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# АНАЛІЗ КОНСТРУКТИВНХ ПАРАМЕТРІВ МОБІЛЬНОЇ БАШТИ ОБСЛУГОВУВАННЯ

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**Анотація:** Стаття спрямована на вирішення проблеми аналізу проектних параметрів мобільної вежі обслуговування, що в даний час розробляється Придніпровською державною академією будівництва та архітектури у співпраці з державним підприємством «Конструкторське бюро «Південь» ім. М. К. Янгеля». Основною ***метою*** даного дослідження було знайти такі параметри конструкції мобільної вежі обслуговування, які допоможуть знизити її вагу, а також матимуть достатню надійність для продовження роботи після впливу урагану. Ця проблема була вирішена нами за допомогою скінченно-елементного аналізу. Нами були створені 36 просторових аналітичних моделей в програмному забезпеченні "Ліра-САПР 2013". У цих моделях була відображена частина можливих комбінацій параметрів конструкції. Особливу увагу було приділено аналізу комбінацій, які включали вплив урагану зі швидкістю вітру 50 м/с. В результаті аналізу просторових концепцій мобільного вежі обслуговування ми отримали значну кількість даних, які потім були зважені та проаналізовані. ***Результати*** показують, що тип системи опирання може значно впливати на ефективність споруди. Був зроблений аналіз і оцінка всіх представлених варіантів. Було представлено пояснення кінцевого вибору концепції споруди. Було також доведено, що екстремальні умови вітру можуть становити серйозну загрозу для конструкції, які не закріплені до фундаменту. Результати, які надаються доводять первісну гіпотезу, що витримувати навантаження від ураганного вітру без додаткових конструктивних заходів конструкція повинна бути збільшена.

**Ключові слова:** мобільні башти обслуговування; вертикальний корпус збірки; скінченно-елементне моделювання; оптимізація конструкції; ЛІРА-САПР

# АНАЛИЗ КОНСТРУКТИВНХ ПАРАМЕТРОВ МОБИЛЬНОЙ БАШНИ ОБСЛУЖИВАНИЯ

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**Аннотация:** Статья направлена на решение проблемы анализа проектных параметров мобильной башни обслуживания, которая в настоящее время разрабатывается Приднепровской государственной академией строительства и архитектуры совместно с государственным предприятием «Конструкторское бюро «Южное» им. М. К. Янгеля». Основной целью данного исследования было найти такие параметры конструкции мобильной башни обслуживания, которые помогут снизить ее вес, а также иметь достаточную надежность для продолжения работы после воздействия урагана. Эта проблема была решена нами при помощи конечно-элементного анализа. Нами были созданы 36 пространственных аналитических моделей в программном обеспечении "Лира-САПР 2013". В этих моделях была отражена часть возможных комбинаций параметров конструкции. Особое внимание было уделено анализу комбинаций, включающих влияние урагана со скоростью ветра 50 м/с. В результате анализа пространственных концепций мобильного башни обслуживания мы получили значительное количество данных, которые затем были структурированы и проанализированы. Результаты показывают, что тип системы опирания может значительно влиять на эффективность сооружения. Был сделан анализ и оценка всех представленных вариантов. Было представлено объяснение конечного выбора концепции сооружения. Было также доказано, что экстремальные условия ветра могут представлять серьезную угрозу для конструкций, не закрепленных к фундаменту. Результаты, которые предоставляются, доводят первоначальную гипотезу, что для того чтобы выдерживать нагрузки от ураганного ветра без дополнительных конструктивных мер, конструкция должна быть увеличена.

**Ключевые слова:** мобильные башни обслуживания; вертикальный корпус сборки; конечно-элементное моделирование; оптимизации конструкции; ЛИРА-САПР

# ANALYSIS OF DESIGN PARAMETERS OF MOBILE SERVICE TOWER

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**Abstract:** This paper tackles with ***the problem*** of analysis of the design parameters of the mobile service tower, that is being devised by Pridneprovs’k State Academy of Civil Engineering and Architecture in collaboration with the «M. K. Yangelya state enterprise «Design Bureau «South»». ***The main goal*** of this study was to find such design parameters which will minimize the weight of the mobile service tower, and also have sufficient reliability for continuation of operation after the case of a hurricane impact. This problem was solved by us with the help of the finite element analysis. 36 spatial analytical models were created in the software "Lira-SAPR 2013". In these models part of the possible combinations of design parameters that defined the scheme of support for mobile service tower was reflected. Special attention was paid to the analysis of combinations that included hurricane impact with wind speed of 50 m/s. As a ***result*** of structural analysis of spatial frame concepts of mobile service tower we obtained significant amount of data that was subsequently evaluated and organized. Results show that supports type can significantly influence performance of the structure. Evaluation and assessment of all the presented options was made. Explanation of the final structural concept choice was presented. It was also proven that extreme wind conditions can pose significant threats to structures that are not significantly restrained by the foundation. Results that are provided prove the initial hypothesis that to withstand hurricane wind loads without additional restraints structure prime dimensions has to be increased.

**Key words:** mobile service tower; vertical assembly building; finite element modeling, design optimization; LIRA-SAPR

## Introduction

Due to the development the aerospace industry a variety of tasks related to the needs of this sphere arises before engineers and designers. One of such tasks is the development of service tower (ST). This building is one of the important components of the launch complex. Depending on the purpose and design of technology ST may vary significantly.

For an explanation of these differences, let’s consider the fundamental technology of assembly of the rocket. First of all, the launch vehicle and the payload is delivered to the launch site. Boosters almost always are delivered unassembled due to the transportation requirements. Then the rocket and payload are assembled into one body. After that they have to undergo certain maintenance in the facility, which for different missiles in different countries has many different names: ATF (assembly and testing facility), technical position, technical complex, VAB (Vertical Assembly Building, Vehicle Assembly Building), assembly building, etc. Then launch vehicle usually combined together with the payload is transported to a special site from which the launch is triggered.

The task of transporting missiles to the launch pad has many possible solutions. Each one of them has both its benefits and drawbacks. First possible solution is rocket assembly directly on the launch pad. Second possible solution is to assemble missile horizontally, deliver the launch vehicle to the starting pad in such position and then start set it upright on the start. Third possible solution is to assemble rocket vertically elsewhere and then deliver it to the launch pad in vertical position. Combination of these options is also a valid solution to the problem. We have considered the first option that involves the use of the mobile service tower (MST).

Mobile Service Tower (MST) is required for vertical assembly of the launch vehicle and the installment of the additional equipment. MST also protects launch vehicle and satellite from the environment; it provides access to all systems of the launch vehicle for the staff and is designed in such a way to ensure rapid evacuation of personnel from all levels of the MST to the areas beyond the zone of possible explosion of the launch vehicle.

Mobile tower is not an isolated phenomenon. They are used at almost all space centers worldwide. Examples of towers are presented in Table 1.

Each of the towers has certain features in common, but due to different technology of launched missiles, different factors of external influences, each new tower is a unique structure with its own technical solutions.

This paper tackles with the problem of analysis of the design parameters of the MST, that is being devised by Pridneprovs'k State Academy of Civil Engineering and Architecture in collaboration with the «M. K. Yangelya state enterprise «Design Bureau «South»»».

## Methodology

The scope of this study was to find such design parameters which will minimize the weight of the MST, and also have sufficient reliability for continuation of operation after the case of a hurricane impact. This problem was solved by us with the help of the finite element analysis software "Lira-SAPR 2013". For these tasks, this approach allows us to estimate the impact of a wide range of changes in various design parameters on the MST general stress-strain state (SSS).

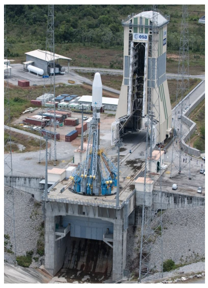
Structure-wise MST is a spatial metal frame consisting of plane frames, united into a single constructive volume by a system of structural ties. Frame of ST provides the ability to perform all work on the installation and assembly of the rocket within the hull of the tower, and is as well designed to provide normal working conditions for all staff irrespective of external weather conditions. MST is equipped with an overhead crane with lifting capacity of 50 t, a lift with carrying capacity of 1 t, external and internal technological ladders, maintenance platforms, system of gates and light well insulated outer fence plates. Construction is sitting on the launch site on a system of trucks.

*Table 1*

**Examples of existing service towers worldwide**

| | | | |
|---|---|---|---|
| Mobile service tower LV «Vega», GSC |  | The mobile service tower complex "Energia" - "Buran", Baikonur |  |
| Mobile service tower launch vehicles "Proton", Baikonur |  | Mobile service tower for LV «Kosmos-3M" Plesetsk |  |

*Continuation of table 1*

| | | | |
|---|---|---|---|
| Mobile service tower for PSLV rockets in Satish Dhawan Space Centre |  | MST for the first manned mission «Mercury-Redstone 3» Cape Canaveral |  |
| Mobile service tower for missile type "Soyuz-2» (draft) |  | Mobile service tower LV «Union», GSC |  |

The main parameter, the effect of which was analyzed in this paper, was a design of a support system of ST. This parameter was chosen due to the sensitivity of SSS of tower to the bearing system design. Special attention was paid to the analysis of combinations that included hurricane impact with wind speed of 50 m/s. To ensure the stability of the structure in such a scenario several measures to prevent overturning of the tower were developed. The use of one or another approach is dictated by the design parameters such as the distance between the outer edges of bogies and the total weight of the design.

To solve the fore mentioned problem 36 spatial analytical models were created in the software "Lira-SAPR 2013". In these models part of the possible combinations of design parameters that defined the scheme of support for MST was reflected. Brief description of these options is presented in table 2. Where: a, b, c, d – distances between elements. Values of this parameters are presented in table 3.

*Table 2*

**Brief description of considered design options**

| № of option | Amount of tracks | Distance between axes of, мм | | | |
|---|---|---|---|---|---|
| | | outside | | inside | |
| | | columns | supports | columns | supports |
| *1* | 4 | *a* | *c* | *b* | *d* |
| *2* | 4 | *a* | *c* | *b* | *d* |
| *3* | 2 | *a* | *c* | *b* | - |
| *4* | 2 | *a* | - | *b* | *d* |
| *5* | 2 | *a* | *c* | *b* | - |

*Table 3*

**Parameter value**

| Parameter name | Parameter value, mm |
|---|---|
| ***a*** | 18000/16400 |
| ***b*** | 10500/9000/7000 |
| ***c*** | 18000/16400/15000/12000 |
| ***d*** | 10500/9000/7000 |

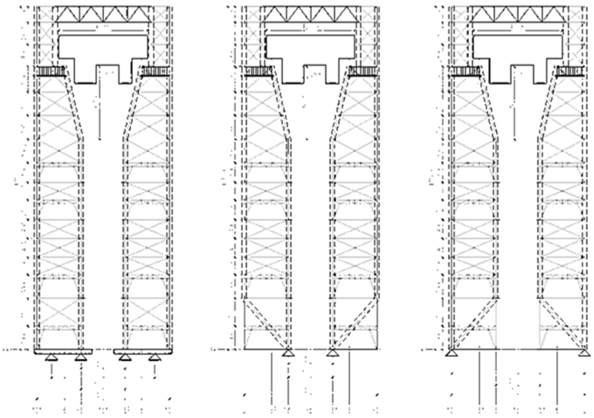


*Fig. 1. Analytical models of MST transverse frames*

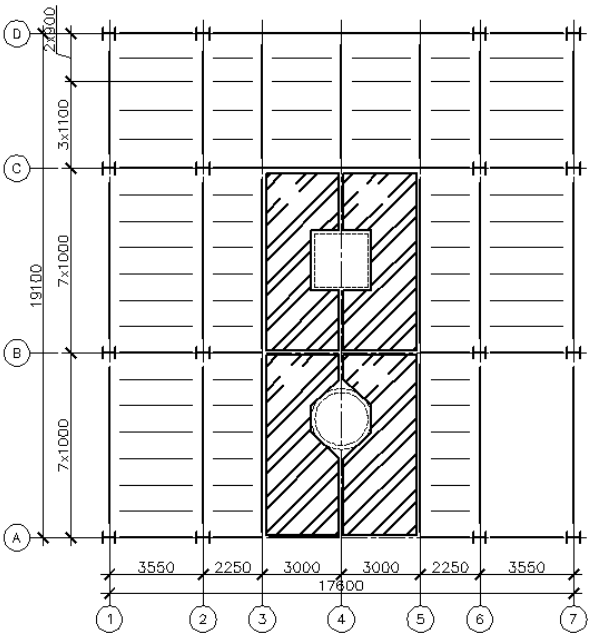



*Fig. 2. MST typical floor plan*

The analytical model was assembled on the basis of finite beam element type10 in «Lira-SAPR 2013» software. This is a spatial beam element with 6 degrees of freedom in a node. Depiction of the element is presented in fig. 4. Beam has a local coordinate system X1, Y1, Z1. Axis X1 is located along the axis of the beam element. Axis Y1 and Z1 are the principal central axes of inertia [11].

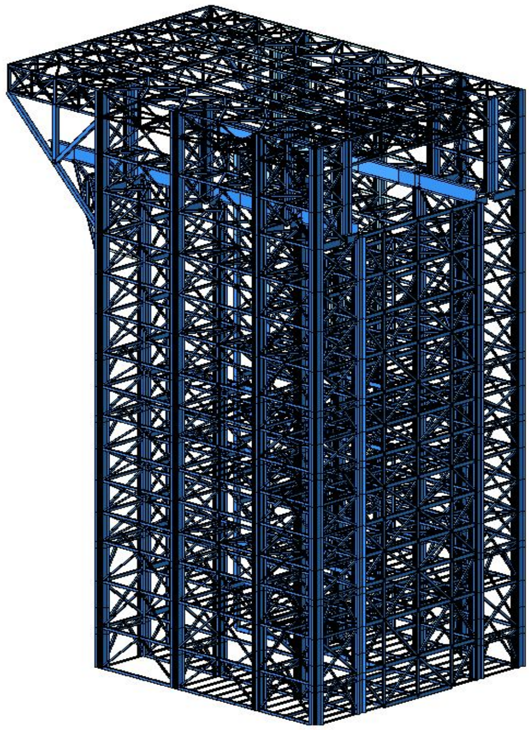


*Fig. 3. Finite element model of MST in 3 dimensional presentation*

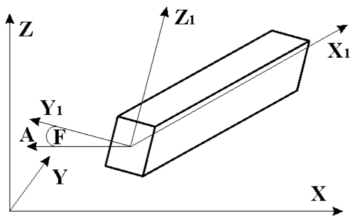



*Fig. 4. BEAM 10 representation [11]*

**Results and discussion**

As a result of structural analysis of spatial frame concepts of mobile service tower we obtained significant amount of data that was subsequently evaluated and organized. After these arrangements all the calculated data can be summarized in-to following categories:

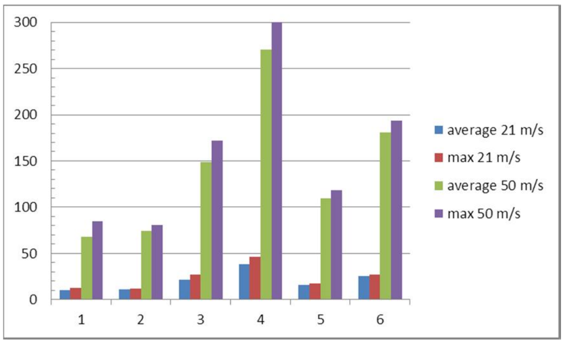
a) MST displacement levels due to the loads and action;

b) Forces in the frame column elements;

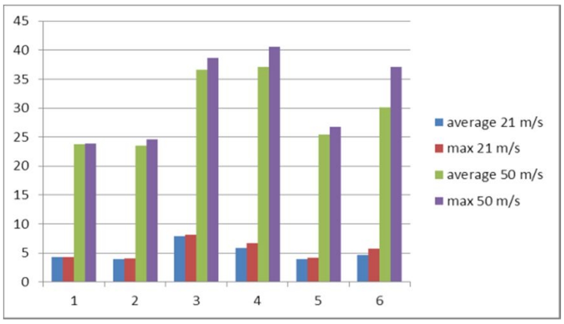
c) Overall weight of structure;

d) Load demand and general type of the MST trucks.

Since one of the main functions of an MST is to provide protection to the launch vehicle and expensive equipment necessary for the technological processes that take place inside the tower, its hull displacements limitation are of paramount importance to the safety of structure. The results are summarized in the table 4. The averaged and maximal between structural options results are presented in fig. 5. From these results it can be observed that displacements caused by the storm with wind speed 50 m/s have great influence on the structure. Displacements at the top level in the direction normal to the rail tracks (X - direction) can reach 325 mm (fig. 5 a)), 40.6 mm (fig. 5 b)) in the direction of the rail tracks(Y - direction) for option 4. Most rigid design options are 1 and 2 with respective displacements equal to 84.4 mm and 81.1 mm in X-direction, and 23.9 mm 24.6 mm. in Y- direction. These results show that supports type can significantly influence performance of the structure.




*a)*



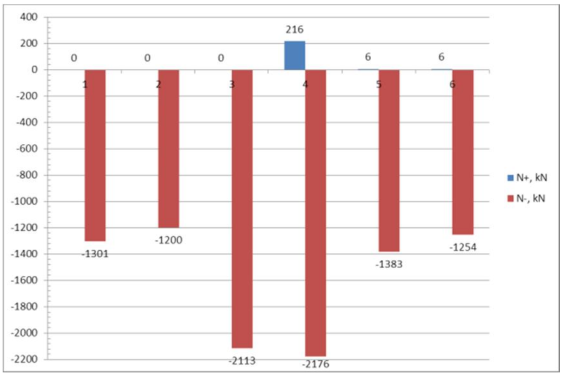

*b)*

*Fig. 5. Displacements in the roof level of MST due to wind action in accordance to the design principal options, mm:*

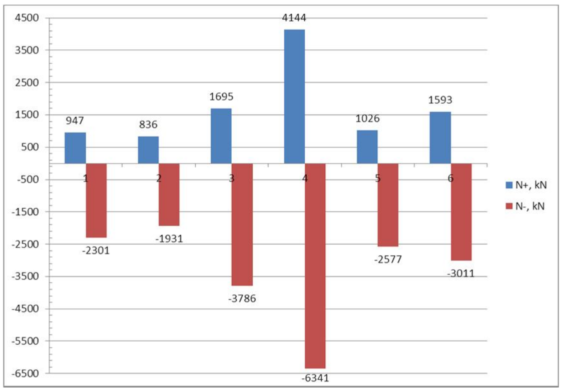
*a) in direction normal to the tower tracks*

*b) in direction of the tower tracks*

MST structure is designed to work in three distinctly different working conditions: the first two of these conditions: positioning and usual operation form up non-exceptional load case. And the third one: operation in extreme weather conditions form up an exceptional load case. Results for maximal force factors in the frame columns are presented in table 5. The maximal positive and negative axial force values are compiled in the diagram on fig 6. Fig. 6 a) represents the results for non-exceptional load case and fig. 6 b) represents the results for exceptional load case. Results in fig 6 a) indicate that options 4 to 6 do not provide for safe operation during the non-exceptional load case since it is under the risk of being toppled due to the wind actions. Results in diagram in fig. 6 b) indicate that the structure needs to be additionally constrained in case of extreme load case. Option 4 has a least stability of all others maximal effort for constraint design reaches 4144 kN. The results also indicate that the first and second options show the lowest values for axial forces in the columns.




*a)*




*b)*

*Fig. 6. Axial forces in frame columns:*

*a) in case of non-exceptional load case*

*b) in case of exceptional load case (storm with wind speed up-to 50 m/s)*

Another crucial point of the design of mobile service tower is its weight. Maximal, minimal and averaged spatial frame weight results for structural options are presented in fig. 7. The results indicate that most cost efficient options for structural concept are 1 and 3 with corresponding weight of spatial frame 567.4 t and 576.2 t respectively.

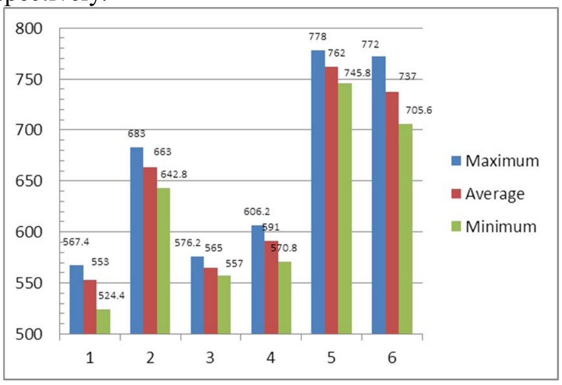



*Fig. 7. Weight of MST frame in accordance to conceptual options, t*

Fig. 8 present the frame weight results for each type of MST hull principal dimensions ***a*** and ***b***. These results indicate that although other parameters have their role, but the most significant parameter that determines the weight of structural frame if the type of support construction. The smallest influence of other parameter is observed for option 3 and the greatest for the option 6.

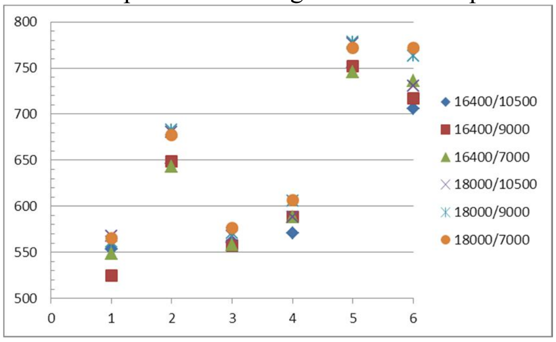
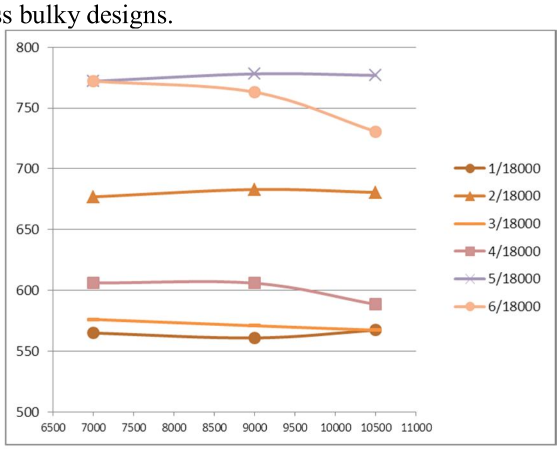
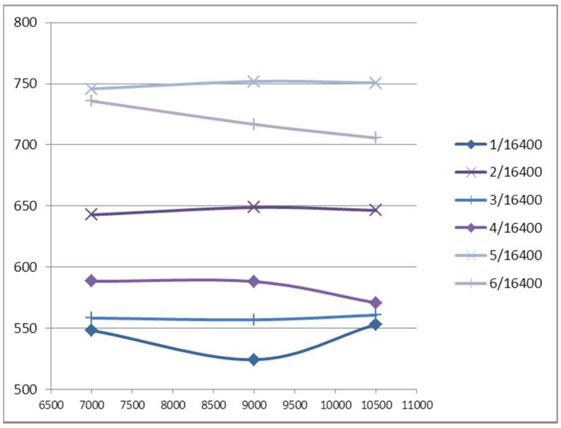



*Fig. 8. Dissipation of frame weight in accordance to the hull principal dimensions and type of support*

Fig. 9 presents weight - inner span – support type dependencies. Fig. 9 a) represents results for outer dimension of 18000 mm and fig. 9 b) represents results for outer dimension of 16400 mm. The results represent that option 6 and 4 show sensible decrease in weight in case of less rigid frame. Smaller sized frames also exhibit less bulky designs.




*a)*




*b)*

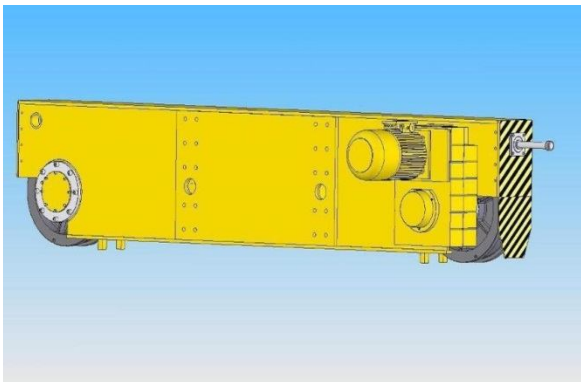
*Fig. 9. Weight - inner span – support type dependency for MST frame with primary dimension:*

*a) 18000 mm*

*b) 16400 mm*

The last portion of design information consists of load capacity of MST trucks. This results are based both on the construction mass and maximal loads that columns are experiencing in case of extreme load case. Different type of column truck joint requires two different types of trucks to be devised. The main difference between these two types would be the amount of track one truck uses for a support. Depiction of the offered truck types can be seen in fig. 10.

*a)*



*b)*

*Fig. 10. Types of MST trucks:*

*a) Type 1 – 2 tracks per truck*

*b) Type 2 – 1 track per truck*

According to the diagram in fig. 11 it is clear that the least load capacity is required for the track of type 2 for option 3 (400 t) and the greatest load capacity is required for type 2 truck for option 4 (660 t).

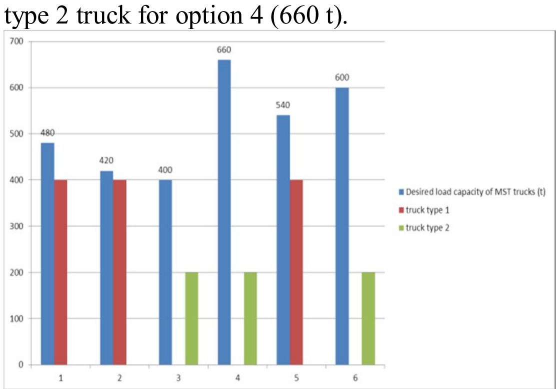



*Fig. 11. Desired load capacity of MST trucks depending on the design option*

Detailed numerical data on the conducted research is presented in tables 4, 5 and 6. Line painted in light grey is the option that was finally accepted as a design concept. The decision to choose this option was based both on the satisfactory performance of option 3 (especially in the way of desired load capacity for tracks and structural frame weight) and also on the ability to provide for the new requirements presented to us in the final stages of the conceptual design, which made some of the considered options unsuitable.

## Conclusions

Research has shown that the MST structure is very dependent on the type of support construction. It was also proven that extreme wind conditions can pose significant threats to structures that are not significantly restrained by the foundation. Results that were provided above prove the initial hypothesis that to withstand hurricane wind loads without additional restraints structure prime dimensions has to be as great as technologically possible.

Further research might be conducted to analyze shape of structure influence on the possible wind load magnitude. Another field of future research would be to investigate the potential of usage of different kind of dampers to decrease the influence of wind oscillation on the structure.

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