8. A Study on Pre-Erection System in Hull Construction

Isoe TAKEZAWA*, *Member*, Masataro MUTO*, *Member*, Akio KANEZAKI*

(*From J.S.N.A. Japan Vol. 133, June 1973*)

Summary

The Shipyard lay-out and facilities have been modernized in line with the adoption of the block construction process. In these days the most modernized shipyards have been newly constructed both in Japan and abroad to cope with the increased demand of super-large type ships.

In the first stage of these new shipyards simply a single building dock each was constructed in view of the then prospect of newship tonnage to be built and the cost of the dock construction.

After that due to the ever increasing demand for super large ships, it became necessary either to lengthen the dock or to add another new dock in which the after block of the hull containing the machinery space to be pre-erected. Even in this case, it was necessary to float and shift the pre-erected after-ship block, and this process was not so easy due to the problems for the adjusting of its draft and trim.

As the next stage the pre-erection process of the aft part of the ship including machinery space and some oil tanks was adopted. But even in this process it was necessary to float and shift the portion, and though the draft problem was solved, the labour manhour balancing problem remained unsettled.

To solve this problem new shipyards with dual entrance dock or two building docks have emerged. In these docks, the pre-erected hull portion are constructed without shifting. At the same time, in some docks the pre-erected hull portions are shifted mechanically in lieu of the floating procedure.

In this essay, the authors intend to explain these aforesaid various construction methods. At first the theoretical explanation of the construction process is made and then calculation of the length of the necessary pre-erection dock to peak-shaving the labour manhours is shown.

As a result, it is concluded that the mechanical shifting of the pre-erected portion from the pre-erection dock with a suitable length shall be very advantageous to solve the problems. Finally the authors describe the fundamental design of the mechanical moving system.

1. Foreword

Since the block construction method was practised for shipbuilding, various aspects of shipbuilding activities were rationalized, such as in the installation of large cranes, expansion of existing facilities, construction of new assembly shops, and so forth. In the meantime, to copy with the rapid growth in ship size, many modern, large shipyards emerged in Japan as well as in Europe.

Of these new shipyards, however, most of the earlier yards had their docks designed for construction of only one vessel at a time, taking into account the production capacity and the construction cost of the yard.

In Japan, the recent increase in the demand for larger vessels necessitated the pre-erection of engine room parts of hulls, and a number of docks for this purpose have been

* Mitsubishi Heavy Industries, Ltd.

newly built, either separately from existing building docks or as extensions to existing ones. However, as the pre-erected bodies have to be floated for transfer, and as this process, in turn, places restrictions on the structual weight or buoyancy of the pre-erected bodies in terms of draft and trim, none of these docks turned out to be as efficient or useful as had been expected.

Meanwhile the construction volume of new shipbuildings in Japan steadily increased, and it became essential to keep large quantities of assembled blocks* in stock. In addition to this, the increased construction volume resulted in greater fluctuation in the number of workers. And these factors posed serious setbacks to the attempts made by shipbuilders to raise production.

A solution was then conceived to pre-erect a longer stern body that would include not only the engine room part but also a part of the cargo tank space. In this case also, the pre-erected body would have to be floated for transfer.

Although this method did help to do away with the restrictions associated with structural weight and buoyancy of the pre-erected bodies, it did not fully solve the problem of uneven distribution of work load. Consequently, dual entrance docks and shipyards with two building docks came to be constructed. In these docks, each hull body could be constructed without transferring it from one place to another. In addition to such shipyards, there also appeared other shipyards which were designed in such a way as to permit mechanical transfer of pre-erected bodies, instead of having them floated for transfer.

Although one gets the impression that such hull construction methods employed by these new yards are quite diverse in character, all of them, actually, are based on the pre-erection system. Even in the yard with two building docks, the method applied is the pre-erected system of which the body is built extending to her entire length.

This paper will discuss, in the first place, the erection procedures at the building dock, and then proceed to find out the relation between the necessary length of the building dock for pre-erection work and the production capacity of the yard to be built. The paper will also deal with the principal mechanism of mechanical transfer device which is already used with successful results in the construction procedures employing the pre-erection method.

* In the following paragraphs "Assembled blocks are shown only with blocks."

2. Discussions on Shipbuilding Methods

2.1 *Basic Erection Procedure*

In every one of the above-mentioned building methods, erection of each individual block in relation to other blocks is restricted to some extent by the time factor. And what the following discussions are aimed at, is to provide some solution to this "time" problem.

As already mentioned, the engine room part of a hull is not constructed as an independent entity in all present cases of construction by the pre-erection method. Rather, the engine room part is incorporated into a pre-erected body which also includes a part of the tank section. This means that studies should be made on the oil tank section, and the discussions which follow concern various issues associated with oil tank sections.

Blocks constituting cross-sectional band of the oil tank section will be numbered ①, ② $\cdots m$ in the order of erection, i.e. from the bottom centre block to the upper deck side block, and the block bands will be longitudinally counted Nos. *1*, $\cdots n$.

For successive erection of blocks of a same kind, the minimum time (number of days) required for election of one block is represented by t_1, t_2, $\cdots t_m$, and the minimum time (number of days) required for erection of blocks of other kinds in the same band is represented by t_{12}, t_{13}, $\cdots t_{m-1,m}$. Fig. 1 represents in a diagram the minimum erection period satisfying the above-specified conditions.

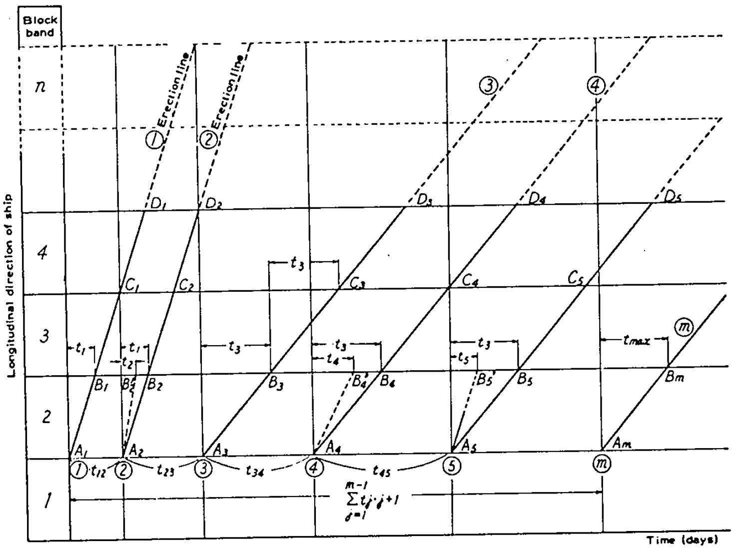


Fig. 1 Diagram of minimum erection period for oil tank parts

A_1, A_2, $\cdots A_m$ in the diagram stand for the minimum construction periods for block band No. 1.

B_1 represents the time when block ① of block band No. 2 is erected, and is behind block ① of block band No. 1 by t_1. In determining the erection time of block ② of block band No. 2, B'_2 is arrived at if the time lapse following the erection of block band No. 1 is given as t_2. However, if $t_1 > t_2$, there is another condition which has to be met and that is t_2. In such a case, the time lapse between A_2 and B_2 would be t_1.

The same reasoning applies to the erection line of ③. If $t_3 > t_1$, and if the interval is to be t_3, then the point sought for will be B_3. The erection time of the last block on the ⓜ erection line is obtained by intersecting the ⓜ erection line with the block band No. n. The point of intersection indicates the time lapse of $(n-1)\times t_{\max}$ from A_m. It follows, then, that the total time spent for erection of the tank section, including one day for erecting ① of No. 1, will be:

$$Ⓣ=1+\sum_{j=1}^{m-1} t_{j\cdot j+1}+1+(n-1)t_{\max} \qquad (1)$$

According to this method and schedule, the erection of block band No. 1 reaching up to the upper deck would be completed first within the shortest possible time. And this would be followed by completion of blocks ① of all block bands stretching out fully in the longitudinal direction of the tank section, within the shortest possible time. All other blocks would also be completed in the same manner. Consequently, it can be safely said that all the blocks can be erected within the shortest possible time.

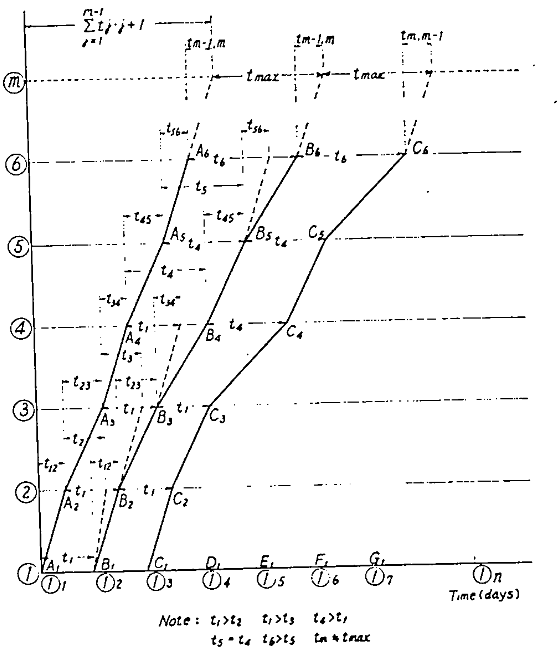


Fig. 2 Diagram of minimum erection period for tank parts

In Fig. 2, blocks ① are plotted along the abscissa under identical erecting conditions as in the above mentioned case. According to this graph, the total time required for erection exactly matches the time obtained through the above Equation (1). While Fig. 1 illustrates how cross-sectional block bands are built, Fig. 2 illustrates the process of layer-by-layer erection. In applying Equation (1) to obtain the time required for erection of blocks for shipbuilding in general, it would follow that the time required would have been extended both in the cross-sectional block band direction and in the layer-by-layer direction. Thus, the equation would be as follows:

$$\textcircled{T}=1+\alpha\sum_{j=1}^{m-1} t_{j\cdot j+1}+\beta(n-1)t_{\max} \qquad (1)'$$

In this equation, cross-sectional block bank erection method can be represented in case when $\alpha=1$ and $\beta>1$. But if this β is enlarged to make the time interval at B_1 larger than A_m in Fig. 1 and C_1 larger than B_m, it would result in erection being carried out one cross-sectional band after another. If, on the other hand, the case $\beta=1$ and $\alpha>1$, shows the erection by the layer-by-layer system.

The following is an example in which calculation is made according to the above-explained method. Fig. 3 illustrates a midship cross section of the tank section, and the encircled figures represent the order in which the blocks are erected.

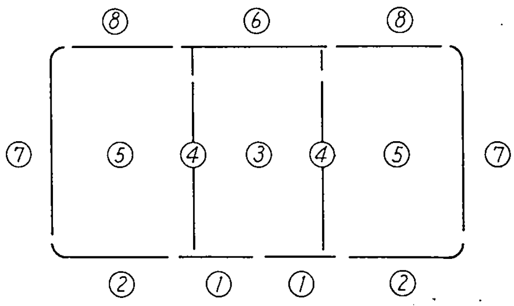
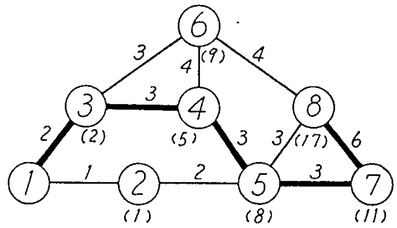


Fig. 3 Cross section of tank part

Fig. 4 shows network of blocks. If a diagram were to be drawn on the postulate that the number of block bands is 6 under the conditions given in Fig. 4, the diagram would be as Fig. 5, if drawn according to the formula of Fig. 1. If, on the other hand, the formula of Fig. 2 is applied, the diagram would be as Fig. 6.

As both diagrams (Fig. 5 and Fig. 6) indicate, the erection of block band No. 1



t_{12} --- 1 day t_{23} --- 1 day t_{34} --- 3 days t_{45} --- 3 days
t_{56} --- 1 day t_{67} --- 2 days t_{78} --- 6 days
$t_1, t_2, t_3, t_4, t_5, t_6, t_7, t_8$, --- 1, 2, 1, 2, 1, 3, 3, 3, days

Fig. 4 Intervals between erection of blocks (days)

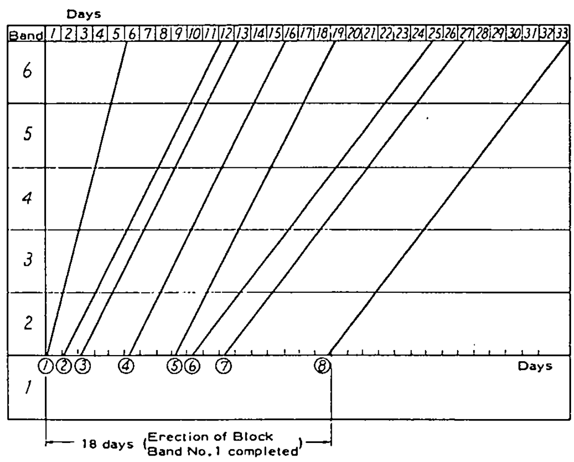


Fig. 5 Diagram of minimum erection period

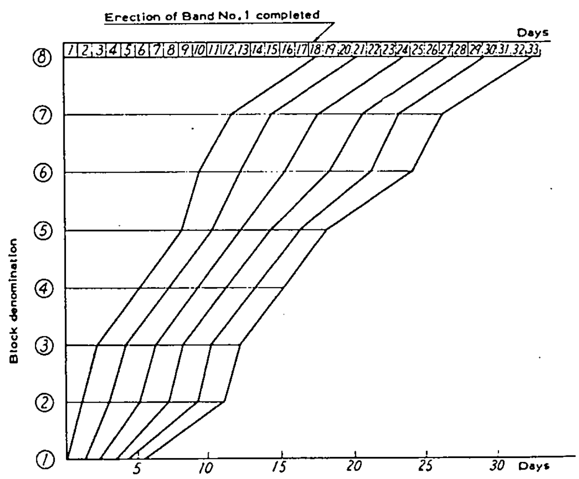


Fig. 6 Diagram of minimum erection period

requires 18 days. Time of erection of all the blocks requires 33 days, which figure can also be calculated from Equation (1). However, these figures represent the minimum number of days in which the blocks can be erected, and although blocks of a same kind can be erected in sequence at constant intervals, erection intervals vary when different types of blocks are erected. And this means that the erection process would not be repetition of the same cycle, which, in turn, means that use of this method for serial construction of the same type of vessels would not help to create even distribution of manhours, nor uniformity in the weight of erected bodies.

2.2 *Floating Transfer System of Pre-Erected Body*

According to this system, a pre-erected body is transferred into the dock to a position to start further erection work, immediately after the preceding ship has been launched. For the purpose of study, the following particulars have been postulated.

Annual output: About seven tankers of 260,000 deadweight tons
Construction time per ship: 36 days
Length of tank section: 240 m
Number of block bands of tank section: 6

For this system to be workable, all finishing work of the vessel to be launched must be completed. Fig. 7 illustrates a situation in which all the above-mentioned conditions are fulfilled and in which the manhours required for construction are distributed over erection days as evenly as possible.

Since the pre-erected body should at least be in a floatable and transferable condition when the preceding vessel is launched, erection is suspended at Point A_1 in the diagram, and in the interval between A_1 and B_1, the pre-erected body is made floatable. The body to be floated should have a tank part of at least 60 metres long and be loaded with ballast.

Thus, in the case of the vessel in question here, it must have the first two block bands pre-erected, and these block bands would be

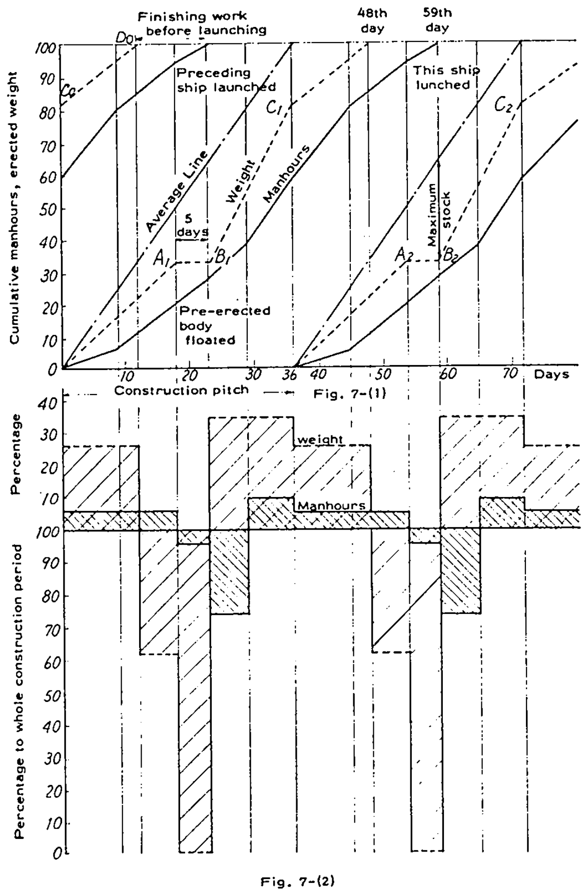


Fig. 7 Weight of pre-erected bodies and distribution of manhours in afloat transfer system

in a transversely cut shape when this pre-erected body is floated. As for the preceding ship to be launched, all finishing work must be completed by them as already mentioned. This means that the erection of this ship must be completed by Point D_0, so as to leave some time before it is launched. Consequently, as illustrated in Fig. 7-(2), no erection work takes place during the period A_1-B_1, and as a result, there is a sharp decrease in the work load immediately after Point B_1.

According to Fig. 7, it takes 18 days to set up the pre-erected body which consists of the first two block bands. The period of 18 days is shorter than the period up to erection of No. 2 block band, envisaged by Fig. 6, because the t_{7-8} interval in Fig. 7 is shorter than in Fig. 6. The remaining 4 block bands are to be erected during the $B_1-C_1-D_1$

period, but the period in Fig. 7 is again shorter than the period of erection of block bands from No. 1 to No. 4, as shown in Fig. 5 (or Fig. 6) because the t_{7-8} interval in Fig. 4 has been shortened in the case of Fig. 7. The process illustrated in Fig. 7 was worked out with a view to creating an even distribution of manhours, but this has been achieved in exchange for considerable difficulties, and Fig. 7-(2) shows that the unevenness has not been fully done away with. The phenomenon that appears in Fig. 7-(2) is accountable to the suspension of erection work on the pre-erected body prior to its transfer by floating, as well as to the speeded-up erection of the preceding vessel. The following are the measures which might help to create an even distribution of manhours under the floating transfer system.

(1) Reduction of the effects of floating transfer system

a) In the process represented by Fig. 7, the erection of the preceding ship is completed at an early date, well ahead of the time of launching. In the process which is proposed here, on the other hand, this completion date is postponed until after the time of launching, and the finishing work is carried out after the ship has been launched. Although such arrangement helps to create an almost completely even distribution of manhours, it would result in lowered production, because the operating efficiency would drop and the outfitting period would be extended.

b) If the afore-mentioned construction target of 7 vessels per year can be reduced, the erected weight-manhour curve would become less steep and the distribution of manhours will be more even. In other words, this would reduce as well as limit the production capacity.

(2) Elimination of the blank period during pre-erection process

According to the afore-mentioned process, pre-erected body is floated for transfer after the preceding ship has been launched, so that no intermediate gate is required. However, if the blank period during pre-erection is to be eliminated, an intermediate gate would be necessary for dividing the main building dock and the pre-erection dock. This gate is to be removed after the launching of the preceding ship, and the pre-erected body is kept in the same position until it is floated at Point C_1 in Fig. 7, which point represents the time when pre-erection work on the ship starts. In the shortest pass erection process illustrated in Fig. 5 (or Fig. 6), this is the stage at which the No. 4 block has just been erected, which means that the work on the side shell has not yet been completed. However, since the finishing work on the bottom shell has by this time been completed, erection can be continued without interruption, provided the waterline is below the top of the bilge shell when the body is afloat. However, since the draft is usually deeper in reality, this problem requires further consideration.

Besides this draft problem, there are other problems associated with employment of this

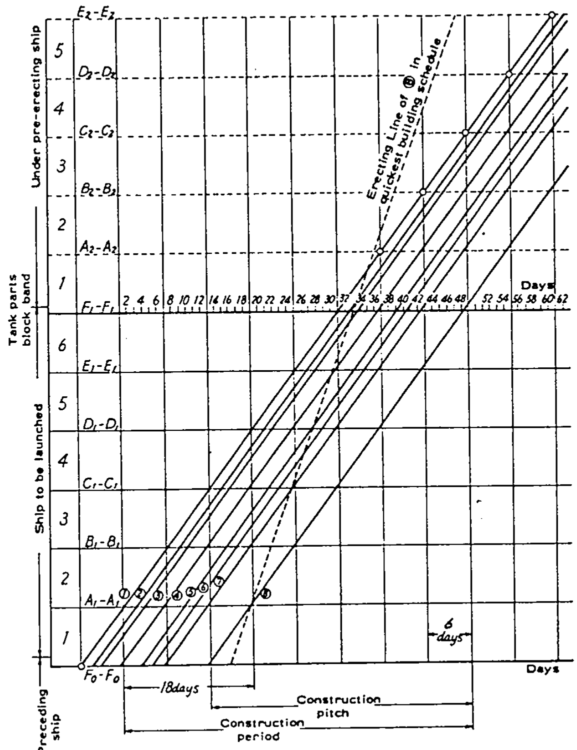


Fig. 8 Pre-erection process by non-floating transfer method

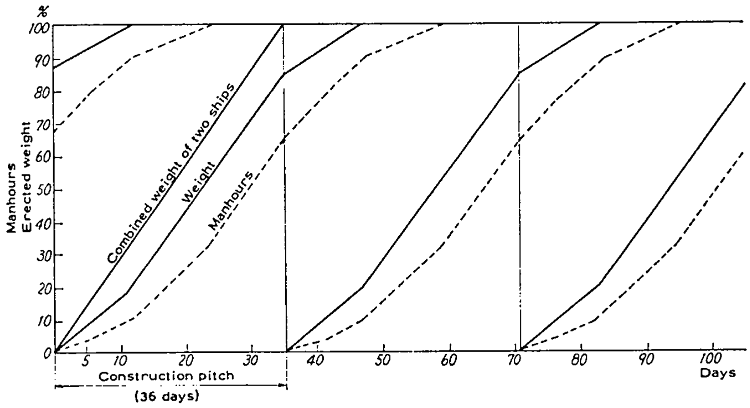


Fig. 9 Pre-erected weight and manhour under non-floating transfer method

method. According to this method, for instance, no space is provided for pre-erection of the hull for the engine department, and this necessitates extension of the dock length. Another disadvantage is that since it is not desirable to transfer the body by the floating method when the body includes the engine room part, this has to be done mechanically.

As is clear from what has so far been stated, pre-erection by floating transfer method does not permit large-scale production, and moreover, it poses problems where levelling off of manhours in concerned.

2.3 *Pre-Erection by Non-Floating Transfer Method*

According to this method, pre-erected body is not floated for transfer, and this means that the erection work can be carried out uninterruptedly. Regarding serial construction of vessels of a same type, it has already been mentioned that since the intervals between erection of one block and another are not uniform, to erect the blocks in the manner represented by the erection lines in Fig. 5 or Fig. 6 would not be desirable. If, however, construction is done in accordance with the conditions postulated in 2.2 and in a manner represented by Fig. 8, the intervals between erection of one block and another would be uniform.

When this manner of erection is employed, the erection lines should not be any steeper than the ⑧ curve in Fig. 5.

Fig. 9 indicates the manhours and erected weight, which are found to be in perfect balance with each other where the pre-erected ship and the preceding ship are concerned. The stock condition is represented by the erection lines above the F_1-F_1 line in Fig. 8, and Fig. 10 represents this condition generally in a diagram. In Fig. 10, at the time (T_0) when Ⓜ$_n$ of the final block band of the launched vessel is erected, the length of the pre-erected vessel is determined by the erected number of ① blocks of that vessel. Similarly, the pre-erected length

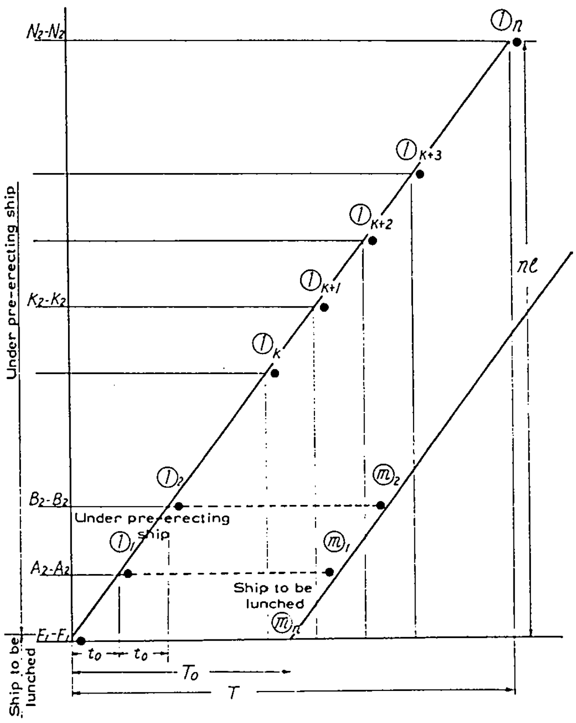


Fig. 10 Required number of pre-erected blocks

at the time of launching is also determined by the erected number of ① blocks. By representing these factors by the following notations, the relationship among these factors would be as in the formula below.

T ......Construction pitch

T_0......Period required for erection of a block band

L ......Length of tank section

n ......Number of bands into which tank section is divided in longitudinal direction

$$l=\frac{L}{n} \qquad t_0=\frac{T}{n}$$

Then, if k represents the number of ① blocks that have been erected by the time the final block ⓜ$_n$ of the launched ship has been erected, the formula would be:

$$(k+1)t_0 \geq T_0-1 > kt_0$$

If, in actual construction process, the erection day of ⓜ$_n$ of the launched ship should happen to fall on the same day as the erection day of ①$_{k+1}$ of the pre-erected ship to be built, ① will not be erected in such a case and the number of pre-erected bodies would thus be reduced.

Since launching normally takes place A days after the erection of ⓜ$_n$, the following formulae can be formulated:

$$(k+1)t_0 \geq T_0-1+A > kt_0, \quad t_0=\frac{T}{n}$$

$$(k+1) \geq \frac{n(T_0-1+A)}{T} > k$$

These formula can be illustrated as in Fig. 11. The value of k increases along with increase in the values of T_0 and A, as well as with increase in output, since increased output decreases the value of T.

When the values of T_0 and A are determined, it should be clear that the value of k in relation to a certain length of construction period per vessel will vary in accordance with the value of n. Therefore, if, when $T_0=18$ days and $n=5\sim11$, a graph was to be drawn in which k would have the maximum value in relation to the number of vessels to be constructed in a year, the graph would be as Fig. 12. And from Fig. 12 it is clear that if the finishing-up period A is 12 days and the number of vessels to be built in a year is seven, then 80 percent of the tank section should be pre-erected. But if 10 vessels are to be built in a year, pre-erecting even the entire length of the tank section would still not be sufficient.

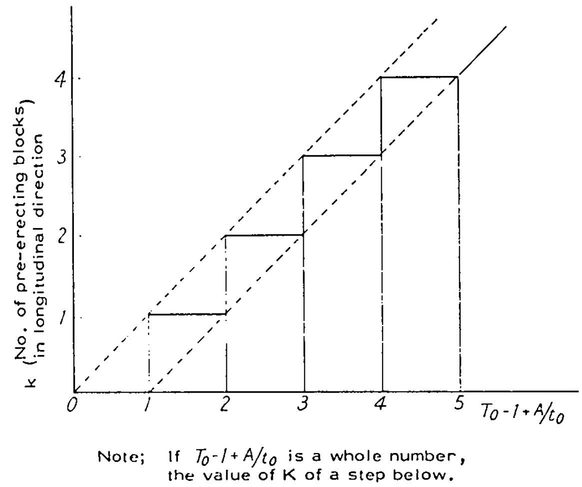


Fig. 11 Required number of pre-erected block bands

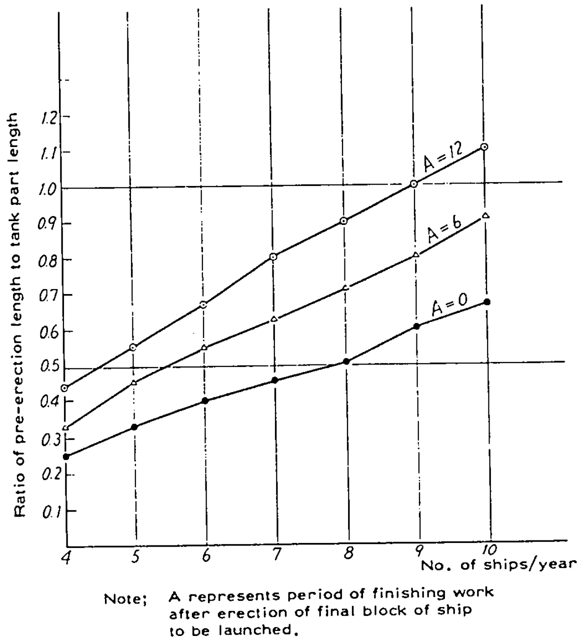


Fig. 12 Relation of pre-erection length and building number of vessels in a year

Fig. 12 also represents a case in which $A=0$, as well as a case in which $A=6$ days. If, as in some of the recently built extra-long docks, there is an additional building space in the rear part of the dock, the ship to be launched can be transferred to this rear space for finishing work. And if side tanks of the oil tank section can be made into one piece or be made of two large blocks consisting of upper and lower blocks, T_0 and A in the afore-mentioned formula can be reduced to shorten the pre-erection length. Fig. 13 represents a case in which seven vessels are to be built in a year, when $T=36$ days, $T_0=18$ days and $n=10$.

The discussions which have so far been made relate only to the tank section, but there are also the bow structure, stern structure and superstructure, and these structures are not sub-divided similar to the tank sections. Therefore, in order to level off manhour distribution, parallel construction of multiple blocks of such structures as mentioned above, is normally carried out. However, even distribution of manhours can also be achieved by unifying large blocks of the bow part and the superstructure, with the stern part. As for pre-erection of the stern part, Fig. 14 is just one example of where the work can be done. In other words, selection of the place for the pre-erection work would depend on the type of dock available—for example, in the case of two docks, a separate building dock may be provided, or in the case of a dual entrance dock, both ands of the dock may be used, or a side-dock may be built for the purpose, and so forth. In addition, various relevant factors should also be taken into consideration such as the production flow from fabrication and assembly shops to the building dock; the relative position of the building dock to the grand assembly shop which also takes care of outfitting of the stern structure; the number of pre-erected blocks which is determined by the number of vessels to be built in a year; effects of fixing erection site for erection of the stern section on overall efficiency; work required for mechanical transfer; the increment in facilities investment

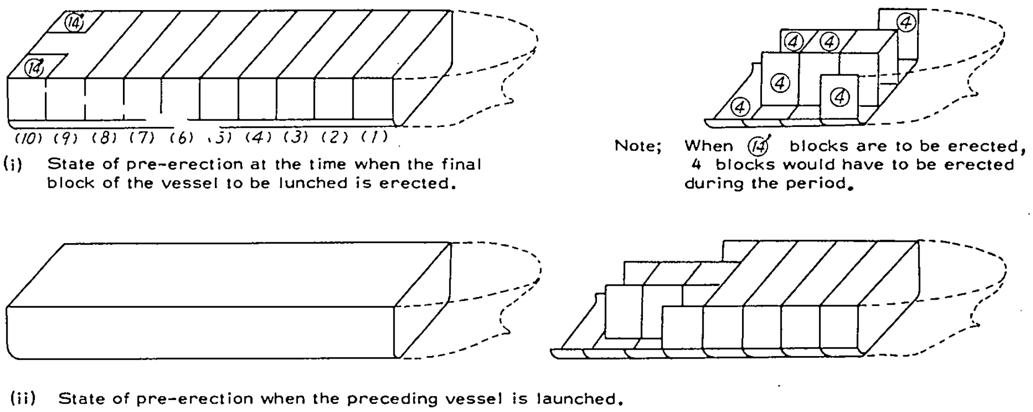


Fig. 13 An example of construction by pre- erection method

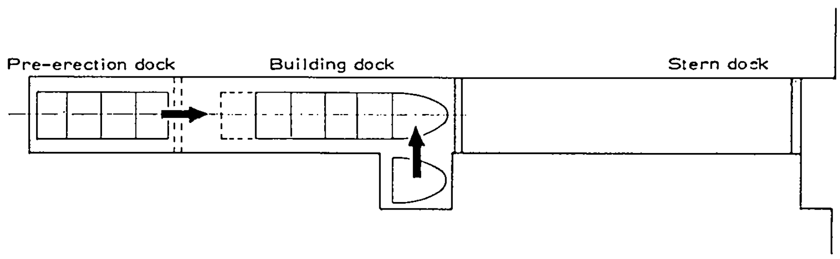


Fig. 14 An example of transfer of the tank and stern parts of hull

if two independent docks are to be built; relative difficulty in joining separately built stern and tank sections; method for and effect of bringing erection work indoors if the tank section is to be built separately; and problems associated with use of movable roofs, etc.

As already pointed out, it is not necessary to suspend work when the erection work is done in a dual entrance dock, or in two docks, or if mechanical transfer system is employed. Whether the work must be suspended or not depends on the length of the pre-erection dock, and any production target that is beyond actual production capacity would invite confusion, while on the other hand, it would be a waste to build an unnecessarily larger dock than that required.

3. Transferring Device for the Pre-Erected Body

3.1. *Basic Requirements on a Transferring Device*

While many different methods are conceivable to mechanically transfer a pre-erected body in a building dock, a safe and dependable method which is simple to practice and does not require expensive facilities should be chosen.

Major factors to be studied in this connection are:

1) Transferring mechanism (antifriction material such as Teflon, rolling balls and truck system.)
2) Method to support the hull (average load, load and slip of the movable platform for the pushing machine, and structure of the movable platform);
3) Conditions of the building dock bottom (flatness, pressure-resistance and inclination of the bottom);
4) External conditions affecting transfers (winds and earthquakes), and
5) Hull transferring device (pulling or pushing system, or self-driving truck system, and track structure).

Consideration of all these factors led to the adoption of a pushing method using balls.

3.2. *Main Features of the Transferring Device*

Even after the conclusion had been reached to adopt a pushing system using balls, there were many conceivable ideas about the pusher, out of which five alternatives were chosen and eventually the following plan was selected from the five.

Main features of this device will be summarized below.

(1) Transfers on Balls

Unlike in ball launching on which many research data were available, balls should be used permanently and continually in this hull construction system, and therefore experimental and theoretical analyses had to be made of the depressions in track plated resulting from continual use, deformation of balls and variation of the friction coefficient with repeated use. Experimental analyses were further needed of the strength, in particular against breading by local load, of the concrete block used as sliding platform.

(2) Constant-Displacement Pumps Used as Pushers

While two pushers each were supposed to be used for the stern body and tank section in the case of the shipyard illustrated in Fig. 14, the center of the resultant frictional force of the sliding face of the stern body would vary with individual ships. It was not easy to set the pushing power of each of the two pushers to meet such variation. Consequently, the use of constant-displacement hydraulic pumps was preferred, and their performances were tested. Their application to an actual vessel endorsed their accurate functioning.

(3) Mechanism of the Pushers

In view of the degree of flatness of the building dock, it was decided to use one hydraulic cylinder per pusher. Use of two cylinders per pusher would prove inconvenient, because the joints of mechanical components should be universal to be able to respond to errors in the footing setup and irregularities of the dock bottom, to be referred to below in (4), and the mechanism would become accordingly more complex.

The pusher works on the hull through the sliding platform which supports the hull. When the cylinder has extended to a certain length, its footing pin resisting the reaction force is disengaged, the cylinder is contracted and the footing pin is inserted into another hole. Further pushing is achieved by repeating this procedure.

As Fig. 15 illustrates, too steep an inclination of the cylinder would result in thrusting up the fore end of the sliding platform and therefore prove unfavorable to the strength of the platform. If the inclination is too easy, the rear end of this device should be behind the intersecting point of the line of action of the cylinder and the track surface in order to prevent the device from overturning. Then, even considering the overturning resistant moment deriving from the weight of the device, the length of the transferring system would have to be about 12 meters. This would not only mean an extra length for the system itself but also a correspondingly longer dock would be required. To reduce the required length, therefore, a sliding beam is installed.

In Fig. 2, the following forces are at work.

V: Force working downward from the sliding platform.

W_1, W_2: Weights respectively of the fore and rear blocks.

F_H: Horizontal force received from the cylinder (pushing force).

V_1, V_2: Forces applied by the fore block to the rear block.

$$V=\frac{F_H(h_1+h_3)-(W_1l_1+W_2l_2)}{L}$$

$$V_1=\frac{1}{L_1-L_2}\{(V-F_V)(L-L_2)+W_1(l_1-L_2)\}$$

$$V_2=\frac{1}{L_1-L_2}\{(V-F_V)(L-L_1)+W_1(l_1-L_1)\}$$

The moment to overturning the rear block is $F_H(h_1+h_2)$, and the moment working against it is:

$$(V_1L_1-V_2L_2)+W_2l_2=F_H(h_1+h_2)$$

The length of the system can be limited to six meters by making this precaution.

(4) Expansion of the Footing Track and Anchors

If a footing track is laid on each side of the movable platform, there will be the problems of difference in accuracy between the two tracks and of the flatness of the dock bottom, as mentioned in (3). If a separate footing track is laid in the middle of the ball track, the designing of the platform will be complicated. In either case, construction would be expensive. There is another problem posed by the expansion of the track, and many anchors are needed to restrain it within a certain limit. When a 22,500-ton tank part, 225 meters long, of a 260-kiloton tanker is transferred by 280 meters, if a single anchor is provided at the end, the expansion will be:

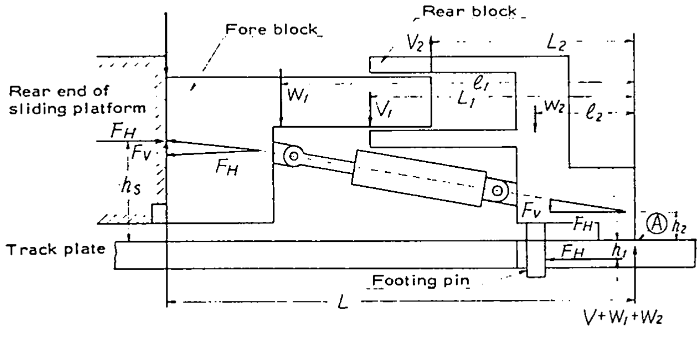


Fig. 15 Composition of the pusher

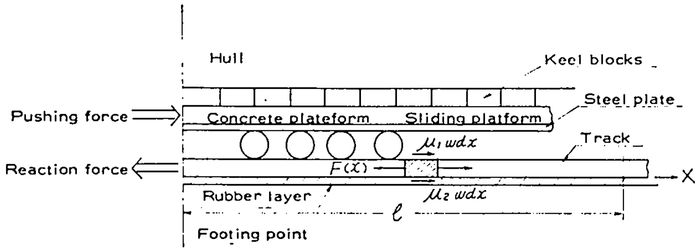


Fig. 16 Extent where the reaction force to the pushing force works on the track plate

Hull pushing force: 450 t (Per pusher: 225 t)
Track cross-section: 48×10^3 mm^2
Average stress: 4.7 kg/mm^2
Expansion: 63 mm

Therefore, in order to eliminate the inconvenience, it is advisable to lay the track on the dock bottom so that there may be no hindrance to traffic and use it as footing. The arrangement is illustrated in Fig. 16. If the force working on the footing is represented by $F(x)$, the following equations will hold on the basis of the equilibrium of the force at a point at a distance of x from the footing.

w: Load of hull weight on each unit length of the pushing track.
μ_1: Friction coefficient of the balls. (0.02)
μ_2: Coefficient of friction between the rubber and track. (0.10)

$$F(x)=F(x)+dF(x)+(\mu_1+\mu_2)wdx$$
$$\int_0^x dF(x)=-\int_0^x(\mu_1+\mu_2)wdx$$
$$F(x)=F(0)-(\mu_1+\mu_2)wx$$

If the distance from the footing point to a point where the pushing force no longer works on the track is represented by l, the above equations will lead to:

$$l=\frac{F(0)}{(\mu_1+\mu_2)w}$$

W: Hull weight
n : Number of tracks (=7)
L : Length of the movable platform−225 m

If two pushers are used;

$$F(0)=\frac{\mu_1 W}{2}, \quad w=\frac{W}{nL}$$
$$l=\frac{n\mu_1}{2(\mu_1+\mu_2)}L=0.58\,L$$

Thus the point where the pushing force ceases to work will always be within the length of the hull which is transferred, and no anchor will consequently be needed. The quantity of expansion represented by δ would then be:

$$\delta=\int_0^l \varepsilon dx=\int_0^l\frac{F(x)}{AE}dx$$
$$=\frac{1}{AE}\int_0^l\{F(0)-(\mu_1+\mu_2)w\}dx$$
$$=\frac{F(0)}{2AE}l$$

If the cross-section of the ball track is the same as that of the above-mentioned special track:

$$\delta=14\text{ mm}$$

While the tracks should be fastened with

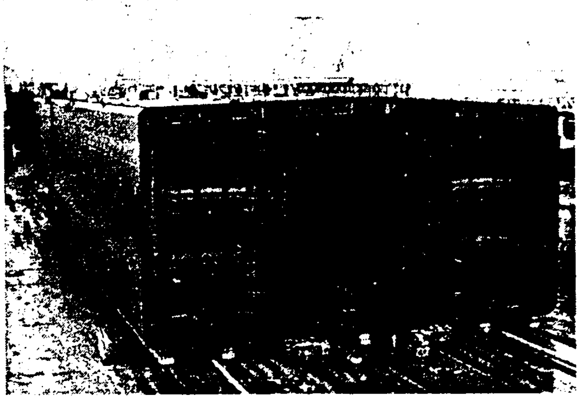


Fig. 17 An example of mechanically transfer of the oil tank part

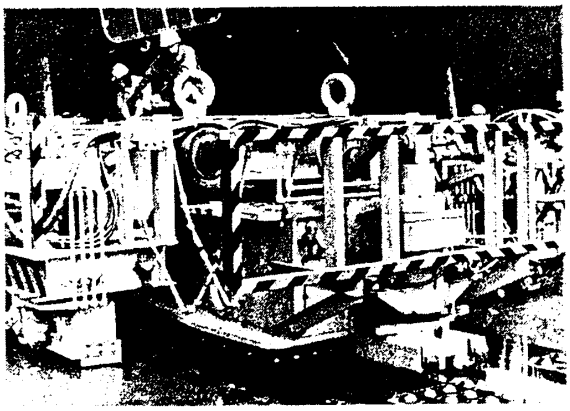


Fig. 18 Rear view of pusher

anchor bolts at suitable intervals, it would be easy to design the system with allowances for slips of this degree. Fig. 17 show the tank parts under mechanically transferring work and Fig. 18 show the appearance of the pusher.

4. Postscript

Large vessels are usually built by assmebling panel blocks, but three-dimensional blocks are sometimes partially used. But whichever method is employed, the final assembly of the hulls of these large vessels is carried out in building docks. To level off manhour distribution in the assembly process, it is necessary to pre-erect certain parts. And the important point here is that pre-erection work must be done in relation to the number of vessels to be built. What has been attempted, through this paper, is to analyze this relationship, to pinpoint the difficulties associated with the floating transfer system, and to explain the mechanism of the mechanical transfer method that would not require the pre-erected bodies to be floated for transfer which would interrupt work.

Should this paper prove to be useful, in one way or another, to anyone who is planning to build a new shipyard or who is presently engaged in shipbuilding at an existing yard, the authors would be more than rewarded. And as for some of the methods which have been explained in this paper, the readers are advised that Mitsubishi Heavy Industries, Ltd., has already filed respective applications for patent.

References

1) T. WATANABE; Layout of Oppama Shipyard, Sumitomo Technical Review, Vol. 20, No. 56 (Jun. 1972) (in Japanese)
2) T. YOSHIDA; Effect of Multi-Berth in Ship Hull Construction, Journal of the Society of Naval Architects of Japan, Vol. 131 (Jun. 1972) (in Japanese)
3) T. YOSHIDA; The New Shipbuilding Method by Shifting Large Stern Block, Journal of Zosen Kiokai, Vol. 103 (Jul. 1958) (in Japanese)
4) H. HIRAO; On the Launching by "Ball System", Journal of Zosen Kiokai, Vol. 83 (Feb. 1951) (in Japanese)
5) I. TAKEZAWA; Development of the Automated Shipyard, Royal Society Meeting, (Jan. 1972)
6) M. MUTO; Construction Method of Oil Tankers on the Several Building Berths, Journal of Zosen Kiokai, Vol. 104 (Jan. 1959) (in Japanese)