ENCLOSURE 5

TEST CORRELATION STUDY
FOR THERMAL USE OF DUCTILITY RATIO
WCG-1-811

QA Record

DNE CALCULATIONS

TVA 10697 (DNE-6-86) Sheet 1 of 55

TITLE : TEST CORRELATION STUDY FOR THERMAL USE OF DUCTILITY RATIO	Plant/Unit WBNP/UNIT 1

PREPARING ORGANIZATION DNE, Ebasco Services Inc.	KEY NOUNS (Consult RIMS DESCRIPTORS LIST) CEB, CALC, THERMAL, TEST		
BRANCH/PROJECT IDENTIFIERS WCG-1-811	Each time these calculations are issued, preparers must ensure that the original (RO) RIMS accession number is filled in.		
	Rev	(for RIMS' use)	RIMS accession number
	R0		B18 910413 253
APPLICABLE DESIGN DOCUMENT(S) WB-DC-20-21 DG-C1.6.12	R		
	R		
SAR SECTION(S) NA YLC 4-4-91 / UNID SYSTEM(S) NA YLC 4-4-91	R		

Revision 0	R1	R2	R3	Safety-related? Yes [X] No [ ]
ECN NO.(or indicate Not Applicable) NA EEC 4-11-91				Statement of Problem. The use of ductility ratio for thermal restraint is to be justified with test data.
Prepared: CHENG-IH WU Cheng-Ih Wu				
Checked/Verified: YAN-LIANG CHEN Yan-Liang Chen				
Reviewed: K. Lanham				
Approved: H. Totuwajily				
Date 4/12/91				
USE FORM TVA 10534 IF MORE SPACE REQUIRED — List all pages added by this revision				
List all pages deleted by this revision				ORIGINAL
List all pages changed by this revision				

Abstract: These calculations contain an unverified assumption(s) that must be verified later. Yes [ ] No [X]

Rev. 0 ANSYS computer program is used to perform four (4) designated problems to correlate test data and consequently, to justify the use of ductility ratio for thermal restraint.

LEGIBILITY EVALUATED and ACCEPTED for issue.

H. Totuwajily 4/12/91

Signature Date

[ ] Microfilm and store calculations in RIMS Service Center Microfilm and destroy. [ ]

[X] Microfilm and return calculations to: Calculations Library Address: WBN N QA BLDG.

cc: RIMS, SL 26 C-K D. Kilgore WBN Trailer No. E-2

7224x

BRANCH/PROJECT ID: WCG-1-811

TVA

TITLE: TEST CORRELATION STUDY FOR THERMAL USE OF DUCTILITY RATIO

PREP. BY: C. Wu DATE: 4-3-91

CHECKED BY: Y. Chen DATE: 4-4-91

REVISION LOG

Revision No.	DESCRIPTION OF REVISION	Date Approved
0	ORIGINAL ISSUE	4-12-91

CALCULATION DESIGN VERIFICATION (INDEPENDENT REVIEW) FORM

WCG-1-811
BRANCH/PROJECT ID:/Calculation No.

0
Revision

Method of design verification (independent review) used (check method used):

1. Design Review X
2. Alternate Calculation
3. Qualification Test

Justification (explain below):

Method 1: In the design review method, justify the technical adequacy of the calculation and explain how the adequacy was verified (calculation is similar to another, based on accepted handbook methods, appropriate sensitivity studies included for confidence, etc.).

Method 2: In the alternate calculation method, identify the pages where the alternate calculation has been included in the calculation package and explain why this method is adequate.

Method 3: In the qualification test method, identify the QA documented source(s) where testing adequately demonstrates the adequacy of this calculation and explain.

DESIGN REVIEW IS APPLICABLE TO THIS CALCULATION, SINCE IT IS BASED ON STANDARD ENGINEERING HANDBOOK METHODS.

Yan-Liang Chen
Design Verifier
(Independent Reviewer)

4-11-91
Date

EBASCO SERVICES INCORPORATED

BRANCH/PROJECT ID: WCG-1-811

BY: C Wu DATE: 4-4-91 DEPT NO.: -

CHECKED BY: Y. Chen DATE: 4-4-91 OFS NO.: -

CLIENT: TVA

PROJECT: WBNP/UNIT - 1

SUBJECT: TEST CORRELATION STUDY FOR THERMAL USE OF DUCTILITY RATIO

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Robert A James 5/30/91
Robert A. James
Civil Engineer

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BY C Wu DATE 4-3-91
CHKD. BY Y. Chen DATE 4-4-91
OFS NO. - DEPT. NO -
CLIENT TVA
PROJECT WBNP-Unit
SUBJECT TEST CORRELATION STUDY FOR THERMAL USE OF DUCTILITY RATIO

5. PURPOSE:

The purpose of this calculation is to correlate test data in References 9 and 10, for thermal restraint use, by using ANSYS computer code.

6. APPLICABLE CRITERIA (MARKED "X"):

____ 1. DS-C1.7.1 R4 General Anchorage To Concrete
____ 2. DS-C1.7.3 R0 Application of Baseplate II
____ 3. DS-C1.8.1 R3 Standard Calculation for Evaluating Type II Embedded Plates
____ 4. WB-DC-20-1 R6 Concrete Structures-General
____ 5. WB-DC-20-2 R6 Reactor Building Concrete Structures
_X_ 6. WB-DC-20-21 R6 Misc. Steel Component for Category I Structures
____ 7. WB-DC-40-31.53 R4 Design Criteria for Pipe Whip Restraints, Jet Deflectors and Sleeves
____ 8. QIR-CEB-WBN-89-361 R0 Auxiliary Control and Reactor Buildings Acceleration & Response Spectra
____ 9. WCG-1-370 R0 Generation of OBE 4% Damping ARS for Unit 1 ICS, SCV, and SB
____ 10. WCG-1-377 R0 Aux. Control Building 4% Damping Curves and Seismic Forces
_X_ 11. (Specify):

DG-C1.6.12 R0 Evaluation of steel structural with thermal Restraint.

7. APPLICABLE CODES AND STANDARDS (MARKED "X"):

_X_ 1. AISC Manual of Steel Construction, 7th Edition
____ 2. AWS D.1.1-83, 1983, Structural Welding Code
____ 3. ACI 318-77 Building Code Requirements for Reinforced Concrete
____ 4. (Specify):

8. ASSUMPTIONS, LITERATURE SEARCHES AND OTHER APPLICABLE BACKGROUND DATA

None

9. APPLICABLE REFERENCES (MARKED "X")

	1.	Design of Welded Structures by O. W. Blodgett 1966
	2.	Formulas for Stress and Strain by R. J. Roark & W.C. Young, 5th Edition
	3.	WCG-1-580 R0 Selection and Grouping of Embedded Plates for Evaluation
	4.	WCG-1-256 R0 Concrete Quality Evaluation
	5.	N3-PA-34 R0 Non-linear Transient Dynamic Analysis of FW Lines-Piping Analysis Calculation No. N3-PA-34
	6.	QIR-CEB-WBN 90757 R0 Active List of Pipe Whip Restraints/Protective Devices (PD's)
	7.	(specified)
X	8.	ANSYS Version 4.3
X	9.	Steel Columns of Rolled Wide Flange Section, Progress Report No. 2 by B. Johnston and L. Cheney, AISC Column Research at Lehigh University, November 1942.
X	10.	Static Load Deflection Tests of Beam-Columns, by F.L. Howland and N.M. Newmark, University of Illinois Structural Research Series No. 65, December 1953.
	11.	Development of Criteria for Seismic Review of Selected Nuclear Power Plants, by N.M. Mark and W.J.Hall, NUREG/CR-0098, May 1978.

10. APPLICABLE DESIGN INPUT DATA:

See section 11.4

11.0 CALCULATION

INDEX

11.1 Objective

The objective of this calculation is to correlate ANSYS analysis results with test data and to demonstrate the applicability of ANSYS nonlinear analysis and ductility for the evaluation of thermally restrained structures.

11.2 Scope

The scope of this calculation includes the following four (4) problems analyzed using the ANSYS computer program:

Problem 1:

Perform static analysis on a simply supported beam subjected to constant axial load and incremental lateral load, as shown in Figure 11.2.1, and correlate the analysis results to the test results from the "Static Load Deflection Tests of Beam-Columns" by Howland and Newmark (Attachment C, Figure 22) .

Problem 2:

Perform thermal stress analysis on a simply supported beam (same geometric configuration as the beam used in Problem 1) subjected to constant lateral load and temperature increases, as shown in Figure 11.2.2, and predict reserve capacity after the displacement ratio limit has been exceeded.

Problem 3:

Perform thermal stress analysis on a member with eccentricity and subjected to temperature increases, as shown in Figure 11.2.3, and predict reserve capacity after the displacement ratio limit has been exceeded. A test specimen used in " Steel Columns of Rolled Wide Flange Section" by Bruce Johnston and Lloyd

Cheney (Attachment D) is considered in this analysis.

Problem 4:

Perform thermal stress analysis on members subjected to constant lateral load and temperature increases, as shown in Figure 11.2.4, and correlate primary member displacement ratio level to secondary member displacement and strain ratios.

Figure 11.2.1 Geometric Configuration for the Member Considered in Problem 1

Constant Axial Load and Increment Lateral Load

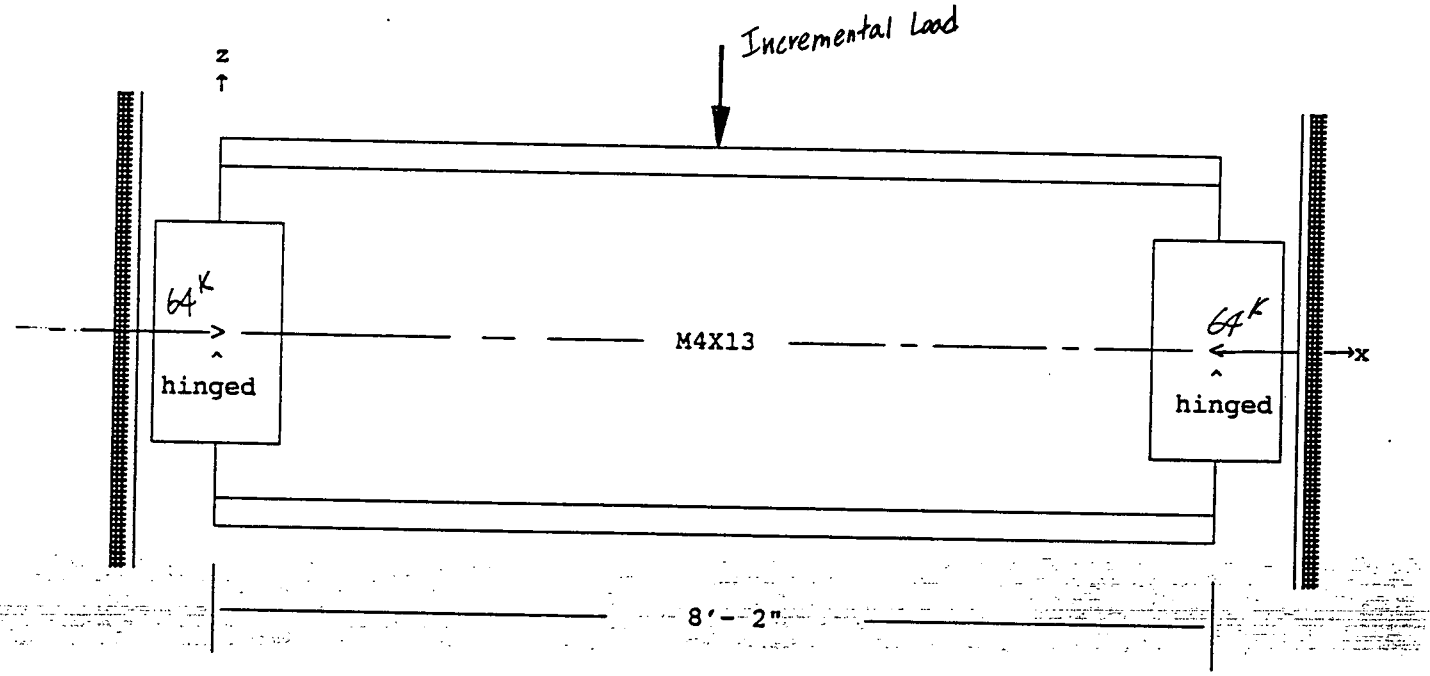
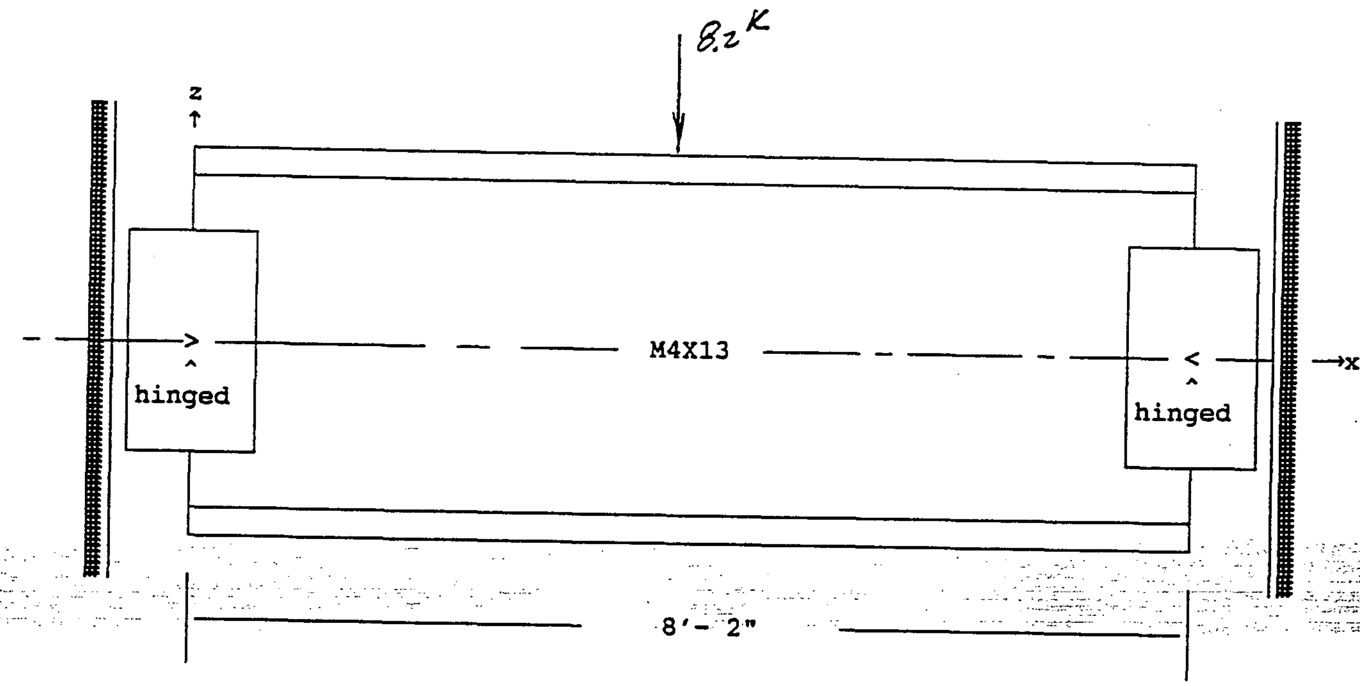


Figure 11.2.2 Geometric Configuration for the Member Considered in Problem 2

Constant Lateral Load and Incremental Temperature Change



Max. ΔT = 400°F

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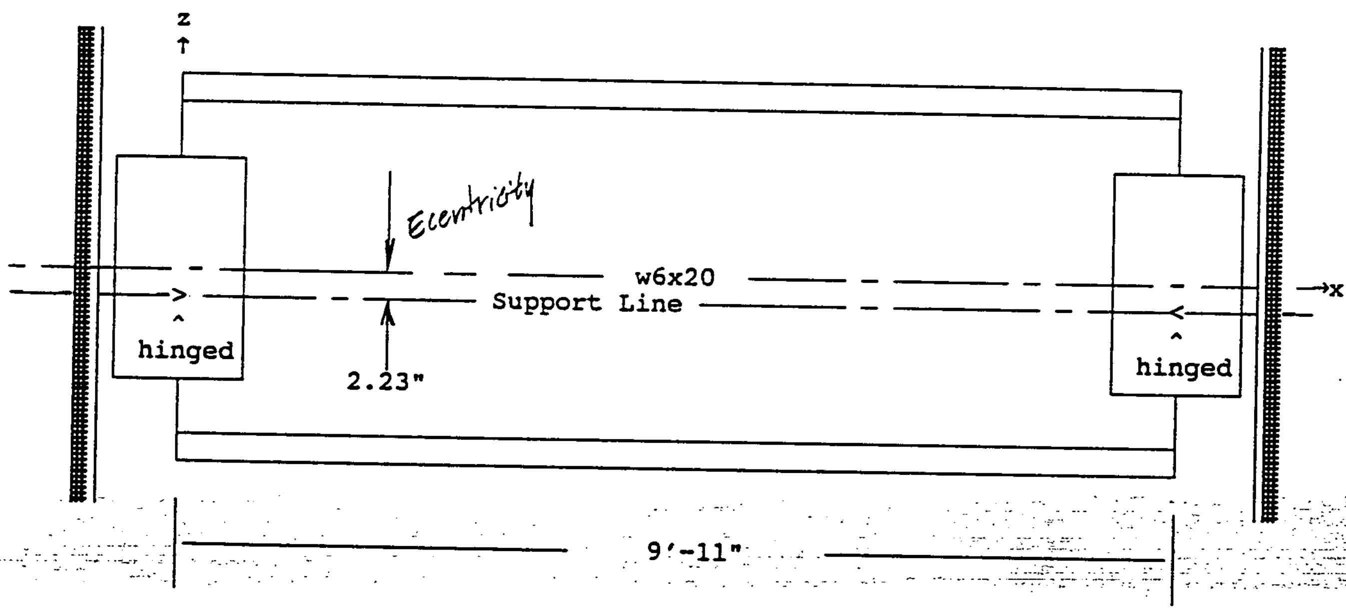
Figure 11.2.3 Geometric Configuration for the Member Considered in Problem 3

Member Ecentricity and Incremental Temperature Change



Max. ΔT = 500 °F

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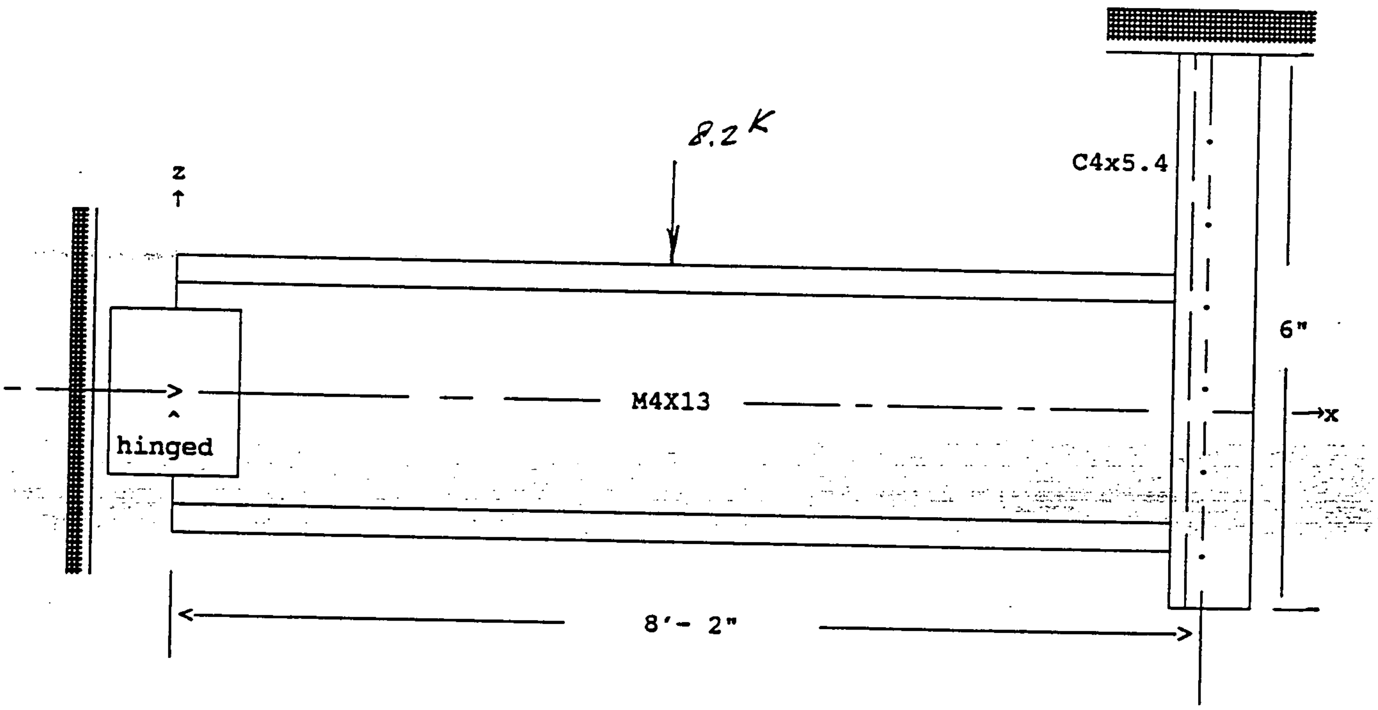
Figure 11.2.4 Geometric Configuration for the Members Considered in Problem 4

Constant Lateral Load and Incremental Temperature Change



Maximum $\Delta T = 400°F$

11.3 Methodology:

ANSYS computer program is used to perform nonlinear analysis for four (4) problems stated in the scope of this calculation. The nonlinear analysis considers an elastic-plastic nonlinear material properties and large deflection effects. ANSYS STIF24 element, a three dimensional thin-wall plastic beam element, is used to construct the mathematical models. The member cross-section can be defined with rectangular segments by specifying stress points on the cross-section for STIF24 element. The calculated stresses and strains (including elastic and plastic strains) at the stress point locations can be observed in the analysis output.

The elastic-plastic behavioris simulated by a bilinear stress-strain relation. Plasticity is included in the analysis by setting KNL = 1 in the ANSYS runs. Nonlinear material properties are defined with the NL family of ANSYS commands using C13 = 10 option.

The ANSYS large deflection solution method is used in the nonlinear analysis so that the stiffness matrix reflects the deformed structure in the iterative solution process. The large deflection is included by setting KAY(6) = 1 in ANSYS runs. With large deflection geometry consideration, the post-buckling behavior for ductile material can be observed.

ANSYS POST26 routine is used to generate graphical presentations of the analysis results.

11.4 Input Data:

11.4.1 Problem 1 input data is based on the Howland-Newmark Test Model specimen 415 S 4 M 13.0.

1. Beam M4x13
2. Hinged at both ends of member
3. Constant axial load = 64 kips
4. Incremental lateral load simulated by imposed displacement at mid-span of the member in the direction of strong axis of cross-section
5. Bilinear stress - strain relation, E = 29,000 ksi, Est (second tangent) = 29 ksi
6. Fy = (58.2+38.3+69.4)/3 = 55.3 ksi (averaged data from test results)

11.4.2 Problem 2 input data is similar to data given in section 11.4.1 except a constant lateral load is applied and the member is subjected to temperature increase.

1. Beam M4x13
2. Hinged at both ends of member
3. Constant lateral load = 8.2 kips
4. Initial temperature = 70 °F. Incremental temperature to a maximum DT = 400 °F.
5. Bilinear stress - strain relation, E = 29,000 ksi, Est (second tangent) = 29 ksi
6. Fy = 55.3 ksi
7. Coefficient of thermal expansion = $(6.5)(10^{-6})$ ("/")/(°F)

11.4.3 Problem 3 input data is based on the test item 6-5 in the Johnston-Cheney test report.

1. Beam W6x20
2. Member hinged at both ends 2.23" below the beam centerline (Eccentricity = 2.23 inch; Eccentricity ratio e/s = eA/S =1, where A = area = 5.88 in^2, S = sectional modulus =13.4 in^3)
3. Initial temperature = 70 °F. Incremental temperature to a maximum DT = 500 °F.
5. Bilinear stress - strain relation, E = 29,000 ksi, Est (second tangent) = 1,500 ksi
6. Fy = 33.0 ksi (based on test data)
7. Coefficient of thermal expansion = $(6.5)(10^{-6})$ ("/")/(°F)

11.4.4 Problem 4 input data:

1. M4x13 for primary member and C4x5.4 for secondary member
2. Hinged at left end of M4x13; moment connection at the joint; moment connection at end of C4x5.4
3. Constant lateral load = 8.2 kips
4. Initial temperature = 70 °F. Incremental temperature to a maximum DT = 400 °F.
5. Bilinear stress - strain relation, E = 29,000 ksi, Est (second tangent) = 1,500 ksi
6. Fy = 55.3 ksi
7. Coefficient of thermal expansion = $(6.5)(10^{-6})$ ("/")/(°F)

11.5 Mathematical Model:

The mathematical models are constructed using ANSYS STIF24 element to represent wide flange I-beams and channels. The cross section is defined by a series of rectangular segments. The orientation of three principal axes is defined by the beam longitudinal axis and a third node. The principal axes form the beam local coordinate system. The x-axis is along the beam longitudinal axis. The third node mentioned above determines the xz-plane and the direction of local z-axis.

A total of four (4) mathematical models are used in this calculation. They are given in sections 11.5.1 through 11.5.4.

Problem 1 model as shown in Figure 11.5.1.3 consists of 31 nodes and 30 elements. Two end nodes (Nodes 1 and 31) are restrained in three traslations and torsional rotation except that Node 1 is free to move in axial translational direction for applying a constant axial force. Node 16 is the center of the member. The input data are given in section 11.4.1. Node 16 is also imposed with incremental displacements in lateral z-direction equivalent to applying incremental lateral forces.

Problem 2 model as shown in Figure 11.5.2.3 is similar to problem 1 model consisting of 31 nodes and 30 elements. Both ends are supported in three translations and torsional translation. Node 16, the mid-point, is applied by a constant force. This model is applied with incremental temperatures and a constant lateral load.

Problem 3 model as shown in Figure 11.5.3.3 consists of 33 nodes, 30 STIF24 elements and two rigid elements. Nodes 1 and 31 as in the previous are two end nodes on the beam neutral axis. The beam is eccentrically supported at elevation 2.23" below the beam neutral axis, at Nodes 32 and 33. Two fictitious rigid elements, connecting nodes 1 and 32 and nodes 31 and 33, are used to account for eccentricity. Support nodes 32 and 33 are restrained in three traslations and torsional rotation. This model is applied with incremental temperature only.

11.5 (continued)

Problem 4 model as shown in Figure 11.5.4.3 consists of 58 nodes and 57 elements. Elements 1 through 50 (from nodes 1 to 51) represent the primary member (M4x13). Elements 52 through 57 (from nodes 52 to 58) represent secondary member (C4x5.4). Element 51 connecting nodes 51 and 52, is a fictitious member which represents the rigid joint connection. The model is supported at nodes 1 and 58. Node 1 is restrained in three translational directions. Node 58 is fully restrained in three translations and three rotations. Node 26 is the center of the primary member. This model is subjected to incremental temperatures and applying a constant lateral load at node 26.

11.5.1 Problem 1: Howland-Newmark Test Model.

11.5 1.1 Model

Figure 11.5.1.1A: Howland - Newmark Model with Applied Displacement

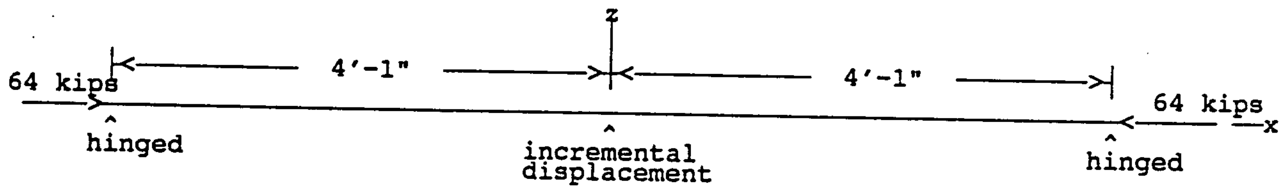
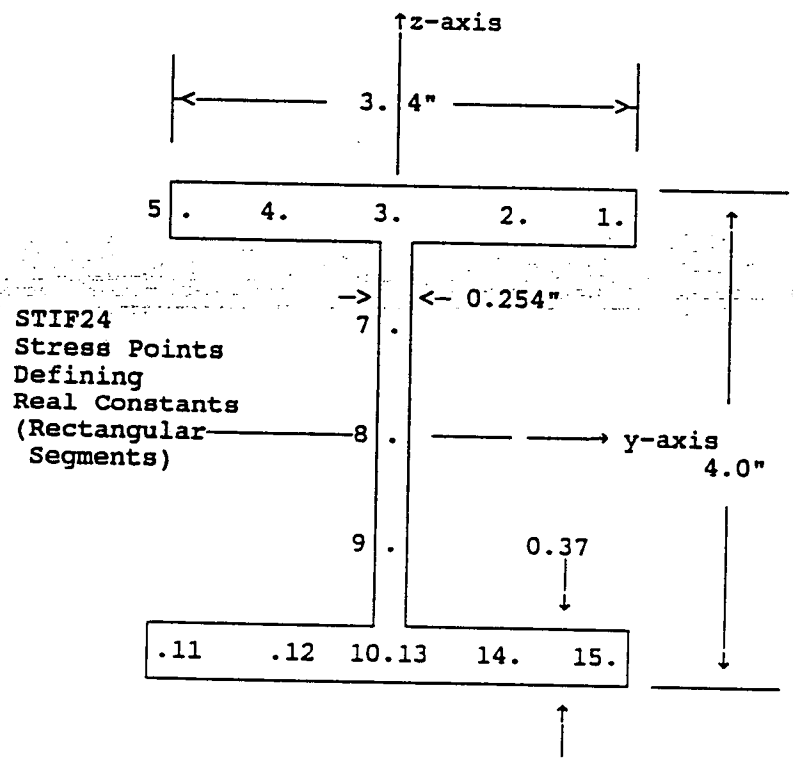


Figure 11.5.1.1B STIF24 Stress Points for M4x13.0



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11.5.1.2 List of ANSYS Input Data for Howland-Newmark Test Model

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********** ANSYS INPUT DATA LISTING (FILE18) **********

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/COM HOWLAND - NEWMARK MODEL
/COM REF. NEWMARK LOAD TESTS
/COM SPECIMEN 415 S 4M13.0
/COM E=29E3 KSI, FY=55.3 KSI
/COM
/COM INPUT: JOHN1C2
/COM OUTPUT: JOCW1C2
/COM FILE12: JFCW1C2
/COM PLOT FILE: JGCW1C2
/COM
/COM
KAN,0
KAY,6,1
KNL,1
ET,1,24,,,,,,1
TREF,70
EX,1,29E3
ALPX,1,6.5E-6
C*** NONLINEAR MATERIAL CONSTANT
NL,1,13,10
NL,1,19,70,470
NL,1,25,55.3,55.3
NL,1,31,29,29
C*** DEFINE BEAM LENGTH AND CROSS SECTION PROPERTIES
L=98                    * BEAM 415 S 4 M13.0
BF=3.940
TF=0.370
D=4.00
TW=0.254
C***
AA=BF/2
BB=(D-TF)/2.
QA=AA/2
QB=BB/2
*STAT
R,1,AA,BB,0,QA,BB,TF          *STIF24 REAL PROP.
RMORE,0,BB,TF,-QA,BB,TF
RMORE,-AA,BB,TF,0,BB,0
RMORE,0,QB,TW,0,0,TW
RMORE,0,-QB,TW,0,-BB,TW
RMORE,-AA,-BB,0,-QA,-BB,TF
RMORE,0,-BB,TF,QA,-BB,TF
RMORE,AA,-BB,TF
C***
NUM=31
MID=(NUM+1)/2
ND=3
AL=L/4
N,1
N,ND+1,AL
FILL
N,NUM-ND,L-AL
FILL
N,NUM,L
FILL
```

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11.5.1.2 (Continued)

1

*********** ANSYS INPUT DATA LISTING (FILE18) **********

```
N,NUM+1,L/2,0,5
E,1,2,NUM+1
RP30,1,1,0                  * RPNNN, NNN=NUM-1
C***
ITER,-20
POSTR,,1,5
/PBC,ALL,1
/VIEW,,0,-1,0
C*** BOUNDARY CONDITIONS:
D,1,UY,0,,,,UZ,ROTX
D,NUM,UX,0,,,,UY,UZ,ROTX
C*** TUNIF,270
F,1,FX,64
C*** DEFINE REPEATING LOADINGS AS MACRO
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*END
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RP23,,DE*0.2
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/PNUM,NODE,1
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EPLOT
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/INPUT,27
FINISH
/POST1
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STRESS,SX01,24,13
STRESS,SX08,24,20
STRESS,SX15,24,27
STRESS,EE01,24,95
STRESS,EE08,24,137
STRESS,EE15,24,179
STRESS,EP01,24,96
STRESS,EP08,24,138
STRESS,EP15,24,180
*CREAT,MAC
SET,ARG1
ERSEL,ELEM,16
NRSEL,NODE,16
PRDISP                 *PRINT SEL. NODAL DISP.
PREFOR
PRSTRS
*END
*USE,MAC,1
RP23,,1
FINISH
/POST26
/SHOW
TVAR,1
DISP,2,16,UZ,UZ64
NFORCE,3,16,16,FZ,FZ64
NFORCE,4,16,16,MY,MY64
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11.5.1.2 (Continued)

1

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*********** ANSYS INPUT DATA LISTING (FILE18) **********

DE=(1)/.6
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ME=(1)/212
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PLVAR,6,7
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PLVAR,4
/GRAPH,LABY,F&M
PLVAR,3,4
FINISH
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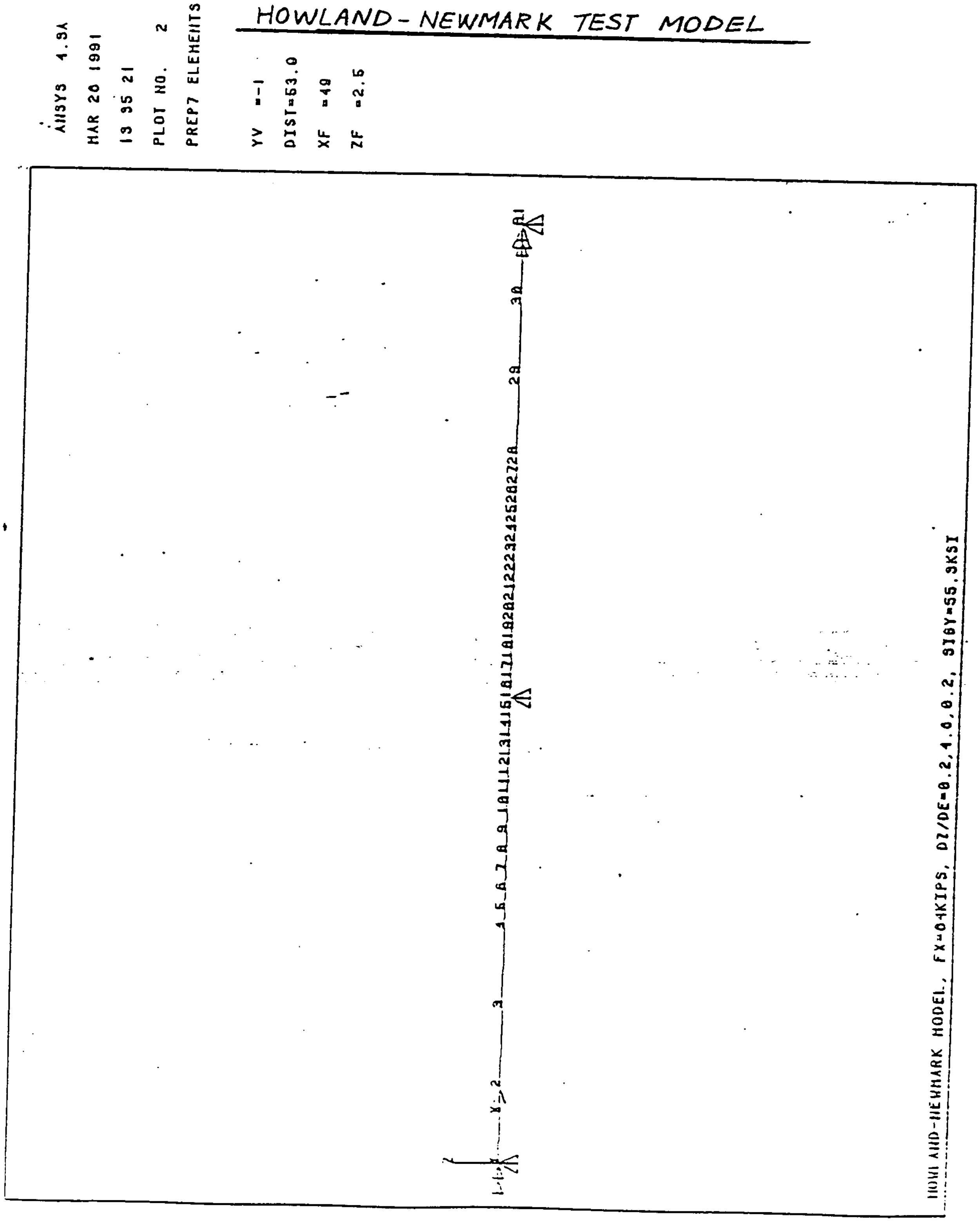
11.5.1.3 ANSYS Model Plot

Figure 11.5.1.3

HOWLAND-NEWMARK TEST MODEL



11.5.2 Problem 2: Howland-Newmark Thermal Model

11.5.2.1 Model

Figure 11.5.2.1A: Howland - Newmark Model with Incremental Temperature

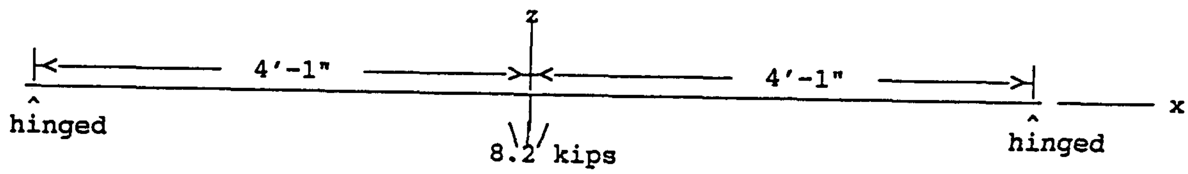
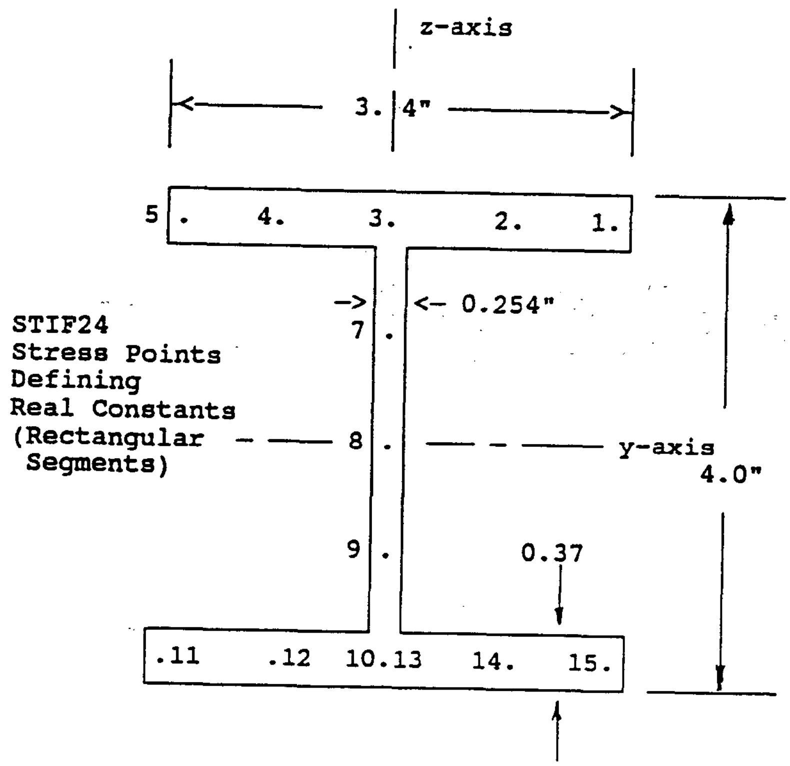


Figure 11.5.2.1B STIF24 Stress Points for M4x13.0



11.5.2.2 List of ANSYS Input Data for Howland-Newmark Thermal Model

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/SHOW
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/COM
/COM HOWLAND - NEWMARK MODEL
/COM REF. NEWMARK LOAD TESTS
/COM SPECIMEN 415 S 4M13.0
/COM E=29E3 KSI, FY=55.3 KSI
/COM
/COM INPUT: JOHN2C1
/COM OUTPUT: JOCW2C1
/COM FILE12: JFCW2C1
/COM FILE33: JGCW2C1
/COM
/COM
KAN,0
KAY,6,1
KNL,1
ET,1,24,,,,,,1
TREF,70
EX,1,29E3
ALPX,1,6.5E-6
C*** NONLINEAR MATERIAL CONSTANT
NL,1,13,10
NL,1,19,70,270
NL,1,25,55.3,55.3
NL,1,31,29,29
C*** DEFINE BEAM LENGTH AND CROSS SECTION PROPERTIES
L=98                    * BEAM 415 S 4 M13.0
BF=3.940
TF=0.370
D=4.00
TW=0.254
C***
AA=BF/2
BB=(D-TF)/2.
QA=AA/2
QB=BB/2
*STAT
R,1,AA,BB,0,QA,BB,TF          *STIF24 REAL PROP.
RMORE,0,BB,TF,-QA,BB,TF
RMORE,-AA,BB,TF,0,BB,0
RMORE,0,QB,TW,0,0,TW
RMORE,0,-QB,TW,0,-BB,TW
RMORE,-AA,-BB,0,-QA,-BB,TF
RMORE,0,-BB,TF,QA,-BB,TF
RMORE,AA,-BB,TF
C***
NUM=31
MID=(NUM+1)/2
ND=3
AL=L/4
N,1
N,ND+1,AL
FILL
N,NUM-ND,L-AL
FILL
N,NUM,L
FILL
```

11.5.2.2 (Continued)

1

********** ANSYS INPUT DATA LISTING (FILE18) **********

```
N,NUM+1,L/2,0,5
E,1,2,NUM+1
RP30,1,1,0                  * RPNNN, NNN=NUM-1
C***
ITER,-10
POSTR,,1,5
/PBC,ALL,1
/VIEW,,0,-1,0
C*** BOUNDARY CONDITIONS:
D,1,UX,0,,,,UY,UZ,ROTX
D,NUM,UX,0,,,,UY,UZ,ROTX
C*** TUNIF,270
F,MID,FZ,-8.2
C*** DEFINE REPEATING LOADINGS AS MACRO
*CREAT,TMP
TUNIF,ARG1
LWRITE
*END
*USE,TMP,70
RP41,,10
/TITLE, HOWLAND-NEWMARK MODEL, FZ=-8.2 KIPS, DT=10,400,10, SIGY=55.3KSI
/PNUM,NODE,-1
EPLOT
/PNUM,NODE,1
NRSEL,1,NUM,MID-1
EPLOT
EPLOT
AFWRITE,,1
FINISH
/INPUT,27
FINISH
/POST1
STORE,REAL,DISP,STRES,NFORC,RFORC
STRESS,SX01,24,13
STRESS,SX08,24,20
STRESS,SX15,24,27
STRESS,EE01,24,95
STRESS,EE08,24,137
STRESS,EE15,24,179
STRESS,EP01,24,96
STRESS,EP08,24,138
STRESS,EP15,24,180
*CREAT,MAC
SET,ARG1
ERSEL,ELEM,16
NRSEL,NODE,16
PRDISP                      *PRINT SEL. NODAL DISP.
PREFOR
PRSTRS
*END
*USE,MAC,1
RP23,,1
FINISH
```

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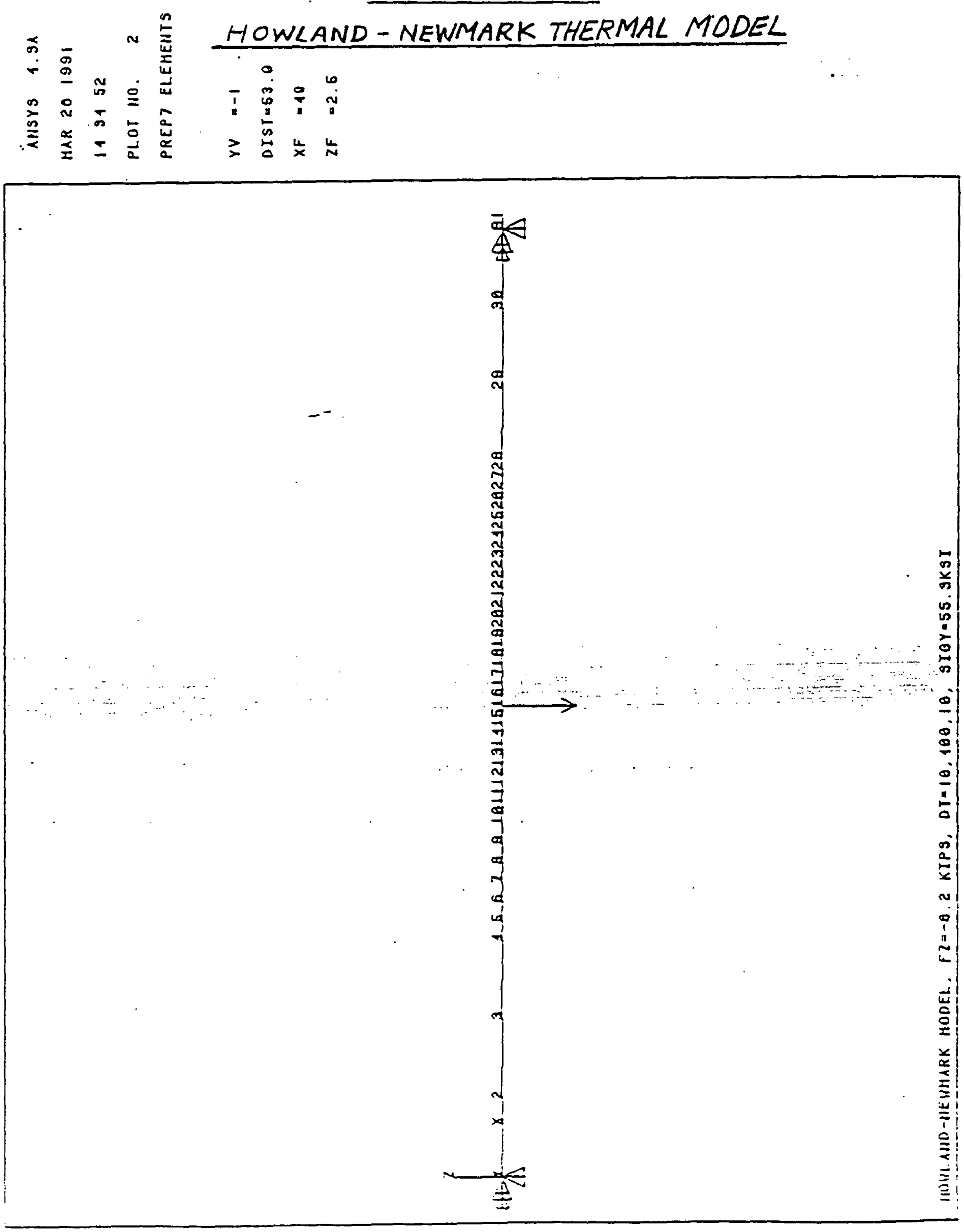
11.5.2.3 ANSYS Model Plot

Figure 11.5.2.3

HOWLAND - NEWMARK THERMAL MODEL



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11.5.3 Problem 3: Johnston-Cheney Thermal Model

11.5.3.1 Model

Figure 11.5.2.1A: Johnston-Cheney Thermal Model with Temperature Increase

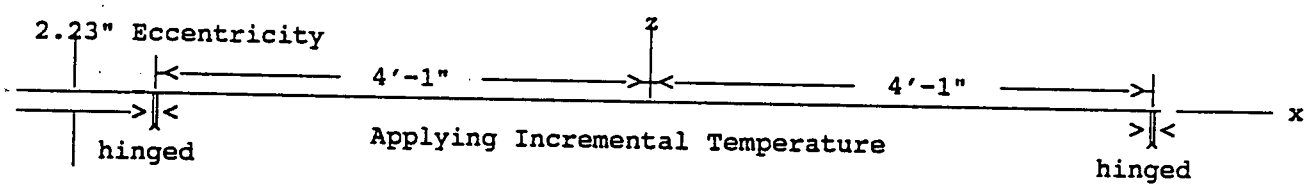
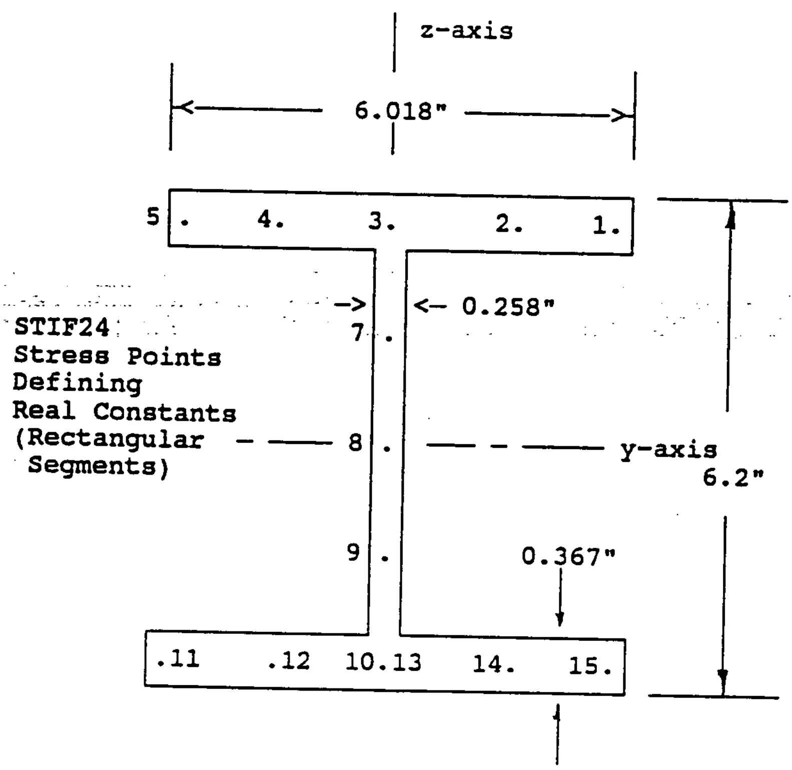


Figure 11.5.3.1B STIF24 Stress Points for M4x13.0



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11.5.3.2 List of ANSYS Input Data for Johnston-Cheney Thermal Model

1

```
********** ANSYS INPUT DATA LISTING (FILE18) **********

/PREP7
/TITLE, JOHNSTON-CHENEY TEST 6-5 (W6X20), EC=2.23", DTEMP=0,400,10
/COM
/COM JOHNSTON - CHENEY MODEL
/COM REF. LOAD TESTS - J&C
/COM SPECIMEN W6X20
/COM ECCENTRICITY=2.23", DT=0,400,10
/COM E=29E3 KSI, FY=33 KSI
/COM ET=1500
/COM
/COM INPUT    JOHN3C1
/COM OUTPUT   JOCW3C1
/COM FILE12   JFCW3C1
/COM PLOT FILE JGCW3C1
/COM
/COM
KAN,0
KAY,6,1
KNL,1
TREF,70
ET,1,24,,,,,,1
ET,2,4
EX,1,29E3
EX,2,29E3
ALPX,1,6.5E-6
ALPX,2,6.5E-6
C*** NONLINEAR MATERIAL CONSTANT
NL,1,13,10
NL,1,19,70,400
NL,1,25,33.0,33.0
NL,1,31,1500,1500
C*** DEFINE BEAM LENGTH AND CROSS SECTION PROPERTIES
L=119                    * BEAM W 6X20 9'-11" LONG
BF=6.018
TF=0.367
D=6.20
TW=0.258
EC=2.23                  * ECCENTRICITY, 2.23"
C***
AA=BF/2
BB=(D-TF)/2.
QA=AA/2
QB=BB/2
*STAT
R,1,AA,BB,0,QA,BB,TF          *STIF24 REAL PROP.
RMORE,0,BB,TF,-QA,BB,TF
RMORE,-AA,BB,TF,0,BB,0
RMORE,0,QB,TW,0,0,TW
RMORE,0,-QB,TW,0,-BB,TW
RMORE,-AA,-BB,0,-QA,-BB,TF
RMORE,0,-BB,TF,QA,-BB,TF
RMORE,AA,-BB,TF
R,2,500,5000,5000,10,10
C***
NUM=31
MID=(NUM+1)/2
ND=3
AL=L/4
N,1
N,ND+1,AL
```

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11.5.3.2 (Continued)

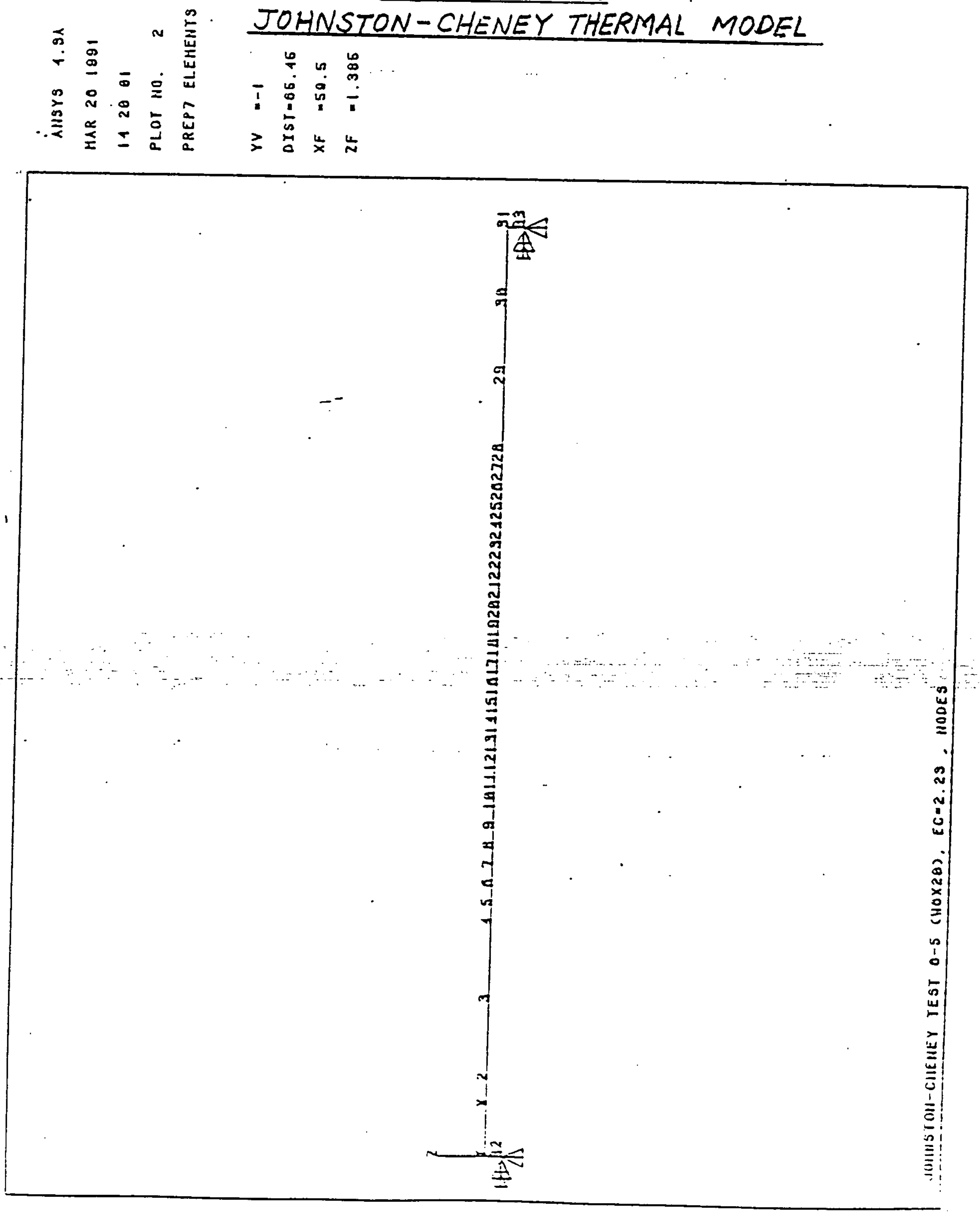
1

```
********** ANSYS INPUT DATA LISTING (FILE18) **********

FILL
N,NUM-ND,L-AL
FILL
N,NUM,L
FILL
N,NUM+1,0,0,-2.23
N,NUM+2,L,0,-2.23
N,NUM+3,L/2,0,5
TYPE,2  $MAT,2   $REAL,2  * RIGID BEAM
E,NUM+1,1,NUM+3
TYPE,1  $MAT,1   $REAL,1  * STIF24 BEAM
E,1,2,NUM+3
RP30,1,1,0              * RPNNN, NNN=NUM-1
TYPE,2  $MAT,2   $REAL,2  * RIGID BEAM
E,NUM+2,NUM,NUM+3
C***
ITER,-20
POSTR,,1,5
C*** BOUNDARY CONDITIONS:
D,NUM+1,UX,0,,,,UY,UZ,ROTX          * WITH THERMAL LOAD
D,NUM+2,UX,0,,,,UY,UZ,ROTX
C*** F,1,FX,64
C*** F,MID,FZ,8.2
C*** DEFINE INCREMENTAL TEMPERATURE
*CREAT,TMP
TUNIF,ARG1
LWRITE
*END
*USE,TMP,70
RP41,,10
C***
/PBC,ALL,1
/SHOW
/VIEW,,0,-1,0
/TITLE, JOHNSTON-CHENEY TEST 6-5 (W6X20), EC=2.23"
/PNUM,NODE,-1
/PNUM,ELEM,-1
EPLOT
/TITLE, JOHNSTON-CHENEY TEST 6-5 (W6X20), EC=2.23", NODES
/PNUM,NODE,1
/PNUM,ELEM,-1
EPLOT
/TITLE, JOHNSTON-CHENEY TEST 6-5 (W6X20), EC=2.23", ELEMENTS
/PNUM,NODE,-1
/PNUM,ELEM,1
EPLOT
C***
AFWRITE,,1
FINISH
/INPUT,27
FINISH
```

11.5.3.3 ANSYS Model Plot

Figure 11.5.3.3
JOHNSTON-CHENEY THERMAL MODEL



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11.5.4 Problem 4: High Ductility Ratio Model

11.5.4.1 Model

Figure 11.5.2.1A: High Ductility Ratio Model with Incremental Temperature

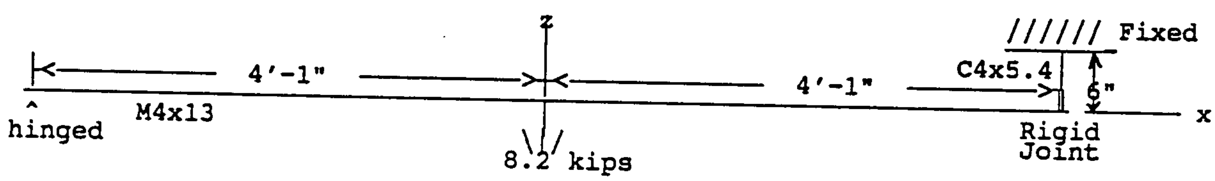
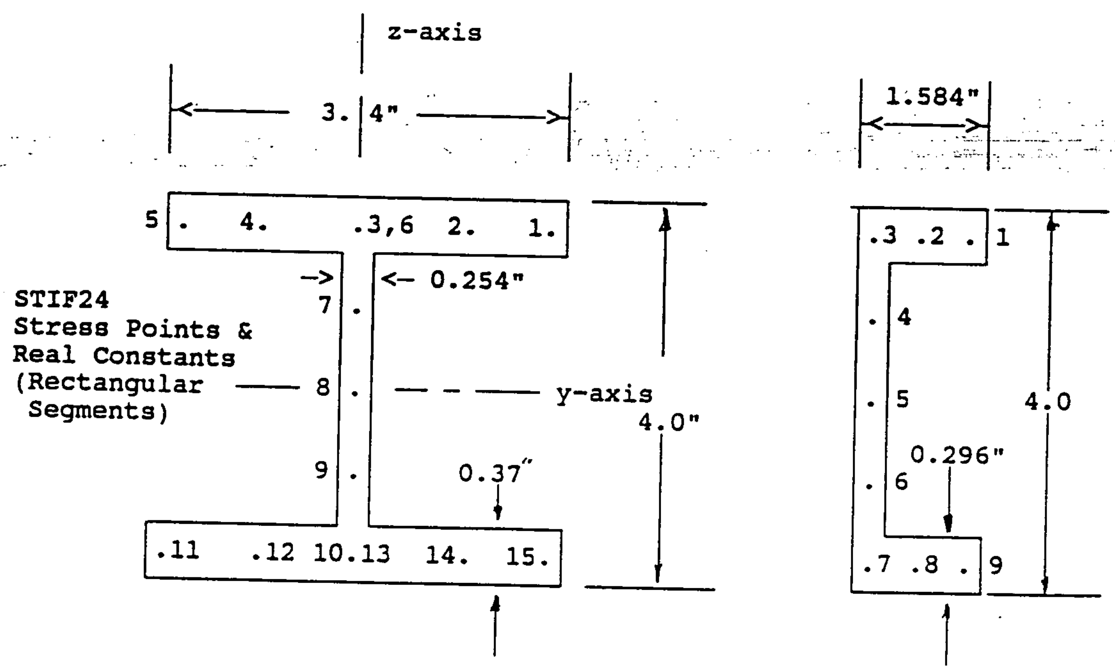


Figure 11.5.2.1B: STIF24 Stress Points for M4x13.0 and C4x5.4



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11.5.4.2 List of ANSYS Input Data for High Ductility Ratio Model

```
*********** ANSYS INPUT DATA LISTING (FILE18) ***********

/PREP7
/TITLE, HIGH DUCTILITY RATIO MODEL, FZ=-8.2, DT=10,400,10, SIGY=36.0 KSI
/COM
/COM HIGH DUCTILITY RATIO MODEL
/COM M4X13.0/C4X5.4
/COM FZ=8.2 KIPS, DT=0,400,10
/COM E=29E3 KSI, FY=36.0 KSI
/COM ET=1500
/COM
/COM INPUT:  JOHN4C2
/COM OUTPUT: JOCW4C2
/COM FILE12: JFCW4C2
/COM PLOT FILE: JGCW4C2
/COM
/COM
KAN,0
KAY,6,1
KNL,1
TREF,70
ET,1,24,,,1,,,1
EX,1,29E3
ALPX,1,6.5E-6
ET,2,4
EX,2,29E3
ALPX,2,6.5E-6
C*** NONLINEAR MATERIAL CONSTANT
NL,1,13,10
NL,1,19,70,270
NL,1,25,36.0,36.0
NL,1,31,1500,1500
C*** DEFINE BEAM LENGTH AND CROSS SECTION PROPERTIES
L=98.458                    * BEAM 415 S 4 M13.0
BF=3.940
TF=0.370
D=4.00
TW=0.254
C***
CL=4                        * CHANNEL C 4X5.4  6" LONG
CF=1.584
TCF=0.296
CD=4.00
TCW=0.184
C***
AA=BF/2
BB=(D-TF)/2.
QA=AA/2
QB=BB/2
C***
X0=(TCW/2)-(0.458)
CC=CF-(TCW/2)
DD=(CD-TCF)/2.
QC=CC/2
QD=DD/2
CC=CC+X0
QC=QC+X0
*STAT
R,1,AA,BB,0,QA,BB,TF              *STIF24 REAL PROP. - M 4X13.0
RMORE,0,BB,TF,-QA,BB,TF
RMORE,-AA,BB,TF,0,BB,0
RMORE,0,QB,TW,0,0,TW
```

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11.5.4.2 (Continued)

1

*********** ANSYS INPUT DATA LISTING (FILE18) ***********

```
RMORE,0,-QB,TW,0,-BB,TW
RMORE,-AA,-BB,0,-QA,-BB,TF
RMORE,0,-BB,TF,QA,-BB,TF
RMORE,AA,-BB,TF
C***
R,2,500,5000,5000,10,10          * RIGID BEAM
C***
R,3,CC,DD,0,QC,DD,TCF            * STIF24 REAL PROP. - C4X5.4
RMORE,X0,DD,TCF,X0,QD,TCW
RMORE,X0,0,TCW,X0,-QD,TCW
RMORE,X0,-DD,TCW,QC,-DD,TCF
RMORE,CC,-DD,TCF
C***
NUM=51
MID=(NUM+1)/2
ND=7
MUM=NUM+ND
N,1,0
N,NUM,L
FILL
N,NUM+1,L,0,2
N,MUM,L,0,6
FILL
N,MUM+1,L,5,0
NLIST,ALL
C***
TYPE,1 $MAT,1 $REAL,1   * M 4X13.0
E,1,2,NUM+1
RP50,1,1,0              * RPNNN, NNN=NUM-1
TYPE,2 $MAT,2 $REAL,2   * RIGID
E,NUM,NUM+1,1
TYPE,1 $MAT,1 $REAL,3   * C 4X5.4
E,NUM+1,NUM+2,MUM+1
RP6,1,1,0               * RPNNN, NNN=ND-1
*STAT
C***
ITER,-20
POSTR,,1,5
C*** BOUNDARY CONDITIONS:
D,1,UX,0,,,,UY,UZ,ROTX
D,MUM,UX,0,,,,UY,UZ,ROTX,ROTY,ROTZ
C*** TUNIF,270
C*** F,1,FX,64
F,MID,FZ,-8.2
C*** DEFINE REPEATING LOADINGS AS MACRO
*CREAT,TMP
TUNIF,ARG1
LWRITE
*END
*USE,TMP,70
RP41,,10
C***
/PBC,ALL,1
/SHOW
/VIEW,,0,-1,0
/TITLE, HIGH DUCTILITY RATIO MODEL (M4X13 / C4X5.4)
/PNUM,NODE,-1
/PNUM,ELEM,-1
EPLOT
/TITLE, HIGH DUCTILITY RATIO MODEL, NODE NUNBERS
```

11.5.4.2 (Continued)

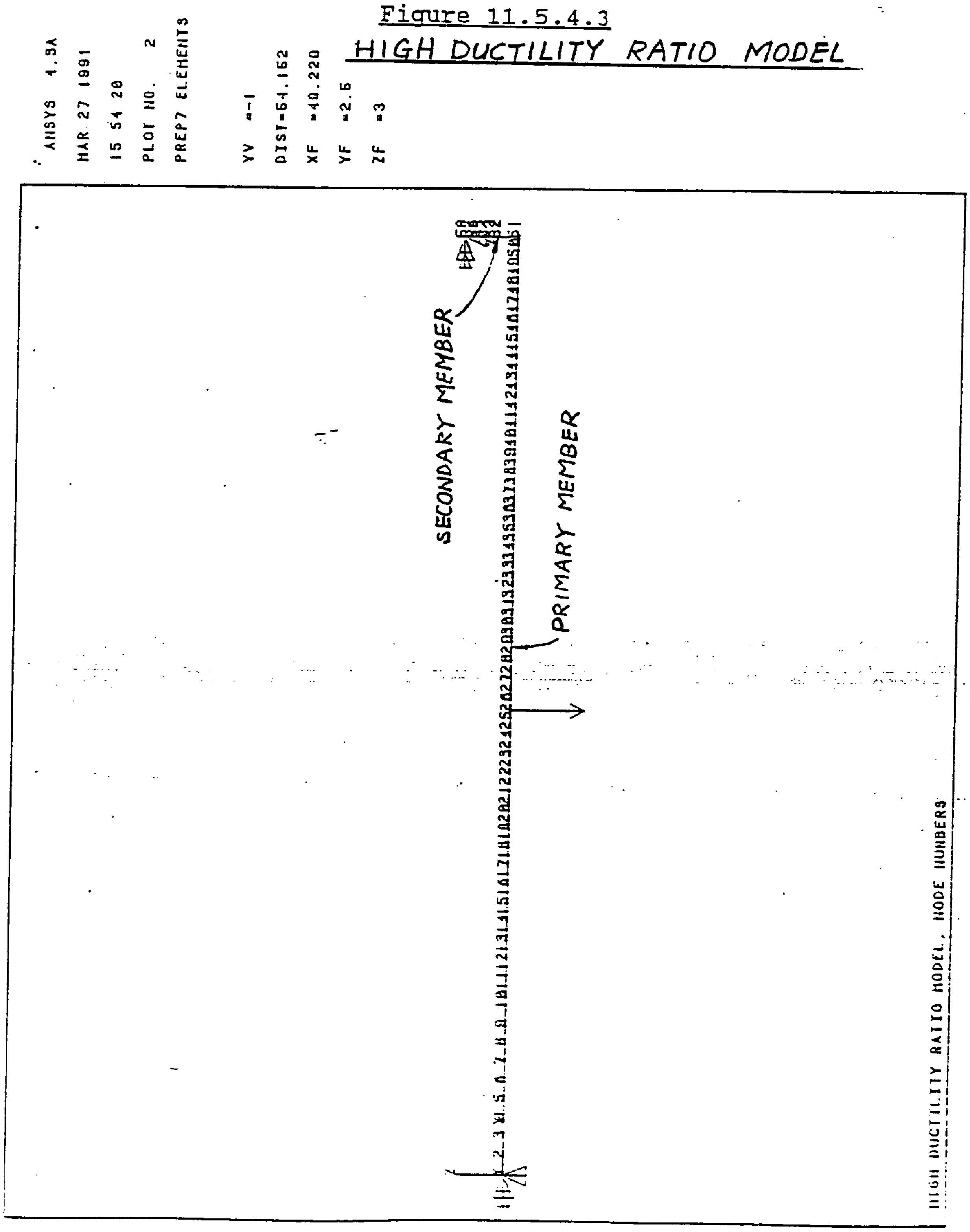
1

*********** ANSYS INPUT DATA LISTING (FILE18) ***********

```
/PNUM,NODE,1
/PNUM,ELEM,-1
EPLOT
/TITLE, HIGH DUCTILITY RATIO MODEL ELEMENT NUMBERS
/PNUM,NODE,-1
/PNUM,ELEM,1
EPLOT
/TITLE, HIGH DUCTILITY RATIO MODEL, PARTIAL
ERSEL,NUM-1,NUM+ND
/PNUM,NODE,1
/PNUM,ELEM,1
EPLOT
/TITLE, HIGH DUCTILITY RATIO MODEL (M4X13 / C4X5.4)
/PNUM,NODE,-1
/PNUM,ELEM,-1
/PNUM,REAL,1
EPLOT
C***
EALL
NALL
AFWRITE,,1
FINISH
```

11.5.4.3 ANSYS Model Plot

Figure 11.5.4.3
HIGH DUCTILITY RATIO MODEL



11.6 Results:

Results from ANSYS nonlinear analyses for Problem 1 through Problem 4 are given in sections 11.6.1 through 11.6.4 respectively.

The ANSYS models are verified for STIF24 member section properties, defined by twelve (12) rectangular segments for the wide flange I-beams and by eight (8) segments for the channel C4x5.4, in comparison to AISC tabulated values.

M4x13 : (Reference computer output file 'JOCW1X1')

	Area (in^2)	Iyy (in^4)	Izz (in^4)
ANSYS Output	3.84	10.6	3.77
AISC	3.81	10.5	3.36

W6X20 : (Reference computer output file 'JOCW3X1')

	Area (in^2)	Iyy (in^4)	Izz (in^4)
ANSYS Output	5.92	41.8	13.3
AISC	5.88	41.5	13.3

C4x5.4 : (Reference computer output file 'JOCW4X2')

	Area (in^2)	Iyy (in^4)	Izz (in^4)
ANSYS Output	1.57	3.81	.378
AISC	1.59	3.85	.319

11.6.1 Results for Problem 1 :

For Problem 1 of Howland-Newmark test configuration, ANSYS results are obtained from computer runs output files 'JOCW1C1' (Appendix B) for Fx = 0 and 'JOCW1C2' for Fx = 64 kips. Results are provided in Figure 11.6.1A through Figure 11.6.1C. The problem 1 applies incremental lateral displacements (Uz) at the center of member (node 16) which is equivalent to an applying incremental lateral loads (Fz) in the test report (Attachment C).

Figure 11.6.1A provides the comparison of, for the case where axial force Fx = 0, the vertical (Z-direction) reaction forces at node 16 with lateral applying loads of test data (Attachment C). The loads are plotted varying with the ratio of actual lateral displacement (Uz) to the yield displacement (Uzy) at node 16.

Figure 11.6.1B provides the comparison of, for the case where axial force Fx = 64 kips, the vertical (Z-direction) reaction forces at node 16 with lateral applying loads of test data (Attachment C). The loads are also plotted varying with the ratio of actual lateral displacement (Uz) to the yield displacement (Uzy) at node 16.

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11.6.1 (Continued)

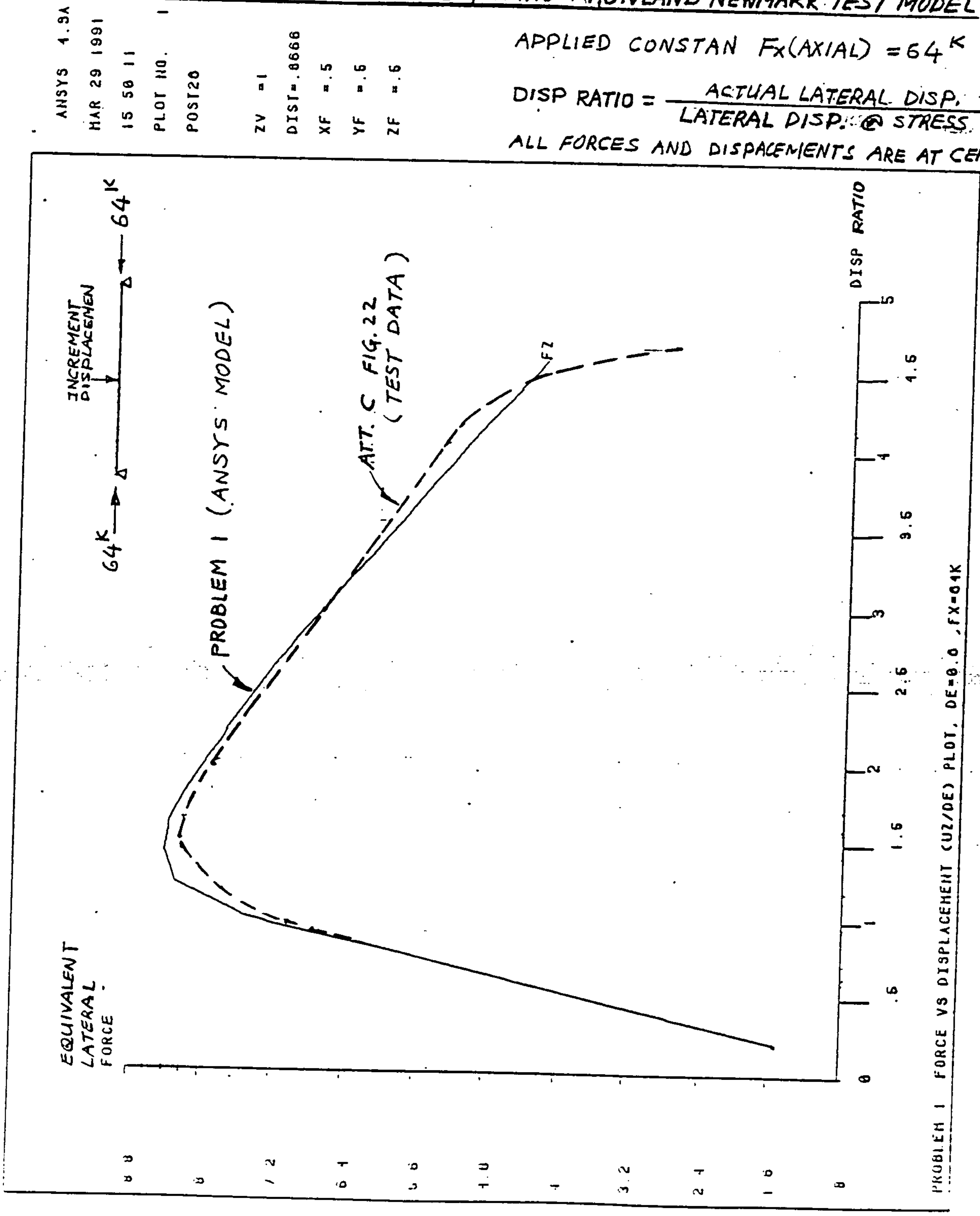
Figure 11.6.1A

LATERAL FORCE VS DISPLACEMENT RATIO - HOWLAND NEWMARK TEST MODEL

APPLIED CONSTAN Fx(AXIAL) = 64 K

$$\text{DISP RATIO} = \frac{\text{ACTUAL LATERAL DISP.}}{\text{LATERAL DISP. @ STRESS YIELD}}$$

ALL FORCES AND DISPACEMENTS ARE AT CENTER SPAN



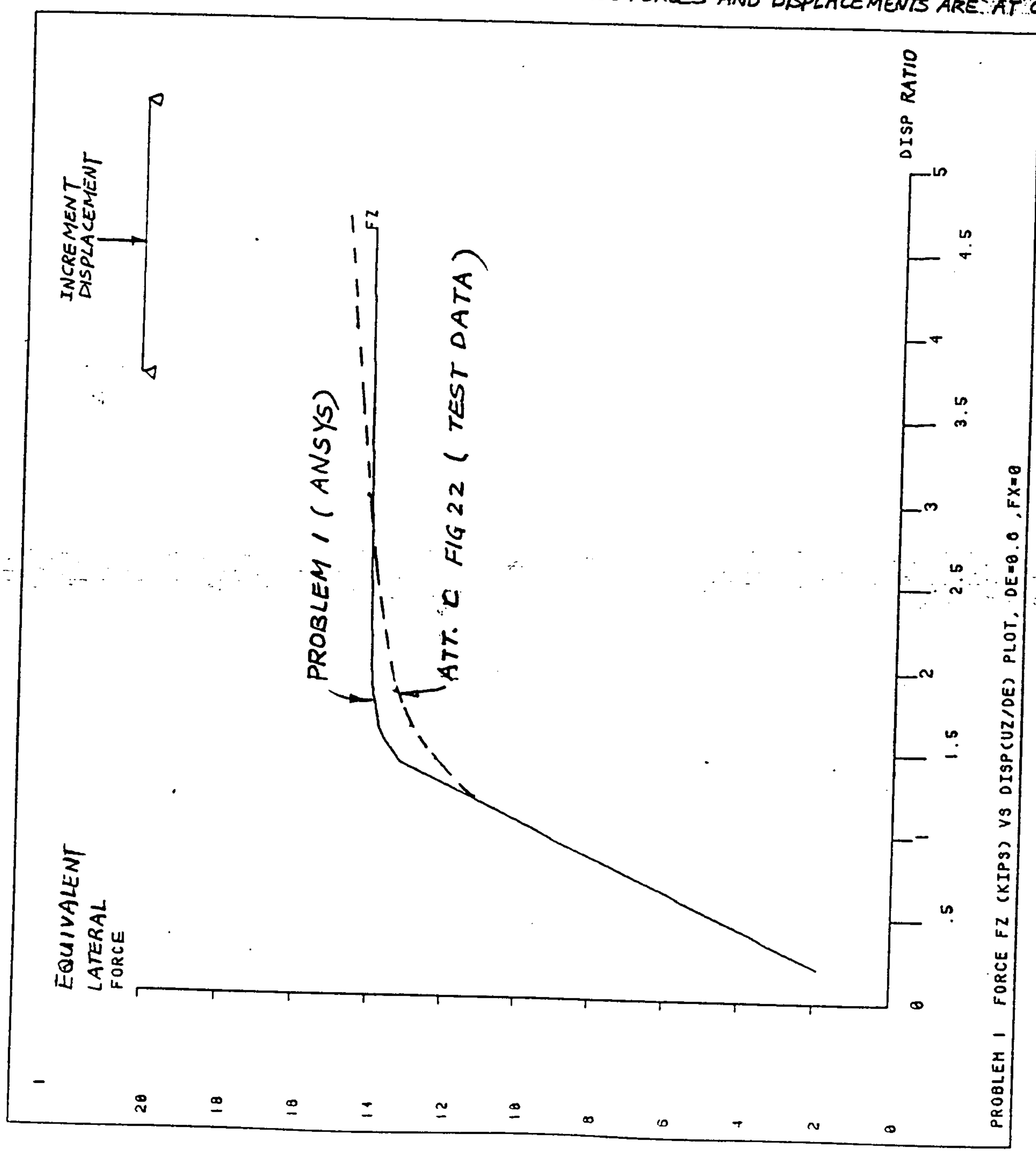
11.6.1 (Continued)

Figure 11.6.1B

LATERAL FORCE VS DISPLACEMENT RATIO – HOWLAND-NEWMARK TEST MODEL
WITHOUT AXIAL FORCE ($F_X = 0$)

$$\text{DISP. RATIO} = \frac{\text{ACTUL LATERAL DISP}}{\text{LATERAL DISP @ STRESS YIELD}}$$

ALL FORCES AND DISPLACEMENTS ARE AT CENTER SPAN



11.6.2 For Problem 2 of Howland-Newmark Thermal Model

For Problem 2 of Howland-Newmark configuration with thermal compression, results are obtained, from computer runs output file 'JOCW2C1' (Appendix B) for the range of temperature from 70 °F to 470 °F, and given in Figures 11.6.2A, 11.6.2B and 11.6.2C.

Figure 11.6.2A provides the displacement ratio varying with temperature and Figure 11.6.2B for the strain ratio versus temperature. Figure 11.6.2C shows the variation of axial force in the member with temperature change.

The displacement ratio is defined as the ratio of the actual displacement to the yield displacement for Node 16 at the center of the member. The strain ratio is taken as the ratio of the actual total strain (elastic plus plastic) to the yield strain for element 16 at node 16. For primary members, the ductility ratio is determined by the displacement ratio based on Section A8.1 of WB-DC-20.

The reserve capacity of the primary member is taken as the temperature at which the ductility ratio reaches a value of 3 in accordance with Section A8.1.4 of WB-DC-20, corresponding to the displacement ratios in Figure 11.6.2A.

Figure 11.6.2A indicates that the temperature limit is 410 ° F or a temperature difference of 340 ° F at a displacement ratio of 3.

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11.6.2 (Continued)

Figure 11.6.2A

DISPLACEMENT RATIO VS TEMPERATURE – HOWLAND NEWMARK THERMAL MODEL

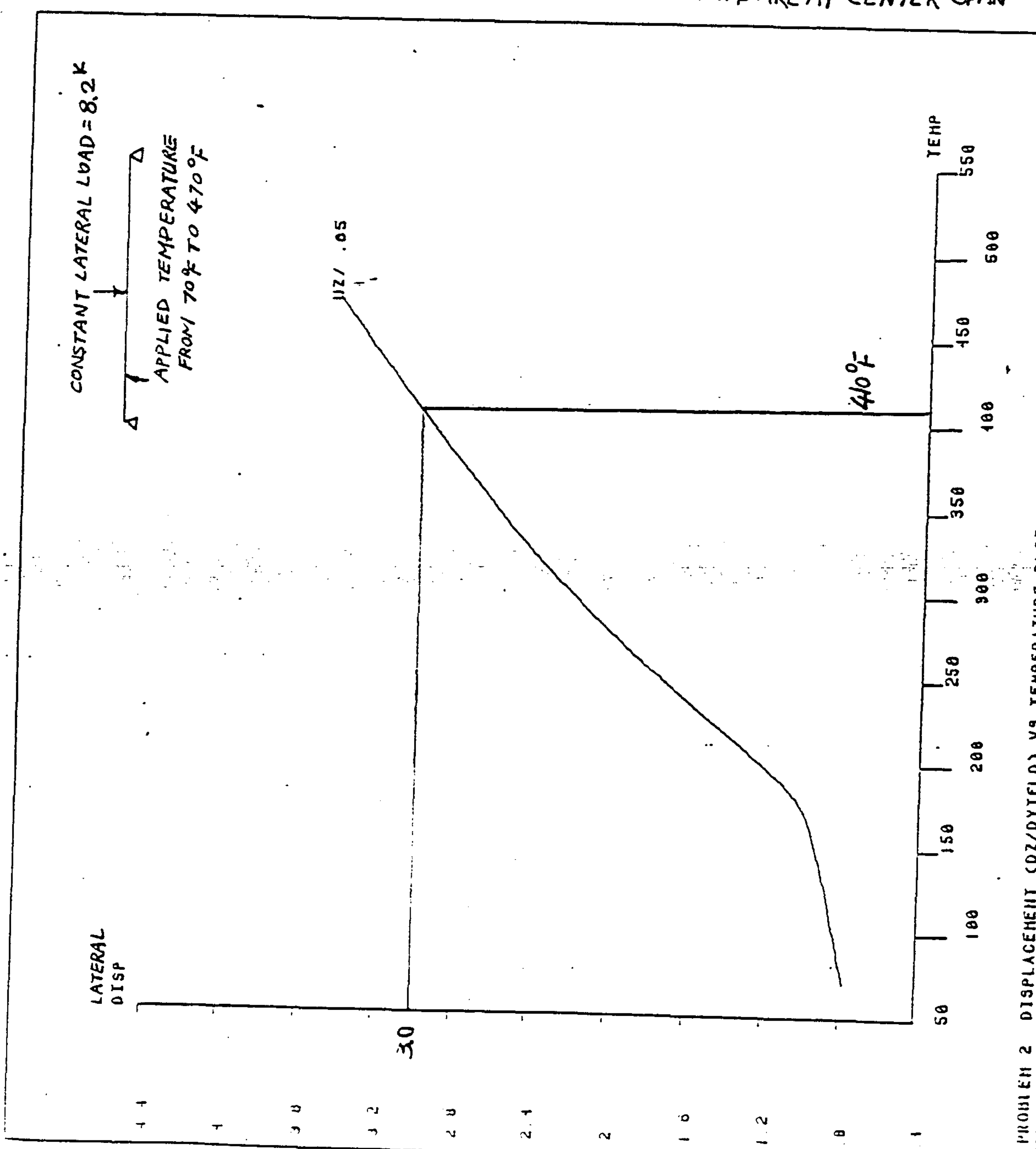
APPLIED CONSTANT LATERAL LOAD ($F_2 = 8.2^k$)

DISP. RATIO = $\frac{\text{ACTUAL LATERAL DISP}}{\text{LATERAL DISP. @ YIELD}}$

ALL DISPLACEMENTS ARE AT CENTER SPAN

ANSYS 4.3A
MAR 28 1991
14 49 33
PLOT NO. 1
POST26

ZV =1
DIST=.8668
XF =.5
YF =.5
ZF =.5



PROBLEM 2 DISPLACEMENT (DZ/DYIELD) VS TEMPERATURE PLOT, DYIELD=0.05

11.6.2 (Continued)

Figure 11.6.2B

STRAIN RATIO VS TEMPERATURE – HOWLAND NEWMARK THERMAL MODEL

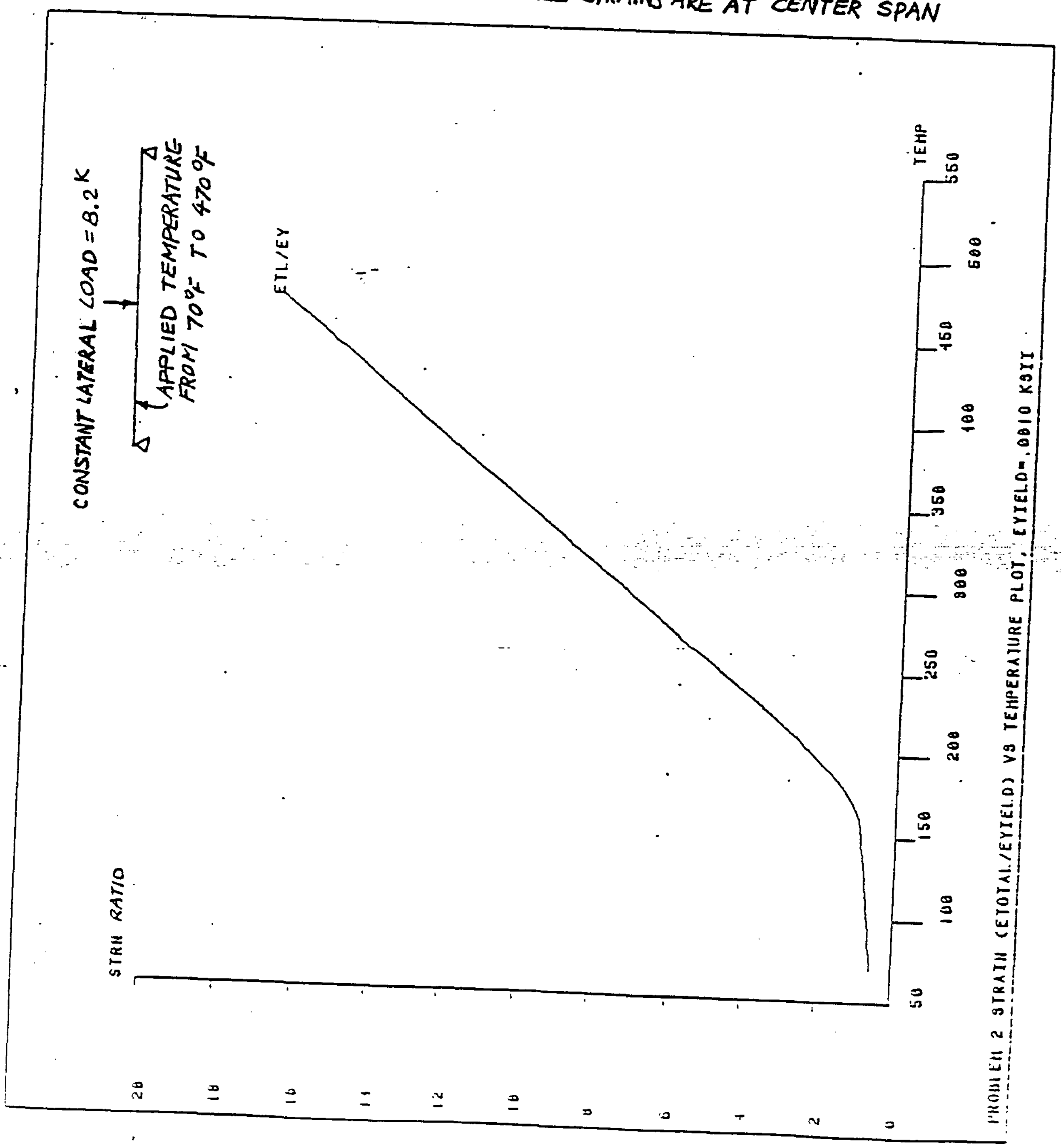
APPLIED CONSTANT LATERAL LOAD ($F_Z = 8.2^K$)

STRAIN RATIO = $\dfrac{\text{ACTUAL COMBINED STRAIN}}{\text{COMBINED STRAIN @ STRESS YIELD}}$

ALL STRAINS ARE AT CENTER SPAN

ANSYS 4.3A
MAR 28 1991
14 49 33
PLOT NO. 2
POST26

ZV =1
DIST=.8666
XF =.5
YF =.5
ZF =.5



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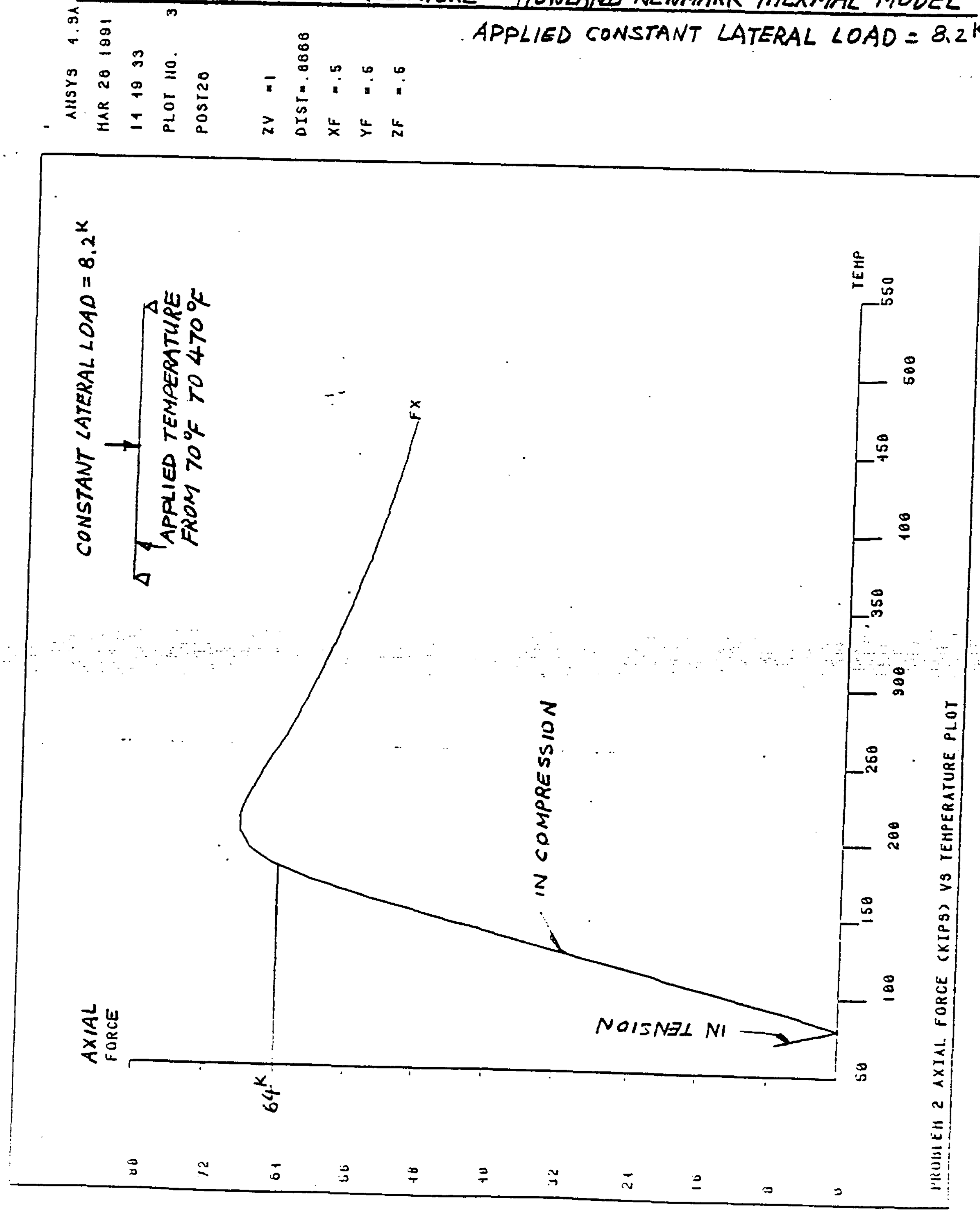
11.6.2 (Continued)

Figure 11.6.2C

AXIAL FORCE VS TEMPERATURE - HOWLAND NEWMARK THERMAL MODEL

APPLIED CONSTANT LATERAL LOAD = 8.2^K



11.6.3 Results for Johnston-Cheney Thermal Model

For Problem 3 of Johnston-Cheney model with eccentric thermal compression, ANSYS results, from computer runs output file 'JOCW3c1' (Appendix B) for the range of temperature from 70 ° F to 470 ° F and later extended to 570 ° F with output file "JOCW3X1". The results are given in Figures 11.6.3A, 11.6.3B and 11.6.3C.

Figure 11.6.3A provides the displacement ratio varying with temperature and Figure 11.6.3B for the strain ratio versus temperature. Figure 11.6.3C shows the axial forces in the member varying with change of temperature.

In the figures, the displacement ratio is defined as the ratio of the actual displacement to the yield displacement for Node 16 at the center of the member. The strain ratio is taken as the ratio of the actual total strain (elastic plus plastic) to the yield strain for element 16 at node 16. For primary members, the ductility ratio is determined by the displacement ratio based on Section A8.1 of WB-DC-20.

Figure 11.6.3A indicates that the reserve capacity, corresponding to a displacement based ductility ratio of 3, in terms of temperature difference is at least 400 ° F.

Figure 11.6.3C gives a yield axial force of 95 kips. The average compressive stress at yield is calculated by

$$f_a = (95)/A = (95)/(5.88) = 16.2 \text{ ksi}$$

For W6x20 member,

$$kl/r = (1)(119)/(2.66) = 44.7$$

In comparison to test data, Figure 28 of Reference 9, the data curve for e/s = 1 with e about strong axis, gives fa = 16.2 ksi at kl/r = 44.7.

11.6.3 (Continued)

Figure 11.6.3B

STRAIN RATIO VS TEMPERATURE – JOHNSTON-CHENEY THERMAL MODEL

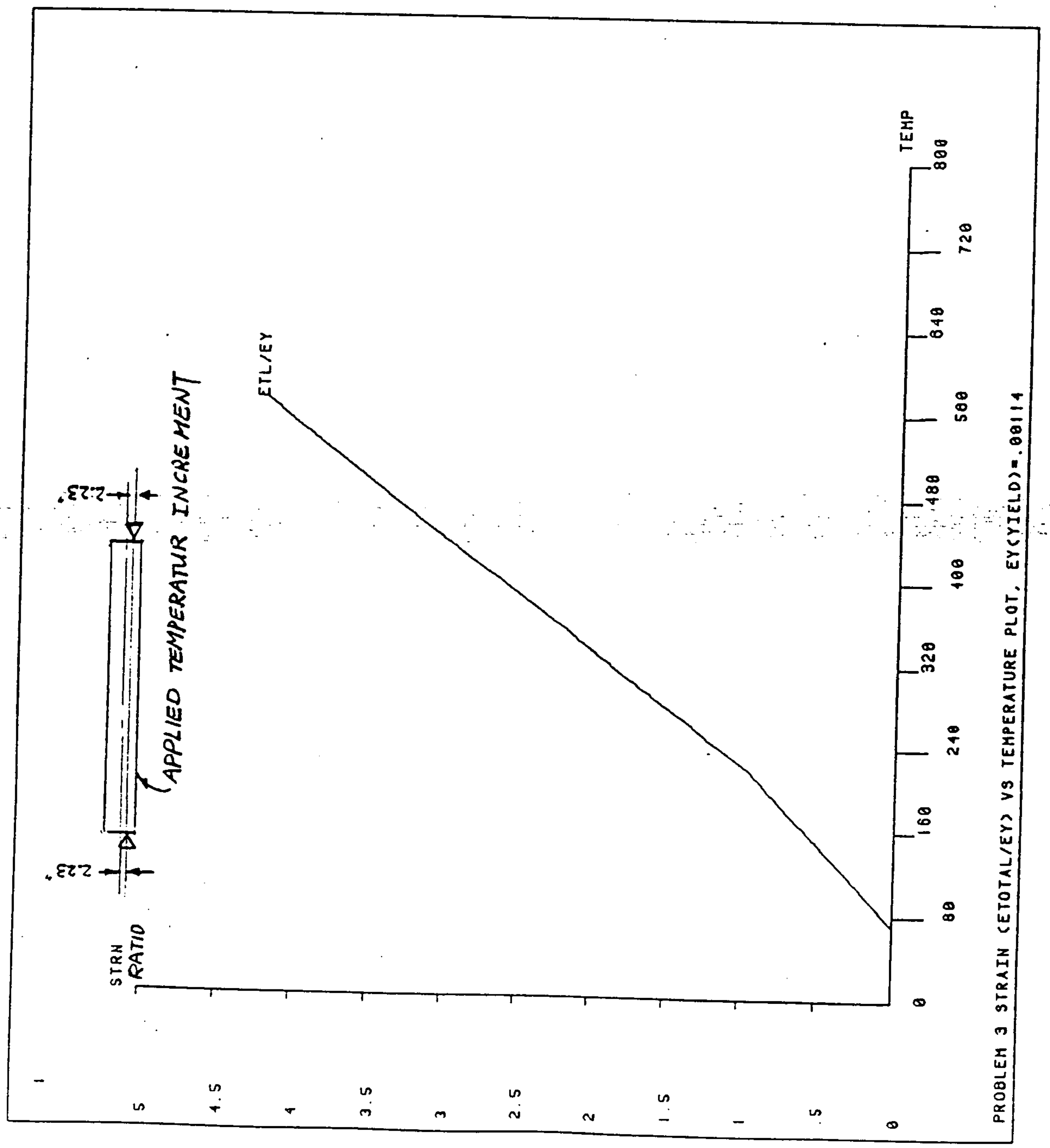
ANSYS 4.3A
APR 10 1991
10 08 53
PLOT NO. 3
POST26

ZV =1
DIST=.6666
XF =.5
YF =.5
ZF =.5

2.23" SUPPORT ECCENTRICITY

STRAIN RATIO = $\frac{\text{ACTUAL COMBINED STRAIN}}{\text{COMBINED STRAIN @ STRESS YIELD}}$

ALL STRAINS AT CENTER SPAN



11.6.3 (Continued)

Figure 11.6.3A

DISPLACEMENT RATIO VS TEMPERATURE - JOHNSTON CHENEY THERMAL MODEL

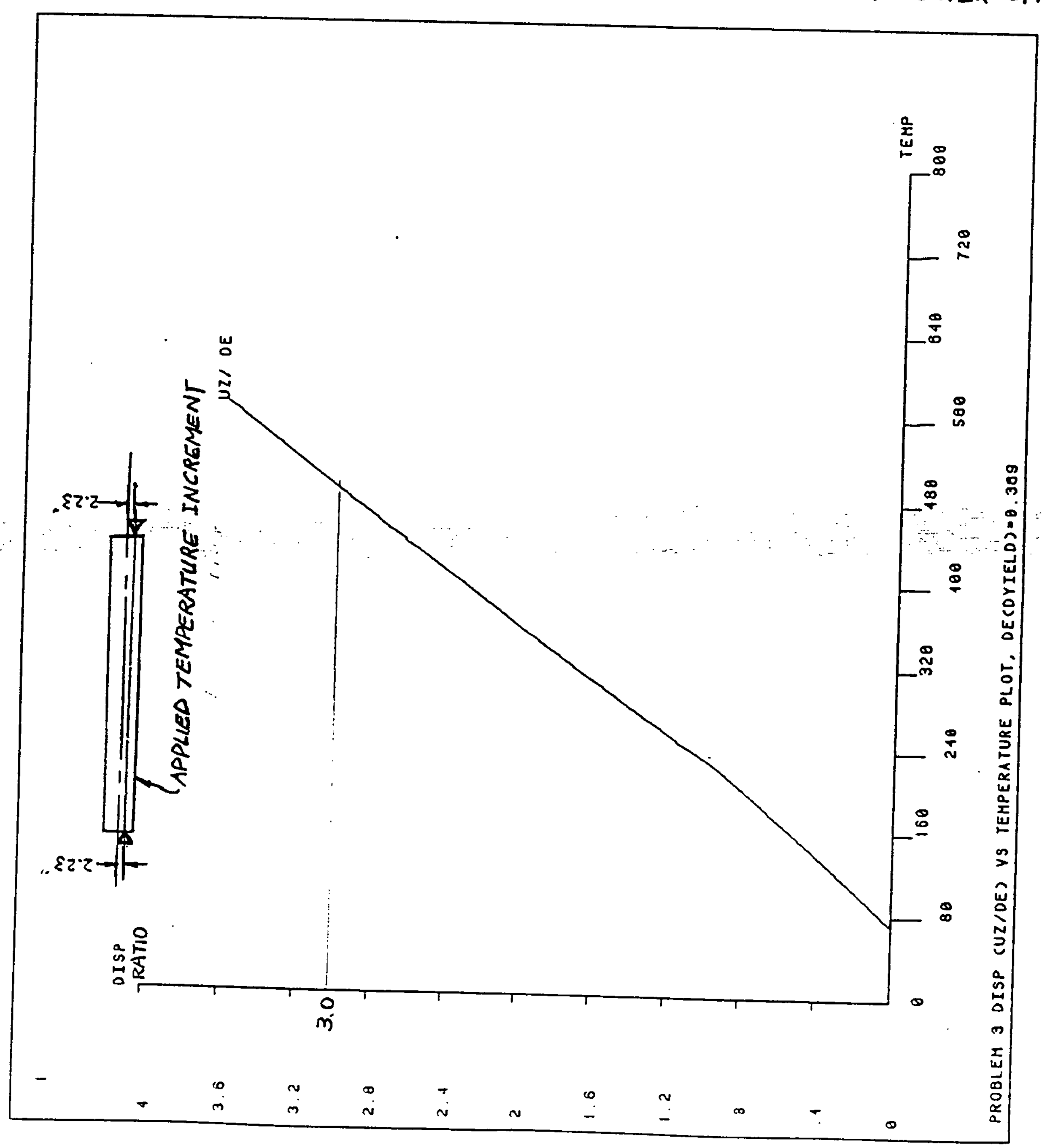
2.23" SUPPORT ECCENTRICITY

DISP RATIO = ACTUAL LATERAL DISP / LATERAL DISP. @ STRESS YIELD

ALL DISPLACEMENTS AT CENTER SPAN

ANSYS 4.3A
APR 10 1991
10 08 53
PLOT NO. 2
POST26

ZV =1
DIST=.6666
XF =.5
YF =.5
ZF =.5

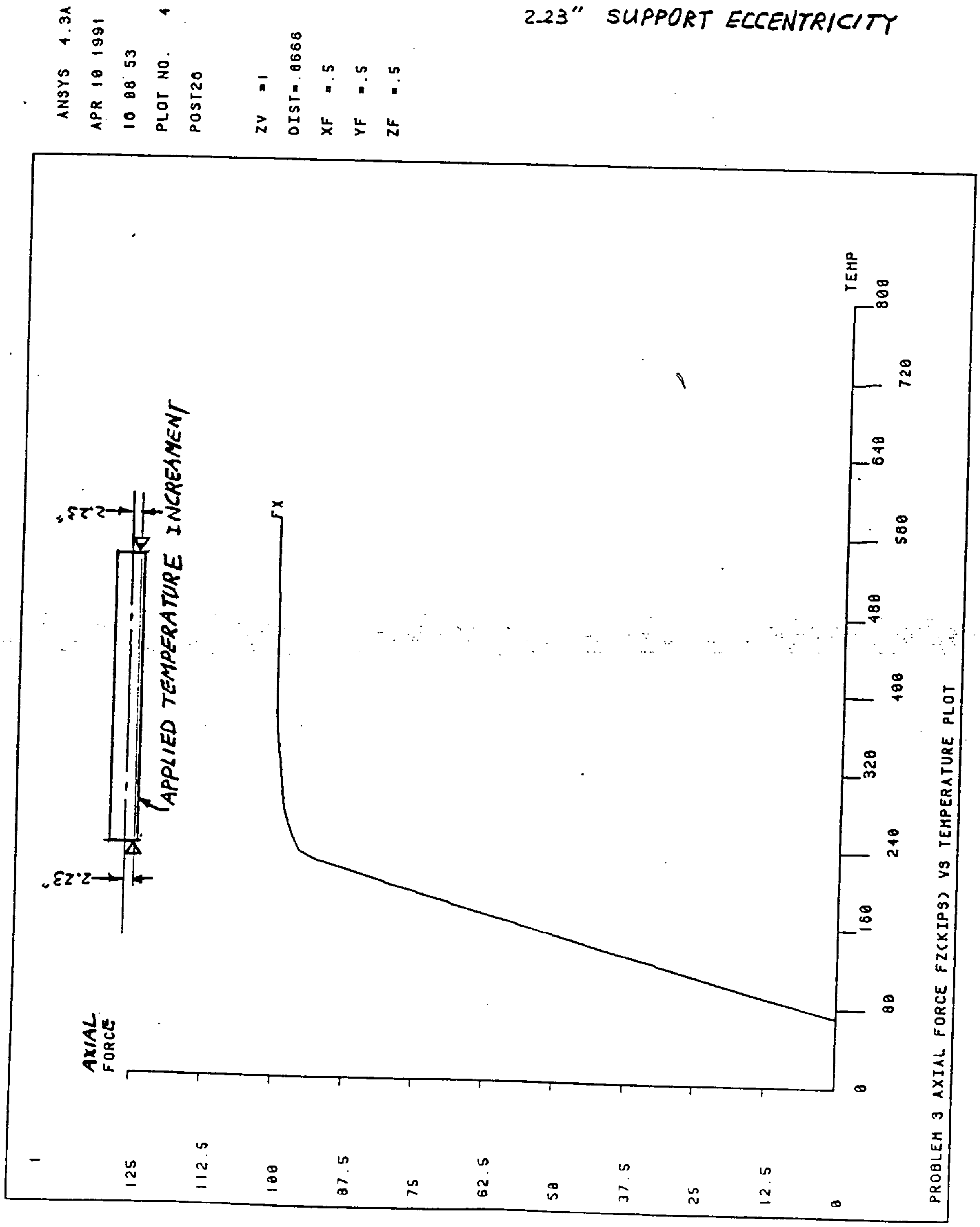


11.6.3 (Continued)

Figure 11.6.3C

AXIAL FORCE VS TEMPERATURE – JOHNSON CHENEY THERMAL MODEL

2.23" SUPPORT ECCENTRICITY



11.6.4 Results for High Ductility Ratio Model

For Problem 4 of High Ductility Ratio Model with increment temperature, ANSYS results are obtained from computer run output files 'JOCW4C2' (Appendix B) and a later run with extensive output information with file 'JOCW4X2', for the range of temperature from 70 ° F to 470 ° F. Results are given in Figures 11.6.4A through 11.6.4D.

Figure 11.6.4A provides the displacement ratio varying with temperature and Figure 11.6.4B for the strain ratio versus temperature for the primary member. Figure 11.6.4D shows the secondary member strain ratio varying with temperature. The axial force in the primary member is given in Figure 11.6.4C for each temperature up to 470 ° F.

In the figures, the displacement ratio is defined as the ratio of the actual displacement to the yield displacement for Node 26 at the center of primary member. The strain ratio is taken as the ratio of the actual maximum total strain (elastic plus plastic) to the yield strain, for element 27 at node 26 for the primary member and for element 57 at node 58 for the secondary member. The ductility ratio is determined by the displacement ratio for primary members, and by strain ratio or displacement ratio for the secondary member, in accordance with WB-DC-20.

From Figure 11.6.4D, at second member strain ratio = 20, the corresponding temperature is 275 ° F. From Figure 11.6.4A, 4B & 4c, at temperature = 275 ° F,

The primary member displacement ratio = 1.27
strain ratio = 2.01
axial force = 11.5 kips

The above results indicate that second member strain ratio controls the allowable limit and that the flexibility of second member tends to limit the axial forces of the primary member. The displacement ratio is not provided for the secondary member since it was initially at 70 ° F.

11.6.4 (Continued)

Figure 11.6.4A

DISPLACEMENT RATIO VS TEMPERATURE – HIGH DUCTILITY RATIO MODEL

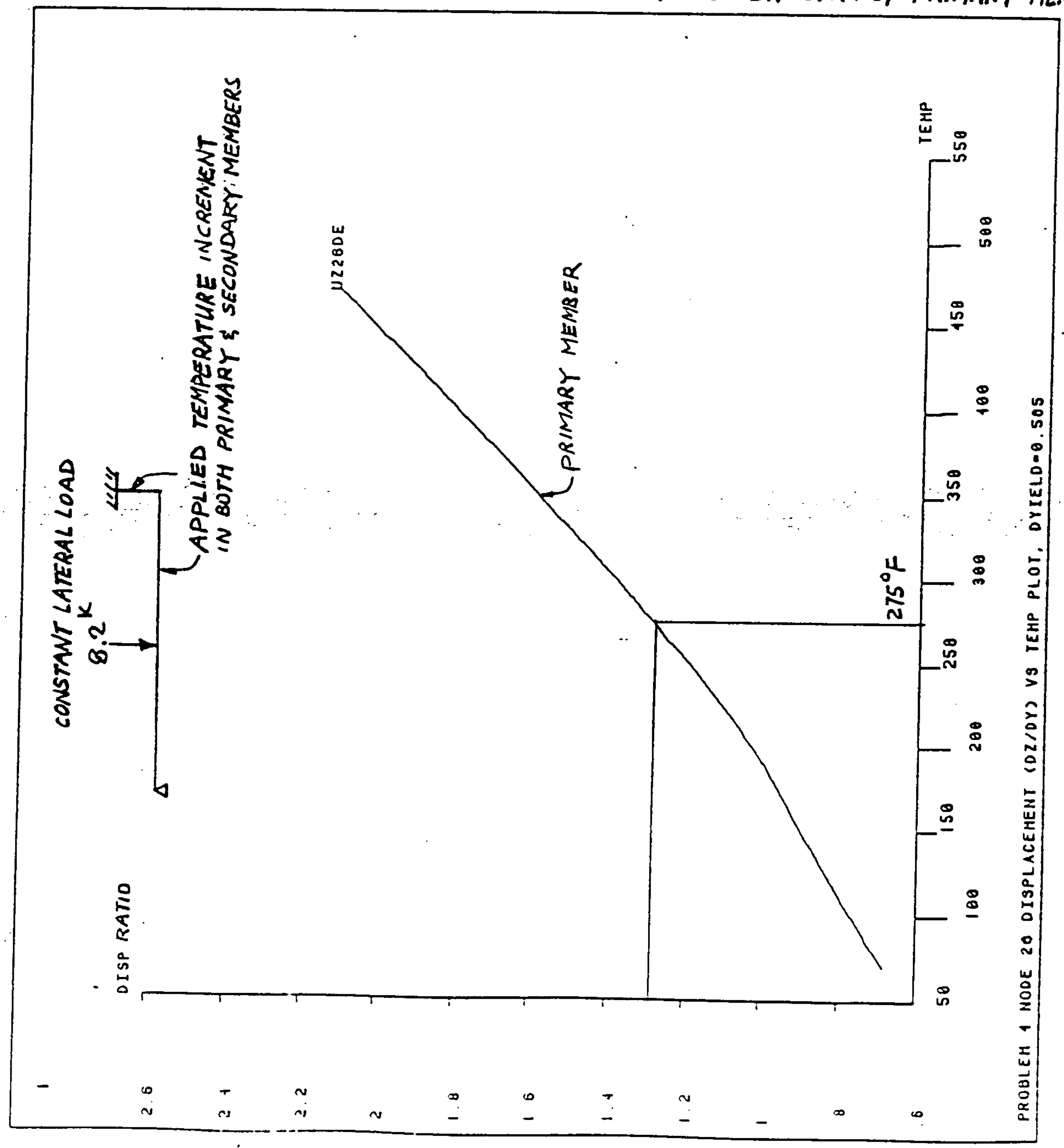
ANSYS 4.3A
APR 3 1991
16 00 13
PLOT NO. 1
POST26

ZV =1
DIST=.6666
XF =.5
YF =.5
ZF =.5

APPLIED CONSTANT LATERAL LOAD = 8.2^K
AT CENTER SPAN OF PRIMARY MEMBER

$$\text{DISP RATIO} = \frac{\text{ACTUAL LATERAL DISP.}}{\text{LATERAL DISP. @ STRESS YIELD}}$$

ALL DISP. AT CENTER SPAN OF PRIMARY MEMBER



11.6.4 (Continued)

Figure 11.6.4B

STRAIN RATIO VS TEMPERATURE – HIGH DUCTILITY RATIO MODEL

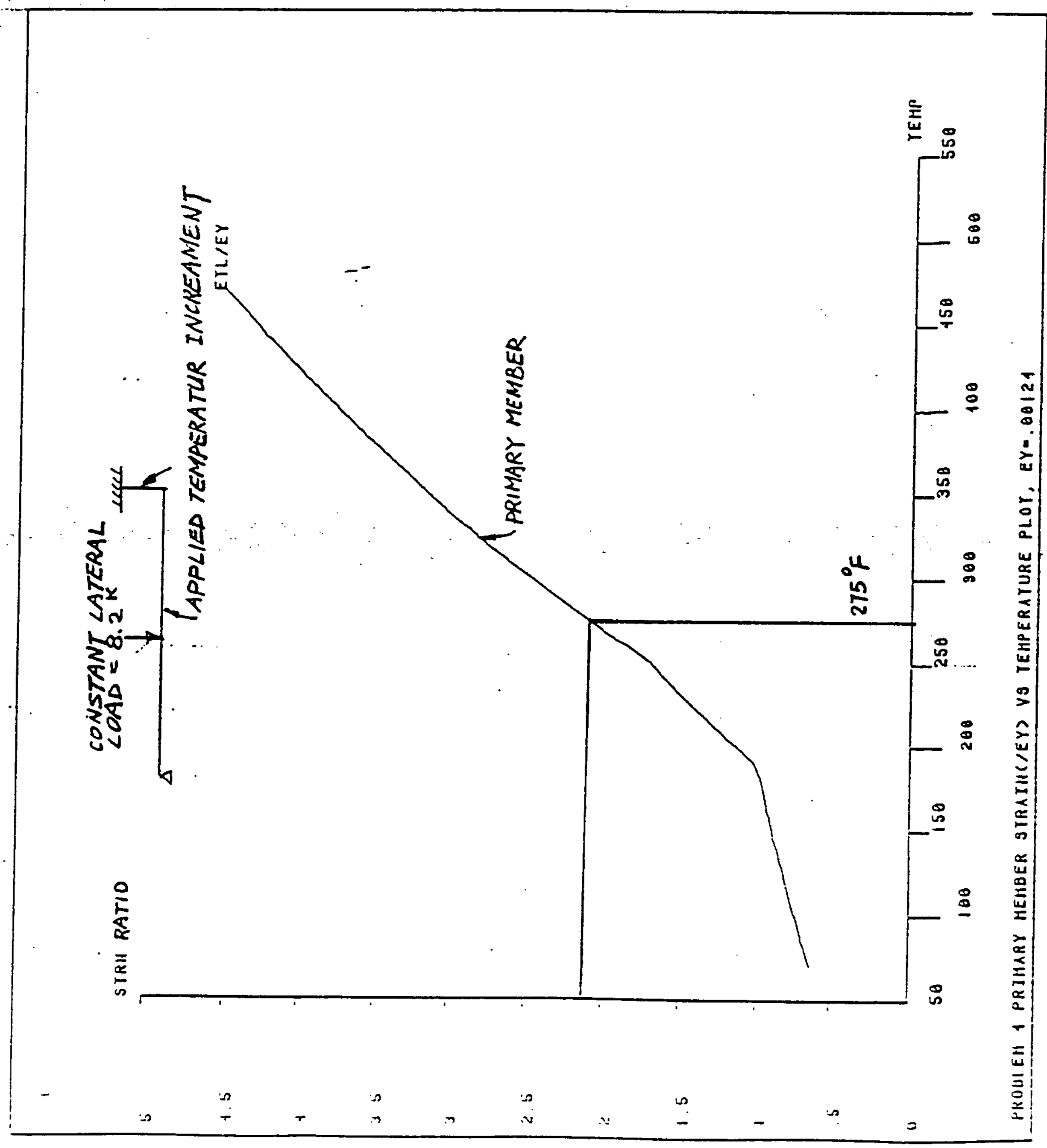
ANSYS 4.3A
MAR 28 1991
15 50 23
PLOT NO. 2
POST20

ZV =1
DIST=.6666
XF =.5
YF =.5
ZF =.5

APPLIED CONSTANT LATERAL LOAD = 8.2 K
AT CENTER SPAN OF PRIMARY MEMBER

STRAIN RATIO = $\frac{\text{ACTUAL COMBINED STRAIN}}{\text{COMBINED STRAIN @ STRESS YIELD}}$

ALL STRAINS AT CENTER SPAN OF PRIMARY MEMBER

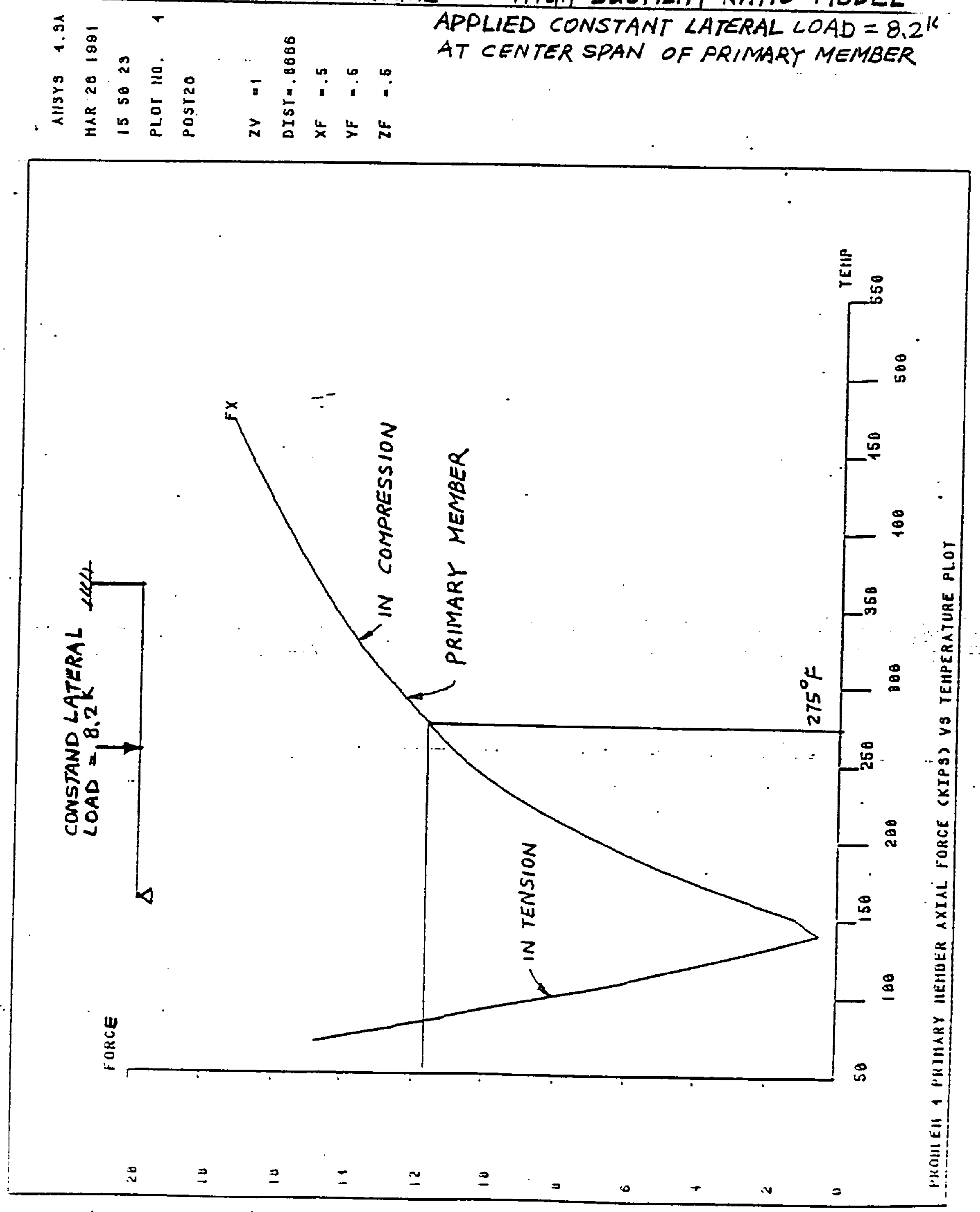


11.6.4 (Continued)

Figure 11.6.4C

AXIAL FORCE VS TEMPERATURE - HIGH DUCTILITY RATIO MODEL

APPLIED CONSTANT LATERAL LOAD = 8.2K
AT CENTER SPAN OF PRIMARY MEMBER



11.6.4 (Continued)

Figure 11.6.4D

SECONDARY STRAIN RATIO VS TEMPERATURE – HIGH DUCTILITY RATIO MODEL

APPLIED CONSTANT LATERAL LOAD = 8.2 K

AT CENTER SPAN OF PRIMARY MEMBER

STRAIN RATIO = $\frac{\text{ACTUAL COMBINED STRAIN}}{\text{COMBINED STRAIN @ STRESS YIELD}}$

ALL STRAINS AT FREE END OF SECONDARY MEMBER

ANSYS 4.3A

APR 3 1991

10 00 14

PLOT NO. 5

POST26

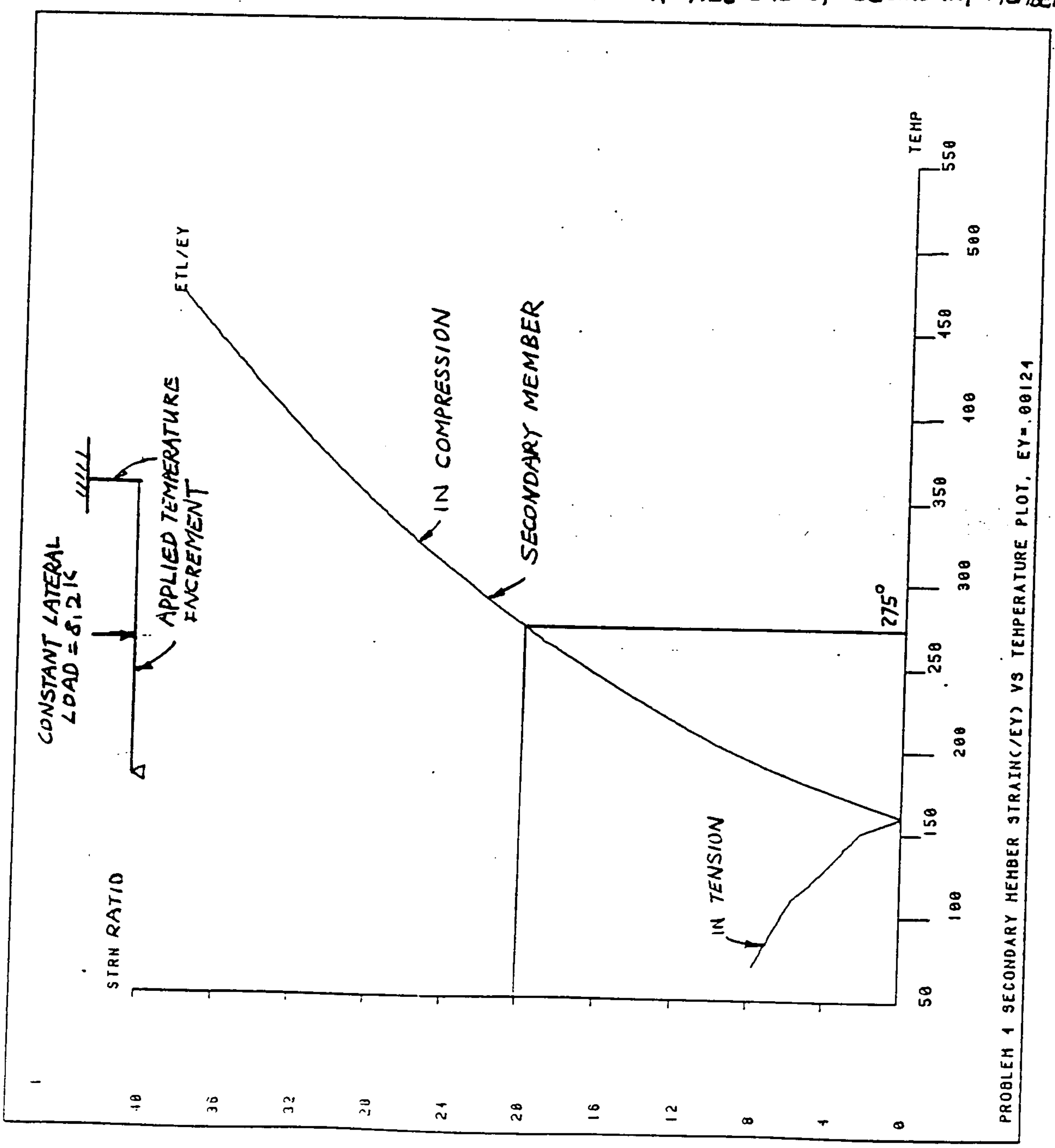
ZV =1

DIST=.8666

XF =.5

YF =.5

ZF =.5



12. SUMMARY OF CALCULATION RESULTS

Problems 1 results are nearly identical to test data in Reference 10.

Problems 2 and 3 exhibit reserve capacity of member when the displacement ratio is above the acceptance criteria (3) at temperature higher than 400 °F (330 °F temperature difference).

Problem 4 shows that at the temperature the strain ratio for second member reaches 20, the corresponding displacement ratio for the primary member is 1.2 and strain ratio is 2.0.

13. CONCLUSION

* ANSYS nonlinear analysis results are in excellent agreement with test data in References 10 and 9. The applicability of ANSYS nonlinear analysis is demonstrated.

* The axial force in a member due to thermal effect is self-limiting. The axial force does not increase as temperature increases after the axial force reaches a peak value.

* The analysis results indicate reserve capacity when the displacement ratio is above the acceptance criteria (3).

* Problem 4 results indicate that high strain ratio may develope in the secondary member while the displacement ratio of the primary member remains below 3.

* Ductile behavior is present in members subjected to static load as well as thermal load.