The Method Research of Setting Standard Principal Dimensions of Inland Ships

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ABSTRACT: Based on the problems of various types of ships and complicated navigational waterway conditions in the development of series of standard principal dimensions of inland ships, and following the principle of conformity, principle of meeting the required minimum grade, principle of adaptability, principle of unity, principle of practicality and principle of perspectiveness, this paper proposes to divide the tonnage series of ships, forms a number of principal dimension programs by the grid method, establishes a technical and economic model and evaluation index system and determines the optimal principal dimension series program by using the comprehensive evaluation method. Examples are given to demonstrate the “series of standard principal dimensions of dry bulk carriers of transport ships in the Ganjiang River, thus proving the correctness of the established model method.

Keywords: standardization of ship type; inland ships; demonstration of principal dimensions; comprehensive evaluation

1 INTRODUCTION

Due to various historical reasons, China’s inland river infrastructure is lack of the waterway with the ultimate characteristics, as well as the long-term comprehensive development planning of navigation facility resources, leading to constant optimization of the principal dimensions of standard ships according to the changes of navigation facilities. Under the background of implementing the policy of standardizing the inland ships in China, the principal dimension is a major basis for measuring whether the ship is a standard type or not. Therefore, it is practical significant to research the method of developing the standard principal dimensions of inland ships.

2 PRINCIPLE OF SETTING PRINCIPAL DIMENSIONS OF INLAND SHIPS

(1) Principle of conformity

Firstly, the principal dimensions of ships should be matched with the waterway level, lock and other navigation structures. The principal dimensions of ships will be limited by the dimensions of the waterway, lock and other navigation structures. The largest dimension of ships should comply with the requirements of the waterway and lock at the grade required by Standards for Inland Navigation on the navigational ships.

Secondly, the principal dimensions of ships should comply with the requirements the national ship construction regulations, specifications and standards. The ratio of principal dimensions of ships (L/D, B/D and so on) should comply with the requirements of the inland ship regulations and specifications, in order to ensure the reliability of the ship structural strength.

(2) Principle of meeting the required minimum grade

Under the premise of meeting the needs, the series of principal dimensions of each tonnage ship and tonnage grade should be reduced as much as possible, in order to promote the improvement of ship standardization level. For the same tonnage ship, the series of principal dimensions should reduce the grade as much as possible in case of taking full account of characteristics of the waterway and goods flow; the grades should be unified to reduce the dimension grade when there is a little difference in the length or width of ship

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for different tons or types of ships, and there is a little impact on the technical and economic performance of ships.

(3) Principle of adaptability
The principal dimensions of ships should be adapted to the demands of inland river transportation to serve the social development of area economy; adapted to the dimension of the lock chamber along the line to improve the utilization rate and carrying capacity of the lock; adapted to the navigation conditions of the waterway and port and terminal facilities to ensure the navigation safety and handling operation of the ships; adapted to the technical characteristics of ship types in the region to ensure the economic efficiency of the ships.

(4) Principle of unity
The inland waters in the same water system are interlinked. The research of principal dimensions of ships should take full account of the interworking of waterway at adjacent grade. On the basis of adapting to the navigation conditions and characteristics in this region, there is a need to take full account of the coordination and connection of standard principal dimensions in the adjacent and interlinked waters.

(5) Principle of practicality
In order to make the series of principal dimensions of ships have a strong operability, in the determination of the series of dimensions of ships, in addition to considering the constraints of the waterway and lock, there is a need to improve the technical and economic performance of the ship as much as possible, in order to reserve space for further optimization of the ships, and improve the practicality of the standards of principal dimension series. Usually, a fixed value is used for the standard of the width of the ship, and the total length of the ship gives a range, while the draught is designed as a recommended value.

(6) Principle of perspectiveness
The development of the series of principal dimensions should not only consider the needs of the current transport development, but also consider the demand of future waterway construction planning for the ships. Appropriate advance should be given to division of tonnage of ships, in order to provide a space for large-scale development of ships after improvement of waterway conditions.

3 TECHNICAL ROUTE OF SETTING STANDARD PRINCIPAL DIMENSIONS OF INLAND SHIPS

The overall idea of the development of standard principal dimensions of the inland ships is to first classify the series of tonnage grade of ships according to the restricted conditions of the waterway and lock, and demands of the transportation market, and then according to the characteristics of the principal dimensions of existing ships, considering changing factors of future waterway conditions, determine the selection range of principal dimensions of each tonnage grade of ship, form a number of principal dimension programs by the grid method, and then establish a technical and economic model and evaluation index system and select an optimal program as a recommended program of the principal dimension standards according to the evaluation index system. Technical route of setting standard principal dimensions of inland ships is shown in Figure 1.

4 DEMONSTRATION METHOD OF PRINCIPAL DIMENSIONS OF SHIPS

4.1 Ship technical and economic demonstration process
The technical and economic demonstration process of the principal dimensions of ships is shown in Figure 2.
4.2 Technical and economic mathematical model

(1) Determination of length between perpendiculars \( L_{bp} \)
It is determined according to the statistical relationship between the total length of existing ship and length between perpendiculars.

(2) Determination of moulded depth \( D \)
It is determined by statistics of existing ratio \( D/d \) of moulded depth and draught of the ship. In addition, the moulded depth must also meet the requirements of the laws and regulations on the ratio of minimum freeboard and principal dimensions of the ship. According to the *Rules for the Construction of Steel Inland Ships* (2009), the ratio of principal dimensions of general cargo ships in Class-A navigation area should meet: \( L/D \leq 25.0 \); \( B/D \leq 4.0 \); the ratio of principal dimensions of general cargo ships in Class-B and Class-C navigation areas should meet: \( L/D \leq 30.0 \); \( B/D \leq 4.5 \); the ratio of principal dimensions of liquid cargo ships in Class-A navigation area should meet: \( L/D \leq 25.0 \); \( B/D \leq 4.5 \); the ratio of principal dimensions of liquid cargo ships in Class-B and Class-C navigation areas should meet: \( L/D \leq 30.0 \); \( B/D \leq 5.0 \).

(3) Light weight \( LW \)
Generally, the length between perpendiculars \( L_{bp} \) and width of ship \( B \) multiplied by moulded depth \( D \) is called as the cubic modulus \( M \), and there is a linear relation between the light weight and cubic modulus. The relation between the light weight and cubic modulus can be obtained by statistics of the data of existing ships.

(4) Initial metacentric height
Relationship between ship waterplane coefficient \( C_W \) and block coefficient \( C_b \): \[ C_W = 0.5583 + 0.477C_b \] (1)
Relationship between the ship buoyant centre height \( KB \) and draught \( d \), waterplane coefficient \( C_W \) and block coefficient \( C_b \): \[ KB = C_W \cdot d/(1.024C_W + C_b) \] (2)
Relationship between the transverse metacentric radius of ship \( BM \) and moulded width \( B \), draught \( d \), waterplane coefficient \( C_W \) and block coefficient \( C_b \): \[ BM = (0.377C_W - 0.25)B^2/(d \times C_b) \] (3)
Metacentric height of ship \( KM \): \[ KM = KB + BM \] (4)
Height of center of gravity of clean ship: \[ KG_{LW} = 0.9D \] (5)
Height of center of gravity of dry bulk carrier and liquid cargo ship load: \[ KG_{DW} = db + 0.52(D + h_c - db) \] (6)
Height of center of gravity of container ship load: \[ KG_{dw} = db + 0.52 \cdot h_c \cdot N_c \] (7)
Height of center of gravity of ship: \[ KG = (LW \cdot KG_{LW} + DW \cdot KG_{DW})/Disp \] (8)
\[ \text{where: } db \text{ is height of double sole; } h_c \text{ is height of hatch coaming; } h_c \text{ is height of container; } N_c \text{ is layer of container; } LW \text{ is light weight; } DW \text{ is load capacity; } Disp \text{ is displacement.} \]
Initial metacentric height of ship \( GM \): \[ GM = KM - KG \] (9)

(5) Estimation of main motor power \( Pb \)
Under the condition of giving the principal dimensions of ships, block coefficient and navigational speed, the required main motor power can be estimated by the effective power and propulsive coefficient of the ships. When the navigational speed is certain, the
effective power and resistance of ships are proportional. Therefore, the calculation of effective power should first estimate the resistance of ships. There are many methods to estimate the resistance of ships, including the following common methods suitable for demonstration of inland ships: Dutch pool method, Alphard, Zivankov method and so on. For Zivankov method, the formula is as follows:

\[ R = 0.17\Omega v^{1.83} + \xi \cdot C_b \cdot A_F v^{1.7} + 4F_r \]  

(10)

Where: \( R \) - ship resistance (kn); \( \Omega \) - wetted surface area (m²); \( v \) - navigational speed (m/s); \( A_F \) - midship section area of wetted surface (m²); \( F_r = v/\sqrt{gL} \); \( \xi \) - residual resistance coefficient, \( \xi = \frac{17.7C_d^{2.5}}{(L/6B)^3} + 2 \)

Effective power:

\[ P_e = \frac{RV}{75} \]  

(11)

Main motor power:

\[ P_m = \frac{P_e}{P \cdot C} \]  

(12)

(\( P \cdot C \): propeller propulsion coefficient)

(6) Ship cost

The cost of ship is mainly composed of the price of hull, turbine, electric, deck machinery and outfitting. The same type of main engine is used for the same tonnage grade of ships, so the price of turbine, electric, deck machinery and outfitting are basically the same, but the price of hull changes due to the difference in dimensions. The cost of ship is estimated as follows:

Cost of whole ship \( P = \) Other price except for steel \( P1 \) + price of hull \( P2 \)

Price of hull \( P2 = \) Price of steel \( \times \) Steel weight of ship

Steel weight of ship\( = K \times Lbp \times B \times D \)

(7) Transportation cost composition

<table>
<thead>
<tr>
<th>No.</th>
<th>Calculating parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gasoline price</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Material moisture cost</td>
<td>3% of fuel charge</td>
</tr>
<tr>
<td>3</td>
<td>Ship port charge</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Shipping agent fee</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Accident loss</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Depreciation cost</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Repair cost, material cost</td>
<td>5% of ship price</td>
</tr>
<tr>
<td>8</td>
<td>Insurance expense</td>
<td>1% of ship price</td>
</tr>
<tr>
<td>9</td>
<td>Number of seaman</td>
<td>According to the minimum safety manning rules</td>
</tr>
<tr>
<td>10</td>
<td>Salary of seaman</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Tax</td>
<td>Business tax and additional</td>
</tr>
<tr>
<td>12</td>
<td>Enterprise management fee</td>
<td>6% of the sum of above costs</td>
</tr>
<tr>
<td>13</td>
<td>Total cost of transportation</td>
<td>A sum of above costs</td>
</tr>
</tbody>
</table>

4.3 Comprehensive evaluation index of principal dimension demonstration

The comprehensive evaluation index of ship principal dimension demonstration should include technical index and economic index. Technical indicators are mainly to obtain green ships with a small resistance, large cargo capacity and good stability that can meet the requirements of waterway draught at the required navigational speed through demonstration of principal dimensions of ships, engine power, navigational speed and high stability. The economic indicators are mainly considered from the investment income of the ships, including ship construction cost, unit transportation cost, unit profitability, net present value index, internal rate of return, required freight rate, investment recovery period, unit loading capacity and so on. In the demonstration calculation, there is a need to first screen the principal dimension program of ships that are in line with requirements, and then calculate the technical and economic indexes of the principal dimension program that is in line with conditions, and finally form a comprehensive evaluation system by various indexes with dimensionless method, and select excellent ships that meet the requirements. The selected evaluation indexes include:

(1) Transport efficiency \( YSXL \) (t.km/KW.h)

\[ YSXL = CW \times V/P_b \]  

(13)

Where: \( CW \) - cargo capacity (t); \( V \) - navigational speed (km/h); \( P_b \) - total power of main engine (kW).

(2) Coefficient of load capacity \( \eta \)

\[ \eta = \frac{DW}{\Delta} \]  

(14)

Coefficient of load capacity \( \eta \) is a ratio of ship load capacity \( DW \) (the container ship is based on the converted load capacity) and the full load displacement \( \Delta \), which reflects the size of ship load capacity.

(3) Required freight rate \( RFR \)

\[ RFR = \frac{(P \times (A/P, i, N) + Y)/(Q \times DA)}{(Q \times DA)} \] (RMB/t.km)  

(15)

Where: \( A \) - annual yield, RMB 10,000; \( Y \) - annual operating expense, RMB 10,000; \( P \) - ship cost, RMB 10,000; \( Q \) - annual volume of traffic, t; \( DA \) - haul distance, km; \( i \) - loan interest rate, %; \( N \) - repayment period, year.

(4) Unit load cost \( P/DW \): ship cost / ship load capacity

The unit load cost reflects the level of initial investment of the ship. If the index is lower, indicating that the initial investment of the ship is fewer. It is an index concerned by the shipping companies.

(5) Use ratio of lock chamber, maximum throughput per lock

The utilization rate of lock chamber is a ratio of the horizontal area of lock ship and the area of lock
chamber. The larger the value is, the higher the utilization rate of the chamber is. The maximum throughput per lock is a sum of load capacity of the lock ship. The larger the value is, the greater the throughput capacity of the lock is.

The principal dimension program of the ship is determined by comprehensive analysis and comparison of multiple indicators in terms of the technical performance and economic performance of the ship. It is just a problem to be solved by a multi-index decision analysis method. Therefore, the commonly used multi-index decision methods, such as fuzzy comprehensive evaluation method, AHP method and artificial neural network model and method can be used for the optimization and ranking decision of ship program [1].

5 DEMONSTRATION CASES OF STANDARD PRINCIPAL DIMENSIONS OF INLAND SHIPS

In this section, examples are given to demonstrate the principal dimensions of dry bulk carriers in the series of standard transport ships in the Ganjiang River, in order to illustrate the demonstration method for the research of series of standard principal dimensions of inland ships. Ganjiang River is located on the right bank of the middle and lower reaches of the Yangtze River, which is the largest river in Jiangxi Province, the largest river in the river system of Poyang Lake, the second largest tributary of the Yangtze River, passing from south to north in Jiangxi Province [2].

5.1 Classification of ship series

According to the dimension of as-built (proposed to build) lock in the Ganjiang River, the width of lock is 14m, 23m and 34m. The research does not consider 34m of lock. In accordance with the principle of principal dimensions of ships being adapted to the lock, by deduction of the rich width of lock, the width of ship should be 1, 1/2 or 1/3 times of the width of lock. Therefore, the corresponding series of width of ship should be 6.4m, 7.8m, 8.6m, 10.8m, 12.8m and 13.6m. Similarly, the length of lock is mainly 180m, and the corresponding total length of ships should be 45m, 56m and 85m. Considering that there is a large span between parts of length of ship, there is a need to increase 60m, 65m and 70m.

Considering the bending radius of waterway, depth of water and ship rules and regulations, the total length and type of the ship are combined to get the series of ship, divided as follows:

- Ship type 1: total length is not more than 45m, and width is not more than 7.8m
- Ship type 2: total length is not more than 56m, and width is not more than 8.6m
- Ship type 3: total length is not more than 60m, and width is not more than 10.8m
- Ship type 4: total length is not more than 65m, and width is not more than 10.8m
- Ship type 5: total length is not more than 70m, and width is not more than 12.8m
- Ship type 6: total length is not more than 85m, and width is not more than 13.6m

5.2 Scope of demonstration of principal dimensions

According to the statistical material of existing ship types in Ganjiang River and the requirements on the displacement of each ton class of ships, considering the conditions of waterway, the variation range of total length of each ton class of ships Loa, width of ship B and draught d of each ton class of ship are determined, in which the changing step size of length of ships is 1m, while the changing step size of width of ship and draught is 0.1m.

The specific conditions of combination are shown in Table 2.

5.3 Block coefficient

Dry bulk carrier is the displacement type of ship. Too small block coefficient leads to reduction in loading capacity, while too large block coefficient leads to a poor ship resistance performance. Generally, the block coefficient of 0.8 to 0.9 can better balance the requirements of displacement and resistance performance. The existing ships are within the range of 90%, so it is taken as the limiting condition of block coefficient of each tonnage ship.

5.4 Combining program for various tonnages of ships

<table>
<thead>
<tr>
<th>No.</th>
<th>Tonnage</th>
<th>Number of combining program</th>
<th>Number of effective program</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300 tons</td>
<td>560</td>
<td>66</td>
</tr>
<tr>
<td>2</td>
<td>500 tons</td>
<td>1117</td>
<td>477</td>
</tr>
<tr>
<td>3</td>
<td>800 tons</td>
<td>1155</td>
<td>172</td>
</tr>
<tr>
<td>4</td>
<td>1000 tons</td>
<td>1617</td>
<td>94</td>
</tr>
<tr>
<td>5</td>
<td>1500 tons</td>
<td>1452</td>
<td>354</td>
</tr>
<tr>
<td>6</td>
<td>2500 tons</td>
<td>1815</td>
<td>242</td>
</tr>
<tr>
<td>In total</td>
<td></td>
<td>1405</td>
<td></td>
</tr>
</tbody>
</table>

The combining program for various tonnages of ships is formed by combination with the total length, width
of ship and draught within the range of variation, and the effective program is formed by the program that is in line with the requirements of block coefficient. The number of combining program and effective program for various tonnages of ships is shown in Table 3.

5.5 Economic demonstration parameters

(1) Route and mileage
300 ~ 500 tons: Ganzhou to Nanchang, 450km
800 ~ 1000 tons: Ganzhou to Jiujiang, 660km
1500 ~ 2500 tons: Nanchang to Shanghai, 1006km

(2) Ship operating rate: 90%

(3) Voyage time
Voyage time: the average operating speed is calculated at 9km/h.
Lockage time: each one-way lockage time is calculated at an hour.
Time in port: the average loading and unloading efficiency of inland wharf in Jiangxi is 150t/h, 1,000t/h in Shanghai port; the average non-productive berthing time per flight is calculated based on 10 hours.

(4) Cargo category: yellow sand in downstream, coal in upstream

(5) Ship loading rate: 100% in downstream, 70% in upstream

(6) Freight rate: RMB 0.024/ton kilometer

5.6 Demonstration results

In the comparison and demonstration, four major evaluation indexes, namely, transportation efficiency, load capacity coefficient, required freight rate and unit cost of dry weight ton are used as the comprehensive evaluation index:

\[ C = \alpha_1 \times C_{\text{TSSL}} + \alpha_2 \times C_\eta + \alpha_3 \times C_{FRR} + \alpha_4 \times C_{P/DW} \]  

(16)

Where: \( \alpha_i \) - weight; other parameters are dimensionless relative values of the corresponding indicators.

\[ C_{\text{TSSL}} = \frac{YSXL - YSXL_{\min}}{YSXL_{\max} - YSXL_{\min}} \]  

(17)

\[ C_\eta = \frac{\eta - \eta_{\min}}{\eta_{\max} - \eta_{\min}} \]  

(18)

\[ C_{FRR} = \frac{RFR_{\max} - RFR}{RFR_{\max} - RFR_{\min}} \]  

(19)

\[ C_{P/DW} = \frac{P / DW_{\max} - P / DW}{P / DW_{\max} - P / DW_{\min}} \]  

(20)

The use ratio of lock chamber and maximum throughput per lock are only as a reference for analysis of ship comparison.

After screening, 300 tons to 3,000 tons of dry bulk carriers in Ganjiang River form a total of 1,405 targeted and effective combinations of the principal dimension program, and a preliminary technical and economic demonstration is given to each program according to the comprehensive technical and economic evaluation method of ships, thus obtaining a total score of each program. On this basis, each program is ranked to obtain a relatively optimal series of principal dimensions.

The recommended program for principal dimensions at various tonnages is as follows:

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Total length (m)</th>
<th>Width of ship (m)</th>
<th>Draught (m)</th>
<th>Tonnage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ganjiang bulk type I</td>
<td>45</td>
<td>7.8</td>
<td>1.4</td>
<td>300</td>
</tr>
<tr>
<td>Ganjiang bulk type II</td>
<td>53</td>
<td>8.6</td>
<td>1.8</td>
<td>500</td>
</tr>
<tr>
<td>Ganjiang bulk type III</td>
<td>59</td>
<td>10.8</td>
<td>2.0</td>
<td>800</td>
</tr>
<tr>
<td>Ganjiang bulk type IV</td>
<td>65</td>
<td>10.8</td>
<td>2.3</td>
<td>1000</td>
</tr>
<tr>
<td>Ganjiang bulk type V</td>
<td>69</td>
<td>12.8</td>
<td>2.7</td>
<td>1500</td>
</tr>
<tr>
<td>Ganjiang bulk type VI</td>
<td>84</td>
<td>13.6</td>
<td>3.4</td>
<td>2500</td>
</tr>
</tbody>
</table>

The technical and economic performance of each program is analyzed as follows:

(1) The recommended principal dimension of 45×7.8×1.4 for 300 tons of ships has a good technical and economic efficiency under conditions of limited depth of water in upstream waterway in Ganjiang River. The index comparison of the recommended principal dimensions and theoretically calculated optimal principal dimensions are shown in the following table:

<table>
<thead>
<tr>
<th>Recommended program</th>
<th>Theoretical optimal solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Program type</td>
<td>Recommended principal dimensions</td>
</tr>
<tr>
<td></td>
<td>Total length (m)</td>
</tr>
<tr>
<td>Ganjiang bulk type I</td>
<td>45</td>
</tr>
<tr>
<td>Ganjiang bulk type II</td>
<td>53</td>
</tr>
<tr>
<td>Ganjiang bulk type III</td>
<td>59</td>
</tr>
<tr>
<td>Ganjiang bulk type IV</td>
<td>65</td>
</tr>
<tr>
<td>Ganjiang bulk type V</td>
<td>69</td>
</tr>
<tr>
<td>Ganjiang bulk type VI</td>
<td>84</td>
</tr>
</tbody>
</table>

As can be seen from the table, compared with the recommended dimensions and theoretically calculated optimal dimensions, due to the increase in the width of ship, the transport efficiency index is reduced, while other indexes have a little change.

The width of ship is increased to 7.8m, mainly considering the continuity of local standards to be consistent with the width of ship, and benefit to improvement of stability of ship.

(2) The recommended principal dimension of 53×8.6×1.8 for 500 tons of ships is also a theoretically
calculated optimal principal dimension program, which can be combined with the ship with width of 12.8 m to improve the utilization rate of lock chamber with width of 23 m.

The index comparison of the recommended principal dimensions and theoretically calculated optimal principal dimensions are shown in Table 8.

As can be seen from Table 8, there is a little difference between indexes of the recommended principal dimensions and theoretically calculated optimal principal dimensions at 1,500t, which are within the acceptable range.

(5) The recommended principal dimension of 84×13.6×3.4 for 2,500 tons of ships is also a theoretically calculated optimal principal dimension program, which has a good technical and economic efficiency, and also fully considers the coordination of the relevant standards of the water system. In addition, the ship with width of 13.6m is combined with the ship with width of 7.8m can effectively use the width of 23m of the lock.

REFERENCES


Table 6. Technical and economic index of the recommended principal dimensions of 500-ton dry bulk carrier in Ganjiang River.

<table>
<thead>
<tr>
<th>Recommended program</th>
<th>Program type</th>
<th>Principal dimensions</th>
<th>Transport efficiency (tkm/kwh)</th>
<th>Coefficient of load capacity</th>
<th>Require freight rate (RMB/tkm)</th>
<th>Unit cost (RMB/t)</th>
<th>Use ratio of lock chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Program type</td>
<td></td>
<td>53x8.6x1.8</td>
<td></td>
<td>0.7205</td>
<td>0.0445</td>
<td>2569</td>
</tr>
</tbody>
</table>

(3) The width of 800, and 1,000 tons of ship is set as 10.8, which can match with the width of 23m and 34m of the lock better, and also consider the continuity of the existing standards. The difference is that the length of ship and draught are different, and it is recommended to be merged into a standard.

The index comparison of the recommended principal dimensions and theoretically calculated optimal principal dimensions are shown in Table 7.

(4) The width of 1,500 tons of ship is set as 12.8, which can make full use of the width of 14 m of the lock.

Table 7. Technical and economic index of the recommended principal dimensions of 800-ton and 1,000 ton dry bulk carrier in Ganjiang River.

<table>
<thead>
<tr>
<th>Tonnage</th>
<th>Program type</th>
<th>Principal dimensions</th>
<th>Transport efficiency (tkm/kwh)</th>
<th>Coefficient of load capacity</th>
<th>Require freight rate (RMB/tkm)</th>
<th>Unit cost (RMB/t)</th>
<th>Use ratio of lock chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>800t</td>
<td>Recommended program</td>
<td>59x10.8x2.0</td>
<td>41.13</td>
<td>0.7235</td>
<td>0.0713</td>
<td>2178</td>
<td>75.3%</td>
</tr>
<tr>
<td></td>
<td>Theoretical optimal solution</td>
<td>60x9.8x2.2</td>
<td>46.91</td>
<td>0.7323</td>
<td>0.0678</td>
<td>2134</td>
<td>71.9%</td>
</tr>
<tr>
<td></td>
<td>Amplitude of variation</td>
<td>-14.05%</td>
<td>-0.94%</td>
<td>4.91%</td>
<td>2.02%</td>
<td>3.2%</td>
<td>0.7%</td>
</tr>
<tr>
<td>1000t</td>
<td>Recommended program</td>
<td>65x10.8x2.3</td>
<td>50.23</td>
<td>0.7250</td>
<td>0.0651</td>
<td>2102</td>
<td>75.4%</td>
</tr>
<tr>
<td></td>
<td>Theoretical optimal solution</td>
<td>60x10.0x2.5</td>
<td>55.12</td>
<td>0.7286</td>
<td>0.0633</td>
<td>2079</td>
<td>74.1%</td>
</tr>
<tr>
<td></td>
<td>Amplitude of variation</td>
<td>-8.87%</td>
<td>-0.49%</td>
<td>2.84%</td>
<td>1.11%</td>
<td>1.3%</td>
<td>0.56%</td>
</tr>
</tbody>
</table>

Table 8. Technical and economic index of the recommended principal dimensions of 1,500-ton dry bulk carrier in Ganjiang River.

<table>
<thead>
<tr>
<th>Tonnage</th>
<th>Program type</th>
<th>Principal dimensions</th>
<th>Transport efficiency (tkm/kwh)</th>
<th>Coefficient of load capacity</th>
<th>Require freight rate (RMB/tkm)</th>
<th>Unit cost (RMB/t)</th>
<th>Use ratio of lock chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500t</td>
<td>Recommended program</td>
<td>69x12.8x2.7</td>
<td>65.70</td>
<td>0.7313</td>
<td>0.0158</td>
<td>1859</td>
<td>64.9%</td>
</tr>
<tr>
<td></td>
<td>Theoretical optimal solution</td>
<td>70x12.5x2.2</td>
<td>67.07</td>
<td>0.7332</td>
<td>0.0156</td>
<td>1827</td>
<td>64.3%</td>
</tr>
<tr>
<td></td>
<td>Amplitude of variation</td>
<td>-2.04%</td>
<td>-0.26%</td>
<td>1.28%</td>
<td>0.66%</td>
<td>0.6%</td>
<td>-0.1%</td>
</tr>
</tbody>
</table>