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DESIGN OF UNIQUE BELOW-THE-HOOK LIFTING DEVICES FOR SPECIFIC LOADS

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Summary: *Mounting of large-scale mechanical systems involves lifting and positioning of the so-called specific loads, namely structures of great dimensions and masses whose functionality and structural integrity should not be jeopardized during the realization of the erection procedures. Two examples of spatial truss roof construction mountings are presented in this paper as case 1, underlying the effect of unique lifting device usage on uniform load distribution on the structures being lifted. Case 2 deals with mounting of three tall vertical pressure vessels of different weights and heights with the same lifting gear and traverse specially designed to accomplish the aforementioned tasks. Case 3 is focused on the redesign of the existing traverse in order to fulfill the task of lifting and precise positioning of the bucket wheel excavator segment, a truss structure of a great span, weighing 90 t. Results presented in this paper represent a contribution in the field of below-the-hook lifting devices design, arising from the specificity of engineering problems dealing with mounting of large-scale structures.*

Keywords: *unique lifting device, large-scale constructions, mounting, FEA.*

1. INTRODUCTION

Mounting of large-scale mechanical systems involves lifting and precise positioning of structures or structural elements of great dimensions and masses. During the lifting and positioning procedures, which are realized with the use of heavy-lifting machines, such as mobile or derrick cranes, one needs to consider the effect of hanging and transportation on the structural integrity and functionality of these, so called, specific loads. Mechanical damages, caused by interaction between wire ropes and lifted structures, such as pressure vessels, must be avoided at any cost. Sufficient number of hanging points has to be provided in order to transfer the load as smoothly as possible to the structure being lifted, thus essentially avoiding the appearance of disallowed deformations and high stress values which may jeopardize functionality of the mounted structure and even lead to failure. There are many cases of construction failures during the mounting process [1-4]. One of the main reasons is the lack of structural integrity calculations for specific leaning and loading, to which mounted constructions are subjected during the lifting, and especially fine positioning procedures. Surrounding structures, as well as lack of the maneuvering space present an additional, very harsh boundary condition.

Listed problems are often solved by designing and manufacturing unique below-the-hook lifting devices. Although these devices are used once, or at best, several times during their operational life, the cost of their production is several times lower than the one which may be caused by failure of mounted structures.

The need for design of the specific lifting device often arises from previous misfortunate engineering experience emerged from technical difficulties which usually appear on site. Such example will be analyzed as case 1 of this paper.

Process plant building involves installation of different kinds of huge pressure vessels. Big engineering challenge is to conduct the lifting and positioning of vessels of different dimensions and masses with the same additional lifting device, without endangering their integrity, also avoiding any mechanical damages. Design of the special lifting device, used to transfer three pressure vessels of 35 t, 40 t and 86 t of weight and 23.7 m, 23.7 m and 24 m of height respectively to installation position, in sugar plant, is presented in case 2.

Mounting process of open cast mining machines such as bucket wheel excavators involves the use of many different lifting devices. In many cases, already existing additional lifting devices are redesigned in order to be used for the same purpose, but on a different way. When truss structures of great span are mounted, usually the need for additional hanging point arises. This problem is overcome by installation of special lifting tool, presented in case 3.

Project documentation of unique lifting devices has to include, beside the stress-strain analysis of the device itself, the influence of special leaning and loading on the mounted construction in order to prevent possible failures which may jeopardize construction and even lead to endangerment of human life.

Results presented in this paper have wider significance since they can help designers realize mounting procedures of truss structures of great masses and dimensions, and overcome the problems of preservation of structural integrity and functionality of process equipment during installation.

2. CASE 1 – MOUNTING OF ROOF SPATIAL TRUSS CONSTRUCTIONS

Spatial truss construction of the roof, which weights 1800 kN is used to cover silos for cement clinkers with diameter of 40.1 m. Mounting procedure of the roof construction was planned to be realized in two phases. In the first phase, the roof construction would be preassembled on the ground from six segments by using the specially designed pylon for leaning and positioning of the segments. After roof preassembling 18 identical lifting lugs are to be welded to construction. In the second phase, 18 ten meter long wire ropes are attached to lifting lugs via shackles and hanged on the lifting hook of derrick crane. Derrick crane is used to lift the roof off the ground, position it above the silos and lower it onto the 34.8 m high silos pylons.

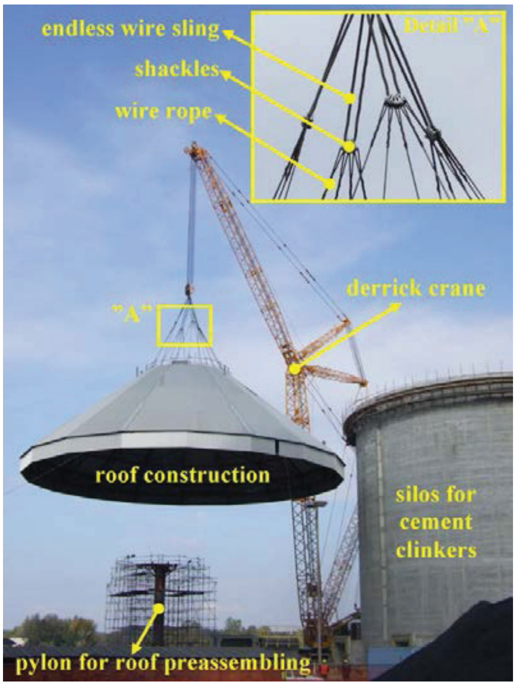
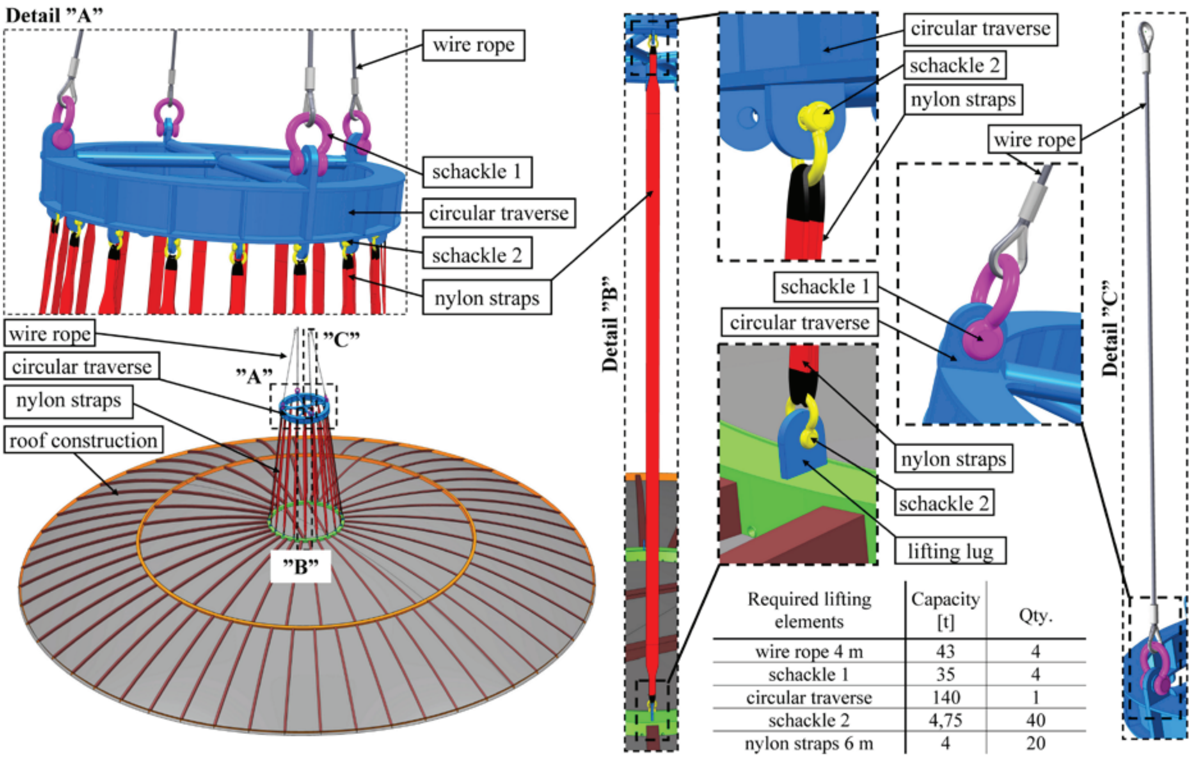


Figure 1: Mounting of the silos roof top

Presented hanging method enabled uniform distribution of roof structure dead weight to all lifting lugs without endangering structural integrity of the lifted construction during the mounting. But, due to technical difficulties which appeared on site, it was impossible to realize roof structure hanging as prescribed by project documentation. Instead, ropes were gathered on four endless wire slings which were attached to the derrick crane hook, Fig. 1. A new hanging method, realized without consulting designers, led to the appearance of serious problems which could jeopardize the mounting process and construction itself. Namely, due to equal length, only 8 of 18 ropes were loaded transferring each 225 kN of weight instead of 100 kN. The problem was diagnosed at the beginning of rooftop lifting, when obvious deformations of lifting lugs and surrounding structural elements appeared. In order to realize more favorable load distribution, the designers suggested the elongation of tensioned wire ropes by attaching additional shackles, tensioning the previously loosened ropes in the process. This way, uniform weight distribution was not achieved, but calculations showed that roof mounting was accomplishable.

Although the problem was solved, and rooftop mounted successfully without endangering construction and human life, it underlined the need for specially designed lifting device which could guarantee uniform distribution of weight and preserve structural integrity of this type of spatial truss construction.

Few years later, a similar problem of sulfuric acid tank roof top mounting was presented to the authors of this paper. The structure of the roof consists of a 8 mm and 16 mm steel plates supported by girders (L120x10 mm and L150x10 mm), with a total mass of 57.9 t and a diameter of 28.6 m. The roof is dome-shaped, with a welded frame positioned on its outer side. The main supporting elements of the roof are made of 3 ring girders, interconnected with profiles and steel plating. The erection of the roof structure is made possible with 20 lifting lugs located on the inner ring. The erection of the roof structure was to be performed with a truck crane via the system of nylon straps, a circular traverse, and steel cables used to connect the traverse to the crane hook. The connection of the nylon straps to the roof construction and the traverse, as well as the connection of the cables to the traverse, is made possible with the use of shackles. The number of lifting elements, along with their specifications, is provided in Fig. 2.



Required lifting elements	Capacity [t]	Qty.
wire rope 4 m	43	4
schackle 1	35	4
circular traverse	140	1
schackle 2	4,75	40
nylon straps 6 m	4	20

Figure 2: Elements for tank roof structure lifting

Stress analysis of the roof construction, conducted using linear finite element method, for specific leaning and loading of structure during mounting procedure (not predicted by the original roof top project documentation) showed that usage of specially designed circular traverse enables uniform load distribution and that the obtained stress values in critical zones of butt welded joints, Fig. 3, are much lower then allowed stress calculated according to [5] for steel quality grade S355J2 as base material.
During the erection of the roof structure a deformation occurs, Fig. 4. The highest deformation value is along the z axis and equals to 19 mm. The cause for such occurrence is twofold; the large diameter of the roof, and its mass. The diameter of the roof shall decrease by 7 mm along the x axis, and shall increase by 6.4 mm along the y axis. This deformation is elastic, and as such, won't permanently affect the shape of the roof, as the original shape restores itself during the positioning of the structure on the reservoir.

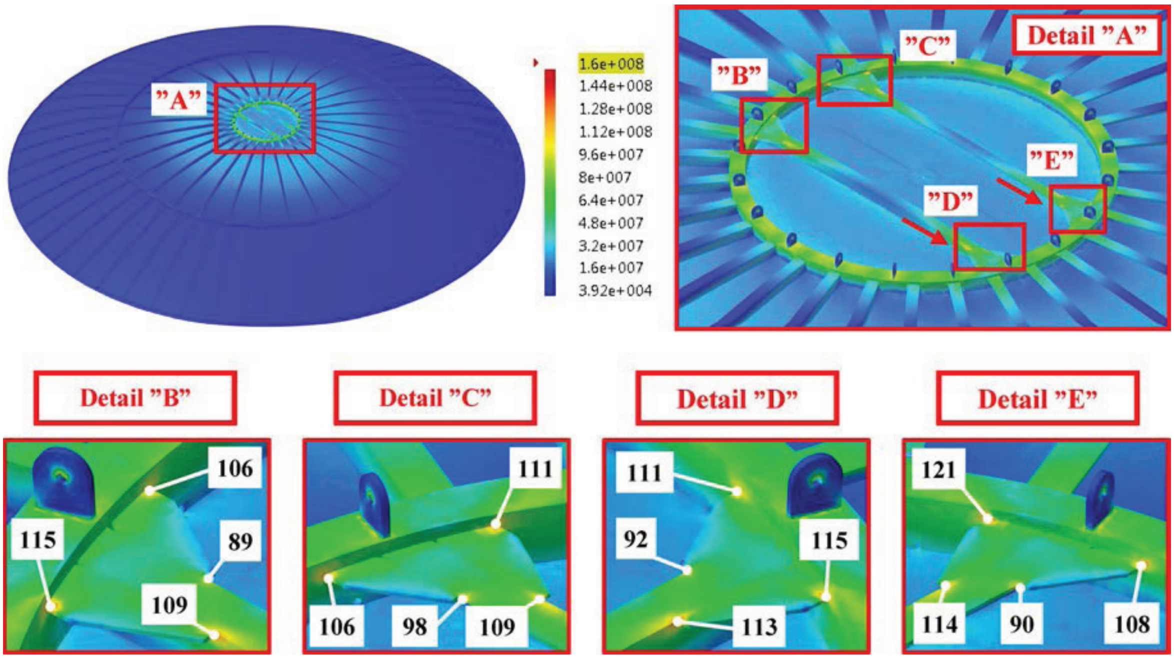


Figure 3: Tank roof structure stress field (values presented in details "B" to "E" are shown in MPa)

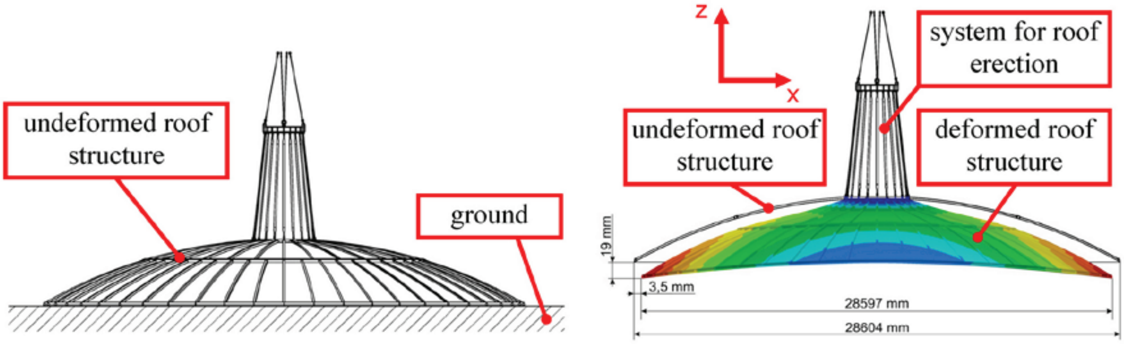


Figure 4: Tank roof structure deformation during lifting

When the aforementioned examples of roof spatial truss constructions mounting are compared it becomes more than obvious that usage of circular traverse preserves structural integrity of lifted construction enabling safe process realization without endangering used equipment or workers life.

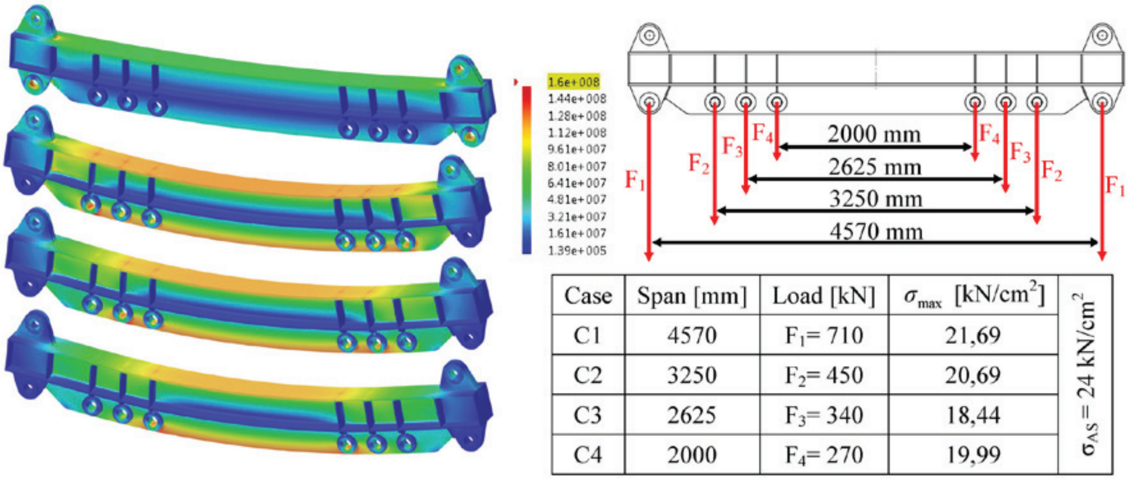
3. CASE 2 – INSTALLATION OF VERTICAL PRESSURE VESSELS

Vertical pressure vessels are, due to their great height, usually transported in horizontal position. When the vessel arrives on site, it should be lifted off the transport vehicle, rotated 90 degrees and carried to the installation position, which is done by engaging two mobile cranes. To realize these operations additional lifting elements have to be installed. On lower-end, lifting lug is usually installed in the zone of vessel bearing plates. In the zone of upper-vessel-end the installment of lugs is usually not possible due to low carrying capacity of the cylinder shell, thus trunnions are used (designed according to [6]).

As aforementioned, during the building of a sugar plant, the need for installation of three tall vertical pressure vessels has appeared. In order to reduce mounting costs, the request of the investor was to use the same lifting gear for the positioning of all three vessels. In order to avoid mechanical damages, caused by interaction between the wire ropes and thin walls of pressure vessels upper cylinder shell, special lifting devices, which could fulfill request of mounting all three constructions, had to be designed, Fig. 5.

Figure 5: Phases of pressure vessel lifting and positioning

Span between trunnions on three different pressure vessels dictates the positions of hanging points on special lifting device. Maximum carrying capacity of each hanging point is determined using finite element method meeting the requirement that maximum stress values obtained by calculations are to be lower than allowed stress value for loading case 1 [7] and steel quality grade S355JR as traverse base material [8]. Results of the finite element analysis (FEA) are presented in Fig. 6.



Case	Span [mm]	Load [kN]	σ_{max} [kN/cm^2]	σ_{AS} = 24 kN/cm^2
C1	4570	F_1= 710	21,69	
C2	3250	F_2= 450	20,69	
C3	2625	F_3= 340	18,44	
C4	2000	F_4= 270	19,99	

Figure 6: FEA of the traverse used for the installation of pressure vessels

Subtle stress-strain analysis has to be conducted for each of the mounting phases, even in case of complex constructions of heat exchangers containing tubesheets, baffles and tube bundle of several hundred tubes, in order to determine the influence of three and afterwards two point leaning on functionality and structural integrity of the mounted structure. Horizontal position, when the heat exchanger is lifted off the transport vehicle engaging two mobile cranes is determined to be the worst loading case. As an example, stress field obtained for 23.7 m tall pressure vessel with weight of 40 t, containing tube bundle of 628 tubes is presented in Fig.7.

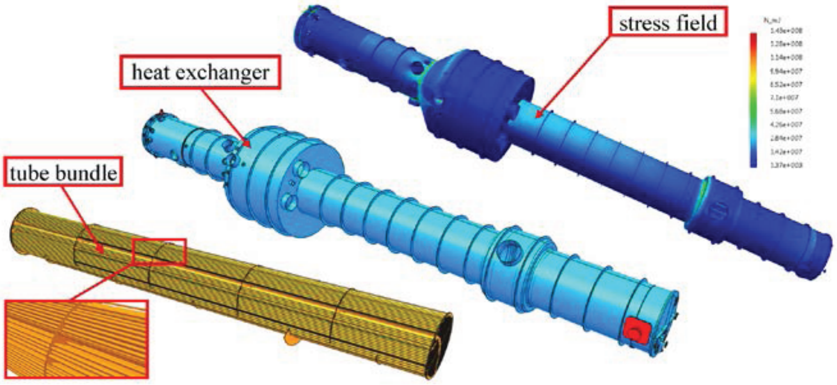


Figure 7: FEA of complex heat exchanger structure in the worst loading case during mounting

4. CASE 3 – REDESIGN OF LIFTING DEVICE

Traverse with carrying capacity of 90 t is used for the mounting and maintenance of open cast mining machines on the erection site of Tamnava West Field, the biggest open pit coal mine in Serbia. The load is lifted with two derrick cranes operating synchronously. According to the original project documentation, the load is hanged on two lifting hooks symmetrically positioned on traverse in four potential positions (span between hooks: 3.20 m, 9.00 m, 12.75 m and 15.20 m). During the mounting of truss structures of great span, weighing around 90 t, it was concluded that hanging on two farthest hooks would cause deformations of structure higher than the allowed ones. The use of other existing hanging points was not possible due to unfavorable load distribution. The problem was overcome by design and implementation of additional hanging tool in the middle of traverse span, Fig. 8. The tool consists of three segments: welded steel structure, axle with bushing and a bearing insert.

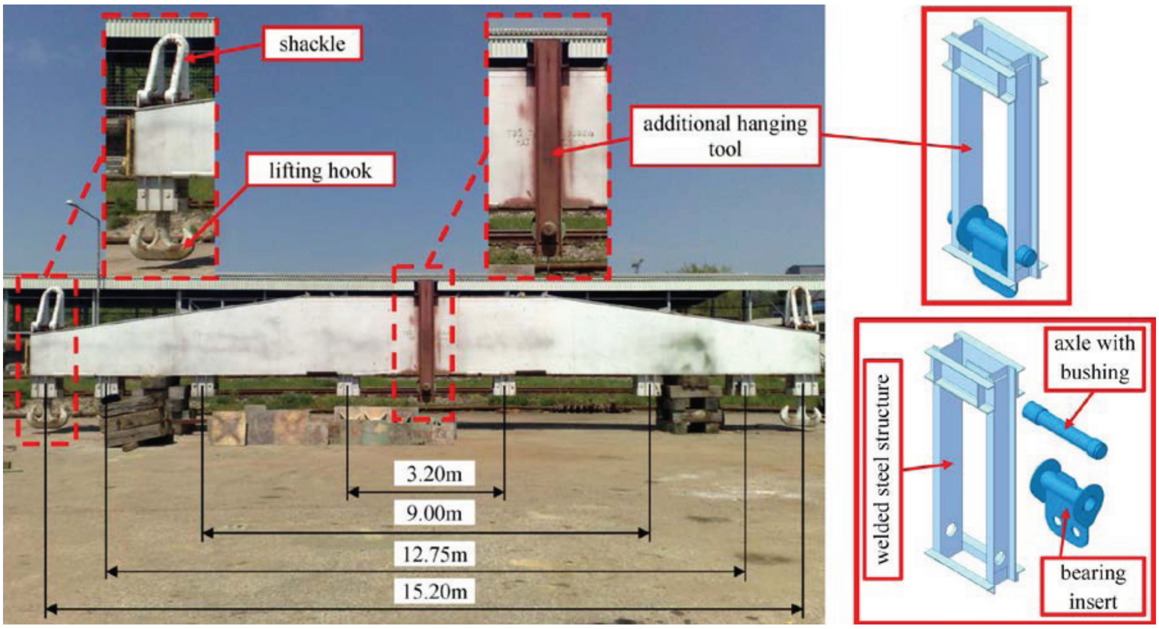


Figure 8: Traverse with additional lifting tool

In order to obtain the permission for traverse usage in way not predicted by project documentation, described in previous paragraph, stress – strain analysis of construction had to be conducted as well as on-site testing using the same hanging method and loads similar to those which traverse will be subjected to during planed mounting process realization. For this purpose, three bucket wheel excavator loading unit segments weighing 30.24 t, 29.42 t and 27.56 t were used as test load, Fig. 9.

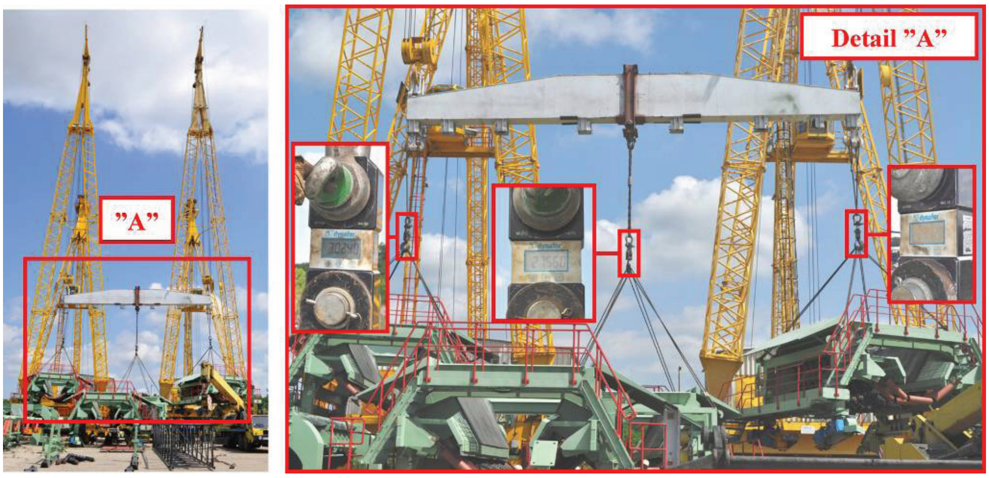


Figure 9: On site testing of redesigned lifting device

The results of FEA showed that the maximum stress values obtained on structure of the traverse, as well as those obtained on the additional hanging tool construction are much lower than allowed ones, Fig.10. The deflection criterion was also met since obtained deflection value on the middle of traverse span of 7.2 mm is lower than the allowed one which is 15.2 mm [9], Fig. 11.

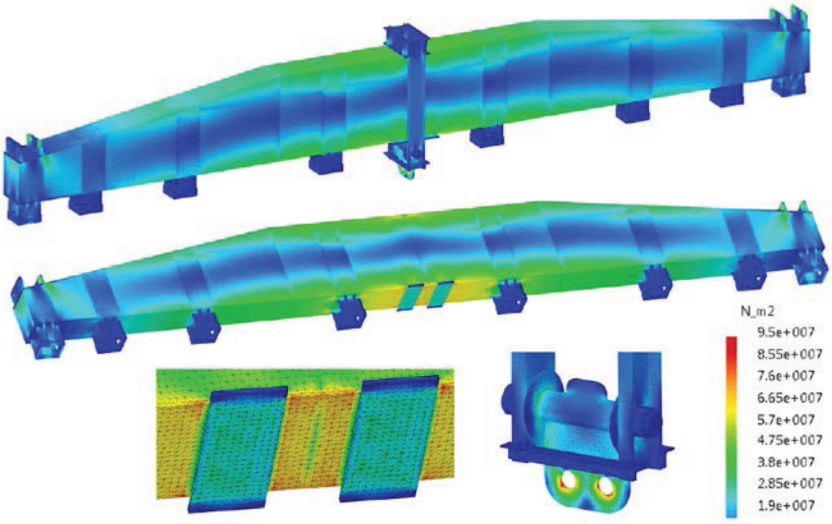


Figure 10: Results of the traverse stress analysis

Figure 11: Traverse displacement field

The validity of calculation models was confirmed on-site, when testing was conducted.

5. CONCLUSION

Design of the unique below-the-hook lifting devices arises from the uncommonness of engineering problem. This field is not covered by known literature, since even the standards dealing with this thematic, such as [10], give only general remarks. These unique devices are geometrically formed according to general principles of bearing constructions design. The importance of such unique structures and their contribution is reflected in preservation of functionality and structural integrity of mounted constructions of great dimensions and masses which, historically, has not always been the case.

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