Computer program for ultimate strength of longitudinally stiffened panels (small b/t), May 1966

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Jun Kondo
Alexis Ostapenko

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**ERRATA**

Page 1 - First paragraph, last sentence
Change; "lengths and panel" to read "lengths a panel".

Page 2 - Second paragraph, second sentence
Change; "completed" to "completely"
Second paragraph, last sentence
Omit "now".

Page 3 - Program part no. 3
Change to read; Function BC which finds the zero root of a
2nd order parabolic equation by using Newton’s Method for
Finding Zeros.

Page 5 - Part III, No. 2b
Change; "acceptable" to "acceptable"

Page 6 - Variable QIC
Change; "interaction" to "iteration"

Acknowledgements - Change "Marily" to "Marilyn"

Page 3 - Program part no. 3
Change to read; Function VAL which computes a value
using a parabolic equation.

<table>
<thead>
<tr>
<th>P. 9 of 13</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Previously read</td>
<td>Should read</td>
</tr>
<tr>
<td>C14 = x(17) + C12 * (C3 - C3 * CS)</td>
<td>C14 = x(17) + C12 * (C3 - REL * CS) * CR</td>
</tr>
<tr>
<td>x(12) = x(11) - (C2 * (C13 - 0.5 * Q * C2) + C3 * (C14 - 0.5 * C12 * C3))/REL</td>
<td>x(12) = x(11) - C2 * (C13 - .5 * Q * C2) + C3 * (C14/REL + .5 * C12 * C3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P. 10 of 13</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>x (18) = C14 + C12 * CR * CS</td>
<td>x(18) = C14 + C12 * CR * REL * CS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P. 11 of 13</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AL(K) = AL(K - 2) - .5 * C1 * C1/C2</td>
<td>AL(K) = AL(K - 2) - 0.125 * C1 * C1/C2</td>
</tr>
</tbody>
</table>
BUILT-UP MEMBERS IN PLASTIC DESIGN

COMPUTER PROGRAM FOR
ULTIMATE STRENGTH OF
LONGITUDINALLY STIFFENED PANELS
(SMALL b/t)

by
Bruce A. Bott
Jun Kondo
Alexis Ostapenko

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Fritz Engineering Laboratory
Department of Civil Engineering
Lehigh University
Bethlehem, Pennsylvania

May, 1966

Fritz Engineering Laboratory Report No. 248.16
INTRODUCTION

One of the more common ship building elements are the longitudinally stiffened plates of Fig. 1(a). Their frequent use in ships makes a thorough knowledge of their behavior important. Consequently, a computer program was developed for the analysis of such sections subjected to the combined transverse and axial loading shown in Fig. 1(b). The program described in this report is an improved Fortran II version of the program originally written in WIZ* by Jun Kondo. The program analyzes a stiffened plate panel and determines the maximum fixed and simply supported lengths and panel can have under a given loading.

The analysis is basically a two step process. The main program first develops a moment-curvature-thrust curve for the given section. Then the integration subroutine determines the maximum fixed and simply supported lengths allowable for a series of midpoint starting curvatures. Plotting these maximum lengths against the midpoint starting curvatures produces a curve which is concave downward. The peak on this curve is the maximum length the panel can have under the given loading.

In the course of this analysis, the effects of residual stresses and differing yield points in the stiffener and in the plate are considered. There are no limitations imposed on the relative proportions of the cross section other than the requirement

* A GE compiler used at Lehigh University
that the ratio of the stiffener spacing to the plate thickness (b/t) be sufficiently small (less than about 40) to prevent plate buckling.

In the integration procedure used in the program, the section is called upon to resist both positive and negative bending moments. However, it was found that, for hybrid sections (different yield points in plate and stiffeners) subjected to high values of axial load, the moment-curvature curve would shift under varying load until it was completed on one side of the curvature axis (only positive or only negative moments). Such a position indicates that under axial load alone, the section requires the application of some internal moment along its center line in order to maintain equilibrium. The integration cannot be performed for such cases and this is now printed out on the output.

In addition to this alteration, provision has also been made for some identifying run or data set number to be included on the output. This number which is part of the input data, appears on the various pages of the output and aids in correlating results with input data.

The text of this report deals primarily with the preparation of data for the program, technical information about the program and its operation, and an explanation of the output. The appendices include a program listing (the main program, integration subroutine, and two required functions) and a series of example runs. The arrangement of the explanatory text conforms to the standards of Ship Design, Division Instruction 10462 of the Bureau of Ships, U. S. Navy.
PART I - IDENTIFICATION

1. **Title:** Ultimate Strength of Longitudinally Stiffened Panels (SMALL b/t)

2. **Brief Description:** On the basis of a computed M-Ø-P curve for the section under analysis, the program makes successive computations of the fixed and simply supported panel lengths corresponding to a given loading for each of a series of mid-point curvatures. By comparing each new set of lengths with those obtained on the last try, the maximum length is determined.

   The program consists of four parts:
   1) The main program which provides the M-Ø-P relationship for the section.
   2) Subroutine INTEG (integration) which determines the simply supported and fixed lengths corresponding to a given combination of axial and lateral load for some midpoint curvature.
   3) Function BC which computes, by parabolic interpolation, the peak value between 3 pts. on a curve.
   4) Function VAL which computes, by parabolic interpolation, the peak value between 3 points on a curve.

   Input data is read directly from cards into the main program. Termination occurs when an END card is read. (The main program will iterate through successive sets of data and within each of these sets, subroutine INTEG will iterate the value of lateral loading).

3. a) **Author:** Jun Kondo, Bruce A. Bott, and Alexis Ostapenko, Lehigh University.

   b) **Date:** May, 1966
4. Code: Fortran II

5. Machine: GE 225 (any other machine accepting Fortran II may be used).


7. Estimated Running Time: Punch input data 1.0 min
   Run time 2.5 min
   Total 3.5 min

PART II - PURPOSE & METHOD


2. Assumptions:
   1) No buckling - as a result, the program is applicable only to sections with low b/t ratios.
   2) The edges of the plate are assumed free.
   3) The distribution of the residual stresses in the plate is assumed to be rectangular. The residual stress distribution in the stiffener flange is assumed to be triangular. The residual stresses in the web of the stiffener have small effect and are therefore neglected. (See Fig. 2).

3. References: See report listed in 1) above.
PART III - RESTRICTIONS

1. General Restrictions: None

2. Limitations For Use:
   a) The condition of $G_{FC} = G_{FT} = 0$ (no residual stress in the stiffener flange) will not run. (It results in division by zero).
   b) Ratios of $G_{ST} > 2.0$ do not produce exceptable results in all cases and the output should be closely examined.

3. Nonstandard Hardware & Tapes: None

4. Maximum Array Sizes: 6 Arrays are used:
   - FI (200)
   - CM (200)
   - EPS (200)
   - AL (30)
   - X (25)
   - B (14)

PART IV - NONSTANDARD MACHINE OPERATING INSTRUCTIONS

1. Special Operating Instructions: None

2. Restart Instructions: None

3. Error Correction: None
## PART V - DATA PREPARATION

### 1. Card Input Form:

<table>
<thead>
<tr>
<th>Card</th>
<th>Format</th>
<th>Variable Name</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I5</td>
<td>IRUN</td>
<td>Label for data set (i.e. - set #15)</td>
</tr>
<tr>
<td>2</td>
<td>7F10.4</td>
<td>AST</td>
<td>Nondimensional area of stiffener</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D</td>
<td>Nondimensional depth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AFF</td>
<td>Nondimensional area of flange</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GRC</td>
<td>Nondimensional residual stress in plate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GST</td>
<td>Ratio of yield stress in stiffener to yield stress in plate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GFC</td>
<td>Nondimensional compressive residual stress in stiffener flange</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GFT</td>
<td>Nondimensional tensile residual stress in stiffener flange</td>
</tr>
<tr>
<td>3</td>
<td>6F10.4</td>
<td>P</td>
<td>Nondimensional axial load</td>
</tr>
<tr>
<td></td>
<td></td>
<td>QI</td>
<td>Nondimensional initial value of lateral load (for iteration in subroutine)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>QIC</td>
<td>Nondimensional increment of lateral load (for iteration in subroutine)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>QMAX</td>
<td>Nondimensional maximum value of lateral load to be run</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DSI</td>
<td>Increment of panel length to be used in subroutine Integ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FIC</td>
<td>Increment of curvature for subroutine Integ</td>
</tr>
</tbody>
</table>

For additional data sets repeat the above sequence.

Last card - End (1st 3 columns) this terminates the run with an illegal character on a data card.
2. **Sample Input:**

```
55
.3 10.0 .45 0.0 1.0 0.3 0.3
.4 0.0 3.0 3.0 .18 .15
```

3. **Output Form Description:**

<table>
<thead>
<tr>
<th>Page</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 2</td>
<td>Lists input data and run number for checking and later identification. Lists some computed member properties (identified on output). Lists 201 points on the M-Ø-P plot for the given panel.</td>
</tr>
<tr>
<td>3(64)*</td>
<td>Lists values of axial load P and lateral load Q. Lists length, lateral midheight deflection, vertical movement of ends, fixed end moment, and end slope for a given midheight curvature. For each value of midheight curvature, this information is produced twice, once for the fixed condition and once for the pinned end condition. As a peak of L is passed in each of the plots of PHC vs. L, (fixed end and pinned end) the peak value of L and the corresponding values of other quantities are computed and printed.</td>
</tr>
<tr>
<td>5</td>
<td>Summary of results for each combination of axial and lateral load.</td>
</tr>
</tbody>
</table>

4. **Symbol List and Definitions:**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Total area of section divided by area of plate</td>
</tr>
<tr>
<td>AF</td>
<td>Area of flange divided by area of plate</td>
</tr>
<tr>
<td>AFF</td>
<td>Area of stiffener flange divided by area of stiffener</td>
</tr>
</tbody>
</table>

* Depending on amount of output
AI: Moment of inertia of the section (Nondimensional)
AMPN: Negative plastic moment capacity of the section (Nondimensional)
AST: Stiffener cross sectional area divided by area of plate
AW: Area of web divided by area of plate
B: Matrix which stores the results obtained by the integration subroutine for later printing in the summary of results
BC: Function which establishes equilibrium and compatibility for each length increment
BRC: Total width of compressive residual stress zone in the plate divided by the total plate width
BRT: Width of tensile residual stress zone in plate divided by total plate width
CM: Moment array for the M - ϕ - P Plot
CMO: Moment at point zero (see EPSO)
COSF: Cosine function
D: Depth of stiffener divided by plate thickness
D1: Total section depth divided by plate thickness
D3: Distance from elastic neutral axis to the extreme fiber in the stiffener flange divided by the plate thickness
DSI: Increment of length used in the integration subroutine
EPS: Strain in the extreme fiber of the plate
EPSO: In the original language used for this program, dimensioning an array for 200 locations reserved 201 machine locations (0-200, inclusive). In Fortran II, dimensioning for 200 locations reserves exactly 200 locations (1-200 inclusive). Therefore in the Fortran II translation, it was necessary to create the variable EPSO to correspond to the location EPS(0) in the original version.
EY: Yield strain
FI: Curvature array for the M - ϕ - P plot
FIC: Increment of curvature in the integration subroutine
FI0: Curvature at point zero (see EPSO)
GFC  Compressive residual stress in the stiffener flange \( \sigma_{fc} \) divided by the yield stress of the plate \( \sigma_{yp} \)*

GFT  Tensile residual stress in the stiffener flange \( \sigma_{ft} \) divided by the yield stress of the plate*

GRC  Compressive residual stress in the plate \( \sigma_{pc} \) divided by the yield stress of the plate*

GST  Yield point in the stiffener divided by the yield point in the plate

H  Resultant force acting on the cross section in the z-direction

I  Counter

IRUN  Run number or data set number

ISW  Switching parameter

ISWA  Switching parameter

ISWB  Switching parameter

ISWC  Switching parameter

ISWD  Switching parameter

JA  Counter

JB  Counter

K  Counter

N  Counter

P  Nondimensional axial load as a fraction of the yield axial load \( P/P_y \)**, where \( P_y = (\text{yield point of plate}) \times (\text{total panel area}) \)

PHC  Curvature at the midheight of the section

Q  Lateral load (Nondimensional) \( Q = (q)(E)(b)(d)/(\text{yield point of plate})^2 \) (total area) where:

\( q = \) Hydrostatic pressure on section
\( E = \) Modulus of elasticity
\( b = \) Stiffener spacing
\( d = \) Distance from elastic neutral axis to extreme fiber in stiffener flange

* See Fig. 2

** Note that this quantity can reach a value greater than 1.0 for some sections.
QI Initial lateral load value to be run
QIC Increment of lateral load in the integration subroutine
QMAX Maximum lateral load value to be run
S Section modulus (Nondimensional)
SINF Sine Function
SQRTF Square root function
VAL Function for parabolic interpolation of curve peaks
W Thickness of the stiffener web divided by the plate thickness

The following variables and arrays are intermediate and have no general definition:

<table>
<thead>
<tr>
<th>AL*</th>
<th>C11</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>C12</td>
<td>X*</td>
</tr>
<tr>
<td>C2</td>
<td>C13</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>C14</td>
<td></td>
</tr>
</tbody>
</table>

* Array
MAIN PROGRAM

THIS IS THE BEGINNING OF THE MAIN PROGRAM WHICH COMPUTES THE
MOMENT - CURVATURE - THRUST CURVE FOR THE GIVEN SECTION.

ALL QUANTITIES ARE PLACED IN COMMON SO THAT THEY WILL BE AVAILABLE
TO THE SUBROUTINE AND THE FUNCTIONS WHICH ARE REQUIRED.

COMMON I, N, EPS, BRT, T, BHC, F, C, CST, EPS, FII, GL, F, JA
1P, HEL, ISHA, ISHA, ISHC, ISHD, SH, AL, DB, CM, CH, XM, JU,
2X: DX, CV, RET, CII, CII, CII, CII, CY, CR, AMNH, C5, CA, CH, X

200 POINTS WILL BE COMPUTED ON THE M - PHI - P CURVE
HENCE, 200 LOCATIONS ARE DIMENSIONED FOR MOMENT (CM), CURVATURE
(1/F1), AND STRAIN IN THE OUTER FIBER OF THE PLATE (EPS).

DIMENSION CM(200), F1(200), EPS(200), AL(30), X(25)

READ IN THE DATA SET NUMBER AND PRINT IT ON THE TOP OF THE FIRST
PAGE OF CUTPLT.

1 READ 33, IRUN
33 FORMAT ( 15 )
PRINT 200, IRUN
200 FORMAT ( 9HIDATA SET, 15 )

READ THE NECESSARY INPUT DATA AND PRINT IT OUT ON THE OUTPUT SHEET
SO THAT INPUT CAN BE CORRELATED WITH RESULTS.

PRINT 201
201 FORMAT (11HWINPUT DATA/)
READ 26, AS5, D5F, GRC, GST, FSC, GFT, F3G, GIC, GMAX, DSI, FIC
20 FORMAT (7F10.4)
PRINT 31
31 FORMAT (1W0, 5X, 3HAST, 7X, 1HD, 7X, 3HAFF, 6X, 3HGHC, 6X,
1 3HGST, 6X, 3HSFC, 6X, 3HSFT, 7X, 1HMP, 7X, 2HQM, 6X, 3HGMC, 7X,
2 4HOMAY, 6X, 3HDSI, 6X, 3HNF, 1/)
PRINT 30, AS5, D5F, GRC, GST, GSC, GFT, F3G, GIC, GMAX, DSI
1 FIC
30 FORMAT (11FH9.5)

COMPLETE SECTION PROPERTIES.

EY = 1.3344595E+3
REV = 1.6913915E-2
D1 = 0 + 1.1
BRT = GRC / [1. + GRC]
BHC = 1. - BRT
AF = AFF - AST
AM = AST - AF
X = AM / C
A = 1. - AST
D2 = 0 + 3
CM = .5 + [ D2 - AM - U]1
FL = CM / A
D3 = U + FL
PRINT OUT THESE SECTION PROPERTIES IN A TABLE.

PRINT 166
FORMAT (15HSECTIN PROPERTIES )
PRINT 167, AST, N, APP, QNC, RR, EL, AMPN, P
PRINT 168, FORMAT ( 8F15.7)

FOR ANY HYBRID SECTION, HIGH AXIAL LOADS WILL CAUSE THE MOMENT - CURVATURE CURVE TO LIE ALL ON ONE SIDE OF THE CURVATURE AXIS.
HENCE, THE FOLLOWING CHECK IS NECESSARY:

SEE IF THERE IS A NEGATIVE LNF ON THE MOMENT - CURVATURE CURVE.
IF NOT, GO ON TO THE NEXT SET OF DATA.

IF (AMPN 1 34, 35, 39)
PRINT 169
FORMAT ( 5H=AXIAL LOAD TOO HIGH [SECTION CANNOT MAINTAIN EQUILIBR
IUM] )
GO TO 1

SET UP THE EQUATIONS FOR THE OUTPUT OF THE MOMENT - CURVATURE - STRAIN RELATIONS.

PRINT 167
FORMAT ( 1=9, 7X, 1HM, 9X, SHF1(N), 11X, SHCOM(N), 11X, 6HPS(N),
1 1IX, 1HM, 9X, SHF1(N), 11X, SHCOM(N), 11X, 6HPS(N), //)

COMPUTE THE EQUIDISTANT 200 POINTS ON THE CURVE.

X(1) = -447
X(2) = M81
X(3) = -346
X(4) = BRC
X(5) = -W
X(6) = W
AL(17) = C1
AL(19) = 31
AL(23) = C
AL(20) = 3
AL(21) = 3
PAGE 3
AL(23) = F • AL(30) / G8
10 = AL(30) = 70, 29
10 = AL(30) = 70, 30
30 = F = AL(30) / G8
C5 = C8 • F
C9 = P • F • D3
CO 107 K = 1, 4
107 ALK1 = 0, 0
X(7) = -C3
X(1) = CS
X(1) = -2,
X(10) = -F-2,
X(11) = GC - L,
CO 100 h = 17, 20
10 = X[14] = X[164] - 2,
X[13] = -F-GST
CD 107 K = 21, 24
109 X[14] = X[K+1] - 2, • GST
CD 12 * = 1, 6
IF AL(23) • X[K+8] > 111, 111, 111
111 ALK1 = X[14]
ALK2 = X[14+1]
GO TO 12
11 IF AL(23) • X[K+16] = 112, 112, 12
112 ALK1 = X[14]
ALK2 = X[14+1]
12 CONTINUE
ALK1 = AL(14) - GFC
ALK2 = AL(16) + GFT
C1 = 0, 0
C2 = A • F
C3 = -2, C3 • C8
C12 = AL(7) + GFC
C12 = AL(13) + GFT
C13 = C11 - C12
C2 = C2 • C1
C3 = C1 • C1 + [C11 • AL(15) + C12 • AL(16)] • [C11 • GFC + C12 • GFT]
CD 110 K = 1, 7, 2
C11 = AL(K) • AL(K+1)
C14 = AL(K) • AL(K+1)
C14 = AL(K) • AL(K)
C14 = AL[K+1] • AL[K+0]
C12 = C14 + C19
C17 = C14 + AL[K+8] + C15 • AL[K+9]
C1 = C1 + C11
C2 = C2 + C12
117 C3 = C1 + C11
IF C2 = C2 + C2 = C1 + C3 • C3, 26, 113, 113
113 C2 = 2, • C2
AL(24) = 3C1, C9, C3, AL(23)
IF XABS[1+AL(24) • AL(23)] = .000001 13, 114, 114
114 JA = JA + 1
THE NEXT STATEMENT IS SENSITIVE TO AXIAL LOAD / SECTION MODULUS S
APPROACHES ZERO AND MAY CAUSE DIVISION BY ZERO FOR HIGH VALUES OF
AXIAL LOAD P,

\[
\text{AL}(27) = \text{AL}(30) + (A*\text{EL}*(\text{AL}(24) - \text{CB})*S*\text{AL}(27)/\text{F1}/S)
\]
\[
\text{LB} = \text{ISW}
\]
\[
\text{CL} = \text{ABS}([\text{AL}(24) + \text{AL}(25) + \text{AL}(27)] / \text{AL}(27) + 1)
\]
\[
\text{IF} (\text{CL} \leq 0.001) \text{ IF1} = 10, 130, 130
\]
\[
\text{IF11} = 10, 16, 131
\]
\[
\text{LB} = \text{ISW}
\]
\[
\text{IF} (\text{CL} > 0.000015) \text{ IF12} = 132, 132, 14
\]
\[
\text{IF12} = 10, 16, 133
\]
\[
\text{LB} = \text{IF12}
\]
\[
\text{IF} (\text{N} > 137) \text{ IF13} = 130, 137
\]
\[
\text{IF13} = 10, 16, 134
\]
\[
\text{CHC} = \text{AL}(27)
\]
\[
\text{EPSQ} = \text{AL}(24)
\]
\[
\text{GO TO 136}
\]
\[
\text{F1} = \text{AL}(20)
\]
\[
\text{CMN} = \text{AL}(27)
\]
\[
\text{EPS(N)} = \text{AL}(24)
\]
\[
\text{IF14} = 10, 16, 135
\]
\[
\text{DO} 134 \text{ K = 25, 29}
\]
\[
\text{AL(K) = AL(K+1)}
\]
\[
\text{LB} = \text{ISW}
\]
\[
\text{X}[25] = 0.02
\]
\[
\text{ISWA} = 16
\]
\[
\text{ISWB} = 18
\]
\[
\text{GO TO 135}
\]
\[
\text{X}[25] = 0.1
\]
\[
\text{ISWA} = 17
\]
\[
\text{ISWB} = 19
\]
GO TO 135
19 X(29) = .5
19 ISWB = 16
19 ISWA = 19
135 LB = ISWD
GO TO 119

PRINT OUT THE COMPUTED POINTS AFTER CHECKING TO SEE IF THERE IS A
POSITIVE BRANCH ON THE MOMENT-CURVATURE CURVE, (THIS CHECK IS
SIMILAR TO THAT PERFORMED AFTER THE PRINT OUT OF SECTION PROPERTIES
ABOVE).

27 N = 0
37 IF (CMO) 47, 37, 139
37 PRINT 36
37 GO TO 1
139 PRINT 169, A, F10, CMO, EPS
169 FORMAT (21X, 13, 3F16.7)
169 GO 142 N = 1, 100
169 KK = N + 100
169 PRINT 560, KK, F10(N), CM(N), EPS(N), KN, F11(N), CM11(N), EPS11(N)
142 CONTINUE

ONCE THE 200 POINTS HAVE BEEN COMPUTED, GO TO THE INTEGRATION STEP

CALL IATE

IF RUN RETURN FROM THE INTEGRATION STEP, GO BACK AND SEE IF THERE IS
ANOTHER SET OF DATA.

GO TO 1

THE NEXT SERIES OF STATEMENTS IS A ROUTINE TO DETERMINE WHERE THE
PROGRAM SHOULD CRUNCH TO NEXT. GIVEN THE VALUE OF THE SWITCHING
PARAMETER ISX, ISWA, ISWF, ISWC, ISWD, THE ROUTINE PICKS THE
STATEMENT NUMBER TO GO TO NEXT.

119 IF (FILH = 0) 119, 88, 120
119 LB = LF = 5
120 GO TO 16, 7, 1, 9, LB
121 IF (FILH = 10) 121, 9A, 122
122 GO TO 114, 9B, 16, 17, 18, 19, LB
127 LB = LF = 25
127 GO TO 120, 27, LB

SHOULD AN INDEX IN SOME IF STATEMENT RUN OUT OF BOUNDS, THIS
STATEMENT WILL BE CALLED AND THE PROGRAM WILL TERMINATE.

97 PRINT 47
97 FORMAT (1H1)
97 CALL IATE
97 END
SUBROUTINE INTEG

SUBROUTINE INTEG IS A PROGRAM WHICH WHEN GIVEN THE MOMEHT - CURVATURE RELATION FOR A SECTION, WILL DETERMINE THE MAXIMUM FIXED AND PINNED LENGTH THAT THE SECTION CAN SUSTAIN UNDER A GIVEN LATERAL AND AXIAL LOAD.

THE FOLLOWING QUANTITIES ARE PLACED IN COMMON SO THEY WILL BE AVAILABLE FROM THE MAIN PROGRAM:

COMMON I, N, EPR, BRT, X, BRF, F1, C7, GSF, FPR, Q1, F, JA, P, REL, ISU, ISUB, ISUC, ISUM, S1, M, CNO, AML, JK, P2, C2, C3, REV, C4, F12, C13, C14, EY, CR, ARPA, C9, CA, CB, X, JF, IP, CNV, QIC, LIRU

DIMENSION CM(2001), FI(2001), EPS(2001), AL(130), X(29), B(14)

STARTING WITH THE ORIGIN, THE POINTS ON THE POSITIVE BRANCH OF THE MOMENT - CURVATURE CURVE ARE CHECKED FOR A POSSIBLE STARTING CURVATURE. IF AN TRANSVERSE LOAD IS ACTING ON THE SECTION, THIS WILL USUALLY BE CHOSEN AT THE ORIGIN. ( POINT 90)

N = 00
102 IF [EPR(N)] .LT. 50, 100, 110
101 IF [EPR(N)] .LE. X(R) + BRC - .991 * 90, 90, 91
50 IF [EPR(N)] .LT. (C7*GST) / 2.0, 100, 101
9 IF [EPR(N)] .LT. 3.0, 4, 101
I IF [EPR(N)] .LT. (C7*GST) / 2.0, 3, 5
3 IF [EPR(N)] .LT. (C7*GST) / 2.0, 3, 101

FROM STATEMENTS 41 AND 42, IT CAN BE SEEN THAT SOME CURVATURE 0.4 LESS THAN THAT DETERMINED ABOVE IS USED AS A STARTING POINT TO INSURE THAT THE PEAK OF THE CURVE WILL BE PASSED THROUGH,

10 G = F11 - 0.4
GO TO 21
101 N = N + 1
IF (N) 1, 2, 102

IF NO SUITABLE POINT CAN BE FOUND, GO ON TO THE NEXT DATA SET.

21 RETURN
51 G = F11 - 0.4
A = 01

THE NEXT STATEMENTS ARE THE ONES WHICH CHOOSE THE CURVATURE AT THE ORIGIN AS A STARTING POINT IF LATERAL LOAD IS ZERO.

IF (Q) 60, 103, 40
169 F = F11 - 0.4
GO TO 31
69 F = 0
69 PHC = F
JA = 20
SET UP THE TITLES FOR THE INTEGRATION AND LIST THE VALUE OF THE
LOAD AT THE TOP OF THE SHEET.

IF JX, JXV, JAU ARE 1, THIS INDICATES THAT CONVERGENCE HAS NOT BEEN
OBTAINED YET FOR EITHER THE FIXED OR PINNED END CASE FOR THE
PRESENT VALUE OF Q. WHEN CONVERGENCE IS OBTAINED, THEY WILL BE
SET TO ZERO AND THIS WILL CAUSE THE RESULTS TO BE PRINTED ON THE
SUMMARY SHEET.

PRINT 400
400 FORMAT (1x, 1)
    PRINT 104, P, 0
104 FORMAT (16MOANIAL LOAD P = 0, F7.4, 4X, LAMINAR LOAD (C) = 1 F7.4)
    0 = GPEL
    JX = 1
    JXV = 1
    PRINT 105
105 FORMAT (1x, 7V, CHICURVATURE, 8V, LENGTH, 9X, 7HORIZONTAL, 9X, 1
    AWERTICAL, 9X, 6P END, 11X, 3SHEAR, 11X, 1MM)
    PRINT 40
11 FORMAT (16V, PHT, PAX, TIIORFIECTON, 7V, ANMOVEMENT, 9V, ANMOMEN
    17, IX, 4HSLPEF)
    PRINT 11
11 FORMAT (8V, GMHIDEIGHT, 21V, 13HAT MIDHEIGHT)
    ISV = 1
    ISL = 7A
    ISL = 1
    MD = 1
    K = 0, 30
10A ALTI = 1
69 ISL = 1
    IX17 = 0
    IX18 = 0
    DST = 0
    DO 117 K = 1, 16
107 IX2 = 0
    SN = 0
    CS = 1
    N = 200
10N N = N + 1
300 IF (N) 76, 200, 100
100 IF (FIN) = PHT, 10A, 110, 110
200 IF (FIN) = HNCR, 10A, 200, 200
201 AMT = (FIN)PHT/FINPHT/FINC/111
    X11 = CPAMTLCHM(CMCMCMCMCM)
    GO TO 202
111 AMT= (FIN) - PHT/FINPHT/FINPHT/FINPHT/FINPHT/FINPHT/FINPHT
    X11 = CPNAMTLCHM(CM+CMCM)
202 IF (X11) 111, 131, 167
111 PHT = PHT + 1.
    GO TO 200
6X IF (N) 203, 204, 205
204 X21 = FSRAMTL+KPSO-EPS111
    GO TO 205
205 X21 = FSNAMTL+AMTL+EPSN1-KPSN111
127 X(29) = X(41)
GO TO 113
69 C1 = X[23] + X[24]
   X(14) = X(13) + .5*REY*REL*PI*X(20)
   SN = SINX(X[14])
   C2 = COSX(X[14])
   X(16) = C1*Q+C1*SN
   X(18) = C1*Q+C1*SN
   X(19) = X(18) + C3
   X(2) = X(2) + 2.6*G2
   X(5) = X(2) + 4.2*X(31)*X(22)*C1*REL*C3
   C5 = X(24) - X(23)
   C6 = X(19)
   C8 = X(20)
GO TO 170, 71, ISW
72 IF X(21) > 23, 71, 74
125 C1 = X(12)*X(11)*X(10)
   C2 = [X(10)*X(11)]*X(20)
   C3 = [X(11)*X(20)]*X(19)*X(20)
   C4 = [F1 - X(19)]/C4
   C4 = [F1 - X(19)]/C4
   C5 = 8*F(C3), C4, X(11) - F1, 0, 1.
   AL(29) = X(13)*[X(10)*X(21)*C5]/X(20)*F1*REL*C1
   AL[30] = 0.
   ISW = P
   ISW = 2
   NCT = 3
   X1 = X
   FOR 1 = 1, 7, 3
   AL(K) = VAL(X(1), X(1)+1, X(1)+P1, C1)
   K = K + 1
   AL(K) = VAL(X(1), X(1)+1, X(1)+P1, C1)
   FOR 1 = 1, 7, 3
   AL(K) = VAL(X(1), X(1)+1, X(1)+P1, C1)
   K = K + 1
   126 K = K + 6
   96 K = X0
   129 PRINT 127, PCH, AL(K-24), AL(K-13), AL(K-13), AL(K-6), AL(K)
   127 FORMAT (h=7, 7F14.8)
   K = K + 1
   IF (X = 261, 129, 128)
   GO TO 175, 77, 128
   72 GO TO 130 I = 1, 2
   13a X(1) = X[1]*X
   I = 1
   GO TO 131
   7a IF(A) = AL(14) + X, 132, 132
   139 GO TO 75, 77, 134
   133 ISW = 2
   KWA
PRINT OUT WHETHER THE PIANERED EN CASE OR THE FIXED END CASE HAS
BEEN FOUND, ACCORDING TO WHETHER THE END MOMENT IS ZERO OR NOT.

IF (AL[*-6]) 13, 12, 13
12 PRINT 14
14 FORMAT (149, FIXFD END CASE )
JX = K
JX = N
GO TO 15
15 PRINT 16
1A FORMAT (149, PLANEED END CASE )
JX = 1
JX = N
16 PRINT 27, AAA
R(JX) = AAA
AAA = F + G*EY + AL[K-181]*COS[AL[K-61]*1.1]*CR
R(JX-1) = AL[K-31]
R(JX+1) = AL[K-24]
R(JX+3) = AL[K-18]
R(JX+4) = AL[K-12]
R(JX+5) = AL[K-61]
R(JX+6) = AAA

PRINT OUT THE REQUIRED INFORMATION.

PRINT 136, AL[K-101], AL[K-241], AL[K-18], AL[K-12], AL[K-6], AAA
1A FORMAT (15B, 15X, AF16.8)
1B IF (15WR-AS) 137, 137, 13A
137 LB = 15WR - 90
GO TO 160, 61, 62, 63, 64, 65, 0B, 1B
138 IF (15WR - 70) 139, 139, 140
139 LB = 15WR - 65
GO TO 166, 62, 63, 64, 70, 1B
140 LB = 15WR - 70
GO TO 171, 72, 73, 74, 75, 76, 7A, 1B
78 IF (AL[*]) = AL[31] 141, 77, 77
141 K = 6
156B = 15WR + 1
156C = 2
GO TO 74
7A 0 = O/REL
PRINT 40R, 1RUN
400 FORMAT (54DATA SET, IX, IX)
   PRINT 104, P, G
   PRINT 400
400 FORMAT (54SUMMARY OF RESULTS 1)
   PRINT 405
   PRINT 10
   PRINT 11
   PRINT 16
   IF (JX = 1) 407, 401, 402
401 PRINT 127, 1(1JX1), JX = 1, 71
   GO TO 405
402 PRINT 406
403 FORMAT (54MON CONVERGENCE 1)
405 PRINT 14
   IF (JX == 404, 403, 404
403 PRINT 127, 1(1JX1), JX = R, 34)
   GO TO 407
404 PRINT 406
   C = 0 + GIC
   IF (G = OPA3) 406, 40, 142
542 RETURN
577 JA = JA + 1
   PHC = PHC + FIC
   DO 145 K = 1, 27, 2
   ALIK = ALIK + 21
147 ALIK+11 = ALIK+3
   GO TO 42
   END OF PROGRAM
FUNCTION BC
FUNCTION BC(BC1, BC2, BC3, BC4)
C3 = BC3
C4 = BC4
MK = CK
C3 = BC1 * (C4 - C4 - MK) = C4 = BC3.
C3 = C4 = C3/2 + BC1 * (C4 + MK)
MK = KK - 1
IF (KK = 1) U U, R180, R180
B190 = (ABS(UG)) - 9.99999991 x 190, B190, B140
RETURN
END

FUNCTION VAL
FUNCTION VAL(AA, B, C, D)
COMMON T, N, EPS, PRT, X, BRC, F1, C7, GST, F340, FIL, Qi, F, JA,
S1, J1, ISJ, JSW, JSW, JSW, JSW, ISW, LA, BBI, D1, BBI, BBI, BBI, BBI, BBI,
D11, D12, D13, D14, D15, D16, D17, D18, D19, D20, D21, D22, D23, D24, D25
DIMENSION CK(2040), FIL(2040), EPS(2040), AL(30), X(125)
AA = (B + C) * C
BB = (C + B) * (C + B)
CC = (A + B) * C
DD = (A + B) * (A + B)
EE = (CC + DD) / HH
RR = (CC + DD) / HH
VAL = H * C + G + C * G + H
RETURN
END
### Integration (First Value of Lateral Load)

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<tr>
<th>Curve</th>
<th>Length</th>
<th>Lateral</th>
<th>Vertical</th>
<th>End</th>
<th>End</th>
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<td>At Midheight</td>
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#### Fixed End Case

(CONVERGENCE OBTAINED FOR FIXED END CASE)

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#### Pinned End Case

(CONVERGENCE OBTAINED FOR PINNED END CASE)

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**DATA SET** 90

**AXIAL LOAD** (P) = 0.6000  **LATERAL LOAD** (Q) = 1.0000

<table>
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<th>SUMMARY OF RESULTS</th>
<th>CURVATURE (at midheight)</th>
<th>LENGTH</th>
<th>LATERAL DEFORMATION (at midheight)</th>
<th>VERTICAL MOVEMENT</th>
<th>END MOMENT</th>
<th>END SLOPE</th>
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## Integration (2nd Value of Lateral Load)

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<th>Curvature at Midheight</th>
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**Fixed End Case**

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<th>Axial Load (P)</th>
<th>Lateral Load (D)</th>
<th>Curvature at Midheight</th>
<th>Lateral Deflection at Midheight</th>
<th>Vertical Deflection</th>
<th>Moment</th>
<th>Slope</th>
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**DATA SET 50**

**AXIAL LOAD (P) = 0.4625  LATERAL LOAD (Q) = 3.0000**

**SUMMARY OF RESULTS**

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## INTEGRATION (II VALUE OF LATERAL LOAD)

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<th>END MOMENT</th>
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### FIXED END CASE

| 1.90112945     | 4.08536609        | 3.96203485             | 0.5475695 | 0.4803654                      | 0                 | 0.0265396 |
| 2.12617445     | 2.72158891        | 2.71739727             | 0.5514470 | 0.42927768                     | 0                 | 0.0265396 |
| 2.32617445     | 2.32976163        | 2.3260995             | 0.4434101 | 0                             | 0                 | 0.0265396 |
| 2.27617445     | 2.71382564        | 2.70918746             | 0.5864402 | 0.42727400                     | 0                 | 0.0265396 |
| 2.27617445     | 2.33224066        | 2.3287178             | 0.4750841 | 0                             | 0                 | 0.0265396 |
| 2.42617445     | 2.71337361        | 2.70851181             | 0.6187749 | 0.42943830                     | 0                 | 0.0265396 |
| 2.42617445     | 2.33366432        | 2.3302429             | 0.5041271 | 0                             | 0                 | 0.0265396 |
| 2.57617445     | 2.70585823        | 2.70153998             | 0.64339913| 0.43093823                     | 0.1             | 0.0246223 |

### PINNEG END CASE

| 2.66078611     | 2.33614207        | 2.33212119             | 0.58073113| 0                             | 0                 | 0.02389781 | 0.74685/3 |

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### Integration (2nd Value of Lateral Load)

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### Fixed End Case

| 2.56958812 |
| 2.21462119 | 2.23044239 | 0.447918477 | -0.43163546 | 0. | 0.0215497 |
| 2.87617644 | 2.22344940 | 2.225262111 | 0.465827999 | -0.4327573 | 0. |
| 2.87617644 | 1.94528833 | 1.930624831 | 0.334650602 | 0. | 0.02155318 |

### Pinned End Case

| 2.67535293 |
| 1.94663361 | 1.94306616 | 0.376143090 | 0. | 0.02115414 | 0.70040712 |
**DATA SET 31**

**AXIAL LOAD (P) = 0.7200  LATERAL LOAD (Q) = 0.0000**

**SUMMARY OF RESULTS**

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<th>CURVATURE</th>
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**Section Properties**

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**Notes:**

- **Axial Load Too High (Section Cannot Maintain Equilibrium) -** (Halt Computations On This Data Set.)
- No Additional Data Set. Therefore The Run Terminates.
(a) TYPICAL MID-SHIP CROSS SECTION

(b) LOADING ON THE SHIP BOTTOM PANEL DUE TO WAVE ACTION-HOGGING

Fig. 1. LONGITUDINALLY STIFFENED PLATE PANELS IN THE SHIP BOTTOM STRUCTURE.
Fig. 2 Typical Cross Section With Simplified Residual Stress Distribution
REFERENCES

1. Kondo, J.
ULTIMATE STRENGTH OF LONGITUDINALLY STIFFENED PLATE PANELS SUBJECTED TO COMBINED AXIAL AND LATERAL LOADING, Fritz Engineering Laboratory Report No. 248.13, Lehigh University, 1965
ACKNOWLEDGEMENTS

This study is part of a research project "Built-Up Members in Plastic Design" currently being carried out at Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pennsylvania. Professor William J. Eney is Head of the Laboratory, and Professor Lynn S. Beedle is Director.

The research has been sponsored by the Department of the Navy under the Bureau of Ships Contract N0bs-94092. The study was initiated by Mr. John Vasta of the Bureau of Ships. His interest in the support of the project is gratefully acknowledged.

The task of translating the original program was greatly facilitated by the cooperation of the staff of the Lehigh University Computer Laboratory.

Messrs. J. Vojta and R. A. Strawbridge made significant contribution by offering general assistance. The report was typed by Miss Marily L. Courtright. Her cooperation is appreciated.