MEASUREMENT OF RESIDUAL STRESSES IN STRUCTURAL
ELEMENTS OF SHIPS USING SECTIONAL METHOD

قياس الجهود المتبقه فى العناصر الانشائية للسفينة باستخدام طريقة التجز،

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الخلاصــــة ــ تم شرح طريقة قياس الجهود المتبقية باستخدام طريقة التجز، بمساعـــــدة
ماكينة القياس الرقمية الاوتوماتيكية وقد عرضت مقارنة بين هذه الطريقــــة
وطريقة الفتحة المعتمة لقياس الجهود المتبقة لقطاع من انشائين مختلفين من العناصـــر
الانشائية لبدن السفينة .
وقد استنتج ان هذه الطريقة عملية ودقيقة واقتصادية لقياس الجهود المتبقية
للعناصر الانشائية للسفينة

ABSTRACT

The structural elements of ships are subjected to several manufactural proce-
sses during the stages of production. As a result of these processes, residual
stresses are created in the structural elements to a large extent.

Many techniques have been proposed and used for measuring residual stresses
in metals. These techiques are classified into the following groups: (a) stre-
ss-relaxation techniques, (b) X-ray diffraction techniques ,(c) techniques
using stress-sensitive properties,and (d) cracking techniques.

The main aim of this research is the measurement of residual stresses in str-
uctural elements of ships using sectional method. Digital electronic automat-
ion machine is used for marking the gage length and then measuring it before
the processing and after the sectioning .

Comparison between the results of sectional method and the blind-hole drilli-
ng method has been made from accuracy and economical points of view.

It is concluded that, the sectional method is adequate ,accurate and economi-
cal for residual stresses measurements in structural elements of ships.

1. INTRODUCTION

Residual stresses in a structural material component are those stresses whi-
ch exist in the object without the application of any service or other exter-
nal loads.

Manufacturing processes are the most common causes of residual stresses. In
shipbuilding these stresses due to the cutting, forming, welding, subassembly,
assembly and heat treatment operations.
In many cases, residual stresses are the predominant factor contributing to
structural failures and fatique, mostly when an alternating sevice stress adds
to the already present residual stress.

Many techniques have been proposed and used for measuring residual stresses in metals.
In this research, the sectional method is used in order to measure residual stresses in structural elements of ship.

Experimental work has been done in the Laboratory of Strength of Material ,Faculty of Mechanical Engineering and Naval Architecture ,Zagreb,Yugoslavia.

2.SECTIONS AND MANUFACTURING PROCESSES USED IN SHIPBUILDING

There are several shapes and types of sections which used in shipbuilding. Fig 1. illustrates some of these sections used in present day construction,The sections range from simple flat bar,edge-welded to the supported plating,to a flanged plate girder with additional face bar reinforcement.Girders are also built up by welding a flange to a lighter web,larger angle sizes may be obtained by cutting one flange from a channel section.
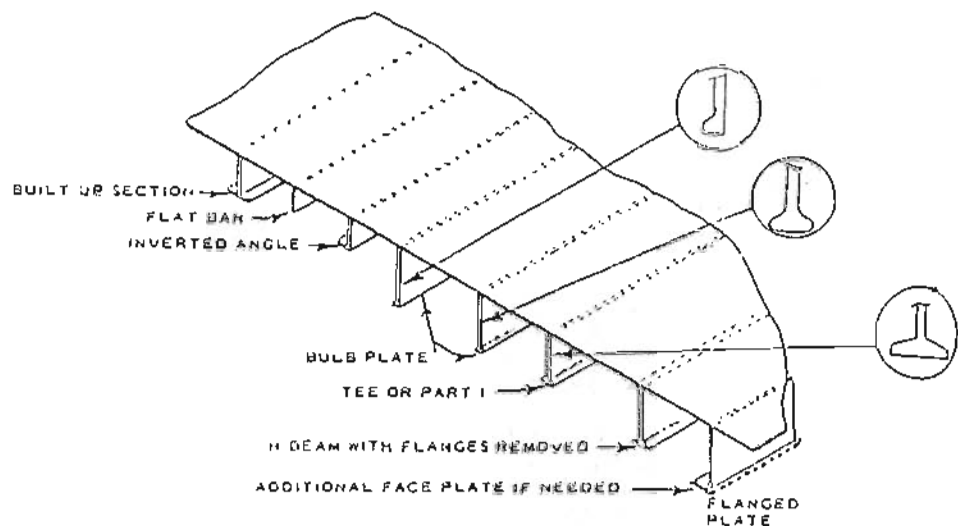

Fig.1.Structural shapes

Sections are stored in separate stock yards and fed into their individual shot-blasting and priming machines.The sections are cleaned by abrasive shot and then coated with a suitable prefabrication priming paint to a limited thickness for ease of welding . The areas of steel are there-fore protected from corrosion during the various manufacturing processes which follow.The sections follow their individual paths to the marking or direct cutting machinery which produces the suitable dimensioned item.Edge preparation for welding may also be done. Various shaping operationsnow take place using cold frame benders.
The sections transfer before,during and after the various processes in shipbuilding utilises many handling appliances.
The various steel parts in plate and section form are now joined together by welding to produce subassemblies,assemblies and units.

3.MEASUREMENT OF RESIDUAL STRESSES BY SECTIONING METHOD

The sectioning method is based on the principle that internal stresses are relieved by cutting the specimen into many strips of small cross section.The stresses distribution over a cross section can be determined with reasonable accuracy by measuring change in length of each strip and by applying Hooks law.

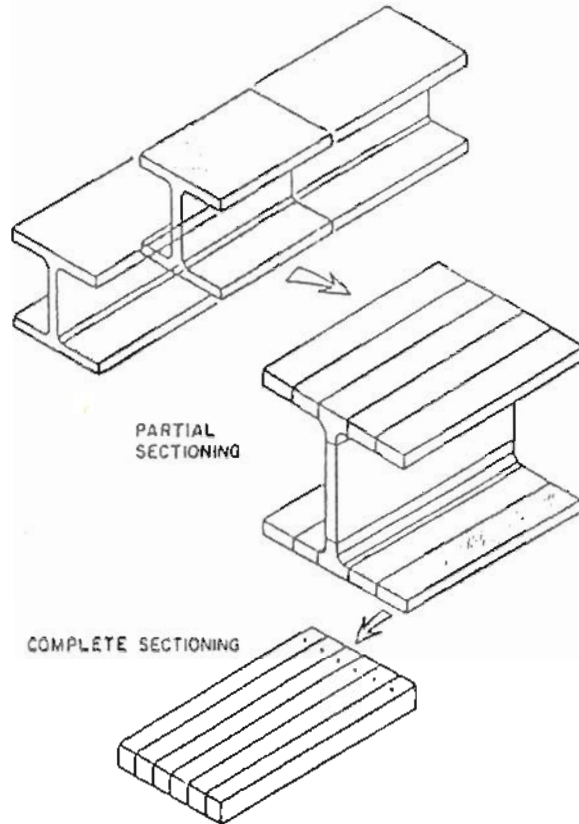The steps in the sectioning and slicing process are illustrated schematically in Fig.2.

PARTIAL
SECTIONING

COMPLETE SECTIONING

Fig.2. Steps in the sectioning method

3.1.PREPARATION OF TEST SPECIMEN

3.1.1.LOCATION OF SPECIMEN

The location of the test piece along the length of the material is the first step to be performed.To reduce end effects,the test section must be far enough from the ends.
A distance 1.5 to 2.0 times lateral dimension is recommended /1/, though theoretically a ratio of 1.0 is sufficient.

3.1.2.PREPARATION OF GAGE HOLES

't is important to prepare the gage holes with care since the accuracy in the rea-

dings depends mainly on the type of gage holes. The hole and gage point details for the specimen used in this work are shown in Fig. 3.
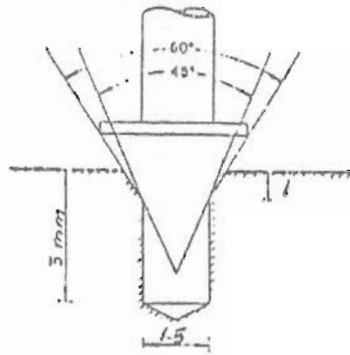

Fig.3. Detail of gage point and gage hole

3.1.3. SECTIONING LOCATIONS

The number of longitudinal strips to be cut depends on the variation of the residual stresses. Steep gradients in residual stresses, for example, would require closer spacings for longitudinal cuttings. To determine residual stresses with a lesser number of longitudinal cuts, the method of partial sectioning may be utilized(see Fig.1.). This method requires a prior knowledge of the pattern of residual stress distribution. In order to make proper cutting locations, a fair estimate of the pattern rather than the magnitude of residual stresses would be of importance. The location of a cut for partial sectioning is so determined that it lies near or at the transitions of residual stresses gradients.

3.2. MEASURING TECHNIQUE

3.2.1. DIGITAL ELECTRONIC MEASURING MACHINE

The digital electronic automation machine is used as an instrument for marking
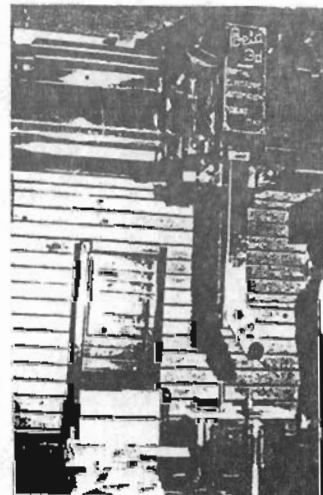

Fig.4. Digital electronic auto-
mation machine,3D

the gage length and measuring it before the processing and after the sectioning .
The machine ,as shown in Fig.4. is three axis measuring and a new approuch to the
problem of measuring.By using a coordinate measuring machine, the part is station-
ary and the machine moves around it in three axes .The result is more accuracy
and speed comparing with other measuring instruments./2/.

3.2.2.PROCEDURE OF MEASUREMENT

In order to avoid the curvature due to processing or sectioning,the gage length
is taken 100 mm. When the curvature is large,correction must be made to this st-
rain computation.On a curved strip,the measurement that can be taken with case in
the offset of the arc over the gage length .Using the offset and the change in
chord length as themeasurement quantities,the true strain may be approximated as
/1/.

$$\bar{\varepsilon} = \frac{\Delta L}{L} + \frac{(\delta/L)^2}{6(\delta/L)^4 + 1} \qquad (1)$$

where

$\Delta L/L$ =strain measured by extensometer

δ/L =ratio of offset to gage length

for strain measurements,the following steps are followed.

1-The contact point (probe tip) is inserted into drilled hole.

2-Each measuring unit is controlled into zero set.

3-Motion between the two points of the gage length is measured directly by di-
   gital read-outs of measuring head position in each axis.

First of all,attention should be given to the importance of obtaining a good set
of initial readings,since these cannot be duplicated after the specimen has been
cut.Some relevant items to be taken into consideration are:

-cleaning the gage hole using cleaning solution and air blast before taking any
measurement.

-taking three sets of measurements for each gage length unless great variation per-
sists,in which case making a new set of holes would be advised.

-protecting the gage holes from damage (such as by covering with tape) which may
occur during moving ,handling ,sawing,etc.

3.3.EVALUTION OF DATA

The computation of residual stresses from measured strains is based on the assump-
tion that the dimensional changes caused by the relaxation are purely linear ela-
stic.

Since strains are read at top and bottom surfaces ,evaluation of residual stresses at the respective surface are computed using experimental data.

Let "$\bar{L}$" be the average value of the readings taken on one gage length. For each gage length.

$$\bar{L} = \frac{1}{n} \sum_{j=1}^{n} L_j \qquad (2)$$

where
   n=number of readings for one gage length.
   Lj=measured value for each cycle.

Let 'Li' be the initial measured gage length and 'Lj' the final measured gage length.. Then the total strain due to relaxation:

$$\varepsilon_r = \left[\frac{L_i - L_j}{\bar{L}} \right] \qquad (3)$$

Using Hooks law the residual stress at the measured surface is

$$\sigma_T = -E \varepsilon_r \qquad (4)$$

By virtue of the linear strain distribution postulated in the beam theory, the average axial stress σ in terms of top and bottom measured strains ε_t and ε_b is

$$\sigma = -E \frac{\varepsilon_t + \varepsilon_b}{2} \qquad (5)$$

"E" is Youngs modulus.

3.3.1.EXPERIMENTAL WORK

Flat bars and Γ- cross-sections with the dimensions shown in Fig.5. were selected for experimental investigations.Also, the dimensioning for gage hole and cutting location used on the flat bar and Γ- cross section test piece are shown in Fig.5a. The total number of cuts for sectioning are 10,15 for flat bar and Γ- cross-section respectively.

All the investigated specimens were stress-relieved by anealing to omit the influence of residual stresses due to the production processes of steel.

To insure that the specimens are free from the internal forces and residual stresses which may existed during the production processes of steel,before welding,all the specimens are heated to 620 °c and then slowly cooled to the room temperature. A sketch of heating and cooling diagram of the specimen is shown in Fig.6.

Residual stresses formed due to sawing alone depend,among many other factors,on the spacing of the saw cuts,the plate thickness and the speed of sawing.For one particular set of parameters,the local stress at the saw-cut edge was observed to be the order of 5 to 15 MPa in compression,(measured by Blind-Holl Drilling method). Accordingly,the effect of sawing is very small and can be neglected. A sketch of sawing machine is shown in Fig.7.
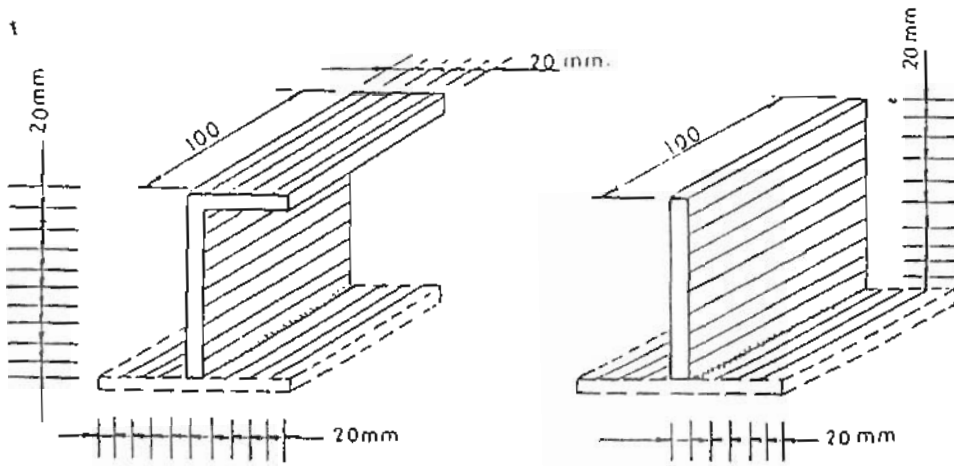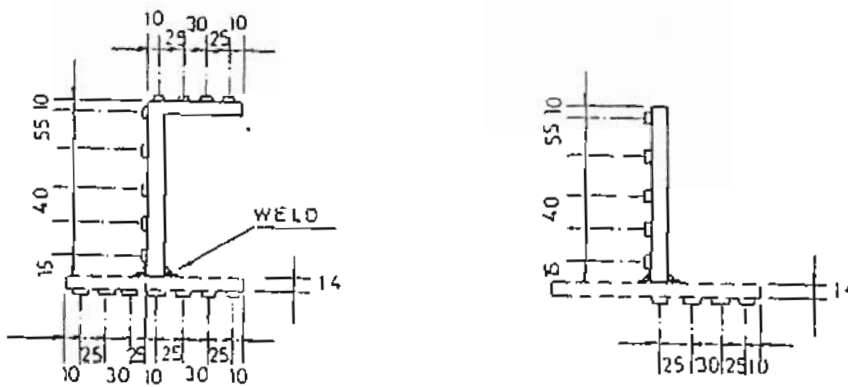
a) Gage hole location and sectioning detail

Γ-section (200.100.12)   flat bar (200.14)

''(tensile strength=400 MPa and yield point=310 MPa)

WELD

b) Locations of strain gage rosettes on the surface of the specimen

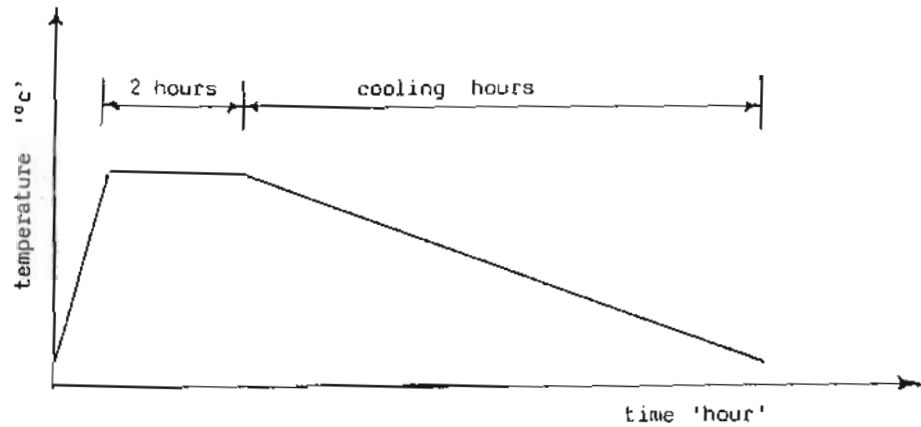Fig.5.Dimensions of the elements used in the experimental work.
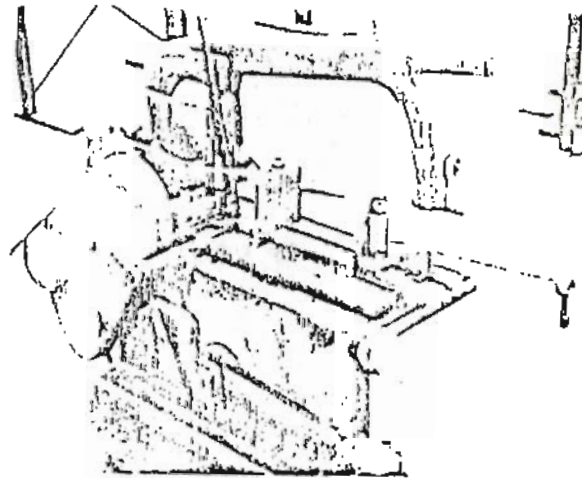
Fig.6. Sketch of heating and cooling diagram

Fig.7. Sawing machine.

For comparing the results of residual stresses measured by sectioning method ,the Blind-Hole Drilling method is used.

With the blind hole drilling method ,after installing strain sensors (rosette 1.5/120 RY 61) on the part surface, a small, shallow hole is drilled in the surface.In Ref.4.a detail description is available on the measuring procedure of this method.After drilling,the change in strain in the immediate vicinity of the hole is measured,and the relaxed residual stresses are computed from these data.

To determine the values of the principal residual stresses in a particular part, the strain relaxation values $\varepsilon_a, \varepsilon_b$, and ε_c are substituted in the following formula,/3/.

$$\sigma_{1,2} = \frac{E}{4A}(\Delta\varepsilon_a + \Delta\varepsilon_c) \pm \frac{E}{4B}\sqrt{(\Delta\varepsilon_a + \Delta\varepsilon_c - 2\Delta\varepsilon_b)^2 + (\Delta\varepsilon_c - \Delta\varepsilon_a)^2} \qquad (6)$$

where
 E =Elastic Modulus
 A,B=Constant
The constant "A","B" can be determined as follows   :

$$A=\frac{a^2(1+v)}{2r_a r_i} \; ,$$

(7)

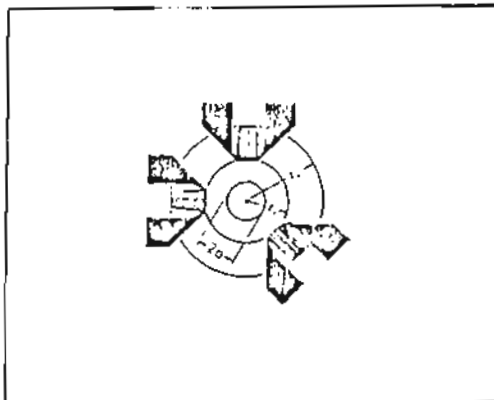$$B=\frac{2a^2}{r_a r_i}\left[1-\frac{a^2(1+v)(r_a^2+r_a r_i+r_i^2)}{4 \; r_a^2 r_i^2}\right]$$

Fig.8. showing the out-side,in-side and bore radius
on the rossette 1.5/120 RY 61.

where
  v =Poissons ratio.
  ra=Outer raduis of strain gage (rossette).
  ri=Inner raduis of strain gage (rossette) .
  a =Raduis of the (bore)drilling hole.

4.EXPERIMENTAL RESULTS AND DISCUSSION

Comparison between the residual stresses distribution for two different sections
(flat bar and r-section)conjunction with plating by welding,as measured by the
sectional and blind-hole drilling methods,is shown in Fig.9.

Generally,the shape of residual stresses distribution measured by sectional and
blind-hole drilling methods is the same.There is a little difference between the
results obtained by sectional and blind-hole drilling methods.

The differences in the stresses distribution of the investigations were probably
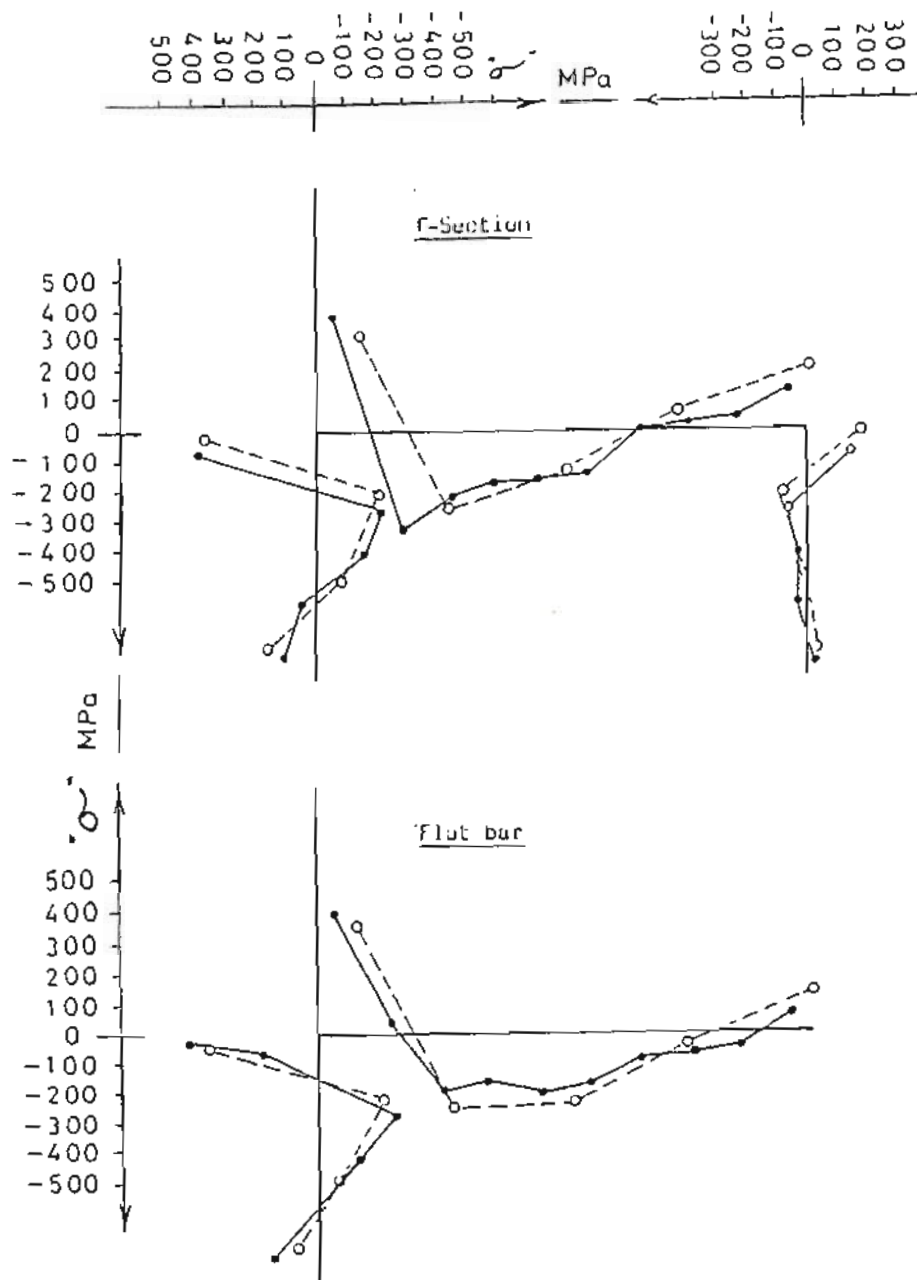caused by the following.

Fig.9.Residual stresses distribution in flut bar and Γ-section
      conjunction with plating.
      (————• Sectional method , •————→Blind-hole drilling method)

Sectional method:

-Cutting operation.Temperature changes appear to be the major cause of errors int-
roduced during residual stresses measurement.

-Errors in measured strain which caused with curvature due to processing or secti-
oning are reflected in the residual stresses measurement.

Blind-hole drilling method:

-The hole acts as a stress raiser and,provided the stress magnitude is sufficient,
localized plasticity will occur round the hole which leads to additional error in
the predicted stresses.This error rise to 10%, /5/.

-Large error in the predicted   principal stresses can result from small error
in measured strain.

-Mechanical cutting methods   currently used for hole forming   introduce
cutting stresses which are reflected in the strain measurements.

To obtain satisfactory results with the sectioning method it is important to per-
form a careful preparation of the test piece such as proper location of the test
section,gage hole location and cutting position.Preparation of gage holes must be
performed with care since unreliable readings can result if the holes are not pre-
pared in a proper manner.

5.CONCLUSIONS

The following conclusions may be made for the residual stresses measurement.
1. The method of sectioning is adequate ,accurate and economical for the residual
   stresses measurement in structural elements of ships.By increasing number of se-
   ctions,accuracy of results can be increased.
2. Digital electronic automation machine can be used as an instrument for marking
   and measuring gage length from which strain and stress can be determined.
   By using this machine the sectional method is more simple and economical than
   other methods of measuring residual stresses.
3. As the disadvantages of the sectioning method ,it is considered destructive method,
   gives average stresses over the area of the piece removed from the specimen,not
   suitable for measuring locally concentrated stresses .For a whole part "Panel" or
   other scalled models the method is expensive and time consuming.

6.REFERENCES

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