

Application of Neural Network and Genetic Algorithm in Subdivision Optimization

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ABSTRACT. It is complicated and time consuming to evaluate the anti-wind capability of a damaged ship. This paper tries to find a way to estimate the ship's anti-wind capability after damage comprehensively with some simplified conditions. The index representing anti-wind capability of damaged ship comprehensively is named "Average Anti-wind Capability". When the change of watertight bulkheads' position is not big, with a series of data calculated by NAPA and programs developed by author, Artificial Neural Network improved by genetic algorithm is applied to study the nature of functional dependency between the "Average Anti-wind Capability" and the positions of transverse watertight bulkheads. Then, genetic algorithm is also employed to find the best combination of watertight bulkhead, making the ship have the best anti-wind capability after damage. This method is verified to be feasible and effective by example calculation.

1. Introduction

The ship's anti-wind capability has been one of the most important issues in shipbuilding field. A ship will keep floating on the water since constructed during its whole lifecycle, owing to the special requirements of shipping. The intact stability criteria has proposed the requirements of the anti-wind capabilities of the intact ships, the fact that ships have been suffering from winds and waves' panting repeatedly when sailing on the ocean. However, it's quite complex to figure out the ship's anti-wind capability after damage. Because it involves the ship's floating states before damaged, the positions and lengths of the damaged compartments, dynamic motions (such as rolling motion) after damage. Actually, it's difficult to simulate them accurately with the limit of computer calculation capability, so there are few achievements in the field of research on anti-wind capability after damage.

The development of the Artificial Neural Network (ANN) technology provides a strong support for the data analysis and data fitting. By far the most commonly used multi-layer network learning method is Back Propagation (BP) algorithm which is easily trapped in local optimal solution when optimizing. Genetic Algorithms (GA) is adaptive and global optimal probability searching algorithm, based on simulating the genetic and evolutionary process of organisms in the natural environment. GA is widely used in many fields because of its robustness and property of being hard to fall into local optimum. In order to obtain the optimal result for the objective function, researchers often combine Neural Network with optimization algorithms (such as Genetic Algorithm, Particle Swarm Optimization) together.

Scholars have been researching the combination of Genetic Algorithm and Neural Network to apply it to actual projects, such as bioengineering^[1], mechanical engineering^[2], information engineering^[3], medical diagnosis^[4], which has achieved good results, making it promising in ship engineering. Actually, some scholars have already applied this method to the naval construction, such as prediction of ship



resistance^[5-6], ship fire alarm system^[7], motion model^[8], and tracking forecast^[9].

NAPA is one of the most excellent tools for ship design and its calculation results are recognized by international researchers. Especially it has a good performance in damage stability calculation. Therefore NAPA is widely used in shipyards, classification societies, research institutes, etc. Based on these facts, this paper combines ANN and GA to optimize the ship subdivision design.

Starting with the watertight compartments arrangement, this paper then calculates the damage probabilities of compartments and the righting arms after damage by NAPA, and calculates the ship's anti-wind capability after damage by programs developed by author at last. Under the condition of the small change of watertight bulkhead positions, "Average Anti-wind Capability" is calculated for each compartments group (subdivision scheme) generated by changing bulkheads' positions. Based on those calculation results, the watertight bulkhead positions will be optimized by ANN and GA to make the damaged ship has a better ability to resist wind.

2. Anti-wind capability calculation after damage

This paper tries to find the best combination of the watertight bulkheads positions, making sure that the damaged ship has the best ability to resist wind in the status of damage. Referring to the calculation method of the intact ship^[10], the anti-wind capability after damage is indicated by rated wind velocity (10 meters above water-level):

$$U = C \cdot C_h \sqrt{\frac{l_c \cdot \Delta}{A_v \cdot Z}} \quad (1)$$

where:

$C = 115.5$; A_v is the windage area of corresponding floating position after damage; Z is the height from baseline to the windage area's centroid; C_h is correction factor for wind speed along height distribution, when $Z > 3.5\text{m}$, $C_h = (10/Z)^{1/8}$, when $Z \leq 3.5\text{m}$, $C_h = 1.140$; l_c is ship's minimum capsizing lever after damage; Δ is ship's displacement after damage.

Referring to intact criteria, the capsizing moment of the damaged ship can be got by energy balance method. As seen from figure 1, φ_0 is the heeling angle corresponding to balance position after damage. The roll angle caused by resonance, which generated by wave effect is φ_m , φ_f is flooding angle. The minimum capsizing lever l_c can be calculated by making area KNH equal to area NJL.

When the damaged ship's rolling period and the wave period is the same, the maximum roll angle φ_m will be generated. φ_m can be acquired by the method used in the literature^[11]. When the change of roll angle is stable in time domain, the maximum roll angle can be gained. It is important to note that the effect of sloshing in the damaged compartment is not considered during the whole calculation process.

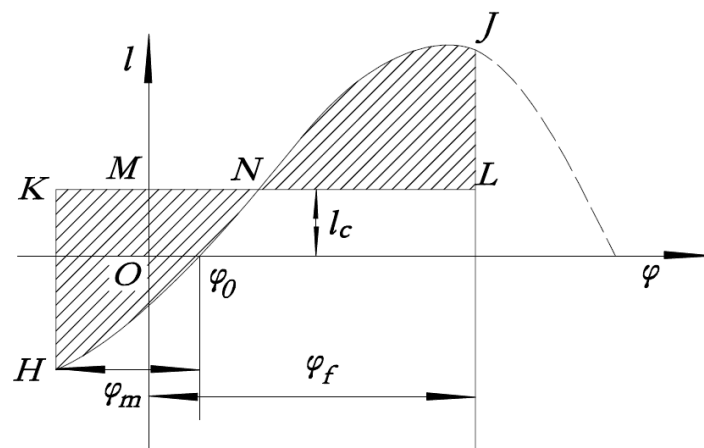


Fig 1. capsizing moment calculation diagram

The three-compartment damage is only considered, because it is the most dangerous in the damage statuses meeting stability criterion. The anti-wind capabilities are different because of the different damage statuses (such as damage location, length, penetration), which makes it a multi-objective optimization problem. Having a significant role in assessing the anti-wind capability (the bigger the probability of damage is, the higher anti-wind capability is expected), the probability of damage is introduced to get the weighting factor.

When each watertight bulkhead position has already been fixed (a certain subdivision scheme has been set up), the number of three-compartment damage groups can be defined. Assuming there are n three-compartment damage groups, the parameter λ_i as the weighting factor is calculated by the following formula:

$$\lambda_i = \frac{P_i}{\sum_{i=1}^n P_i} \quad (2)$$

U_{mean} is put forward as the ship's anti-wind capability index and it is named "Average Anti-wind Capability" or "Average Rated Wind Velocity". It can be given by:

$$U_{mean} = \sum_{i=1}^n \lambda_i \cdot U_i \quad (3)$$

U_i is the anti-wind capability corresponding to i -th three-compartment damage.

3. Optimization of watertight bulkhead positions

Optimizing the watertight bulkhead positions is equal to maximize the "Average Anti-wind Capability" U_{mean} . Under the condition of the small change of watertight bulkhead positions, the GZ curves and the damage probabilities of three-compartment damage are calculated by NAPA. And then the maximum roll angles, the capsizing moments, the anti-wind capabilities, the weighting factors and "Average Anti-wind Capabilities" corresponding to three-compartment damage groups are acquired by programs. Finally, ANN and GA are utilized to get the best combination of watertight bulkhead positions (Fig 2).

In a loop of "Average Anti-wind Capability" program flow, it is assumed that there are $n + 1$ watertight bulkheads (that is to say, there are n three-compartment damage groups). The input parameters are the positions of watertight bulkheads $X = (x_1, x_2, x_3, \dots, x_{n+1})$ and the output values are the "Average Anti-wind Capabilities" U_{mean} . The mathematical model can be constructed by ANN improved by GA, which is based on a number of calculated samples. BP algorithm is adopted in the modeling process and Sigmoid is the neuron activation function. Uniform design method is used to define the number of single or double hidden layer neurons, learning speed and the initial weight matrix [1]. The objective function is constructed:

$$\max U_{mean} = F(x_1, x_2, x_3, \dots, x_{n+1}) \quad (4)$$

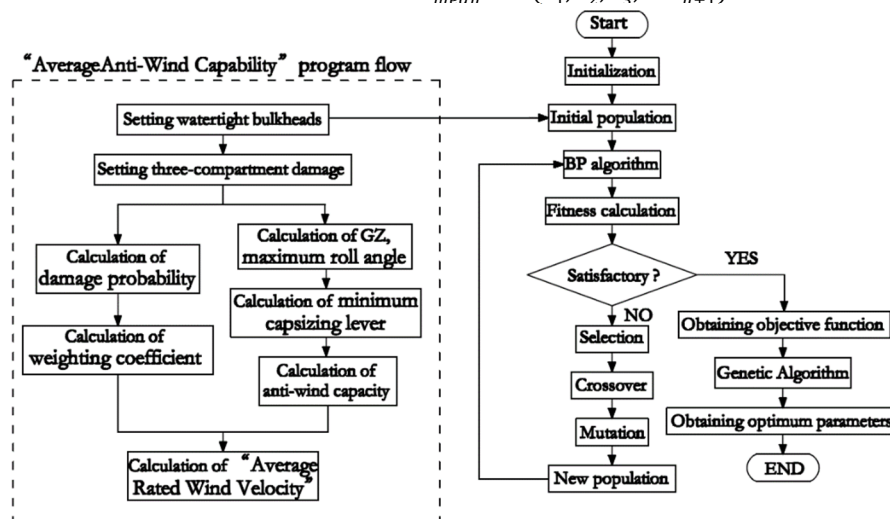


Fig 2. The flow chart of calculation

The following constraint conditions should be met:

$$F_i \geq F_{allow} \quad (5)$$

$$GM_i \geq GM_{allow} \quad (6)$$

Where F_i , GM_i are representing the freeboard and initial metacentric height separately in the damage condition of i -th three-compartment group, F_{allow} , GM_{allow} are the minimum freeboard and minimum initial metacentric height, respectively.

During the process, there are four watertight bulkheads namely the first one, the second one, the n -th one and the $(n+1)$ -th one which influence only one three-compartment damage. So in order to make them conducive to the anti-wind capability, some special settings are set up in the calculation aiming to improve “Average Anti-wind Capacity”.

4. Calculation Example

Optimal computation for a certain ship is performed to verify the effectiveness of the method. The parameters of ship are shown in the Tab 1.

Tab 1. Parameters of a certain ship

Parameters	Abbreviation	Standard Displacement	units
Length Between Perpendiculars	L_{pp}	137.5	m
Breadth	B	14.5	m
Molded Depth	D	9.0	m
Designed Draft	d	4.25	m
Displacement	Δ	3780	t
Initial Metacentric Height	GM	1.122	m

The optimization calculation is conducted based on above-mentioned method assuming the shape of the ship body stays unchanged. The initial positions are illustrated in fig 3, which contains 14 transverse watertight bulkheads represented by X_1 - X_{14} dividing the ship body into 15 watertight compartments, separately expressed by NO.1-NO.15. NO.8-NO.10 are engine room and auxiliary engine room, bulkheads of which should be constant. The effect of bulkhead positions to vertical height of gravity is ignored with the objective to simplified calculation. The bulkhead's position and variation range are illustrated in Tab 2.

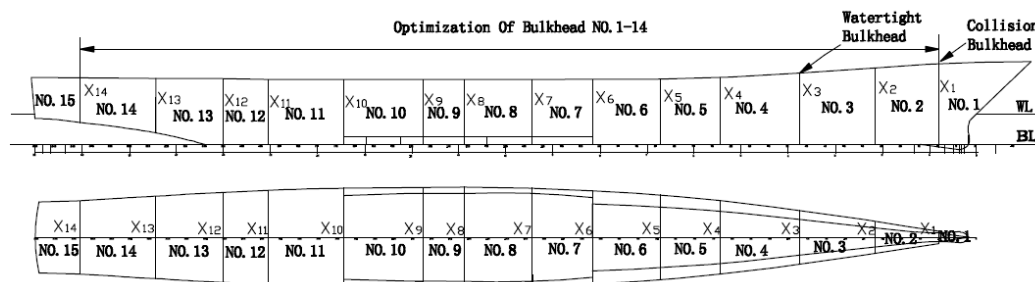


Fig 3. Initial bulkhead positions

Tab 2. Variation range of bulkheads' positions

Serial Number	Code Name	Initial Position (from bow, m)	variation range
1	X_1	5.5	5.0-6.5
2	X_2	14.5	12.5-16.0
3	X_3	25.5	22.0-27.5
4	X_4	37.5	34.0-41.0
5	X_5	46.0	42.0-50.0
6	X_6	56.0	52.0-60.0
7	X_7	65.0	fixed
8	X_8	75.0	fixed
9	X_9	81.0	fixed
10	X_{10}	92.5	fixed

11	X_{11}	103.5	100.0-107.5
12	X_{12}	110.0	107.0-114.0
13	X_{13}	120.0	116.0-123.0
14	X_{14}	130.0	129.0-132.0

According to the above conditions, ten watertight bulkhead positions are changed. Every time a set of data (a subdivision scheme) is gained, "Average Anti-wind Capability" will be calculated. Forty-seven subdivision schemes have been set, and, subsequently, "Average Anti-wind Capabilities" of them are obtained. Finally, ANN and GA are employed to simulate the results, which are compared with the calculated values (Fig 4).

As can be seen in fig 4 and fig 5, the prediction errors are small. Most of the predicted values are consistent with the calculated values. These show a good match for three-compartment damage case. The simulated objective function $U_{\text{mean}} = F(x_1, x_2, x_3, \dots, x_{n+1})$ is optimized by Genetic Algorithm. The optimum conditions are shown in Tab.3 and the optimization results are shown in Fig 6.

After about 140 generations, it can meet the requirements. "Average Anti-wind Capacity" after optimization is improved by 0.8m/s (the initial "Average Anti-wind Capacity" is 50.65m/s and the optimized "Average Anti-wind Capacity" is 51.45m/s). Figure 8 is bulkhead's position illustration after optimization. It can be seen from figure 7 that some bulkheads (such as X_6, X_{11}) have little change in positions and some bulkheads (such as X_4, X_5) have great change.

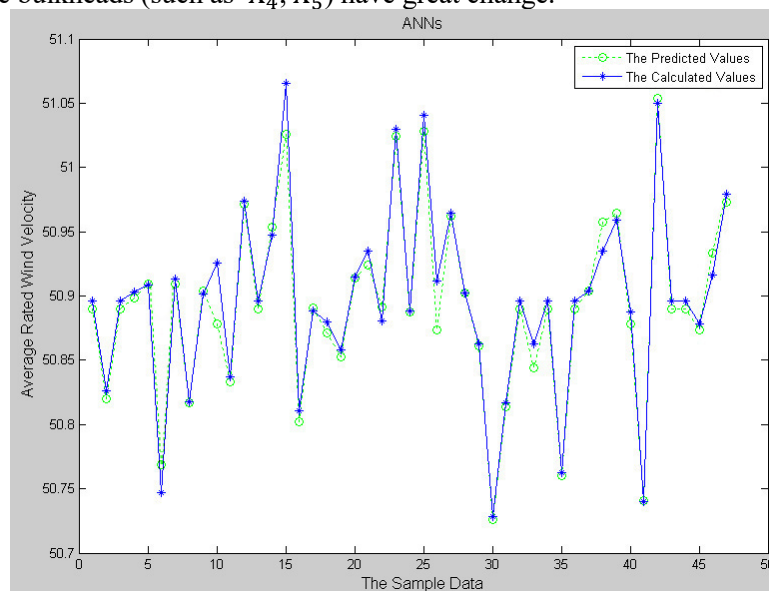


Fig 4. Simulation results of ANN

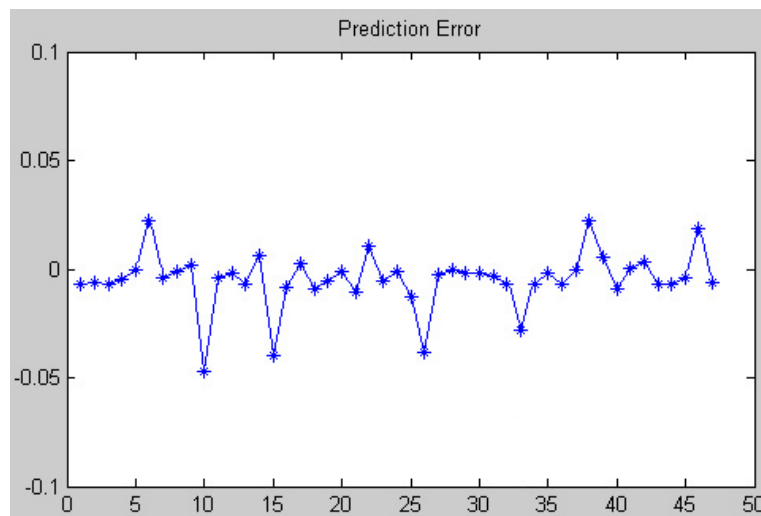


Fig 5. The prediction error of ANN

Tab 3. Simulation Condition

Serial	Number	TYPE	SGA
1		Population Size	20
2		Generation Size	200
3		Crossover Rate	0.6
4		Mutation Rate	0.2
5		Selection	Roulette
6		Crossover Method	N-Point Crossover

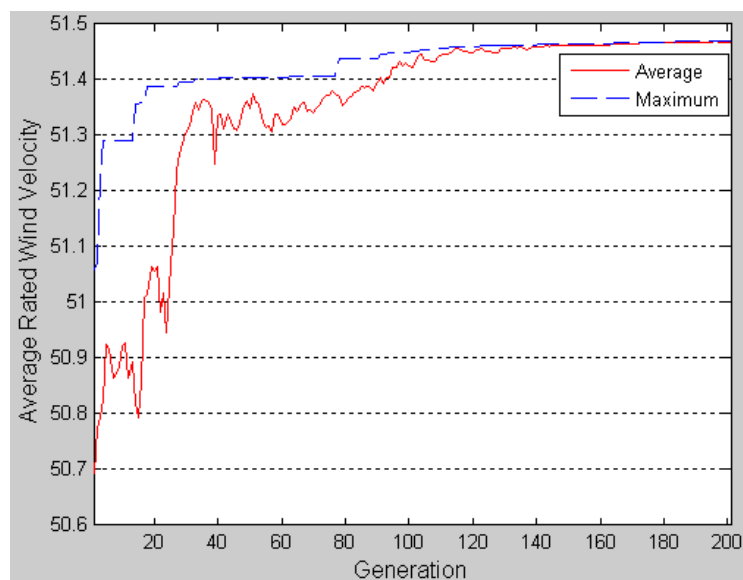


Fig 6. Genetic Algorithm optimization

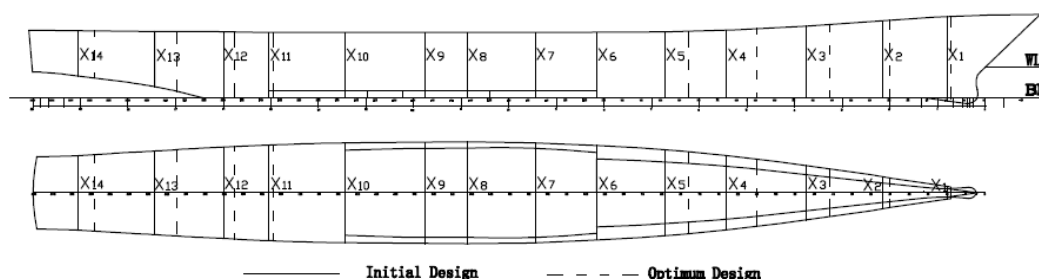


Fig 7. the comparison of the positions before and after optimization

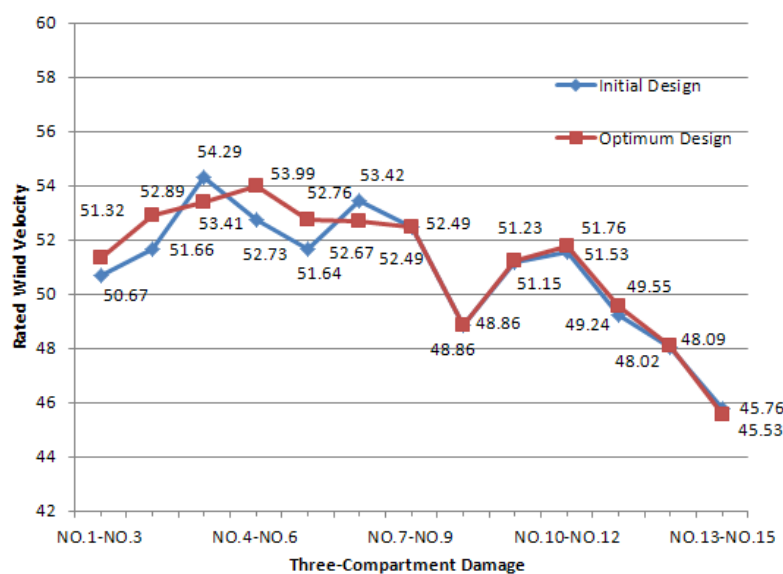


Fig 8. Results comparison before and after optimization

As shown in fig 8, comparing with the initial subdivision scheme, there is a significant improvement in the anti-wind capabilities corresponding to the forebody of the ship. In other words, the initial compartment arrangement for the forebody is not the best, only considering from anti-wind capability. The conclusion can also be drawn from Fig 7. The change of the other part is little, which shows the initial subdivision layout of the latter part is better. The key point to increase anti-wind capability of this ship is watertight bulkheads arrangement of the forebody.

5. Conclusions

It is a hard work to evaluate the anti-wind capability of damaged ship which does involve complex problems (such as the weight of each three-compartment damage group, roll motion in time-domain, which add up many difficulties to estimate the damaged ship's anti-wind capability comprehensively).

This paper proposes a simple method to resolve those kinds of complicated problems. When the ship is designed referring to the parent ship, the change of watertight bulkhead positions is small in most cases. Parameters are calculated by NAPA to get the maximum roll angle and the capsizing moment corresponding to each three-compartment damage group. Based on these values, "Average Anti-wind Capability" can be obtained. In the end, the best combination of watertight bulkhead positions (within a bounding) is found by ANN and GA. The result of calculation example shows that when the change of watertight bulkhead positions is not big, this method is feasible and accurate. On the other hand, it is worth reminding the reader that when the change is big, these calculations should be realized by computer programming, which is the further research direction. The influence of sloshing in the damaged compartments should also be taken into account for the purpose of getting the maximum roll angle precisely.

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