Preliminary estimation of total hours for forming ship hulls

Y. A. Abdel – Nasser
Naval Architecture and Marine Engineering Dept., Alexandria University, Alexandria, Egypt

The international competition between the shipbuilding industrialists has given the momentum to develop several software for solving most of shipbuilding problems. Among these problems is the evaluation of the curvature of the ship structural elements, which plays an important role in the selection of the forming methods. However, a preliminary estimation of total hours to form a ship hull is not available. Therefore, this paper suggests a new approach capable to calculate total hours that are necessary to form ship hulls. Two main arguments related to our objective are investigated namely, the principal curvature and the work done. The evaluation of the curvature and the associated work done for each curved structural element enable shipyards or designers to assess total labor hours for forming these elements. These arguments are calculated for ship plates and frames on the basis of a mathematical formulation by the finite element method. Several examples are executed on small ships to demonstrate the validity of the proposed approach. The influence of ship design parameters such as the rise of floor and bilge radius on the forming total hours is demonstrated.

أشتد التنافس في الآونة الأخيرة بين شركات إنتاج البرمجيات في حل معظم مشاكل ترسانات السفن. من هذه المشاكل تقدير درجة تقوس الألواح .درجة تقوس ألواح السفن من العوامل المهمة التي تساعد ترسانات السفن على تحديد عدد الساعات اللازمة لتشكيل الألواح وثنى الأعواد خاصة في المراحل الأولية من التصميم. إلا أنه لا توجد طريقة لحساب الساعات اللازمة لتشكيل الألواح .أقترح في هذا البحث طريقة تقريبية لحساب الساعات اللازمة لتشكيل الألواح وثنى الأعواد بواسطة حساب الشغل المبذول المطلوب لتشكيل ألواح السفن. في هذا البحث تم تناول عدة عوامل قد تؤثر عل تكلفة تشكيل الألواح مثل درجة التقوس وكمية الشغل المبذول. استخدمت طريقة الوحدة المحددة لحساب هذه العوامل وتأثيرها علي تكلفة تشكيل الألواح. تم عمل دراسة مقارنة لعدة سفن لدراسة تأثير بعض العوامل علي تكلفة تشكيل الألواح مثل درجة التقوس و ارتفاع القاع.

Keywords: Ship surface generation, Hull forming, Principal curvatures, Work done, Total hours

1. Introduction

The need for solving shipbuilding problems got the attention between shipbuilding industries to develop several software. Among these problems is the evaluation of the curvature of ship structural elements, such as plates and frames (transverse and longitudinal). In reality, the degree and orientation of the curvature play an important role in the calculation of total hours to be required to form the ship hull [1]. However, a preliminary estimation of the total hours used to bend the curved ship structural elements is not available. Therefore, the main objective of this work is to estimate approximately the total hours that are necessary for forming operations.

Two arguments related to total hours required to bend curved elements are discussed. These are the principal curvature and the associated work done for each ship structural element. The calculation of these arguments may help shipyards to estimate accurately total hours, which are required for the forming operations. The degree of curvature determines whether the structural element will be rolled, pressed or flame bent. The work done is not only function of the plate curvature but also depends on the geometrical and mechanical properties of plates and frames. Therefore, the acquired work done for each structural element is necessary in order to estimate the total hours for forming operations.

These arguments are calculated by applying the FEM procedure for the generation

Alexandria Engineering Journal Vol. 41 (2002), No. 4, 633-639

of the ship surface [2]. A computer program based on the beam and plate elements is developed. The program can be applied for ships with a parallel middle body or with a flat side; however, discontinuities of curves have shown up when ships of flat bottoms are generated. At the beginning of calculations, the ship surface (lines) are generated based on imposed ship design constraints and boundary conditions [3] . Secondly, the curvature of each ship structural element is calculated. After that, the associated work done to fulfill the degree of curvature is calculated. Finally, when the forming method is selected, the forming total hours may be estimated approximately. Several examples are executed on small ships with slight rise of floors to demonstrate the capability of the proposed approach. The influence of design parameters such as the rise of floor and bilge radius is also discussed. The influence of material and geometrical properties of ship plates on the assessment of forming total hours is not considered.

2. Curvature of ship structural elements

Shapes of ship plates may be divided into three categories namely, cylindrical, pillow and saddle as shown in fig. 1 [4]. A cylindrical shape has a single curvature in one direction; pillow shapes have two curvatures in the same direction while saddle shapes have two curvatures in opposite directions. These plates normally exist in the stern region of a ship as well as in the bow region.

In this section the curvature formulation of the ship structural elements is briefly described. The general mathematical formulation of the ship surface could be represented by a three-dimensional vector as follows,

$$Y = f(x,z). \tag{1}$$

The above equation is assumed as a polynomial function of the third degree. In order to form a plate to double curvatures, the curvatures in x and z directions are assumed to be treated separately. They are given by differentiating the surface function, Y, as follows:

$$K_{xx} = (\partial^2 Y/\partial x^2)/\ (1+[\partial Y/\partial x]^2)^{3/2}, \text{ and} \tag{2-a}$$

$$K_{zz} = (\partial^2 Y/\partial z^2)/\ (1+[\partial Y/\partial z]^2)^{3/2}. \tag{2-b}$$

Where, K_{xx} and K_{zz} are the curvatures in x and z-directions, respectively.

The above equation is rewritten in the matrix form as follows [3]:

$$K_{xx} = [N_{xx}]\{\delta\} \text{ and } K_{zz} = [N_{zz}]\{\delta\}. \tag{3-b}$$

Where, $\{\delta\}$ = Nodal displacement vectors and $\{N_{xx}\}$ and $\{N_{zz}\}$ are the shape matrices, which are function in x and z , respectively.

The product of the two principal curvatures K_{xx} and K_{zz} is known as the Gaussian curvature. It is given as follows [5]:

$$K_G = K_{xx}\, K_{zz}\,. \tag{4}$$

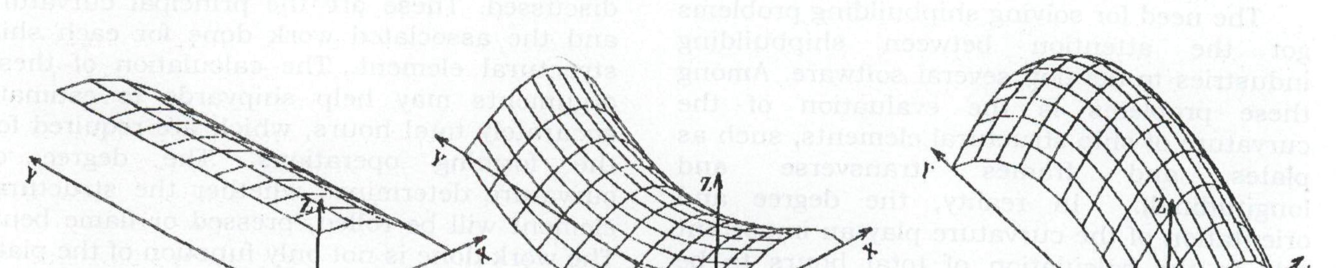

Fig. 1. Types of curvature.

The Gaussian curvature, K_G, has three categories. These are:

1- K_G is greater than 0 ($K_G > 0$); that is the elliptic shape.

2- K_G equals zero ($K_G = 0$); that is the parabolic or flat shape .

3- K_G less than zero ($K_G < 0$); that is the hyperbolic shape.

When the value of K_G is positive, the shape of the surface is either convex or concave. When K_G equals zero, the surface is either ruled or planar. In a planar surface both curvatures are zero. When K_G is negative, the surface has a saddle shape involving reverse or opposite curvature in the two directions. A bulbous bow is an example of the most complicated shape to be produced.

3. The work done

The work done is defined numerically as the total work required to form ship structural elements(plates and frames). The total work done is divided into elastic and plastic components as shown in fig. 2. The plastic work gives the permanent desired shape to ship elements and takes into account the effect of the spring back [6]. The spring back is influenced by several parameters such as the thickness and the degree of curvature of the element. It is difficult to calculate precisely the amount of the spring back. For the sake of simplicity, the effect of spring back is taken into account by multiplying the total work done by a magnification factor [4]. The total work done of a ship structural element is approximately estimated by calculating the elastic work done that is equivalent to the total inherent curvature to bend that element. It may be calculated as follows [7]:

$$W = \sum_{i}^{n} D * F * \alpha . \qquad (5)$$

Where,

W = the work done,

D = flexural rigidity of the ship structural component,

D = EI for beams or girders,

D = $Et^3/[12(1-\upsilon^3)]$ for plates,

n = No. of ship structural elements,

α = a factor taking the effect of the spring back, and

F = the energy number. The energy number is given as follow [8].

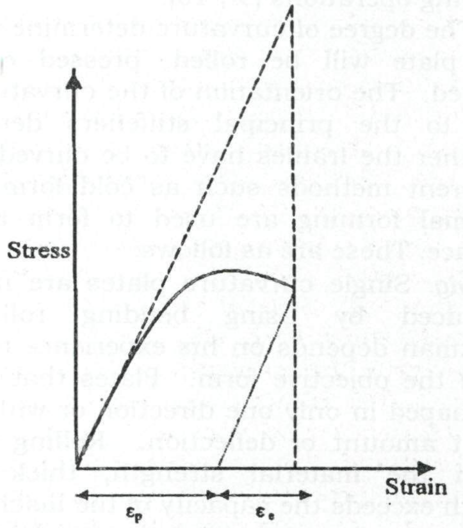

Fig. 2. Stress-strain relationship.

$$F = 1/2 \iint_A w_x K_{xx}^2 + w_z K_{zz}^2 \, dA. \qquad (6)$$

The above equation may be rearranged in the matrix form as follows,

$$F = 1/2 \iint_A \{\delta\}([N_{xx}]^T [N_{xx}] + [N_{zz}]^T [N_{zz}])\{\delta^T\}dA, \qquad (7)$$

or

$$F = 1/2 \iint_A \{\delta\}\{G\}\{\delta\}dA.$$

Where:

[G] is the the assembly matrix $=[N_{xx}]^T [N_{xx}] + [N_{zz}]^T [N_{zz}]$, and

A is the area of the surface.

The significance of the energy number is the tendency for measuring the degree of smoothness of the curved ship structural elements. As the value of the energy number is small, the curved element acquires a minimum number of inflection points. Thus, the minimum work done is required to form the plate or frames and a saving in labor hours could be achieved.

4. Forming total hours

The forming total hours of ship structural elements is directly related to the degree of curvature of the ship structural elements and the curvature orientation relative to the principal transverse and longitudinal stiffeners. The large varieties of curved plates particularly in the aft and fore ends of the ship will increase the total hours required for forming operations [9 , 10].

The degree of curvature determine whether the plate will be rolled, pressed or flame formed. The orientation of the curvature relative to the principal stiffeners determines whether the frames have to be curved or not. Different methods such as cold forming and thermal forming are used to form the hull surface. These are as follows:

Rolling: Single curvature plates are normally produced by using bending rolls. The workman depends on his experience to determine the objective form. Plates that need to be shaped in only one direction or with only a slight amount of deflection. Rolling is used when the material strength, thickness or length exceeds the capacity of the machine.

Pressing: Double curvature plates are produced by different methods depending on the shipyard facilities. Plates with large curvature in both directions are fabricated using large hydraulic presses. They are used whenever; the rolling machine can not used.

Thermal forming: When the required shapes exceeds the capacity of the cold forming techniques, the curved plates are produced using thermal forming. Line heating is the process of heating plates in a series of lines to produce the required shape.

The total hours of curved structural elements may be assumed as the sum of total hours used for rolling, pressing and /or thermal forming. It may be estimated as follows:

$$N = \Sigma W_i / P. \quad (8)$$

Where, N is total hours, W_i is the work done for ship structural element i and, P is the power of a forming machine.

5. Applications

In this section, the FEM procedure is applied on ships with different rise of floors. The flow chart of the developed computer program is as shown in fig. 3. The program is capable to calculate the curvature and the work done for each ship structural element such as the frame and the plate. Selecting the forming machine, it may estimate approximately the forming total hours by using eq. (8).

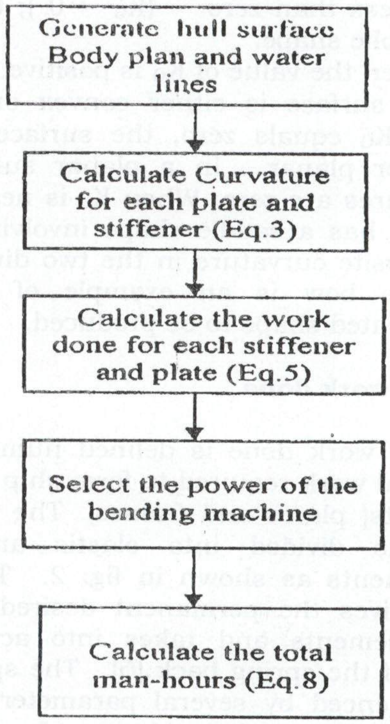

Fig. 3. The flow chart of FEM program.

5.1. Frames

In order to calculate curvature and work done that are necessary to form frames, a computer code based on a beam element with two degrees of freedom at each node is used. A ship side stringer of a length 69 m and having a flexural rigidity (EI) equal to10000 kN.m^2 is adopted. The whole length of the side stringer is divided into twenty elements (about 3.45m for each). Two different shapes of the sidestringer are assumed to be formed as shown in fig. 4. The curvature (in x- direction), and the associated work done for each part of the stringer are calculated. It is obvious from fig. 4 that the stringer with inflection points at the stern and bow requires higher energy for forming than that without inflection points. Negligible effect on the curvature due to variations in the form of the side stringer is observed.

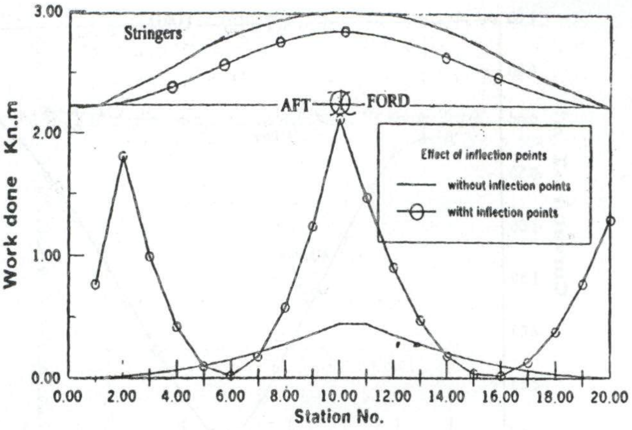

Fig. 4. The work done versus station no. for ship side stringer.

5.2. Ship plates

A rectangular plate element with three degrees of freedoms at each node is selected when calculate curvatures (in x-and z directions) and the work done that are necessary to form ship plates. To demonstrate the effect of variations of rise of floor and bilge radius on the curvature and the work done of ship plates, two ships with different prismatic coefficients of 0.55 and 0.66 are considered. A typical size of ship plate (1x6m) is selected. These plates are assumed to have the same material and geometrical properties.

Fig. 5 shows the generated body plane for the first ship (Cp=0.55). Figs. 6 - 8 show the curvature and the associated work done for each ship plate. Two different plots for the curvature of ship plates are made. One is characterizing the curvature for plates along water lines such as at the bottom and the deck as shown in fig 6. The other is characterizing the curvature for plates around the ship transverse section (stations) as shown in fig. 7. It is obvious from fig. 7 that the curvatures of plates in z-direction are higher than those in x-direction. The plates exiting in stern and at the bilge regions have the highest curvature and consequently need a lot of work done for forming operation as shown in fig. 8.

Fig. 9 shows the generated body plane for the second ship (Cp=0.66). The corresponding

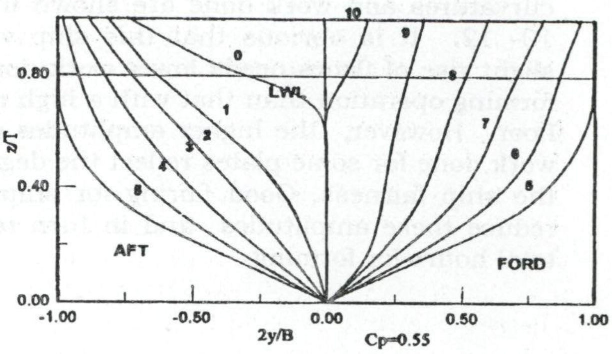

Fig. 5. The body plan of a ship (Cp=0.55).

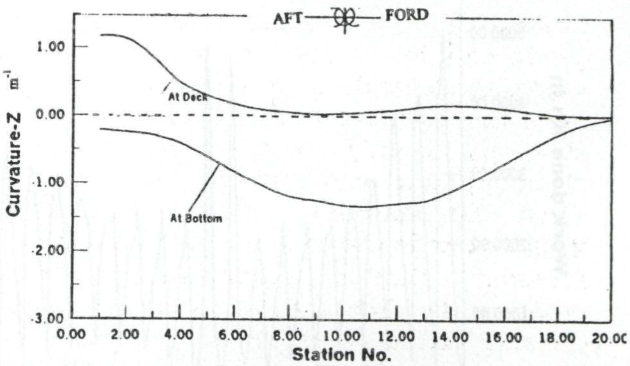

Fig. 6. The curvature versus ship plates along water lines (Cp=0.55).

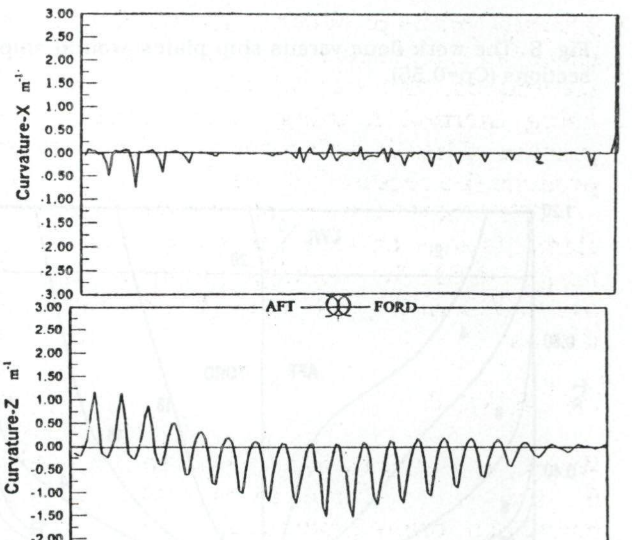

Fig. 7. The curvature versus ship plates around ship sections (Cp=0.55).

curvatures and work done are shown in figs. 10- 12. It is obvious that this ship with a slight rise of floors needs lower work done for forming operation than that with a high rise of floor. However, the higher amplitudes of the work done for some plates reflect the degree of the ship fairness. Good fairing for ships will reduce these amplitudes and in turn reduce total hours for forming.

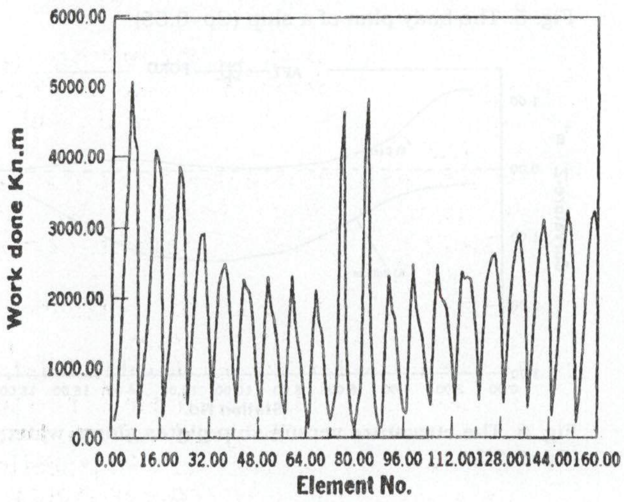

Fig. 8. The work done versus ship plates around ship sections (Cp=0.55).

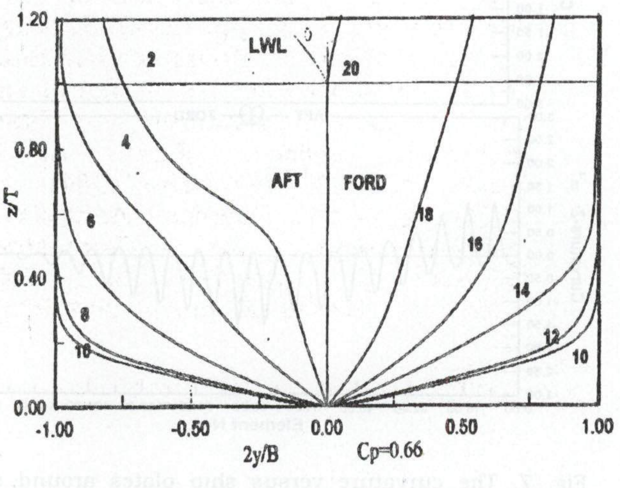

Fig. 9. The body plan of a ship (Cp=0.66).

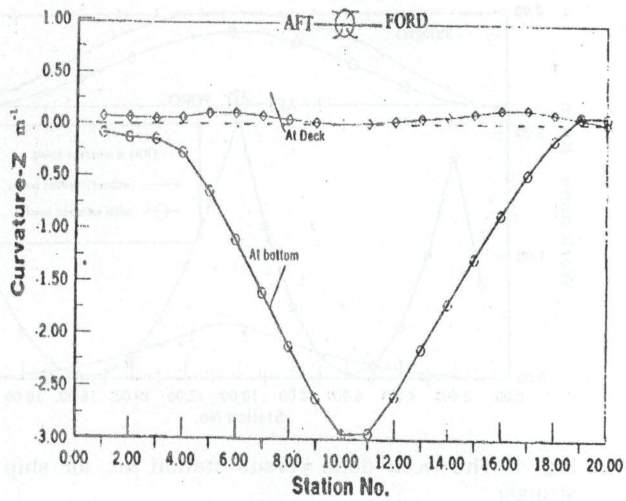

Fig. 10. The curvature versus ship plates along water line (Cp=0.66).

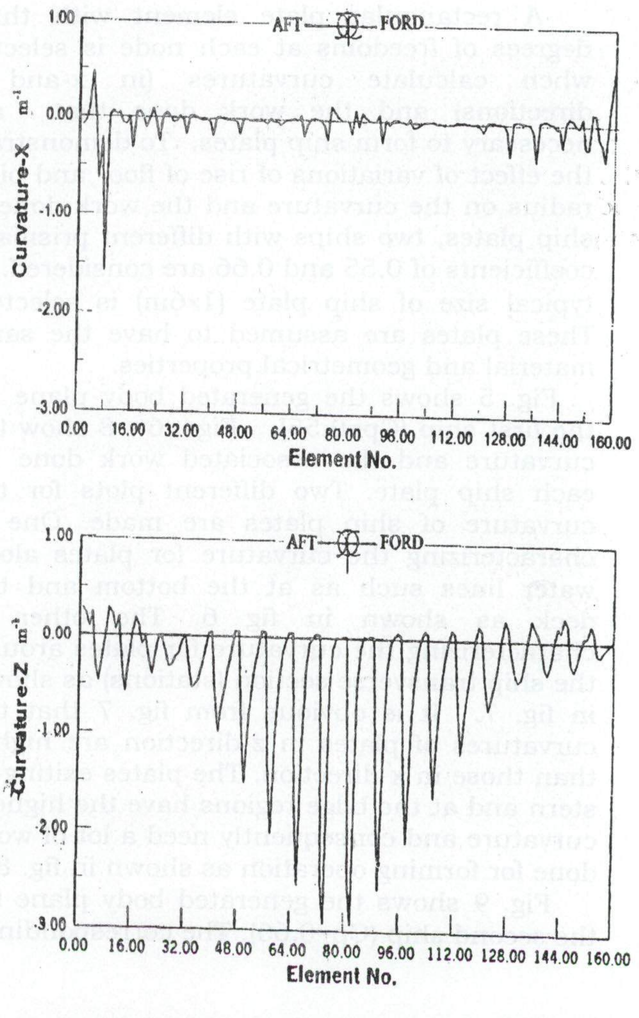

Fig. 11. The curvature versus ship plates around ship sections (Cp=0.66).

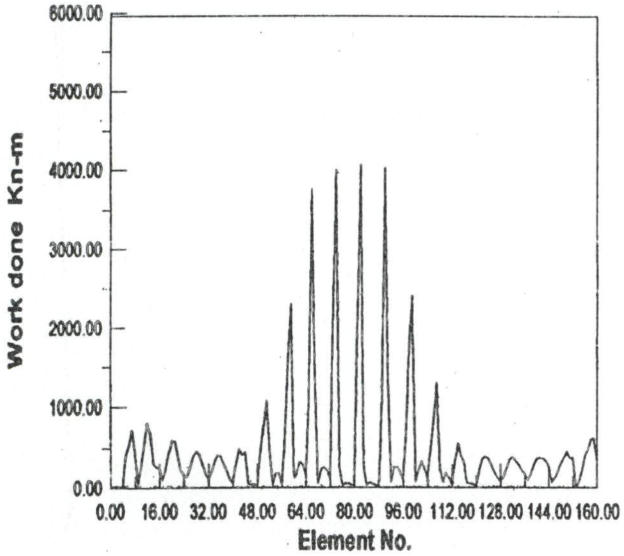

Fig. 12. The work done versus ship plates around ship sections (Cp=0.66).

6. Conclusions

In this work, the FEM approach is applied to calculate the curvature and the associated work done that need to form ship structural elements such as plates and frames. The influence of varying hull form parameters on the work done is investigated. Current study revealed the followings:

1-The proposed method given above could be easily applied to estimate approximately the total work done that is necessary to form the ship hull for the purpose of calculating the forming total hours.

2-The total work done is more sensitive to variation of the curvatures of ship plates in particular the curved plates in stern and bilge regions. This work done may be optimized by selecting and designing a faired ship with a minimum curvature or with a single curvature.

3-The amount of work done that is necessary to form the ship hull is influenced by ship design parameters such as the rise of floor and the bilge radius. Relatively lower work done may be achieved when the ship has a slight rise of floor.

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Receivad May 21, 2002
Accepted July 31, 2002