A model of performance-oriented risk-based assessment of safety of container ships

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ABSTRACT

The paper presents some information on a performance-oriented risk-based model for assessment of safety of ships in damaged conditions. The design for safety process is integrated with the risk analysis. As safety is treated as one between the main design objectives such an approach is called the risk-based design. The assessment of safety is based on the risk level. The risk level is evaluated according to the risk-based criteria. For the risk analysis the Formal Safety Assessment methodology has been applied.

Keywords: safety of ships, design for safety, risk analysis, Formal Safety Assessment (FSA)

INTRODUCTION

The paper presents some information on modelling safety of ships in damaged conditions at the preliminary design stage by using an alternative performance-oriented risk-based method. The present regulations related to safety of damaged ships are included in SOLAS Chapter II-1 parts A, B and B-1. Those regulations are prescriptive in their character and are based on the semi-probabilistic and probabilistic approaches. Application of requirements included in those regulations to certain types of ships e.g. large passenger vessels, Ro-Ro vessels or car-carriers may lead to insufficient level of ship safety or provide unnecessary design restrictions. Instead of prescriptive regulations IMO has decided to use within the rules improving and new rules making process the safety assessment based on satisfying the objectives. One of the objectives, between the standard design objectives, is a sufficient level of safety. For this purpose IMO has recommended an application of Formal Safety Assessment methodology published as MSC Circ. 1023.

The current method of assessment of safety of ships in damaged conditions is based on the harmonized SOLAS Chapter II-1 parts A, B and B-1. The proposed alternative method is a kind of performance-oriented risk-based analysis incorporated in the design process with reduction of risk embedded as a design objective. It should be underlined that this method can easily be adopted for assessment of safety of undamaged ships as it very much depends on the problem (system) definition.

In the paper the performance-oriented risk-based method of assessing safety of ships including modelling is briefly discussed because of limited space available. Some examples of safety assessment for two container ships using the proposed method are presented in the paper. The detailed discussion regarding the method and modelling will be published by the Gdansk University of Technology later this year.

CURRENT METHOD OF ASSESSMENT OF SAFETY OF SHIPS IN DAMAGED CONDITIONS

The current method for safety assessment of ships in damaged conditions is based on the regulations included in the SOLAS chapter II-1 parts A, B and B-1. Using the current methodology the measure of safety of a ship in damaged conditions is the attained subdivision index "A". It is treated as the probability of survival of flooding any group of compartments.

The basic design criteria is the condition as follows, IMO (2005):

$$A > R \tag{1}$$

where :

A - attained subdivision index calculated according to the formula :

$$A = \sum p_i s_i \tag{2}$$

p_i - probability of flooding the group of compartments under consideration

s_i - probability of survival after flooding the group under consideration

R - required subdivision index.

The logical structure of the system for assessing the condition (1) according to the current SOLAS methodology is presented in Fig. 1.

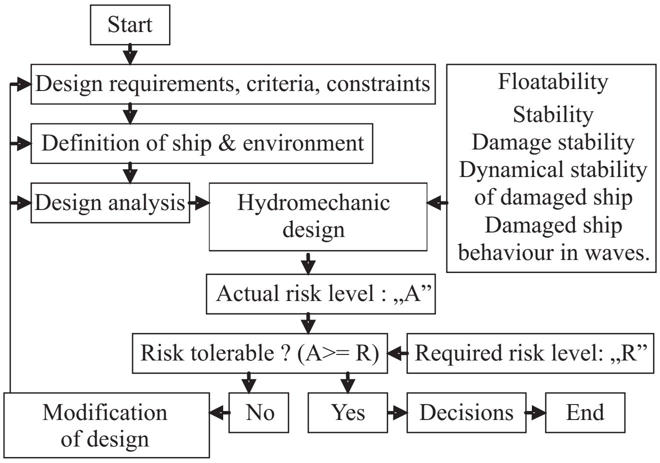


***Fig. 1.** Basic logical structure of system for assessing the condition (1) according to the current SOLAS requirements.*

Both the indices A and R are calculated according to the well known formulae accepted by IMO. For the following example we may use the formula included in the Resolution MSC 19/58 regarding the subdivision and damage stability of cargo ships over 100 m. Lets consider the survivability of the 1100 TEU container ship at the early stage of design.

The main data for the calculations are as follows, Gdynia Shipyard (1999-2005) :

- length between perpendiculars L_{BP} = 145.000 m,
- subdivision length L_s = 158.655 m,
- subdivision (full) draught dL = 10.200 m,
- partial draught dP = 7.560 m,
- light ship: Mass = 6800 t,
- coordinates of centre of gravity: LCM = 58.10 m from A.P., VCM = 11.10 m above B.P.

A few graphical examples following from the survivability analysis of this ship are presented in Fig. 2.

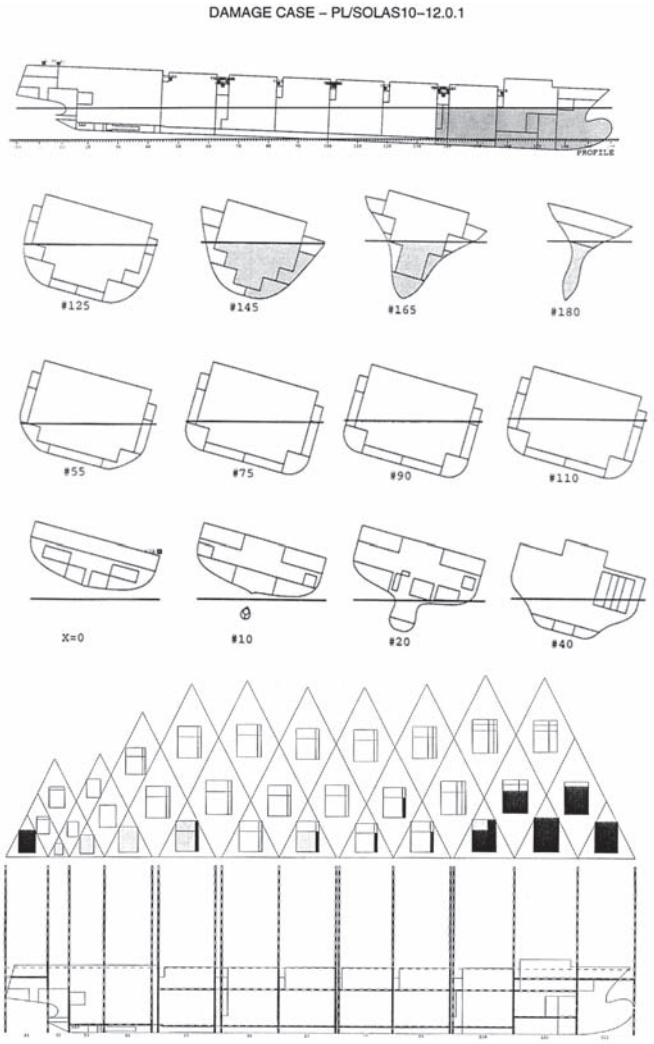


Fig. 2. *The general arrangement of internal spaces, example of final stage of flooding the data group of compartments and example of "p_i" factor calculation for the 1100 TEU container ship, Stocznia Gdynia (1999-2005).*

The calculations of the attained subdivision index A are connected with the large scale numerical calculations and they are time consuming. The final results of the probabilistic damage stability analysis for the given example are as follows :

$$A = \sum \Delta A_i = 0.52605 \quad (3)$$

$$R = 0.52510 \quad (4)$$

$$A > R \text{ as } 0.52605 > 0.52510 \quad (5)$$

From a designer point of view a question can arise if the ship is safe indeed. The briefly presented prescriptive method has been the base for creating the new techniques for solving some design problems. The nature of these techniques was prescriptive as well. It concerns the procedures for optimization of the index A and optimization of the local safety indices. Good examples concerning these are presented in the previous publications, Gerigk (2005).

A PERFORMANCE-ORIENTED RISK-BASED DESIGN

The risk-based design is a formalized design methodology that integrates systematically risk analysis in the design process with the prevention/reduction of risk embedded as a design objective, along standard design objectives, SSRC (2005). This methodology applies a holistic approach that links the risk prevention/reduction measures to ship performance and cost by using relevant tools to address ship design and operation. This is a radical shift from the current treatment of safety where safety is a design constraint included within the rules and regulations. The risk-based design offers freedom to the designer to choose and identify optimal solutions to meet safety targets. For the risk-based design safety must be treated as a life cycle issue. The risk-based design in the maritime industry should follow the well-established path of quantitative risk assessment used in other industries. The term "risk based design" is also in common use in other industries. The following steps are needed to identify the optimal design solution: set objectives, identify hazards and scenarios of accident, determine the risk, identify measures and means of preventing and reducing risk; select designs that meet objectives and select safety features and measures that are cost-effective, approve design solutions or change the design aspects. This approach is briefly introduced in the logical structure of the risk-based design system presented in Fig. 3.

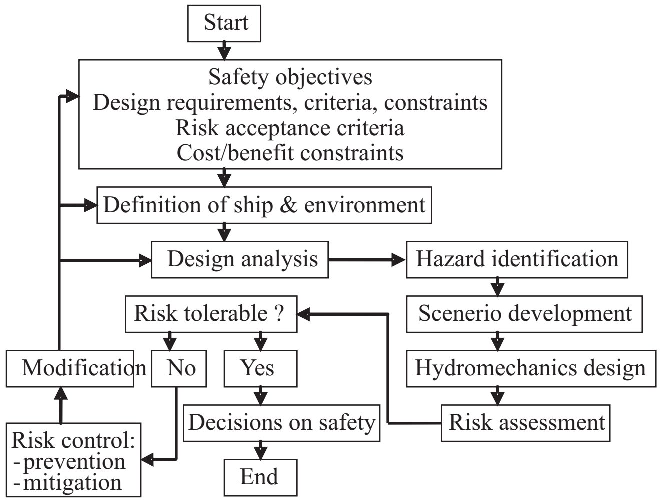


Fig. 3. *Logical structure of the risk-based design system (method).*

Because of limited space available the performance-oriented and risk-based approaches applied within the alternative method will be presented during the KONBIN Conference.

A PERFORMANCE-ORIENTED RISK-BASED METHOD FOR SAFETY ASSESSMENT OF SHIPS

The modern approach to ship safety is connected with combining the elements of system approach to safety and Formal Safety Assessment (FSA) methodology, IMO (2002). The major elements of the FSA methodology are as follows: hazard identification, risk analysis, risk control options, cost-benefit assessment, recommendations for decision making.

Combining the above mentioned with the modern ship design spiral the basis for the performance-oriented and risk-based formal method for safety assessment of ships is considered. Integrating the systematically used risk analysis in the design process with the prevention/reduction of risk embedded as a design objective (along standard design objectives) the risk-based design method is proposed as presented in Fig. 3.

The entire structure of the method is published by Gerigk, Gerigk (2005).

Regarding the risk assessment methods, there is a research going on further incorporating the risk assessment techniques into the design procedure regarding the safety assessment of damaged ships. The following methods are used for the risk assessment, ABS (2000): hazard identification methods, frequency assessment methods, consequence assessment methods and risk evaluation methods. The current set of the hazard/risk analysis methods includes: preliminary hazard analysis (PHA), preliminary risk analysis (PRA), what-if/checklist analysis, failure modes and effects analysis (FMEA), hazard and operability analysis (HAZOP), fault tree analysis (FTA), event tree analysis (ETA), relative ranking, coarse risk analysis (CRA), pareto analysis, change analysis, common cause failure analysis (CCFA) and human error analysis (HEA).

The following risk reduction principles and strategies have been adopted for the method, Grabowski (2000) :

- ❖ reducing the probability of an accident
- ❖ reducing the probability of consequences of accident.

A method for the ships safety estimation when surviving is introduced and it is associated with solving a few problems regarding the naval architecture, ship hydromechanics and ships safety and it is novel to some extent. When preparing the method for the preliminary design purposes the global and technical approaches are used, Barker (2000). The global approach mainly regards the problems associated with the development of methodology, ship and environment definition, hazard identification and hazard assessment, scenario development, risk assessment, risk mitigation measures, hazard resolving and risk reduction and decisions made on ships safety. The technical approach concerns the logical structure of design system and computational model, design requirements, criteria and constraints, library of required analytical and numerical methods and library of application methods. There are two approaches to risk management: bottom-up approach and top-down approach. The top-down risk management methodology has been applied for the method which is suitable for design for safety at the preliminary design stage. This approach should work in the environment of performance-based standards and help designing the ships against the hazards they will encounter during their operational life.

The key issue when using the proposed method is to model the risk contribution tree. The risk associated with different hazards and scenario development in estimated according to the formula:

$$\text{Risk} = P \times C \qquad (6)$$

where :

P – probability of occurrence a given hazard

C – consequences following the occurrence of data hazard and scenario development, in terms of fatalities, injuries, property losses and damage to the environment.

A logical structure of a risk contribution tree is presented in Fig. 4.

For the complex safety assessment of ships in damaged conditions the model of risk assessment has been anticipated as presented in Fig. 5.

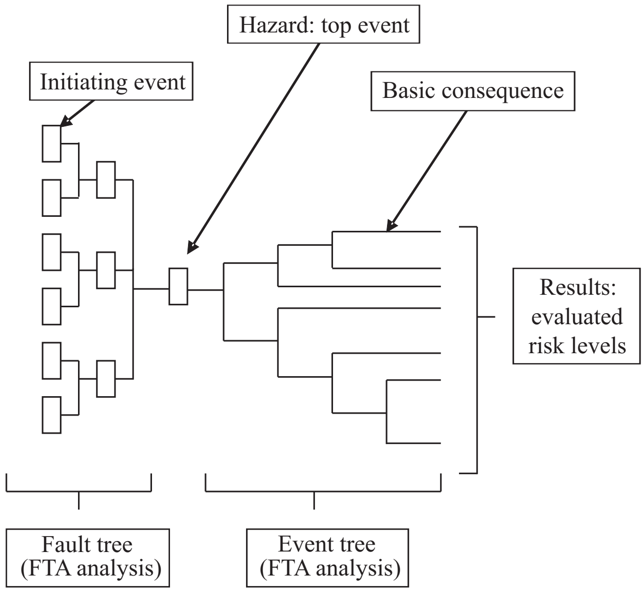


Fig. 4. *Logical structure of a risk contribution tree.*

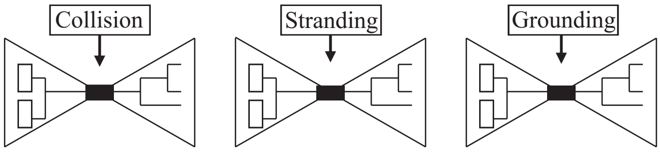


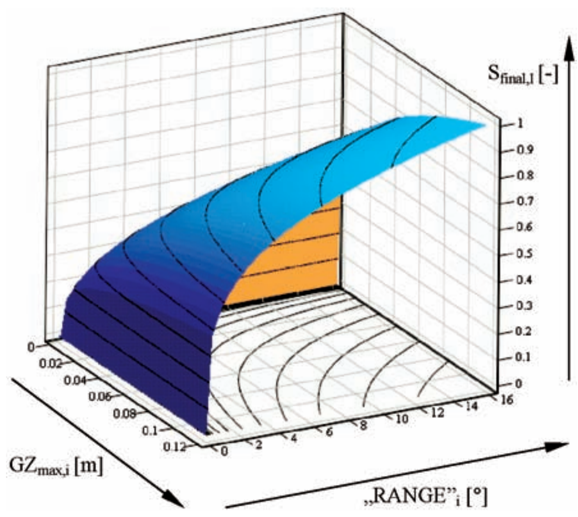
Fig. 5. *Example of model of risk assessment.*

A good example of risk and safety assessment according to the proposed method is the design analysis conducted for a container ship presented in Tab. 1.

Tab. 1. *Basic data for a container ship used for the example risk assessment.*

1.	Length between perpendiculars	L_{BP}	163.00 [m]
2.	Subdivision length	L_S	174.95 [m]
3.	Breadth	B	26.50 [m]
4.	Design draugth	d_f	9.00 [m]
5.	Tonnage	P_N	22286.00 [DWT]
6.	Service speed	V_s	20.40 [kn]
7.	Range	R	12000.00 [Nm]

In Fig. 6 the distribution of consequences “C” in terms of conditional probability of surviving the collision in the final stage of flooding “s_{final}” are given, Woznicki (2005).



The risk distribution in the form of risk levels (in terms of surviving the collision) taking into account all the possible hazards and scenarios are presented in Tab. 2.

Tab. 2. *An example of risk distribution in the case of flooding the data compartments.*

Case	Compartment	Comp. length [m]	p_i [-]	s_i [-]	$Risk_i$ [-]
1	1	6.65	0.0779	0.9991	0.0483
2	2	24.59	0.0357	0.9991	0.0357
3	3	42.59	0.0324	0.9628	0.0312
4	4	57.99	0.1107	0.9991	0.1106
5	5	82.09	0.1115	0.0000	0.0000
6	6	112.39	0.0330	0.6379	0.0211
7	7	134.79	0.0172	0.9650	0.0166
8	8	150.19	0.0357	0.0000	0.0000
9	9	166.52	0.0215	0.0000	0.0000
10	1 + 2	13.29	0.0629	0.9991	0.0628
11	2 + 3	35.89	0.0490	0.9991	0.0490
12	3 + 4	49.29	0.0682	0.9991	0.0681
13	4 + 5	66.69	0.0918	0.0000	0.0000
14	5 + 6	97.49	0.0641	0.0000	0.0000
15	6 + 7	127.29	0.0345	0.0000	0.0000
16	7 + 8	142.29	0.0336	0.0000	0.0000
17	8 + 9	158.09	0.0314	0.0000	0.0000
18	1 + 2 + 3	24.65	0.0209	0.9991	0.0209
19	2 + 3 + 4	39.99	0.0237	0.9833	0.0233
20	3 + 4 + 5	55.45	0.0023	0.9991	0.0023
21	4 + 5 + 6	94.45	0.0017	0.0000	0.0000
22	5 + 6 + 7	104.49	0.0136	0.5695	0.0077
23	6 + 7 + 8	127.79	0.0185	0.0000	0.0000
24	7 + 8 + 9	151.12	0.0047	0.1307	0.0006

CHALLENGES

Currently, there are a few problems under consideration regarding the safety of ships in damaged conditions which are associated with the existing prescriptive method included in the SOLAS Chapter II-1 parts A, B and B-1. The first problem concerns how to obtain the same required level of safety for different types of ships. The second regards updating the statistical data for the p_i factor estimation. The next problem which can probably not be solved using the prescriptive approach is the problem of calculation of the s_i factor according to the pure probabilistic concept. The new formula for s_i factor should include the components following from the fact that there are a few stages during the flooding process, IMO (2002), IMO (2004), Dudziak (2001), Santos (2001), Santos (2002), STAB (2003): creation of damage (stage 1), transient heel and intermediate flooding (stage 2), progressive flooding (stage 3), final stage (stage 4). During the above mentioned stages the internal and external impacts may appear according to the following: wind heeling moment, action of waves, ballast/cargo shift, crowding of people, launching life saving appliances, etc.

SUMMARY

The alternative performance-oriented risk-based method for assessment of safety of damaged ships is briefly presented in the paper. No details given because of limited space available. The current work regarding the method is associated with integrating the performance-oriented and risk-based analyses into the system briefly presented in Fig. 3. The method is novel to some extent and is currently published by the Gdansk University of Technology.

The method uses the performance-oriented risk-based approach. The elements of Safety Case and Formal Safety Assessment methodologies are incorporated within the method. The hazard identification, scenario development, ship hydromechanics analysis, risk estimation and risk control options are combined together. In this respect, the method is a risk-based design method as it integrates the systematic risk analysis in the design process with the reduction of risk embedded as a design objective.

NOMENCLATURE

- A - attained subdivision index
- R - required subdivision index
- p_i - accounts for the probability that only the compartment or group of compartments under consideration may be flooded, disregarding any horizontal subdivision, as defined in regulation 7-1
- s_i - accounts for the probability of survival after flooding the compartments or group of compartments under consideration, and includes the effect of any horizontal subdivision, as defined in regulation 7-2
- ΔA_i - components of the attained subdivision index A concerning flooding each group of compartments for the data set of deepest, partial and light service draughts
- Risk - combination of the frequency and the severity of the consequence
- $Risk_i$ - components of the Risk value concerning flooding each group of compartments for the data set of deepest, partial and light service draughts
- P - probability of occurrence of a given hazard
- C - consequences following the occurrence of the data hazard or sequence of events (outcome of an accident)
- s_{final} - probability to survive in the final equilibrium stage of flooding

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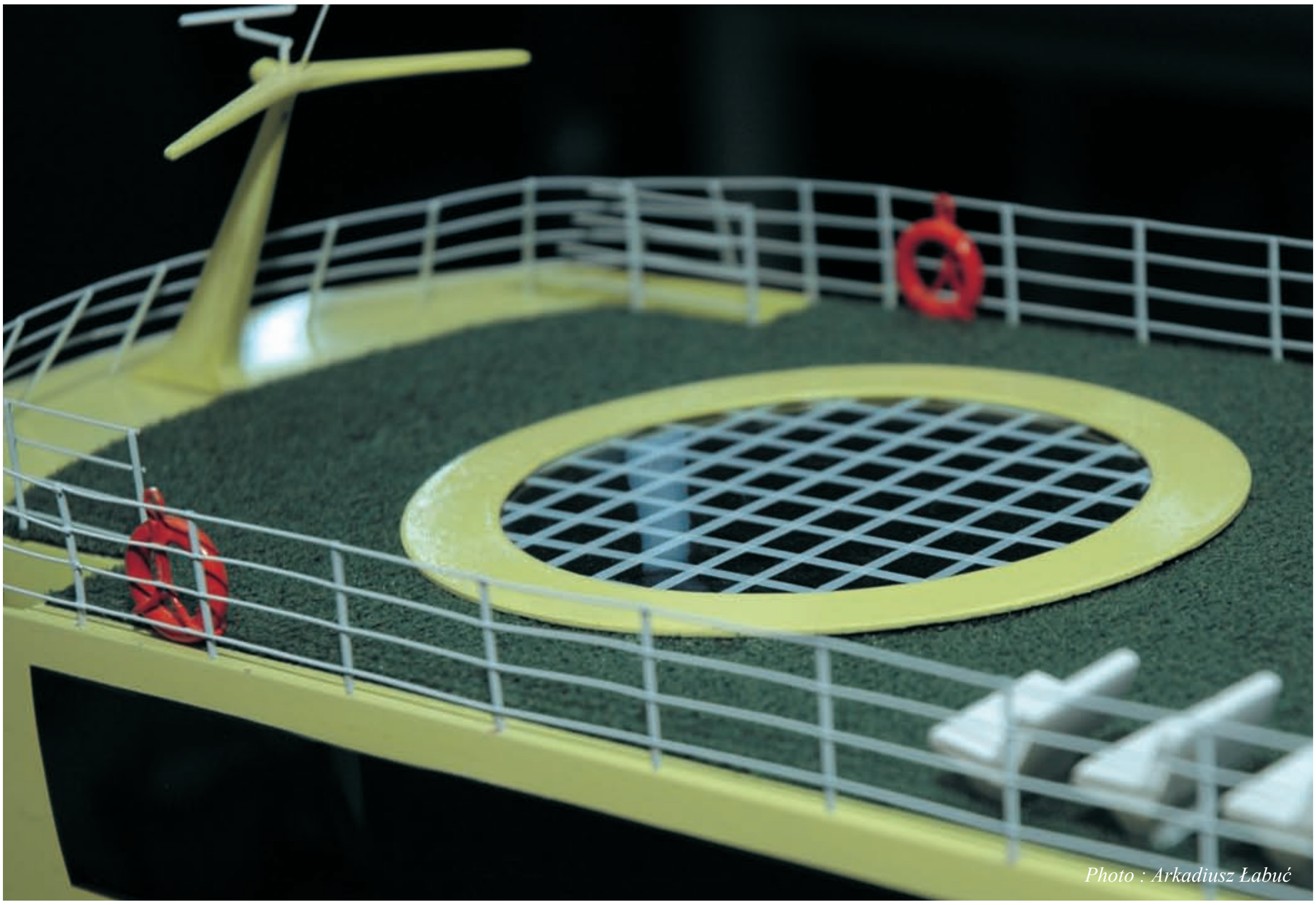
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