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On the estimation of the design loads on container stacks due to excessive acceleration in adverse weather conditions

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ABSTRACT

A large number of containers is lost every year from ships along shipping routes. Even though the economic losses are in most cases covered by insurance, the containers drifting in sea may compromise the safety of navigation. Moreover, there can be serious consequences for the environment, in terms of pollution.
All the reported losses were caused by extremely violent motions of containerships, due to adverse weather conditions. This pointed out the need of further researches on safer container shipping, through heavy sea states. The accurate determination of design accelerations and loads on container stacks are of prime importance for safety.
This paper proposes a realistic numerical modeling approach of the critical ship motions, including the pertinent nonlinearities. A method to evaluate a map of the dynamic loads along the container arrangement is presented. This calculation is based on a fine description of the acceleration distribution on the ship.
Area exposed to higher accelerations will be highlighted.
The method can be used to guide the design of lashing systems for containerships to sustain the actual accelerations and forces. Sample calculation of the forces acting at the container locks is provided for a conventional and a non-conventional container arrangement on board.

1. Introduction

Thousands of containers fall off the ships every year along international shipping routes [11]. Apart from commercial problems (in most cases cargo is covered by insurance), the lost containers drifting in the sea, could lead to dangerous situation for the navigation of other vessels. Nevertheless, there are serious consequences also for the environment, in terms of pollution. Damaged containers could release their content to the sea and, in case of dangerous goods, could lead to serious environmental damages [45].

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Nomenclature

a_h, a_v inertial accelerations at the center of the container stack above the top of the first container, in the direction of the y- and z-axes of the body-fixed co-ordinate system
a_x, a_y, a_z acceleration values provided by the rules, in the body-fixed co-ordinate system
a_{xC}, a_{yC}, a_{zC} acceleration components at (x_C, y_C, z_C), comprising inertial and gravitational effects, in the body-fixed co-ordinate system
$a_{xc1/3}$, $a_{yc1/3}$, $a_{zc1/3}$ average of one-third highest value of the accelerations a_{xC}, a_{yC}, a_{zC}
$a_{xc1/10}$, $a_{yc1/10}$, $a_{zc1/10}$ average of one-tenth highest value of the accelerations a_{xC}, a_{yC}, a_{zC}
a_{yg}, a_{zg} acceleration components at the center of the container stack above the top of the first container, comprising inertial and gravitational effects, in the direction of the y- and z-axes of the body-fixed co-ordinate system
$a_{yG1/3}$ average of one-third highest value of the accelerations at the ship center of gravity comprising inertial and gravitational effects, in the direction of the y- axes of the body-fixed co-ordinate system
θ pitch angle
ϕ roll angle
M mass of the analyzed cargo
m_s mass of the container stack above the top of the first container
F_x, F_y, F_z Inerial forces applied at (x_C, y_C, z_C), in the body-fixed co-ordinate system
x_C, y_C, z_C co-ordinates of the center of the cargo, in the body-fixed co-ordinate system
δx_C, δy_C displacement of the center of the cargo, in the direction of the x- and y-axes of the body-fixed co-ordinate system
p,q,r angular velocities in the body-fixed co-ordinate system
u,v,w translational velocities in the body-fixed co-ordinate system
G constant of gravitational acceleration
A single container width
B single container height
L single container length
Y racking force at the container lock
Z_1 lifting force at the container lock
Z_2 corner post force at the container lock
z'_G distance between the stack center of gravity and topside of the first container in the stack, positive downward
I_{sx} mass moment of inertia (of the container stack above the top of the first container) calculated in the stack center of gravity with respect to the longitudinal axes
KG vertical center of gravity of the ship
GM metacentric height
V ship speed
H_S significant wave height
T_1 mean wave period
β ship heading

Recently the classification societies introduced new rules regarding container lashing system design [12]; [27]. Despite the rules increased the design acceleration values, it has been recognized that in parametric roll scenarios, containerships could experience accelerations higher than expected.

Most of the recent accidents, occurred on containerships, report about extremely violent motions in adverse weather conditions [10,46]. Lashing and other securing systems of container ships, at the time of the accidents, were not able to prevent container stacks to fall apart. Thus, the determination of accurate design accelerations and the evaluation of the loads on container stacks are of primary importance for safety. This ensures reliable and safe container loadings and adequate dimensioning of lashing equipment. A deeper analysis of ship motions and accelerations in heavy sea states, would improve the safety of container shipping. In this context, a more realistic modeling of the ship behavior in critical scenarios is strongly required and all the pertinent nonlinearities need to be taken into account [14,22,24,43,49]. The primary loads on container stacks are of static and inertial nature; thus, an accurate knowledge of the acceleration distribution on board would contribute to a safer design of the container securing systems, and to avoid cargo shifting.

Previous research works report about different methods for evaluating the risk of the container shifting in waves [17,26,39]. The main assumptions of linear roll motions, done in these papers, allow for long-term and short-term probabilistic analysis. Although linear methods seem to be the fastest and easiest approach to deal with ship motions in waves, they neglect large amplitude motions and they are not capable to simulate non-linear phenomena [2]. In particular, parametric roll cannot be detected without taking into account the non-linarites linked to change of the immersed hull in wave [37]. Further