Acta Technica 62 (2017), No. 5A, 297–304

A counter-flooding decision support system for survivability evaluation onboard warship

HU Li-fen[2], QI Huibo[2], ZHANG Kezheng[2], CHEN Shude[2], CAO Guofeng[2]

Abstract. In this paper, a counter-flooding decision support system which could evaluate survivability and aid real-time decision in shipboard flooding accident is presented. It mainly comprises damage stability model, optimization model and decision model. To evaluate the feasible scheme acquired, tilt angle is established as the decision criterion. The decision model relies on different methods to solve the optimization model, which comprises GA(Genetic Algorithm), NLP (Nonlinear Programming) and M-H(a quickly generation) method. It selects available CFTs(counter-flooding tanks) combination to provide shift and effective decision-making support for shipboard personnel on warship. By means of comparison within several methods, the computational results validate that NLP and M-H method offer remarkable advantage over GA method on solution time, which could aid real-time decision for damage control in case of emergency, while GA and M-H method show good solution stability.

Key words. Counter-flooding, decision support, ga, nlp, m-h method.

1. Introduction

Safety onboard ships has always been one of the primary concerns in Maritime Industry. Despite of all the modern safety systems and equipment on-board, the risk of accidents is always present, and many have occurred with serious consequences such as the sinking of ships, loss of human lives and irreversible costs to the natural environment. Even when dealing with the supposedly most advanced safety systems and modern ship designs, the accident can always occur as recently shown by the

[1]Acknowledgment - This paper is part of result of the financial support from National Natural Science Foundation of China (51509124, 51681340360), Natural Science Fund of Shandong Province (ZR2013EEL007). The authors would like to extend their sincere gratitude to the above organizations.

[2]Workshop 1 - School of Transporation, Ludong University, Yantai, 264025, China; e-mail: hlfgffff2008@aliyun.com

collision and grounding case of the cruise ship (Varela, 2014). When a flooding emergency occurs, a good scheme is critical to the decision maker for mitigating the consequences of a flooding accident and restoring the warship's survivability to the utmost extent. In such cases, perfect counter-flooding decision support system would help to offer the reasonable scheme and maintain the survivability of warship. So it is necessary to have an automatic and intelligent system, which could generate responses rapidly and give a counter-flooding advice for the corresponding flooding scenario to the operator.

Decision-support systems for such situations must anticipate the status of the ship in advance. Some scholars made great contribution to enhancing survivability through intelligent decision support system (Hu, 2015; Lee, 2006; Lee, 2005), which does a lot help to the decision making. The current paper presents an on-board decision support system for ship flooding emergency response, which relies on different methods to give the optimal scheme.

The software system is composed by three main modules: damage stability model, optimization model and decision model. To evaluate the feasible scheme acquired, tilt angle is established as the decision criterion. The decision model relies on three methods to solve the optimization model, which comprises GA (Genetic Algorithm), NLP and M-H (a quickly generation) method, and selects available CFTs (counter-flooding tanks) combination to provide shift and effective decision-making support for shipboard personnel on warship.

2. Implementation of System

In this paper the proposed counter-flooding decision support system incorporates different methods to solve the optimization model, for the purpose of finding a feasible solution for a damage case as soon as possible so that the warship can be uprighted efficiently by using the most effective CFTs to obtain the optimal schemes, and the decision maker could obtain different counter-flooding scheme according to several solution methods, which is capable of adopting the optimal one on the basis of his requirement and current loading condition on board. The 25 CFTs in this paper, which are ballast water, potable fresh water and fuel oil tanks, are used for uprighting the warship. The architecture of the system is presented in Figure 1.

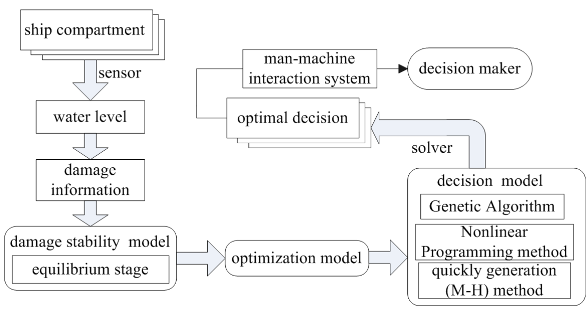

Fig. 1. System structure

2.1. Optimization model

The previous investigation has considered minimal freeboard as objective function, which is required to calculate the freeboard values of different transverse sections, then seeks for the minimal one as the final result, the elapse time is longer. Comparing with the freeboard calculation, the tilt angle is easier to do. Owing to tilt angle takes heel and trim into consideration simultaneously, it is selected as the criterion to evaluate the counter-flooding scheme (1977), which converts a multiple attribute decision-making problem into a single-objective programming one.

2.2. Decision model

2.2.1. G-A method Generally, for solving search and optimization problems, most of classical optimization algorithms take this point-to-point search approach, which takes the danger of falling in local optima. However, GA is based on the Darwinian principle of natural selection, which uses probabilistic transition rules to select someone to be reproduced and someone to die so as to guide their search toward regions of the search space with likely improvement. A GA normally starts with a set of potential solutions (called initial population) of the decision making problem. Individual solutions are called chromosomes. Crossover and mutation operations happen among the potential solutions to get a new set of solutions and it continues until terminating conditions are encountered (Holland, 1975).

Because of its generality and other advantages over conventional optimization methods, GA has been extensively used/ modified to solve complex decision making problems in different field of science and technology (Rahli, 1999; Manas, 2011; Lee,2002), especially for the case objective function is implicit one that is difficult to search the gradient descent direction, it is introduced to solve the optimization model.

2.2.2. Nonlinear programming method The nonlinear programming problem can be formally stated as:

$$\begin{array}{ll} \min & f(x) \\ s.t. & h_i(x) = 0 \quad i = 1, ..., m \\ & g_i(x) \geq 0 \quad i = m+1, ..., p \end{array} \tag{1}$$

Where $h_i(x)$ are m linear and/or nonlinear equality constraints; $g_i(x)$ are (p-m) linear and/or nonlinear inequality constraints. The nonlinear programming algorithm SUMT (Rahli, 1999), is an extension of the created response surface technique and extended it to accommodate equality constraints. In the 1967 coded version of SUMT the nonlinear programming problem is converted into a sequence of unconstrained problems by dening the$P$function as follows:

$$P(x_k, R_k) = f(x_k) + \frac{1}{R_k} \sum_{i=1}^{m} h_i^2(x_k) + R_k \sum_{i=m+1}^{p} \frac{1}{g_i(x_k)} \tag{2}$$

Where the weighting factors R is positive and form a monotonically decreasing sequence of values. The function of the inequality constraints is chosen originally in the form of an added 'barrier'. As $R_k$is reduced, the effect of the barrier is reduced, and x may move closer to an inequality constraint boundary. For the different initial value R_0, the final scheme obtained is different, which will lead to various R_k,or even no convergence.

2.2.3. M-H Method M-H is a quickly generation method, which is proposed to enable us to easily gain the superior result, and approaches to the optimal one but satisfies the engineering requirement (Hu, 2013). It is a problem-solving approach that is different from CBR, which relies on counter-flooding principle and reasoning logic to search for the feasible region of CFTs, then calculates the scheme accurately with damage floating position model, sorts all the feasible schemes according to the index of tilt angle and finds the most effective one. In this process, a scheme of single tank operation is generated for one iterative process, which is the optimal among the feasible ones under the current loading condition. Here, the scheme of single tank operation means: ballasting a CFT, transmit load between a pair of CFT and evacuate a CFT in spite of heel or trim adjustment. Iterative process continues until terminating conditions are encountered, and the final output is composed of all the scheme of single tank operation by means of linear superposition. The proposed method is characterized with high solution quality and short computation time, which is vital important to decision making in case of emergency.

3. Case Study

To verify the developed system, certain warship was conducted case, the principal dimensions are as follows:

L_{pp}=130m D=11m B=18m T=5.0m.

Here, L_{pp} means length between perpendicular; D means ship's depth; B means ship's breath; T means ship's draft. Taking certain loading condition onboard into account, an illustrative examples on the particular damage cases, are conducted to illustrate the effectiveness of proposed different methods. The damage conditions can be described as shadow parts in schematic diagram of Figure 2: damage case lies in mid of the warship (Fr72-Fr138).

The loading condition of intact state is standard displacement. The damaged warship is not safe according to heeling angle, and ballast operation could be conducted to restore floating position. To compare this method's convergence, the initial R_0 is given different value, which is defined as NLP1 (R_0=0.0001) and NLP2 (R_0=0.00001) separately.

Table 1 presents the result of floating position and initial stability at different stages, which include intact state, damage condition and after counter-flooding operation is finished. Figure.3 presents the static stability curve at different stages, where Ls is the static stability curve. Figure.4 shows the calculation time by different method. From the result after counter-flooding operation by three methods, we could conclude that the scheme generated by NLP adopts the largest number

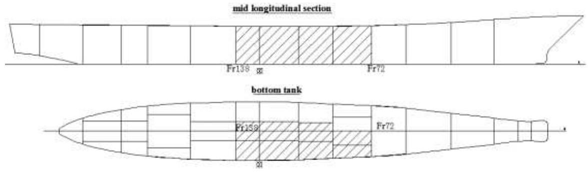

Fig. 2. Position of assumed damage

of liquid load and the largest quantity of CFTs, so stability restoration is the best. Comparing within NLP, given the different initial value R_0(0.0001/0.00001), when the termination condition is met, the final R_k output 0.00001 and 0.000001 respectively. If R_0 is changed to other values, the result could be not convergence, or if the damage condition is changed, R_0 should be changed to other values. So NLP method is very sensitive to the initial parameters. However, GA method is easy to obtain the optimal solution once the iterative formula is encountered, though the initial population, evolutionary generation and so on are changed. In this paper the evolutionary generation defined is 200. For the calculation time contrast of Figure.3, the scheme by M-H method adopts the least time, then NLP and then GA.

Table 1.Result of floating position and initial stability at different stage

	intact state	damage condition	after counter-flooding operation			
			NLP1	NLP2	GA	M-H method
Mean draft (m)	4.047	5.512	5.645	5.631	5.651	5.617
Heeling angle(°)	0.000	6.720	-0.930	-0.631	0.591	0.697
Trim (m)	-0.256	2.642	1.102	1.230	1.162	1.107
Minimal freeboard (m)	2.143	1.241	1.654	1.805	1.735	1.712
Initial stability height (m)	1.078	0.930	1.035	1.020	1.040	0.983

4. Conclusion

This paper describes a counter-flooding decision support system for survivability maintenance in case of emergency on the basis of different methods. Using this system, in the event of flooding accidents, the final decision and responses can be made based on three methods, then the flooding situation could be countered through posture control of warship, thereby reducing the risk to life, property and environment. In this paper, decision model applies GA, NLP and M-H method to solve the optimization model, then to provide shift and effective decision-making support for shipboard personnel on warship. By means of comparison with three methods' solution stability and convergence rate, each method's advantage is obtained, which

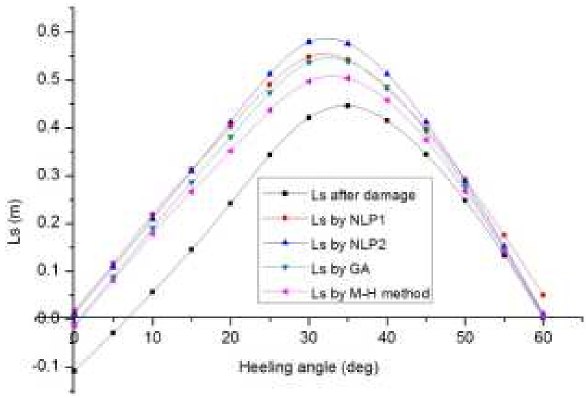

Fig. 3. Static stability curve by different method

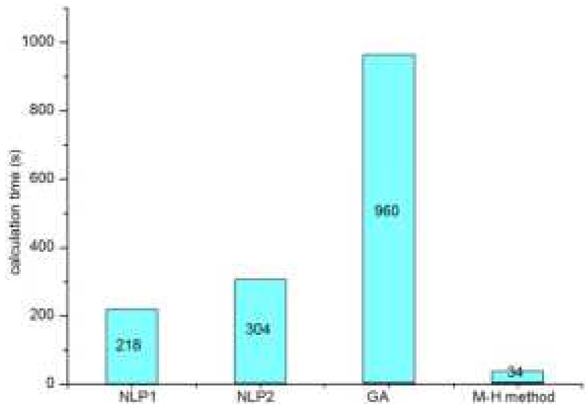

Fig. 4. Calculation time by different method

is convenient for decision making in case of emergency.

References

[1] D. Lee, S. S. Lee, B. J. Park: *A study on the framework for survivability assessment system of damaged ships*. Ocean Engineering *32* (2005), 1122–1132.

[2] J. H. Holland: *Adaption in natural and artificial system*. Michigan: University of Michigan Press (1975), 232.

[3] J. M. Varela, J. M. Rodrigues, C. G. Soares: *On-board Decision Support System for ship Flooding Emergency Response*. Procedia Computer Science *29* (2014), 1688–1700.

[4] K. Y. Lee, S. N. Han, M. I. Roh: *Optimal compartment layout design for a naval ship using an improved genetic algorithm*. Marine Technology *39* (2002), 159–169.

[5] L. F. Hu, Z. M. Tian, Z. Y. Sun: *Genetic algorithm-based counter-flooding decision support system for damaged surface warship*. International Shipbuilding Progress *62* (2015), 1–15.

[6] L. F. Hu, K. Ma: *Genetic algorithm-based counter-flooding decision support system for damaged surface warship*. International Shipbuilding Progress *55* (2008) 301–315.

[7] L. F. Hu, K. Ma, Z. S. JI: *A M–H method-based decision support system for flooding emergencies onboard warship*. Ocean Engineering *58* (2013), 192–200.

[8] M. K. Maiti: *A fuzzy genetic algorithm with varying population size to solve an inventory model with credit-linked promotional demand in an imprecise planning horizon*. European Journal of Operational Research *213* (2011), 96–106.

[9] M. Rahli, P. Pirotte: *Optimal load flow using sequential unconstrained minimization technique (SUMT) method under power transmission losses minimization*. Electric Power Systems Research *52* (1999), 61–64.

[10] Z. W. Lyu, K. Ma, F. Liu: *Military ship's subdivision optimization for reinforcement of anti-wind capacity after damage*. Journal of Marine Science and Technology *20*, (2015), 579–589.

Received November 16, 2017