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Design And Modelling Of A Rail Structure For Dismantling, Dragging And Lifting A Horizontal Shell-and-tube Heat Exchanger

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Abstract— **The paper is a practical case of dismantling, dragging, and lifting a horizontal shell-and-tube heat exchanger with dimensions of 1,453 m, 4,675 m, and 1,931 m, weighing 10 tons. Due to the cramped conditions of the device's location (on the second floor in the middle of the building's span), there was a need for a safe technology for mounting the device using a rail structure that provides horizontal movement of 5.5 m. It was decided to strengthen the frame of the base of the apparatus for the perception of horizontal traction load and to design rails for horizontal sliding of the heat exchanger with a total overall dimension of 7.55 m x 6.8 m. The nomenclature of rod profiles for the manufacture of the structure was limited and represented only by small sections. A decision was made to design a composite rail structure (built-up members with lacings). The analytical calculation was carried out in accordance with the regulatory and technical documentation. After the preliminary selection of the sections of the main rods, the analysis of the rail structure by the finite element method was performed to optimize the lengths of the span beams and struts. With the specified parameters of the composite rod from built-up members, the maximum span value between supports should be no more than 6.15 m.**

Keywords— Lifting scheme, finite element model, shell-and-tube heat exchanger, pressure vessel lifting, safety assessment, structure integrity.

I. INTRODUCTION

Shell-and-tube heat exchangers with fixed tube gratings represent a large share of the equipment of chemical plants. During operation, the devices require periodic repacking of the tube bundle. This operation is preceded by the dismantling of devices from industrial buildings and structures. This Paper considers a complex case of the device location in an industrial facility (see Fig. 1). The purpose of the work is to develop a technology for dismantling and mounting a heat-exchanger using rails that ensure horizontal movement of the device by 5.5 m. To ensure the safety of the rail structures and vessel during lifting, it is necessary to simulate the actual mechanism during the lifting and dragging process. The finite elementanalysis is performed to get the stress status of the typical positions, based on which to evaluate the structure safety.

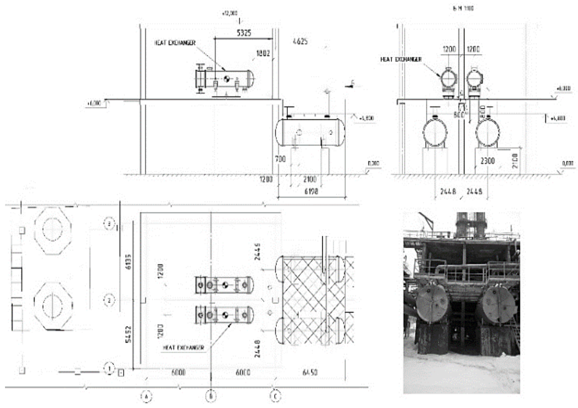

Fig. 1: Explication of equipment and piping

I. DESIGN CONSIDERATION

The selection of the type of dismantling and lifting of a vessel depends on many key factors including the type of vessel, weight, diameter, site conditions, environmental conditions, and available lifting equipment. The selection of rails used for dismantling and lug for lifting is based on vessel design, vessel surroundings and site and environmental limitations.

A. Equipment location considerations

The device is surrounded by piping, has dimensions of 1,453 m × 4,675 m × 1,931 m. It is located at +6,000m in the middle of the span of an industrial structure. Horizontal movement of the device is possible only in the direction of the "C" axis (see Fig. 1). The difficulty for dismantling the heat-exchanger in this direction is represented by tanks at around 0.000 m with piping and a service platform at +4,800 m.

B. On-site environmental considerations

The weather conditions taken into consideration during the design as following: The ambient temperature is up to -35 degrees Celsius. The height of the snow cover is up to 0.5 m the permissible wind speed for crane operation is 11.1 m/s. Humidity up to 30%.

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C. On-site weight considerations

The heat exchanger weights 10.850 tons according to the datasheet. A weight margin of about 20% is accepted.

D. On-site dismantling, dragging and lifting considerations

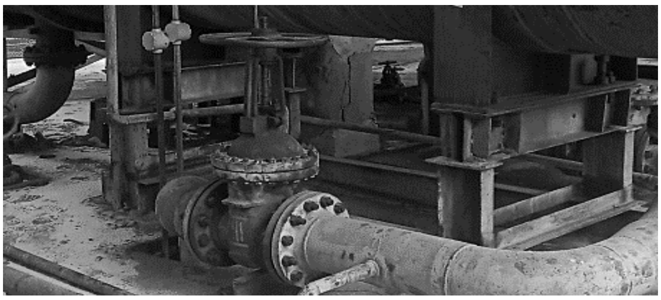
The device is equipped with mounting fittings. 4 textile loop slings are used to hook onto the crane.
Horizontal movement is carried out using two lever winches. The strapping of the device is carried out for the saddle support "on the choker" with a flexible textile loop sling. The fastening of the winch to the rail structure is also carried out with the use of a textile sling fixed "on a choker".

II. LIFTING SCHEME

After studying the work site, it was revealed that it is located on a metal frame with a height of 0.8 m. Strengthening of the frame structure is required to perceive horizontal loads from moving the device.
The required dimensions of the rail are 7.55 m × 6.8 m. The following technical requirements are imposed on the rails:
- must withstand a load of 10 tons;
- must be suitable for two devices (main and backup);
- During the dismantling process, it is necessary to remove as few structures and pipelines as possible

A. Construction of the support frame.

For the reinforcement scheme of the support frame, see Fig. 2.



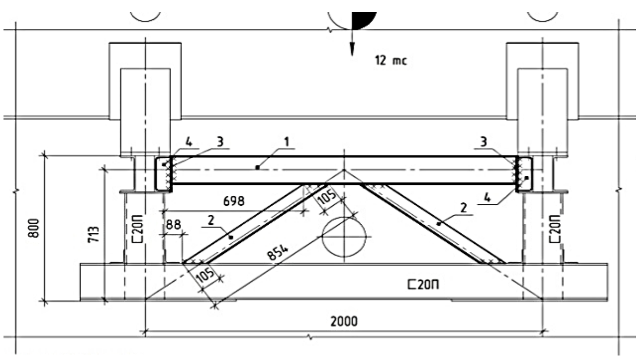


Fig. 2: Reinforcement of the supporting metal frame of the heat-exchanger

Pos.1: I-beam 16 DIN 1025, pos.2 : corner 75x7 DIN 1028, item 3, 4 : sheet 10.

The design scheme of the beam (rails) is a hinge attachment with a load of 10t in the middle of the span. A test calculation for the strength, rigidity and stability of the flat bending shape according to [1, 2, and 5] was performed. The strength condition was verified.

B. Rail construction.

For the manufacture of rails, the Rails were provided according to the following profiles and characteristics presented in Table 1.

Table 1: profile characteristics

Section	**A, cm²**	**P, kg/m**	**I_y, cm⁴**	**W_y, cm³**	**i_y, mm**
16 DIN1025	22.8	17.9	935	117	64
			I_z, cm⁴	W_z, cm³	i_z, mm
			54.7	14.8	15.5
88.9x3.2 DIN2448	8.62	6.9	79.2	17.8	30.3
75x7 DIN1028	10.1	7.94	42.4	9.67	22.8
219.1x6.3 DIN2448	53	41.6	2955.4	218	74.65

According to [1, 2, 5], calculated the maximum distances between the support racks so that the beams of the rails 16 DIN 1025 are strong, rigid and stable.

Strength condition:

$$f_y = \frac{M}{W} \leq R_{eh} \qquad (1)$$

Rigidity condition:

$$l = \frac{F \cdot l^3}{48 \cdot E \cdot I} \leq [l] \qquad (2)$$

From the conditions (1), (2) the maximum length between the rail support racks is not more than 1.4 m. The loads are applied from the weight of the heat-exchanger with a distance between the supports of 2 m.
The Bending Moment Diagram of the rails is shown in Fig. 3.

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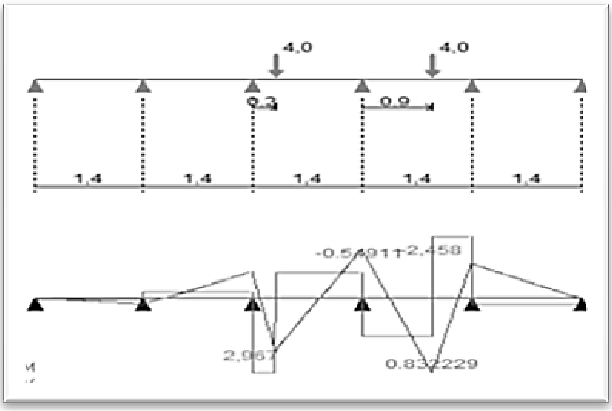


Fig. 3: Bending Moment Diagram of a rail beams

Using the SCAD program, we calculate the stability of the flat shape of the bending of the rail beams. The result is presented in table 2.

Table 2: the result of calculating the stability of the flat shape of the bending of the beams 16 DIN1025 [2].

Conditions	factor (k < 1)
Strength under the action of transverse force	0,33
Strength under the action of bending moment	0,35
Stability of the flat shape of the bend under the action of the moment	0,35

Since the length of the rails requires more than 7 m, and the platform of the industrial structure where the racks can be placed is only 2 m (see Fig. 1), the rails are designed as a composite rod (built-up members with lacings) with the console resting on the stand support (see Fig. 4).

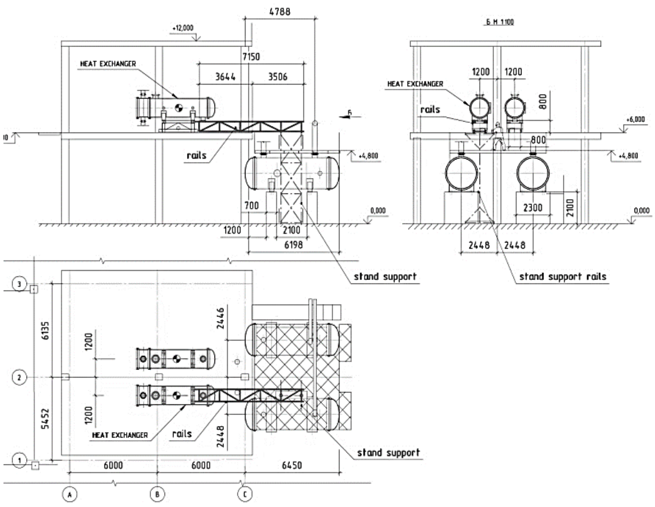
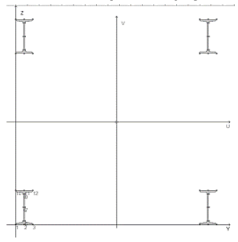


Fig. 4 – Construction of rails and support-racks.

Table 3: Characteristics of the composite rod.

Section	**A, cm²**	**P, kg/m**	**I_y, cm⁴**	**W_y, cm³**	**i_y, mm**
4 x 16 DIN1025 	64,72	71,6	73236	1792	336
			I_z, cm⁴	W_z, cm³	i_z, mm
			103769	2353	400

The Bending Moment Diagram of the composite rod from the built-up members is shown in Fig. 5.

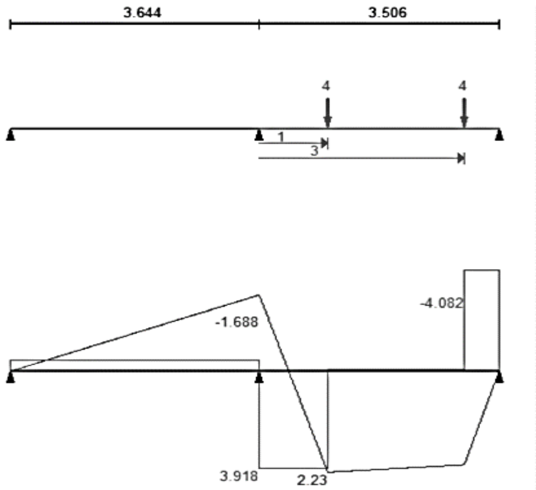


Fig. 5: Bending Moment Diagram of composite rod

According to the diagram in Fig. 5, a calibration calculation of a composite section rail for bending in a span of 3,506 m was performed. The strength condition is met.

The support racks of the composite rails are made of 88.9x3.2 DIN2448 pipes, the braces are made of 75x7 DIN 1028 corners. The listed elements are checked for strength and resistance to compression.

C. Construction of the stand support

Since tanks are located at the 0.000 m mark, the stand support for the rails is designed as two-chords with lacings and a traverse (Fig. 4). The support elements are checked for compression resistance. The radius of inertia is assumed to be in the worst condition in the plane not secured by spacers. The chords length is accepted with a factor of 2.

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D. Design of rod connection nodes.

The joints of the struts and beams are designed to be hinged according to a series of standard nodes.
For the convenience of transporting assembly units, collapsible flange connections are provided.

E. Selection of mechanisms for horizontal movement.

The required force for horizontal movement can be calculated by the equation:

$$F \geq 1.5 \cdot \mu \cdot m \cdot g, \quad (3)$$

Where 1.5 is a factor equal to the load margin for pulling from place (50%)

According to (3) F = 2.25 t. Two manual lever winches with a lifting capacity of 1.6 tons were selected (Fig. 6).

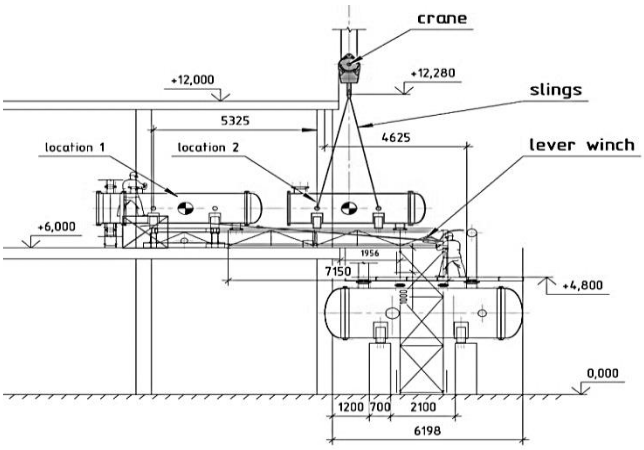

Fig. 6: Moving the heat-exchanger using a lever winch

III. SELECTION OF THE CRANE.

The crane was selected according to three parameters: lifting height, lifting capacity, departure, taking into account the explication of buildings and structures. The diagram is shown in Fig. 7.

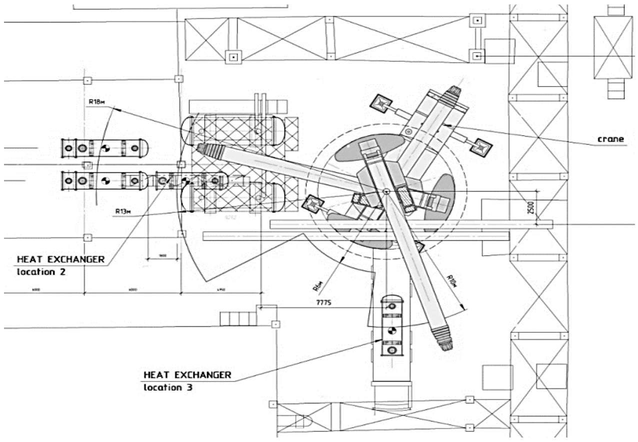

Fig. 7: Crane operation diagram

1 FINITE ELEMENT MODEL

A. Model boundary conditions

Investigating the construction of composite rails and a stand support by the finite element method. The strength and stability analysis of the rails and supports is performed using finite element method. For computation convenience, the boundary conditions are set as following:

- Supports at the base of the rack with a ban on movement and rotation, at the points of attachment of the rail with permission to rotate relative to the x axis;

- Horizontal forces from the winch;

- Vertical Forces from the heat exchanger in the span between the industrial structure and the support;

- Wind and snow load.

B. Finite Element Model Analysis

A finite element model has been compiled from the profiles presented in Table 1 as presented in Fig. 8.

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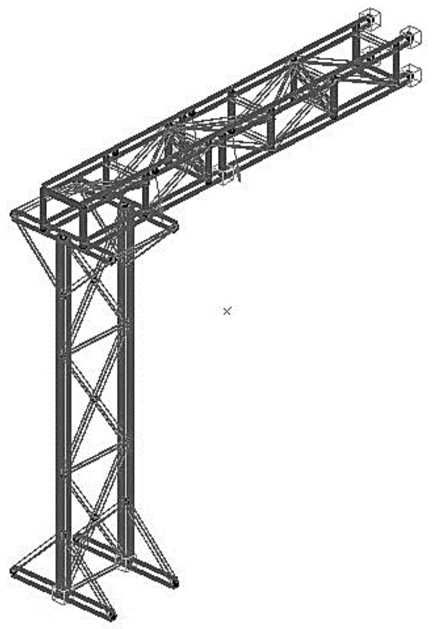

Fig. 8: Finite element model of metal structures of rails and supports

IV. RESULTS AND DISCUSSION

A. Structure Analysis and verification

1) Optimal cross section of the rod for the rail's verification.

Design scheme of the rod is shown in Fig. 9.

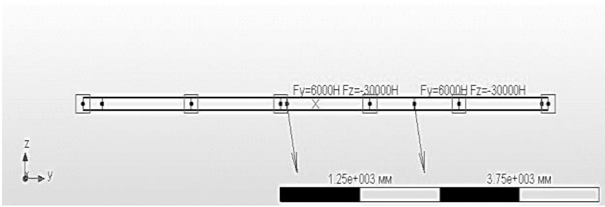

Fig. 9: Scheme of the rod

In Fig. 10, the graph shows that the stress changes depending on the distance between the supports d.

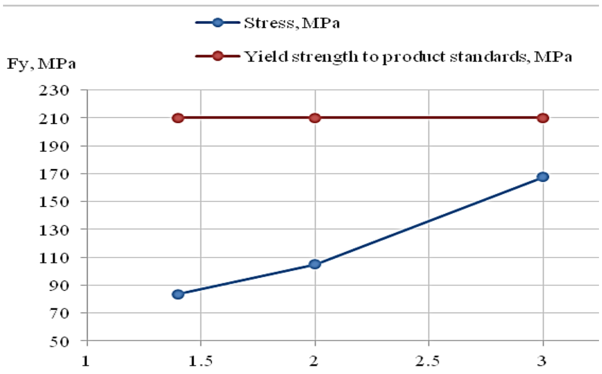

Fig. 10: Stresses Distribution at different "d"

In Fig. 11, the graph shows that the displacement of the Z axis changes depending on the distance between the supports d.

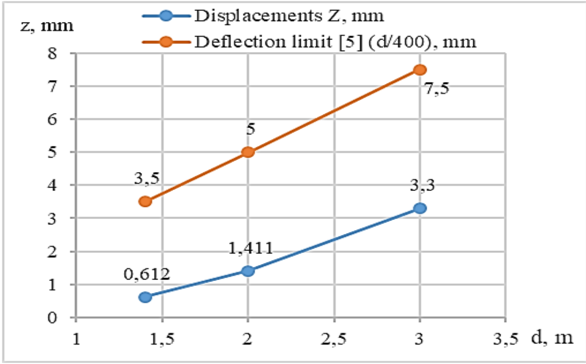

Fig. 11: Displacement about Z axis distribution at different "d"

The qualitative analysis of stresses and displacements at a span of 1.4 m are shown in Fig. 12.

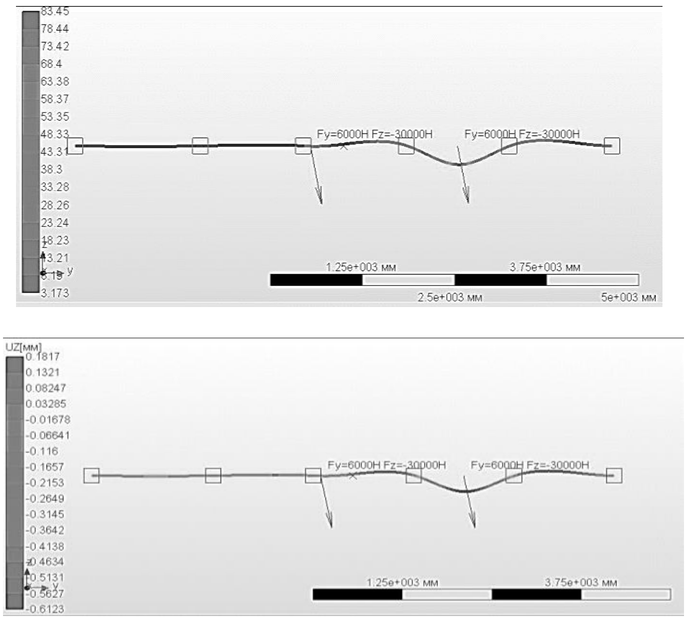

Fig. 12: Stress and displacement diagram of a rail beam (a) analysis of stresses, (b) analysis of displacement

The rails are designed from a 16 DIN 1025 beam section available in stock. For the selected section, the span between the supports can be increased to 3 m.

The height of composite rod from built-up members h = 800mm, while it is recommended to strive for d /h = 1. (Fig. 13). In this regard, the distance d= 1.4m is selected. In this case, the condition of stability of the composite rod under load is fulfilled.

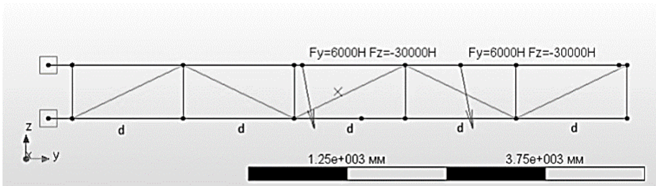

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Fig. 13: Composite rod from built-up members

Bending moments diagram is shown in Fig. 14. Maximum moment is 8863000 Nm.

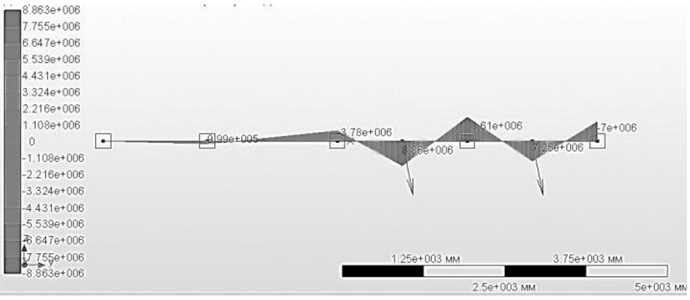

Fig. 14: Bending moment diagram

According to equation (1), the required moment of resistance is Wy=42sm3. It is possible to reduce the cross section of the rod for rails from 16 DIN 1025 to 12 DIN 1025 Wy =54.7sm3.

2) The stresses and displacements of the rail structure verification

Design scheme of the composite rod from built-up members is shown in Fig. 15.

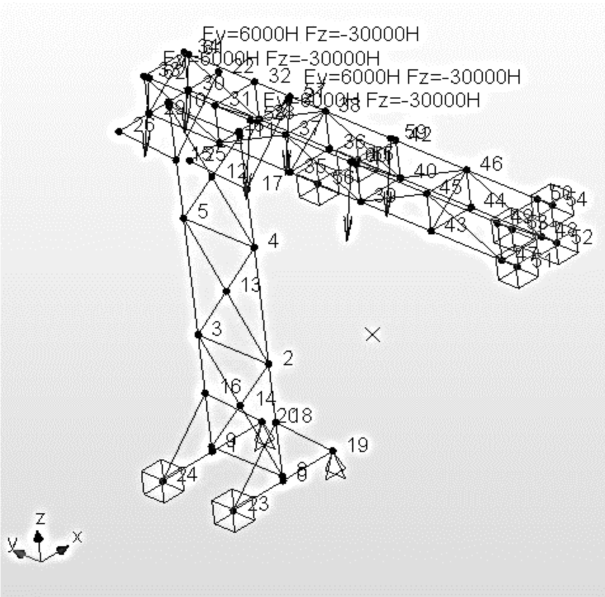

Fig. 15: Design scheme

Investigating the equivalent stresses and general displacements in the structure at different lengths "D" (the span between the building and the stand support) see diagram Fig. 16.

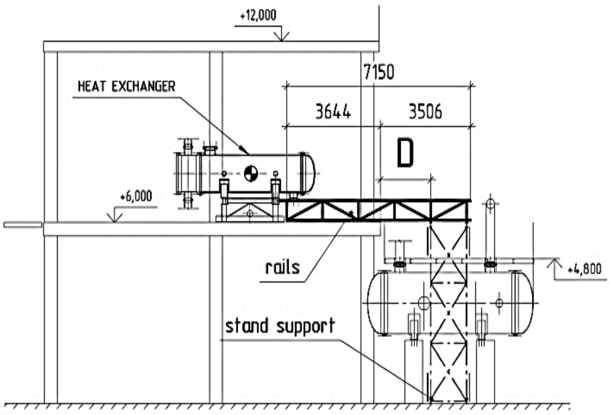

Fig. 16: Span between the building and the stand support D

The results of calculating stresses and displacements of build-up members of rails depending on the distance between the building and the stand support "D" are presented in Table 4.

Table 4 - Stresses and displacement of build-up members of rails.

	Max stress, MPa	**Yield streng to product standards, MPa**	**Displacements Z mm**	**Deflection limit [5] (d/400), mm**	**D, m**	**Overall length, m**
1	83,3	210	1,232	4,875	1,95	7,15
2	159,0	210	3,597	11,875	4,75	9,95
3	209,3	210	7,855	15,375	6,15	11,35

The qualitative analysis of stresses at different «D» as per Fig. 17 and Fig 18:

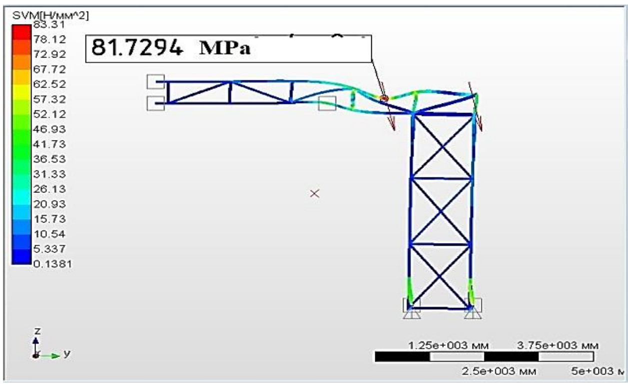

Fig. 17: Stresses Distribution at D = 2 m

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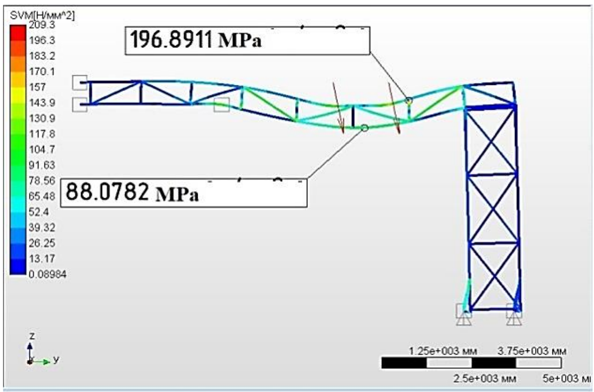

Fig. 18- Stresses Distribution at D = 6.15 m

As shown in Fig 17. and Fig. 18, with an increase in the span between the building and the support, the values of mechanical stresses in nods of the rods increase (not in the cross section of the rail rods).

With the specified parameters of the composite rod from built-up members, the maximum span value should be no more than 6.15 m. Rails structure installation and vessel dragging and lifting operation shown in Fig. 19.

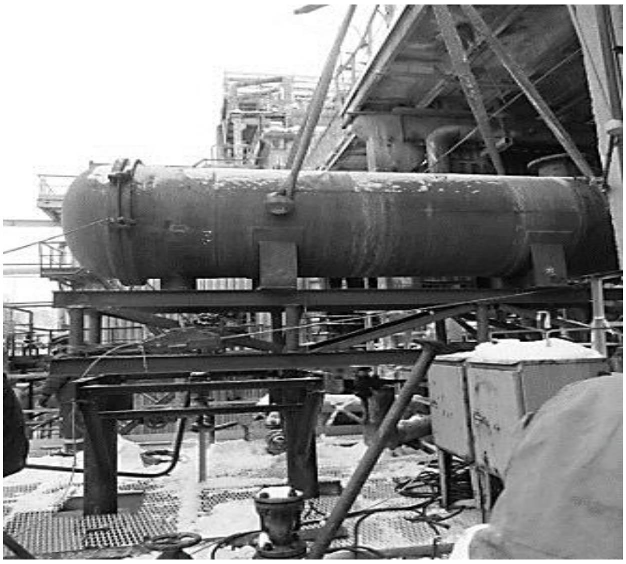

Fig. 19: Installation of metal structures of rails (a) Pipe racks (b) Rail support rack

V. CONCLUSION

As a result of calculations and model analysis, the optimum rail design was selected. The manufacturing process of the rail structure and its installation at the work site was carried out as per calculations, standards and safety regulations. The dismantling, dragging and lifting of the vessel was carried out successfully and safely.

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