are welded on the side beams of the frame when transporting bulk cargoes loaded above the sides.

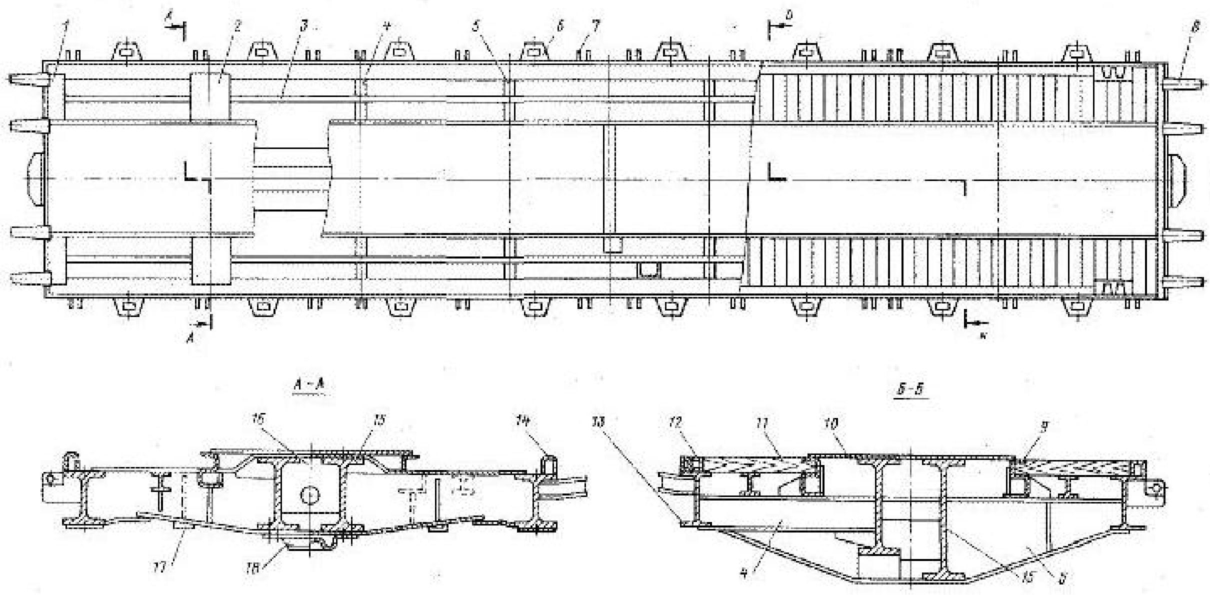


Figure 1.28. Design features of the load-bearing structure of a universal flat wagon

The frame of the body is welded. It consists of a spine 15, two side 13, two end 1, two pivot 2, three main 5 and two intermediate transverse 4 beams, which as well as the auxiliary longitudinal beams 3 and 9 serve to support the flooring.

Two I-beams № 70 of variable height in length form a spinal beam 15.

I-beams are connected by diaphragms and stops of automatic couplings. The junctions of the ridge and pivot beams are reinforced with suprapubic diaphragms 16.

The side beam 13 is made of I-beam № 30 of constant height along its entire length. Wooden staples 6 and wedge locks holders 7 are welded to it from the outside.

The end beams are welded, constant in length and made of L-shaped 8 mm thick sheet and elements used for reinforcing it: two angle bars (150 x 60 x 6 mm) and four ribs, welded on the inside of the beam in the areas of the brackets 8.

The pivot beams 2 are welded, of closed box section, variable height in length. They consist of two vertical (8 mm), upper and lower horizontal sheets (10 mm).

Sliders 17 are riveted to the lower horizontal sheets of pivot beams, and center plated 18 are installed on the bolts in the areas of connection with the spine beam.

The main cross beams 5 are welded of I-beam section, constant height in length and consist of a vertical sheet (8 mm) and two horizontal (10 mm) ones.

Auxiliary transverse 4 and extreme longitudinal 3 beams used to support the flooring are made of I-beam № 10.

The transverse beams 4 are located in the frame below the floor level at the height of the auxiliary longitudinal beams 3 in order to ensure the location of their top in the same plane with the side ones and to simplify the laying of flooring.

We will consider the design features of some models of flat wagons.

The universal platform with a wood-metal flooring is intended for transportation of wheeled and caterpillar vehicles, piece and other freights, both with evenly distributed, and with the concentrated loading on a floor. The flat wagon of 13-4012 model (Figure 1.29) has a specific floor structure: the central part is metal, and the edges are made of metal. The floor is reinforced with four beams.

The main technical characteristics of the flat wagon are listed in table 1.16 [4].

Figure 1.29. A flat wagon of 13-4012 model

Table 1.16

Main technical characterictics of flat wagon of 13-4012 model

The name of the parametre	*Value*
Load capacity, t	72,0
Wagon weight, t	22,0
Estimated load from the wheelset on the rail, kN	230,5(23,5)
Length of the wagon on axes of coupling of autocouplings, mm	14620
Base, mm	9720
Internal dimensions of the body – length, mm – width, mm – height, mm	 13300 2770
Dimensions	0-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120

The universal flat wagon of 13-401 model has a different from 13-4012 model design of a frame: two longitudinal beams of rigidity are used instead of four ones, the floor is completely wooden (Figure 1.30). The sides of the flat wagon are metal. The flat wagon is used to transport wheeled and caterpillar vehicles, piece and other freight that do not require protection against precipitation.

Figure 1.30. A flat wagon of 13-401 model

The main technical characteristics of a flat wagon are listed in Table 1.17.

Table 1.17

The main technical characteristics of a flat wagon of 13-401model

The name of the parametre	*Value*
Load capacity, t	70,0
Wagon weight, t	20,92
Estimated load from the wheelset on the rail, kN	223,01(22,73)
Length of the wagon on axes of coupling of autocouplings, mm	14620
Base, mm	9720

The name of the parametre	*Value*
Internal dimensions of the body – length, mm – width, mm – height, mm	 13300 2770
Dimensions	0-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120

A flat wagon of 13-4085 model (Figure 1.31) is developed on the basis of the flat wagon of a universal 13-4012 model and is designed for transportation of wheeled and caterpillar vehicles, large containers, unitized cargo, metal structures, long and other goods, both evenly distributed and with a concentrated load on the floor. Special supports mounted on the frame of the flat wagon ensure reliable fixing of containers and their preservation during transportation.

Figure 1.31. A flat wagon of 13-4085 model

The flat wagon is designed to transport two containers of size 1C, 1CS, 1CX or one container of size 1AA, 1A, 1AX, as well as other universal and specialized large-capacity containers with a length of 6096 mm (20 feet) with a gross weight of up to 36 t and a length of (40 feet) with a gross weight of up to 40 tons.

The main technical characteristics of the flat wagon are listed in Table 1.18.

Table 1.18

The main technical characteristics of the flat wagon of 13-4085 model

The name of the parametre	*Value*
Load capacity, t	72,0
Wagon weight, t	22,0
Estimated load from the wheelset on the rail, kN	230,0
Length of the wagon on axes of coupling of autocouplings, mm	14620
Base, mm	9720
Internal dimensions of the body – length, mm – width, mm – height, mm	 13300 2770
Dimensions	0-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120

A flat wagon of 13-9004 model (Figure 1.32) is designed for the transportation of large containers and wheeled vehicles: wheel loaders, trucks, various construction equipment, transportation of mobile buildings and cabins. A flat wagon with end sides is equipped with hinged fitting stops (the stop is included in the lock of the container). The frame of the wagon is welded.

Figure 1.32. A flat wagon of 13-9004 model

The main technical characteristics of a flat wagon are listed in Table 1.19.

Table 1.19

The main technical characteristics of a flat wagon of 13-4085 model

The name of the parametre	*Value*
Load capacity, t	65,0
Wagon weight, t	26,0
Estimated load from the wheelset on the rail, kN	223,0
Length of the wagon on axes of coupling of autocouplings, mm	19620
Base, mm	14720

The name of the parametre	*Value*
Internal dimensions of the body – length, mm – width, mm – height, mm	 18300 2870
Dimensions	0-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120

The flat wagon of 13-4012-09 model (Figure 1.33) is intended for transportation of containers-tanks. Two containers of size 1C, 1CS, 1CX or one container of size 1AA, 1A, 1AX can be placed on the frame of the flat wagon at the same time [6].

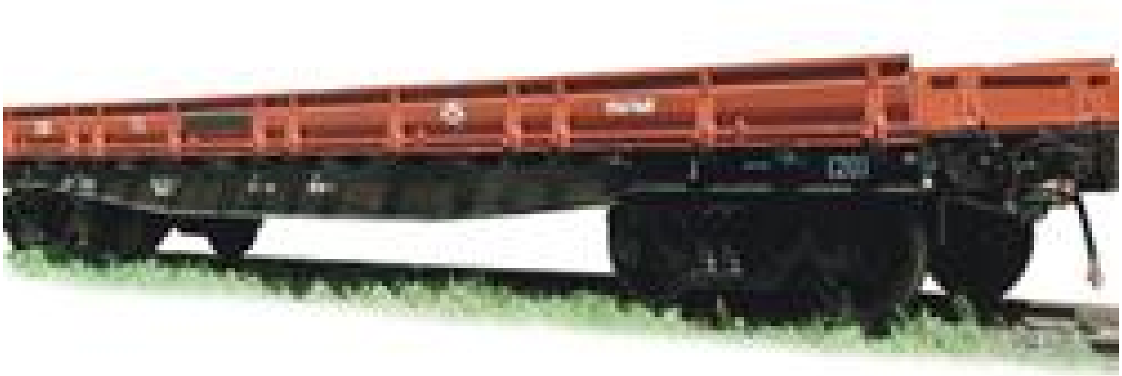


Figure 1.33. A flat wagon of 13-4012-09 model

The main technical characteristics of a flat wagon are listed in Table 1.20.

Table 1.20

The main technical characteristics of a flat wagon of 13-4012-09 model

The name of the parametre	*Value*
Load capacity, t	72,0
Wagon weight, t	18,24
Estimated load from the wheelset on the rail, kN	221,1 (22,56)
Length of the wagon on axes of coupling of autocouplings, mm	14620
Base, mm	9720
Internal dimensions of the body – length, mm – width, mm – height, mm	 13300 2770
Dimensions	0-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120

The flat wagon of 13-4012-10 model (Figure 1.23) with the fixed equipment is intended for transportation of blocks. The design of the wagon is developed taking into account convenience of loading and unloading, compactness of placement of freight and the maximum use of loading capacity of the flat wagon. The original solution used in the design of stop bars allows to change the length of the freight hole and get 12 options of fixed lengths for different sizes of cargo with its reliable attachment to the flat wagon without the use of temporary (one-time) mounting details.

Figure 1.34. A flat wagon of 13-4012-10 model

The main technical characteristics of the flat wagon are listed in Table 1.21.

Table 1.21

The main technical characteristics of the flat wagon of 13-4012-10 model

The name of the parametre	*Value*
Load capacity, t	68,0
Wagon weight, t	26,0
Estimated load from the wheelset on the rail, kN	230,0 (23,5)
Length of the wagon on axes of coupling of autocouplings, mm	14620
Base, mm	9720
Internal dimensions of the body – length, mm – width, mm – height, mm	 13300 2770
Dimensions	0-BM
Height to the pulling face from the level of the rail heads, mm	1060±20

The name of the parametre	*Value*
Railway track gauge, mm	1520
Construction design speed, km/h	120

The flat wagon with removable equipment of 13-4012-11 model (Figure 1.35) is intended for transportation of profile rolled steel. The wagon is developed on the basis of the flat wagon of the universal 13-4012 mode, it is a specialized vehicle for transportation of profile rolled steel on a network of main railways of 1520 mm [7].

The design is developed taking into account convenience of loading and unloading, compactness of placement of freight on a flat wagon frame wagon and the maximum use of loading capacity of the wagon. Removable equipment provides reliable fastening of cargo without application of temporary (one-time) fastening requisites and allows to transport profile rolled steel of the following sizes: from 3000 to 12700 mm in length; from 1500 to 2500 mm wide; from 8 to 30 mm thick.

Figure 1.35. A flat wagon of 13-4012-11 model

The main technical characteristics of flat wagon are listed in Table 1.22.

Table 1.22

The main technical characteristics of a flat wagon of 13-4012-11 model

The name of the parametre	*Value*
Load capacity, t	68,0
Wagon weight, t	26,0
Estimated load from the wheelset on the rail, kN	230,0 (23,5)
Length of the wagon on axes of coupling of autocouplings, mm	14620
Base, mm	9720
Internal dimensions of the body – length, mm – width, mm – height, mm	 13300 2770
Dimensions	0-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120

A 13-H451 model flat wagon (Figure 1.36) is designed to transport wheeled and caterpillar vehicles, piece and other freights that do not require protection from precipitation [8].

The flat wagon is equipped with metal drop side planking: longitudinal – 8, transverse – 2. The frame from the serial model of the universal flat wagon is used in this model.

Figure 1.36. A 13-H451 model flat wagon

The main technical characteristics of a flat wagon are listed in Table 1.23.

Table 1.23

The main technical characteristics of a 13-H451 model flat wagon

The name of the parametre	*Value*
Load capacity, t	63,0
Wagon weight, t	21,3
Estimated load from the wheelset on the rail, kN	206,78
Length of the wagon on axes of coupling of autocouplings, mm	14620
Base, mm	9720
Internal dimensions of the body – length, mm – width, mm – height, mm	 13300 2770
Dimensions	0-BM
Height to the pulling face from the level of the rail heads, mm	1060±20

The name of the parametre	*Value*
Railway track gauge, mm	1520
Construction design speed, km/h	120

A 13-926 model flat wagon is designed to transport wheeled and caterpillar vehicles, piece and other freights that do not require protection from precipitation (Figure 1.37) [9].

Figure 1.37. A 13-926 model flat wagon

The main technical characteristics of a flat wagon are listed in Table 1.24.

Table 1.24

The main technical characteristics of a 13-926 model flat wagon

The name of the parametre	*Value*
Load capacity, t	71,0
Wagon weight, t	23,0
Estimated load from the wheelset on the rail, kN	230,0 (23,5)
Length of the wagon on axes of coupling of autocouplings, mm	19620
Base, mm	14400

The name of the parametre	*Value*
Internal dimensions of the body – length, mm – width, mm – height, mm	 18400 2930
Dimensions	1-BM
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120

The frame of the flat wagon is a welded structure with a spine beam, equipped with rear and front stops. The wagon has a combined flooring, 12 longitudinal and 2 transverse sides. The sides are hinged to the frame and held by wedge-shaped locks in the raised (closed) position. In the lowered position, the longitudinal sides are below floor level. The end boards are equipped with torsions, which keep them in a raised position above the support brackets and ensure the rolling of rolling cargo and wheeled equipment along the train.

The flat wagon of 13-935 model is intended for transportation of caterpillar and wheeled equipment, as well as multi-tonnage containers (Figure 1.38). The wagon is equipped with end boards, folding fitting stops, a wooden floor with a metal strip (575 mm).

Figure 1.38. A 13-935 model flat wagon

The main technical characteristics are listen in Table 1.25.

Table 1.25

The main technical characteristics of a 13-935 model flat wagon

The name of the parametre	*Value*
Load capacity, t	73,0
Wagon weight, t	27,0
Estimated load from the wheelset on the rail, kN	245,0
Length of the wagon on axes of coupling of autocouplings, mm	19620
Base, mm	14400
Internal dimensions of the body – length, mm – width, mm – height, mm	 18300 2950
Dimensions	1-ВМ
Height to the pulling face from the level of the rail heads, mm	1060±20

The name of the parametre	*Value*
Railway track gauge, mm	1520
Construction design speed, km/h	120

A 13-785 model flat wagon (Figure 1.39) is designed to transport packaged piece freights, various types of metals in the form of plates and profiles, universal multi-tonnage containers (three containers 20 feet long or one container 40 feet long and one container 20 feet long) and other freights, which do not require protection from precipitation [4].

Figure 1.39. A 13-785 model flat wagon

The main technical characteristics are listed in Table 1.26.

Table 1.26

The main technical characteristics of a 13-785 model flat wagon

The name of the parametre	*Value*
Load capacity, t	68,0
Wagon weight, t	26,0
Estimated load from the wheelset on the rail, kN	230,5 (23,5)

The name of the parametre	*Value*
Length of the wagon on axes of coupling of autocouplings, mm	19880
Base, mm	14860
Internal dimensions of the body – length, mm – width, mm – height, mm	 18520 2670
Dimensions	IIRR (RAI)
Height to the pulling face from the level of the rail heads, mm	1060±20
Railway track gauge, mm	1520
Construction design speed, km/h	120

The wagon is equipped with 2 end and 18 longitudinal folding boards, rotary racks for fastening of freight. The design of the wagon allows to wagonry out mechanical loading and unloading with epy use of cranes and loaders. To facilitate loading and unloading the sides of the wagon can be folded: longitudinal sides with the rotation by 180 °, and the end sides – by 90 °. The wagon has an automatic pneumatic, manual brake. The chassis consis of two two-axle trolleys of 18-100 model of type 2 for a track of 1435 mm. The harness device of the wagon is equipped with an absorbing device of T1 class.

1.4. Design features of tank wagons

Tank wagons are designed to transport liquid, gaseous and powdered goods. A significant variety of transported goods has led to significant changes in the design of tank wagons, and therefore the latter can be classified into[1–3]:

– for general purpose;
– for transportation of a wide range of oil products;
– for special purpose;
– for transportation of certain types of cargo.

Today, a large percentage of general-purpose tank wagons are in circulation (Figure 1.40). Therefore we will consider their design.

Figure 1.40. A 15-1443-06 model tank wagon for transporting light oil products

A four-axle tank wagon with a capacity of 60 tons has a boiler with a capacity of 71.7 m^3 and a total of 71.3 m^3. The inner diameter of the boiler is 3000 mm. The thickness of the armor plate is 11 mm, upper and side – 9 mm, bottoms – 10 mm. All sheets and bottoms are joined by butt welds. The container of the tank wagon is 23.2 tons.

The frame has light end and side beams, the latter are left only in the cantilever parts of the frame. There are also no intermediate crossbeams.

The copper is fixed on a frame in its middle and final parts. The shaped legs are welded to the middle part of the armor plate, connected by bolts sharpened to the holes, with support bars, which are welded to the spine beam of the frame.

At the ends, the copper rests on wooden bars fixed by means of gutters, bolts with nuts and diaphragms on the pivot and ridge beams of the frame.

The boiler is fixed to the extreme supports by expansion coupling designed to prevent its vertical and transverse movements relative to the frame. The length of the expansion coupling is regulated by socket screw.

The tank wagon is equipped with external ladders with platforms at the crown, a universal drain device and a safety inlet valve. The armor plate is curved so that it has a slope to the drain device to ensure complete emptying of the cargo.

A four-axle tank with a capacity of 60 tons manufactured by the Mariupol plant of 15-1443 model (Figure 1.41) has a copper with a useful capacity of 71.7 m^3 with a total capacity of 73.1^3 m and an internal diameter of 3.0 m.

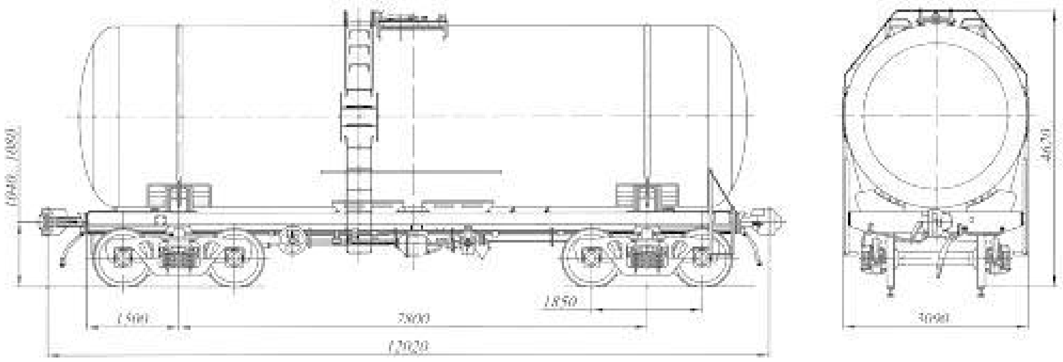


Figure 1.4. A 15-1443 model tank wagon

The copper is fixed on a frame in its middle and final parts. The copper is fastened to the extreme supports by expansion coupling designed to prevent its vertical and transverse movements relative to the frame.

A specific feature of the design of the tank wagon frame of 15-1443 model is that it has no side longitudinal beams, but it has strong end beams and lightweight longitudinal side beams only at the ends of the frame. There are also no intermediate crossbeams. As a result, the mass of the tank container decreased by 1.4 tons. With such a design, the forces acting on the tank are perceived by the copper, the stiffness of which is much higher than the stiffness of the longitudinal side beams, and then transmitted to the carriages through its extreme supports.

4-axle tanks with an increased base (7.8 m instead of 7.12 m) and shortened consoles (1.5 m instead of 1.84 m) have been recently built at the Mariupol Rail Wagon Manufacturing Plants. This greatly improves the dynamic qualities of the tank, especially in the horizontal plane, and increases the safety of freight trains, which have such tank wagons.

A 4-axle tank with a specific copper volume of 1.4 m^3 / t has been designed for the transportation of gasoline. This tank is inscribed in the 02-VM dimension, which allows it to be operated on foreign railways with a track 1435 *mm* wide. The capacity of such a tank is 62 tons, the weight of the container is 25.3 tons, the axial load is 216 kN, and the running load is 64 kN / m.

A modern representative of tank wagons is a 15-7076 model tank wagon (Figure 1.42) constructed by the Kriuksv Rail Wagon Manufacturing Plant. The tank wagon is intended for transportation of oil products on all railways network with a 1520 *mm* wide track. The tank wagon has a frame of the strengthened design and a copper of the increased durability. The resistance of the tank to climatic influences meets the requirements of GOST (State Standard) 15150 with maintenance of operational reliability at the lower working value of air temperature from -60 to +50 ° C. This tank wagon has an automatic pneumatic brake with separate braking of wagonts as well as a parking one. The chassis of the tank wagon are two two-axle wagonriges of 18-7055 model of type 2 GOST 9246 (this is an analog of the carriage of 18-100 model). The automatic coupling is CA-3. The absorbing apparatus is of T 2 class.

Figure 1.42. A tank wagon of 15-7076 model

Table 1.27

The technical characteristics of modern tank wagon of 15-7076 model

The name of the parametre	*Значення*
Load capacity, t	67,3
Full volume of the copper (useful), m³	85,56 (83,91)
Container weight, not more, t	26,7
Estimated static load from the wheelset on the rails, kN	230,5 (23,5)
Length of the wagon on axes of automatic couplings, mm	12020
Dimension according to GOST (State Standard) 9238	1-VM
Height to the axis of adhesion from the level of the rail heads, mm	1060±20
Wagonrige	18-7055
Track width, mm	1520
Inter-repair run, years (thous. km)	3 (210)
Design speed, km/h	120

CONCLUSIOND TO CHAPTER 1

1. The design features of the main types of wagons operated on wide gauge railways have been analyzed. The following types of wagonsare described: gondola wagons, covered wagons, flat wagons, hopper wagons, as well as tank wagons, manufactured by the leading rail wagon manufacturing enterprises of Ukraine.

2. The main advantages of modern load-bearing structures of recently manufactured wagons in comparison with the prototype wagons and prospects of their operation have been determined.

3. The main technical characteristics of wagons have been explained. Promising designs of flat wagons, including the wagons for the transportation of containers and removable bodies, have been studied.

2. DEVELOPMENT AND ANALYSIS OF DYNAMIC LOADING FUNCTIONAL DEPENDENCE OF TYPICAL DESIGNS OF DOMESTIC PARK FREIGHT WAGONS WITH NOMINAL PARAMETERS

2.1. Calculation of dynamic loading of load-bearing structures of freight wagons in the vertical plane

Mathematical modeling has been performed to determine the specified dynamic loads acting on the load-bearing structures of freight wagons of the domestic fleet with nominal parameters.

The oscillations of the load-bearing structures of freight wagon in the vertical and longitudinal planes are taken into account.

The dynamic load of the load-bearing structures of freight wagons in the vertical plane was calculated according to the mathematical model developed by professor Dyomin Yu. V. and associate professor Chernyak G. Yu. [10]. It is taken into account that the freight wagon moves in an empty state with a junctural unevenness. The track is considered to be elastic-viscous. The reactions of the track are proportional to both its deformation and the speed of this deformation. The scheme of calculation is shown in Figure 2.1.

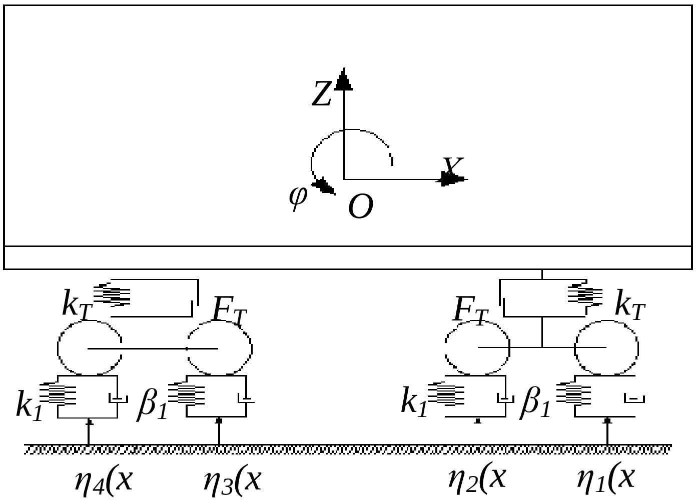


Figure 2.1. The calculated scheme of the wagon

The computational model motion equations are the following:

$$M_1 \cdot \frac{d^2}{dt^2} q_1 + C_{1,1} \cdot q_1 + C_{1,3} \cdot q_3 + C_{1,5} \cdot q_5 = \\ = -F_{TP} \cdot \left(sign\left(\frac{d}{dt}\delta_1 \right) + sign\left(\frac{d}{dt}\delta_2 \right) \right), \tag{2.1}$$

$$M_2 \cdot \frac{d^2}{dt^2} q_2 + C_{2,2} \cdot q_2 + C_{2,3} \cdot q_3 + C_{2,5} \cdot q_5 = \\ = F_{TP} \cdot l \cdot \left(sign\left(\frac{d}{dt}\delta_1 \right) + sign\left(\frac{d}{dt}\delta_2 \right) \right), \tag{2.2}$$

$$M_3 \cdot \frac{d^2}{dt^2} q_3 + C_{3,1} \cdot q_1 + C_{3,2} \cdot q_2 + C_{3,3} \cdot q_3 + B_{3,3} \cdot \frac{d}{dt} q_3 = \\ = F_{TP} \cdot sign\left(\frac{d}{dt}\delta_1 \right) + k_1 (\eta_1 + \eta_2) + \beta_1 \left(\frac{d}{dt}\eta_1 + \frac{d}{dt}\eta_2 \right), \tag{2.3}$$

$$M_4 \cdot \frac{d^2}{dt^2} q_4 + C_{4,4} \cdot q_4 + B_{4,4} \cdot \frac{d}{dt} q_4 = -k_1 \left(\eta_1 - \eta_2\right) \\ - - \beta_1 \cdot a \cdot \left(\frac{d}{dt}\eta_1 - \frac{d}{dt}\eta_2 \right), \tag{2.4}$$

$$M_5 \cdot \frac{d^2}{dt^2} q_5 + C_{5,1} \cdot q_1 + C_{5,2} \cdot q_2 + C_{5,5} \cdot q_5 + B_{5,5} \cdot \frac{d}{dt} q_5 = \\ = F_{TP} \cdot sign\left(\frac{d}{dt}\delta_2 \right) + k_1 \left(\eta_3 + \eta_4\right) + \beta_1 \left(\frac{d}{dt}\eta_3 + \frac{d}{dt}\eta_4 \right), \tag{2.5}$$

$$M_6 \cdot \frac{d^2}{dt^2} q_6 + C_{6,6} \cdot q_6 + B_{6,6} \cdot \frac{d}{dt} q_6 = -k_1 \cdot a \cdot \left(\eta_3 - \eta_4\right) - \beta_1 \cdot a \cdot \left(\frac{d}{dt}\eta_3 - \frac{d}{dt}\eta_4 \right), \tag{2.6}$$

where *M1*, *M2* – respectively the mass and moment of inertia of the load-bearing structure of the wagon during oscillations of jumping and galloping; *M3*, *M4* – respectively the mass and moment of inertia of the first carriage facing the engine during oscillations of jumping and galloping; *M5*, *M6* – respectively the mass and moment of inertia of the second carriage facing the engine during oscillations of jumping and galloping, *Cij* – characteristics of the elasticity of the oscillating system elements; *Bi* – difusion function; *a* – half of the base of the carriage; *qi* – generalized coordinates corresponding to the translational movement relative to the vertical axis and the angular movement around the vertical axis; *ki* – stiffness of the spring suspension; *βi* – the damping coefficient; F_{TP} – force of absolute confrication in the spring set.

The initial displacement and speed are taken to be zero. The input parameters of the model are the technical characteristics of the load-bearing structure of the wagon with the nominal parameters, the spring suspension of the carriages as well as the disturbing action (table 2.1).

The parameters of the spring suspension of the 18-100 model carriage were taken into account during calculations.

For the differential equations (2.1) – (2.6) to be solved they were reduced to the normal Caushy form. After that, they are integrated by the method of Runge – Kutt [11, 12]. Based on the calculations, the accelerations acting on the studied structures of wagons are determined.

Table 2.1

The input parameters to the mathematical model

The name of the Parametre	*Value*
CARRIAGES	
weight, t	4,3
half base, m	0,925
stiffness of spring suspension, kN / m	8000
relative friction coefficient	0,1
TRACK	
damping factor, kN · s / m	200
stiffness, kN / m	100000
inequality amplitude, m	0,01
length of inequality, m	25

Spatial models were built in the SolidWorks software package to determine the mass and moments of inertia of the load-bearing structures of the studied types of wagons with nominal parameters. The most widespread models of freight wagons which have found use on the CIS railways are taken into account:

– 12-757 model gondola wagon (Figure 2.2);
– 11-217 model covered wagon (Figure 2.3);
– 13-401 model flat wagon (Figure 2.4);
– 15-1443-06 model tank wagon (Figure 2.5);
– 20-9749 model hopper wagon (Figure 2.6).

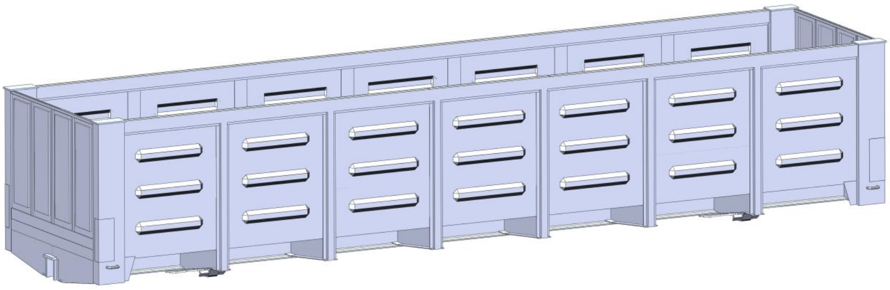


Figure 2.2. A spacial model of the load-bearing structure of gondola wagon

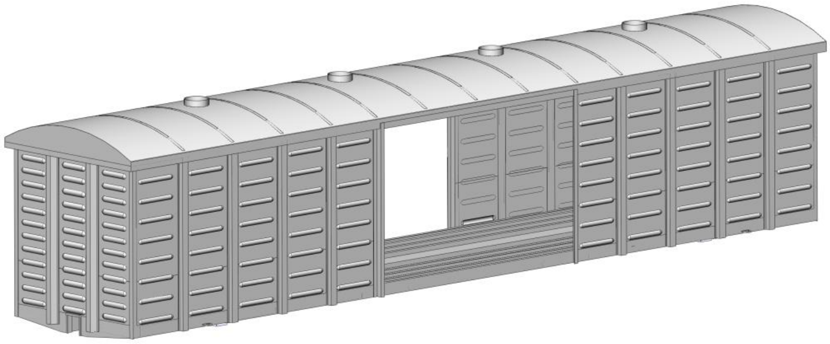


Figure 2.3. A spacial model of the load-bearing structure of covered wagon

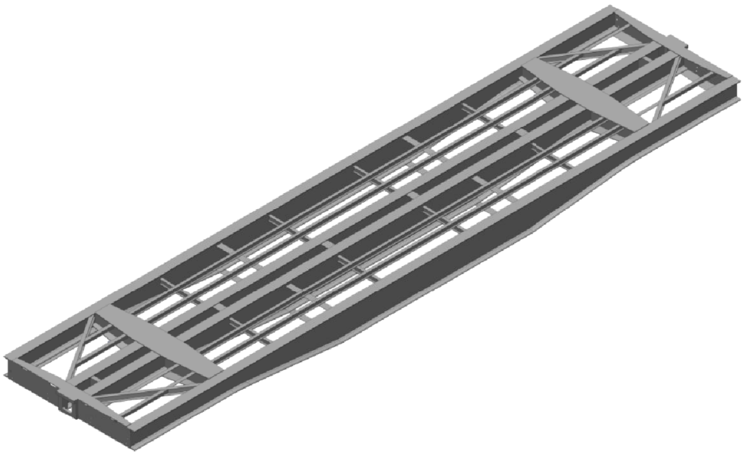


Figure 2.4. A spacial model of the load-bearing structure of flat wagon

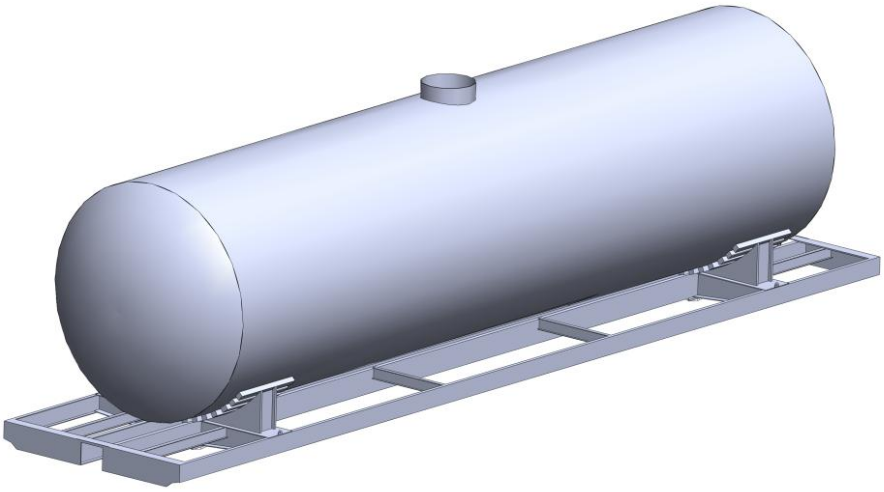


Figure 2.5. A spacial model of the load-bearing structure of tank wagon

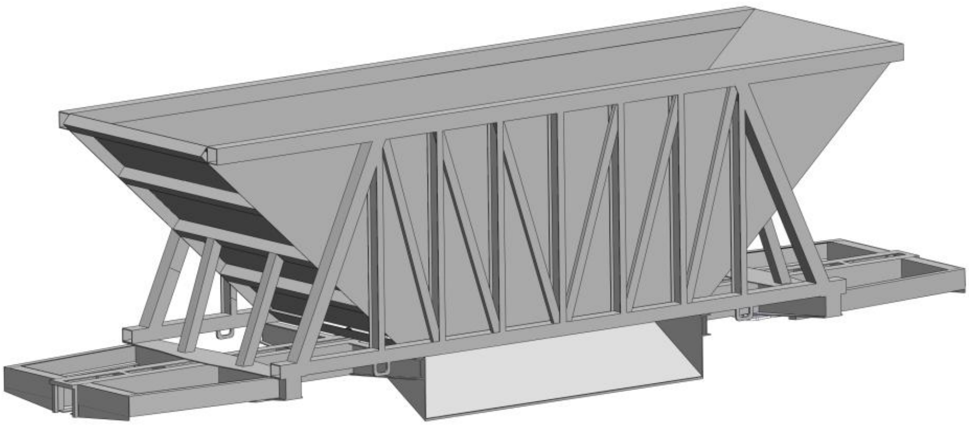


Figure 2.6. A spacial model of the load-bearing structure of hopper wagon

Inertial coefficients of load-bearing structures of the considered types of wagons are listed in Table 2.2.

Table 2.2

Inertial coefficients of load-bearing structures of wagons

The type of wagon	*Weight, t*	*The moment of inersion, $t \cdot m^2$*
Gondola wagon	15,6	283,1
Covered wagon	15,3	320,8
Flat wagon	11,5	105,6
Tank wagon	14,9	223,9
Hopper wagon	15,6	242,3

The basic performance variables of dynamics of the considered wagon types are obtained on the basis of the calculations. The results of the calculation are given below.

The acceleration that affects the load-bearing structure of the gondola in the center of mass is shown in Figure 2.7, and the acceleration at the points of support on the carriages is shown in Figure 2.8.

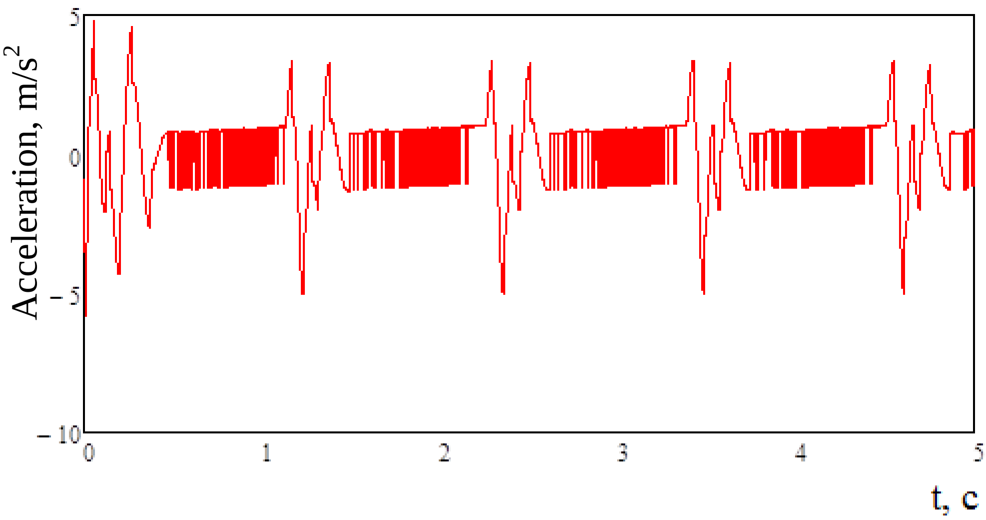


Figure 2.7. Acceleration of the load-bearing structure of the gondola in the center of weight

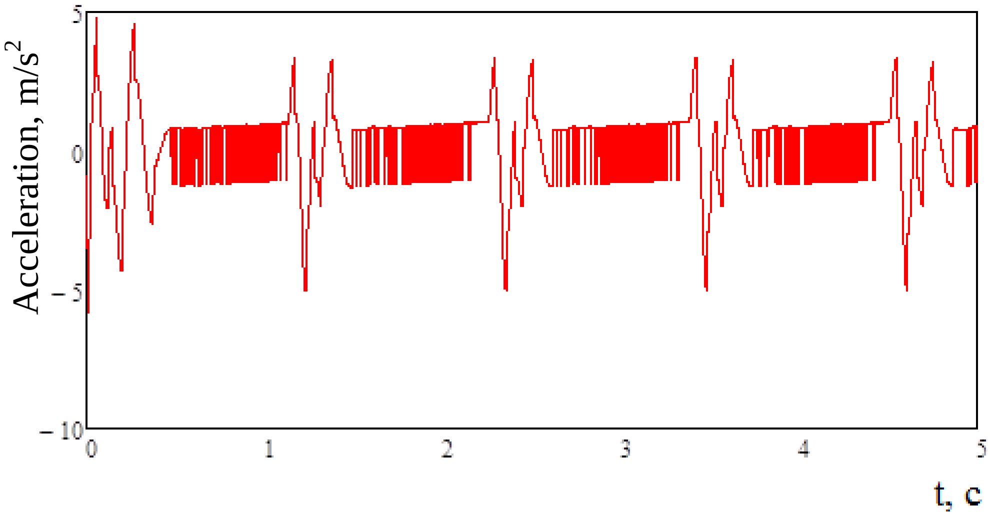


Figure 2.8. The acceleration of the load-bearing structure of the gondola wagon at the points of support on the carriages

According to the mathematical model (2.1) – (2.6), other performance variables of the gondola dynamics are determined (Table 2.3). The calculation was performed at a wagon speed of 80 km / h.

Table 2.3

Dynamic performance variables of a gondola moving wagon in an empty state

Parameter	*Value*
Body acceleration, m/s^2	4,1
Body acceleration in the area of leaning on the first carriage facing the engine, m/s^2	5,96
Body acceleration in the area of leaning on the second carriage facing the engine, m/s^2	5,97

Parameter	*Value*
Force in a spring suspension of the first carriage, kN	44,6
Force in a spring suspension of the second carriage, kN	44,6
Dynamics coefficient of the first carriage	0,57
Dynamics coefficient of the second carriage	0,57

Accoding to the results we can conclude that the dynamics performance variables are within acceptable limits. The operation of the wagon is assessed as «excellent» [13, 14].

The acceleration affecting the load-bearing structure of the covered wagon in the center of mass is shown in Figure 2.9, and the acceleration at the points of leaning on the carriages is shown in Figure 2.10.

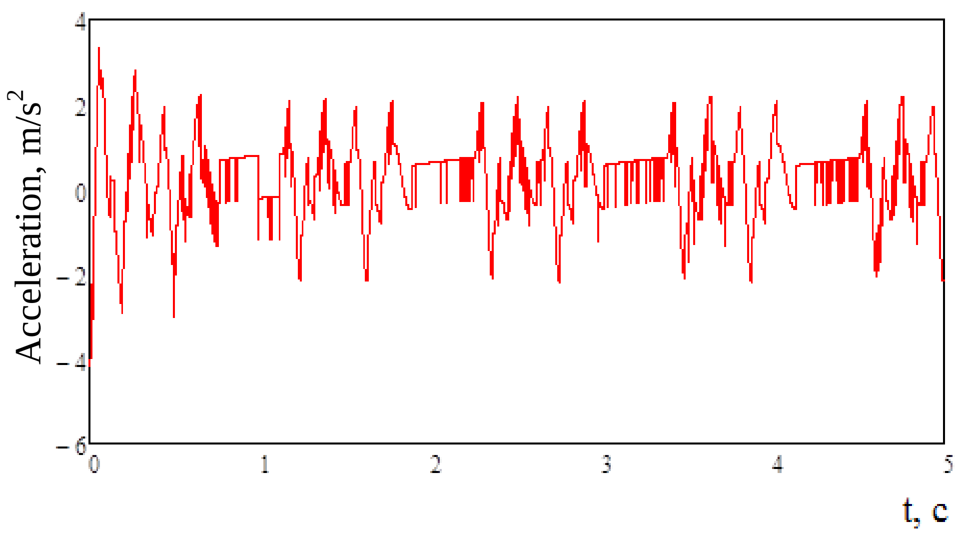


Figure 2.9. The acceleration of the load-bearing structure of a covered wagon in the center of mass

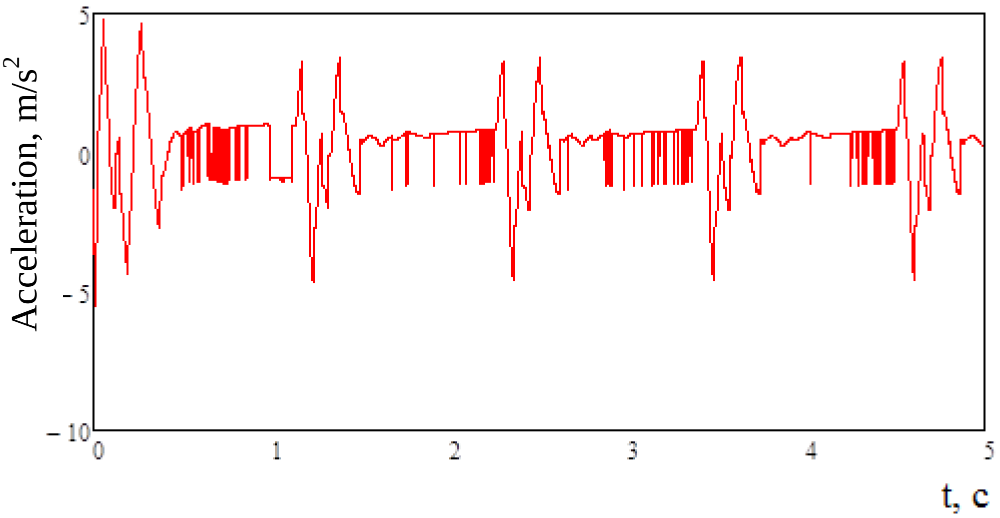


Figure 2.10. The acceleration of the load-bearing structure of a covered wagon at the points of support on the carriages

Other performance variables of dynamics of the covered wagon are defined according to the mathematical model (2.1) – (2.6) (Table 2.4).

Table 2.4

Dynamic performance variables of a covered wagon moving in an empty state

Parameter	*Value*
Body acceleration, m/s^2	4,18
Body acceleration in the area of leaning on the first carriage facing the engine, m/s^2	5,51
Body acceleration in the area of leaning on the second carriage facing the engine, m/s^2	5,51
Force in a spring suspension of the first carriage, kN	44,3

Parameter	*Value*
Force in a spring suspension of the second carriage, kN	44,3
Dynamics coefficient of the first carriage	0,58
Dynamics coefficient of the second carriage	0,58

The obtained results allow us to conclude that the dynamics performance variables are within acceptable limits. The operation of the wagon is assessed as «excellent» [13, 14].

The acceleration acting on the load-bearing structure of the flat wagon in the center of mass is shown in Figure 2.11, and the acceleration at the points of leaning on the carriages is shown in Figure 2.12.

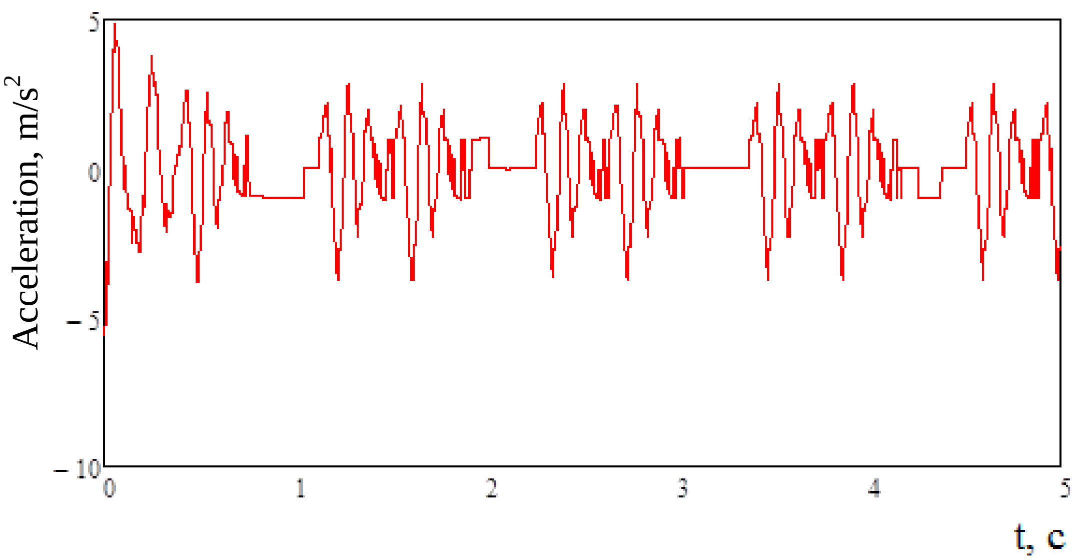


Figure 2.11. The acceleration of the load-bearing structure of a flat wagon in the center of mass

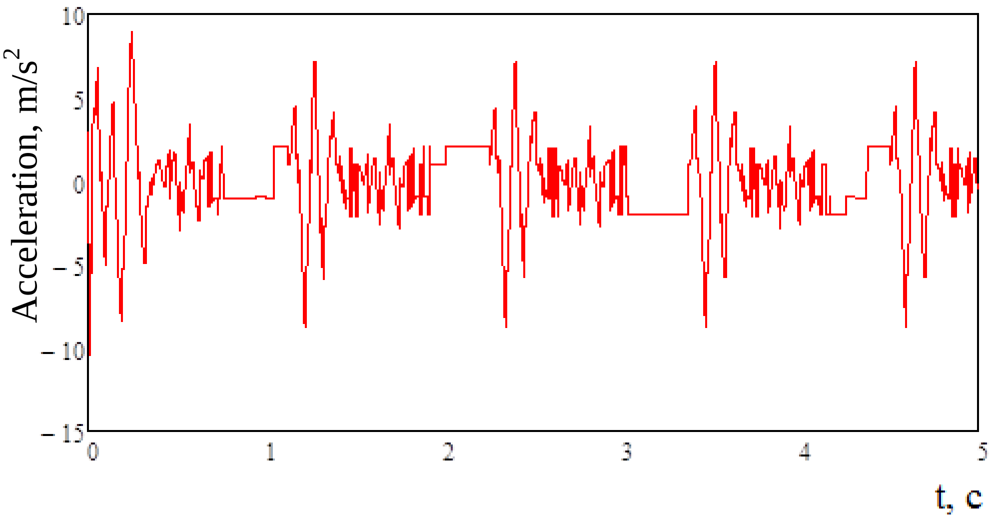


Figure 2.12. The acceleration of the load-bearing structure of a flat wagon at the points of support on the carriages

Other performance variables of the dynamics of the flat wagon are determined according to the mathematical model (2.1) – (2.6) (Table 2.5).

Table 2.5

Dynamic performance variables of a flat wagon moving in an empty state

Parameter	*Value*
Body acceleration, m/s^2	5,57
Body acceleration in the area of leaning on the first carriage facing the engine, m/s^2	10,4
Body acceleration in the area of leaning on the second carriage facing the engine, m/s^2	10,4
Force in a spring suspension of the first carriage, kN	42,7

Parameter	*Value*
Force in a spring suspension of the second carriage, kN	42,7
Dynamics coefficient of the first carriage	0,74
Dynamics coefficient of the second carriage	0,74

The obtained results allow us to conclude that the dynamics performance variables are within acceptable limits. The operation of the wagon is assessed as «excellent» [13, 14].

The acceleration acting on the load-bearing structure of the hopper wagon in the center of mass is shown in Figure 2.13, and the acceleration at the points of leaning on the carriages is shown in Figure 2.14.

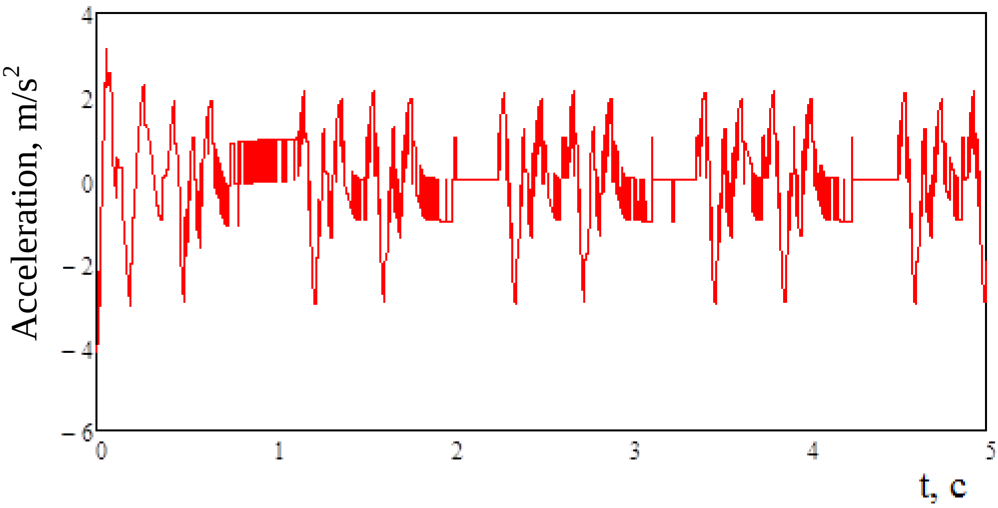


Figure 2.13. The acceleration of the load-bearing structure of a hopper wagon in the center of mass

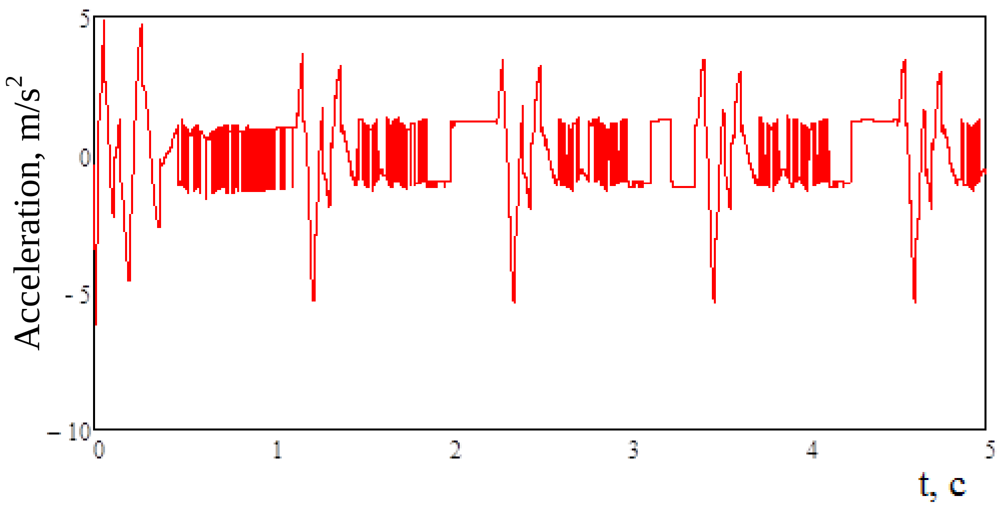


Figure 2.14. The acceleration of the load-bearing structure of a hopper wagon at the points of support on the carriages

According to the mathematical model (2.1) – (2.6) other performance variables of hopper wagon dynamics are determined (Table 2.6).

Table 2.6

Dynamic performance variables of a hopper wagon moving in an empty state

Parameter	*Value*
Body acceleration, m/s^2	4,1
Body acceleration in the area of leaning on the first carriage facing the engine, m/s^2	6,2
Body acceleration in the area of leaning on the second carriage facing the engine, m/s^2	6,2
Force in a spring suspension of the first carriage, kN	44,6

Parameter	*Value*
Force in a spring suspension of the second carriage, kN	44,6
Dynamics coefficient of the first carriage	0,57
Dynamics coefficient of the second carriage	0,57

The obtained results allow us to conclude that the dynamics performance variables are within acceptable limits. The operation of the wagon is assessed as «excellent» [13, 14].

The acceleration that affects the load-bearing structure of the tank wagon in the center of mass is shown in Figure 2.15, and the acceleration at the points of leaning on the carriages is shown in Figure 2.16.

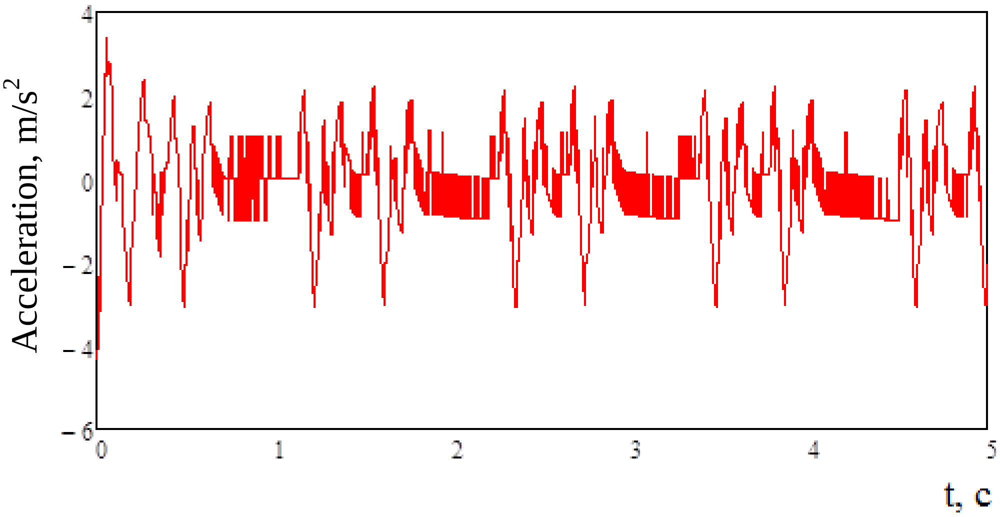


Figure 2.15. The acceleration of the load-bearing structure of the tank wagon in the center of mass

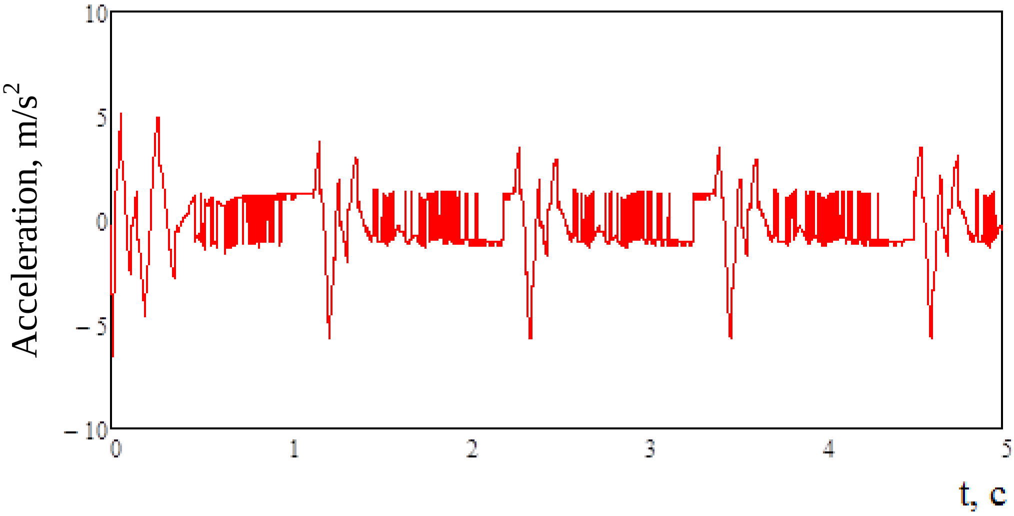


Figure 2.16. The acceleration at the points at the points of support on the carriages

According to the mathematical model (2.1) – (2.6), other performance variables of the dynamics of the tank wagon are determined (Table 2.6).

Table 2.6

Dynamic performance variables of a tank wagon moving in an empty state

Parameter	*Value*
Body acceleration, m/s^2	4,3
Body acceleration in the area of leaning on the first carriage facing the engine, m/s^2	6,5
Body acceleration in the area of leaning on the second carriage facing the engine, m/s^2	6,5
Force in a spring suspension of the first carriage, kN	44,2
Force in a spring suspension of the second carriage, kN	44,3

Parameter	*Value*
Dynamics coefficient of the first carriage	0,59
Dynamics coefficient of the second carriage	0,59

The obtained results allow us to conclude that the dynamics performance variables are within acceptable limits. The operation of the wagon is assessed as «excellent» [13, 14].

2.2. Calculation of dynamic loading of load-bearing structures of freight wagons in the longitudinal plane

To determine the dynamic loads acting on the load-bearing structures of wagons under the action of longitudinal force on the load-bearing structures (shunting collision), the mathematical model given in [15] was used. This model is designed to determine the acceleration as a component of the dynamic load acting on the flat wagon with tank-containers during shunting collisions. Therefore, it has been modified to determine the acceleration as a component of the dynamic load exerted upon the wagon under the action of the longitudinal impact force. The calculation model of the wagon is shown in Figure 2.17.

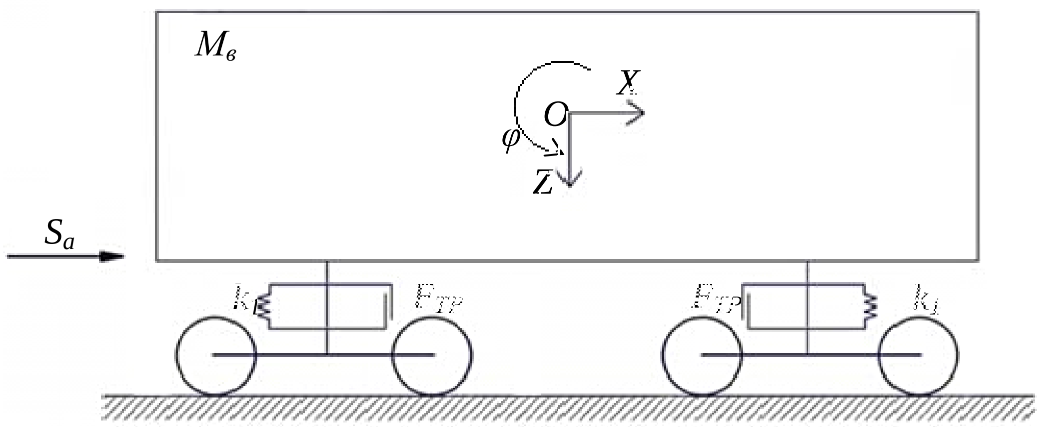


Figure 2.17. The calculation model of the wagon

$$M'_B \cdot \ddot{x}_B + M' \cdot \ddot{\varphi}_B = S_a, \tag{2.7}$$

$$I_B \cdot \ddot{\varphi}_B + M' \cdot \ddot{x}_B - g \cdot \varphi_B \cdot M' == l \cdot F_{TP}\left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2\right) + l\left(C_1 - C_2\right), \tag{2.8}$$

$$M_B \cdot \ddot{z}_B = C_1 + C_2 - F_{TP}\left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2\right), \quad (2.9)$$

де

$$M'_B = M_B + 2 \cdot m_T + \frac{n \cdot I_{КП}}{r^2};\ M' = M_B \cdot h;\ C_1 = k_1 \cdot \Delta_1;\ C_2 = k_2 \cdot \Delta_2;$$

$$\Delta_1 = z_B - l \cdot \varphi_B;\ \Delta_2 = z_B + l \cdot \varphi_B$$

M_B – weight of the load-bearing structure of the wagon; I_B – the moment of inertia of the wagon relative to the longitudinal axis; S_a – the magnitude of the longitudinal force of impact on the automatic coupling; m_T – weight of the carriage; $I_{КП}$ – moment of inertia of the wheel pair; r – the radius of the average worn wheel; n – the number of axles of the carriage; l – half of the base of the wagon; $F_{тр}$ – the absolute value of the dry friction force in the spring set; k_1, k_2 – rigidity of springs of spring suspension of carriages of the wagon; x_B, φ_B, z_B – coordinates corresponding, respectively, to the longitudinal, angular around the transverse axis and the vertical movement of the wagon.

Differential equations are solved in the MathCad software environment. In this case, they were reduced to the standard form of Cauchy, and then integrated using the Runge-Kutta method [11, 12].

The initial displacements and speed are set to zero. The input parameters of the mathematical model include the technical characteristics of the load-bearing structures of wagons, the parameters of the spring suspension, as well as the value of the force of the longitudinal impact in the automatic coupling. The parameters of the spring suspension, which were taken into account in the calculations, are considered equal to those that are characteristic of freight carriage of 18-100 model. The longitudinal impact force acting on the vertical surface of the rear druft lungs of the automatic coupling is assumed to be 3.5 MN [13, 14]. The value of the longitudinal force in the calculations is taken to be equal to 2.5 MN for the tank wagon. Inertia coefficients of load-bearing structures of the considered types of wagons are given in Table 2.7.

Table 2.7

Inertia coefficients of load-bearing structures of the considered types of wagons.

The type of wagon	*Gross weight of wagon, t*	*The mass of the load-bearing structure, t*	*The point of inertia, t·m^2*
A gondola wagon	94,0	84,6	1286,3
A covered wagon	92,7	83,3	1246,4
A flat wagon	90,9	81,5	1116,7
A tank wagon	93,0	83,6	1118,3
A hopper wagon	94,0	84,6	1255,1

On the basis of calculations the basic parameters of dynamics of the abovementioned types of wagons are received. The results of the calculation are presented in Table 2.8, as well as illustrated in Figure 2.19.

Table 2.8

The accelerations acting on load-bearing structures of wagons

The type of wagon	*Acceleration, m/c^2*
A gondola wagon	37,42
A covered wagon	37,95
A flat wagon	38,7
A tank wagon	26,65
A hopper wagon	37,45

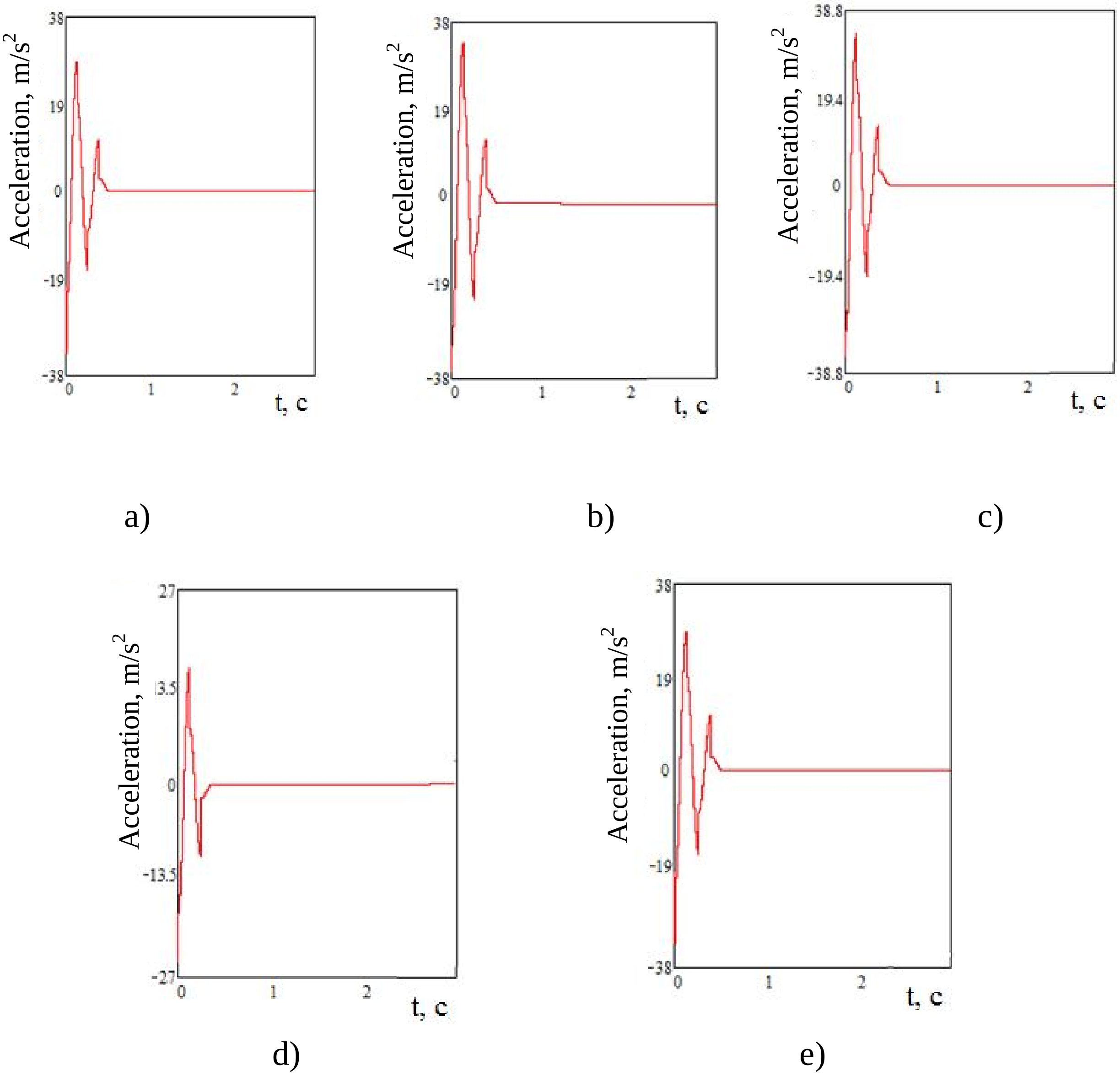


Figure 2.19. The accelerations acting on load-bearing structures of wagons

a) a gondola wagon; b) a covered wagon; c) a flat wagon; d) a tank wagon; e) a hopper wagon

Therefore, the maximum accelerations acting on the load-bearing structures at their longitudinal load are about 0.4 g, the maximum acceleration for a tank wagon under the action of a longitudinal load of 2.5 MN was approximately 0.27 g.

CONCLUSIONS TO CHAPTER 2

1. The dynamic loading of load-bearing structures of freight wagons with nominal dimensions in the vertical plane has been determined. The calculation was performed under the condition of the movement of empty wagons on the junctural surface. The main performance variables of wagon dynamics are obtained: body acceleration, body acceleration in the zone of leaning on carriages, forces in spring suspension of carriages, coefficient of dynamics. The operation of the wagon is assessed as «excellent».

2. The dynamic loading of load-bearing structures of freight wagons with nominal dimensions in the longitudinal plane is determined. It is taken into account that the longitudinal impact force acting on the vertical surface of the rear druft lungs of the autocoupling is equal to 3.5 MN. The value of the longitudinal force for the tank wagon in the calculations is considered to be 2.5 MN.

It has been established that the maximum acceleration acting on the load-bearing structures at their longitudinal load is about 0.4 g, the maximum acceleration for a tank wagon under the action of a longitudinal load of 2.5 MN was about 0.27 g.

3. RESEARCH OF TYPICAL DESIGNS DURABILITY OF DOMESTIC PARK FREIGHT WAGONS WITH NOMINAL PARAMETERS AT OPERATIONAL (STANDARDIZED AND EXCESSIVE) LOADINGS

3.1. Research of typical designs durability of gondolas with nominal parameters at operational loadings

Increased rates of cargo transportation through the territory of Ukraine, which is part of the most important transport arteries between Europe and Asia, necessitate the introduction of new designs of wagons with improved technical and operational parameters. A gondola wagon is known to be one of the most popular types of wagons in operation [16–18].

For this purpose a spacial model of the body of the 12-757 model gondola wagon produced by Kriukivskyi Rail Wagon Manufacturing Plant public joint-stock company (Figure 3.1) has been constructed.

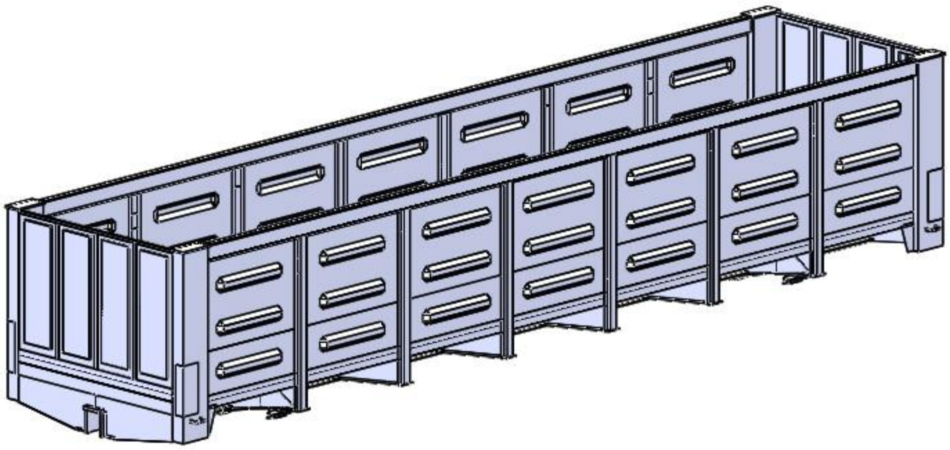


Figure 3.1. A special model of 12-757 model gondola wagon

The numerical values of the forces acting on the gondola wagon in operation are presented in Tables 3.1 and 3.2. It is taken into account that the full load capacity of the wagon is used. Coal is accepted as flowable cargo, as this type of cargo is the most common for transportation through the territory of Ukraine.

Table 3.1

The numerical values of the forces acting on the 12-757 model gondola wagon in operation

The type of force	*I r. c.*	*III r. c.*
Vertical static, kN	829,926	829,926
Vertical dynamic, kN		99,59
Centrifugal, kN		156,35
Frame, kN		202,94
Wind, kN		17,1

Table 3.2

The values of longitudinal forces affecting a flat wagon in operation

The value of longitudinal force, MN			
Rating conditions			
I		*III*	
Quasi-static force	*Impact, jerk*	*Quasistatic reaction*	*Impact, jerk*
–3,0 +2,5	–3,5 +2,5	–1,0 +1,0	–1,0 +1,0

The force of expansion of the flowable freight on the side walls and end-type doors of the gondola wagon body, determined by the method described in [3]. According to this technique, it is assumed that the load of the flowable load on the side walls of the wagon body is distributed according to the law of the triangle with a maximum at its base, and it is distributed on the end according to the law of trapezoid. The maximum loads at the bases of the side wall posts are determined by:

$$q_1 = 0{,}5 \cdot p_a \cdot l_1,$$

$$q_2 = 0{,}5 \cdot p_a \cdot (l_1 + l_2), \qquad (3.1.)$$

$$q_3 = 0{,}5 \cdot p_a \cdot (l_2 + l_3),$$

$$q_4 = 0{,}5 \cdot p_a \cdot (l_3 + l_4),$$

where p_a – active (static) pressure of the expansion of the flowable cargo per unit of the area of the vertical wall at the floor level, kPa;

l_1 – distance from the end beam of the frame to the geometric axis of the central plate of the carriage, m;

l_2 – distance from the geometric axis of the central plate of the wagon to the second vertical stay of the body, m;

l_3 – distance from the second body vertical stay to the third, m;

l_4 – distance from the third body vertical stay to the vertical geometric axis of the wagon body, m.

The active pressure of the bulk cargo is determined by the formula:

$$p_a = \gamma \cdot g \cdot H \cdot tg^2\left(\frac{\pi}{4} - \frac{\varphi}{2}\right), \tag{3.2.}$$

where γ – flowable freight density, t/m^3;

H – the height of the side wall, m;

φ – angle of natural slope of the cargo, rad;

g – the acceleration of free fall, m / s.

Taking into account the characteristics of coal, the active pressure of the flowable cargo on the side wall of the wagon body was:

$$P_a^I = 0{,}9 \cdot 9{,}81 \cdot 2{,}315 \cdot tg^2\left(\frac{\pi}{4} - \frac{0{,}52}{2}\right) = 6{,}86 \text{ kN/m}^2;$$

$$P_a^{III} = 0{,}9 \cdot 9{,}81 \cdot (1 + 0{,}12) \cdot 2{,}315 \cdot tg^2\left(\frac{\pi}{4}\right) = 22{,}86 \text{ kN/m}^2$$

The calculated values of the expansion forces of the flowable freight on the side walls of the gondola wagon body are shown in Table 3.3.

Table 3.3

Numerical value of the flowable freight pressure on the elements of the gondola wagon body side wall

Side wall vertical stay	*Flowable freight pressure, KPa*
side:	
I r. c.	7,083
III r. c.	23,6
the first vertical stay from the side of the stub end:	
I r. c.	13,03
III r. c.	43,42
the second vertical stay from the side of the stub end:	
I r. c.	11,895
III r. c.	39,64
the third vertical stay from the side of the stub end:	
I r. c.	8,92
III r. c.	29,73

The pressure of the unevenly distributed freight, which is applied to the door leaf of the end door is determined by the formula:

$$p = p_a + p_n, \qquad (3.3.)$$

where p_n is the passive pressure of the flowable cargo, which is determined by formula (3.1), in which the square of the tangent of the difference of the two angles is replaced by the square of the tangent of their sum and taking into account the coefficient of vertical dynamics and the angle of natural slope.

$$P_n^{I} = 0,9 \cdot 9,81 \cdot 2,315 \cdot tg^2\left(\frac{\pi}{4} + \frac{0,52}{2}\right) = 60,7 \text{ kN/m}^2;$$

$$P_n^{III} = 0,9 \cdot 9,81 \cdot 2,315 \cdot tg^2\left(\frac{\pi}{4}\right) = 24,9 \text{ kN/m}^2$$

The intensity of the trapezoidal load on the corner vertical stay is determined by:

$$q_{T1}^{н} = 0,5(p_a + p_n) \cdot b_1;$$

$$q_{T1}^{в} = 0,5 \cdot p_n \cdot b_1;$$

on the intermediate vertical stay:

$$q_{T2}^{н} = 0,5(p_a + p_n) \cdot (b_1 + b_2);$$

$$q_{T2}^{в} = 0,5 \cdot p_n \cdot (b_1 + b_2);$$

on the middle vertical stay:

$$q_{T3}^{н} = 0,5(p_a + p_n) \cdot b_2;$$

$$q_{T3}^{в} = 0,5 \cdot p_n \cdot b_2$$

The calculated values of the expansion forces of the flowable freight on the end wall of the gondola wagon body are given in Table 3.4.

Table 3.4

Numerical value of the flowable freight expansion pressure on the elements of the gondola wagon body gangway door

Gangway door element	*Flowable freight pressure, kPa*
corner vertical stay	
I r. c.	50,06*
	44,98**
III r. c.	35,39* 18,45**
intermediate vetical stay:	
I r. c.	100,12*
	89,96**
III r. c.	70,78*
	36,9**
middle vertical stay:	
I r. c.	50,06*
	44,98**
III r. c.	35,39*
	18,45**

In addition, the model takes into account the reactions in the central plates caused by the effect of the lateral and longitudinal forces on the load-bearing structure.

The calculation for the durability was performed using the finite element method [38–42] in the CosmosWorks software environment [19, 20].

* pressure on the lower part of the vertical stay;

** pressure on the upper part of the vertical stay.

Figure 3.2 shows the finite element model of the gondola wagon. The optimal number of grid elements was determined using the graphoanalytical method [21–23]. The number of grid elements was 473652, the number of nodes was 154365. The maximum size of the grid element is 80 mm, the minimum size of the grid element is 16 mm, the maximum ratio of the sides of the elements is 566.7, the percentage of elements with a ratio of less than three was 25, the percentage of elements with a ratio more than ten was 27.4.

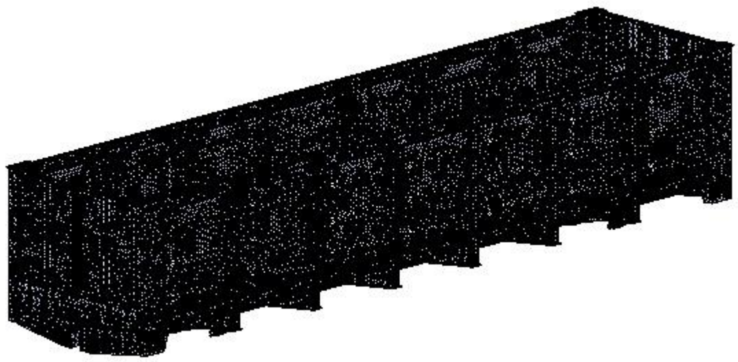


Figure 3.2. The finite element model of the gondola wagon of 12-757 model

The computer model of the durability of the load-bearing structure of the gondola wagon is shown in Figure 3.3.

The model is limited by the lack of difference in the levels of the bodies of automatic couplings of gondola wagons that interact with each other. The model was fixed on the centre plates and slides of the pivot beams of the wagon load-bearing structure.

When studying the durability of the gondola wagon under load, which corresponds to the impact-compression mode the longitudinal force was applied to the rear stop of the automatic couplings, and fixing was perfomed to the same element of the gondola wagon automatic coupling equipment from the other side of the gondola wagon. When modeling the durability of the gondola in the conditions of «tensile-jerk» mode, the longitudinal force was applied to the front stops from one end of the gondola wagon, and from the other was fixed to the front stops.

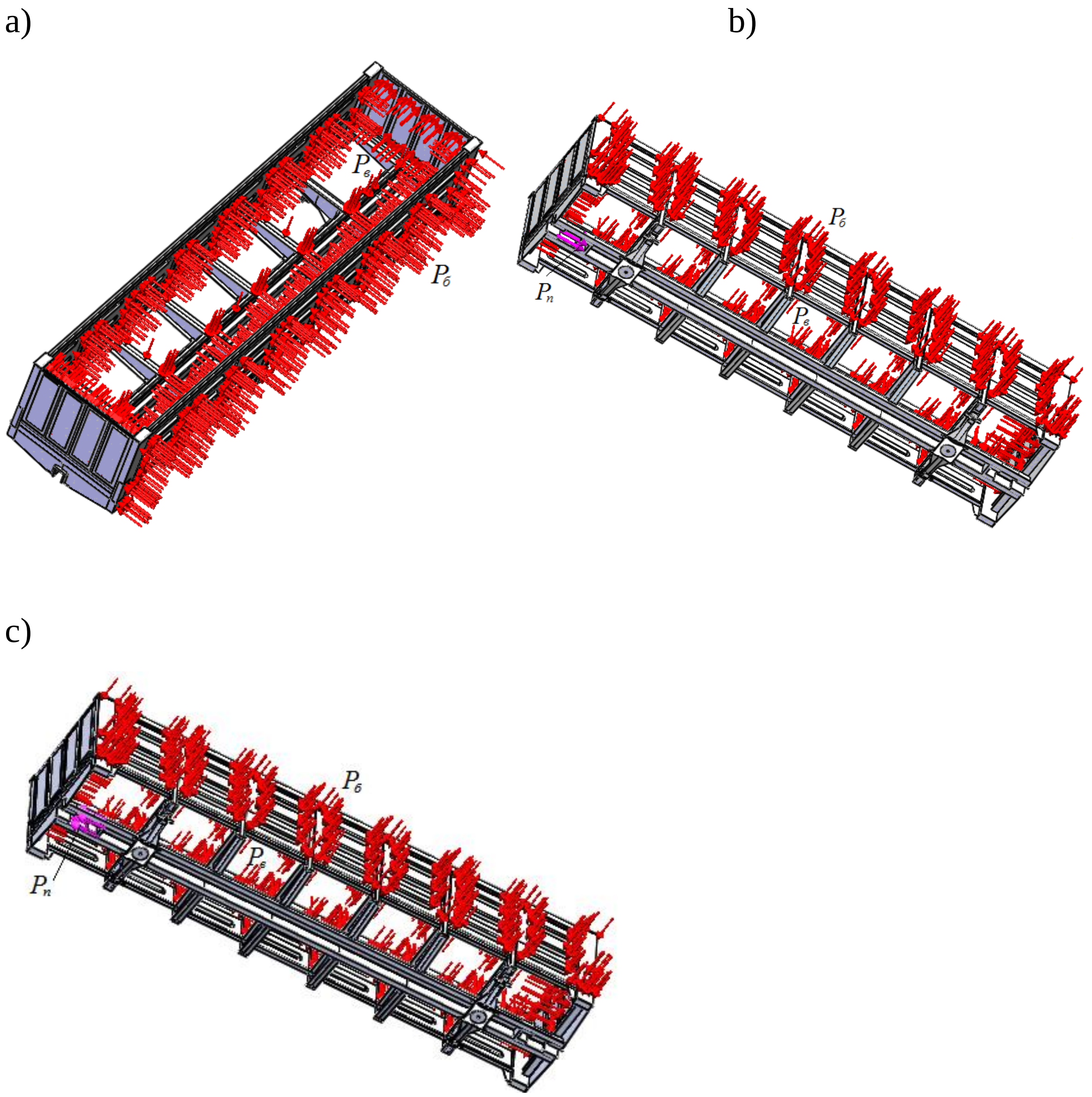


Figure 3.3. Computer model of the load-bearing structure durability of the 12-757 model gondola wagon

a) top view; b) view from below (blow, squeezing); c) bottom view (stretching, jerk)

$P_{в}$ – vertical load; $P_{б}$ – lateral load; $P_{п}$ – longitudinal load

The results of the calculation of the load-bearing structure durability of the gondola wagon in rating condition I (impact) are shown in Figure 3.4.

The maximum equivalent loades occur in the lower zone of interaction of the pivot beam with the spine beam, they are about 340 MPa, the maximum displacements in the nodes of the structure are recorded in the middle part of the gondola wagon frame and they are 3.6 mm, the maximum deformation was 2.73 · 10-3.

The results of the calculation of the load-bearing structure durability of the gondola wagon in rating condition I (jerk) are shown in Figure 3.5.

The maximum equivalent loades occur in the zone of interaction of the pivot beam with the spine beam and are about 310 MPa, the maximum displacements at the nodes of the structure are 3.62 mm, the maximum deformation was 2.97·10-3.

Figure 3.6 shows the results of the calculation of the load-bearing structure durability of the gondola wagon in rating condition I (compression).

The maximum equivalent loades are about 300 MPa, the maximum displacements at the nodes of the structure are 3.54 mm, the maximum deformation was 2.86 · 10-3.

The results of the calculation of the load-bearing structure durability of the gondola wagon at rating condition III (impact, compression) are shown in Figure 7. The vertical dynamic force acting on the body of the gondola wagon when moving relative to the rail track is taken into account in quasi-statics.

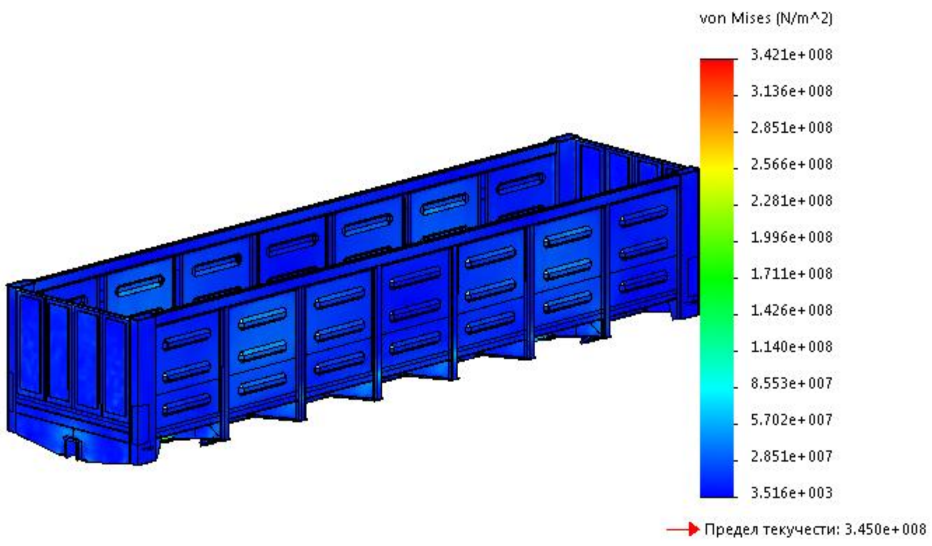
The maximum equivalent loades are about 250 MPa, the maximum displacements in the nodes of the structure are 11.2 mm, the maximum deformation was 4.86 · 10-3.

The results of the calculation of the load-bearing structure durability of the gondola wagon at rating condition III (jerk, tension) are shown in Figure 8.

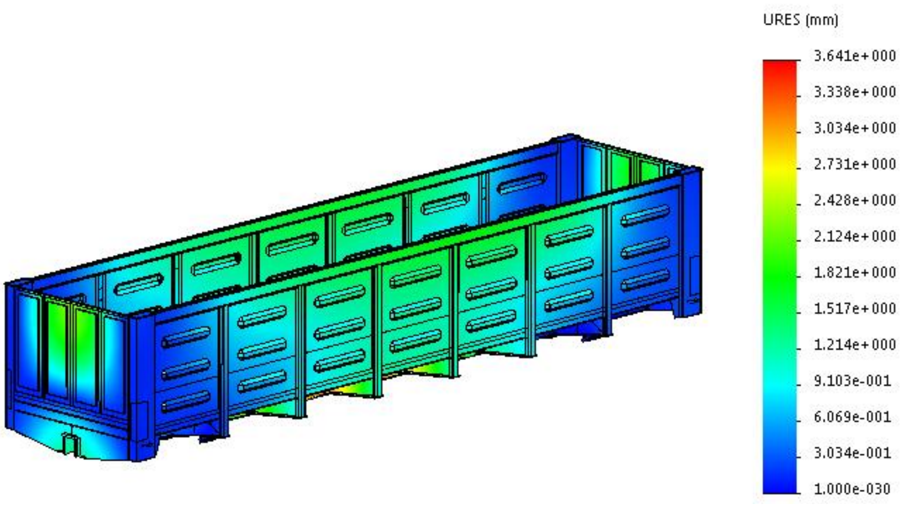
The maximum equivalent loades are about 260 MPa, the maximum displacements in the nodes of the structure are 11.4 mm, the maximum deformation was 4.8 · 10-3.

From the conducted researches it is possible to draw a conclusion that the maximum equivalent loades in a supporting strucсture of a gondola wagon arise at rating condition I in the conditions of blow. It is important to note that the maximum equivalent loades in the body components are less than the allowable ones and they have a significant margin of safety.

a)



b)



c)

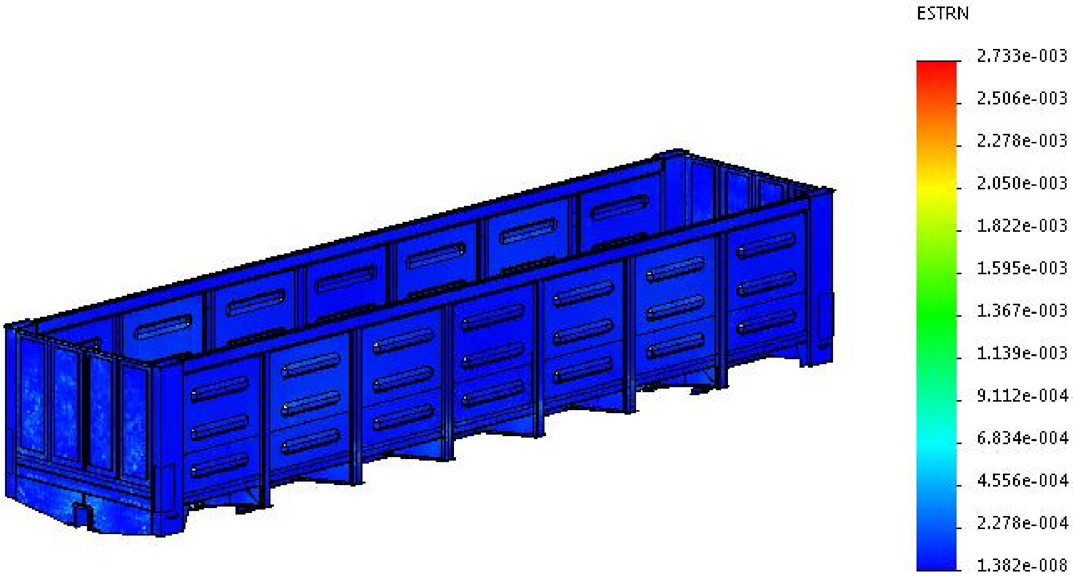
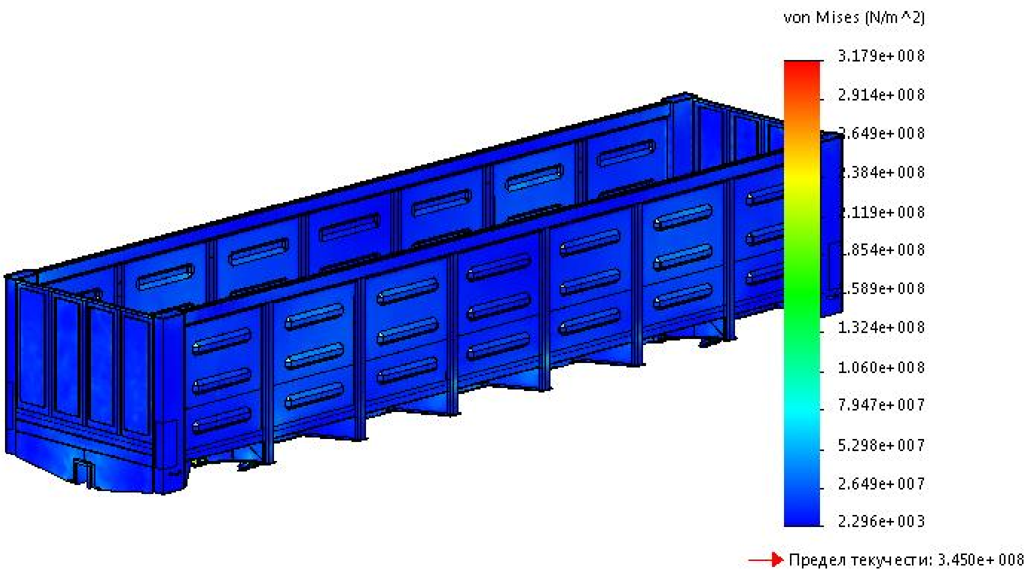


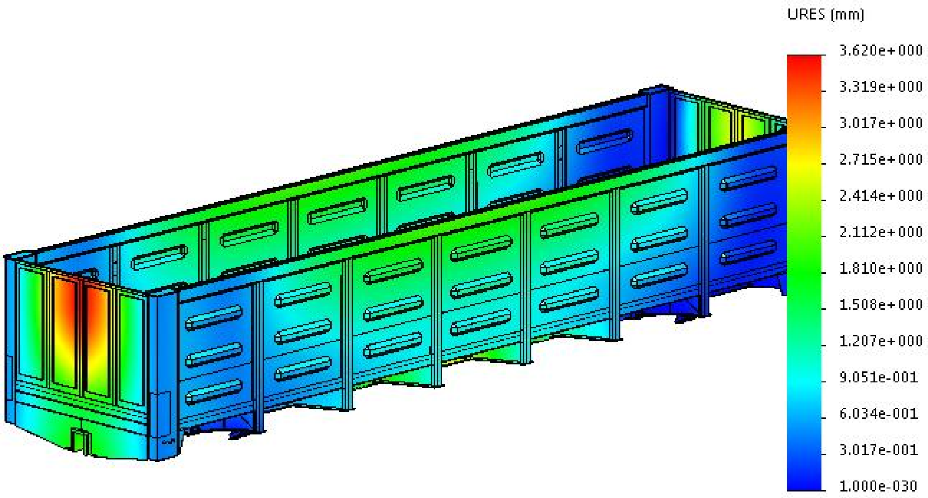
Figure 3.4. The results of the calculation of the load-bearing structure durability of the 12-757 model gondola wagon in rating condition I (impact)

a) load; b) movement in the nodes of the structure; c) deformation

a)



b)



c)

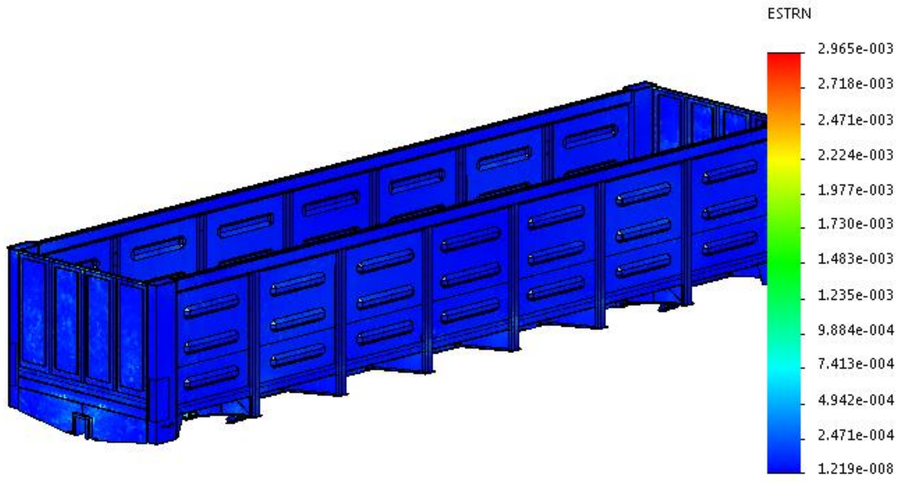
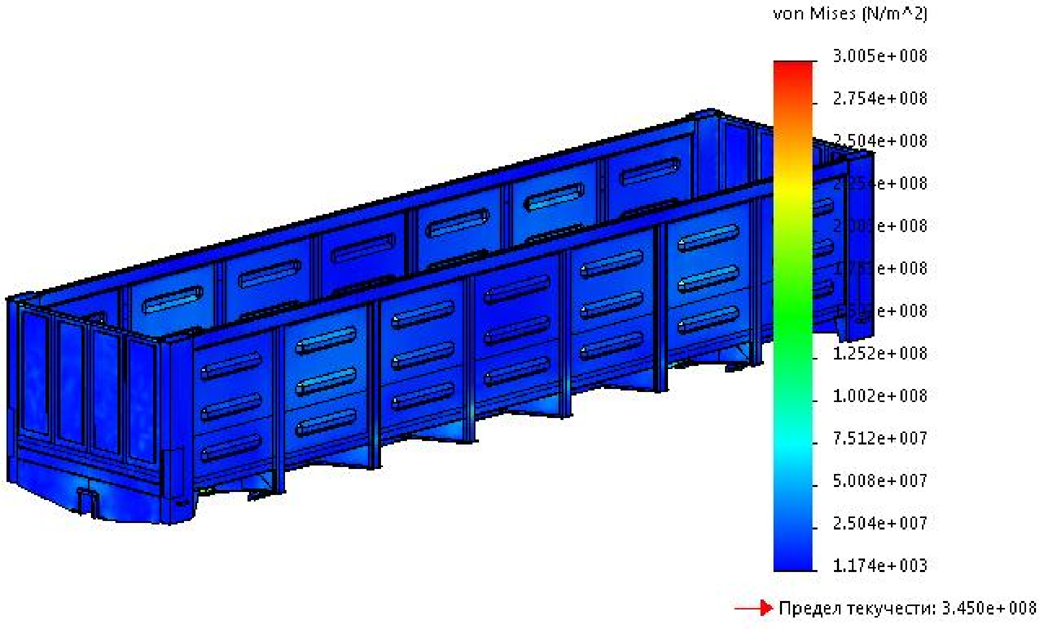


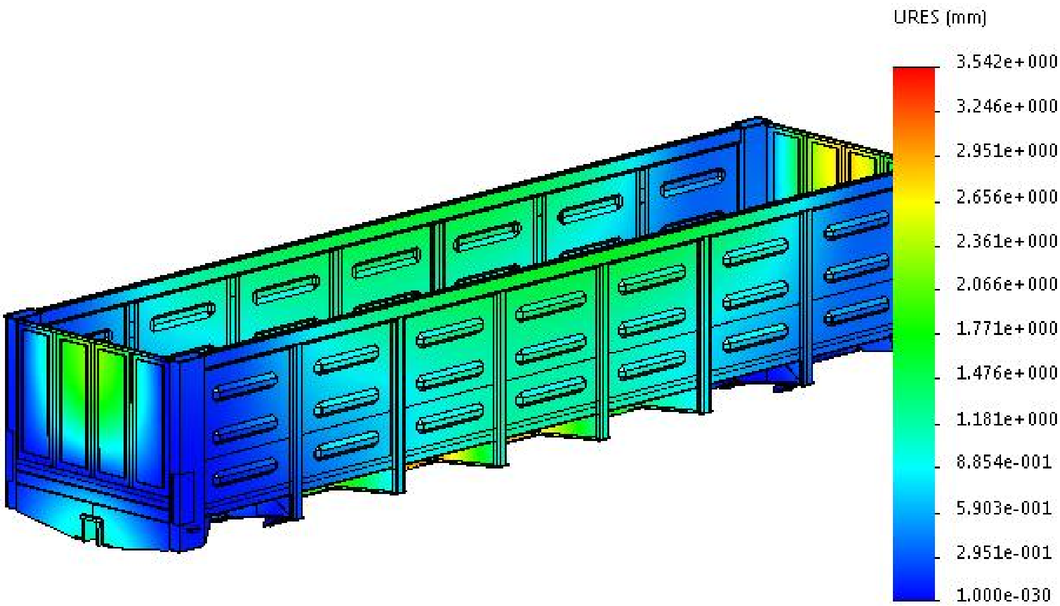
Figure 3.5. The results of the calculation of the load-bearing structure durability of the 12-757 model gondola wagon in rating condition I (jerk)

a) load; b) movement in the nodes of the structure; c) deformation

a)


von Mises (N/m^2)
3.005e+008
2.754e+008
2.504e+008
1.252e+008
1.002e+008
7.512e+007
5.008e+007
2.504e+007
1.174e+003
Предел текучести: 3.450e+008

b)


URES (mm)
3.542e+000
3.246e+000
2.951e+000
2.656e+000
2.361e+000
2.066e+000
1.771e+000
1.476e+000
1.181e+000
8.854e-001
5.903e-001
2.951e-001
1.000e-030

c)

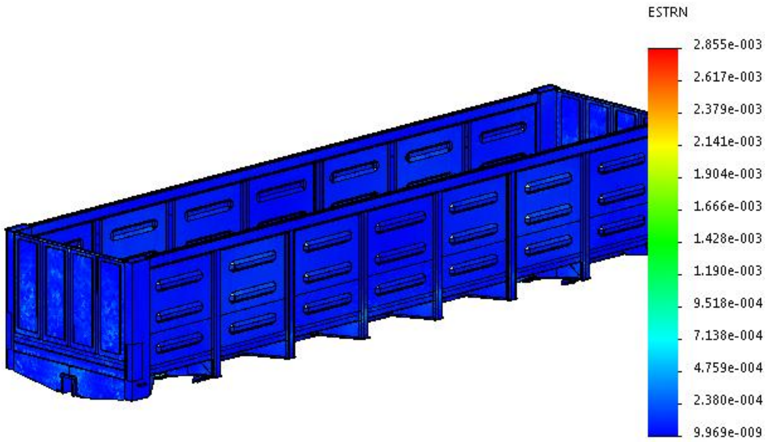
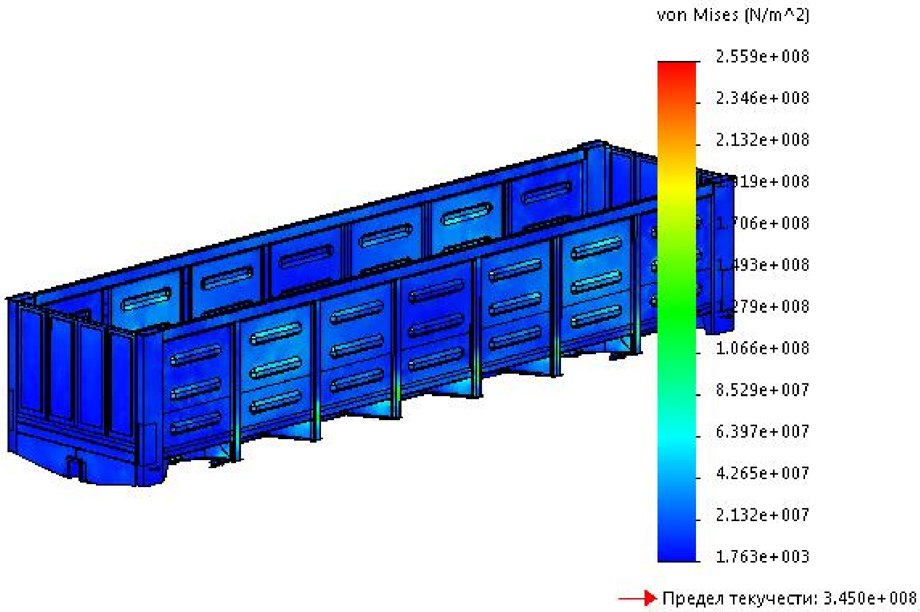


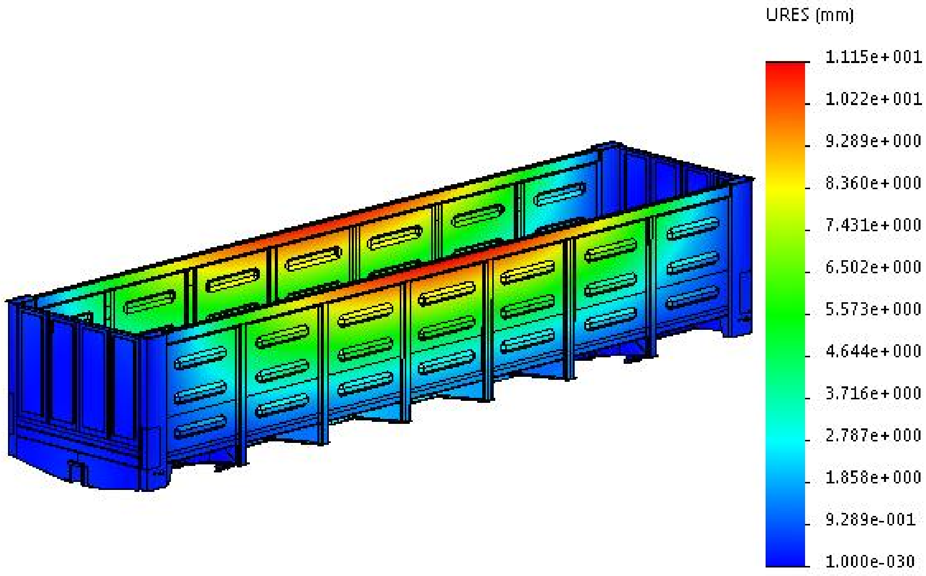
Figure 3.6. The results of the calculation of the load-bearing structure durability of the 12-757 model gondola wagon in rating condition I (compression)

a) load; b) movement in the nodes of the structure; c) deformation

a)



b)



c)

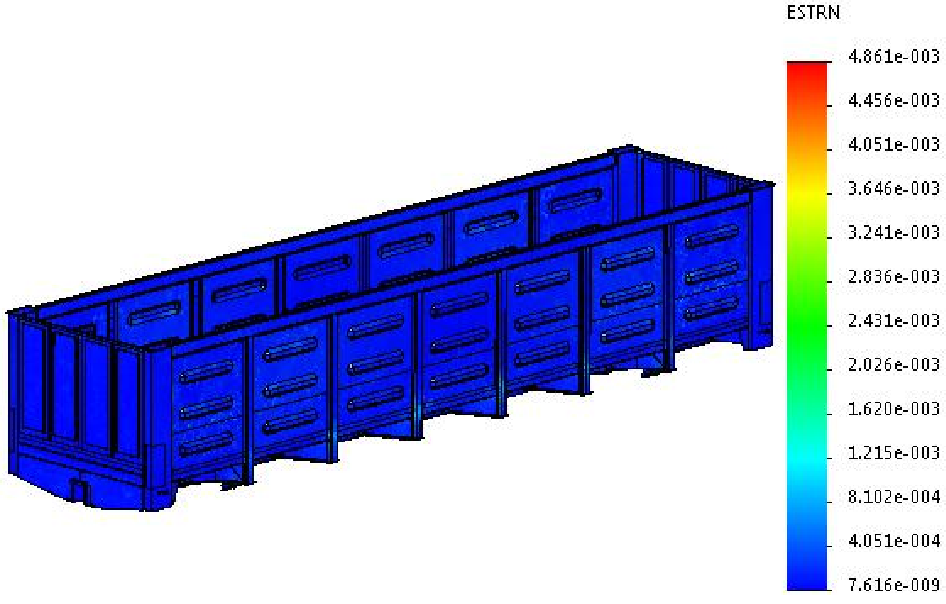
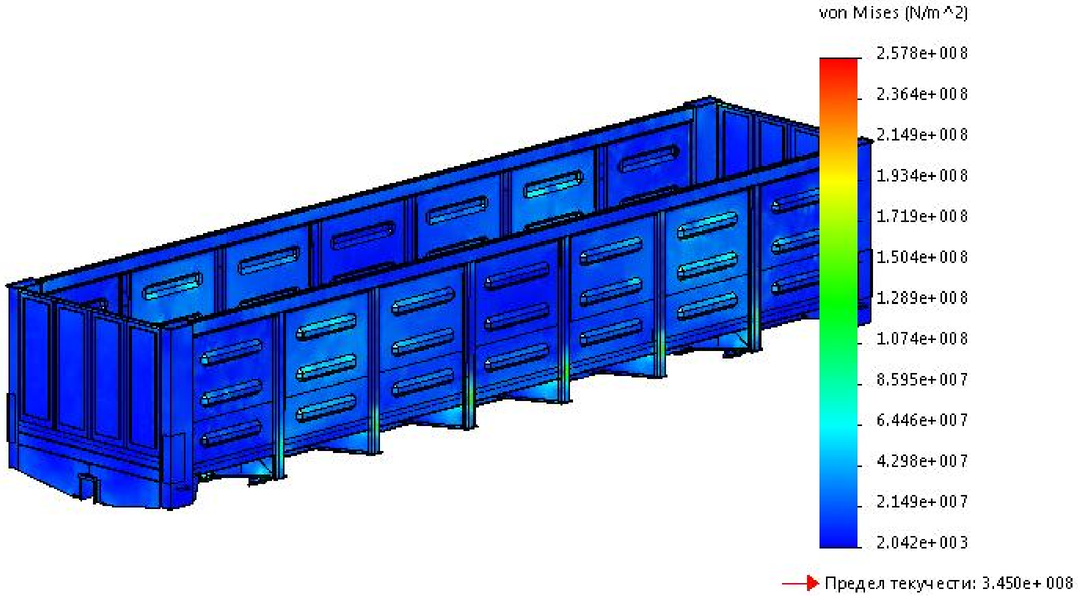


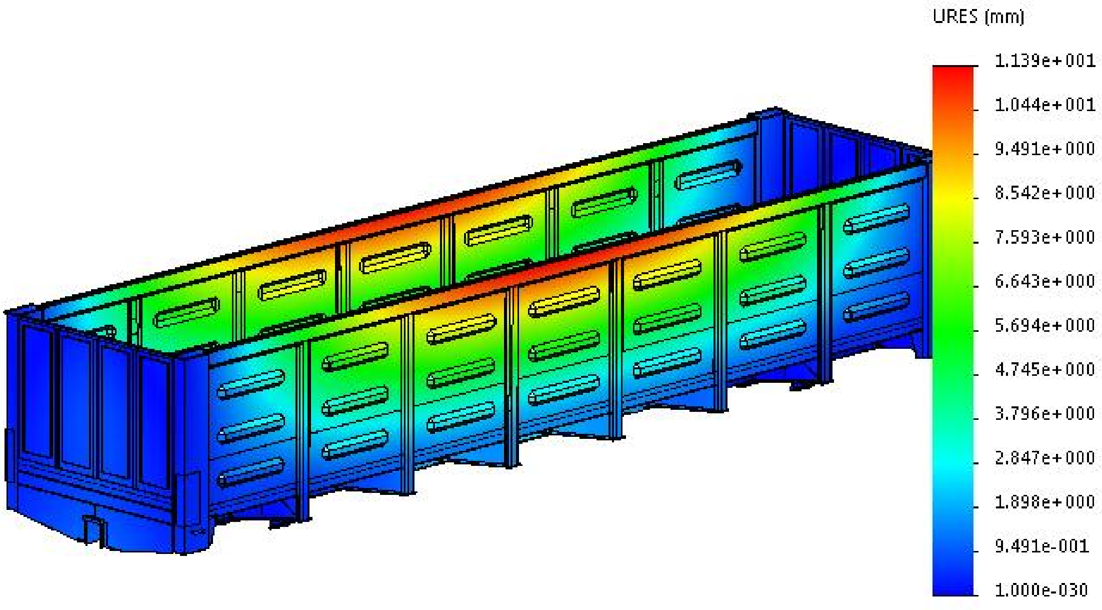
Figure 3.7. The results of the calculation of the load-bearing structure durability of the 12-757 model gondola wagon in rating condition I (impact, compression)

a) load; b) movement in the nodes of the structure; c) deformation

a)


von Mises (N/m^2)
2.578e+008
2.364e+008
2.149e+008
1.934e+008
1.719e+008
1.504e+008
1.289e+008
1.074e+008
8.595e+007
6.446e+007
4.298e+007
2.149e+007
2.042e+003
Предел текучести: 3.450e+008

b)


URES (mm)
1.139e+001
1.044e+001
9.491e+000
8.542e+000
7.593e+000
6.643e+000
5.694e+000
4.745e+000
3.796e+000
2.847e+000
1.898e+000
9.491e-001
1.000e-030

c)

Figure 3.8. The results of the calculation of the suppporting structure durability of the 12-757 model gondola wagon at rating condition III (jerk, tension)

a) load; b) movement in the nodes of the structure; c) deformation

3.2. Research of typical designs durability of covered wagons with nominal parameters at operational loadings

To study the loaded and deformed condition of the load-bearing structure of the of the 11-217 model covered wagon body (Altaivagon open joint-stock company), its spatial model was built in the SolidWorks software environment (Figure 3.9). The construction of the model takes into account the elements of the body, which interact rigidly with each other; it means that the model did not take into account the mobile self-sealing doors. This approach is used in the design of wagons in the conditions of Kriukivskyi Rail Wagon Manufacturing Plant public joint-stock company.

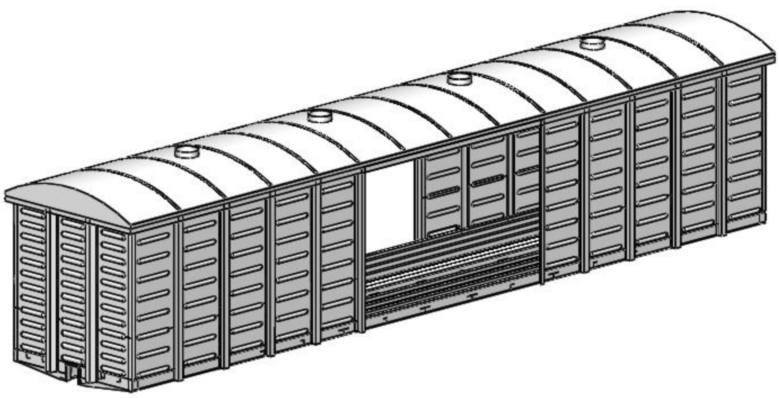


Figure 3.9. Spatial model of a 11-217 model covered wagon body

Numerical values of the forces acting on the covered wagon in operation are given in Table 3.5. It is taken into account that the full load capacity of the wagon is used. It is also taken into account that the struts of the wagon body are subjected to the forces of expansion of the flowable cargo, in the capacity of which grain is taken. The efforts of flowable freight pressure on the racks of the body of the covered wagon are calculated in accordance with the method given in 9962.01.000P2.

Table 3.5

Numerical values of the forces acting on the load-bearing structure of the 11-217 model covered wagon body in operation

Type of force	*I r. c.*	*III r. c.*
Vertical static, kN	810,306	810,306
Vertical dynamic, kN		
Centrifugal, kN		152,66
Wind, kN		13,75
Flowable freight presure, kN:		
Corner vertical stay	5,24	0,988
the first from the console vertical stay	4,99	0,941
the second-forth from the console vertical stay	4,74	0,895
door vertical stay	11,57	0,218

The durability calculation was performed using the finite element method in the CosmosWorks software environment.

The finite element model of the covered wagon body is shown in Figure 3.10. The optimal number of grid elements was determined using the graphoanalytical method [21–23]. The number of grid elements was 637520, the number of the nodes was 225092. The maximum size of the grid element is 100.0 mm, the minimum size of the grid element is 20.0 mm, the maximum ratio of the sides of the elements is 525.19, the percentage of elements with a ratio of less than three is 11.1, of more than ten – 46.7. The minimum number of elements in the circle is 22, the ratio of increasing the size of the element is 1.8, the coefficient of simplification of the model in the areas of rounding and holes is 0.4.

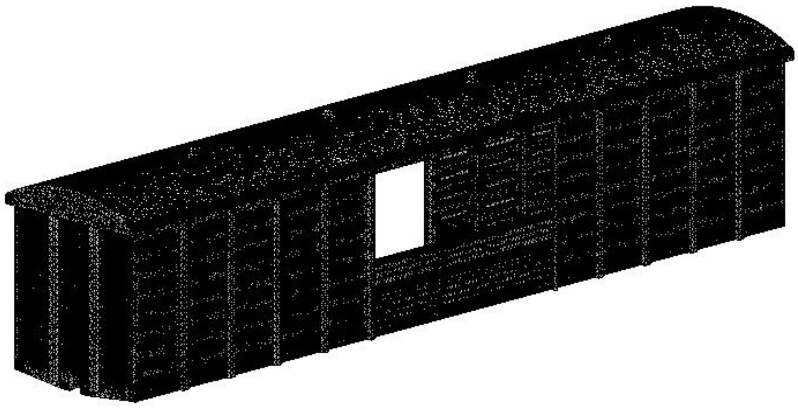


Figure 3.10. Finite element model of a 11-217 model covered wagon body

The computer model of the durability of the load-bearing structure of the covered wagon body in the conditions of rating condition I is shown in Figure 3.11.

The limitations of the model are the lack of difference in the levels of the bodies of autocouplings of wagons that interact with each other. Fastening of the model was wagonried out on center plates and slides of pivot beams of the bearing structure of the body.

When studying the durability of the body of a covered wagon under load, which corresponds to the impact-compression mode longitudinal force was applied to the rear stop of the hitch, and on the other side of the body fastening was performed to the same element of hitch. When modeling the durability of the body of a covered wagon in the mode of «tension-jerk» longitudinal force was applied to the front stops from one end of the wagon, and fixation was perfomed to the front stops from the other.

The results of the calculation of the durability of the load-bearing structure of the body of the covered wagon in rating condition I (impact) are shown in Figure 3.12.

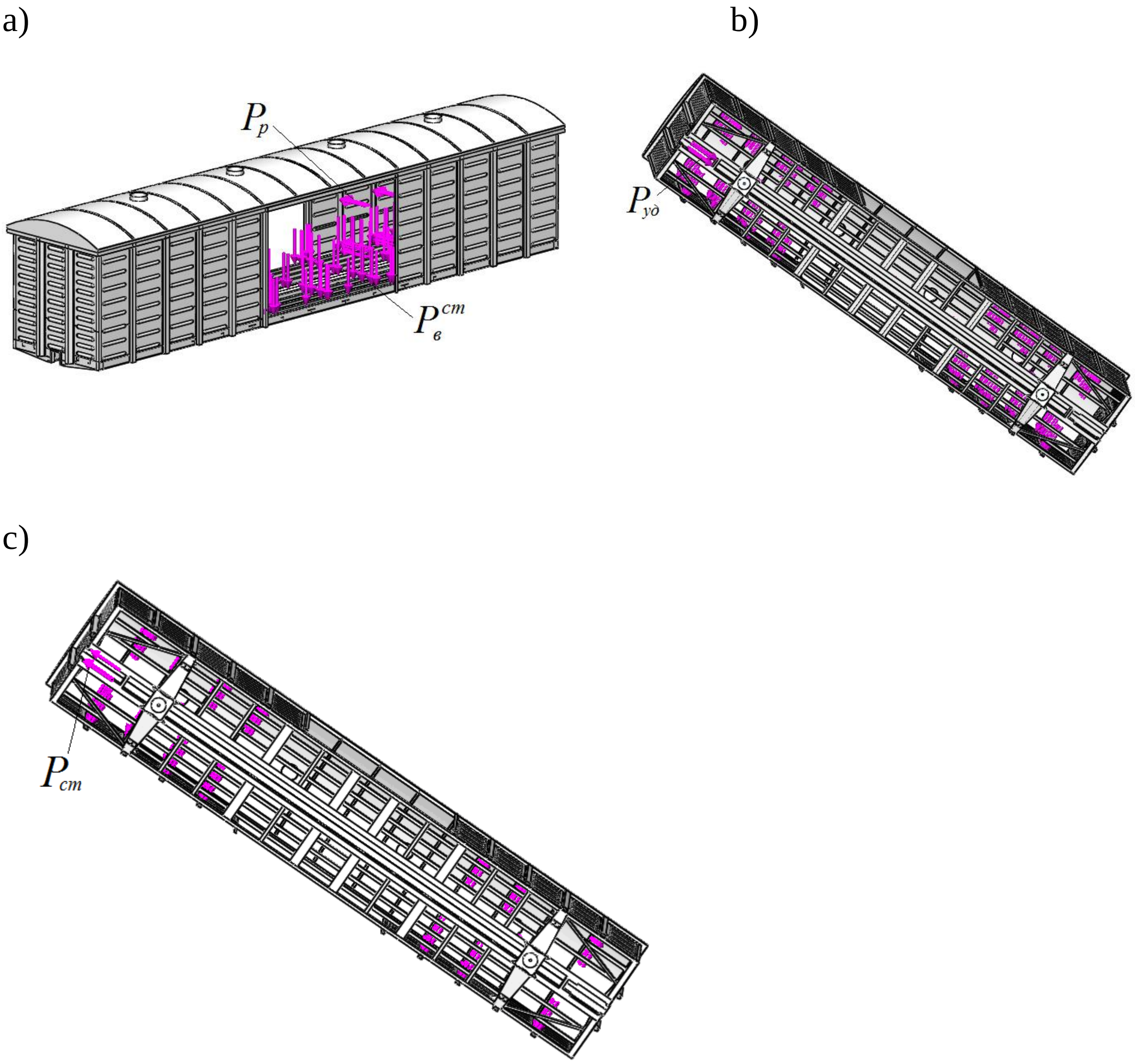


Figure 3.11. Computer model of the load-bearing structure durability of a 11-217 model covered wagon body in the calculation mode I

a) front view; b) bottom view (impact); c) bottom view (compression)

$P_в^{ст}$ – vertical static force; P_p – flowable freight force pressure;

$P_{уд}$ – longitudinal force

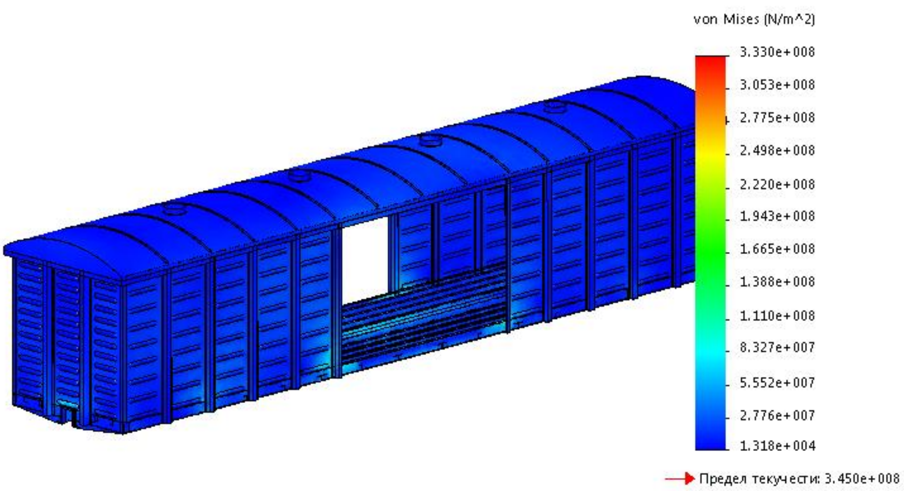
The maximum equivalent loades occur in the lower zone of interaction of the pivot beam with the spine beam and are about 330 MPa, the maximum displacements in the nodes of the structure are recorded in the middle of the frame and are about 11 mm, the maximum deformation was $4.04 \cdot 10^{-3}$.

The results of the calculation of the durability of the load-bearing structure of the body of the covered wagon in rating condition I (jerk-tension) are shown in Figure 3.13.

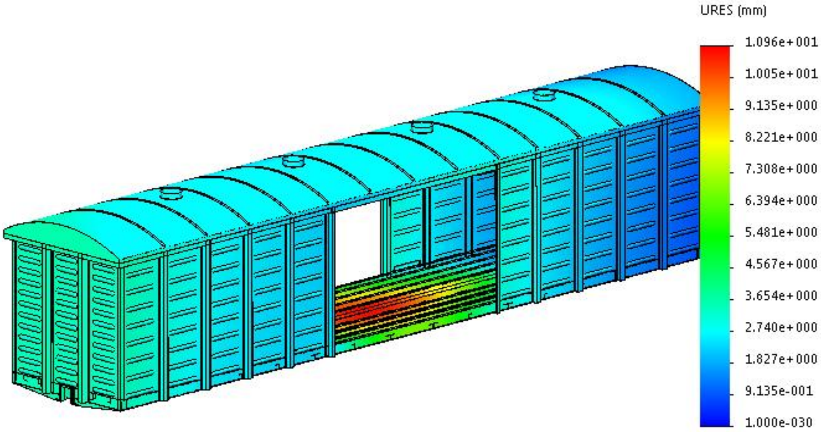
The maximum equivalent loades occur in the lower zone of interaction of the pivot beam with the spine beam and are about 316.6 MPa, the maximum displacements in the structural units are 10.6 mm, the maximum deformation was $4.05 \cdot 10^{-3}$.

The results of the calculation of the durability of the load-bearing structure of the covered wagon body in rating condition I (compression) are shown in Figure 3.14. The maximum equivalent loades are about 310 MPa, the maximum displacements in the structural units are 11 mm, the maximum deformation was $4.04 \cdot 10^{-3}$.

a)



b)



c)

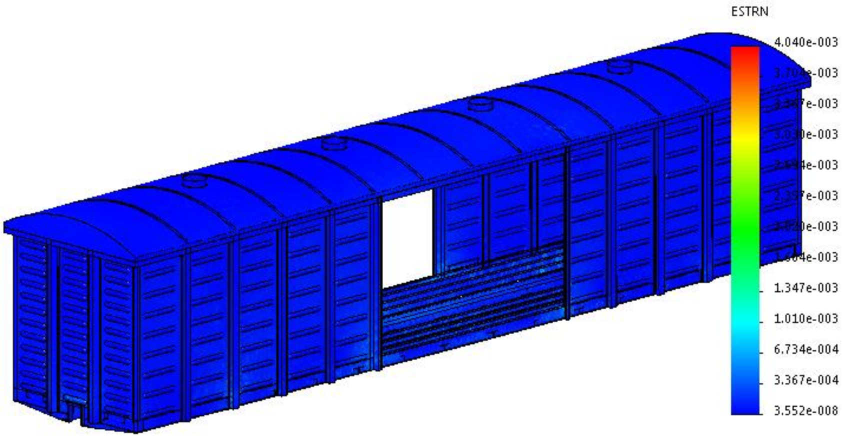
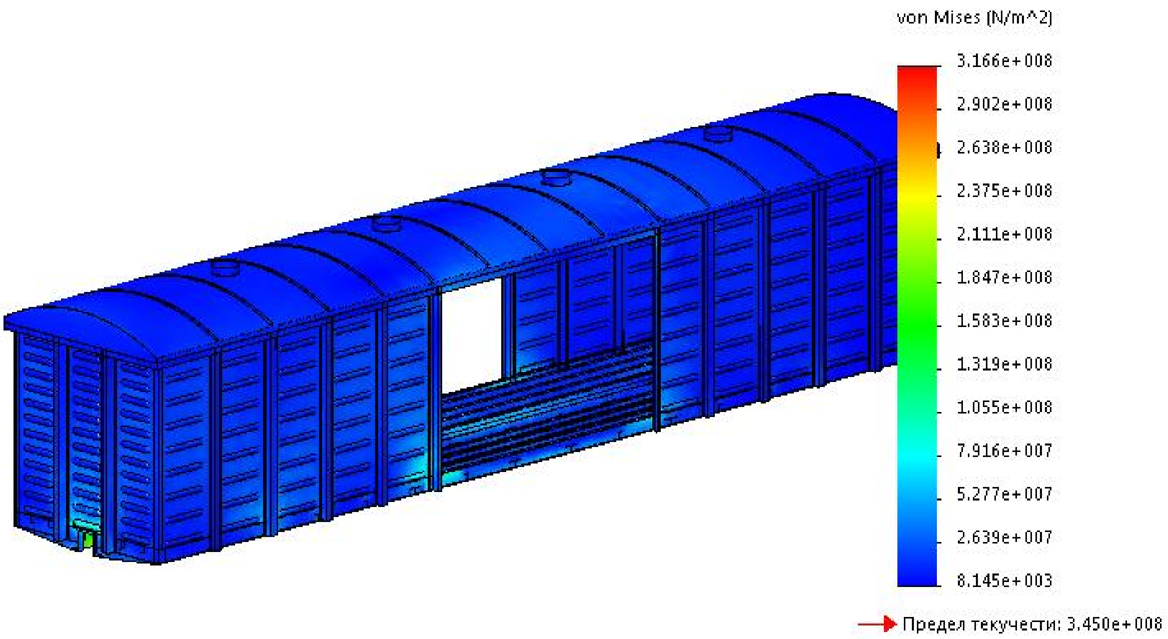


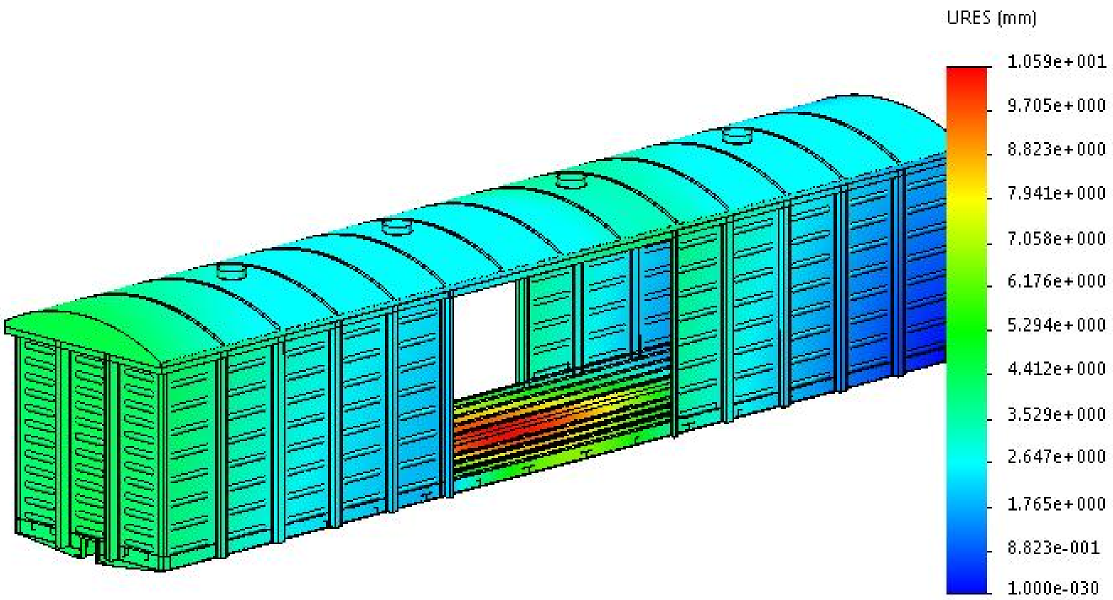
Figure 3.12. The results of the calculation of the load-bearing structure of the 11-217 model covered wagon body in rating condition I (impact)

a) loaded condition; b) movement in the nodes of the structure; c) deformation

a)


von Mises (N/m^2)
3.166e+008
2.902e+008
2.638e+008
2.375e+008
2.111e+008
1.847e+008
1.583e+008
1.319e+008
1.055e+008
7.916e+007
5.277e+007
2.639e+007
8.145e+003
Предел текучести: 3.450e+008

b)


URES (mm)
1.059e+001
9.705e+000
8.823e+000
7.941e+000
7.058e+000
6.176e+000
5.294e+000
4.412e+000
3.529e+000
2.647e+000
1.765e+000
8.823e-001
1.000e-030

c)

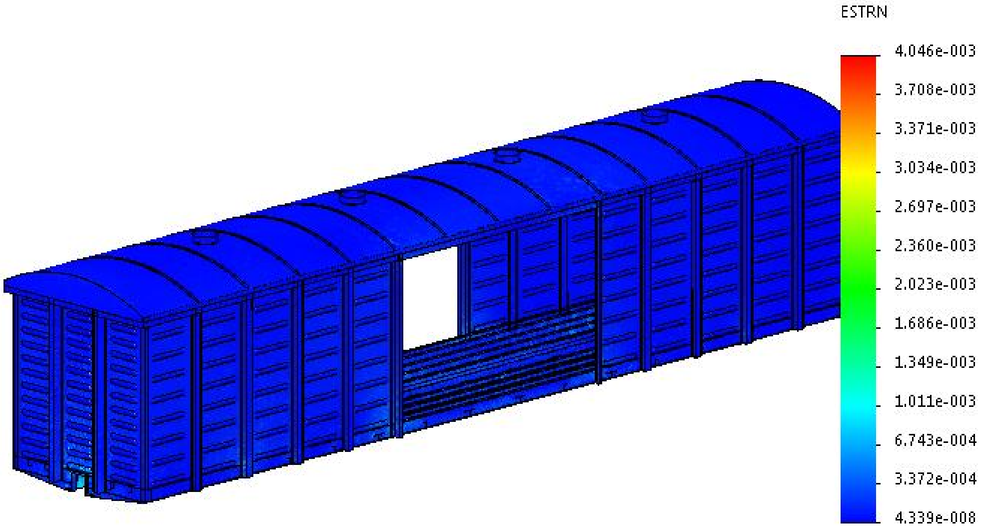
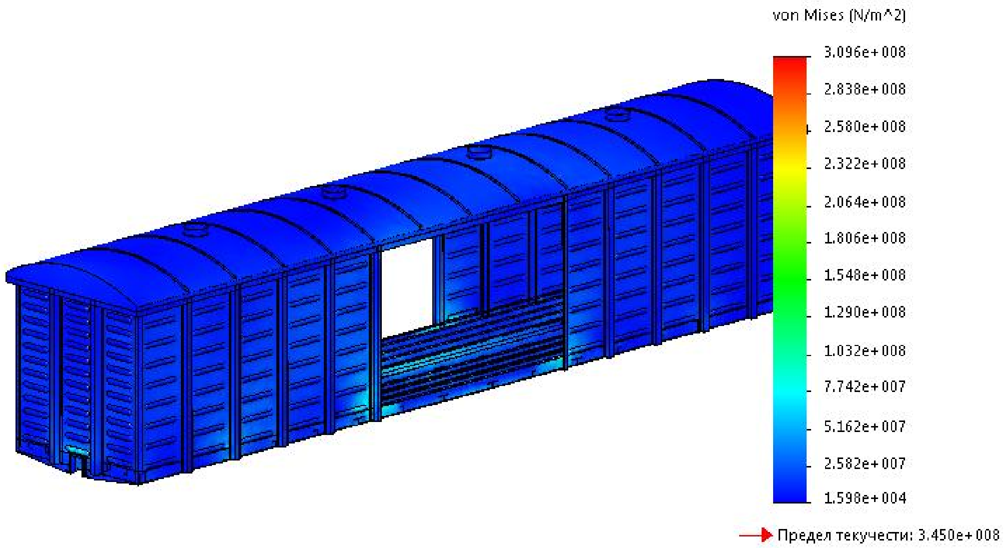


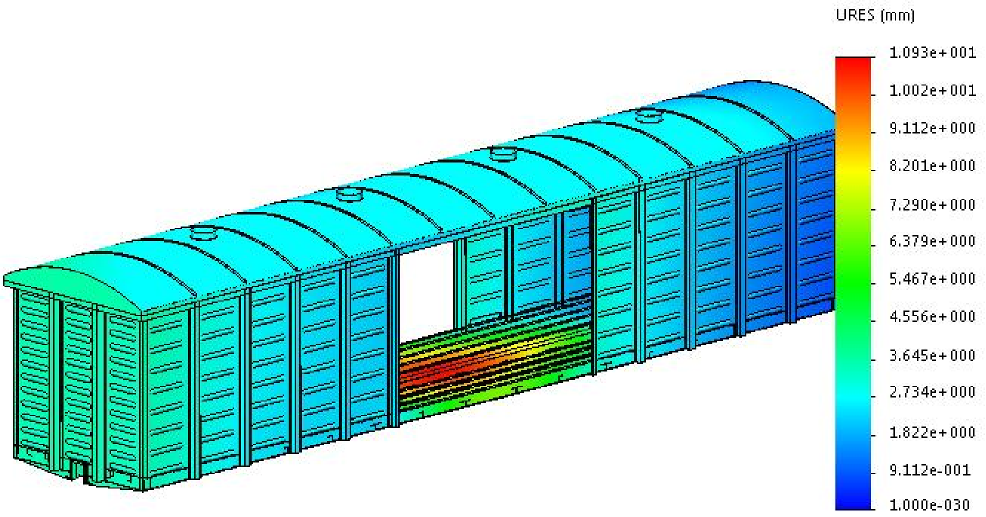
Figure 3.13. The results of the calculation of the load-bearing structure durability of the 11-217 model covered wagon body in rating condition I (jerk-tension)

a) loaded condition; b) movement in the nodes of the structure; c) deformation

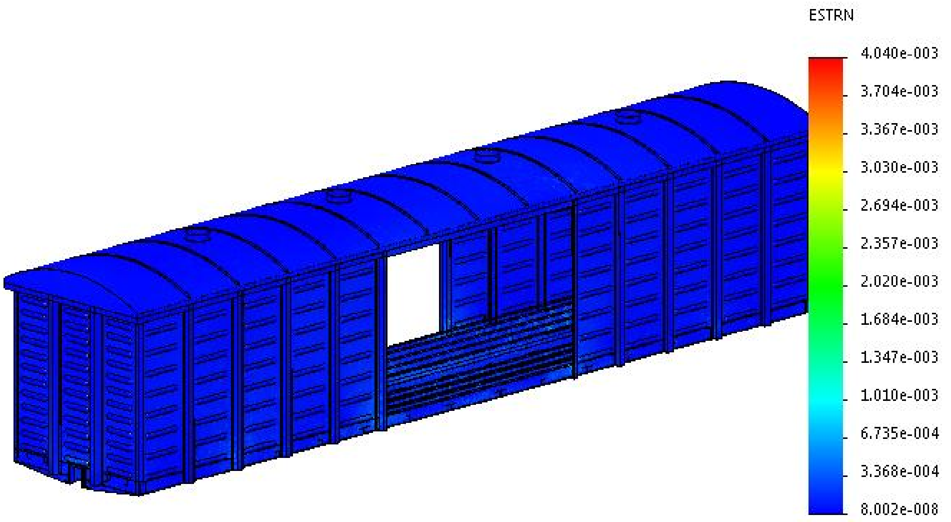
a)



b)



c)



Ficure 3.14. The results of the calculation of the load-bearing structure durability of the 11-217 model covered wagon body in rating condition I (compression)

a) loaded condition; b) movement in the nodes of the structure; c) deformation

The results of the calculation of the load-bearing structure durability of the body of the covered wagon in rating condition III (impact-compression) are shown in Figure 3.15. In this case, the side loads acting on the covered wagon in operation are taken into account as transverse reactions in center plates. The vertical dynamic force acting on the load-bearing structure of the covered wagon when moving relative to the rail track is taken into account in the quasi-statics.

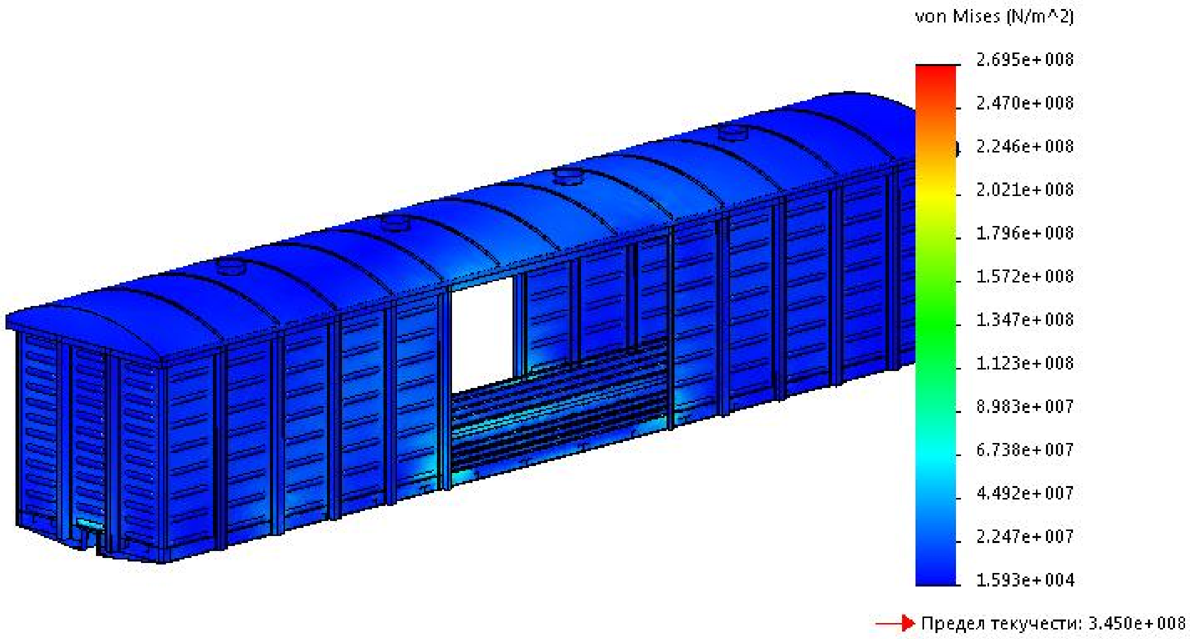
The maximum equivalent loades are about 269.5 MPa, the maximum displacements in the nodes of the structure are 9.44 mm, the maximum deformation was $5.05 \cdot 10^{-3}$.

The results of the calculation of the load-bearing structure durability of the covered wagon body at III (jerk-tension) are shown in Figure 3.16.

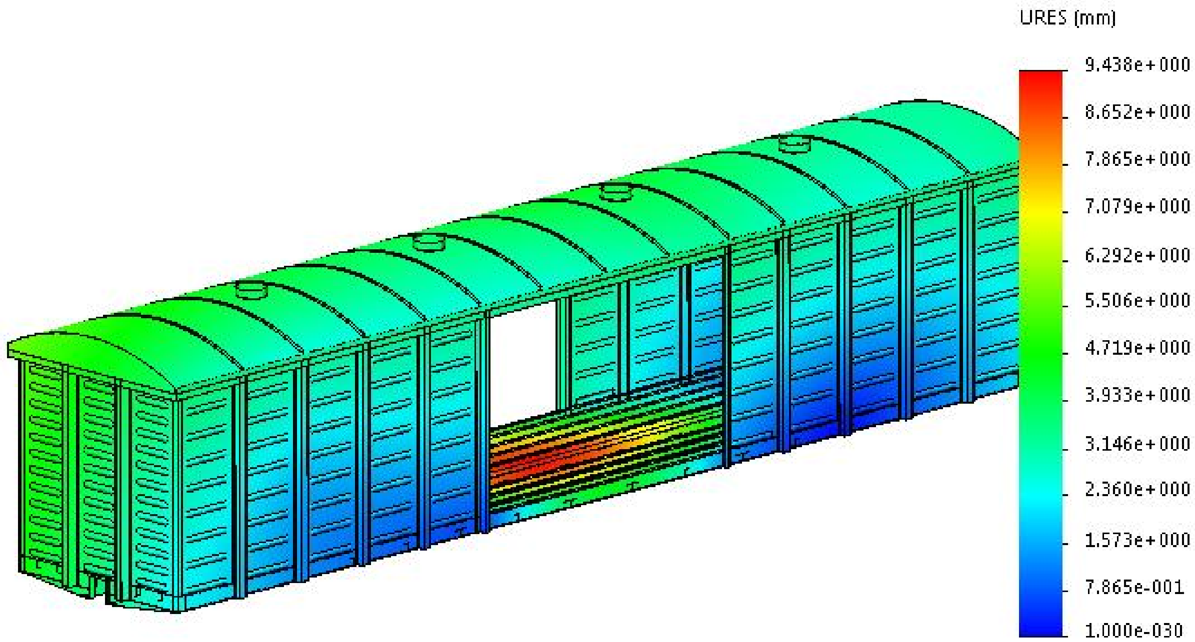
The maximum equivalent loades are about 270 MPa, the maximum displacements in the nodes of the structure are 9.2 mm, the maximum deformation was $4.3 \cdot 10^{-3}$.

The obtained results allow us to conclude that the maximum equivalent loades in the load-bearing structure of the covered wagon body occur in rating condition I in the conditions of impact-compression. In this case, the maximum equivalent loades in the components of the frame are less than the allowable ones and have a significant margin of safety. Therefore, in order to increase the efficiency of the load-bearing structure of the covered wagon body, it is necessary to improve it.

a)


von Mises (N/m^2)
2.695e+008
2.470e+008
2.246e+008
2.021e+008
1.796e+008
1.572e+008
1.347e+008
1.123e+008
8.983e+007
6.738e+007
4.492e+007
2.247e+007
1.593e+004
Предел текучести: 3.450e+008

b)


URES (mm)
9.438e+000
8.652e+000
7.865e+000
7.079e+000
6.292e+000
5.506e+000
4.719e+000
3.933e+000
3.146e+000
2.360e+000
1.573e+000
7.865e-001
1.000e-030

c)

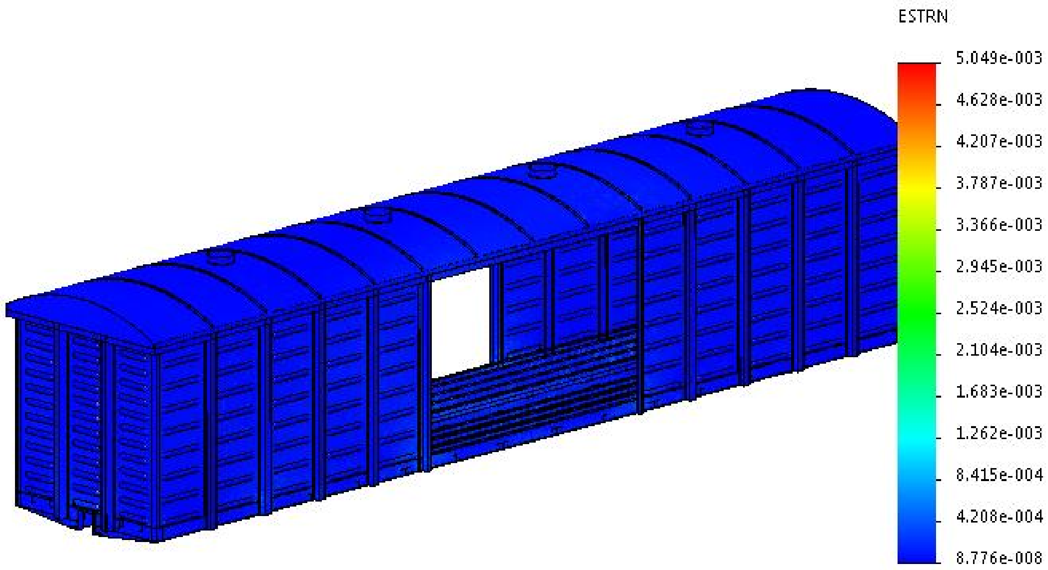
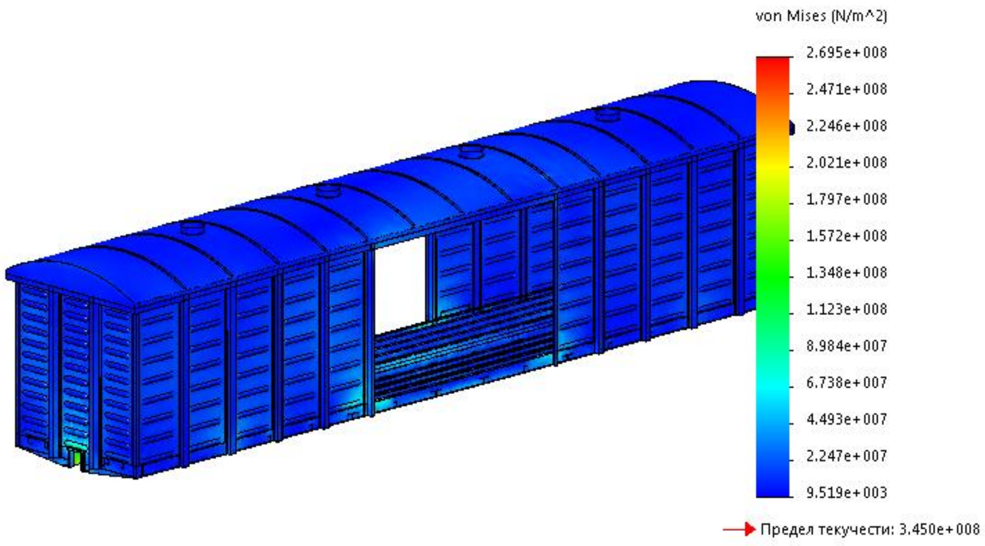


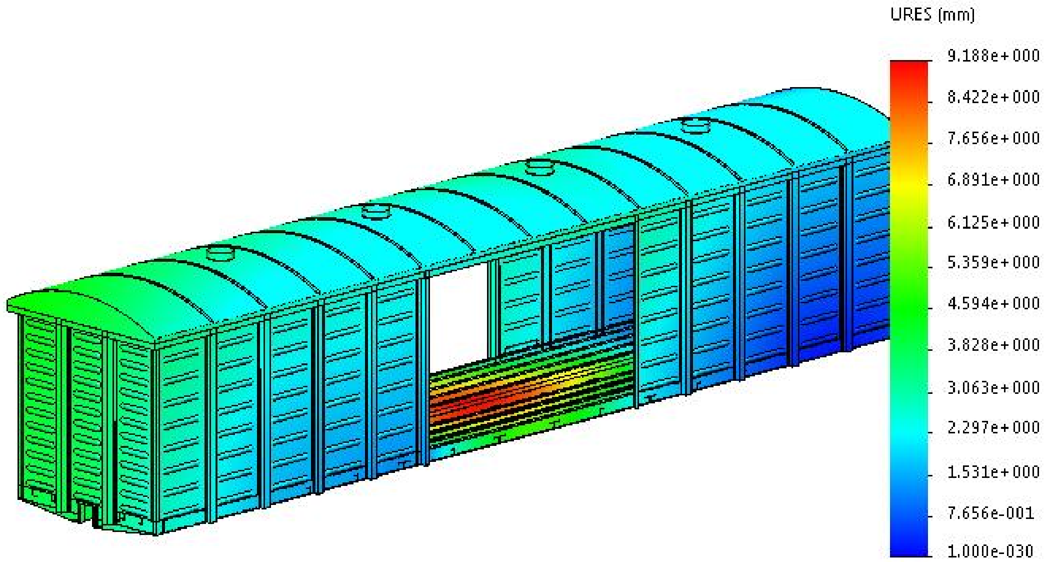
Figure 3.15. The results of the calculation of the load-bearing structure durability of the 11-217 model covered wagon body at rating contition III (impact-compression)

a) loaded condition; b) movement in the nodes of the structure; c) deformation

a)



b)



c)

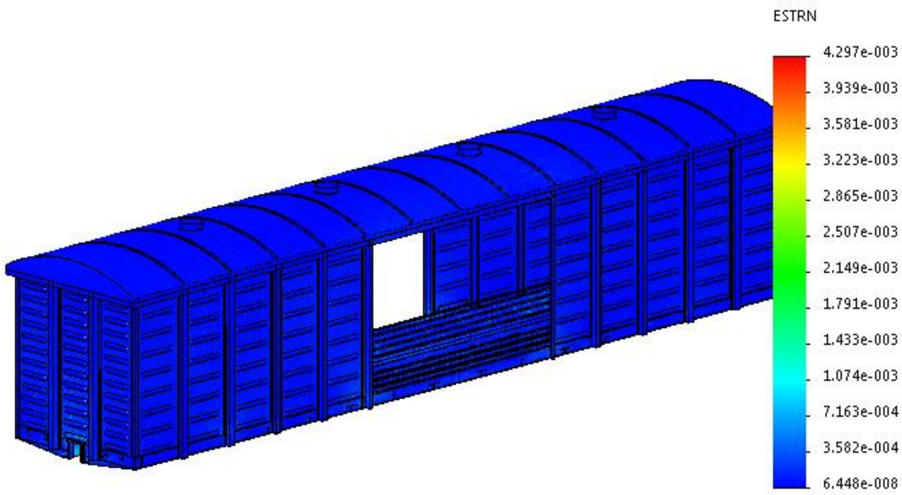


Figure 3.16. The results of the calculation of the load-bearing structure durability of the 11-217 model covered wagon body at rating condition III (jerk-tension)

a) loaded condition;
b) movement in the nodes of the structure;
c) deformation

3.3. Research of typical designs durability of flat wagons with nominal parameters at operational loadings

In order to study the loaded and deformed condition of the load-bearing structure of the flat wagon, its spatial model was built in the SolidWorks software environment (Figure 3.17).

The numerical values of the forces acting on the flat wagon in operation are given in Table 3.6. It is taken into account that the full load capacity of the flat wagon with conditional load is used. The vertical forces acting on the load-bearing structure of the flat wagon were applied in a ratio of 5/16 to the main side beams, 10/16 to the spine beam.

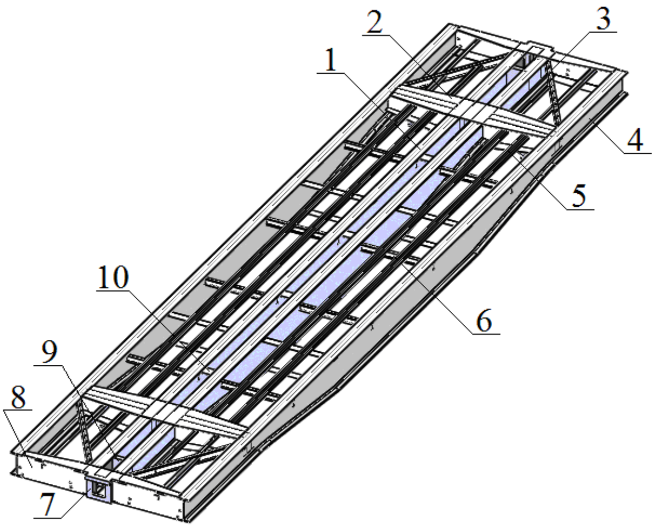


Figure 3.17. Space model of 13-401 model flat wagon

1 – spine beam; 2 – pivot beam; 3 – brace; 4 – the main longitudinal beam; 5 – intermediate longitudinal beam; 6 – cross beam; 7 – shock socket with front stops; 8 – frontal leaf; 9 – rear stop; 10 – diaphragm

Table 3.6

Numerical values of forces acting on the 13-401 model flat wagon in operation

Type of force	*I r. c.*	*III r. c.*
Vertical static, kN	800,496	800,496
Vertical dynamic, kN		112,87
Centrifugal, kN Відцентрове, кН		150,81
Framework, kN		194,21
Wind, kN Вітрове, кН		2,65

The durability calculation was performed using the finite element method in the CosmosWorks software environment.

The finite element model of the flat wagon is shown in Figure 3.18. The optimal number of grid elements was determined using the graphoanalytical method [21–23]. The number of grid elements was 368732, the number of nodes was 14938. The maximum size of the grid element is 235.62 mm, the minimum size of the grid element is 47.12 mm, the maximum ratio of the sides of the elements is 332, the percentage of elements with a ratio of less than three is 24.6, of more than ten is 31.5.

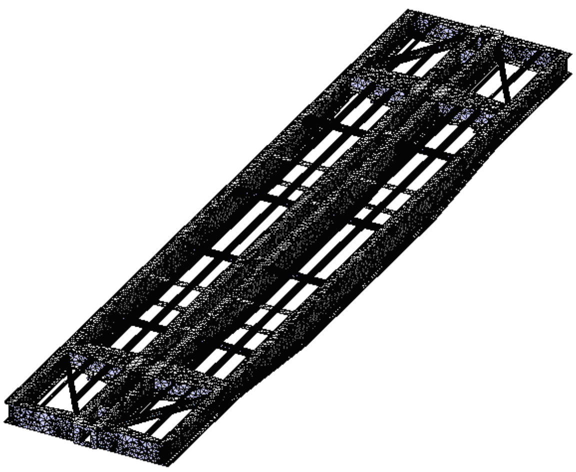
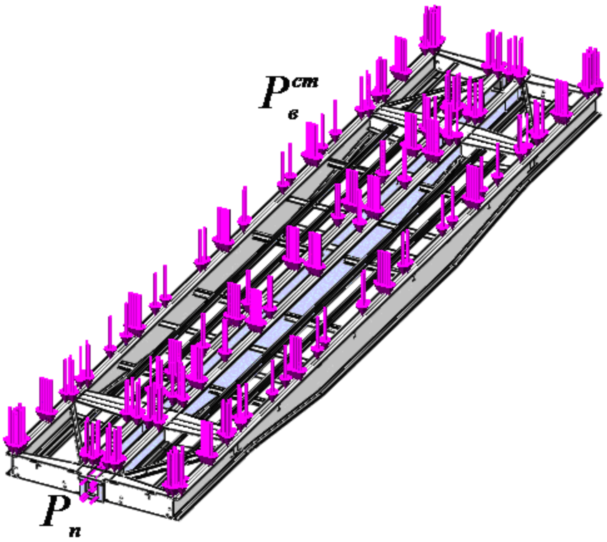


Figure 3.18. Finite element model of the 13-401 model flat wagon

The computer model of the load-bearing structure durability of the flat wagon in the conditions of calculation mode I is shown in Figure 3.19.

a)



b)

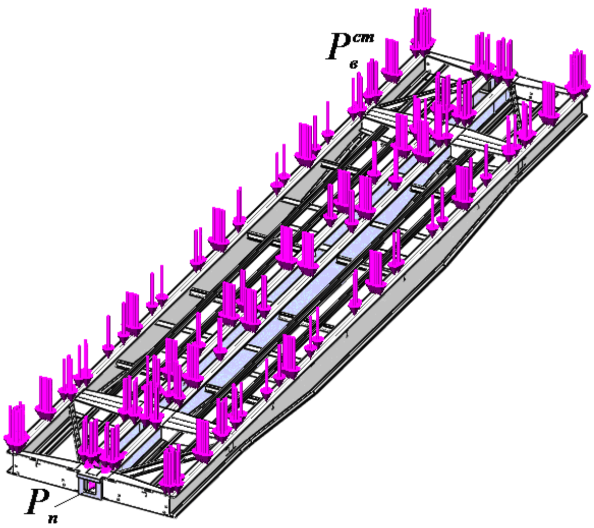


Figure 3.19. Computer model of the load-bearing structure durability of the 13-401 model flat wagon in calculation mode I

a) shock-compression; b) stretching-jerk

$P_в^{cm}$– vertical static force; P_p – longitudinal force

The limitations of the model are the lack of difference in the levels of the bodies of autocouplings of flat wagons that interact with each other. The model was fixed on center plates and slides of the pivot beams of the lsupprting structure of the flat wagon.

When studying the durability of the flat wagon under load conditions corresponding to the shock-compression mode, the longitudinal force was applied to the rear stop of the autocoupling, and on the other side of the flat wagon fixing was attached to the same element of autocoupling equipment. When modeling the durability of the flat wagon in the mode of tension-jerk longitudinal force was applied to the front stops from one end of the flat wagon, and fixing was performed to the front stops from the other side of the wagon.

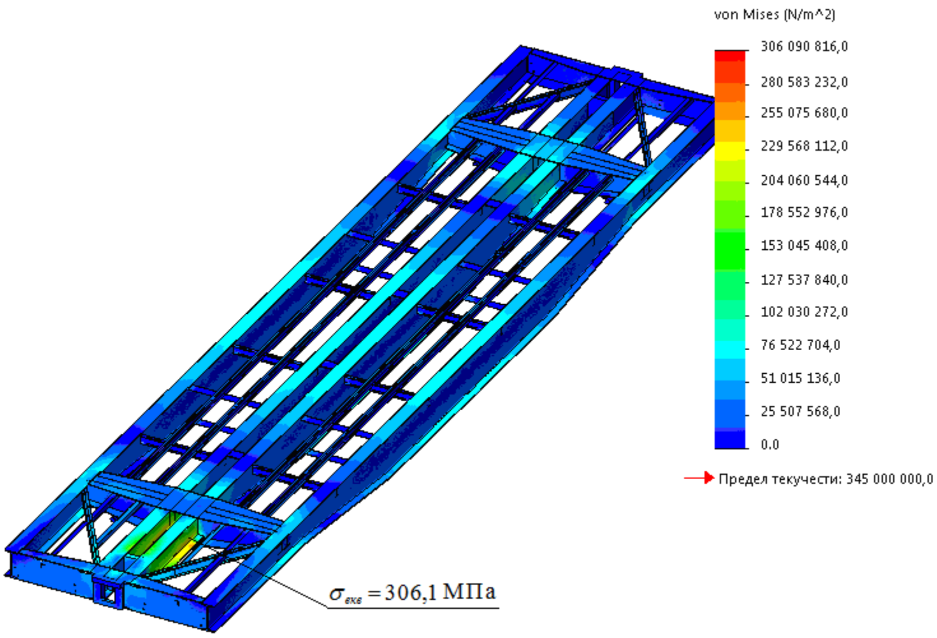
The results of the calculation of the durability of the load-bearing structure of the flat wagon in rating condition I (impact) are shown in Figure 3.20.

The maximum equivalent loades occur in the lower zone of interaction of the pivot beam with the spine and are about 306 MPa, the maximum displacements in the nodes of the structure are recorded in the middle of the frame and are 7.6 mm, the maximum deformation was $2.4 \cdot 10^{-3}$.

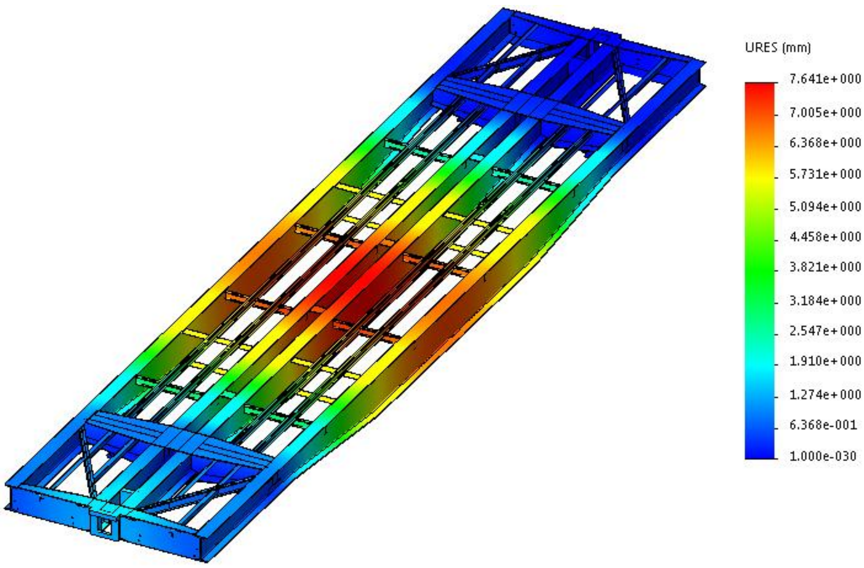
The results of the calculation of the durability of the load-bearing structure of the flat wagon in rating condition I (jerk) are shown in Figure 3.21.

The maximum equivalent loades occur in the lower zone of interaction of the pivot beam with the spine beam, it is about 242.8 MPa, the maximum displacements in the fixed components are 7.6 mm, the maximum deformation was $2.4 \cdot 10^{-3}$.

a)


von Mises (N/m^2)
306 090 816,0
280 583 232,0
255 075 680,0
229 568 112,0
204 060 544,0
178 552 976,0
153 045 408,0
127 537 840,0
102 030 272,0
76 522 704,0
51 015 136,0
25 507 568,0
0.0
Предел текучести: 345 000 000,0
$\sigma_{екв} = 306{,}1$ МПа

b)


URES (mm)
7.641e+000
7.005e+000
6.368e+000
5.731e+000
5.094e+000
4.458e+000
3.821e+000
3.184e+000
2.547e+000
1.910e+000
1.274e+000
6.368e-001
1.000e-030

c)

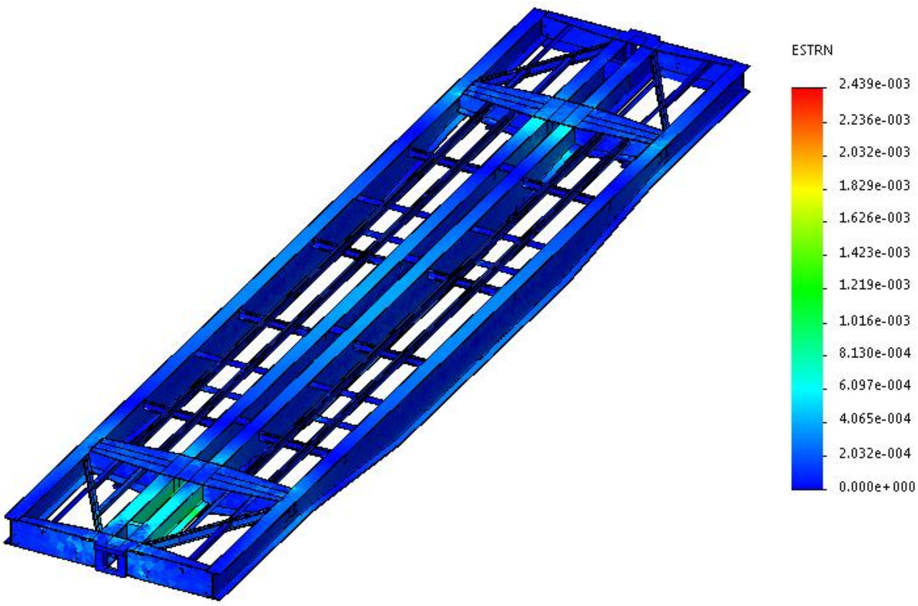
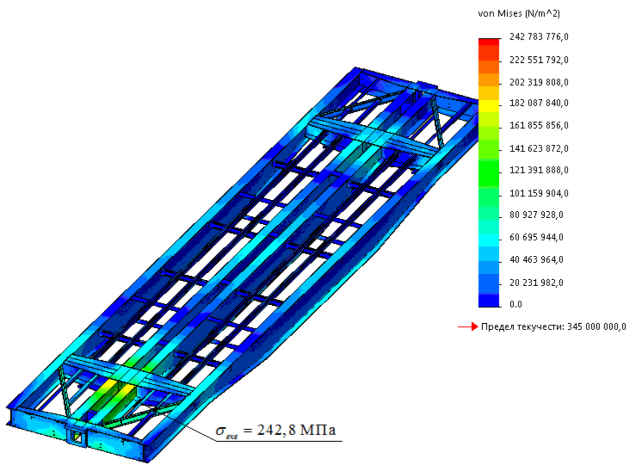


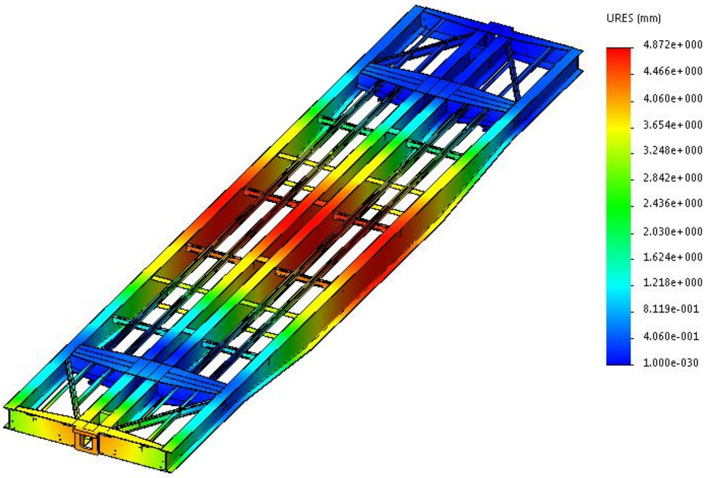
Figure 3.20. The results of the calculation of the load-bearing structure durability of the 13-401 model flat wagon in rating condition I (impact)

a) loaded conditin; b) movement in the nodes of the structure; c) deformation

a)



b)



c)

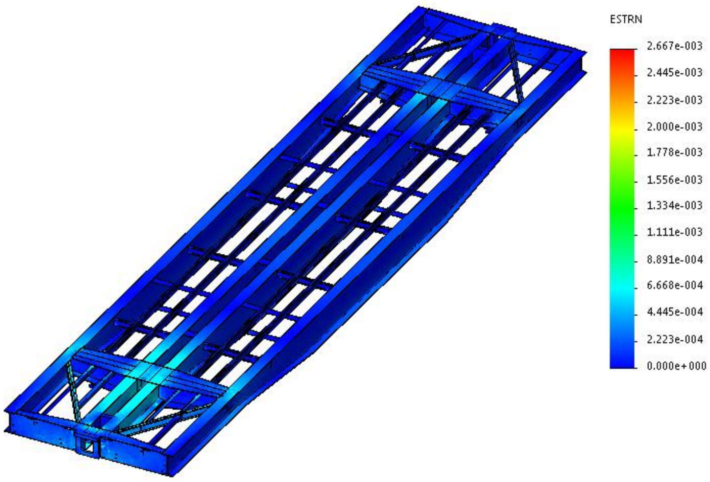
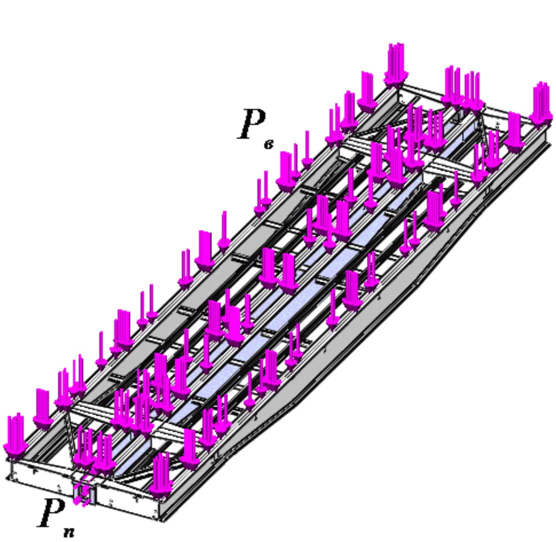


Figure 3.21. The results of the calculation of the load-bearing structure durability of the 13-401 model flat wagon in rating condition I (jerk)

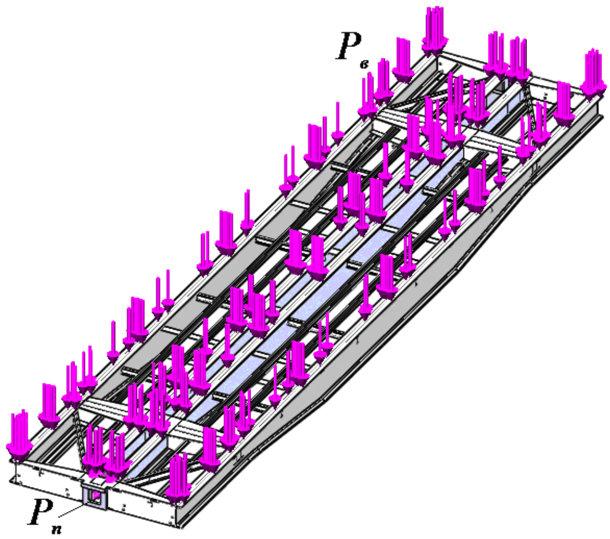
a) loaded conditions; b) movement in the nodes of the structure; c) deformation

The computer model of the flat wagon durability in rating condition III is shown in Figure 3.22.

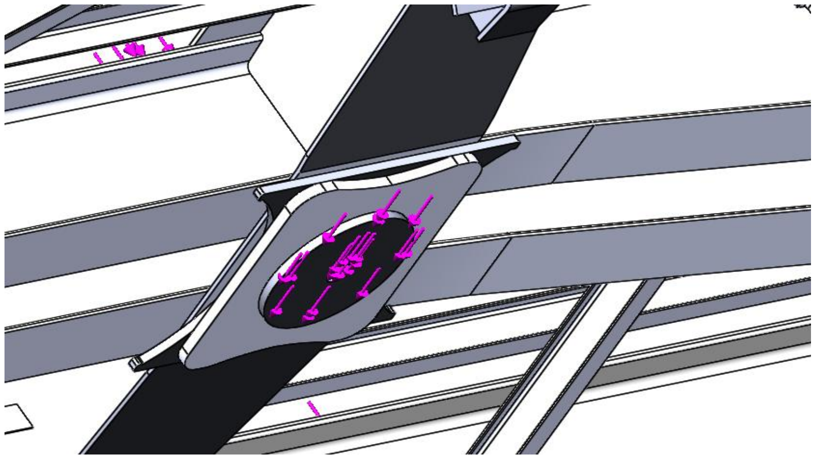
a)



b)



c)



$P_в$ – vertical force (static and dynamic); $P_п$ – longitudinal force

Figure 3.22. Computer model of the load-bearing structure durability of the13-401 model flat wagon at rating condition III

a) shock-compression; b) stretching-jerk; c) the effect of the transverse force on the center plate of the flat wagon

The results of the calculation of the load-bearing structure durability of the flat wagon in rating condition III (impact) are shown in Figure 3.23. In this case, the lateral loads acting on the flat wagon in operation are taken into account as transverse reactions in center plate nodes. The vertical dynamic force acting on the load-bearing structure of the flat wagon when moving relative to the rail track is taken into account in the quasi-statics.

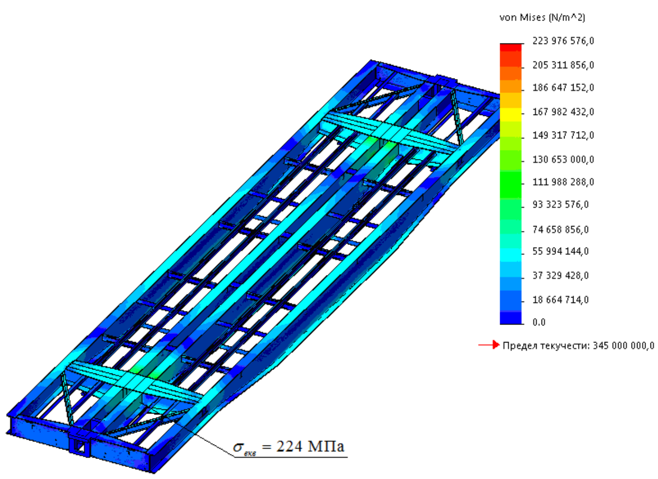
The maximum equivalent loades are about 224 MPa, the maximum displacements in the structural units are 78.2 mm, the maximum deformation was $3.3 \cdot 10^{-3}$.

The results of the calculation of the suppoting structure durability of the flat wagon in rating condition III (jerk) are shown in Figure 3.24.

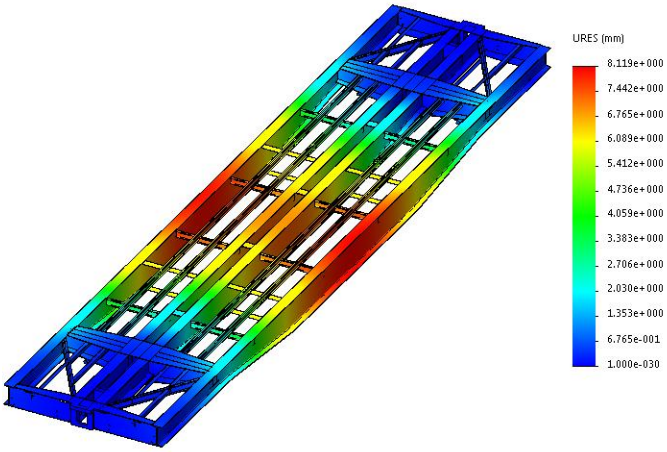
The maximum equivalent loades are about 230.8 MPa, the maximum displacements at the nodes of the structure are 6.8 mm, the maximum deformation was $5.67 \cdot 10^{-3}$.

The obtained results allow us to conclude that the maximum equivalent loades in the load-bearing structure of the flat wagon occur in rating condition I in the conditions of impact-compression. In this case, the maximum equivalent loades in the components of the frame are much less than the allowable ones and have a significant margin of safety. Therefore, in order to increase the efficiency of the load-bearing structure of the flat wagon, it is necessary to improve it.

a)



b)



c)

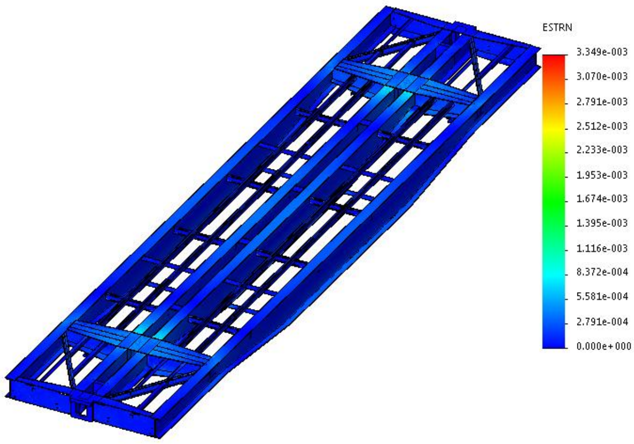
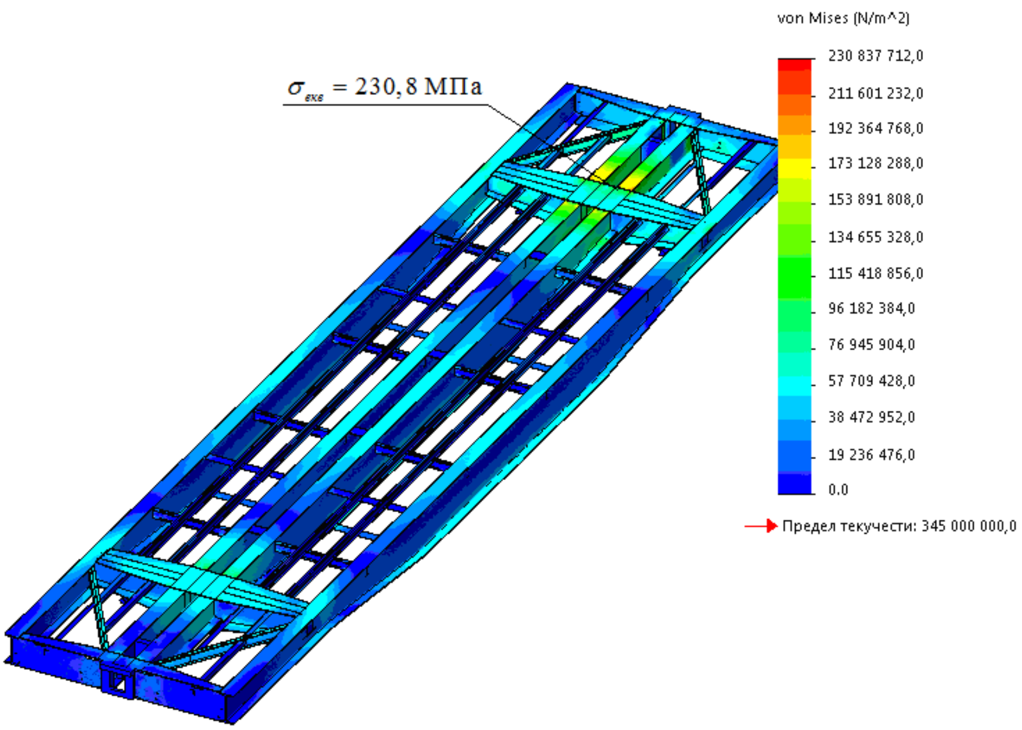


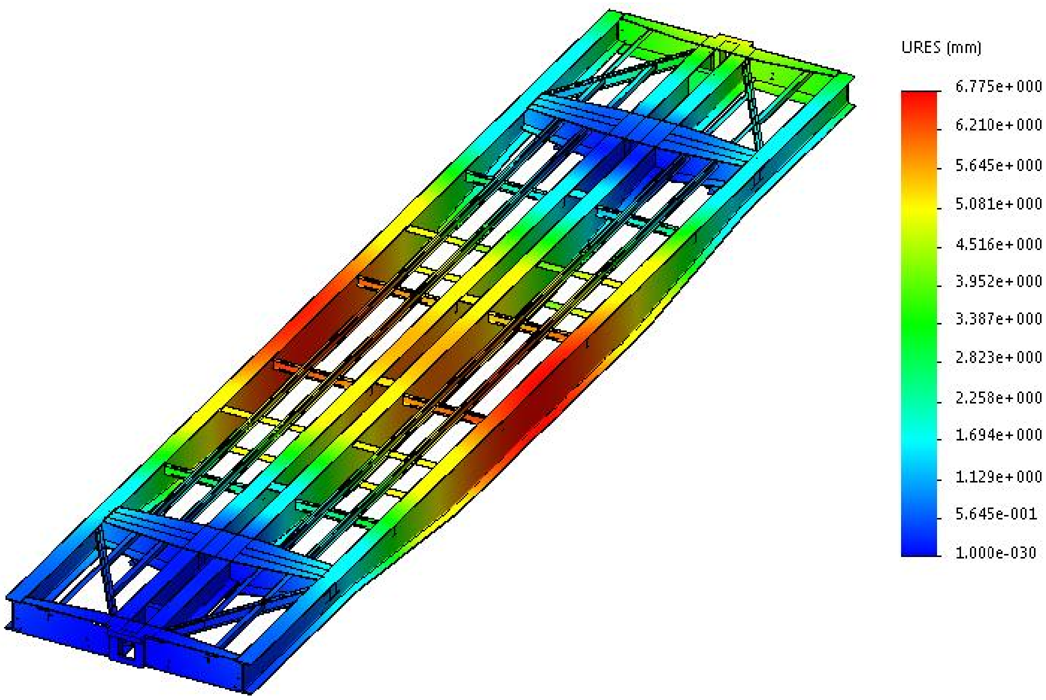
Figure 3.23. The results of the calculation of the load-bearing structure durability of the 13-401 model flat wagon at rating condition III (impact)

a) loaded condition; b) movement in the nodes of the structure; c) deformation

a)


$\sigma_{екв}$ = 230,8 МПа
von Mises (N/m^2)
230 837 712,0
211 601 232,0
192 364 768,0
173 128 288,0
153 891 808,0
134 655 328,0
115 418 856,0
96 182 384,0
76 945 904,0
57 709 428,0
38 472 952,0
19 236 476,0
0.0
Предел текучести: 345 000 000,0

b)


URES (mm)
6.775e+000
6.210e+000
5.645e+000
5.081e+000
4.516e+000
3.952e+000
3.387e+000
2.823e+000
2.258e+000
1.694e+000
1.129e+000
5.645e-001
1.000e-030

c)

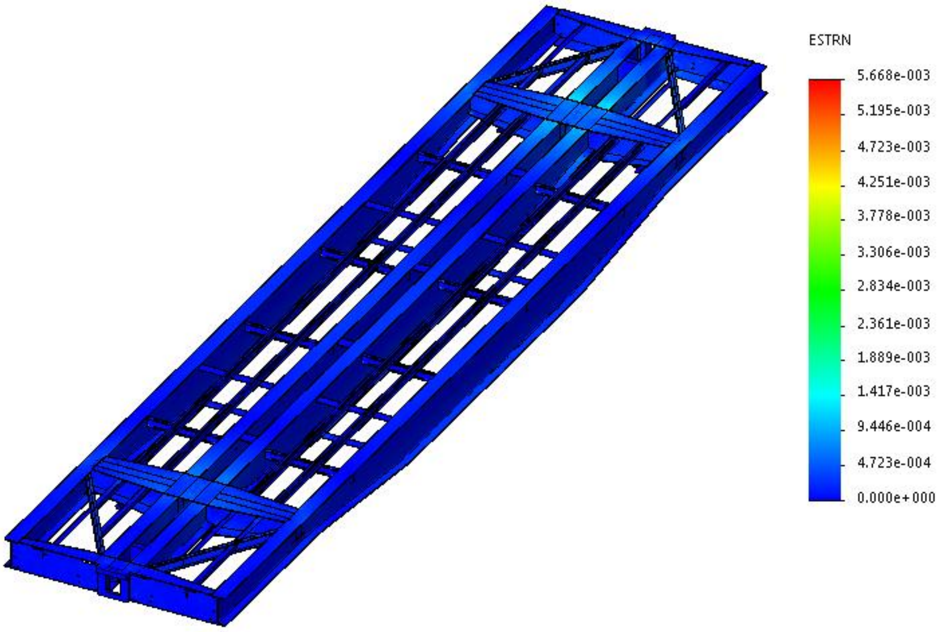


Figure 3.24. The results of the calculation of the load-bearing structure durability of the 13-401 model flat wagon at rating condition III (jerk)

a) loaded condition; b) movement in the nodes of the structure; c) deformation

3.4. Research of typical designs durability of tank wagons with nominal parameters at operational loadings

To determine the load on the load-bearing structure of the tank wagon in the main operating modes, the durability was calculated. As a prototype, a 15-1443-06 model tank wagon was chosen, which is designed to transport gasoline and other light petroleum products. The spatial model of the tank wagon was created in SolidWorks (Figure 3.25).

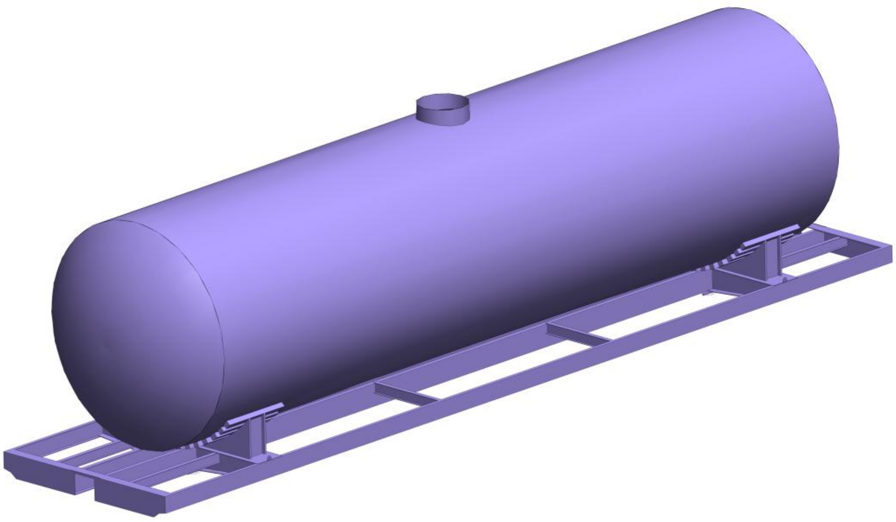


Figure 3.25. A special model of a tank wagon supporting atructure

Durability calculation is implemented in SolidWorks Simulation.

When determining the total pressure in the copper the following parametres are taken into account [1–3]:

– excess vapor pressure (0.15 MPa);

– pressure on the bottom due to the movement of flowable cargo (hydraulic shock);

– hydrostatic pressure.

The value of the maximum pressure from the hydraulic shock is determined by the ratio of the load inertia force to the area of the vertical projection of the bottom:

$$P_{Г} = N \cdot \frac{m_{в}}{m_{бр}} \cdot \frac{1}{F}, \qquad (3.4)$$

where N is the force of impact in the autocoupling, MN;

$m_{в}$ is weight of cargo in the boiler of the tank wagon, kg;

$m_{бр}$ is gross mass of the tank wagon, kg;

T is the area of the internal cross section of the copper, m^2.

Based on the calculations at T = 2.5 MN, mb = 66000 kg, mbr = 91800 kg and T = 7.07 m2, the value of WG = 0.25 MN was obtained.

Gasoline is considered as liquid cargo.

Hydrostatic pressure is calculated by the formula:

$$P_{гідр} = \rho \cdot g \cdot h, \qquad (3.5)$$

where ρ is the density of liquid cargo, kg / m^3;

h is the height of the load distribution relative to the copper, m.

Based on the calculations at ρ = 780 kg / m^3 and h = 3.0 m, $P_{гідр}$ = 22.96 kN was obtained.

Numerical values of longitudinal forces, which are taken into account in the calculations of the tank wagon are given in Table 3.2.

The finite element model of the tank wagon is shown in Figure 6.26. The optimal number of grid elements was determined using the graphoanalytical method [21–23]. The number of grid elements was 771284, the number of nodes was 251278. The maximum size of the grid element is 40 mm, the minimum is 8 mm, the maximum ratio of the sides of the elements is 123.84, the percentage of elements with a ratio of less than three is 19.4, more than ten – 0.365.

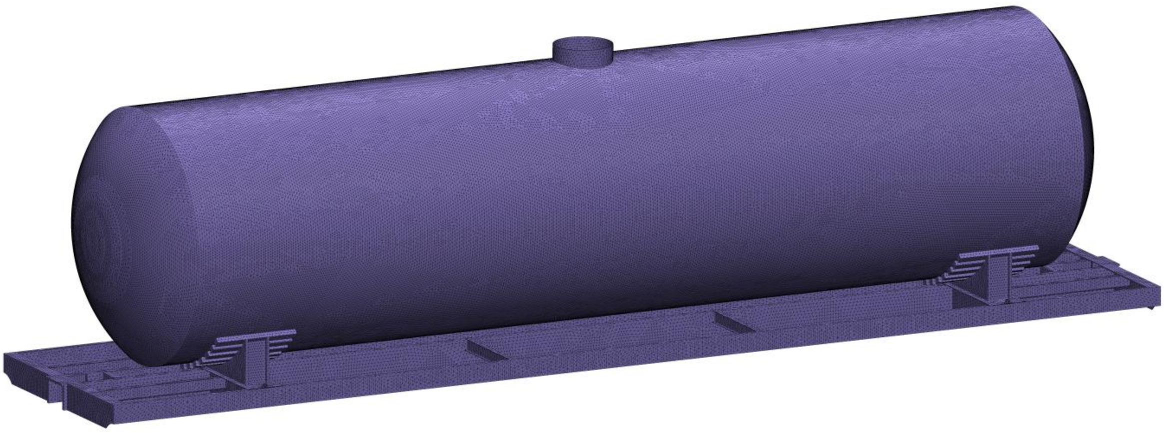
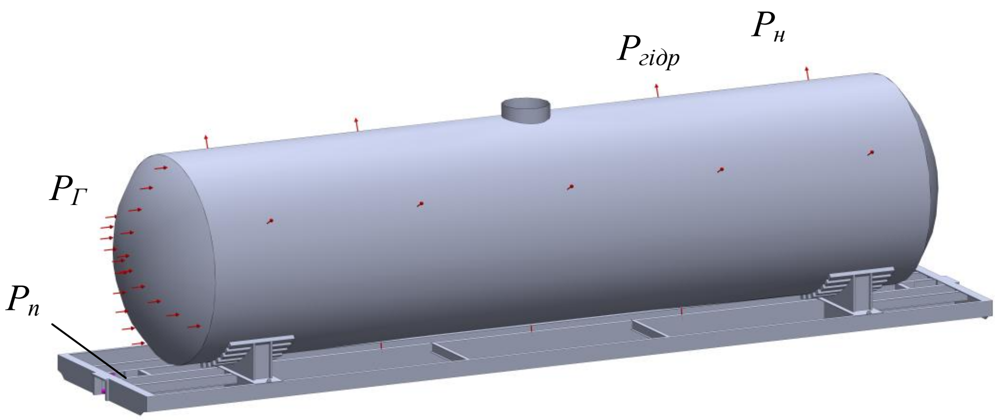


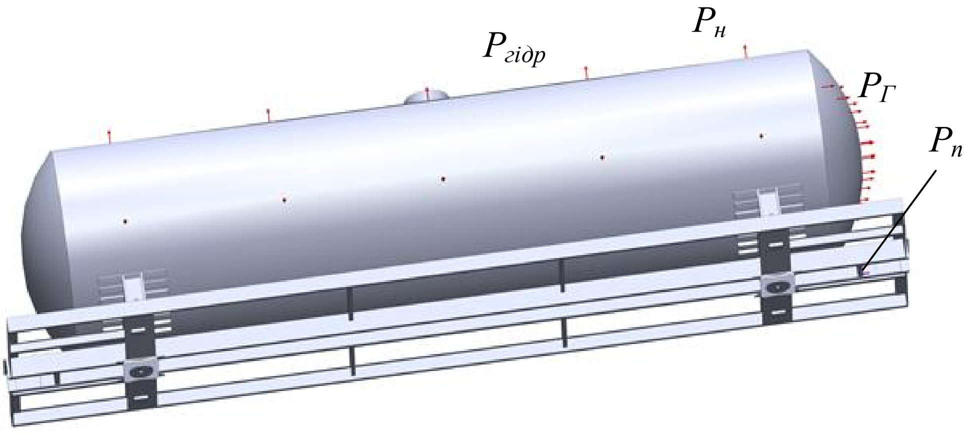
Figure 3.26. Finite element model of a tank wagon

Estimated schemes of the load-bearing structure of the tank wagon are shown in Figure 3.27.

a)



b)



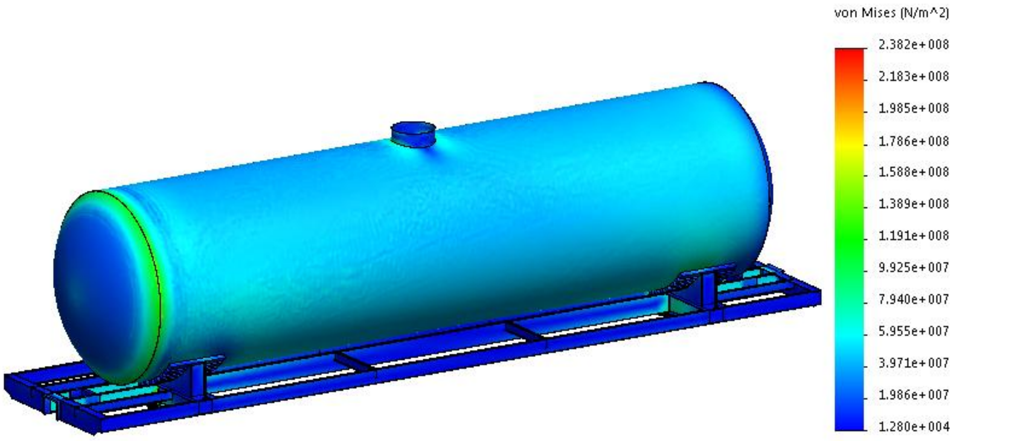
a) jerk-stretching; b) shock-compression

$P_п$ – longitudinal load on the front stops; $P_Г$ – pressure on the bottom from the hydraulic shock; $P_{гідр}$ – hydrostatic pressure; $P_н$ – excess pressure

Figure 3.27. Computational model of the load-bearing structure of the tank wagon

The model was fixed in the areas where the load-bearing structure rests on the carriages. The material used is the steel of 09G2S grade. The results of the calculation of the load-bearing structure durability of the tank wagon in rating condition I (jerk) are shown in Figure 3.28.

a)



b)

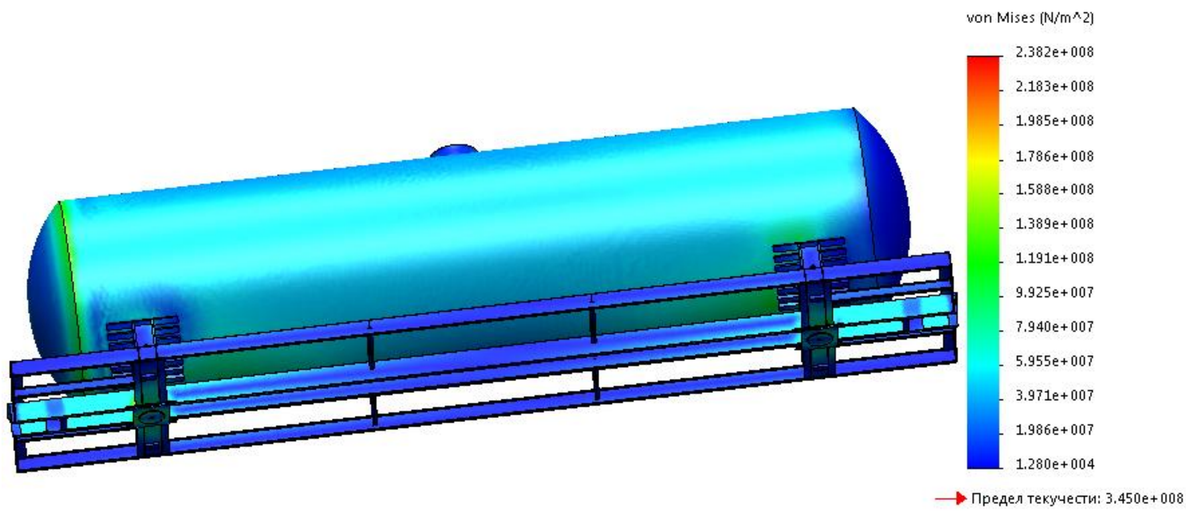


Figure 3.28. Loaded condition of the load-bearing structure of the tank wagon in rating condition I (jerk)

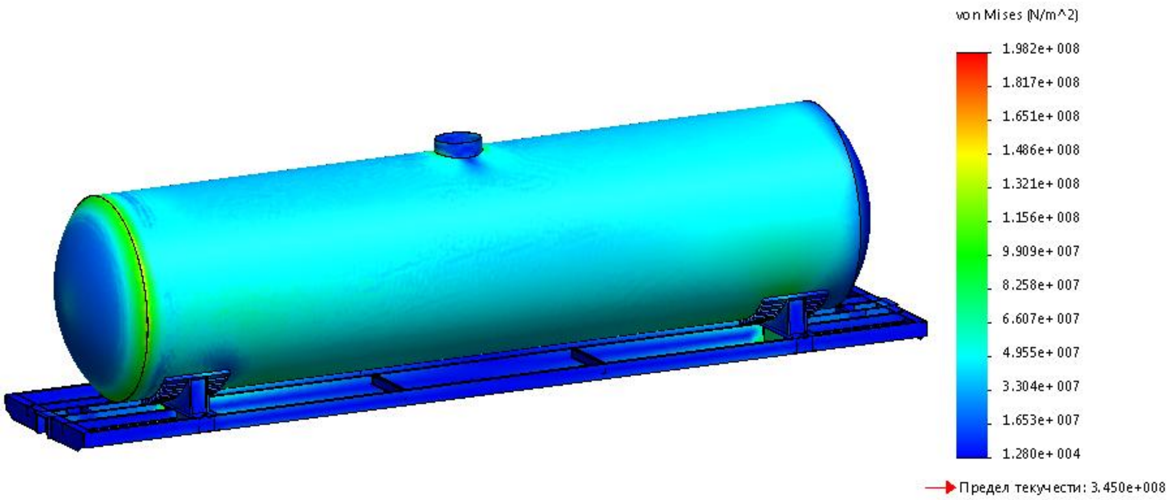
a) side view; b) bottom view

The maximum equivalent loads occur in the area of the loading hatch and are about 238 MPa, the maximum displacement was 5.8 mm, the maximum deformation was $3.125 \cdot 10^{-3}$.

The results of the calculation of the durability of the load-bearing structure of the tank wagon in rating condition III (jerk) are shown in Figure 3.29.

The maximum equivalent loads are about 198.2 MPa, the maximum displacement is 5.5 mm, the maximum deformation was $3{,}171 \cdot 10^{-3}$.

a)



b)

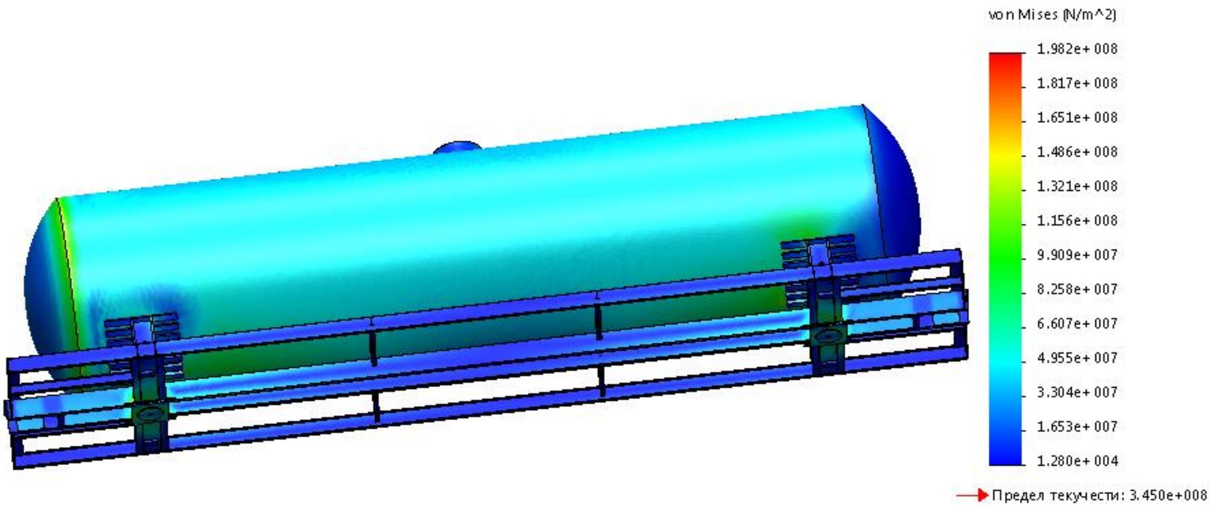
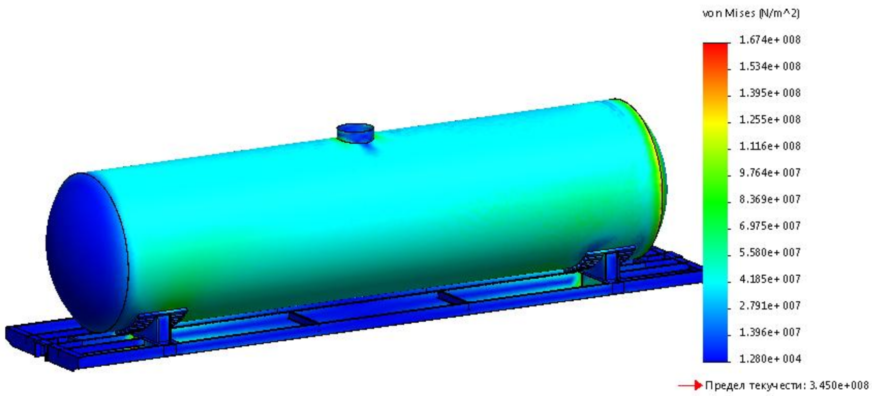


Figure 3.29. Loaded condition of the load-bearing structure of the tank wagon at rating condition III (jerk)

a) side view; b) bottom view

The results of the calculation of the durability of the load-bearing structure of the tank wagon in rating condition III (impact) are shown in Figure 3.30.

a)



b)

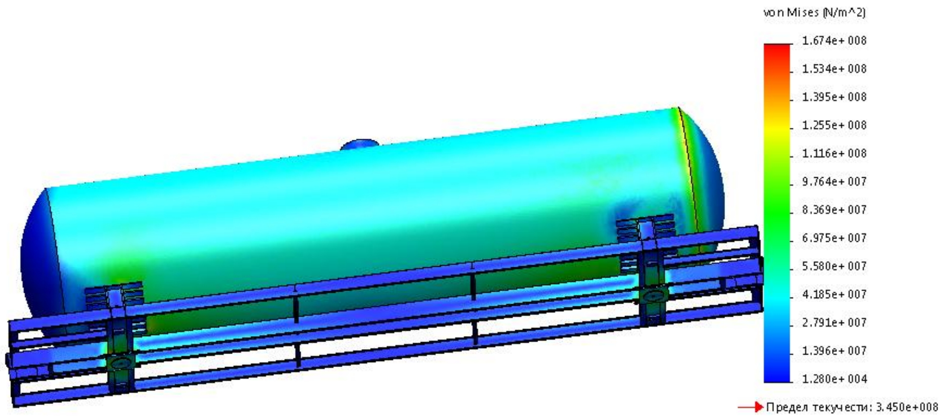


Figure 3.30. Loaded condition of the suporting of the tank wagon at rating condition III (impact)

a) side view; b) bottom view

The maximum equivalent loads are about 167.4 MPa, the maximum displacements are 5.5 mm, the maximum deformations were $3.125 \cdot 10^{-3}$.

The calculations show that the highest loads concentration is centred in the area of the loading hatch, as well as in the area of interaction of the bottom with the cylindrical part of the copper. However, for all the considered computational models, these loads do not exceed the allowable ones.

3.5. Research of typical designs durability of hopper wagons with nominal parameters at operational loadings

The calculation of the durability of the load-bearing structure of the hopper wagon was performed by the finite element method, implemented in the CosmosWorks software environment. The finite element model of the hopper wagon is shown in Figure 3.31.

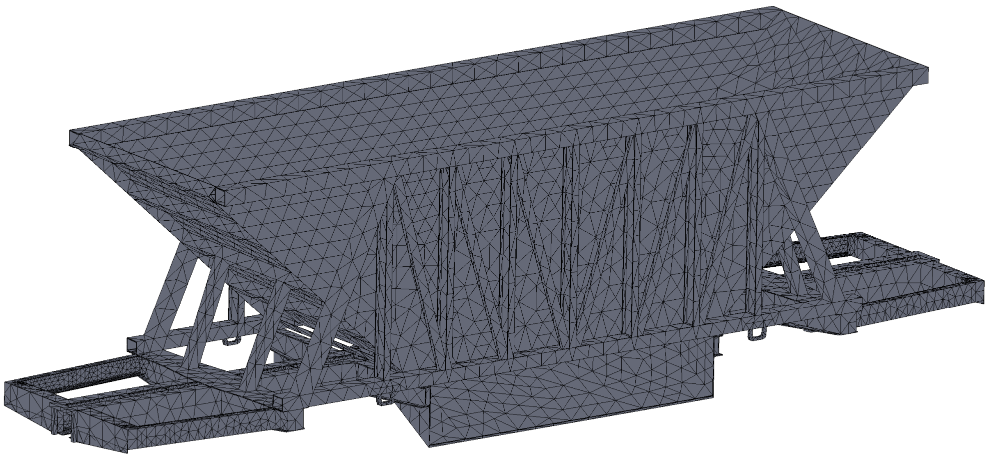


Figure 3.31. Finite element model of a hopper wagon

The optimal number of grid elements was determined using the graphoanalytical method [21–23]. The number of grid elements was 376670, the number of the nodes was 126221. The maximum size of the grid element is 60 mm, the minimum one is 12 mm, the maximum ratio of the sides of the elements is 1298.6, the percentage of elements with a ratio of less than three is 7.43, of more than ten is 32,5.

The design scheme of the load-bearing structure of the hopper wagon in the most unfavorable operating mode – shunting collision – is shown in Figure 3.32.

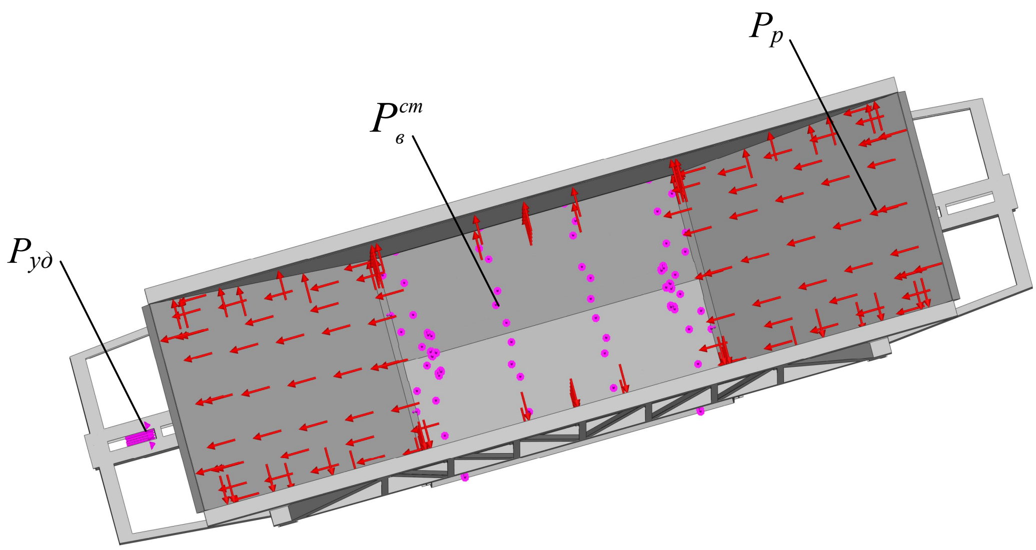


Figure 3.32. The computational model of the hopper wagon load-bearing structure durin shunting collision

It is taken into account that the supproting structure of the wagon is subject to vertical static load $P_в^{ст}$ due to the weight of the load. The design of the body is also affected by the forces of expansion from the bulk cargo P_p , the numerical values of which are calculated according to the formula (3.6). The vertical surface of the rear stop is affected by the impact load $P_{уд}$, the numerical value of which in accordance with regulations is 3.5 MN.

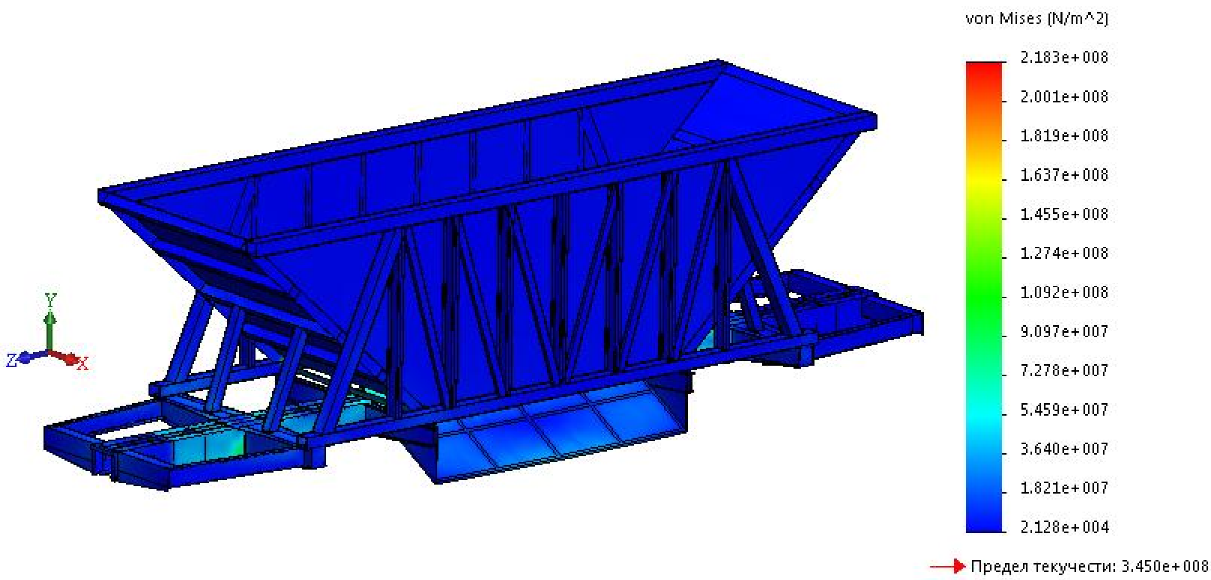
The active flowable freight pressure is determined according to the formula [1–3]

$$P_а = \gamma \cdot g \cdot H \cdot \mathrm{tg}^2\left(\frac{\pi}{4} - \frac{\varphi}{2}\right), \quad (3.6)$$

where γ is the density of the flowable cargo, t/m^3; H is the height of the side wall, m; φ is the natural slope of the cargo rolling, rad; g is the acceleration of free fall, m / s^2.

The model was fastened in the places where the the body rests on the chassis. The model is made of steel of grade 09G2S. The results of the calculation are shown in Figure 3.33, 3.34.

a)



b)

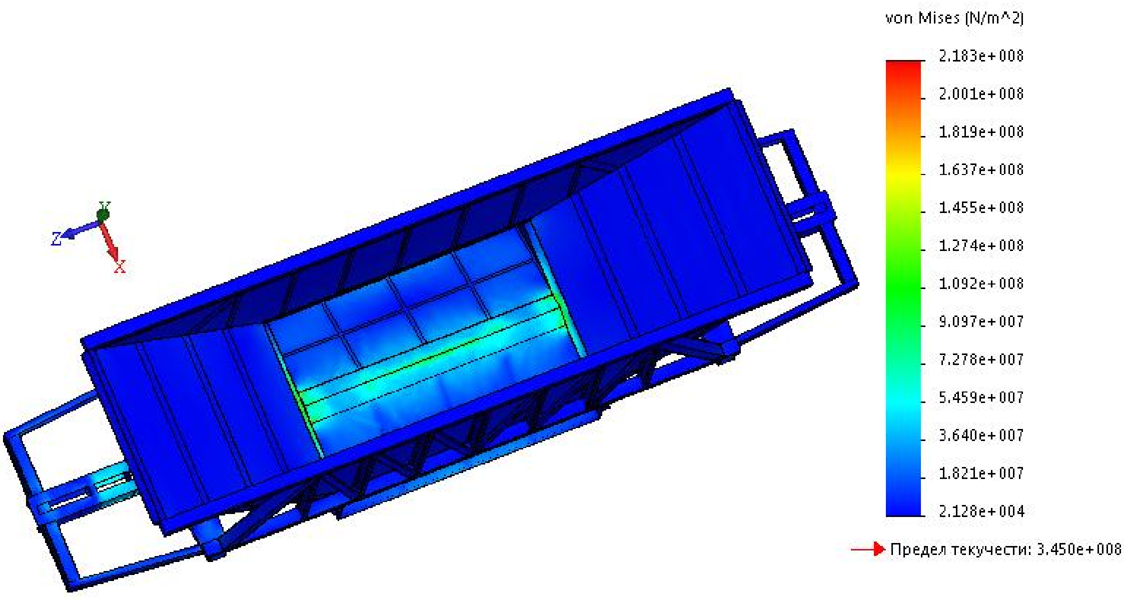
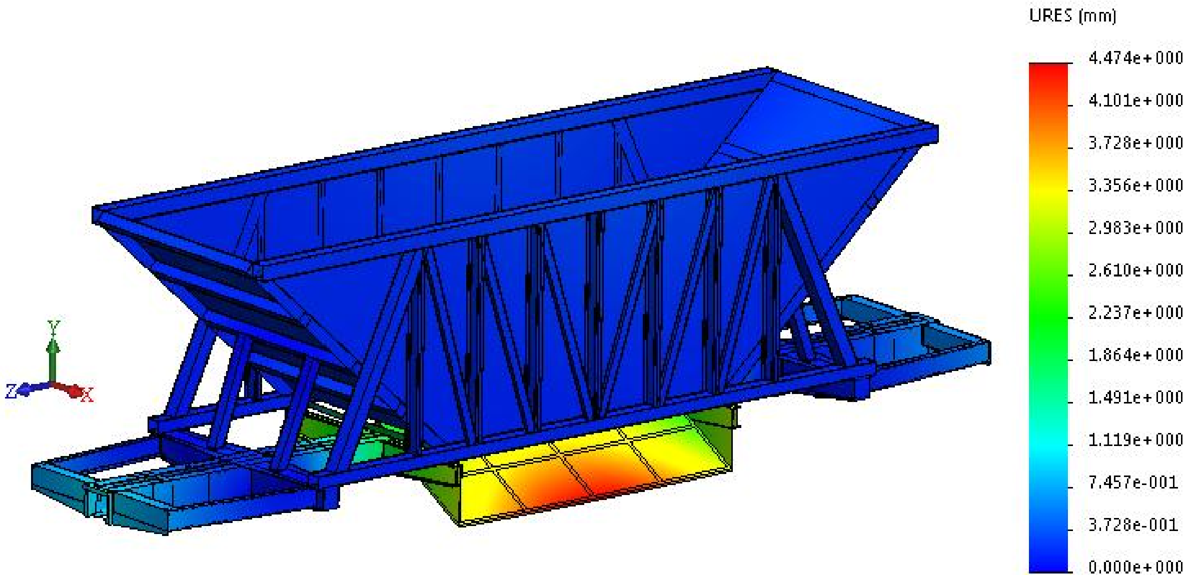


Figure 3.33. Loaded condition
of the hopper wagon load-bearing structure

a) side view; b) bottom view

a)



b)

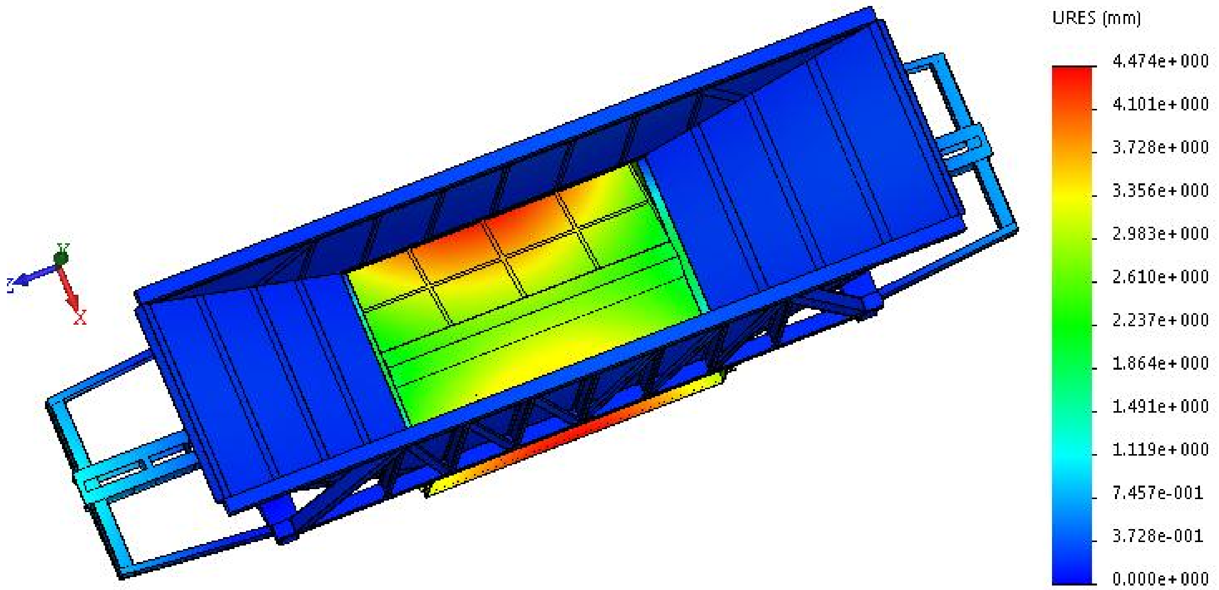
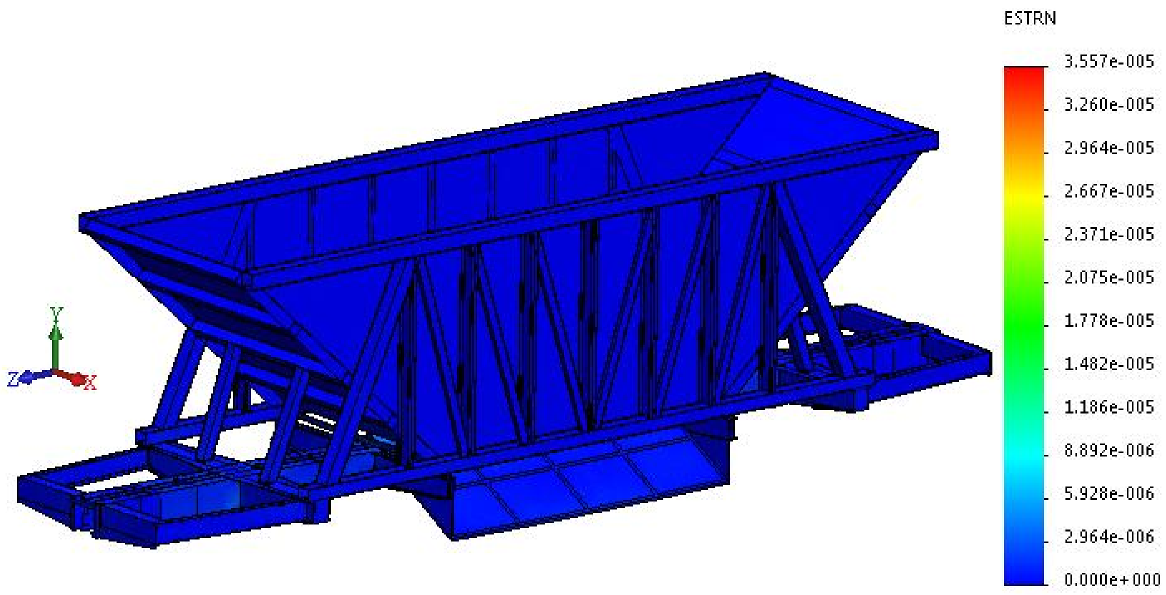


Figure 3.34. The movement in the nodes of the load-bearing structure of the hopper wagon

a) side view; b) bottom view

a)



b)

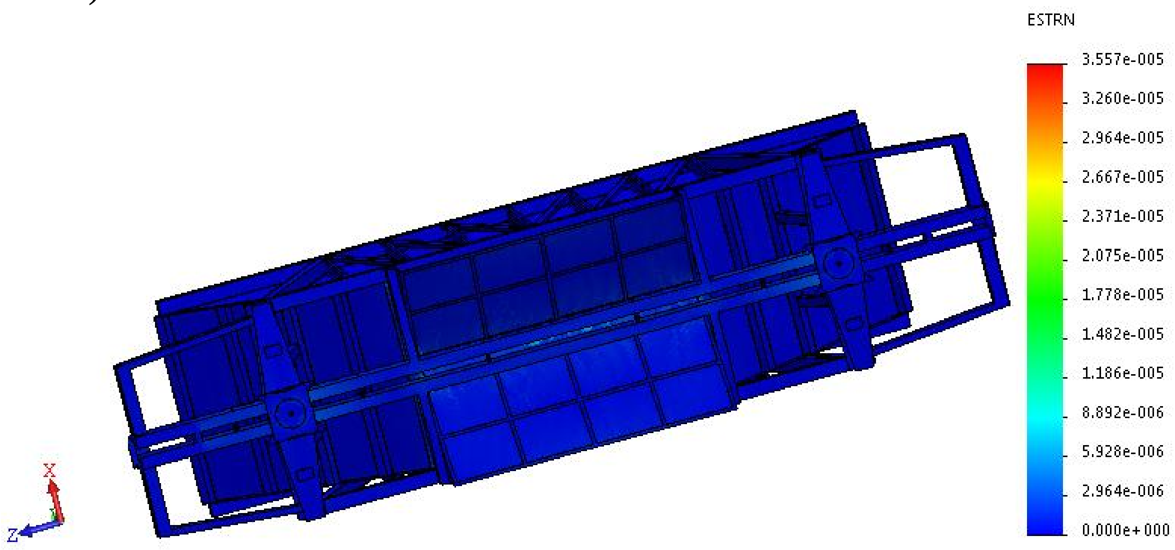


Figure 3.35. Deformations in the load-bearing structure of the hopper wagon

a) side view; b) bottom view

The calculation was also performed for other operational load schemes. The results of the calculation are given in Table 3.7.

Table 3.7

The results of the calculation of the load-bearing structure durability of the hopper wagon

Durability value	*Load mode*				
	I			III	
	Impact	*compression*	*Jerk-stretching*	*impact – compression*	*jerk – stretching*
Load, MPa	220	186,6	175,4	196,8	169,5
Movement in the nodes, mm	4,5	3,8	3,7	4,1	3,6

The maximum equivalent loads in the load-bearing structure of the hopper wagon occur in rating condition I (impact) and are about 220 MPa. They are concentrated in the area of interaction of the spinal beam with the pivot beam. The maximum displacements occur in the unloading hoppers and are about 4.5 mm. Maximum deformation is $3,6 \cdot 10^{-5}$.

CONCLUSIONS TO CHAPTER 3

1. Spatial models of supporting load-bearing structures of the main types of freight wagons with nominal sizes of constituent elements have been created. To this end albums of drawings of the corresponding types of wagons were used, which were taken into account during the research.

2. The durability of the created load-bearing structures of wagons has been calculated by the method of finite elements. The main rating conditions of wagons – I and III – were taken into account.

The numerical values of the maximum equivalent loads and their distribution fields are determined. It is established that the maximum values of equivalent loads are observed in rating condition I (shock). They are concentrated in the zones of interaction of pivot beams with the spine beams. The margin of safety is about 1. This value of the margin of safety is obtained for the steel grade 09G2S, which is typical for the manufacture of load-bearing structures of wagons.

Calculations were made for other load schemes. In all calculation options, the maximum equivalent loads do not exceed the allowable ones for steel grades of metal structures of bodies.

4 DEVELOPMENT AND ANALYSIS OF DYNAMIC LOADING FUNCTIONAL DEPENDENCES OF TYPICAL DESIGNS OF DOMESTIC PARK FREIGHT WAGONS WITH ACTUAL PARAMETERS

4.1. Determination of dynamic loading of load-bearing structures of freight wagons in the vertical plane

To determine the actual dynamic load of the load-bearing structure of the gondola gar, the wear of its supporting elements in operation is taken into account (Figures 4.1, 4.2). In this case, the upper index of the ordinal number of the structural element characterizes the nominal value of the thickness, and the lower index characterizes the actual value, which is recorded during field studies [24, 25].

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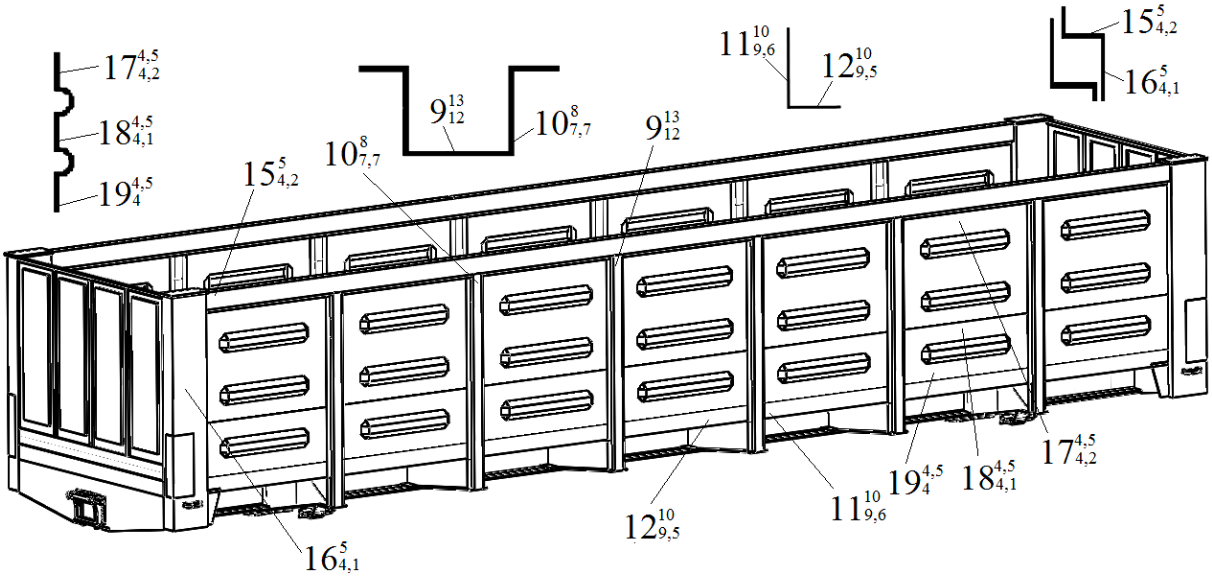


Figure 4.1. A spatial model of the gondola wagon load-bearing structure with indication of nominal and defined minimum actual average thicknesses of elements of supporting components

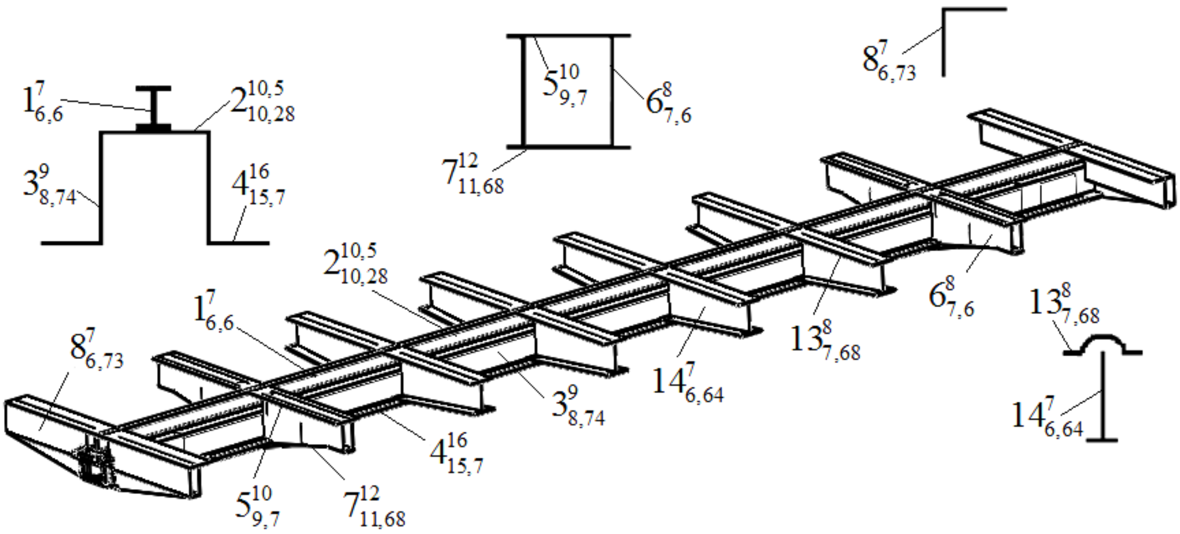


Figure 4.2. A spatial model of the gondola wagon frame with indication of nominal and defined minimum actual average thicknesses of elements of supporting components

On the basis of the research, it was established that the weight of the load-bearing structure of the gondola wagon is less by 16.3 % than the weight of the load-bearing structure with nominal dimensions [26].

Thus, the mass of the load-bearing structure of the gondola wagon is 13.1 tons, and the moment of inertia is 260.1 tons· m^2. Taking into account the received data the basic indicators of dynamics of a load-bearing structure of a gondola wagon are defined. The results of the calculation are shown in Figures 4.3, 4.4.

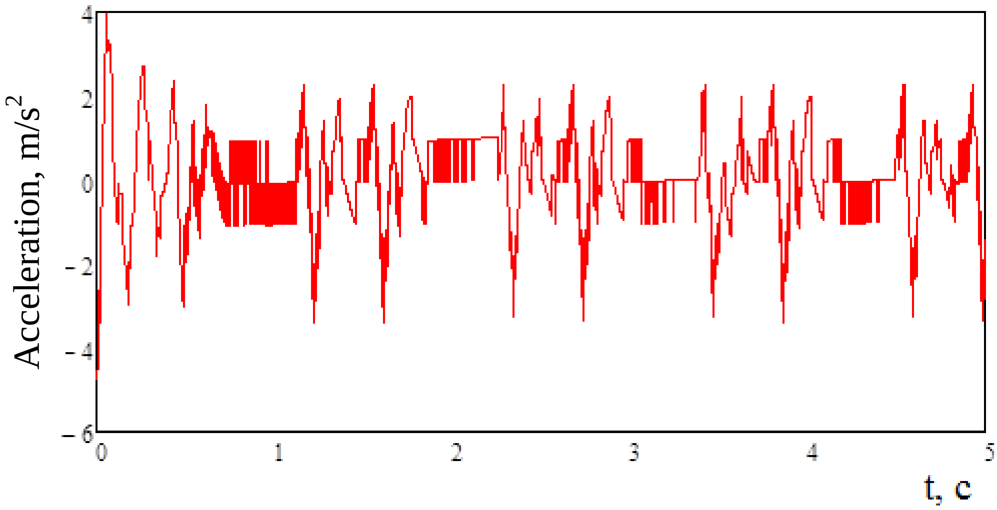


Figure 4.3. Acceleration of the load-bearing structure of the gondola wagon in the center of mass

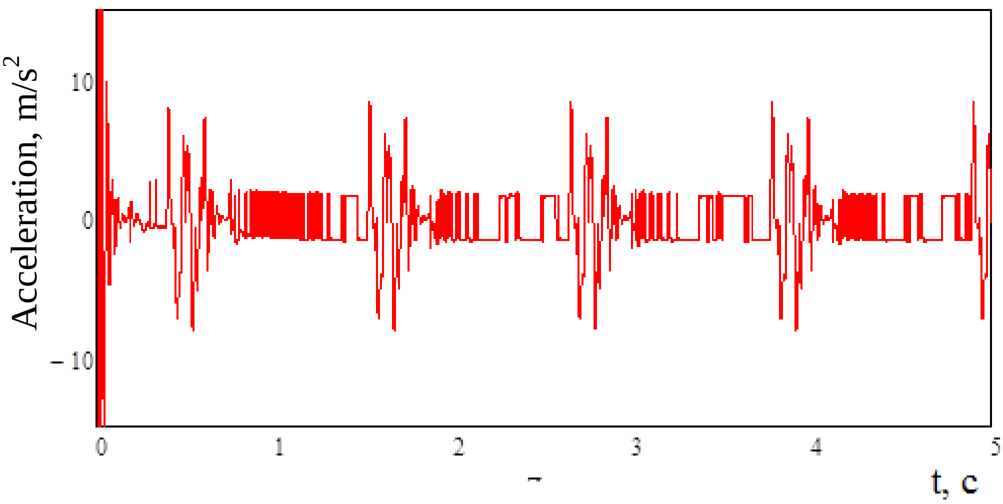


Figure 4.4. Acceleration of carriages

According to the mathematical model (3.1) – (3.6), other indicators of the gondola wagon dynamics are determined (Table 4.1). The calculation was performed at a wagon speed of 80 km / h.

Table 4.1

Dynamic performance of a gondola wagon moving in an empty state

Indicator	*Value*
Body acceleration, m/s^2	4,87
Acceleration of the body in the area of basing on the first carriage facing the engine, m/s^2	6,4
Acceleration of the body in the area of basing on the second carriage facing the engine, m/s^2	6,4
Force in the spring suspension of the first carriage, kN	42,7
Force in the spring suspension of the second carriage, kN	42,7
Dynamics coefficient of the first carriage	0,65
Dynamics coefficient of the second carriage	0,65

The obtained results allow us to conclude that the dynamics are within acceptable limits. The movement of the wagon is assessed as «excellent».

To determine the dynamic load of the aupporting structure of the covered wagon, the abrading of its supporting elements in operation is taken into account (Figures 4.6, 4.7).

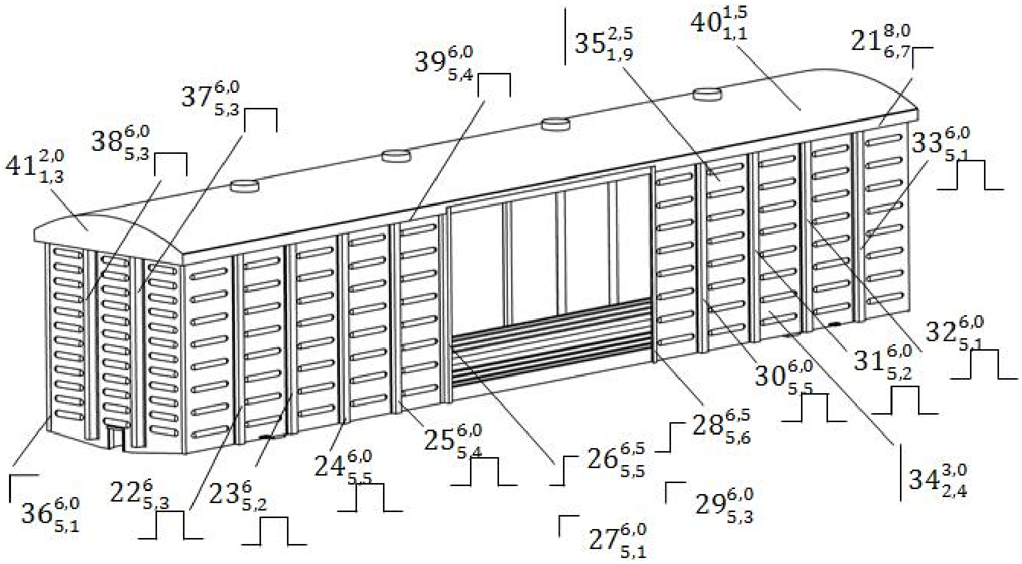


Figure 4.6. A spatial model of the load-bearing structure of a covered wagon with indication of nominal and determined minimum actual average thicknesses of elements of supporting components

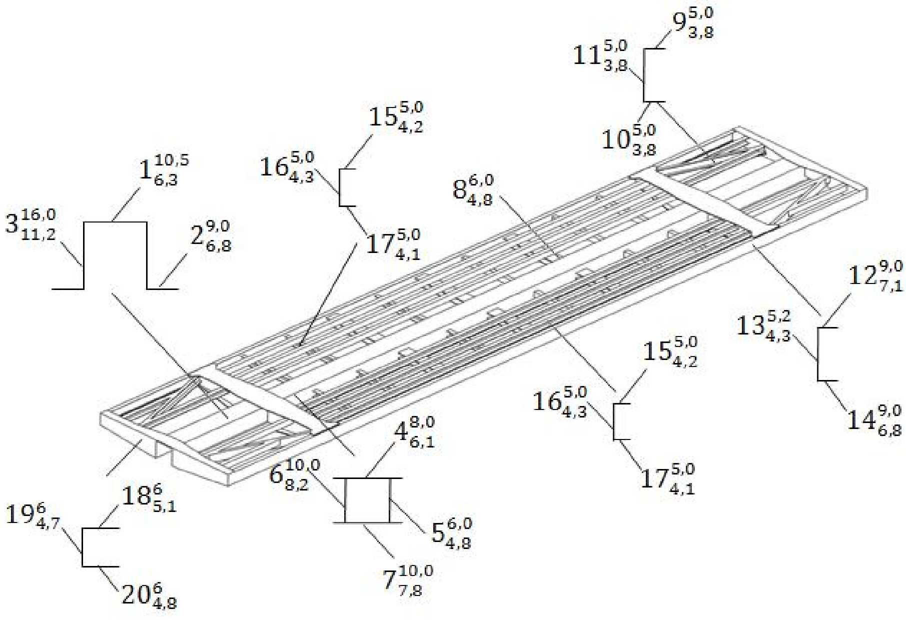


Figure 4.7. A spatial model of a covered wagon frame with indication of nominal and defined minimum actual average thicknesses of elements of supporting components

On the basis of the conducted researches it has been established that the weight of a load-bearing structure of the covered wagon is less by 17 % for weight of a load-bearing structure with the nominal sizes.

Thus, the mass of the load-bearing structure of the gondola wagon is 12.7 tons, and the moment of inertia is 265.6 tons· m^2. Taking into account the obtained data, the main indicators of the dynamics of the load-bearing structure of the covered wagon are determined. The results of the calculation are shown in Figures 4.8, 4.9.

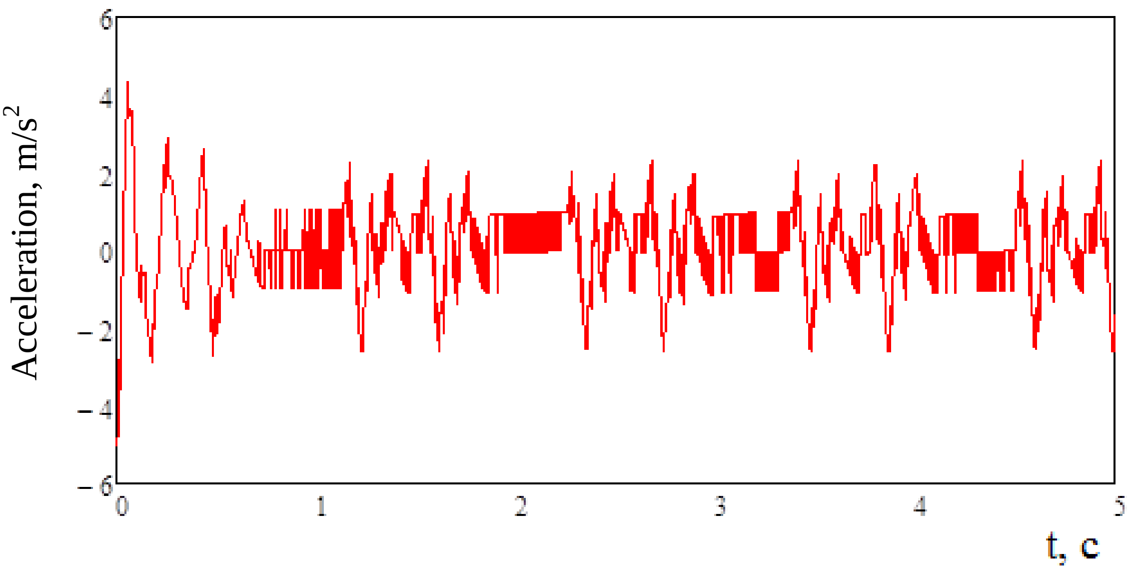


Figure 4.8. Acceleration of the load-bearing structure of the covered wagon in the center of mass

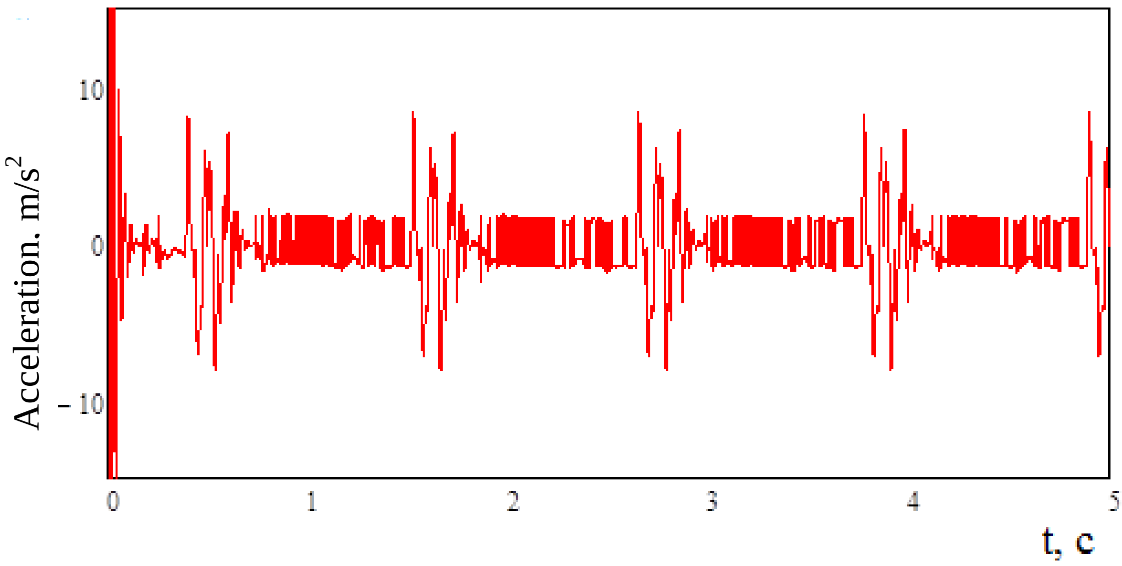


Figure 4.9. Acceleration of carriages

Other indicators of dynamics of the covered wagon are defined (table 4.2.) according to the mathematical model (3.1.) – (3.6). The calculation was performed at a wagon speed of 80 km / h.

Table 4.2

Dynamic performance of a covered wagon moving in an empty state

Indicator	*Value*
Body acceleration, m/s^2	5,6
Acceleration of the body in the area of basing on the first carriage facing the engine, m/s^2	8,7
Acceleration of the body in the area of basing on the second carriage facing the engine, m/s^2	8,7
Force in the spring suspension of the first carriage, kN	41,2

Indicator	*Value*
Force in the spring suspension of the second carriage, kN	41,2
Dynamics coefficient of the first carriage	0,73
Dynamics coefficient of the second carriage	0,73

The obtained results allow us to conclude that the dynamics are within acceptable limits. The movement of the wagon is assessed as «good».

To determine the dynamic load of the load-bearing structure of the flat wagon, field studies of the technical condition of the main supporting elements of the frame were wagonried out on the basis of the wagon depot. The basis of the branch is the Southern Railway Ukrzaliznytsia joint stock company.The value measured during field research is the thickness of the I-beam leg (Figure 4.10).

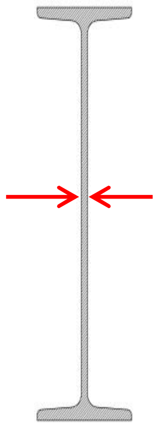


Figure 4.10. The measurement area of the I-beam leg thickness

The number of measurements is 20. The measurement results are shown in Tables 4.3, 4.4.

Table 4.3

The measurements results of the spine beam abrading of the flat wagon frame 13-401

Progressive wagon number	1	2	3	4	5	6	7	8	9	10
Measurement value, mm	11,74	11,74	11,74	11,74	11,72	11,72	11,72	11,7	11,7	11,72
Progressive wagon number	11	12	13	14	15	16	17	18	19	20
Measurement value, mm	11,72	11,72	11,76	11,74	11,74	11,72	11,7	11,7	11,72	11,72

Table 4.4

The measurements results of abrading of the longitudinal beam I-beam of the flat wagon frame 13-401

Progressive wagon number	1	2	3	4	5	6	7	8	9	10
Measurement value, mm	11,7	11,69	11,7	11,71	11,71	11,7	11,72	11,7	11,7	11,72
Progressive wagon number	11	12	13	14	15	16	17	18	19	20
Measurement value, mm	11,72	11,72	11,72	11,7	11,71	11,7	11,7	11,7	11,72	11,72

It is established that the mass of the load-bearing structure of the flat wagon, taking into account the largest amount of abrading of its elements recorded during field research, is 3.5 % less than the load-bearing structure of the flat wagon, which has nominal dimensions.

Thus, the mass of the load-bearing structure of the flat wagon is 11.1 tons, and the moment of inertia is 102 tons·m^2. Taking into account the received data the basic indicators of dynamics of a flat wagon load-bearing structure are defined. The results of the calculation are shown in Figures 4.11, 4.12.

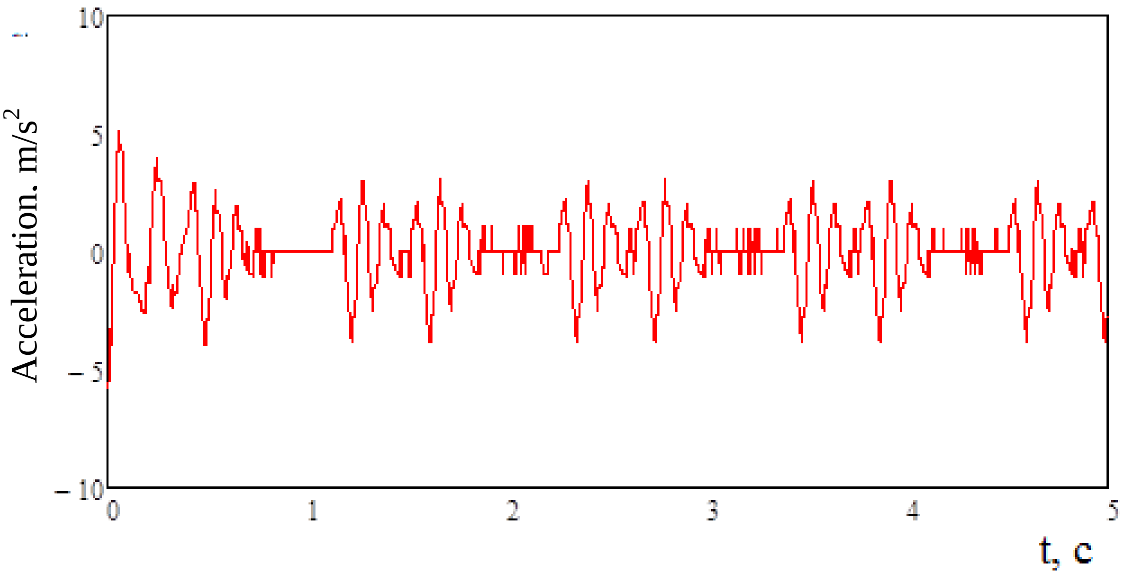


Figure 4.11. Acceleration of the load-bearing structure of the flat wagon in the center of mass

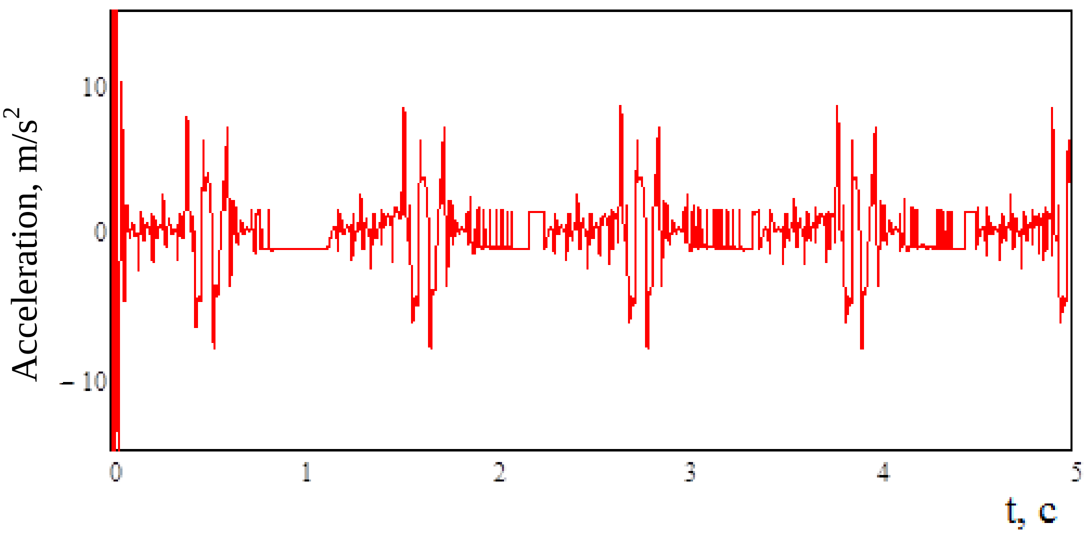


Figure 4.12. Acceleration of carriages

According to the mathematical model (3.1) – (3.6) other indicators of the flat wagon dynamics have been determined (Table 4.5). The calculation was performed at a wagon speed of 80 km / h.

Table 4.5

Dynamic indicators of a flat wagon moving in an empty state

Indicator	*Value*
Body acceleration, m/s^2	5,8
Acceleration of the body in the area of basing on the first carriage facing the engine, m/s^2	10,1
Acceleration of the body in the area of basing on the second carriage facing the engine, m/s^2	10,1
Force in the spring suspension of the first carriage, kN	42,5
Force in the spring suspension of the second carriage, kN	42,5
Dynamics coefficient of the first carriage	0,77
Dynamics coefficient of the second carriage	0,77

The obtained results allow us to conclude that the dynamics is within acceptable limits. The movement of the wagon is assessed as «good».

To determine the dynamic load of the load-bearing structure of the hopper wagon, the abrading of its supporting elements in operation is taken into account (Figures 4.13, 4.14).

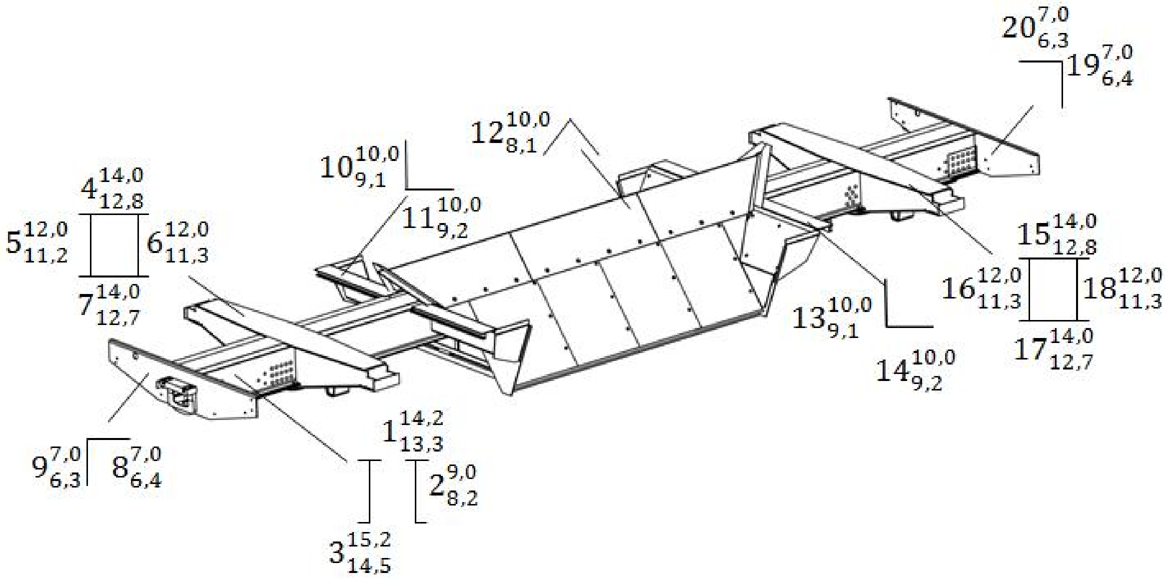


Figure 4.13. A spatial model of the hopper wagon frame with indication of nominal and defined minimum actual average thicknesses of supporting components elements

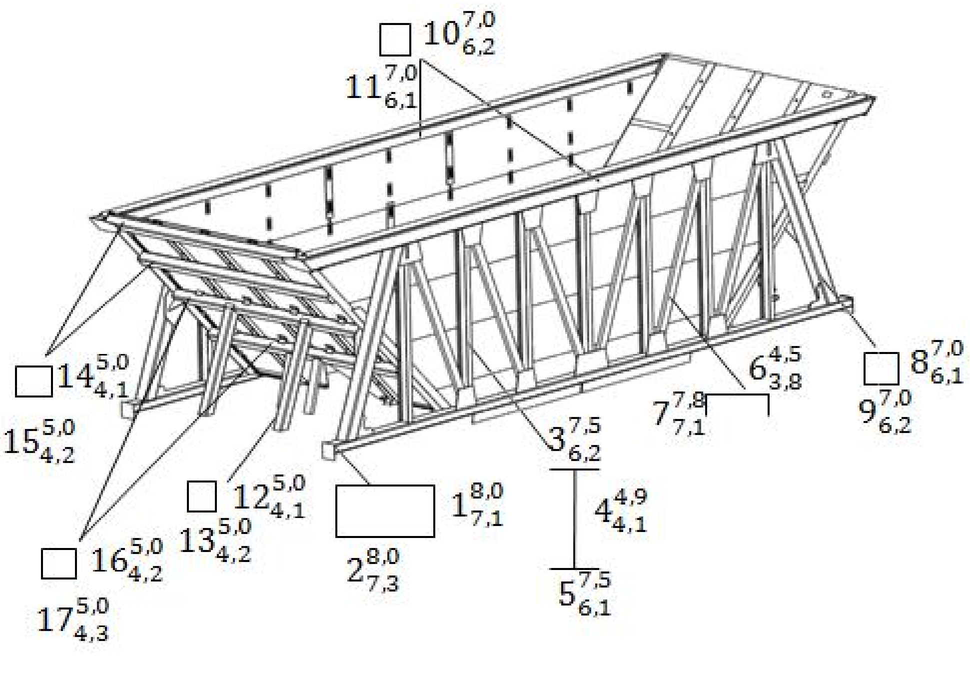


Figure 4.14. A spatial model of the hopper wagon body with indication of nominal and defined minimum actual average thicknesses of supporting components elements

It has been established that the weight of the hopper wagon load-bearing structure, taking into account the largest amount of elements abrading recorded during field research, is 9.3 % less than the load-bearing structure of the hopper wagon, which has nominal dimensions.

Thus, the mass of the load-bearing structure of the hopper wagon is 14.1 tons, and the moment of inertia is 105.5 tons·m^2. Taking into account the obtained data, the main dynamics indicators of the hopper wagon load-bearing structure have been determined. The results of the calculation are shown in Figures 4.15, 4.16.

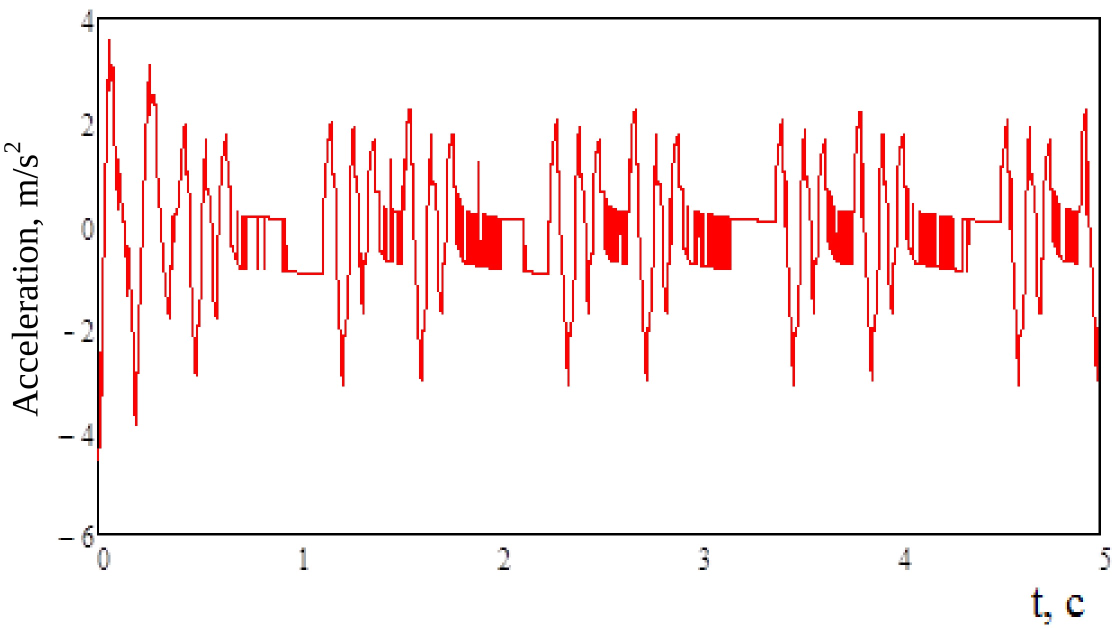


Figure 4.15. Acceleration of a hopper wagon load-bearing structure in the center of mass

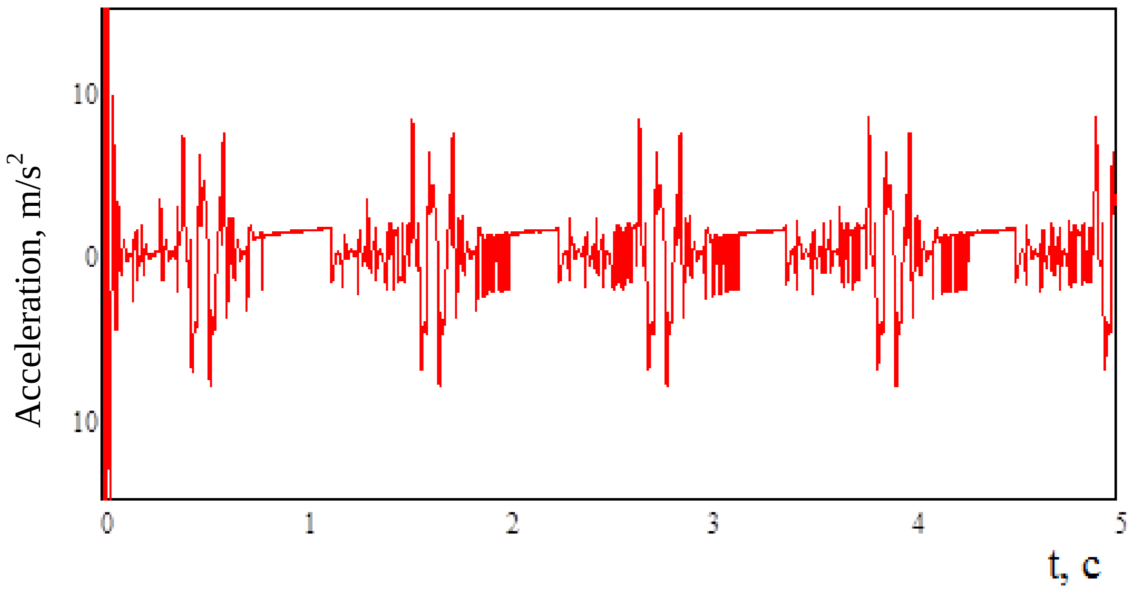


Figure 4.16. Acceleration of carriages

За математичною моделлю (3.1) – (3.6) визначені і інші показники динаміки вагона-хопера (таблиця 4.6). Розрахунок проведений при швидкості руху вагона 80 км/год.

Other dynamics indicators of the hopper wagon have been determined (Table 4.6) according to the mathematical model (3.1) – (3.6). The calculation was performed at a wagon speed of 80 km / h.

Table 4.6

Dynamic indicators of a hopper wagon moving in an empty condition

Indicator	*Value*
Body acceleration, m/s^2	4,5
Acceleration of the body in the area of basing on the first carriage facing the engine, m/s^2	10,3

Indicator	*Value*
Acceleration of the body in the area of basing on the second carriage facing the engine, m/s^2	10,3
Force in the spring suspension of the first carriage, kN	44,6
Force in the spring suspension of the second carriage, kN	44,6
Dynamics coefficient of the first carriage	0,63
Dynamics coefficient of the second carriage	0,63

The obtained results allow us to conclude that the dynamics is within acceptable limits. The movement of the wagon is assessed as «good».

To determine the dynamic load of the load-bearing structure of the tank wagon, the abrading of its supporting elements in operation is taken into account (Figures 4.17, 4.18).

It has been established that the weight of the tank wagon load-bearing structure, taking into account the largest amount of abrading of its elements recorded during field research, is 8.2 % less than the load-bearing structure of the tank wagon, which has nominal dimensions.

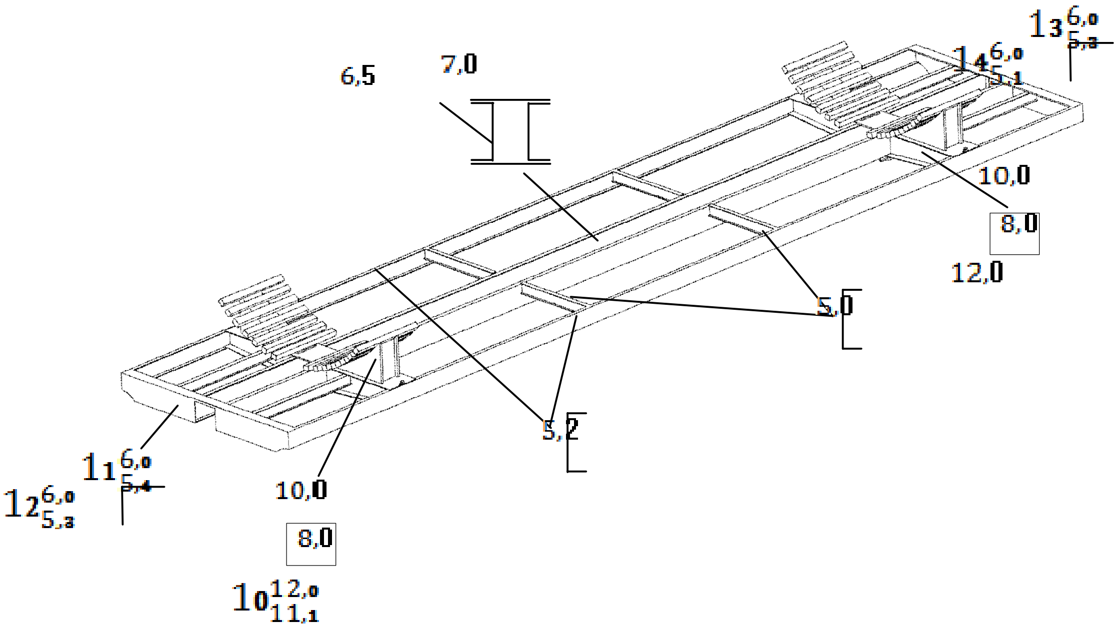


Figure 4.17. A spatial model of the tank wagon frame with the indication of nominal and determined minimum actual average thicknesses of supporting components elements

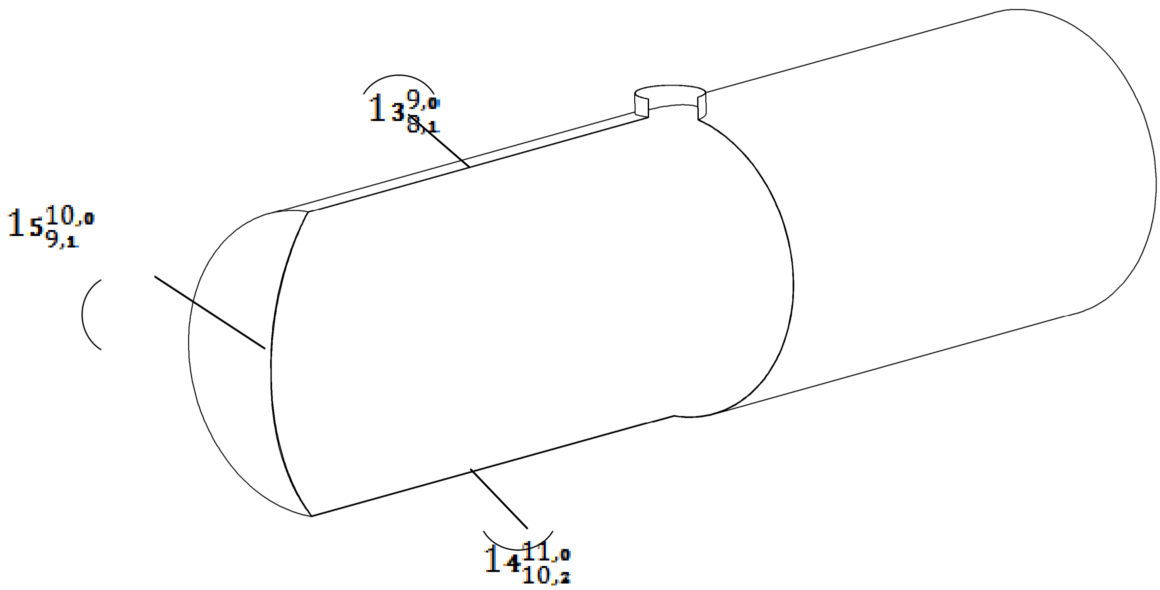


Figure 4.18. A spatial model of the tank wagon copper with the indication of nominal and defined minimum actual average thicknesses of supporting components elements

Thus, the mass of the load-bearing structure of the tank wagon is 15.05 tons, and the moment of inertia is 223.9 t · m^2. Taking into account the obtained data, the main indicators of the dynamics of the tank wagon load-bearing structure have been determined. The results of the calculation are shown in Figures 4.19, 4.20.

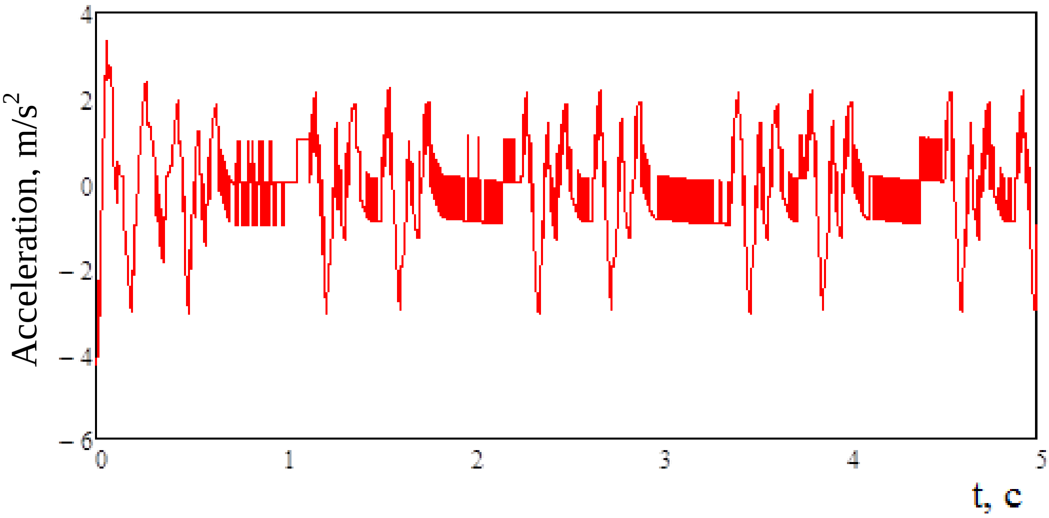


Figure 4.19. Acceleration of a tank wagon load-bearing structure in the center of mass

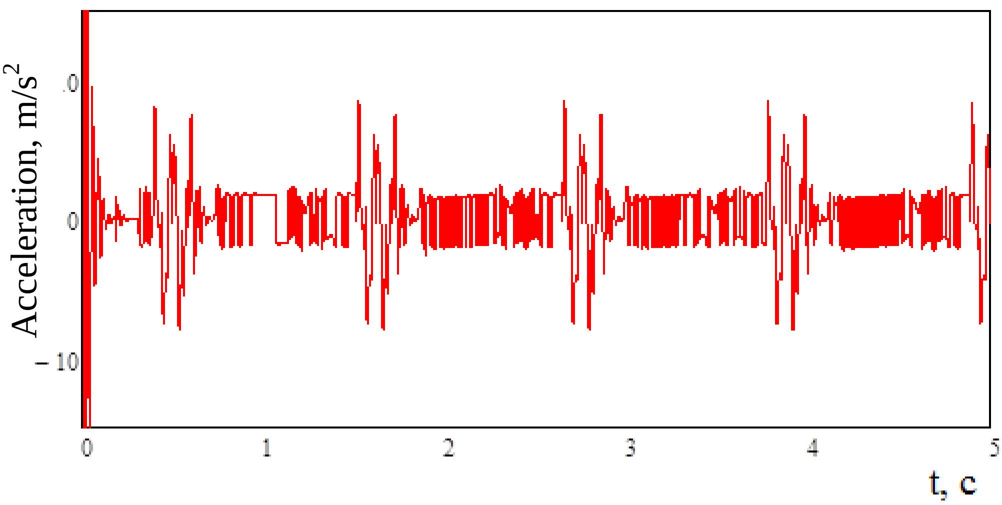


Figure 4.20. Carriages acceleration

Other indicators of the the tank wagon dynamics have been determined (Table 4.7) according to the mathematical model (3.1) – (3.6). The calculation was performed at a wagon speed of 80 km / h.

Table 4.7

Dynamic indicators of a tank wagon moving in an empty condition

Indicator	*Value*
Body acceleration, m/s^2	4,25
Acceleration of the body in the area of basing on the first carriage facing the engine, m/s^2	9,98
Acceleration of the body in the area of basing on the second carriage facing the engine, m/s^2	9,98
Force in the spring suspension of the first carriage, kN	44,3
Force in the spring suspension of the second carriage, kN	44,3
Dynamics coefficient of the first carriage	0,59
Dynamics coefficient of the second carriage	0,59

The obtained results allow us to conclude that the dynamics is within acceptable limits. The movement of the wagon is assessed as «excellent».

4.2. Determination of dynamic loading of freight wagons load-bearing structures in the longitudinal plane

To determine the dynamic loads acting on the load-bearing structures of wagons with actual dimensions under the action of longitudinal force (shunting collision), the mathematical model given in [4] was used. Inertial coefficients of load-bearing structures of the considered types of wagons are given in Table 4.8.

Table 4.8

Inertial coefficients of supporting of wagons

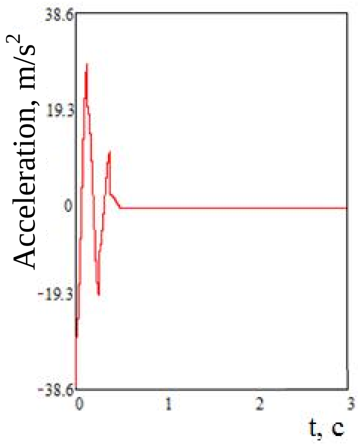
Wagon type	*Gross mass of the wagon, t*	*Load-bearing structure mass, t*	*Inertia amoment, t·m²*
A gondola wagon	91,5	82,1	1228,5
A covered wagon	90,1	80,7	1207,4
A flat wagon	90,5	81,1	1111,6
A tank wagon	90,45	81,05	1084,3
A hopper wagon	92,5	83,1	1232,4

The basic dynamics indicators of the considered wagon types have been received on the basis of the wagonried out calculations. The results of the calculation are given in Table 4.9, as well as illustrated in Figure 4.19.

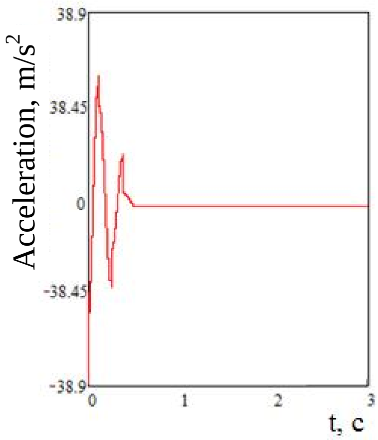
Table 4.9

Acceleration affecting the supporting wagon structures

Wagon type	*Acceleration, m/s²*
A gondola wagon	38,35
A covered wagon	38,6
A flat wagon	38,9
A tank wagon	27,4
A hopper wagon	38,5



a)



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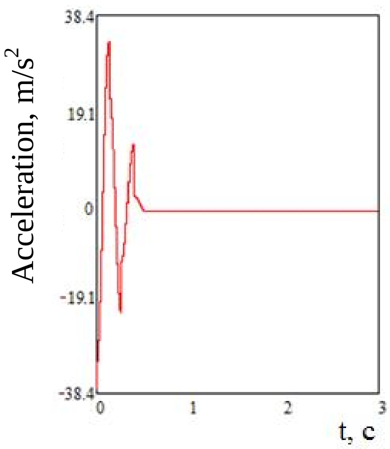


c)

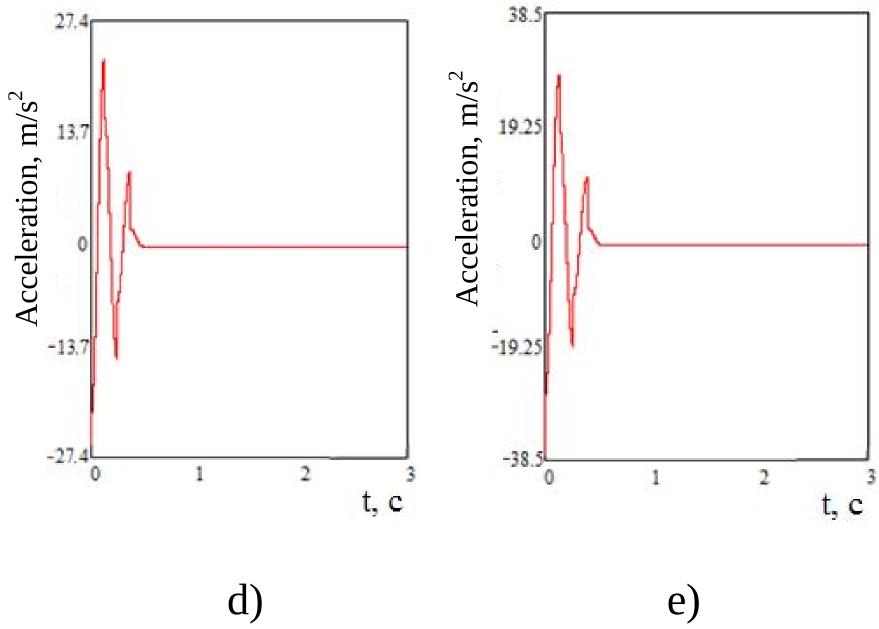


Figure 4.19. Accelerations affecting the supporting wagon structures

a) a gondola wagon; b) a covered wagon; c) a flat wagon; d) a tank wagon; e) a hopper wagon

Therefore, the acceleration affecting the supporting wagon structures with actual dimensions exceed those obtained at nominal: for a gondola wagon by 2.4 %, for a covered wagon – 1.7 %, for a flat wagon – 1 %, for a tank wagon – 2.7 %, for a hopper wagon – 2.7 %.

CONCLUSIONS TO CHAPTER 4

1. Spatial models of load-bearing structures of the main types of freight wagons with the actual dimensions of the constituent elements have been created. It has been established that taking into account the abrading of structural elements of wagon load-bearing structures, the actual weight decreases in comparison with prototype wagons: a gondola wagon – 16.3 %, a covered wagon – 17.0, a flat wagon – 3.5 %, a tank wagon – 8.2 %, and a hopper wagon – 9.3 %.

2. The dynamic loading of load-bearing structures of freight wagons with actual dimensions in the vertical plane has been determined. The calculation was wagonried out under the condition that the wagons moved in an empty condition. It has been established that the acceleration acting on the load-bearing structures of wagons with the actual dimensions of the elements are within acceptable limits. At the same time, the acceleration acting on the load-bearing structures of wagons with actual dimensions exceed those obtained from the wagons with nominal dimentions: for a gondola wagon by 16 %, for a covered wagon – 25 %, for a flat wagon – 4 %, for a tank wagon – 9 % , for a hopper wagon – 2 %.

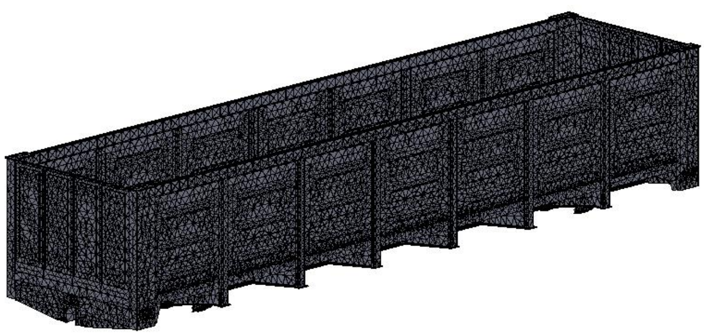
3. The dynamic loading of load-bearing structures of freight wagons with actual dimensions in the longitudinal plane has been determined. The calculation is performed for the case of shunting collision of wagons or «jerk» (a tank wagon). This takes into account the full use of load capacity of wagons. It has been established that the acceleration affecting the load-bearing structures of wagons with actual dimensions exceed those obtained from the wagons with nominal dimentions: for a gondola wagon – by 2.4 %, for a covered wagon – by 1.7 %, for a flat wagon – by 1 %, for a tank wagon – by 2,7 %, for a hopper wagon – by 2,7 %.

5. RESEARCH OF TYPICAL DESIGNS DURABILITY OF DOMESTIC PARK FREIGHT WAGONS WITH ACTUAL PARAMETERS AT OPERATIONAL (STANDARDIZED AND EXCESSIVE) LOADINGS

5.1. Research of typical designs durability of gondola wagons with actual parameters at operational loading

To study the durability of the load-bearing structure of the gondola wagon body, taking into account the simulation of abrading, characteristic of 1.5 service life, the thickness of the components of the supporting elements is reduced by the amount of possible abrading. The calculation is performed by the finite element method. The finite-element model of the load-bearing structure of the gondola wagon with the simulation of abrading characteristic of 1.5 service life is shown in Figure 5.1 [24].

a)



b)

Figure 5.1. A finite-element model of the load-bearing structure of the gondola wagon body

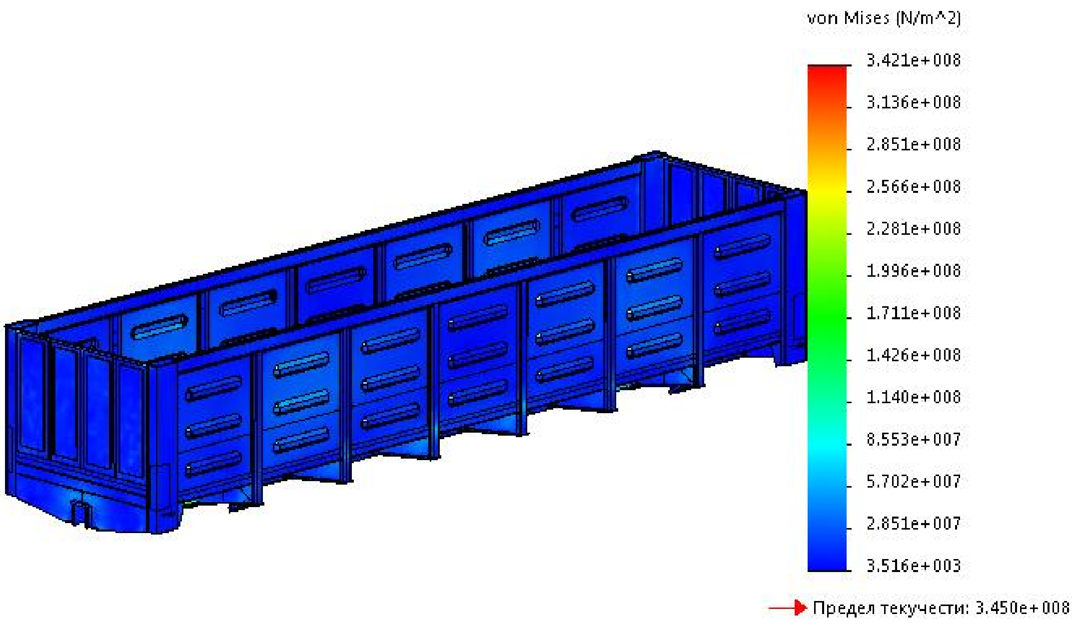
a) side view; b) bottom view

The number of grid elements was 473652, the number of nodes was 154365. The maximum size of the grid element is 80 mm, the minimum size is 16 mm, the maximum ratio of the sides of the elements is 566.7, the percentage of elements with a ratio of less than three is 25, of more than ten is 27.4. The results of the calculation are shown in Figure 5.2.

The maximum equivalent load occurs in the lower zone of interaction of the pivot beam with the spine beam, it is about 330 MPa; the maximum displacements in the nodes of the structure are recorded in the middle part of the gondola wagon frame, thye are 3.6 mm, the maximum deformation was $2{,}73 \cdot 10^{-3}$.

The results of the calculation of the gondola wagon load-bearing structure durability in other rating conditions are shown in Table 5.1.

а)



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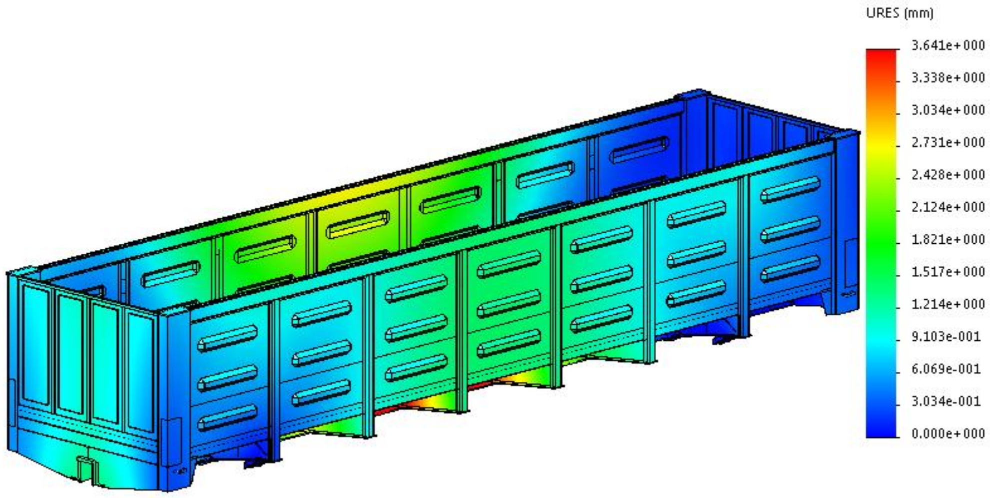


Figure 5.1. The results of the durability calculation of the 12-757 model gondola wagon load-bearing structure in the first mode I (impact)

a) loaded condition; b) movement in the nodes of the structure

Table 5.1

The results of the durability calculation of the load-bearing structure of the gondola wagon with the actual dimensions

Durability indicator	*Load mode*				
	I			*III*	
	impact	*compression*	*jerk-stretching*	*impact – compression*	*jerk – stretching*
Load, МПа	342,1	250	280	220	260
Movement in the nodes, mm	3,6	4,1	3,2	2,2	2,4

Table 5.1 shows that the maximum equivalent load occurs at I r.c. (impact), but they are within acceptable limits and do not exceed the yield durability of the material [13, 14].

5.2. Research of typical designs durability of covered wagons with actual parameters at operational loadings

To determine the main durability indicators of the load-bearing structure of the covered wagon with the abrading value shown in Figures 4.6, 4.7, the calculation was performed by the finite element method, which is implemented in the CosmosWorks software environment [27 – 30]. The finite element model of the load-bearing structure of the covered wagon is shown in Figure 5.2.

The graphoanalytical method was used to determine the number of grid elements. Ten-node isoparametric tetrahedra were used as finite elements. The number of elements of the grid was 661885, the number of the nodes was 231671. The maximum size of the element was 100 mm, the minimum size was 20 mm, the maximum sides ratio was 845.3, the percentage of elements with a sidet ratio less than 3 was 11.6, of more than 10 – 46.7.

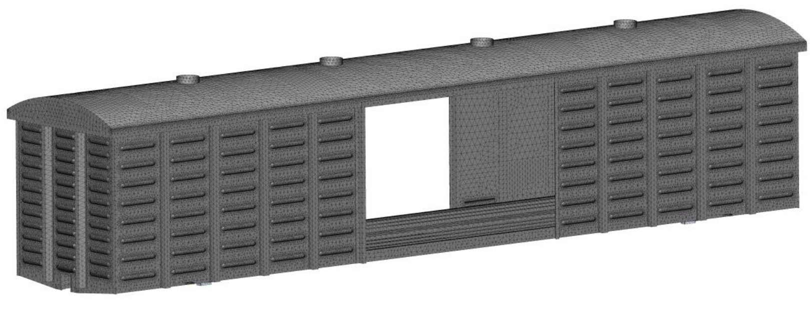


Figure 5.2. A finite element model of the load-bearing structure of a covered wagon

The ratio of increasing the size of the element is 1.8. The minimum number of elements in the circle is 22. The model was fixed in the places where the load-bearing structure was based on the carriages. When calculating scheme of the load-bearing structure of the covered wagon, it is taken into account that it is affected by the vertical static load $P_{в}$, as well as the longitudinal load of the $P_{уд}$ on the rear stops of the autocoupling, which is equal to 3.5 MN (Figure 3.11). The results of the calculation are shown in Figures 5.3, 5.4.

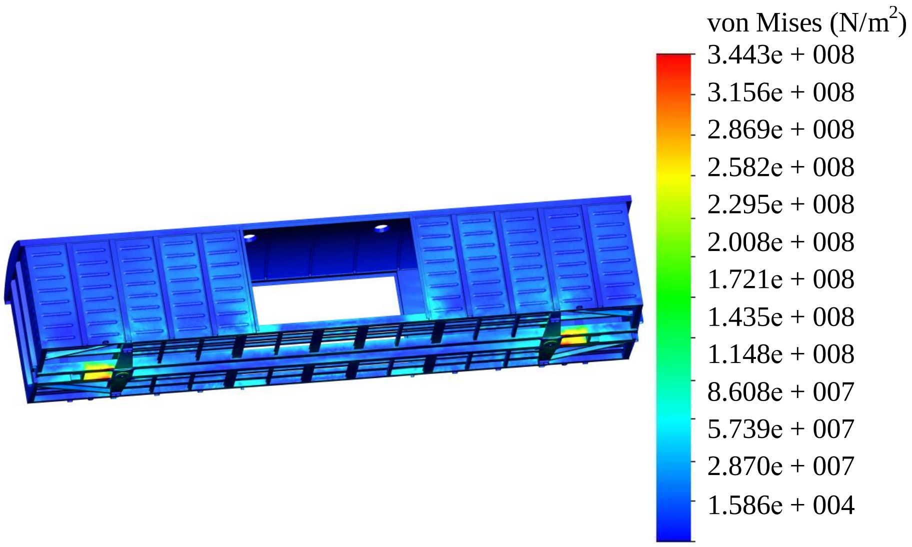


Figure 5.3. The loaded condition of a covered wagon supporting structure

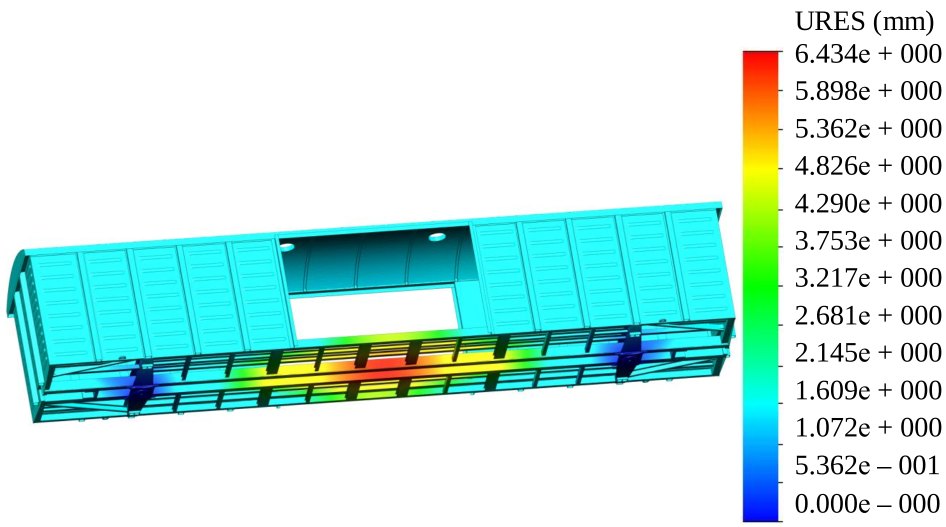


Figure 5.4. Movement in the nodes of a covered wagon load-bearing structure

The maximum equivalent load occurs in the area of interaction of the spine beam with the pivot beam, it is 344 MPa. That is, the maximum equivalent load does not exceed the allowable one [26]. The maximum displacements occur in the middle part of the spine beam, thay are equal to 6.4 mm. The maximum deformation was $3.85 \cdot 10^{-3}$.

The calculation of the covered wagon load-bearing structure is wagonried out for other calculation modes. The results of the calculation are shown in table 5.2.

Table 5.2

The results of the durability calculation of the covered wagon load-bearing structure with the actual dimensions

Durability indicator	*Load mde*				
	I			*III*	
	impact	*contraction*	*jerk – stretching*	*Impact – contraction*	*jerk – stretching*
Load, MPa	344,3	336,6	307,4	296,8	269,5
Displacemnents in the nodes, mm	6,4	5,4	4,8	4,9	4,8

Table 5.2. shows that the maximum equivalent load occurs at I r.c. (impact), but it is within acceptable limits and does not exceed the yield durability of the material [13; 14].

5.3. Research of typical designs durability of flat wagons with actual parameters at operational loadings

The method described in [31] was used to verify the possibility of extending the service life of the load-bearing structure of the flat wagon. This technique allows to determine the residual life of the elements of the load-bearing structures of wagon bodies, taking into account the probability of their failure in operation and the maximum values of equivalent loades. The statistical data of geometrical sizes of the basic supporting elements of flat wagon frames (a back beam and the main longitudinal) having service life about 25 years are used as input parameters to this technique

The spine beam and the main longitudinal beam of the flat wagon 13-401 are known to consist of two I-beams № 60, which has a variable length in height (Figure 5.5). In cantilever parts of a frame the I-beam is 360 mm high.

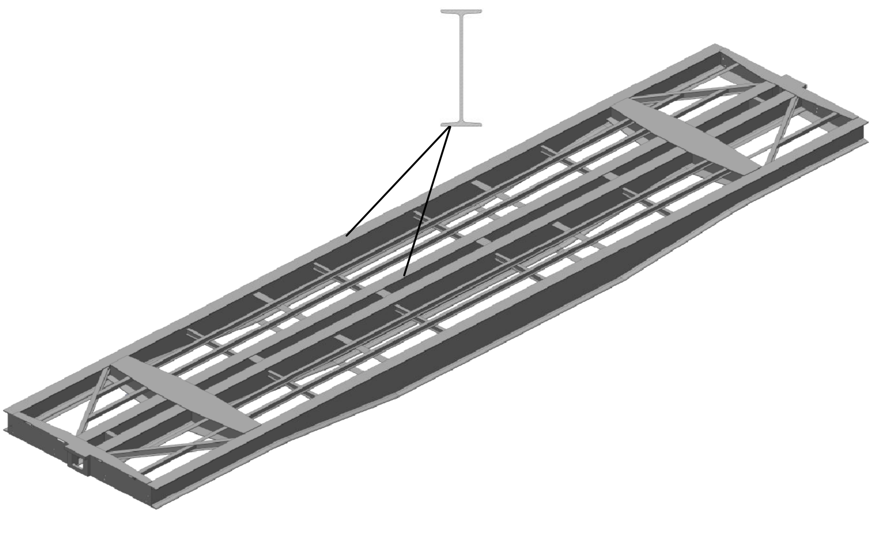


Figure 5.5. A 13-401 model flat wagon load-bearing structure

To determine the number of statistics needed to obtain an adequate result is very importan. The required number of static data is determined by the formula [32–35].

$$n = \frac{t^2 \cdot \sigma^2}{\delta^2}, \tag{5.1}$$

where t – is determined from the ratio $\Phi(t) = \gamma / 2$;

$\Phi(t)$ – Laplace function, tabular value

σ – the standard deviation of the random variable under study, which must be known a priori before the experimental measurements;

δ^2 – absolute error limit of measurement result.

But in practice, the standard deviation in most cases is unknown and is determined during the study.

If σ is unknown, the properties of the Student's distribution are used and in formula (5.1) the value of the function argument $\Phi(t)$ is replaced by the Student's distribution parameter t_γ, which depends on the given probability γ and the volume of measurements n (tabular value). In this case, it σ is determined by the results of measurements. Thus, the formula reveals two values that depend on the volume of measurements n, and the usual analytical dependence of the form (1) can no longer be obtained.

In technical measurements, the value of measurement reliability is usually taken equal to p = *0.95*. When the number of measurements $n = 20$, we take the parameter of the Student's distribution t_γ equal to 2.1

The absolute error limit of the measurement result is defined by the formula [32]:

The standard deviation σ is equal to the square root of the variance of the random variable:

$$n = \frac{t^2 \cdot \sigma^2}{\delta^2}, \tag{5.1}$$

$$\delta = \frac{t \cdot \sigma}{\sqrt{n}}, \tag{5.2}$$

$$\sigma(x) = \sqrt{D(x)}, \tag{5.3}$$

where *D(x)* is ariance, determined by the formula

$$D(x) = \frac{\sum (x_i - m_x)^2}{N - 1}, \tag{5.4}$$

where m_x is the mathematical expectation (first-order statistical moment) – the average value of a sample of a random variable, calculated by the formula

$$m_x = \frac{\sum_{i=1}^{N} x_i}{N}, \tag{5.5}$$

where x_i is the values of a random variable значення випадкової величини;

N is sample size (total number of random variables).

On the basis of the calculations it was found that for the samples shown in Tables 4.3 and 4.4 the number of measurements is sufficient to obtain an adequate assessment of the result.

The used technique essentially increases reliability of the chosen decision on appointment of new service life of the wagon in comparison with an expert assessment. In addition, this technique allows you to determine the residual service life with the same reliability for any number of wagons.

In accordance with the method, the probability of failure Pi of the load-bearing structure of the flat wagon in operation is determined by the formula

$$P_i = \frac{\sum_{1}^{k} \frac{R_H}{R}}{k}, \tag{4.6}$$

where k is the number of the reseached wagons;

R_H is the number of defective elements of one type in the wagon;

R is the total number of elements of one type.

Design service life estimation was done according to the formular [31, 36]:

$$T_k = \frac{\left(\frac{\sigma_{a_i N}}{[n]}\right)^m \cdot N_0}{N_{cI} \cdot \sum_j \left(\sigma_{a_j}^I\right)^m \cdot P_j^I + N_{cII} \cdot \sum_k \left(\sigma_{a_k}^{II}\right)^m \cdot P_k^{II}}, \tag{4.7}$$

where $\sigma_{a_i N}$ is the average value of the endurance limit;

$[n]$ is the allowable coefficient of durability reserve;

N_0 is the base of the research;

N_{cI}, N_{cII} is the number of faulty structural elements of the wagon of the same name under investigation;

m is the indicator of the degree of fatigue curve;

$\sigma_{a_j}^I$, $\sigma_{a_k}^{II}$ is the durability limit of the material of the structure under study;

P_j^I, P_k^{II} is the probability of failure of the structural element.

The initial data have the following values:

– the average value of the endurance limit σ_{a_iN}=245 MПa;

– the allowable coefficient of durability reserve [*n*]=2;

– the base of the research N_0=10^7;

– the number of faulty structural elements of the wagon of the same name under investigation is 1 (the spine beam) and 2 (the longitidanal beam);

– the indicator of the degree of fatigue curve *m*=2;

– the durability limit of the load-bearing structure material is equal 490 MPa for steel 09G2D;

– the probability of failure of the structural element was 0.2.

The obtained results allowed to conclude that the design service life of the spine and longitudinal beams of the studied flat wagons taking into account the continuation of their operation is not less than 32 years. To test the obtained results, the main indicators of the durability of the load-bearing structure of the flat wagon with the highest amount of abrading recorded during field research (Tables 4.2, 4.3) were also determined. The finite element method, which is implemented in the CosmosWorks software environment, was used for the research.

The finite element model of the load-bearing structure of the flat wagon is shown in Figure 5.6. The graphoanalytical method was used to determine the number of grid elements. Ten-node isoparametric tetrahedra were used as finite elements. The number of elements of the grid was 838084, the number of the nodes was 274584. The maximum size of the element was 100 mm, the minimum size was 20 mm, the maximum sides ratio was 4702.9, the percentage of elements with a side ratio less than 3 was 39.3, of more than 10 was 10.2. Fastening of the model was wagonried out in the places where the wagon body is based on the carriages.

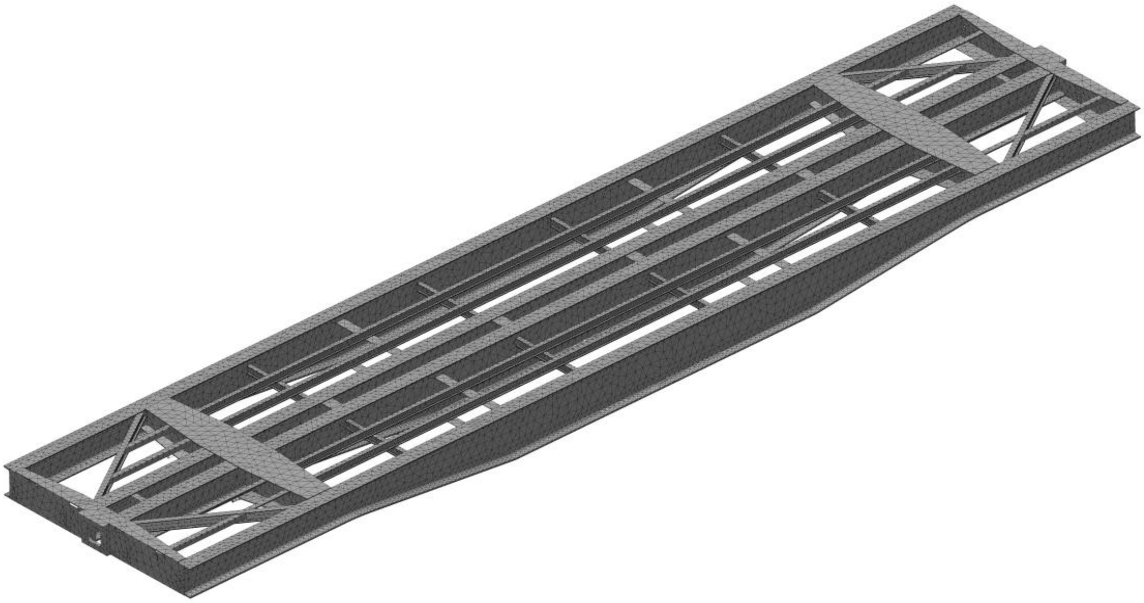


Figure 5.6. A finite element model
of the load-bearing structure of the flat wagons

The calculation scheme of the load-bearing structure of the flat wagon, takes into account the following loadsnt: vertical $P_в$ and longitudinal N (Figure 3.19).

It is taken into account that the full load capacity of the flat wagon loaded with conditional cargo is used. The calculation was performed for I and III calculation modes. The results of the calculation of the durability of the load-bearing structure of the flat wagon in rating condition I «impact» are shown in Figures 5.7, 5.8.

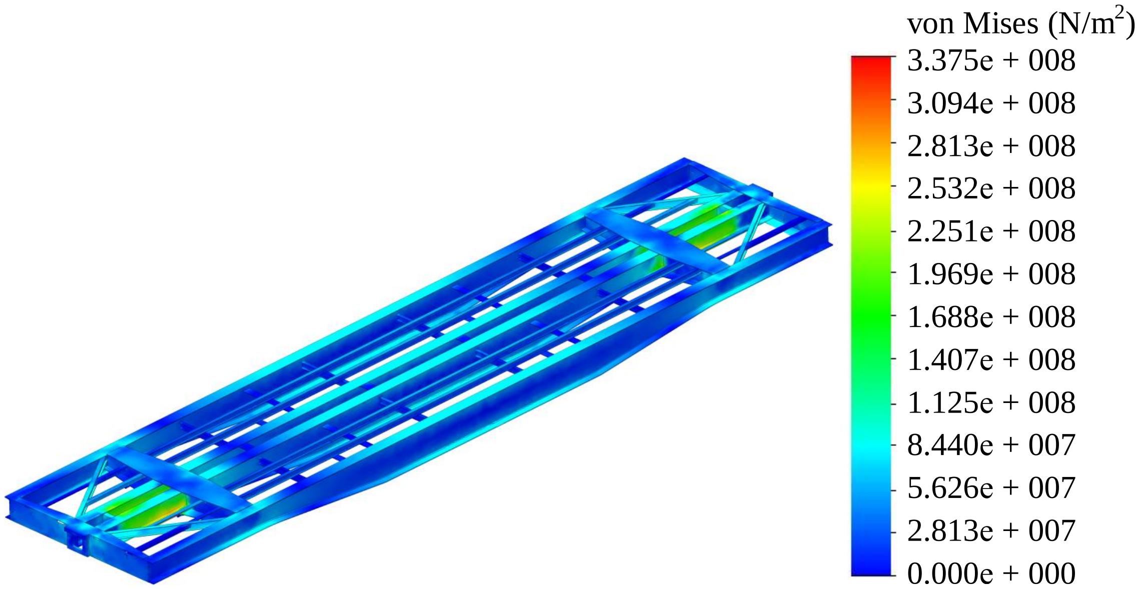


Figure 5.7. The flat wagon load-bearing structure in the loaded condition

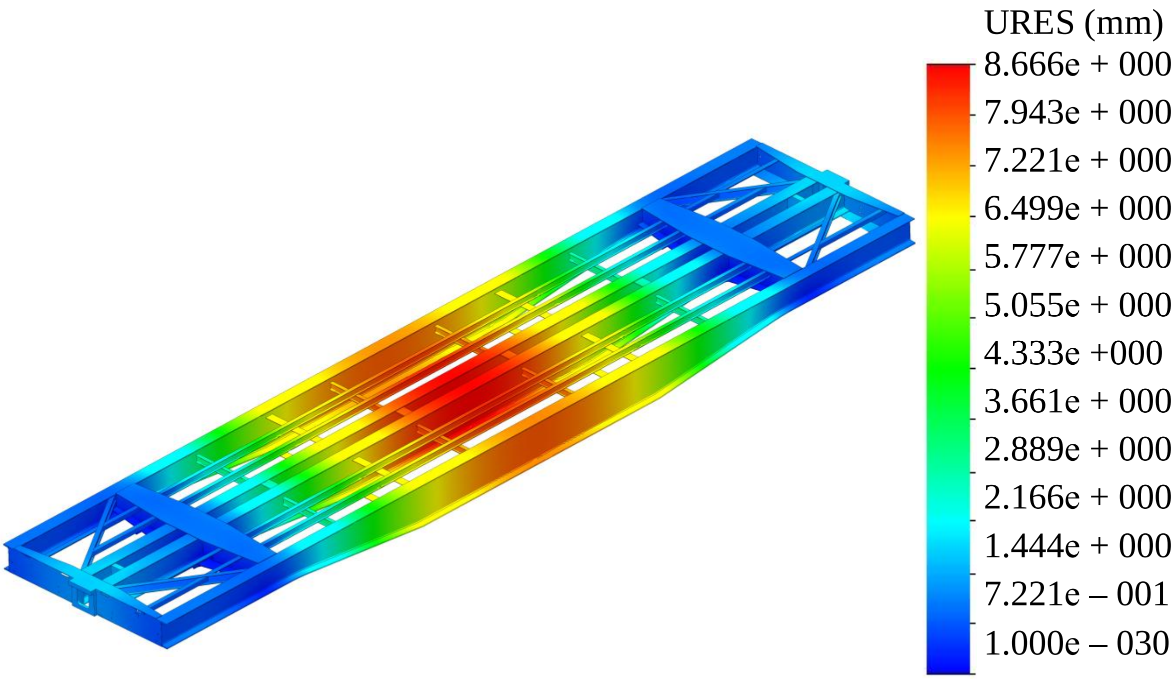


Figure 5.8. The movement in the nodes of the load-bearing structure of the flat wagon

The results of the calculation of the durability of the load-bearing structure of the flat at I and III calculation modes are given in table 5.3.

Table 5.3

The indicators of durability of the load-bearing structure of the flat wagon under operating loading conditions

Durability indicators	*Load mode*				
	I			III	
	impact	compression	jerk-stretching	impact – compression	jerk-stretching
Load, MPa	337,5	313,6	296,8	287,98	280,8
Movement in the nodes	8,6	8,4	8,3	8,1	7,8

Based on the calculations, we can conclude that the maximum equivalent load occurs in the area of interaction of the spine beam with the pivot beam, it is equal 337.5 MPa. The maximum displacements in the nodes of the load-bearing structure of the flat wagon are fixed in the middle part of the frame are 8.6 mm. Therefore, the durability of the load-bearing structure of the flat wagon is provided.

5.4. Research of typical designs durability of tank wagons with actual parameters at operational loadings

To determine the main indicators of the durability of the load-bearing structure of the tank wagon with the abrading shown in Figures 4.17 and 4.18, the calculation was performed by the finite element method, which is implemented in the CosmosWorks software environment. The finite element model of the load-bearing structure of the tank wagon is shown in Figure 5.9.

The graphoanalytical method was used to determine the number of grid elements. Ten-node isoparametric tetrahedra were used as finite elements. The number of elements of the grid was 769695, the number of nodes was 250941. The maximum size of the element was 40 mm, the minimum size of the element was 8 mm, the maximum aspect ratio was 98.741, the percentage of elements with a side ratio of less than 3 was 19.2, of more than 10 was 0.358. The ratio of increasing the size of the element is 1.7.

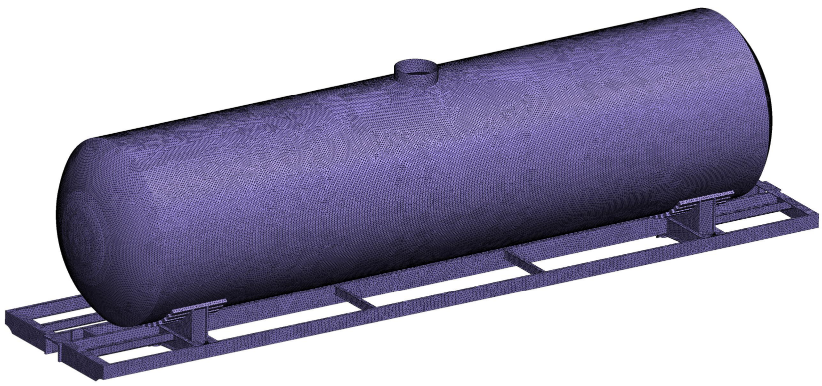
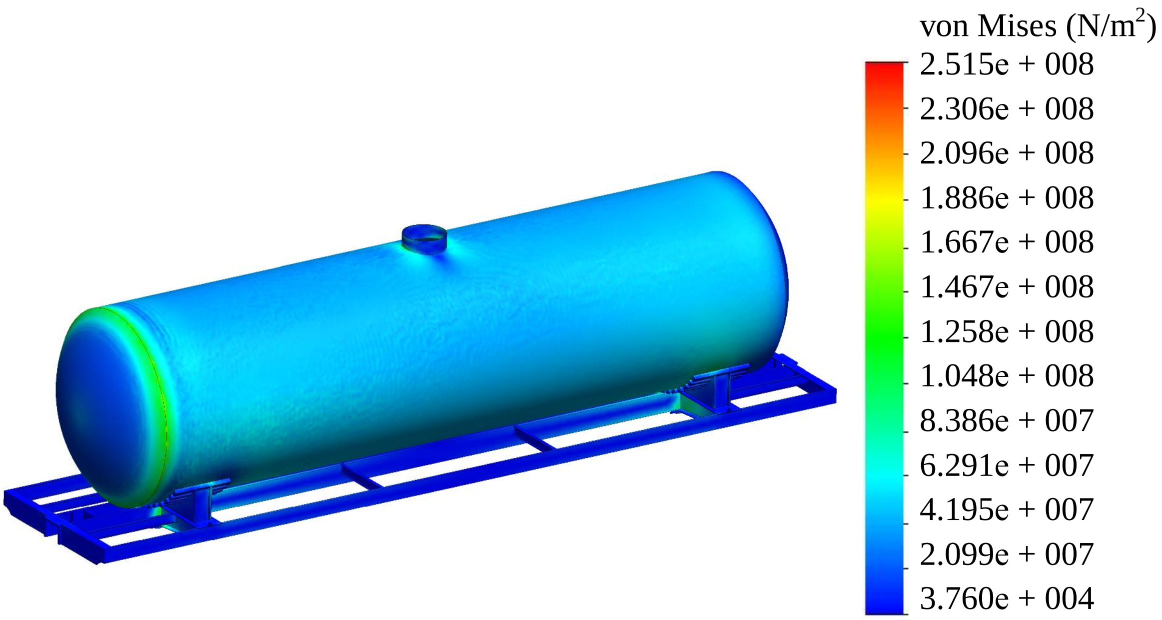


Figure 5.9. Finite element model of the load-bearing structure of the tank wagon

The minimum number of elements in the circle is 9. The model was fastened in the places where the load-bearing structure was based on the carriages. When compiling the calculation scheme of the load-bearing structure of the tank wagon, it is taken into account that it is affected by the vertical static load $P_в$, as well as the longitudinal load of $P_{уд}$ on the front stops of the automatic coupling, which is equal to 2.5 MN (Figure 3.27). The results of the calculation are shown in Figures 5.10, 5.11.

a)



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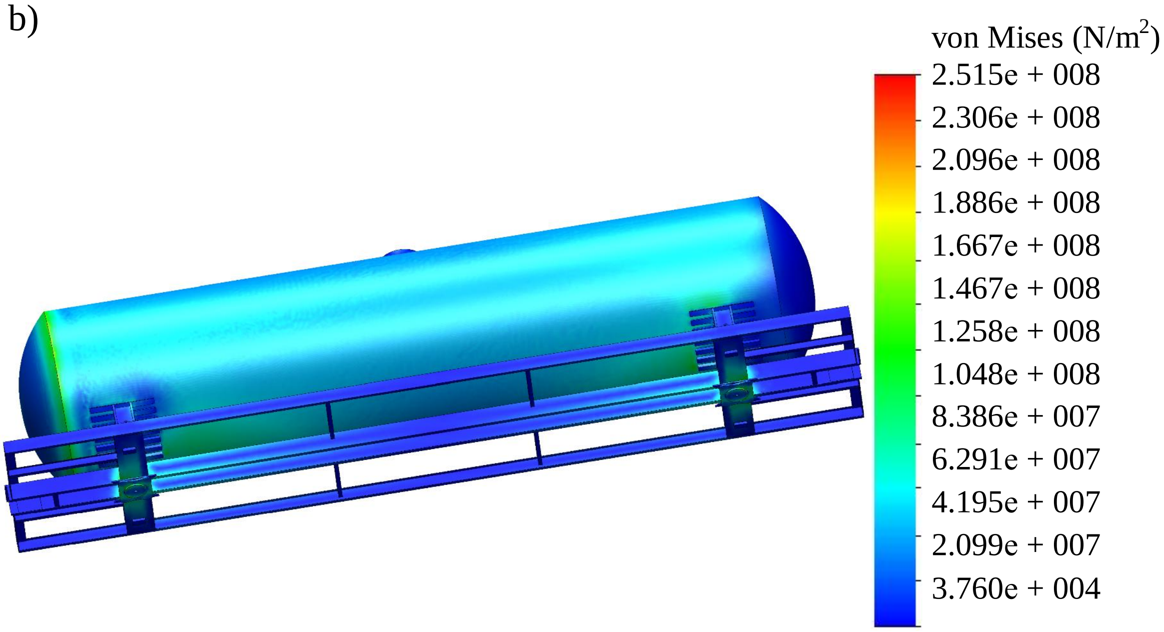
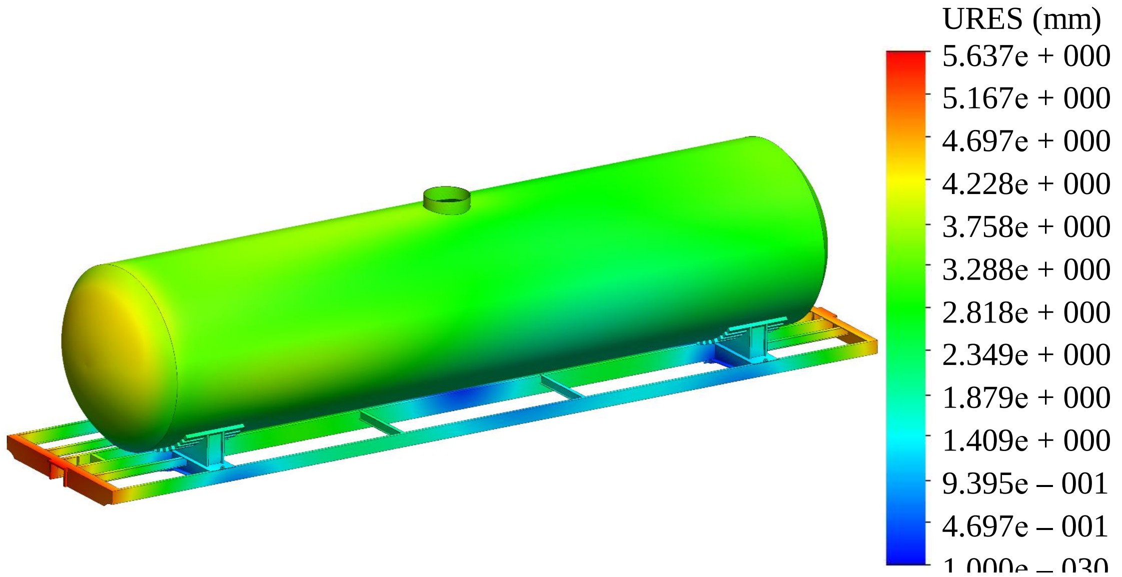


Figure 5.10. The condition of tension of the tank wagon load-bearing structure

a) side view; b) bottom view

a)



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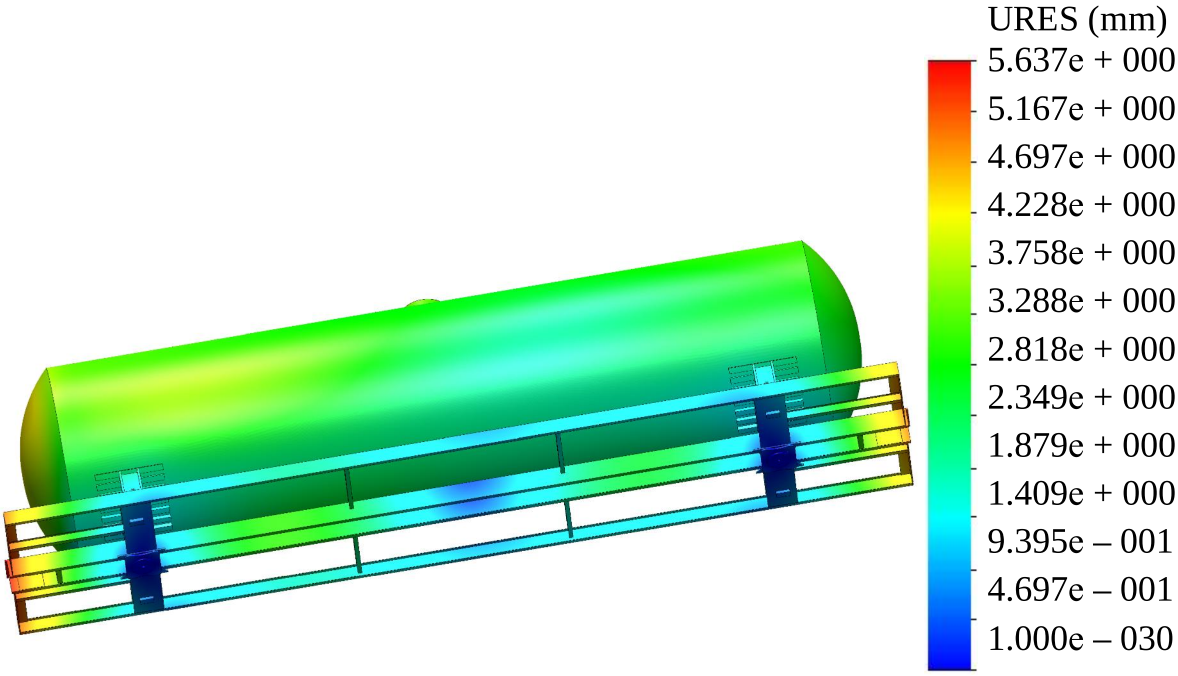

Figure 5.11. Movement in the nodes of the load-bearing structure of the tank wagon

a) side view; b) bottom view

The maximum equivalent load occurs in the area of interaction of the spine beam with the pivot beam, it is 251.5 MPa. That is, the maximum equivalent load does not exceed the allowable one [13–14]. Maximum displacements occur in the cantilever part of the spine beam, they are equal to 5.6 mm. The maximum deformations were $3.27 \cdot 10^{-3}$.

The calculation of the load-bearing structure of the tank wagon is performed for other calculation modes. The results of the calculation are shown in Table 5.4.

Table 5.4

The results of the calculation of the durability of the load-bearing structure of the tank wagon with the actual dimensions

Durability indicator	*Load mode*			
	I		III	
	compression	jerk – stretching	impact – compression	jerk – stretching
Load, MPa	251,5	238,4	212,3	236,5
Displacements in the nodes, mm	5,6	5,2	4,9	5,1

Table 5.4. shows that the maximum equivalent load occurs at I r.c. (compression), but it is within acceptable limits and does not exceed the yield durability of the material [13, 14].

5.5. Research of typical designs durability of hopper wagons with actual parameters at operational loadings

To determine the main indicators of the durability of the load-bearing structure of the hopper wagon with the amount of abrading shown in Figures 4.13, 4.14, the calculation was performed by the finite element method, which is implemented in the CosmosWorks software environment. The finite-element model of the load-bearing structure of the hopper wagon is shown in Figure 5.12 [37].

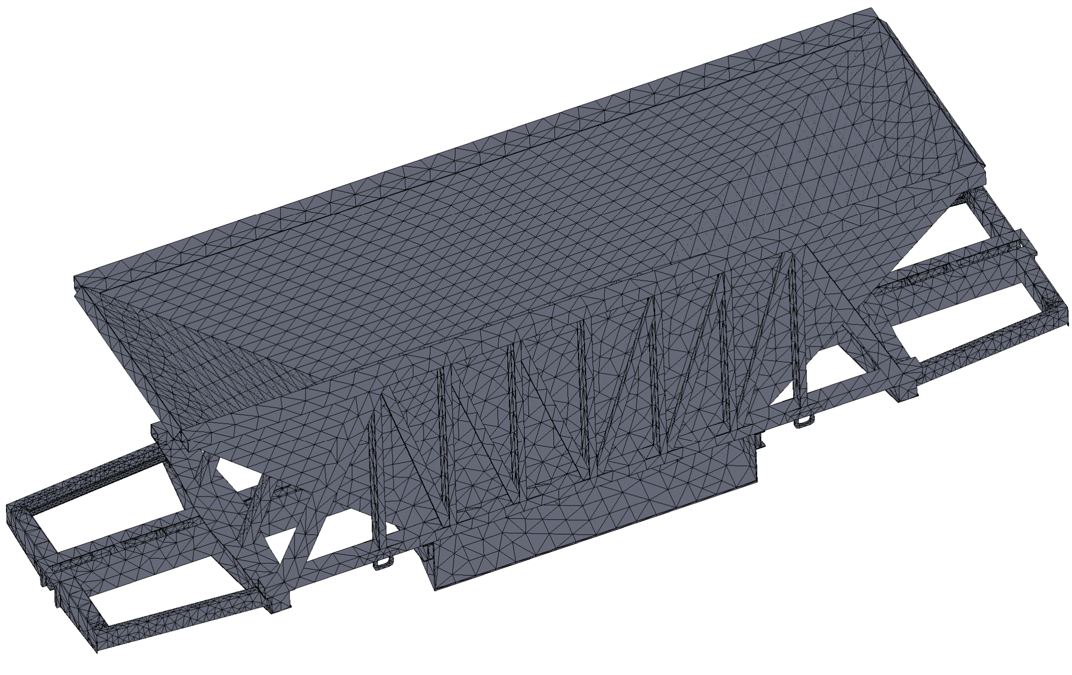

Figure 5.12. A finite element model of a hopper wagon

The graphoanalytical method was used to determine the number of grid elements. Ten-node isoparametric tetrahedra were used as finite elements. The number of elements of the grid was 657778, the number of nodes was 22449. The maximum size of the element was 200 mm, the minimum size was 40 mm, the maximum aspect ratio was 8981.9, the percentage of elements with an aspect ratio less than 3 was 1.67, of more than 10 was 78.4. The ratio of increasing the size of the element is 1.7.

The minimum number of elements in the circle was 9. The model was fastened in the places where the load-bearing structure is based on the carriages. When compiling the calculation scheme of the load-bearing structure of the hopper wagon, it is taken into account that it is affected by the vertical static load $P_{в}$, as well as the longitudinal load $P_{уд}$ on the rear stops of the autocoupling, which is equal to 3.5 MN (Figure 3.32). The results of the calculation are shown in Figures 5.13, 5.14.

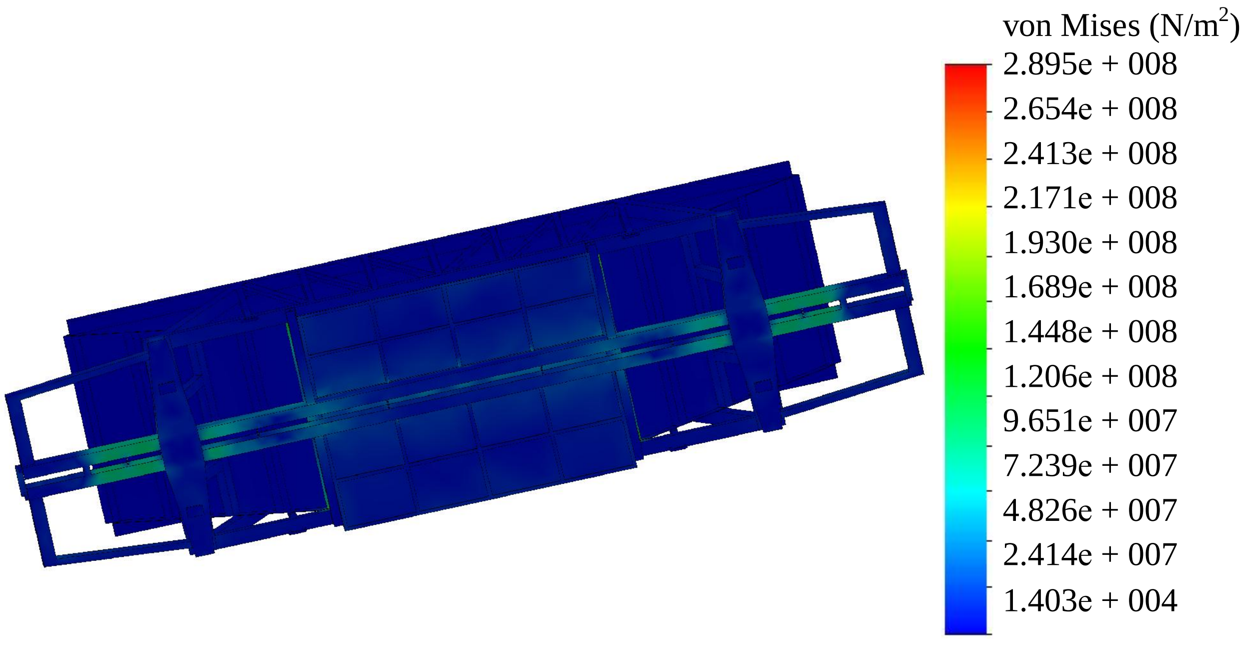

Figure 5.13. The conditions of load of the hopper wagon load-bearing structure

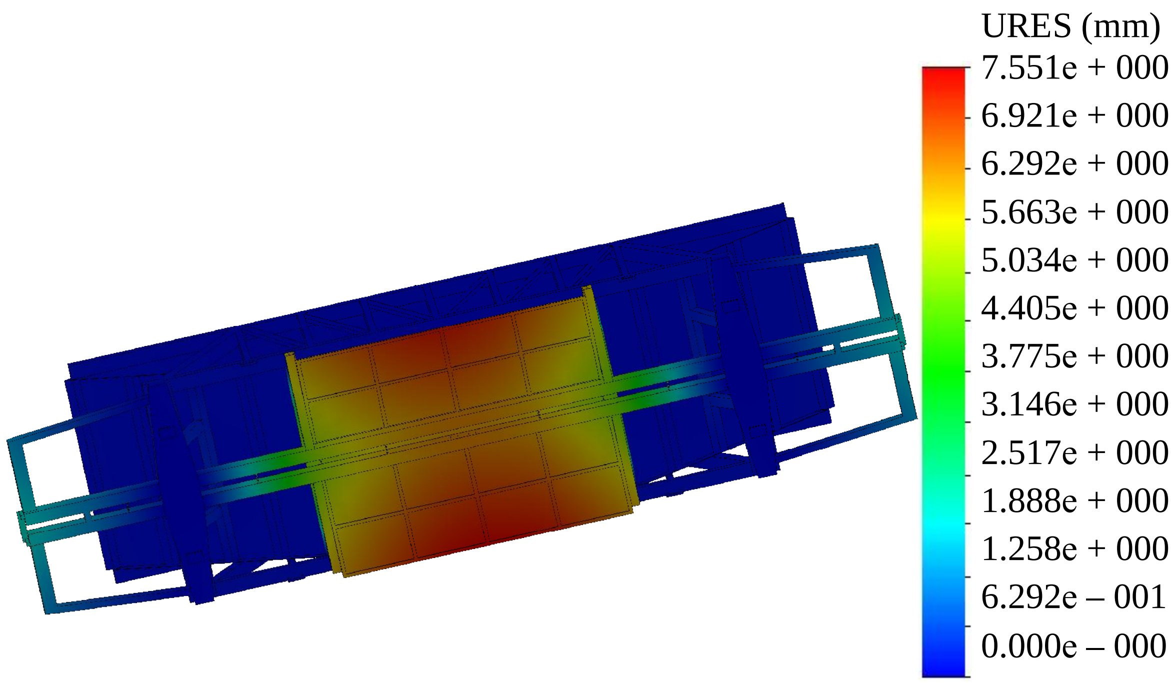

Figure 5.14. Movement in the nodes of the hopper wagon load-bearing structure

The maximum equivalent tension occurs in the area of interaction of the spine beam with the pivot beam, it is 344 MPa. That is, the maximum equivalent tension does not exceed the allowable one [13, 14]. The maximum displacements occur in the middle part of the spine beam, they are equal to 6.4 mm. The maximum deformation was $3.85 \cdot 10^{-3}$.

The calculation of the load-bearing structure of the hopper wagon is also wagonried out for other calculation modes. The results of the calculation are shown in Table 5.5.

Table 5.5

The results of the calculation of the durability of the hopper wagon load-bearing structure with the actual dimensions

Durability indicator	*Load mode*				
	I			III	
	impact	compression	jerk – stretching	impact-compression	jerk – stretching
Tension, MPa	344,3	336,6	307,4	296,8	269,5
Movements in the nodes, mm	6,4	5,4	4,8	4,9	4,8

Table 5.5 shows that the maximum equivalent tension occurs at I r.c. (impact), but it is within acceptable limits and does not exceed the tension of the material fluidity [13, 14].

Thus, the amount of abrading of the wagons supporting elements contributes to the increase of the maximum equivalent load in them: a gondola wagon – 1 %, a covered wagon – 4.2 %, a flat wagon – 9.3 %, a tank wagon – 5.3 %, a hopper wagon – 24, 6 %. However, this tension does not exceed the allowable one.

CONCLUSIONS TO CHAPTER 5

1. The main indicators of durability of the gondola wagon load-bearing structure have been determined. It is established that the maximum equivalent load occurs at I r.c. (impact), it is equal to 330 MPa, but it is within acceptable limits and does not exceed the fluidity durability of the material. The maximum displacements in the load-bearing structure of the gondola wagon occur in the middle of the spine beam. They are 3.6 mm.

2. The main indicators of the durability of the load-bearing structure of the covered wagon have been determined. It is established that the maximum equivalent load occurs at I r.c. (impact), it is equal to 344.3 MPa. At the same time it is within acceptable limits. The maximum displacement is 6.4 mm.

3. The main indicators of tension of the flat wagon load-bearing structure have been determined. It is established that the maximum equivalent load occurs at I r.c. (impact), it is equal to 337.5 MPa, but it is within acceptable limits. The maximum displacement is 8.6 mm.

4. The results of the calculation of the durability of the load-bearing structure of the tank wagon showed that the maximum equivalent load occurs at I r.c. (jerk), it is equal to 251.5 MPa, but it is within acceptable limits. The maximum displacement is 5.6 mm.

5. The results of the calculation of the durability of the load-bearing structure of the hopper wagon showed that the maximum equivalent load occurs at I r.c. (jerk), it is 344.3 MPa, so it is within acceptable limits. The maximum displacement is 6.4 mm.

6. The conducted researches allow to draw a conclusion that the maximum equivalent load in the load-bearing structures of wagons with the actual sizes which have exhausted their standard resource of operation does not exceed the admissible one. This contributes to the creation of measures to restore their effective functioning.

GENERAL CONCLUSIONS

1. The constructions of a modern domestic fleet of freight wagons have been analyzed. The following types of wagons are taken into account: gondola wagons, covered wagons, flat wagons, hopper wagons, as well as tank wagons, manufactured by the leading wagon-building enterprises of Ukraine. The main technical characteristics of wagons are explained.

2. The dynamic loading of structures of freight wagons of the domestic park with nominal parameters has been investigated. The dynamic loading of load-bearing structures of wagons in vertical and longitudinal planes is taken into account. The main indicators of wagon dynamics are obtained: body acceleration, body acceleration in the places of basing on the carriages, forces in spring suspension of carriages, coefficient of dynamics. The operation is assessed as «excellent».

It was found that the maximum accelerations acting on the load-bearing structures at their longitudinal load is about 0.4 g, the maximum acceleration was about 0.27 g for a tank wagon under the action of a longitudinal load of 2.5 MN.

3. The durability indicators of the load-bearing structures of freight wagons of the domestic park with nominal parameters have been investigated. It is established that the maximum values of equivalent tension in the investigated load-bearing structures of wagons are observed at calculation mode I (impact). At the same time they are concentrated in the zones of interaction of pivot beams with the spine beams. The margin of safety is about 1. This value of the margin of safety is obtained for the steel of grade 09G2S, which is typical for the manufacture of load-bearing structures of wagons.

4. The load of the structures of freight wagons of the domestic park with the actual parameters has been investigated. It is established that the accelerations acting on the load-bearing structures of wagons with the actual dimensions of the elements are within acceptable limits. At the same time, the accelerations acting on the load-bearing structures of wagon with actual dimensions exceed those obtained at nominal ones: for a gondola wagon by 16 %, for a covered wagon by 25 %, for a flat wagon by 4 %, for a tank wagon by 9 %, for a hopper wagon by 2 %.

The dynamic loading of load-bearing structures of freight wagons with actual dimensions in the longitudinal plane has been determined. The calculation is performed for the case of shunting collision of wagons or «jerk» (a tank wagon). This takes into account the full use of load capacity of wagons. It is established that the accelerations acting on the load-bearing structures of wagons with actual dimensions exceed those obtained in case of the nominal ones: for a gondola wagon by 2.4 %, for a covered wagon by 1.7 %, for a flat wagon by 1 %, for a tank wagon by 2,7 %, for a hopper wagon by 2,7 %.

5. The durability indicators of the load-bearing structures of freight wagons of the domestic park with the actual parameters have been investigated. It is established that the amount of abrading of supporting elements of wagons contributes to the increase of maximum equivalent tensions in them: a gondola wagon – 1 %, a covered wagon – 4.2 %, a falt wagon – 9.3 %, a tank wagon – 5.3 %, a hopper wagon – 24.6 %. However, this tension does not exceed the allowable one.

Therefore, it is important to develop conceptual frameworks for the restoration of obsolete freight wagons, which will increase the efficiency of rail transport.

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