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Foran Application on Damage Stability Assessment on a Container Vessel

Abstract

The paper focuses on two aspects. One is SENER incentives to work with the educational community by providing the FORAN software as a collaboration mean that centres on helping to develop the FORAN system, and the other way around the use of the FORAN system for academic purposes in universities, to improve and complement the teaching and training process for students.
The second part of the paper focuses more on a technical details on the design procedure for the damage stability and the safety assessment criteria that is established accordingly. Stability assessment is performed using the FORAN software, with the creation of explicit damage events by a fully automated simulation, established from the uniformly distributed random numbers with given probability distributions for size and position of damage and an example on a container ship presented.

Keywords: stability, damage condition

1. Introduction

The first part of the paper addresses the implementation of the FORAN software into the teaching process into Faculty of Engineering Rijeka. The effect of this implementation is two-way. It helps FORAN developers to ensure that expected business systems and product features behave correctly as expected and it complements the teaching and training process for students. It is up to academic staff to not only instruct students in modernized courses but also to teach faculty members how to be effective instructors. At the moment the faculty is introducing not only the FORAN software but 3D experience software as well. Student learning impact should be shared through research and thought pieces about this new instructional methods.

The second part of the paper presents the damage stability calculation for a specific ship that can be calculated by way of deterministic damage stability and probabilistic damage stability. The deterministic method is largely omitted from this presented work. However, both methods aim to provide safety of ships against sinking/capsize in case of loss of their watertight integrity which is the main concern to regulatory bodies, society and the industry itself.

2. FORAN implementation in universities

2.1. FORAN incentives to work with universities

SENER collaborates with educational programs of universities around the world by offering FORAN licenses for leaning purposes, supporting the education of future professionals and fosters student talents; by sharing their knowledge in lectures, seminars and workshops, and by carrying out joint projects with universities, technology centers and research institutes.

In this regard, SENER and the University of Rijeka has established relationships in which SENER offers its FORAN system, a CAD/CAM/CAE software for the design and production of ships and offshore structures that has celebrated its 50th anniversary in 2015, half a century of continuous reinvention that makes it the longest running shipbuilding software available in the market. FORAN is a system used in the design and construction of vessels and marine structures, developed by SENER and it encompasses every aspect of design in a fully integrated manner and because it is used at every stage of the design and production of a vessel.

This co-operation agreement between Rijeka University and SENER for the use of FORAN has entered its third year and the System has been used by the students at the time that have had the opportunity to receive classes in different modules. What is more, among these students, some of them have finished their MSc based on the FORAN System. In this sense the present has been very helpful to test, between others, the latest probabilistic calculation improvements introduced by SENER's programmers and helping SENER in its mission to offer a better and easier to use software.

As previously stated Faculty of engineering Rijeka has a collaboration with SENER for the last couple of years and this paper aims to present the results of this cooperation both in terms of teaching and learning outcomes as well as the technical aspect of the software implemented.

From the broad range of FORAN products the faculty has obtained the licence for the Initial design module comprising of FSURF, FGA and FBASIC subsystems.

It is well documented, that SENER values the importance of its relationship with the educational community. Its focus is on the use of the FORAN system for academic purposes, to improve and complement the training process for students and to help in developing the FORAN system. That way SENER can meet the requirements that guided its design and development, check its software functions that are installed and run in its intended environments to respond correctly to all kinds of inputs so that it achieves its general purpose and result.

Of course, prior to its commercial launch, the software is tested within the company itself. But the use of the software in the universities can additionally help to identify any possible defects, errors or bugs that could potentially be made during the development phase, so that the results delivered are more accurate, consistent and reliable.

SENER also values the possible benefit in incorporation within the FORAN team of the most outstanding students with the best academic records. In the technical disciplines as such, research/funding can provide an opportunity for students to participate and to present their research work to national forums, conferences, and journals.

The contribution in this paper includes the development of probabilistic study with FORAN to compare its results with previous jobs helping to highlight areas of the software that were difficult to handle without a deeper training such as multi-patch surfaces, continuity between surface patches, automatic sections areas recalculation after bulkheads/compartments modifications and others issues that would be managed by the software and will facilitate the job of future users.

2.2. University incentives to implement the software into the classes

The faculty, on the other hand also has a significant gain in implementing such solutions into the teaching process. Universities have sought, through research grants obtained by faculty members, to expand facilities and purchase equipment necessary to conduct classes using the software at hand. It aims at the improvement in the quality of undergraduate teaching while also providing adequate access to undergraduate education to improve the faculty members' teaching effectiveness.

Too often the transition from the classroom to blended learning via software implementation is difficult. Many educators think that this research orientation has led to growing neglect of the art of teaching. Articulate faculty members steeped in traditional classroom instruction may find their style translates poorly to an environment where they don't feel confident. Ideally, the teaching staff has to be a software expert to be an effective instructor. As a first step, we need to communicate that we aren't flipping traditional classrooms for introducing or increasing only software instruction. It is complimentary. However integrating new technologies, and building the step-by-step process to make this happen takes time. There is always a possibility to assign students with a project that needs to be delivered as individual work. It requires the student to get acquainted with the software, to get a concept about its routines, but of course to be sound technically. In this sense, to possess sufficient knowledge about the ship damage stability calculation.

Fortunately, SENER not only provided the software but it organised FORAN workshop and FORAN webinar to get not only students involved but professors as well since professors should be adaptable and seek to find the most appropriate means for delivering information to students. During the workshop SENER has provided thorough documentation with manuals and the full digital description of the AHTS ship based on which whole instruction was conducted.

Depending on the overall basic preparation of the students, courses should be modified if necessary to accommodate student needs and abilities with this novel approach.

At the moment, FORAN has been implemented in the Faculty within the group of courses associated with the ship modelling and stability. For instance, in courses auditory exercises, deterministic stability is quite presentable since it is possible to simulate and achieve steady state solution of certain heel and trim of a ship. Unlike the deterministic stability, the probabilistic damage stability is difficult to explain in a conventional manner since there aren't any classical exercises that could provide further insight into the matter. That's when FORAN comes in very handy.

The course excellence is grounded in the three interrelated activities expected of them: teaching, research, and service. These three components should be mutual. Research and service experiences improve teaching by broadening knowledge and experience. The service has been provided by FORAN representatives to the highest standard, promptly and efficiently. During this work FORAN developers provided support on a number of issues that occurred, some that have arisen from the modelling standpoint and some that were related to the probabilistic damage methodology implementation.

2.3. FORAN software implementation

FORAN Initial Design comprises the Hull Forms, General Arrangement and Naval Architecture calculations. Those subsystems are all integrated with the other modules in the FORAN database, which enable the reuse of information in later stages through data integrity.

Hull forms definition is obtained through FSURF, a tools to define the ship surface model by means of interactive graphic functions, possibilities to imports/exports surfaces from/to other standard formats (IGES, DXF, STEP…).

The definition of deck and bulkhead surfaces of the ship, and their intersection with the hull surface is automatically calculated.

The definition of the ship's general arrangement is preformed through FGA module. The 3D model of any ship topologically defines compartments which can be subdivided into subspaces by selecting the boundary surfaces, defining several sections or parametrically. By inserting data related to the contents and type of compartment, it enables a more accurate calculation of relevant data (weights, volumes,…) that will be used later in the analyses. In addition, it is possible to position all the equipment already existing in the database or in the 3D model. This does not apply only to machinery in equipment, but also to deck equipment, accommodation units, etc. General plans are generated directly from the 3D model, and any changes to the 3D model automatically updates the designs.

Finally, the third module used in this work is FBASIC a relatively new single calculation process tool [1] that features the complete calculation of hydrostatic values (and some other naval architecture capabilities) which will be reported later in the paper. FBASIC enables an accurate calculation of the flooding conditions and damage stability according to the deterministic and probabilistic methods, based on defined watertight characteristics, appendages, draught marks, openings, wave and wind profiles, etc. All calculations are in accordance with the latest international regulations and rules.

To conclude, the process starts in FORAN managing the hull forms, creation of the decks and main bulkheads in FSURF, the compartment definition in FGA followed by the FBASIC in order to perform the naval architecture calculations.

While designing the work here, some technical problems were encountered. Below are listed and described the problems that have arisen during this work along with the solutions which were resolved and submitted by FORAN representatives.

Problem 1: Defining the spaces (tanks) on a ship, the program does not recognize the curved parts of the external hull of the ship as a boundary.

Solution: When mirroring the right side of the ship's shape to the left to obtain a closed form, there was a small hole in the joint at the bottom of the ship, so the program did not recognize the form as one unit.

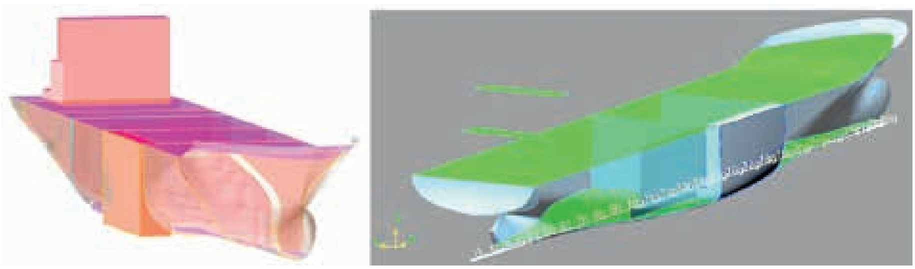

Figure 1: Problem and the solution whilst defining tank spaces

Problem 2: Defining the watertightness of the hull (shape) of a ship. The program did not read the form as watertight for the propeller shaft openings, nor after closing the aforementioned openings.

Solution: It was necessary to go back to the FSURF module and close the shaft opening and redefine the form as one unit but without the propeller shaft opening, and then move to the FGA module, where the form was successfully defined as watertight.

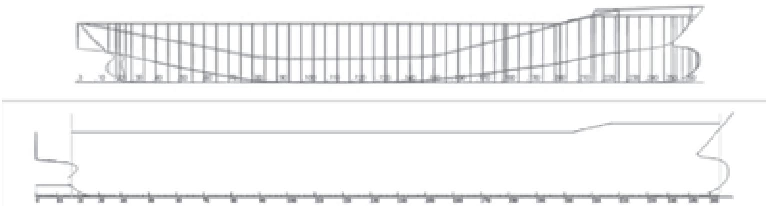

Figure 2: Problem and the solution while defining the watertightness of the hull

Problem 3: Probabilistic regulations. After defining tanks, spaces, zones, subzones and flooding, the program started with calculations. It reported an error and replaced the defined tanks with some new unknown tanks and the calculation could not be performed.

Solution: The problem was a wrongly calculated parameter *b*, because it subsequently moved the bulkhead and after which it did not update all the spaces and zones, thus the parameter *b* remained unchanged. Parameter *b* is mean transverse distance in metres measured from the shell to the longitudinal barrier in question that accounts for probability factor *r* for the transverse damage extent ($r = f(b)$) which in turn affects the probability of survival *A*, which will be explained further below.

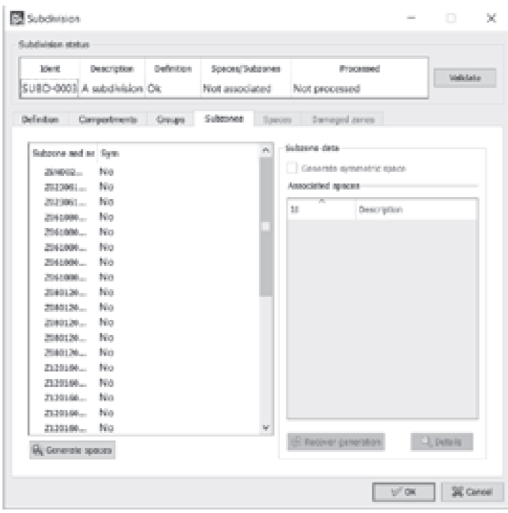

Figure 3: Problem and the solution while running probabilistic damage regulations

3. Case study

The ship taken as an example is a container ship with following principal dimensions: L_{oa} = 201.41 m, L_{pp} = 189 m, B = 32.24 m, D = 18.692 m, T = 11.017 m, DWT = 30 887 t, v = 19.33 kn.

All functions within FORAN were performed using a graphical multi-window environment consistent with all other FORAN modules. Data is displayed in form of tables and figures. Additionally, the permeability of the different compartments used in this study are pre-set by FORAN, but of course in accordance with the rules. The latest probabilistic regulations applicable to cargo, ferries and passenger ships FORAN incorporates/implements in the software.

3.1. Theoretical background

To keep the ship upright and afloat, due to an accident such as collision or grounding, where the ship hull is penetrated, undamaged compartments have to provide sufficient buoyancy. There are several ways to evaluate the trim and stability of a ship after flooding, one being the deterministic method specifically the 'Lost Buoyancy Method' adopted by IMO where the margin line represents the key element. In the early concept studies it is possible to select an appropriate hull form and with simple damage extent criteria, position the main watertight bulkheads so that "at the button click" a range of damage GZ curves can be derived.

However, in this work the focus is on the probabilistic methodology which will be presented in brief. The current probabilistic damage stability regulations are based on damage statistics from Lutzen [2]. Damage parameters, such as longitudinal location, damage length, vertical extent damage and damage penetration were investigated to obtain relations between those damage parameters and main particulars of the struck vessel.

Probability of survival denoted *A* which indicates whether the stability is sufficient once a compartment (or group of adjacent compartments) is flooded, is given as a summation over all possible damage cases as,

$$A=A(p,v,r,s) \quad (1)$$

p - Probability that only the compartment or the group of compartments under consideration may be flooded, disregarding any horizontal subdivision.

v - Probability that the damage will not exceed a given height above the waterline.

r - Reduction factor, which represents the probability that inboard spaces will not be flooded.

s - Probability of survival after flooding the compartment or the group of compartments under consideration.

Based on uniformly distributed random numbers and given probability distributions for position and size of damage, the generation of explicit damage events for a damage stability calculation can be performed by a fully automated simulation. Thus, the probability distribution is assigning the probability to a certain event.

The loading conditions are defined by their trim, *GM* value and the mean draught d. The *A*-index is determined from the three loading conditions corresponding from the percentual time (40% time spent on *ds*, 40% time spent on *dl* and 20% time spent on *dp*) the spends in operation. Attained subdivision index, *A*, should be calculated as:

$$A = 0.4As + 0.4Ap + 0.2Al \quad (2)$$

- *ds* – Deepest subdivision draught
- *dp* – Partial subdivision draught
- *dl* – Light service draught

The base of the probabilistic concept is a comparison of the attained index *A* against the required index, regulatory one, *R*, [3] such that

$$A \geq R \quad (3)$$

The contribution of all damage cases makes a sum for each partial index,

$$A = \sum p_1 s_1 \quad (4)$$

Main aspects taken in consideration in determination of *R* were satisfactory number of ships per type, the robustness of formulae at ship type level that may vary with ship type and that the level of safety should be uniform.

In the case of cargo ships greater than 100 m in length (*Ls*) MSC.194(80) [4]:

$$R = 1 - \frac{128}{L_S + 152} \quad (5)$$

The so-called harmonized regulations in SOLAS 2009 [5] which are applicable from January 1, 2009 to January 1, 2020. for cargo vessels over 80 m state that minimum values of the attained subdivision index at specific draughts and its partial indices *As*, *Ap* and *Al* are to be are not to be less than 0.5*R* for cargo ships. For cargo ships, the required subdivision index is now between 0.47-0.74.

The regulations for cargo vessels over 80 m as well as passenger vessels, that will come into force from January 1, 2020. are gathered within SOLAS 2020 regulations.

3.2. Discussion and results

The damage stability calculations were performed in FBASIC (Naval architecture) module a novel FORAN subsystem, where advanced features and the relevant characteristics are set within all other applications that are used in conjunction with concept design to operation. Naval architecture calculations are based on a SQLITE database with the possibilities of multiple design alternatives produced rather quickly using tree element structure. However, Naval architecture program can be integrated in an intuitive and user-friendly manner with other modules in a single database based in Oracle thus enabling the complete ship design and production activities [6].

After suitable fixed discretization in a number of zones, in the longitudinal, transverse and vertical direction the probabilistic calculation will yield *A*-index. A zone is a portion of the vessel between two boundaries (e.g. transverse bulkheads). The ten zones were divided according to the actual watertight subdivision of the ship as evident from figure 4.

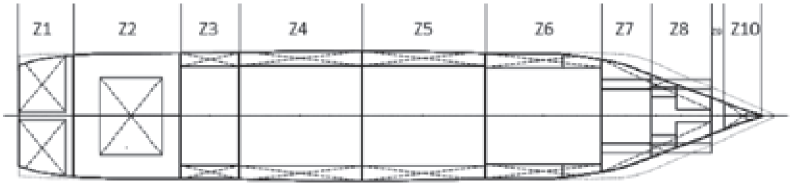

Figure 4: Subdivision zones.

The longitudinal bulkhead is further away from the side of the ship in the fore region while the engine room area doesn't have one. A double bottom is extending from the aft peak bulkhead to the collision bulkhead. By using the probability distribution for every transverse location along a longitudinal direction that defines the extremes length L_S for subdivision, the probability of damage can be calculated.

The bottom line triangles indicate single-zone damages, while the parallelograms indicate multi-zone damages in this the ten-zone division of a ship as illustrated in figure 5. All combinations of adjacent zones contribute to the *A*-index but the use of the zonal concept forces the subdivision model into regularity, since, in general more zones will yield higher *A*-index, thus avoiding certain pitfalls of a more refined subdivision.

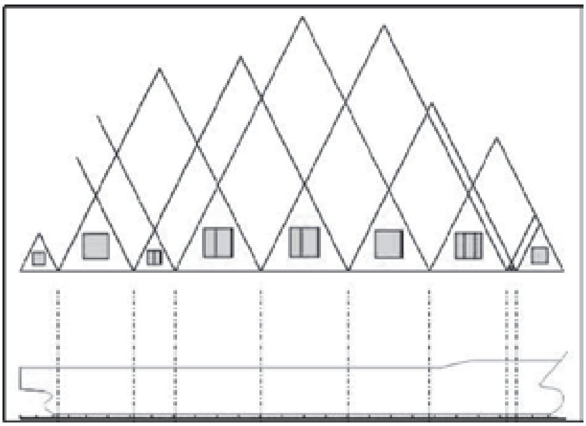

Figure 5: Possible single- and multi zone damages for a ship with 10 zones.

Based on the MSC.216 (82) [7] as given in equation (1) to (5) the partial attained indexes A for the various draughts have to exceed the partial required index R. Related damage probabilities with the list of damages sets is provided after generation of all damages with complex sets of adjacent compartments automatically covered as seen on an example of the output given in figure 6. As the simulation is fully automated the number of damage combinations is nearly unlimited but of course for practical reasons the number of zones should be limited to some extent [8].

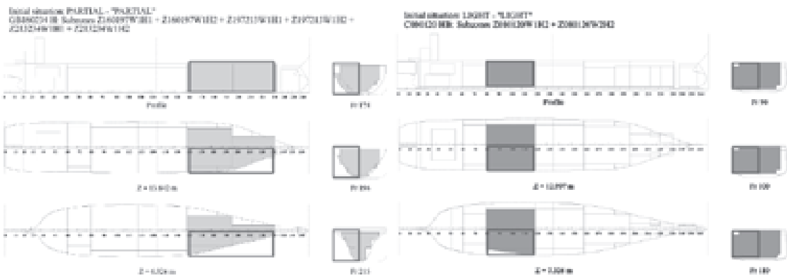

Figure 6: FORAN example output for a partial subdivision and light service draught

In order to obtain index A probabilistic values p and v with the dimension of the damage and righting lever curve, and factor of survivability s have to be calculated beforehand. Since R = 0,636, each loading condition corresponds to the following:

Table 1: Partial attained indexes A for the various draughts

ds	*dp*	*dl*
0,5*R* = 0,318	**0,5*R* =** 0,318	**0,5*R* =** 0,318
As* > 0,5*R	***Ap* > 0,5*R***	***Al* > 0,5*R***
0,675 > 0,318	0,55 > 0,318	0,98 > 0,318

The total attained index using eq. (2) is then,

$$\boldsymbol{A} = 0.4\boldsymbol{A_S} + 0.4\boldsymbol{A_P} + 0.2\boldsymbol{A_L} > \boldsymbol{R}$$
$$\boldsymbol{A} = 0.4 \cdot 675 + 0.4 \cdot 0{,}55 + 0.2 \cdot 0{,}98 > 0{,}636 \tag{6}$$
$$0{,}684 > 0{,}636$$

Since the calculated damage stability indexes are above the threshold of the required index the ship is rated safe according to the rules and regulations.

In the past, it was found that for the same ships using the same proposed methodology but with the different software's the results were uneven [9]. That is the reason the new harmonised regulations were implemented. The same ship was analysed using the different software in [10]. However, the structural arrangement was not quite the same and the number of zones as well. The results for the partial indices *As* and *Al* corresponding to the deepest subdivision draught and light service draught were almost equal possibly due the same main particulars and ships capacity. However, the partial subdivision draught index was surprisingly quite distant.

The more detailed subdivision generally has lower attained index than the simplified subdivision [11]. As the internal subdivision of the vessels vary according to its zones, the development of the attained index would vary according to the internal arrangement. The probabilistic methodology of course inherits some uncertainties connected to the vessel in this study. To limit the uncertainties of the development of the attained index, the design of each vessel should be as authentic as possible which wasn't the case in this study. This study has not analysed how the attained index develops for the different loading conditions for the vessel.

Djupvik [12] reported that for some of the vessels the attained index for one loading condition develops very differently from another loading condition for the same vessel and arrangement. In order to get a deeper understanding of the development of the total attained index, the development of the attained index for the different loading conditions should be furthered analysed.

4. Conclusion and further work

Modern education needs to work closely with educational technology systems to enable faculty members to translate their classroom courses to new blended learning environments. Focused training should include how to set up courses, and discussions about new software tools that can be used to enhance learning. The experience shared by the Faculty of Engineering in Rijeka and SENER was presented in this paper.

The paper presented an example of probabilistic damage stability on a container ship using FORAN software. There are still some issues that were raised by this research due to uncertainties of the development of the attained index, with respect of the design of each vessel that was backed up by references.

The focus on how the method of the study could be improved to get more reliable results using design alternatives is one of the topics of future work. The aim is to get more generic results that could be applied for all vessel types preferably using different software's (FORAN, etc.) as a benchmark study.

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