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

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CALCULATION DESIGN VERIFICATION (INDEPENDENT REVIEW) FORM

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Justification (explain below):

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- <u>Method 1</u>: 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.).
- <u>Method 2</u>: 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.
- <u>Method 3</u>: 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.

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	_3. DS-C1.8.1 R3 Standard Calcula	tion for Evaluation The TT	D_L _11_1
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	4. WB-DC-20-1 R6 Concrete Struct	uroa Conoral	
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	_0. WD-UC-2U-21 Kb Misc. Steel Co	mponent for Category I Stru	ctures
	_/. WB-DU-40-31.53 R4 Design Crit	eria for Pipe Whip Restrain	ts,
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	1. AISC Manual of Steel Constructi	on, 7th Edition	
	2. AWS D.1.1-83, 1983, Structural	Welding Code	
	3. ACI 318-77 Building Code Requir	ements for Reinformed Comer	ata
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8.	ASSUMPTIONS, LITERATURE SEARCHES AND OTHER APPLICATE BACKGROUND DATA
	None
9.	APPLICABLE REFERENCES (MARKED "X")
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· · ·	3. WCG-1-580 R0 Selection and Grouping of Embedd Plates for Evaluation
	 4. WCG-1-256 R0 Concrete Quality Evaluation 5. N3-PA-34 R0 Non-linear Transient Dynamic Analysi of FW Lines-Piping Analysis Calculation No. N3-F 34
	6. QIR-CEB-WBN 90757 R0 Active List of Pipe Wh Restraints/Protective Devices (PD's)
	/. (specified) X8. ANSYS Version 4.3 X9. Steel Columns of Rolled Wide Flange Section
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	X 10. Static Load Deflection Tests of Beam-Columns, F.L. Howland and N.M. Newmark, University Illinois Structural Research Series No. 6 December 1953.
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	Selected Nuclear Power Plants, by N.M. Mark a W.J.Hall, NUREG/CR-0098, May 1978.

See section 11.4

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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

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Cheney (Attachment D) is considered in this analysis.

Problem 4:

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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.

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Figure 11.2.1 Geometric Configuration for the Member Considered in Problem 1

Constant Axial Load and Increment Lateral Load



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Figure 11.2.2 Geometric Configuration for the Member Considered in Problem 2





Max &T= 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. AT = 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



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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 stressstrain 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 $C\overline{13} = 10$ 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.

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11.4 Input Data:

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

- Beam M4x13 1.
- Hinged at both ends of member 2.
- 3.
- Constant axial load = 64 kips Incremental lateral load simulated by imposed displacement at mid-span of the member in the 4. direction of strong axis of cross-section
- Bilinear stress strain relation, E = 29,000 ksi, 5. Est (second tangent) = 29 ksi
- Fy = (58.2+38.3+69.4)/3 = 55.3 ksi (averaged data 6. 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
 - Constant lateral load = 8.2 kips 3.
 - Initial temperature = 70 °F. 4. Incremental
 - temperature to a maximum DT = 400 °F. Bilinear stress - strain relation, E = 29,000 ksi, 5.
 - Est (second tangent) = 29 ksi Fy = 55.3 ksi
 - 6. Fy = 55.3 ksi 7. Coefficient of thermal expansion = $(6.5)(10^{-6})$ ("/")/(F)
- Problem 3 input data is based on the test item 6-5 in the 11.4.3 Johnston-Cheney test report.
 - 1. Beam W6x20
 - Member hinged at both ends 2.23" below the beam 2. centerline (Eccentricity = 2.23 inch; Eccentricity ratio e/s = eA/S = 1, where $A = area = 5.88 in^2$, S = sectional modulus =13.4 in³)
 - 3. Initial temperature °F. = 70 Incremental temperature to a maximum DT = 500 °F.
 - Bilinear stress strain relation, E = 29,000 ksi, 5. Est (second tangent) = 1,500 ksi
 - 6. Fy = 33.0 ksi (based on test data)
 - Coefficient of thermal expansion = $(6.5)(10^{-6})$ 7. ("/")/(°F)

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11.4.4 Problem 4 input data:	· ·

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

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Coefficient of thermal expansion = $(6.5)(10^{-6})$ 7. ("/")/(°F)

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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.

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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.

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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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	By C Ule Date 9-3-9! Sheet 20 of 55
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	Subject Test Correlation Study for Thermal Mag of Busiling
	Doug Ior Inermal Use of Ductility Ratio
	11.5.1.2 List of ANSYS Input Data for Howland-Newmark Test Model
	********* ANSYS INPUT DATA LISTING (FILE18) *********
	1 /PREP7
	2 /PMODE 3 /SHOW
	4 /TITLE, HOWLAND-NEWMARK MODEL, FX=64KIPS, DZ/DE=0.2,4.6,0.2, SIGY = 55.3KSI
•	5 /COM HOWLAND - NEWMARK MODEL
	7 /COM REF. NEWMARK LOAD TESTS
	8 /COM SPECIMEN 415 S 4M13.0 9 /COM E=29E3 KSL FY=55.3 KSL
	10 /COM
et e j	12 /COM OUTPUT: JOCWICZ
	13 /COM FILE12: JFCW1C2
	14 /COM PLOT FILE: JGCWIC2 15 /COM
	16 /COM
	17 KAN,0 18 KAY,6,1
	19 KNL,1
	20 ET,1,24,,,,,,1 21 TREF.70
	22 EX,1,29E3
	23 ALPX,1,6.5E-6 24 C*** NONI INFAR MATTERIAL CONTRACT
	25 NL,1,13,10
	26 NL,1,19,70,470 27 NL 1 25 55 2 55 2
•	28 NL,1,31,29,29
I	29 C*** DEFINE BEAM LENGTH AND CROSS SECTION PROPERTIES
	31 BF=3.940
	32 TF=0.370
	33 D=4.00 34 TW=0.254
ina sinanan Arianan Arianan	37 BB=(D-TF)/2
	38 QA=AA/2
	39 QB≃BB/2 40 *STAT
-2	41 R,1,AA,BB,0,QA,BB,TF *STIF24 REAL PROP.
	42 RMORE,0,BB,TF,-QA,BB,TF 43 RMORE,-AA,BB,TF,0,BB,0
	44 RMORE,0,QB,TW,0,0,TW
	45 RMORE,0,-QB,TW,0,-BB,TW 46 RMORE,44, BB,0,0A, BB,TW
	47 RMORE,0,-BB,TF,QA,-BB,TF
	48 RMOREAA,-BB,TF 49 C***
	50 NUM=31
	51 $MID = (NUM + 1)/2$ 52 $ND = 3$
	53 AL=L/4
	54 N,1 55 N ND+1 AT
	56 FILL
	57 N,NUM-ND,L-AL 58 FUL
	59 N,NUM,L
	60 FILL

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		Sul	bjed	st_	Test (Corre	latio	n Stud	y for	Therma	1 Use o	f Duo	+ ;] ; + .			
											<u>~_000_0</u>	<u>r Duc</u>	LILLCY	Ratio		
			F	4	o (o-	•									• •	
		**	. · · · ·		2 (00	ntir	lued)									
		1				Neven										
			c1	\ \\\\		<u>1919 II</u>	NFUI DA.	IA LISTING	3 (FILEI8)	*******	•					
		6	52 E,	NUM- 1,2,NI	+1,172,0,5 JM+1											
		6	i3 RP i4 C*	'30,1,1	1,0	* 1	RPNNN, N	NN=NUM	-1							
	•	6	5 11	ER,-20)											
		6	0 PO 7 /PI	STR,, BC,AI	1,5 I,1											
100		6	8 /VI	EW,,(0,-1,0	~~ > T ~ PP										
		7	0 D,1	1,UY,(0,,,,UZ,RO	TX	IONS:									
		7. 7.	1 D,1 2 C*	NUM, ** TU	UX,0,,,,UY NIF.270	,UZ,RO	TX									
		7. 7	3 F,1	,FX,6	4											
		7	5 DE	=0.6	FINE KEPE	ATING.	LOADING	is as mac	RO							
		τ	5 °CI 7 D.N	REAT,	,TMP Z.ARGI											
		78	J LW	RITE	-,											
		80) *US	SE,TM	P,DE*0.2											
		81 82	(RP2 2 /TT	/3,,DE	1001 AND	NEWA	ADVNOT									
	÷	83	/PN	UM,N	IODE,-1	-115, W ML	AKK MUL)EL, FX=6	KIPS, DZ/	DE=0.2,4.6	,0.2, SIGY = 5	55.3KSI				
		. 85	i /PN	.OT UM,N	ODE,1											
		· 86 87	NRS	SEL, 1,	NUM, MID	-1										
		88	EPL	ŌT												
		89 90	AFV FIN	VRITE ISH	4,1											
		91 97	/INP	UT,27	7											
		93	/POS	ST1												
		94	STO STR	RE,RI ESS.S	EAL_DISP,S X01.24.13	TRES, N	FORC, RF	ORC	· ·		· . · · · ·			· · · · · · · · · · · · · · · · · · ·	مار به آگرد سری همه در در اور آرایش می در مهری در اور در آمایش در می می در	
		÷ 96	STR	ESS,S	X08,24,20						· · · · · · · · · · · · · · · · · · ·	· · · · ·	and a second second Second second second Second second			2
		98	STR	ESS, 5. ESS, E	E01,24,27										· · · · · ·	
, .		99 100	STR	ESS,E	E08,24,137											
		101	STR	ESS,E	P01,24,96											
2 17		102	STR	ESS,E ESS,E	P08,24,138 P15,24,180											
		104 105	*CRI SET.	EAT, M	MAC										·	
		106	ERSI	EL,EL	EM,16											
		107	PRD	EL,NC ISP	DDE,16	*PRIN	IT SEL. N	ODAL DISI	2							
		109 110	PREF	POR TRS		_			•							
		111	*ENI)	• •											
		112	PUSE RP23	:,MAC ,,1	.,1											
		114 115	FINIS	3H T76												
		116	/SHO	W												
		117 118	TVAF DISP	R,1 .2.16.1	JZ 11764											
-		119	NFOF	CE,3	,16,16,FZ,F	Z64										
		120	NFOR	кСЕ,4	,16,16,MY,	MY64										

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Subject Test Correlation Study for Thermal Use of Ductility Ratio

11.5.1.2 (Continued)

ANSYS INPUT DATA LISTING (FILE18)

- 121 DE=(1)/.6122 PE=(2)/9.64 123 ME=(1)/212 124 ABS,5,2,,,UZ/,DE,,DE 125 ABS,6,3,,,FZ/,PE,,PE 126 ABS,7,4,,,MY/,ME,,ME
- 127 /TITLE, HOWLAND-NEWMARK MODEL, FX=64KIPS, DZ/DE=0.2,4.6,0.2, SIGY=55.3KSI 128 /GRAPH,LABX,DISP
- 129 XVAR,5
- 130 /GRAPH, LABY, FORC
- 131 PLVAR,6
- 132 PLVAR,6

1

No. and

÷.,

- - - -

- 133 /GRAPH, LABY, MON.
- 134 PLVAR,7
- 135 PLVAR,7
- 136 /GRAPH,LABY,F&M
- 137 PLVAR, 6,7
- 138 PLVAR, 6,7
- 139 /TITLE, HOWLAND-NEWMARK MODEL, FX=64KIPS, DZ/DE=0.2,4.6,0.2, SIGY=55.3KSI 140 /GRAPH,LABX,DISP
- 141 XVAR,2
- 142 /GRAPH, LABY, FORC
- 143 PLVAR,3
- 144 /GRAPH, LABY, MON.
- 145 PLVAR,4
- 146 /GRAPH, LABY, F&M 147 PLVAR, 3,4
- 148 FINISH



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Project <u>WBNP Unit 1</u> Subject <u>Test Correlation Study for Thermal Use of Ductility Ratio</u>

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



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		II Study IOF T	<u>nermaı</u>	<u>Use of Duct</u>	<u>ility 1</u>	Ratio	
11	.5.2.2 List of Al Model	NSYS Input	Data	for Howl	and-Ne	wmark	Thermal
	********* ANSYS INPUT DAT	ra listing (file18) 🔹					
2 2 2 2 2 2 2 2 2 2 2 2 2 2	 /PREP7 /PMODE /SHOW /TITLE, HOWLAND-NEWMARK MOI /COM HOWLAND - NEWMARK MOI /COM HOWLAND - NEWMARK MOI /COM REF. NEWMARK LOAD TESTS /COM SPECIMEN 415 \$ 4M13.0 /COM E=29E3 KSI, FY = 55.3 KSI /COM E=29E3 KSI, FY = 55.3 KSI /COM NPUT: JOHN2C1 /COM OUTPUT: JOCW2C1 /COM FILE12: JFCW2C1 /COM FILE13: JGCW2C1 /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 CONST NL,1,13,10 NL,1,19,70,270 NL,1,2,55.3,55.3 NL,1,31,29,29 C*** DEFINE BEAM LENGTH AND C 	DEL, FZ≈-8.2KIPS, DT= DEL 3 TANT CROSS SECTION PROPE	-10,400,10, 1	SIGY = 55.3KSI			
31	BF=3.940	M13.0					
32 33	TF=0.370 D=4.00						
34	TW=0.254						
35 36							
37	BB = (D-TF)/2.				,		
38	QA=AA/2						
39 ∡∩	QB=BB/2 •STAT						
41	R,1,AA,BB,0,QA,BB,TF	TP24 REAL PROP					
42 42	RMORE, 0, BB, TF, -QA, BB, TF						
44	RMORE.0.0B.TW 0.0 TW						
45	RMORE, 0,-QB, TW, 0,-BB, TW						
46 47	RMORE,-AA,-BB,0,-QA,-BB,TF						
48	RMORE AA. BR TF						
49	C***						
50	NUM=31						
51 52	MID = (NUM + 1)/2						
53	AL=1/4						
54	N,1						
55	N,ND+1,AL						
56	FILL						
57 59	N,NUM-ND,L-AL						
.	i lida						
59	N.NUM.L.						

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Subject Test Correlation Study for Thermal Use of Ductility Ratio

11.5.2.2 (Continued)

1

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

6	1 N,NUM+1,L/2,0,5	
6	2 E,1,2,NUM+1	
6	3 RP30,1,1,0	* RPNNN NNN=NTR()
6	4 C***	1211111, 11111-110M-1
. 6	5 ITER10	
. 6	6 POSTR.1.5	
6	7 /PBC.ALL.1	
6	8 /VIEW01.0	
6	C*** BOUNDARY C	
2	D.1.UX.0UY.UZ.T	ROTY
P	D.NUM.UX.0	IZ BOTY
7.	2 C*** TUNIF.270	
7.	F.MID.FZ8.2	
74	C*** DEFINE REPEA	TING LOADINGS AS MACRO
7	CREAT.TMP	THE FOUNDING AS WACKO
76	TUNIF.ARG1	
au	LWRITE	
78	*END	
79	*USE TMP 70	
80	RP41 10	
81	TTTLE HOWT AND	NEWALARY MODEL FELS & CAMPAGE
82	/PNUM NODE .1	The what is model, $FZ = -8.2$ KIPS, $DT = 10,400,10$, SIGY = 55.3KSI
83	EPLOT	
84	PNUM NODE 1	
85	NRSET 1 NILL MID 1	
86	EPI OT	
87	EPLOT	
88	AFWRITE 1	
89	FINISH	
90	/INPUT.27	
91	FINISH	
92	/POST1	
93	STORE REAL DISP ST	THE NEORC BRONC
94	STRESS SX01 24 13	ALD, AFORC, RFORC
.وو. الله الشامية الماريج الماريج	"STRESS SX08 24 20	and a second s • (α) α α α α α α α α α α α α α α α α α α
96	STRESS SX15 74 27	n second and a second secon
97	STRESS FE01 24 95	ew propries rewards to a contract of the track state to the two sets of the track o
. 98	STRESS EF08 24 137	
99	STRESS FE15 24 179	
100	STRESS EP01.24.96	
101	STRESS, EP08, 24, 138	
102	STRESS EP15 24 180	
103	*CREAT MAC	
104	SET.ARGI	
105	ERSEL ELEM 16	
106	NRSEL NODE 16	
107	PRDISP	PRINT SEL NODAL DIOD
108	PREFOR	TRUT SEL. NUDAL UISP.
109	PRSTRS	
110	*END	
111	*USE MAC.1	
112	RP23 1	

113 FINISH



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Project_WBNP Unit 1
Subject Test Correlation Study for Thermal Use of Ductility Ratio
11.5.3 Problem 3: Johnston-Cheney Thermal Model

11.5.3.1 Model

10,000 A

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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	Client TVA
	Project_WBNP Unit 1
-	Subject Test Correlation Study for Thermal Use of Ductility Ratio
	11.5.3.2 List of ANSYS Input Data for Johnston-Cheney Thermal Model
	1 ANSYS INPIT DATA LISTING (211 119) ARABARARA
	2 /TITLE, JOHNSTON-CHENEY TEST 6-5 (W6X20), EC=2.23", DTEMP=0,400,10 3 /COM 4 /COM JOHNSTON - CHENEY MODEL
	5 /COM REF. LOAD TESTS - J&C 6 /COM SPECTMEN W6C20
a	7 /COM ECCENTRICITY = 2.23° , DT = $0,400,10^{\circ}$
	9 /COM ET=1500
	10 /COM 11 /COM INPUT JOHN3C1
	12 /COM OUTPUT JOCW3C1 13 /COM FILE12 JFCW3C1
	14 /COM PLOT FILE JGCW3C1 15 /COM
1	16 /COM
	17 KAN,U 18 KAY,6,1
	19 KNL,1 20 TREF.70
	21 ET,1,24,,1 22 ET,2.4
	23 EX,1,29E3
	24. EX,2,29E3 25 ALPX,1,6.5E-6
	26 ALPX,2,6.5E-6 27 C*** NONLINEAR MATERIAL CONVERSION
	28 NL,1,13,10
	29 NL,1,19,70,400 30 NL,1,25,33.0,33.0
	31 NL,1,31,1500,1500 32 C*** DEFINE BEAM LENGTH AND CROSS SECTION PROPERTIES
	33 L=119 • BEAM W 6X20 9'-11* LONG 34 BE=6 018
ng ang kanang kanang ka Kanang kanang kanang Kanang kanang	35 TF=0.367
	36 D=6.20 37 TW≈0.258
	38 EC=2.23 • ECCENTRICITY, 2.23* 39 C***
	40 AA≈BF/2 41 BB≂(0, TE)/2
	42 QA = AA/2
	43 QB≈BB/2 44 *STAT
	45 R,1,AA,BB,0,QA,BB,TF *STIF24 REAL PROP. 46 RMORE 0.BB,TF -OA, BB, TF
	47 RMORE,-AA,BB,TF,0,BB,0 48 RMORE 0.0 TW 0.0 TW
	49 RMORE, 0, -QB, TW, 0, 0, 1W 49 RMORE, 0, -QB, TW, 0, -BB, TW
	50 KMURE,-AA,-BB,O,-QA,-BB,TF 51 RMORE,0,-BB,TF,QA,-BB,TF
	52 RMORE,AA,-BB,TF 53 R.2.500.5000 5000 10 10
	54 Case
	56 MID= $(NUM+1)/2$
	57 ND=3 58 $AL=\frac{1}{4}$
	59 N,1 50 N ND 41 AT
-	

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11.5.3.2 (Continued)			· ·
1 •••••• ANSYS INPUT DAT	A LISTING (FILE18)		
61 FILL 62 N.NUM-ND,L-AL 63 FILL 64 N.NIM I	- - -		

109 FINISH 110 /INPUT,27

102 EPLOT

65 FILL

76 C*** 77 ITER,-20 78 POSTR, 1,5

84 85

87

88

89

99

66 N,NUM+1,0,0,-2.23 67 N,NUM+2,L,0,-2.23

68 N,NUM+3,L/2,0,5

72 E,1,2,NUM+3 73 RP30,1,1,0

82 C*** F,1,FX,64 83 C*** F,MID,FZ,8.2

*CREAT,TMP 86 TUNIF, ARG1

LWRITE

94 /VIEW,,0,-1,0

96 /PNUM,NODE,-1

97 /PNUM,ELEM,-1 98 EPLOT

100 /PNUM,NODE,1 101 /PNUM,ELEM,-1

104 /PNUM,NODE,-1 105 /PNUM,ELEM,1 106 EPLOT 107 C*** 108 AFWRITE,,1

*END *USE,TMP,70

90 RP41,,10 91 C*** 92 /PBC,ALL,1 93 /SHOW

70 E,NUM+1,1,NUM+3

75 E,NUM+2,NUM,NUM+3

79 C*** BOUNDARY CONDITIONS: 80 D,NUM+1,UX,0,...,UY,UZ,ROTX

81 D,NUM+2,UX,0,,,,UY,UZ,ROTX

69 TYPE,2 \$MAT,2 SREAL,2 * RIGID BEAM

71 TYPE,1 \$MAT,1 \$REAL,1 • STIF24 BEAM

74 TYPE,2 \$MAT,2 \$REAL,2 • RIGID BEAM

C*** DEFINE INCREMENTAL TEMPERATURE

1 -

95 /TITLE, JOHNSTON-CHENEY TEST 6-5 (W6X20), EC=2.23*

/TITLE, JOHNSTON-CHENEY TEST 6-5 (W6X20), EC=2.23", NODES

103 /TITLE, JOHNSTON-CHENEY TEST 6-5 (W6X20), EC=2.23°, ELEMENTS

• RPNNN, NNN=NUM-1

WITH THERMAL LOAD

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11.5.4 Problem 4: High Ductility Ratio Model

11.5.4.1 Model

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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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		Project WBND Unit 1
		Subject Test Correlation Study for The Land
;		The study for Thermal Use of Ductility Ratio
		11.5.4.2 List of ANSYS Input Data for High Ductility Ratio Model
		1 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
		6 /COM FZ=8.2 KIPS, DT=0,400,10 7 /COM E=29E3 KSI, FY=36.0 KSI 8 /COM ET=1500
		9 /COM 10 /COM INPUT: JOHNAC2
		11 /COM OUTPUT: JOCW4C2 12 /COM BUT BUD: NOCW4C2
		13 /COM PLOT FILE: JGCW4C2
		15 /COM
		16 KAN,0 17 Kay,6,1
		18 KNL,1 19 TREF.70
		20 ET,1,24,1,1 21 EY 1 2993
	,	22 ALPX,1,6.5E-6
		23 ET,2,4 24 EX,2,29E3
		25 ALPX,2,6.5E-6 26 C*** NONLINEAR MATERIAL CONSTANT
		27 NL,1,13,10 28 NL 1 19 70 770
		29 NL,1,25,36,0,36,0
		30 NL, 1, 51, 1500, 1500 31 C*** DEFINE BEAM LENGTH AND CROSS SECTION PROPERTIES
14 g		32 L=98.458 • BEAM 415 S 4 M13.0
		35 D=4 00
•		36 TW=0.254
		38 CL=4 • CHANNEL C 4X5.4 6• LONG
· .:		40 TCF=0.296
		41 CD=4.00 42 TCW=0.184
		43 C*** 44 AA=BF/2
		45 BB=(D-TF)/2.
		47 QB=BB/2
		48 C 49 X0=(TCW/2)-(0.458)
		50 CC=CF-(TCW/2) 51 DD=(CD-TCF)/2
		52 QC=CC/2 53 OD=DD/2
		$\frac{55}{54} = \frac{55}{52} = \frac{55}{54}$
		23 QC=QC+X0 56 *STAT
		57 R,1,AA,BB,0,QA,BB,TF •STIF24 REAL PROP M 4X13.0
(59 RMORE, -AA, BB, TF, 0, BB, 0
		ου ταποτηγυχαλι W.U.U.I.W

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	11.5.4.2 (Continued)
	(1 DYODE O OD THE OT DATA LISTING (FILE18) **********
	61 KMORE, 0,-QB, TW, 0,-BB, TW 62 RMORE, -AA,-BB, 0,-QA,-BB, TF
	63 RMORE,0,-BB,TF,QA,-BB,TF 64 RMORE,AA,-BB,TF
•	65 C***
	67 C***
- 228 - 228 - 339	68 R.S.CC,DD,U,QC,DD,TCF • STIF24 REAL PROP C4X5.4 69 RMORE,X0,DD,TCF,X0,QD,TCW
	70 RMORE,X0,0,TCW,X0,-QD,TCW 71 RMORE,X0,-DD,TCW,OC,-DD,TCF
	72 RMORE,CC,-DD,TCF
	74 NUM=51
	75 $MD = (NUM+1)/2$ 76 $ND = 7$
	77 MUM=NUM+ND 78 N 1 0
	79 N,NUM,L
	80 FILL 81 N,NUM+1,L,0,2
·* *	82 N,MUM,L,0,6 83 FILL
	84 N,MUM+1,L,5,0
	8/ TYPE,I \$MAT,1 \$REAL,1 • M 4X13.0 88 E,1,2,NUM+1
	89 RP50,1,1,0 • RPNNN, NNN=NUM-1 90 TYPE 2 SMAT 2 SPEAL 2 • PIGT
	91 E,NUM,NUM+1,1
•	92 TIPE, I SMAT, I SREAL, 3 * C 4X5.4 93 E,NUM+1,NUM+2,MUM+1
الدين الله الصيفة بلاد المالية. المالية الله الصيفة بلادة المالية المال	94 RP6,1,1,0 • RPNNN, NNN=ND-1 95 •STAT
	. 96 - Сеее на сладите и сталите на сталите на сталите на сталите на сталите и сталите и сталите и сталите и с 197 - ГГЕР - 20
	98 POSTR, 1,5
	99 Case BOUNDARY CONDITIONS: 100 D,1,UX,0,,,,UY,UZ,ROTX
	101 D,MUM,UX,0,,,,UY,UZ,ROTX,ROTY,ROTZ 102 C*** TUNIF 270
	103 C*** F,1,FX,64
	105 C*** DEFINE REPEATING LOADINGS AS MACRO
	106 *CREAT,TMP 107 TUNIF,ARGI
	108 LWRITE 109 •END
	110 *USE,TMP,70
	113 /PBC,ALL,1 114 /SHOW
	115. /VIEW, 0,-1,0 116. /TILLE, HIGH DUCTU ITY DATES NODE: CONTRACTOR
	117 /PNUM, NODE, -1
	118 /PNUM,ELEM,-1 119 EPLOT
	120 /TITLE, HIGH DUCTILITY RATIO MODEL, NODE NUNBERS

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11.5.4.2 (Continued)

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

- 121 /PNUM,NODE,1 122 /PNUM,ELEM,-1
- 123 EPLOT

1

10.033

3**4** 12 1

- 124 /TITLE, HIGH DUCTILITY RATIO MODEL ELEMENT NUMBERS 125 /PNUM,NODE,-1
- 126 /PNUM, ELEM, 1
- 127 EPLOT
- 128 /TITLE, HIGH DUCTILITY RATIO MODEL, PARTIAL 129 ERSEL,NUM-1,NUM+ND
- 130 /PNUM,NODE,1
- 131 /PNUM, ELEM, 1
- 132 EPLOT
- 133 /TITLE, HIGH DUCTILITY RATIO MODEL (M4X13 / C4X5.4)
- 134 /PNUM,NODE,-1
- 135 /PNUM,ELEM,-1
- 136 /PNUM, REAL, 1
- 137 EPLOT
- 138 C***
- 139 EALL
- 140 NALL
- 141 AFWRITE,,1
- 142 FINISH

Project chkd. Subject 11.5.4.3 Client BУ ANSYS 4.9A HAR 27 1991 Уд 3 15 54 20 Test Correlation Study WBNP Unit TVA 12 ANSYS PLOT NO. 2 200 PREP7 ELEHENTS Model Y۷ a - | Date Date DIST=54.152 XF =49.220 Plot $\mathbb{R}^{1}_{\mathbf{r}}$ 4 ۵ ۱ BRANCH/PROJECT ID: WCG-1-81 EBASCO SERVICES YF =2.6 HIGH 4 -5-9 ZF = 3 Figure for 16 SECONDARY MEMBER DUCTILITY 田 Thermal 1.0.0.10111213141516171810202122232425262728203031323349550373830401142434445464748405461 北 -5.4.3 INCORPORATED PRIMARY MEMBER đse of, OFS No RATIO Ductility Ratio MODEL Sheet 36 Dept. No. .1 'e HIGH DUCTTLITY RATIO HODEL, HODE HUNBERS S

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11.6 Results:

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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		

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11.6.1 Results for Problem 1 :

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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 (2-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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11.6.2 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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11.6.3 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.



. . BУ 11.6.3 Subject Project Client chkd. 1 3 2.23 ANSYS 4.9A DISPLACEMENT ЪY APR 10 1991 DISP TRATIO (Continued) Test Correlation Study WBNP Unit 10 98 53 TVA 55 APPLIED TEMPERATURE INCREMENT PLOT NO. Z POST28 6 3.6 UZ/ DE Date Date ZV =1 3.2 DIST=.6666 RATIO 3.0 4-11-91 XF =.5 9-11-BRANCH/PROJECT ID: WCG-1-8// EBASCO SERVICES INCORPORATED 2.8 YF #.5 5 ZF =.5 Figure 2.4 for Thermal 6 TEMPERATURE -2 11.6.3A ALL DISPLACEMENTS DISP RATIO = 2.23 " 1.6 Use OFS of JOHNSTON CHENEY THERMAL MODEL 1.2 SUPPORT ECCENTRICITY No Ductility ACTUAL LATERAL DISP LATERAL DISP. @ STRESS YIE 8 . 4 Ratio AT Sheet Dept. 0 CENTER SPAN TEHP 0 160 320 47_of_ 2) 488 840 800 80 240 100 580 720 No. PROBLEM 3 DISP (UZ/DE) VS TEMPERATURE PLOT, DE(DYIELD)=0.369 **TIBIL** 5 ł



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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 The axial force in the primary temperature. 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 $275 \degree$ F. From Figure 11.6.4A, 4B & 4c, at temperature = $275 \degree$ 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.



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By <u>GHL for C. Wu</u> Date $4-17-91$ Chkd. by <u>H. Towney for VI</u> Date $4/12/91$ Client <u>TVA</u>	Sheet <u>54</u> of <u>55</u> OFS No Dept. No
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12. SUMMARY OF CALCULATION RESULTS

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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.

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- 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 selflimiting. 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.