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NECESSITY OF PROPER LASHING OF CONTAINERS ON THE SHIP'S DECK AS PART OF OPTIMIZATION OF THE SEA VOYAGE

ABSTRACT

These days we are witnessing an increase of container traffic in general and at sea in particular. In order to economize their business the ship owners are building bigger container vessels which can carry up to 8000 TEUs (Maersk line) and other big carriers are following suit. On the drawing board is the vessel of 12000 TEUs from the mentioned ship owner. Obviously, such large quantity of containers requires highly efficient lashing equipment in order to secure them, particularly those stowed on the deck. Under the deck, almost as a rule all contemporary container ships have cell guides as securing devices. Attention in this work is focused on container lashing system exposed on the ship's deck and the relevant forces acting on the lash system during transportation at sea. Once containers are loaded on the ship's deck they should be safely secured by one of the lashing systems in order to prevent damage and that is the principal task of the lashing equipment engaged within the frame of the lash system. In order to fulfill its objective the forces acting on the container should be properly calculated. The acting forces, their influence and the way of calculating them have been explained for all the major ship movements and suggestions for optimum lashing equipment are given.

KEY WORDS

cell guides, TEU, static force, dynamic forces, green sea, corner castings, pitch, roll, heave, surge, sway, yaw, racking, tipping (toppling), twistlock, lashing rod, container, container stack, domino effect

1.0. INTRODUCTION

Large container vessels carry thousands of containers on deck and failure of the lashing system can cause enormous expenses as result of damage and container loss. Last year we experienced container loss due to bad weather, which caused failure of the lashing system on the container stacks.

The consequence of single container lashing breakdown generates the domino effect on the adjacent stacks which then causes big damage. A striking example was the container ship APL-China, which alone lost in the Pacific storm 700 hundred containers due to failure of the deck lashing system and consequently produced the domino effect. Similar cases happen from time to time on the oceans across the world, only the number of containers lost is different.

The tendency is to build bigger container vessels which automatically brings more containers onto deck and therefore there are more containers exposed to the perils at sea. This is a very significant case, with the post panamax container ships in particular.

As things are, loading of containers on deck requires utmost attention on behalf of all parties involved in marine transport such as naval architectures, ship masters, ship owners - operators, shippers, receivers, underwriters, etc.

Claims based on the aforesaid reason are increasing in number and this has become a serious problem in the present shipping which requires due attention.

2.0. Requirements of container securing system

The principal aim of all the lashing systems is prevention of damage and container loss. Besides the mentioned, the designer of the system has to make the lashing system as economical as possible in order to cut the initial costs while at the same time maintaining safe standards of the lashing equipment. Often, these aims are hard to achieve but generally, the system should satisfy the following demands:

2.1. reliability
2.2. simplicity,
2.3. compatibility of equipment,
2.4. flexibility,
2.5. speed of use,
2.6. ease of use,
2.7. minimum maintenance,
2.8. cost efficiency.

2.1. Reliability

This is a lashing system requirement. In order to prevent damage to the ship structure and loss of containers overboard, all the lashing equipment should be in very good shape. The main intention is to build its components from strong and tested materials approved by responsible classification societies. Usually, the lashing equipment is manufactured from high tensile steel or mild steel such as twistlocks, lashing rods, turnbuckles, lashing plates, cones etc. If a designer employs more lashing components then he runs the risk of having a greater chance of one component failing; therefore, this pattern should be avoided.

The realization of the fact that the racking of the container, rather than tipping is the critical cause of failure, has led to the abandonment of vertical lashings which had been used in early stages of container transportation, thus reducing the number of lashing components.

2.2. Simplicity

All the lashing equipment should be simple to handle thus preventing delays during lashing of containers loaded on the deck and in that way actually minimizing port stay, enabling faster turnarounds of the ship on a particular trade route.

2.3. Compatibility

The principal requirement is that the strength of each component must be compatible with the loads within that component. An upper limit to lash strength is set by the strength of the ISO standard for corner casting which must withstand a force up to 300 kn depending on the direction. Most corner castings have strength exceeding this figure and that excess is actual safety factor. Usually, it is the breaking strength of 360 kn or 420 kn, respectively. It is possible to determine the racking restraint forces necessary to stop racking by calculating the forces on the container caused by ship motions. After this initial step has been performed then it is possible to check whether the strength of the lash is adequate and to apply the necessary lashing components accordingly. Among various lashing components such as wires, chains and lashing rods the latter have proven to have the best performance regarding rigidity and flexibility, simplicity in handling, as well.

2.4. Flexibility

Flexibility of lashings is determined from the racking flexibility of the containers and ultimate strength of the lashings is based on the ultimate strength of the containers. It includes the possibility of serving different heights of containers in use on the ship deck. They are 8 feet, 8.5 feet and 9.5 feet high containers, the most common ones found in container transport. Today, it is quite normal that one container ship carries all the mentioned heights of containers in a single voyage. Due to the aforementioned fact which produces an uneven level of the uppermost tier of containers loaded on the deck the use of bridge fittings becomes impossible, unfortunately, in such configuration of loading. Bridge fittings as securing devices could be helpful in high stacks but due to uneven level of the last tier their application has become a matter of the past times when vessels had been carrying all containers of the same height.

The direct result of the mentioned is the necessity to lash each stack individually. This was made possible by the development of solid rods and twistlocks of various types (base twistlock, middle ones, semiautomatic and automatic ones).

The ability to lash each stack individually began to emerge as trades developed and the ship operators wanted to increase the number of ports of call with a variety of types of containers involved in the transportation process. The real benefit of this is that individual container stacks could be worked without affecting stacks next to them on the same hatch cover or container bay. This arrangement of loading simplifies the overall system and makes it more flexible.

2.5. Speed of use

The speed of use is directly proportional to the time spent in the port, therefore, it is of paramount importance that the design of lashing equipment be practical and deployed fast, ultimately enabling fast ship turnarounds.

2.6. Easy to use

This is in compliance with item 2.5, and as well, the handling of all lashing components should be handy and consequently easy to use.

2.7. Minimum maintenance

Due to fast ship turnaround in the port and short in-between-ports distance there is very little time for maintenance of lashing equipment. Therefore lashing components are usually galvanized which prolongs their lives but does not make them immune to corrosion and physical damage and needs proper treatment in order to stay operable as it is of paramount importance for the safety of the ship, loaded containers and cargo within them.

2.8 Cost efficiency

This is done in the pre-planning stage of shipbuilding and is included in overall ship's costs. The main objective should be to fulfill the task for which the lashing system is built and that is to safely secure containers on the deck while at the same time being cost effective. Both aims are difficult to achieve at the same time as the ship owners are trying to cut costs on expanse of safety or at least are satisfying the minimum safety standards required by the classification societies based on the container securing manual approved for each ship in particular.

3.0. Motions and forces at sea

In optimizing the container securing system on the ship's deck it is absolutely essential to establish reliable estimation of the forces affecting the containers loaded on the deck already in the design phase of the lashing system for a particular vessel. Underestimation leads to failure of the lashing system which produces loss and damage while overestimation increases the cost of the lashing system. Optimization is also based on experience and on simulation, as well. It is preferable that the original estimation is as accurate as possible.

Here we encounter two main aspects, which are:
- calculations of the ship motions,
- calculation of the forces imposed on the securing system.

Determination of the forces acting on the container could be undertaken by the following methods:
3.1 Classical method
3.2 Empirical method
3.3 Stochastic method

3.1 Classical method

The main aim of this method is to identify the components of the forces acting on the container, calculating their maximum values and finally obtaining their resultant. They could be summoned up as follows:
3.1.1 Forces produced by ship motions
3.1.2 Forces produced by green seas
3.1.3 Pre-tension forces
3.1.4 Wind forces

3.1.1 Forces produced by ship motions

They are divided in two major groups and these are:
- Static (gravity) force or dead load force,
- Dynamic (acceleration) forces.

Static force is inherent to every body on this planet and is the result of gravity force of the Earth while acceleration forces are grouped into 6 basic ship's movements of which roll, pitch and heave are of major magnitude and are the principal fields of investigation. Others like yaw, sway and surge are of minor influence and their forces will not be elaborated in this work.

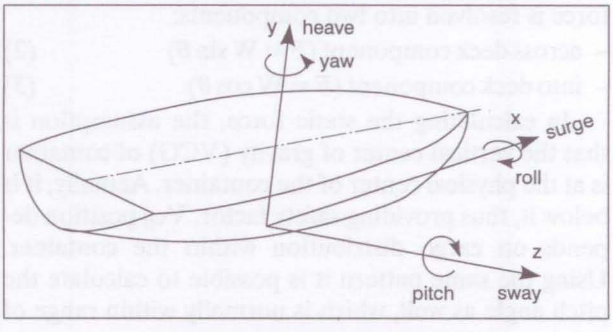

Figure 1 - Basic ship motions

Static force or dead load

W= gross weight of container

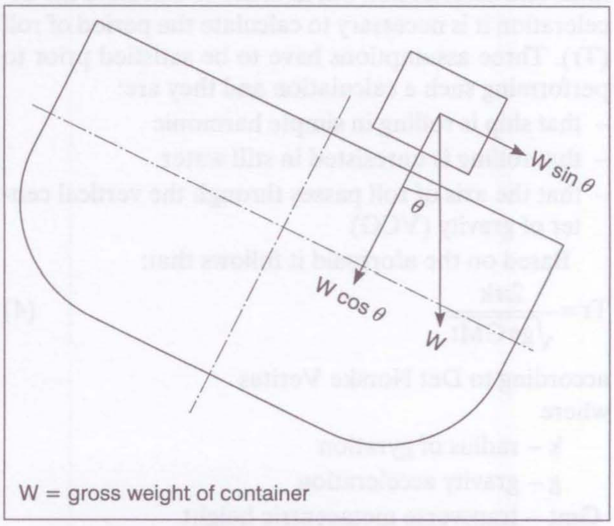

Figure 2 - Static force in container during roll

The principal manifestation of static force is in opposing tipping of container and increasing of the racking force in container. The transverse component of static force produces racking within the container frames and is proportional to the angle of roll. Calculation is based on maximum or near maximum roll angle, which is 30 degrees. Det Norske Veritas has given formulae for calculating maximum roll angle, which is:

$$Ra = \frac{50c}{B+75} \text{ radians} \quad (1)$$

Where

$c = 1.1$	for ships without bilge keel when $Tr < 20$ sec (period of roll)
$c = 1.0$	for ships with bilge keel when $Tr < 20$ sec
$c = 0.8$	for ships with roll damping facilities when $Tr < 20$ sec
$c = 0.5$	in general when $Tr < 30$ sec

For 20 sec < Tr < 30 sec the -c- value may be varied linearly

B = breadth of the ship

Ra = max. roll angle (θ)

During ship's roll static - gravity force or dead load force is resolved into two components:

- across deck component ($F = W \sin\theta$) (2)
- into deck component ($F = W \cos\theta$) (3)

In calculating the static force, the assumption is that the vertical center of gravity (VCG) of container is at the physical center of the container. Actually, it is below it, thus providing safety factor. Vcg position depends on cargo distribution within the container. Using the same pattern it is possible to calculate the pitch angle as well, which is normally within range of 5-8 degrees in most cases.

Dynamic roll forces

These forces are proportional to the container mass and acceleration but in order to calculate the acceleration it is necessary to calculate the period of roll (Tr). Three assumptions have to be satisfied prior to performing such a calculation and they are:

- that ship is rolling in simple harmonic
- that rolling is unresisted in still water
- that the axis of roll passes through the vertical center of gravity (VCG)

Based on the aforesaid it follows that:

$$Tr = \frac{2\pi k}{\sqrt{g * GMt}} \quad (4)$$

according to Det Norske Veritas

where

k – radius of gyration

g – gravity acceleration

Gmt – transverse metacentric height

The radius of gyration varies linearly with the breadth of the ship (B) and for container vessels varying between 0.34 B to 0.40 B.

Period of roll (Tr) can be calculated among various methods simply by the empirical formulae given by Det Norske Veritas :

$$Tr = 1.7\sqrt{B} + 20sec \quad (5)$$

Acceleration caused by roll could be further divided into two components and they are:

- centrifugal force,
- tangential force.

Centrifugal force acts radically away from the axis of roll while tangential force acts tangentionally to the axis of roll. Centrifugal force could be calculated by the following formulae:

$$F = \left[\frac{W}{g}\right] w^2 r \quad (6)$$

given by Det Norske Veritas

where:

W – gross weight of the container

g – is gravity force

w – is roll angular velocity of ship

r – radius of roll

The centrifugal force is at maximum when the ship is upright and zero when the vessel is at maximum roll angle. Due to the fact that critical moments are developed at maximum roll (maximum strain on lashing equipment) then centrifugal force could be ignored. Contrary is the situation with tangential component of acceleration force, which is caused by the angular acceleration of the ship and is at maximum value when roll angle is at maximum. The tangential force could be further calculated as follows:

$$Ft = \frac{W}{g} R \frac{dw}{dt} \quad (7)$$

Because rolling of the ship is periodical roll then:

$$\theta = \theta_{max} \sin\frac{2\pi t}{T} \quad (8)$$

and because angular speed is

$$w = \frac{d\theta}{dt} = 2\pi \frac{\theta_{max}}{T} \cos\frac{2\pi t}{T} \quad (9)$$

therefore tangential force is

$$Ft = -4\pi \frac{W}{g} \frac{\theta_{max}}{T^2} \sin\frac{2\pi t}{T} \quad (10)$$

then max. tangential force is

$$F_{max} = 4\pi^2 \frac{W}{g} \frac{\theta_{max}}{T^2} \quad (11)$$

Tangential roll acceleration force could be further resolved into two components and they are:

- the component across the deck
- the component into the deck

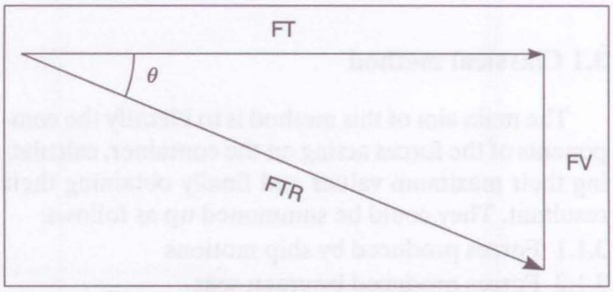

Figure 3 - Tangential acceleration forces

Tangential roll acceleration (FTR) is proportional to Rr (distance from roll center to vertical center of gravity -Vcg of container).

$$FT = FTR \cos\theta \quad (12)$$

$$H = Rr \cos\theta \quad (13)$$

$$FV = FTR \sin\theta \quad (14)$$

$$Y = Rr \sin\theta \quad (15)$$

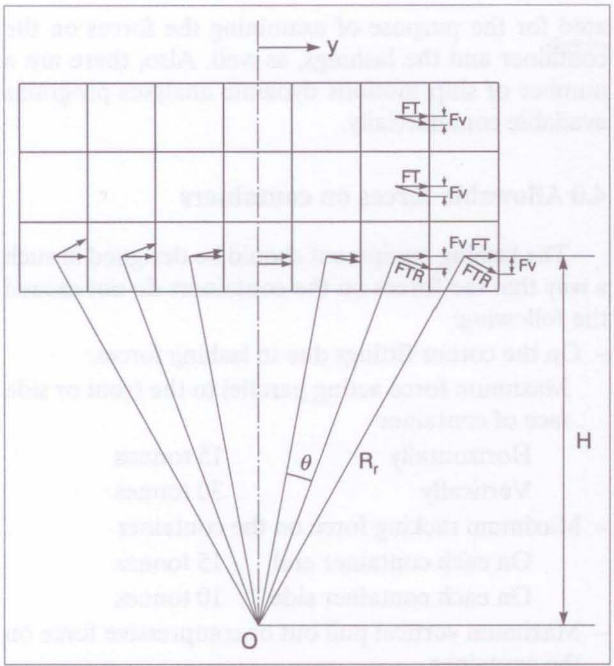

Figure 4 - Tangential roll force – FIR in the container on the deck

Heaving Dynamic Force

- Heaving motion could happen with any state of the sea. It could increase or decrease the gravity or load force. The heave period is given in the following formulae by Lloyd's register of shipping:

$$TH = 0.5\sqrt{L} \quad (17)$$

Where:

L – is the length of the vessel (length between perpendicular – LBP)

Th – is the heave period

Then we can write heave acceleration as:

$$ah = Zh\left[\frac{2\pi}{TH}\right]^2 \quad (18)$$

when zh = half amplitude of heave
then it is

$$Fh = \frac{W}{g} Zh\left[\frac{2\pi}{Th}\right]^2 \quad (19)$$

The resultant forces

Having produced calculations for single ship's motions in particular, it is very interesting to find out the resultant forces of combined components and to predict the worst possible cases. The main function of the lashing system is to prevent container movements once the container has been secured to the ship's deck. In the first instance a lashing system is implemented in order to prevent racking and tipping of containers on the deck then logically the worst situation is when these two forces are maximized. The maximum racking force we find at the moment of maximum roll with bow down while ship is at the bottom of wave through and heave down, as well. Containers at outmost lateral positions experience most of the force imposed on the lashings and therefore it is recommended to reinforce the lashings of the mentioned containers as they are also exposed to the wind which brings extra load on the securing equipment.

The maximum tipping force occurs at the maximum roll with bow up and the ship on the crest of the wave and heave up. The most affected are outboard and forward containers. This way, the dynamic components are maximized and until the roll angle of 45 degrees the static component will oppose tipping. The second point of interest is how these forces could act simultaneously? In reality it is almost impossible that the maximum roll, maximum pitch and maximum heave happen at the same time, therefore the calculation of their maximum values appearing at the same time is far from reality.

3.1.2 Green seas

In the early stages of container vessels these were built with the so-called flush deck type enabling during heavy weather boarding of green seas on the containers loaded on the deck thus increasing the load on lashings and at the same time creating buoyancy effect on the impacted containers. This resulted directly in overloading of the securing system which caused breaking of the lashing equipment and consequently ship suffering damage to its structure and to containers or loss of containers overboard. In order to minimize the damages, contemporary container vessels are built with breakwater on the forecastle, improved lashing systems and some of them have cell guides extending on the deck from underneath. The introduction of the aforesaid has significantly reduced the damages on deck containers, however not eliminated the threat.

The magnitude of green seas depends on the sea impact at a particular moment, which is caused by the state of sea and wind in that particular moment, as well as ship's speed.

3.1.3 Pre-tension forces

They appear in the case of lashing being fastened too tight, but their maximum value is not more than 5 kn. It is a small force but it is important from the standpoint of breaking load, which is brought closer to 5 kn with pre-tensioned lashings. This practically means that if the designed breaking load of high tensile steel rod is 360 kn then if pre-tensioned, it will bring breaking load to 355 kn from the very beginning.

3.1.4 Wind forces

The force of wind in all calculations is taken by all classification societies and is 40 ms^{-1}. The apparent

Figure 5 - Proper lashing

side area is calculated as actual side area multiplied by cos č and the aforementioned could be calculated by the following formulae according to the Lloyd's register of shipping:

$$Fw = 8.25AV^2 \cos\theta \cdot 10^{-5} \qquad (20)$$

Where:

Fw – wind force on the side of container stack

A – apparent area of container or a stack

V – speed of wind in ms^{-1}

3.2 Empirical calculations

This type of calculation is based on experience from previous cases and is quite reliable. It is particularly useful to compare the results based on theoretical calculations with the empirical ones.

3.3 The stochastic method

With the introduction of computers which has enabled simulations, the possibility of risk analyses has been enlarged. Using stochastic approach it is possible to start from different factors and to forecast distribution of forces under certain conditions. By the force of numerous simulations the optimum cost/risk balance could be found. Nowadays, programs have been created for the purpose of examining the forces on the container and the lashings, as well. Also, there are a number of ship motions dynamic analyses programs available commercially.

4.0 Allowable forces on containers

The lashing equipment should be designed in such a way that the forces on the containers do not exceed the following:

– On the corner fittings due to lashing forces:

Maximum force acting parallel to the front or side face of container

Horizontally	15 tonnes
Vertically	30 tonnes

– Maximum racking force on the container

On each container end	15 tonnes
On each container side	10 tonnes

– Maximum vertical pull out or compressive force on the container

Vertical pull out at each corner

At top corner	15 tonnes
At bottom corner	20 tonnes

– Vertical compressive force in each corner post

20 ft container	45 tonnes
40 ft container	67.5 tonnes

– Maximum transverse compressive or tensile force acting parallel to the top or bottom face:

At top of container

20 ft container	22.5 tonnes
40 ft container	34.0 tonnes

At bottom of container

20 ft container	35.0 tonnes
40 ft container	50.0 tonnes

5.0 Conclusion

Container lashing on the deck of container vessels is a great problem particularly on post Panamax container ships which carry several thousands of units on deck. Being so, such huge quantity of containers is exposed to the perils of sea. These containers and their lashings have to withstand occasionally severe ship's motions due to bad sea conditions and enormous load passes through the lashing equipment implemented in securing containers on the ship's deck. In case of failure in the lashing system the domino effect is produced and consequently the ship suffers damage to its structure and damage is done to containers with container loss overboard, outboard stack, in particular.

The possible damage could be minimized with alternate ship design, which carries fewer containers on the deck but in that case more should go under the deck thus increasing the ship's depth and gross ton-

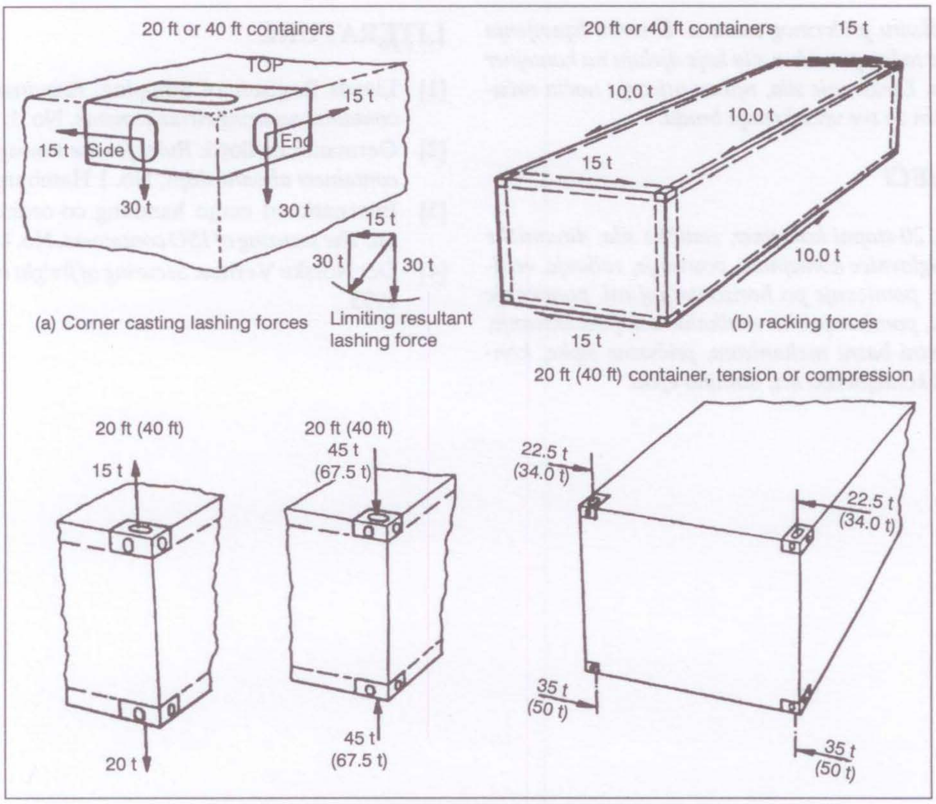

Figure 6 - Allowable forces for FEU and TEU

nage. Secondly, such vessel will face more resistance and this requires stronger engine in order to maintain the requested speed. The consequence is the increase in the fuel consumption, meaning, higher costs. Alternatively, instead of the lashing equipment the ship could have cell guides on the deck which offers more security but also some negative side effects. Everything depends on the demands for particular trade route and capital investment by the ship owners - operators and other parties involved. However, so far, the best on-deck lashing system herewith recommended means the following configuration:

- Base twistlocks in corner castings at the first tier,
- Middle twistlocks in the interlayer positions (successive tiers),
- At the end of containers semiautomatic or automatic twistlocks (successive tiers),
- Fore and aft lashing rods attached to the second and third bottom tier in inside lashing pattern,
- Additional lashings on outboard stacks due to radial force and wind influence,
- Bridge fittings if possible, but today due to different heights of containers not likely.

In the front of 25% of LBP (length between perpendicular) lashings should be reinforced at least by 20% due to increased load on lashings in these positions.

The aforementioned lashing configuration is recommended in this work as it is based on the experience of the author. Post Panamax container ships regularly carry on-deck container stacks up to 7-8 high with the intention of going even higher and there is a great problem in securing such stacks.

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SAŽETAK

POTREBA ISPRAVNOG PRIČVRŠĆENJA KONTEJNERA NA PALUBI BRODA KAO DIO OPTIMIZACIJE POMORSKOGA PUTOVANJA

Danas smo svjedoci povećanog kontejnerskog prometa uopće, a pogotovo na moru. U svrhu ekonomizacije poslovanja brodari grade sve veće kontejnerske brodove koji mogu ponjeti do 8000 TEU-a (Maersk line) i ostali veliki prijevoznici ih slijede. Na projektnim panoima je brod od 12000 TEU-a spomenutog brodara. Očigledno da ovako velika količina kontejnera zahtjeva veliku efikasnost pričvrsne opreme uključene u osiguranje na palubi složenih kontejnera. U podpalublju kontejnerski brodovi kao u pravilu imaju vodilice kao osnovno pričvrsno sredstvo. Pozornost u ovom radu je fokusirana na kontejnerski pričvrsni sustav izložen na palubi i odnosne sile koje djeluju na pričvrsni sustav za vrijeme prevoza morem. Nakon što su kontejneri ukrcani na palubu broda isti trebaju biti sigurno pričvršćeni jednim od pričvrsnih sustava u svrhu prevencije štete i to je osnovni zadatak pričvrsne opreme *upotrebljene u okviru pričvrsnog sustava. U svrhu ispunjenja spomenutog cilja točan proračun sila koje djeluju na kontejner treba biti izvršen. Djelovanje sila, njihov utjecaj i način računanja je objašnjen za sve veće kretnje broda.*

KLJUČNE RIJEČI

ćelijske vodilice, 20-stopni kontejner, statička sila, dinamičke sile, živo more, uglovnice kontejnera, posrtanje, valjanje, vertikalno podizanje, pomicanje po horizontalnoj osi, pomicanje po poprečnoj osi, pomicanje oko vertikalne osi, poskakivanje, prevrtanje, zakretni bazni mehanizam, pričvrsne šipke, kontejner, vertikalni kontejnerski niz, domino efekt

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