論文内容の要旨

Dissertation Abstract

論文題目 Study on the Dynamic Response of Container Stacks Using Non-Linear Finite Element Analysis
（非線形有限要素法を用いたコンテナスタックの動的挙動の研究）

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During the centuries that followed the Age of Discovery, when Europeans, notably Portugal and Spain, started to cruise the Seven Seas, the first navigators faced a dilemma that threatened their well being and the success of their enterprise: how to transport goods safely and efficiently across the oceans? Moreover, how to do it avoiding deterioration and consequent losses? The final answer for these questions was the creation of containers: a geometrically simple structure that facilitated maritime transportation. Nowadays, sea surface transportation accounts for 99% of all international transportation. Of this amount, the biggest part of the fleet corresponds to container ships. The use of containers to transport numerous manufactured goods is relatively new. Since this piece of equipment was invented in 1937 by Malcolm MacLean, a revolution was seen in maritime transportation, with consequent improvements in efficacy and reliability.

Despite its young age, containers became broadly popular and their use quickly spread around the globe. Nowadays, about 90 % of all non-bulk cargo maritime transportation worldwide is performed employing containers stacked in container ships. However, such popularization brought some concerns: tight schedules allied a recent increase in the height of stacks carried on deck and the growing size of container, coinciding with a substantial increase in the number of containers lost at sea. This number is estimated in something around 10 thousand each year, and although the total number is involved is a matter of controversy among experts, this still represents a significant economical loss to the liner industry. Often, extreme sea conditions that eventually induce parametric rolling in the vessel are considered the most probable culprit behind those losses. However, present regulation and norms for securing equipment are calculated based on static loads, an unrealistic approach considering the dynamic nature of the conditions faced by containers during maritime transportation. Thus, questions have been raised about the safety of prolonged use of these standards, which might underestimate real values of forces acting on container stacks and their securing elements.

In this panorama, the problem of container stack dynamics must be addressed properly to understand the mechanisms behind container losses, helping to set new standards and promoting valuable advice to the liner industry. To achieve this goal, the authors propose

the study of the container loss problem in the light of science using a strong methodology. The study was divided in four main stages: scaling of a 20 ft ISO freight container, pilot study using scaled model in a two-tiers single stack arrangement (2x1), container stack dynamics study using scaled model in a seven-tiers single stack arrangement (7x1) and the same study of a seven-tiers three stack arrangement (7x3). These stages were segregated in two sub-stages: experimentation using shaking table testing, and numerical simulation employing finite element method. For both sub-stages a set of control variables were idealized: amplitude and frequency of the driving excitation, payload added to the scaled models, horizontal rotation of the stack base and twist lock's gap size. Additionally, 2x1, 7x1, and 7x3 systems' linking connectors, denominated twist locks were modeled for both cases (experimental and numerical).

The first part of the research presents a method to scale down 20 ft containers using dimensional analysis, similarity theory, and finite element analysis. The scaling study was separated into four sub-stages: determination of similitude parameters using Froude scaling laws, design testing (Finite Element Method - F.E.M.), scaled model manufacture and experimental validation (static and dynamical). The physical (dimensions, mass, and moments of inertia) and structural (longitudinal, transversal and torsional stiffness) characteristics of the scaled models were decided based on two dimensionless numbers: ratios between gravity force and inertia force, and elastic force divided by inertia force, through experimental and numerical analysis. Furthermore, the choice of each similitude parameter and its determination using dimensional analysis are presented in detail. Additionally, model geometrical design based on finite element analysis, posterior static and dynamic validation are explained thoroughly. In conclusion, study qualifications and limitations are logically presented with further prospect.

The second part of the research presents a pilot study used to identify some important points before the last two stages of the study. Among these points author can emphasize: adequacy of the instruments and their operations, checking the design of the research protocol, assessing whether the research protocol is realistic and workable, establishing whether the sampling frame and technique are effective, identifying logistical problems which might occur using proposed methods, estimating variability in outcomes to help determining sample size, collecting preliminary data, assessing the proposed data analysis techniques to uncover potential problems, and the assess the adequacy of the control variables.

The third part of the research describes an approach to simulate the 7x1 system, subjected to dynamical load induced by its base. Series of experiments with controlled parameters (amplitude and frequency of driving excitation, payload, shaking table base rotation and gap size) were performed using a shaking table test to understand the effects of each variable in the container stack dynamics and present enough data to validate the numerical model. Finally, the last stage describes an approach to simulate the 7x3 system using shaking table test in three cases only. The main goal of this stage is to identify and quantify the contact among stacks in order to calibrate the numerical model.

The study helped to elucidate some points regarding the system's fundamental mechanical behavior, where correlation of dynamic properties depending on amplitude, frequency, base rotation, container load and twist lock gap size, were obtained and used to calibrate and validate a numerical model. After this strenuous validation, the scaled numerical model was used as a valid tool to simulate the behavior of multi-stack configuration in some simple situations faced by containers during maritime transportation. Among these situations some common were studied in detail: heaving, pitching and rolling, employing cases reported in the literature. Additionally, the problem of how simple changes in basic variables affect force in the bottom twist lock was addressed providing useful advice for the industry, trying to maintain the problem complexity to a minimum. Undoubtedly, this is one of the most significant findings to emerge from this study. In this panorama, it may contribute significantly to the understanding of container stack dynamics, an area where intuition and old standards are still preferred over more solid scientific principles.