A Study on The Hull Form Property and Comparision of Korea · China Ancient Ship

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<Abstract>

Hull forms of ancient ships in Korea and China have been changed according to their voyages and routes. Therefore it is necessary for shipbuilding engineers to reestablish the ancient shipbuilding history, and to presume, restore and revive the lost cultural inheritances.

We, however, do not have many historical documents or credible materials that can assure our ancestors' great shipbuilding techniques : at the same time we do not have paid much attention to the research on such documents and materials.

This paper aims not only to study and compare shifting process of ancient ships' hull forms in Korea and China by making use of verifiable materials obtained in the process of excavating and restoring Shinan ancient ship.

The results of comparing structural characteristics and hull forms of ancient ships in Korea and China are as following :

(1) Korean ancient ships have transverse beam instead of frame. Judged from the bottomform, Korean ancient ships are grooved clinker type ships of flat bottom type, in which bottom planking is fixed by wooden bar.

(2) Chinese ancient ships have transverse bulkhead structure instead of frame. Judged from the bottom form, Chinese ancient ships are rabbetted clinker type ships of V - bottom type with a bar keel.

The form, the position, and the size of a sail are closely related with the wind force. It is not only quite difficult to presume forms and sizes of ancient ships' sails precisely, but also impossible to come to an accurate conclusion without much experience.

Current 10 - year - statistics of the wind force are used to obtain presumed routes of ancient ships in Korea and China.

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Conclusions obtained from the hull form, sail form and size, and mast height of Shinan ancient ship will provide credible data for sea trade routes and transformation capability, and will be used for effective materials on the study of the shifting process of ancient ships in Korea and China.

1. Introduction

As the Korean peninsula is surrounded by sea, Koreans have been interested in cultural exchanges and trades with foreign countries through sea. This fact is reflected not only in historical records but also in present Korean industrial structures. Topographical conditions and historical backgrounds show that sea trades are necessary to preserve and expand Korean industry. Therefore shipbuilding engineers have been required to play important roles in developing shipbuilding technology.

Historically, General Jang Bo-go of Silla dynasty had the command of the sea trade around the Korea peninsula. General Lee Sun-sin met the Japanese Invasion of Korea in 1592 with Turtle-Shaped Battle Ships.

Unfortunately, few historical records which show shipbuilding techniques of our ancestors, are handed down to the present. So it is very difficult to revive fully ancient shipbuilding techniques. Despite these difficult conditions, it is necessary for our shipbuilding engineers to restore our ancestors' lost great shipbuilding techniques.

Researches on the history of ancient ship development are the beginning stage, just presuming it through salvaged ships, and have not been applied to the practical shipbuilding engineering.

Empirical materials of ancient Korean ships from the comparative studies on the ancient ships of Korea, China and Japan will make it possible to develop the history of Korean shipbuilding and to investigate actively the restoration design of ancient Korean ships based on the shipbuilding engineering design.

This paper, through data from restoration process of the Shin-san ancient ship, is aimed to study the hull structure, the characteristics of hull form and the propulsion system of the ancient ship, to complete the missing parts in the history of Korean shipbuilding and to provide empirical materials of shipbuilding technique.

2. Research Purpose and Content

2.1 Necessity of Research

Hull forms of ancient ships in Korea, China and Japan were developed and transformed in accordance with ancient sea trade routes and places. It is shipbuilding engineers' responsibility to examine histories of ancient trades, navigation and shipbuilding, and to excavate, presume and then restore lost cultural inheritances.

2.2 Outline of Research Contents

This paper analyzes structural properties of restored ancient ships under the standpoint of naval architecture engineering on the basis of the empirical materials from the Shin-an ancient ship.
The form, place and size of a sail is closely related to wind power. It is a very difficult research task to presume exactly the form and size of a sail of an ancient ship.
Statistically analyzed materials of wind power for 10 years, which are applied to presumed voyage routes of ancient ships of Korea, China and Jaapan, are used to presume the sea speed and the size and form of a sail to driving force with the coefficient of drag and lift force.

3. Voyage Routes of Ancient Ships

In the first stage, Korea traded with several Chinese dynasties along the south and west coast. It is presumed that they might use a primitive hull form at that time because there are no historical materials on it.
Koreans ships had two ancient voyage routes to China: north China route through which they traded with ancient countries around Korea and north regions of China, and south China route to south regions of Korea and China.
The north China route is subdivided into the coastal route of Korea, the

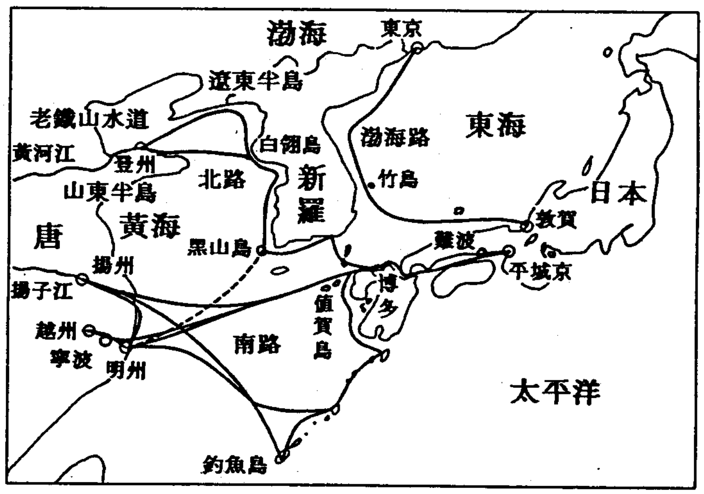

Fig. 1 The voyage routes of ancient ships

shortest Sandong route and the trans-Yellow Sea route. The south China route is subdivided into the route linking the coast of China to the west coast of Korea, and the route crossing the East China Sea which connects main land China and the south region of Korea.

4. Structural Property of Ancient Ships

4.1 Chinese Ancient Ships

Because the people at the coastal regions in ancient China had various the ways of life and coastal circumstances, the wooden ships made by them had their unique forms by regional groups.

For example, the sea was shoaly and calm at the regions in the Yellow Sea and East China Sea. so the ships had wide and long forms. Its bottoms was flat for easy beach-landing. On the contrary, the sea was deep and surgy at the regions in the South China Sea. The value of L/B was large at the ship in this region.

The coastal ships were built in wide form and were excellent in the initial stability. Sea-going ships had rather long and narrow Hull form. So, they were high speed and excellent in the direction stability.

There were two kinds of hull forms according to geographical conditions in China: Flat Bottom Type and V-Bottom Type

While Flat Bottom Type had U-Typed hull section, V-Bottom Type had V-Type.

The fore peak in the fore corrosion bulkhead of Chinese ancient ship had the perforated shell planking in the stem for sea water to come and go freely in sea-going voyage. It served as a damping system to produce pitching damping effect and resulted in reducing the pitching motion. #7 watertight bulkhead of Shinan ancient ship proves this fact.

The bottom of most Chinese ancient ships was a V-Bottom Type and was equipped with a keel.

Joseph Needham said that the keel, which was made of three pieces of big-sized wood adhered to Bottom part, was useful to avoid sunken rocks when sailing the South Seas. In this case, the keel was the same kind as the West ancient ship had.

The sunken ship was buried in the mud 20 meter below the surface of water 4 kilometer off IMJA island and WHOI island near BANG CHOOK RI, WHOI DO MYUN, SHIN-AN KUN, JUN NAM. The sunken ship was first known to the world in 1976 by fishers who picked up ancient porcelains around the island.

After the salvage operation, It turned out that the sunken ship was the greatest ancient ship in the orient, which we judge is a very important material for studying ancient ships shipbuilding techniques from the archeological aspect.

Adata ship like the Shin-an sunken ship which has a peculiar structure has never been discovered both in orient and in europe.

Therefore it is supposed that the sunken ship is a very important material for the study of the structure of ancient ships.

Two major things excavated in the sunken ship were porcelains and various kinds of woods which are very important sources to denote the nationality and the construction period of the sunken ship.

(1) Many porcelains and coins are identified as remains of SUNG and YUAN Dynasties which were existed about Six Hundred years ago in China.

(2) Red pine trees and black pine trees were used for the shell planks ; Camphor trees and chestnut trees were used for the inner construction members ; Cedars were used for the bulwark. The place of origin of all these trees was western and southern areas of China.

Judged from these sources, the sunken ship can be concluded a Chinese trade ship which was constructed in the fourteenth century.

Now let me tell you the characteristics of the sunken ships structure which are main theme of my study.

Ancient ships generally have two kinds of stem forms ; One is blunted, the other is pointed.

The sunken ship is identified to have a blunted stem, Judged from the fact that the breadth of the ship becomes narrowerinthe fore and rear end parts. The transom stern of the sunken ship seems to have taken stern-voide-space structure which is peculiar to oriental ships, But I am not sure because the upper part of the transom planking was lost.

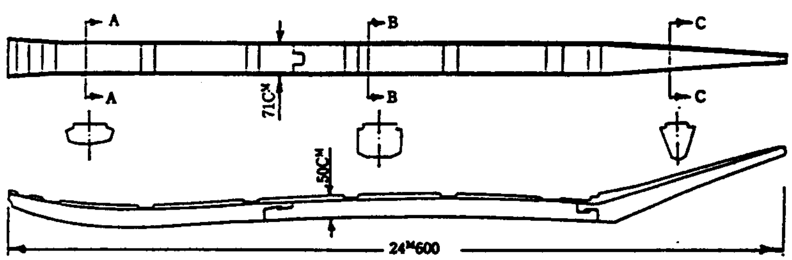

Fig. 2. Assembly of the bar keel

The bar keel of the sunken ship is divided into Forefoot, Middle part and Stern part, all of which are firmly jointed to one another.

The forefoot keel is slanted in 20 degrees and the keel of the stern part is curved. One interesting thing is that the keel of the middle part is gently curved upward when middle part is laid horizontally. It is deflection is 0.540 meter. The deflection seems to have been made artificially. The reason has been unanswered yet.

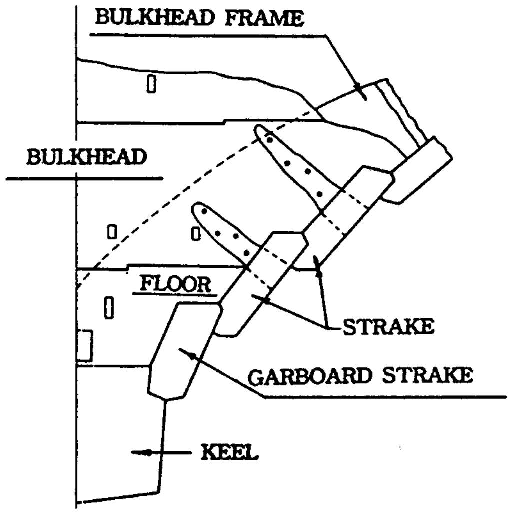

Fig. 3. The joint method of shell planking

The characteristics of bottom structure of the sunken ship are that the garboard strake is fastened to the bar keel, On whose upper part the floor is placed in order to fasten tightly the bar keel to the inside of the garboard strake. There is a groove 30 mm deep on the lower part of the floor, which is judged a limber hole for draining out dirty water.

The sunken ship has seven complete transverse bulkhead but the space of each transverse bulkhead is variable. The thickness of floor and bulkhead planking is different.

The peculiar joint method between the bulkhead and the shell planking is that only thefront part of the bulkhead planking is consistently fastened to the bulkhead frame because the thickness of the bulkhead floor and the bulkhead planking is different.

The bulkhead is reinforced by setting up bulkhead in front part of the bulkhead and wooden stiffener inthe rear part of it.

Spike method of construction members are all same. That is, all spikes are fixed downward obliquely.

But the section of the steel nail has two different forms ; One is round, the other is square.

As a joint method, they used a mortise and tenon joint method, which are generally available in wooden ancient ships.

This joint method seems to have been taken very carefully in order to strengthen nails grip force.

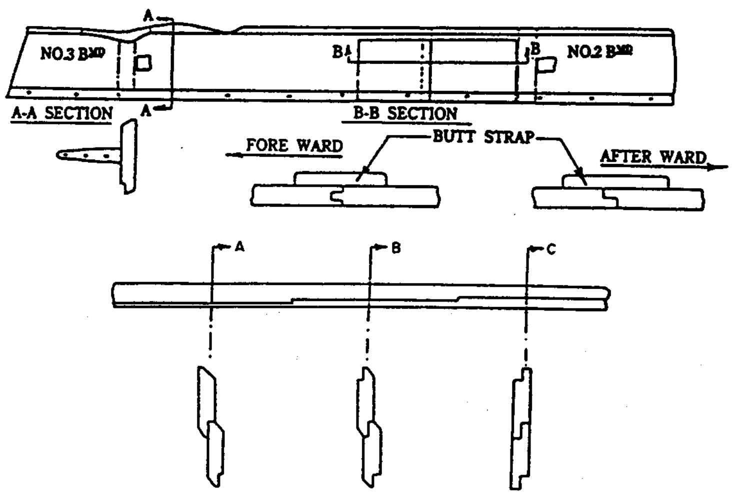

Fig. 4. The adherence method of shell planking

The rabbetted clinker joint method between the stern part and middle part is gradually converted to shiplap joint method between the middle part and the fore part. By the shiplap joint method, the upper part of the shell planking is fastened tothe lower part of the shell planking.

This shiplap joint method of the sunken ship is completely opposite to that of Korean ancient ship.

The sunken ships power plant for navigation seems to have been sails, and any rows have not been found.

There are two masts ; Fore and mizzen mast, whose upper parts corroded away. There are only lower parts of the two masts. Each mast consists of four wooden pieces of different sizes which are unioned close together.

Therefore the mast seems to be a union type mast which are similar to a assembly type mast which is used in todays sailing ancient ship.

4.2 Korean Ancient Ships

The ancient ship of the United Silla Dynasty was excavated when Anapji in Kyoungju City was restored in 1975. The ship was long and wide and had Flat Bottom Type.

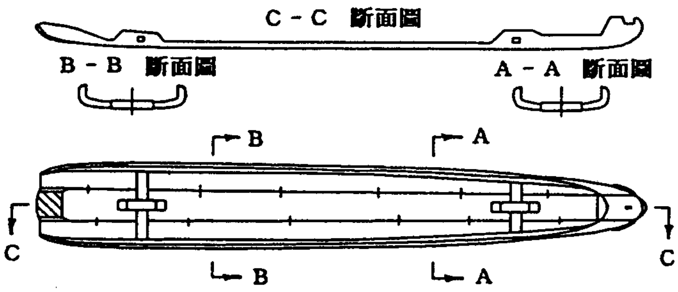

Fig. 5 The bottom planking of Korea ancient ship in Anabpji

As shown in Fig. 2. the Silla ancient log ship was made up of three wooden parts; Port Side Planking and Starboard Side Planking had 'ㄴ' form and inverted 'ㄴ' form, and Bottom Planking was placed in the middle of the ancient log ship.

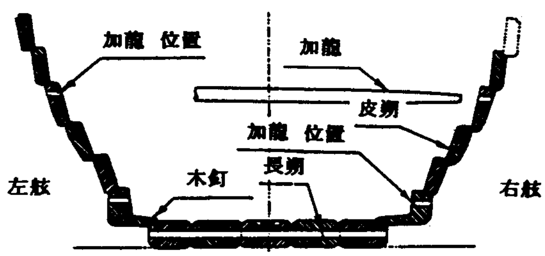

Fig. 6. The preceding term of Koryo for Korea ancient ship

But judged from the structure method, we cannot say that the silla ancient log ship had a ship-type structure, but we can consider it as a half-constructed or semi-constructed boat-type ship in the beginning stage.

As shown in Fig. 3. Koryo ship in the early Koryo Dynasty excavated at the Wan-do was similar in structure method to the ship previously stated. Both of them had unique structural properties of Korean ancient ships such as wood nail, Ga-rong-mok and Garboard strake shaped like ' ㄴ' shape. The Planking of the Koryo ship was jointed by Grooved Clinker Jointed Method. The Shell of Port and Starboard Side was connected with Ga-rong-mok. Bottom Planking and Shell were not directly connected each other. Bilge strake was similar to Longitudinal Scantling Member equipped to Chine part, which was a 'ㄴ'- shaped member and was placed between Bottom Shell Planking and Side

Shell Planking.

Compared to the Chinese Junk ship, the Korean ancient ship had Flat Bottom Planking and no frame alike, but Korean ship had a different structure method in other scantling members from the Chinese and Japanese.

The Koryo ship had Flat Bottom type. Its thick Keel Planking of Bottom Planking had a strong structure connected with Transverse Scantling Member.

It means that the unique structure method of the ancient Korean ship, which was to combine Ga-rong-mok with Flat Bottom type and to joint Bottom Planking to Garboard strake, was already established in the early Koryo Dynasty., and that the method was to combine Ga-rong-mok with Flat Bottom type and to joint bottom planking to garboard strake.

In Flat Bottom Typed structure, Bottom Planking and Shell Planking in the lowest part were directly steel-nailed. Generally Port and Starboard Side were connected with Ga-rong-mok and was stiffened. But the Koryo ship excavated in Wan-do shows a different method. Instead of connecting directly Bottom Planking with Shell Planking, Garboard strake made elaborately was interposed between them.

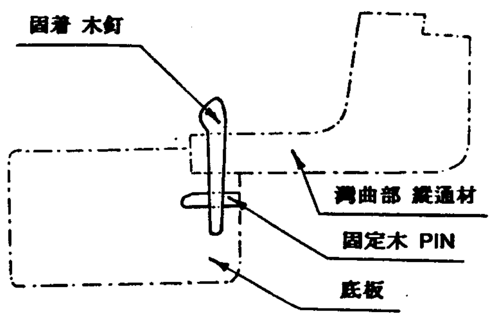

Fig. 7. The adherence of bilge strake and bottom planking for Korean ancient ship

Because wooden nails used in Garboard strake were not good for watertight, Grooved Clink Joint method was used to improve watertight of Hull as shown in Fig. 4. Though Ga-rong-mok was used, Flat planking at the Bulkhead was not equipped.

Round bars jointing Shell Planking of both side to each Shell Planking under Ga-mok was Ga-rong-mok, Transverse Scantling Member, which can be found only in the ancient Korean ship. Ga-rong-mok, as shown in Fig. 5. was made of slightly bent pine tree was fixed to Shell Planking with wedge. Shell Planking in Port and Starboard Side were connected by the Shiplap Joint method like 'ㄴ' shape. .

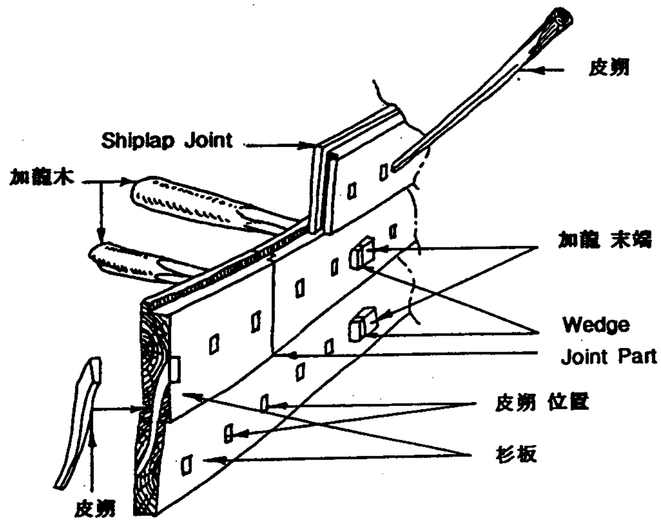

Fig. 8. The adherence method of scantling member

Because there were no frame and no Bulkhead of Flat Planking in the ancient Korean ship, Ga-rong-mok played the role in preserving Transverse strength and dividing the section of Hull instead of Beam, Frame and Bulkhead. The number of places equipped with Ga-rong was different according to ships, but was not many. Beam should be equipped on Ga-rong-mok and Beam spaces were generally irregular. It was considered as Strength Scantling Member equal to Web frame.

5. Structural Characteristics of the Ancient Ship

Structural characteristics of the ancient ships in Korea and China are as following.

(1) Chinese ancient ship: Rabbeted clinker type.
(2) Korean ancient ship: Grooved clinker type.

Ancient ships are classified by hull form, structure type, shell planking structure type.
Shell planking structure type has two types; Clinker joint method fixing upper-planking upon under-planking and Carvel joint method fixing two shell plankings up and down.
Korean and Chinese ancient ships adopted Clinker joint method in the shell planking structure type.

6. Propulsion System of Ancient Ships

6.1 The Theory of Sail

The driving force of a sailing ship is attained from the stream of air around sails. That is to overcome the hydrodynamic resistance, which is generated when the hull proceeds on the surface of water, with the aerodynamic force by the air stream around the sail.

There are various forms of sail such as triangle, rectangle, and so on. The most important element is the Aspect ratio.

$$AR = L^2 / S_A$$

here, $L =$ the height of the sail (m)

$S_A =$ the area of the sail (m2)

In the case of the rectangular sail, the aspect ratio is as following:.

$$AR = \frac{l}{L}$$

here, $l =$ the chord length of the sail

When the aspect ratio is large, the maximum lift is generated according to the relative angle between the wind and the sail. So proceeding forward in the close hauled has the benefits of reducing the time to handle the sails in comparison with the case of the sail which has the small aspect ratio. Therefore, the sail, whose aspect ratio is large, is preferred in case of racing yacht. For it has to sail almost a half in the close hauled especially in case of triangular sailing route. But navigating yacht which sails less in the close hauled, has a tendency to prefer the sail whose aspect ratio is smaller in comparison with the racing yacht. The reason is not only that the sail, whose aspect ratio is small, can get larger lift than the sail whose aspect ratio is large, but that the stall phenomenon is delayed. It surely has excellent efficiency in many ways.

The sum total of the lift and the drag generated by the sail can be presented as a total force (F_T) as in Fig 6. This force can be divided into driving force(F_R) used for the propulsion of the ship and heeling force(F_H) inclining ship to the transverse.

Therefore the driving force and heeling force can be calculated by using the lift and the drag, and coefficient of driving force(C_R) and the coefficient of heeling force(C_H) by using the lift coefficient and the drag coefficient.

If the entrance angle of the propulsion direction and wind is set as β, the expression of their relation can be presented as following.

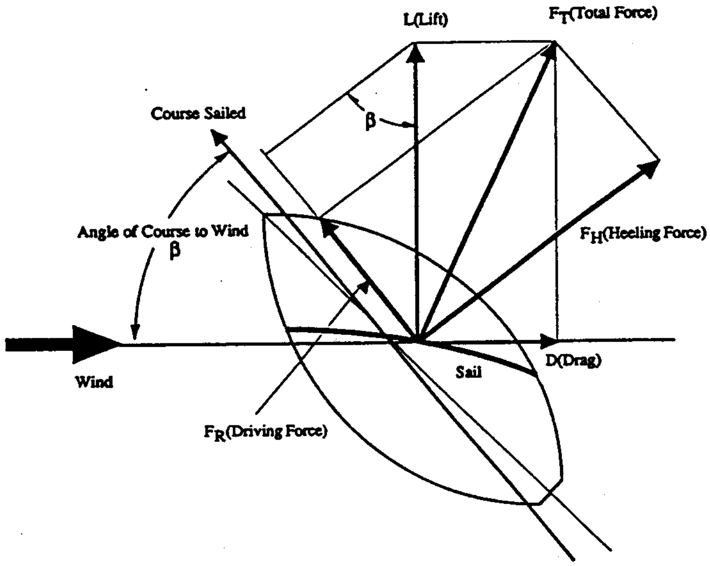

Fig. 9. The aerodynamic force created by the sail

$F_R = L \sin\beta - D \cos\beta$

$F_H = L \cos\beta + D \sin\beta$

$C_R = C_L \sin\beta - C_D \cos\beta$

$C_H = C_L \cos\beta + C_D \sin\beta$

As the above equation shows, the drag of the sail makes driving force decrease and the subversion power increase in the close hauled which blows from 90° to the propulsion direction of the ship. At this time only the element of the lift by the sail contributes to the propulsion of the ship. But in the occasion of the following which blows at an angle of 90° to 180° to the propulsion direction of the ship, the element of the drag as well as the element of the lift works as the driving force of the ship. As the entrance angle comes close to 180° , the lift caused by the sail becomes very small, in terms of which the drag forms most of the driving force.

6.2 Sails of the Chinese Ancient Ship

With the increase of the angle of the sail to the wind, the lift coefficient of the Chinese ancient ship is shown to increase considerably more than the drag coefficient. But when it is over 30°, only the drag coefficient increases.

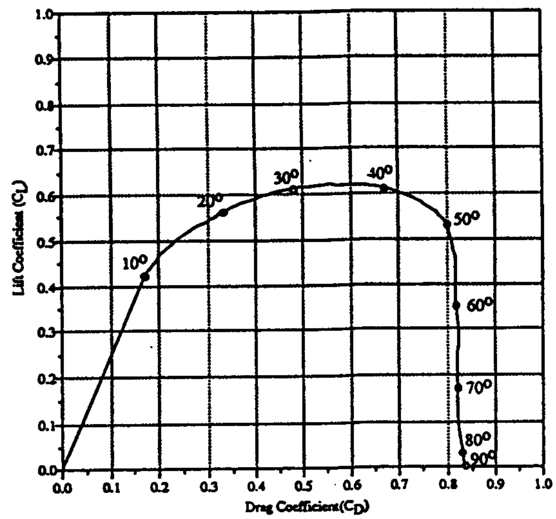

Fig. 10. The polar diagram for the balanced lug sail

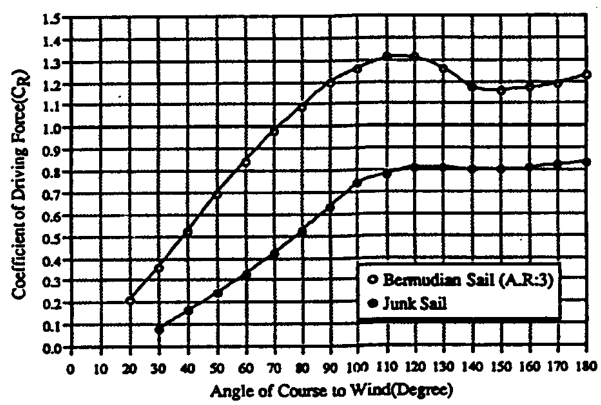

Fig. 11. The driving force coefficient of Junk sail

When the angle of the sail to the wind is over 50° , the life coefficient is invariable while the dag coefficient decreases rapidly. And when the angle reaches 90° the lift element perishes completely and only the drag element remains.

In Fig 7 and 8. is shown the driving force of the ship acquired from the collective considerations about the propulsion direction of the ship, the angle of the wind, and the angle of the sail. The Bermudian sail is generally more efficient than the lug sail as is shown in Fig 5.7. The Bermudian sail has the maximum driving force coefficient when the angle of the propulsion of the ship to the wind is 110° to 120°, and the driving force coefficient decreases with the increase of the angle. The Chinese lug sail has nearly maximum driving force at the angle of 110° to 180° . And the change of the angle doesn't make a prominent difference in the driving force. This means that the lug sail is designed to have excellent efficiency in the state of running or board reaching.

6.3 The presumption of the form and size of the lug sail

It is difficult to presume the exact the size and the form of the lug sail of Shinan Ancient Ship. It is due to difficulties in finding the historical sources and materials which describe or help us trace them.

This study tries to find out the form and the size of the lug sail on the basis of historical sources and information about the exhumed and restored Shinan Ancient Ship.
The actual height of a sail should be measured by subtracting from the mast height, the depth of the hull, the camber, and the mast foundation and the structures which interfere with the movement of sails. Therefore as it seems to be very difficult to presume the heights of the masts with all these things taken into consideration, the heights of several kinds of possible masts are derived by theoretically calculating the maximum and the minimum height of the masts .
The height of the fore mast is assumed to be 100%, 90%, and 80% of the length of water line in reference to the related source, and the actual height of the sail is decided with the consideration of the length of the mast, the depth of the ship, and the height of the superstructure (assumed to be 2 meter).
The height of the fore sail mast is assumed to be 80%, 70%, and 60% of the length of water line in reference to the related sources, and the actual height of the sail is decided with the consideration of the length of the mast, the depth of the hull, and the height of superstructure (assumed to be 2 m). The heeling angle of the mast is chosen to be 25° inclined toward the stern in reference to exhumation sources about the bulkhead heeling.

Table 1. The effective area of sail

Sail Height (m)	Sail Lower Breadth (m)	Sail Upper Breadth (m)	Aspect Ratio	Sail Area (m^2)	Sail Effe. Area(m^2)
14.32	8.60	7.74	1.75	117.00	106.03
11.78	8.60	7.74	1.44	96.24	87.23
9.24	8.60	7.74	1.13	75.49	68.42

The breadth at the lower part is assumed to be the hull breadth at the part at which the mast is set up, and that at the upper part to be 90% of max breadth. In accordance to this assumption the heights, the breadths, the aspects, the areas, and the valid areas of the fore sail are presumed as in Table 1. when the inclination considered.

6.4 The presumption of the driving force by sails

The driving force(F_A) can be calculated as below with the velocity of the wind, the area of the sail, and the driving force coefficient(C_R) dependent on the angle of the wind and the direction the ship is proceeding in.

$$F_R = \frac{1}{2} C_R \rho v_A^2 S_A$$

The driving force coefficient can be acquired from Fig. 8. There are three cases in the proceeding direction of the ship in the route and in the angle of the wind. And the driving force coefficients in those cases are approximately 0.63, 0.8, 0.83. The wind velocity is about 3.2～3.6 m/sec in case that the wind blows from China to Japan by way of the coast of Korea, and about 1.4～2.3 m/sec in case of the opposite direction. For the convenience of calculation the wind velocity is set at 3.4 m/sec and the driving force coefficient at 0.7 in the former case, and the wind velocity is set at 1.9 m/sec and the driving force coefficient at 0.8 in the latter case.

In the sea speed of the sail ship the effect H.P. for total resistance value of the hull form is the same as the actual propulsion force. So when the driving force by the sails is converted into the actual propulsion force, the sea speed of the sail ship is the ship speed correspondent to the value of the hull form and the effect H.P. of the sail's driving force. The sea speed is presumed on the basis of the total resistance and the driving force of the sail estimated by the sources of the hull form of the Shinan Ancient Ship.

Table 2. Comparison of ship speed

Voyage	청도(靑島) ↓ 인천(仁川) (β=90°)	인천(仁川) ↓ 목포(木浦) (β=180°)	목포(木浦) ↓ 진해(鎭海) (β=90°)	진해(鎭海) ↓ 하까다(博多) (β=180°)
Voyaging [Mile]	330	219	180	134
Mean Speed [Knot]	2.811	2.379	2.811	2.379
Voyaging time [Hour]	118	92	64	56
Total sea speed [Knot]	4.843 (Distance 863 sea miles)			

As shown in the Table 2. the sea speed on the average is 4.843 Knot, which must have been an amazing speed judging from the steady voyage performance at that time.
Before sinking down at the sea near Bangchook-ri, Whoido-myun, Shinan- kun, Junnam, the Shinan Ancient Ship must have had such great sea speed and steady voyage performance beyond our imagination.

7. Conclusion

This paper aims not only to study and compare shifting process of ancient ships hull forms in Korea and China by making use of verifiable materials obtained in the process of excavating and restoring Shin - an ancient ship.
The form, the position, and the size of a sail are closely related with the wind force. It is not only quite difficult to presume forms and sizes of ancient ships sails precisely, but also impossible to come to an accurate conclusion without much experience.
The average sea speed of Shinan ancient ship is equivalent to 8.33 knots on the basis of the fact written in the log book that Japanese ancient ship ran 680 sea miles for six days.

① When the wind is abeam, compared to sea speed and steady voyage performance, the average sea speed of Shinan ship is equivalent to 7.8-11.7 knots at wind velocity of 20-30 knots.

② When the wind is following, result value of sea speed to theoretical Effect H.P. and driving force of a sail is about 6.15 knots. Under the calm water condition it is nearly exact by the fact that sea speed to steady voyage performance is 6.6 knots at wind velocity of 20 knots.

Conclusions obtained from the hull form, sail form and size, and mast height of Shin - an ancient ship will provide credible data for sea trade routes and transformation capability, and will be used for effective materials on the study of the shifting process of ancient ships in Korea and China.

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