Tennessee Valley Authority, Post Office Box 2000, Spring City, Tennessee 37381

John H. Garrity
Vice President, Watts Bar Nuclear Plant

NOV 27 1991

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555

Gentlemen:

In the Matter of the Application of	)	Docket Nos. 50-390
Tennessee Valley Authority	)	50-391

WATTS BAR NUCLEAR PLANT (WBN) UNITS 1 AND 2 - SUPPLEMENTAL INFORMATION ON THERMAL EVALUATION CRITERIA FOR STRUCTURAL STEEL MEMBERS (TAC No. M79717 AND M80346)

References:

1. NRC Meeting Summary, November 8, 1991, Meeting with the Tennessee Valley Authority regarding Outstanding Issue 19(j) (TAC Nos. M79717 and M80346).

2. E. G. Wallace to USNRC Document Control Desk, May 8, 1991, Responses to NRC Request for Additional Information, FSAR Amendments 54-64 Review

3. E. G. Wallace to USNRC Document Control Desk, June 6, 1991, Evaluation Criteria for Steel Structures with Thermal Restraint

4. John H. Garrity to USNRC Document Control Desk, August 22, 1991 - Response to NRC Request for Additional Information on Structural and Geosciences Issue 19(j) (TAC Nos. M79717 and M80346)

5. John H. Garrity to USNRC Document Control Desk, October 16, 1991, Revised response to NRC RAI on SSER 6 Issue 19(j)

On October 31, 1991, TVA met with NRC representatives in Rockville, Maryland to discuss the Watts Bar Thermal Evaluation Criteria for Structural Steel Members. This issue was originally derived from Outstanding Issue 19(j) as described in the WBN Safety Evaluation Report, Supplement 6. Outstanding Issue 19(j) concerned NRC questions on the Final Safety Analysis Report, Section 3.8, "Category I Structures".

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NOV 27 1991

Upon conclusion of this technical meeting, the staff summarized its concerns within the referenced meeting report (Reference 1). The purpose of this submittal is to formally respond to those NRC concerns.

Enclosures 1 and 2 provide the TVA responses to the identified NRC issues. Enclosure 3 provides additional information TVA considers will expedite answering other questions which were raised in the meeting. This information supplements that previously transmitted by References 2, 3, 4, and 5 for this review item.

The enclosures should satisfactorily address NRC's outstanding concerns. However, in order to expedite a mutually agreeable resolution of this issue, as discussed with the NRC staff, TVA will impose an upper bound ductility ratio limit of 1.3 for the thermal evaluation of primary structural members. This approach will provide additional margin to the original criteria.

Final Safety Analysis Report (FSAR) revisions associated with these criteria will be incorporated in an upcoming amendment. The revised page of the FSAR is included as Attachment 3.3 of Enclosure 3.

If you have any questions, please telephone P. L. Pace at (615) 365-1824.

Sincerely,

John H. Garrity

Enclosures
cc: See page 3

cc (Enclosures):

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50-390 TVA WATTS BAR

SUPPL INFO ON THERMAL EVALUATION CRITERIA
FOR STRUCTURAL STEEL MEMBERS

REC'D W/LTR DTD 11/27/91....9112090142

Supplemental Information on Thermal Evaluation
Criteria for Structural Steel Members

ENCLOSURE 1

CONCERN 1

TVA should provide experimental data demonstrating that the proposed ductility ratio of three does not mean a state of imminent structural instability (collapse) due to lateral loading, and represents the maintenance of sufficient margin. The experimental data should include, as a minimum, the following parameters:

a. beam-column effect,

b. compatability and comparability of transverse and axial loads tested to those of Watts Bar beams being evaluated,

c. dynamic response due to safe-shutdown earthquake in a post-inelastic region, and

d. combination of a. and c. above.

RESPONSE

1. Introduction

TVA utilizes the following provision of section 3.8.4 of the Standard Review Plan to address thermal loads.

> "For factored load combinations, thermal loads can be neglected when it can be shown that they are secondary and self-limiting in nature and where the material is ductile."

In order to apply the standard review plan provision, TVA utilizes the following definitions of key terms.

secondary - loads which are imposed by strains or deformations.

self-limiting - loads which are relieved by the capability of the structure to deform in a ductile manner.

ductile material - material capable of sustaining large strains without fracturing. A36 steel is a ductile material.

The TVA approach provides guidance on how to show that temperature loads are self limiting and secondary in nature. The approach:

° explores the deformation capability of the structure since deformation relieves thermal stresses

° provides limits on such deformation to ensure the load carrying capability of the structure is not adversely affected

° checks connections and members to ensure compatibility of behavior

2. Enclosure 1 References

1. Calculation WCG-1-811, "Test Correlation Study for Thermal Use of Ductility Ratio." This calculation was provided by letter dated June 6, 1991 and during the NRC audit of September 9-13, 1991.

2. Calculation WCG-1-1047, "Study on the Effect of Repeated Load and Load Sequence for Thermal Evaluation." This calculation was provided during the NRC audit of September 9-13, 1991.

3. Search for Experimental Data

A literature search for the subject of beam-column tests in the inelastic range of structural steel was conducted by using the databases COMPENDEX, ENERGY SCIENCE AND TECHNOLOGY and NTIS. Upon entering these databases, keywords were used to identify papers containing information on the subject. All of the abstracts on the papers identified were reviewed for applicability to the Watts Bar thermally loaded structures subjected to lateral mechanical loading. The result of the abstract review indicated that none of the papers had direct application to the thermally (or strain) loaded structures. Most of the papers dealt with beam-column tests for mechanical (follower) loads either in the lateral direction or a combination of lateral and axial directions. No tests were identified which combined lateral mechanical loads with axially induced thermal loads.

In addition, the following experts in the field of structural steel were contacted regarding the availability of related experimental data. They indicated no knowledge that any tests on the subject of interest had been performed.

1. Dr. Joseph Penzien - University of California at Berkeley
2. Dr. James Jirsa - University of Texas
3. Dr. Mete Sozen - University of Illinois
4. Dr. Richard White - Cornell University
5. Pat Newman - AISC

4. Evaluation of Beam-Column Effect by Test Correlation

Recognizing the lack of experimental data for thermally loaded structures, TVA has performed a test correlation study utilizing the test data for a beam-column subjected to lateral and axial mechanical loads. This study is documented in enclosure 1 reference 1. The objectives of this study were to correlate analysis results using the ANSYS computer code with test data and to demonstrate the applicability of ANSYS nonlinear analysis. By comparison of analysis results this study also demonstrates that structural behavior under thermal load, which is strain-induced and self-limiting in nature, has a distinct difference from structural behavior under mechanical loads. The test data presented in the report "Static Load Deflection Tests of Beam-Columns" by Howland and Newmark, University of Illinois were used in the test correlation study. This report is included in enclosure 1 reference 1. The study results are summarized as follows:

° Based on the comparison of load-deflection data, the ANSYS analysis results match very well with the test data. The comparison of results is provided in attachment 1.1.

- The test data showed that the specimen becomes unstable when subjected to an 8.2 kip lateral and 64 kip axial load (mechanical load). This was also predicted by the ANSYS analysis. The study also demonstrated that the structure is stable when the axial load is generated by the restrained thermal expansion. This is demonstrated in plots of the displacement ratio versus temperature and axial force versus temperature. These plots are provided in attachment 1.2. The plots show that initial yield for this problem occurs at 160 degrees and the peak axial reaction occurs at 200 degrees.

  It should be noted that the thermally induced axial load decreases after 200 degrees because of relaxation in the member. This relaxation is caused by the yielding and curvature in the member. This demonstrates that the structural behavior under thermal loads is different from the structural behavior under mechanical loads.

5. Comparability of Test Data to Watts Bar Applications

The structures being evaluated at Watts Bar support a wide range of attached loads. These loads vary from small loads from instrumentation tubing to large loads from pipe supports. Some of the structures also support multiple loads. Therefore, it is difficult to establish a correlation between the configuration and loads represented in the tests and the configuration and loads in the Watts Bar applications, except to note that the test loads are in the upper range of loads applied to the actual structures.

In order to understand the effect of changing the magnitude of load on the results, an additional ANSYS evaluation was performed. This evaluation used the same configuration as used in enclosure 1 reference 1 but used a lateral mechanical load of 10.7 kips. This is the load which will produce a member bending stress of 0.9Fy, which is the maximum allowable bending stress as specified in the Watts Bar steel design criteria. The results of this additional evaluation are shown in the plots in attachment 1.3. The plot of displacement ratio versus temperature for the 10.7 kip lateral load is very close to the plot for 8.2 kips. The plot of the axial load versus temperature for the 10.7 kip lateral load is comparable to the plot for the 8.2 kip load. Both plots show that the maximum load occurs around 200 degrees and then reduces. This relaxation is caused by the yielding and curvature in the member.

6. Seismic Loads and Beam-Column Effect

The steel structures of Watts Bar are evaluated based on the AISC allowables for all applicable load combinations with an upper limit of 0.9Fy, except those with thermal loads (Ta). This evaluation ensures that the structures remain in the elastic range under all mechanical (follower) loads including the seismic loads.

When a repeated loading such as seismic loads is applied to a structure which is at the yielded stage after thermal loadings, the structural deflection (or strain) response would stabilize after a few cycles of load application so long as the amplitude of seismic load response is limited to be within the elastic range. This has been demonstrated in the repeated load study which is documented in enclosure 1 reference 2. Two worst cases of the thermally restrained structures were considered in the study. The ANSYS computer program was used. The results of the repeated load study are summarized as follows:

- ° The strain difference between SSE cycles decrease as the number of loading cycles increases. The differences of strain are less than 0.1 percent after six cycles of SSE load. (see attachment 1.4 for summary tables)

- ° The displacement difference between SSE cycles decreases as the number of loading cycles increases. The differences of displacement are less than 0.1 percent after three cycles of SSE load. (see attachment 1.5 for summary tables)

The study results indicate that although structures subjected to the combination of thermal and other applicable loads are in the inelastic range, they do not "ratchet" significantly when the repeated seismic loads are applied. The increment of strains and displacements are negligible and diminishes when repeated SSE load cycles are applied.

7. Effect of Mechanical Load and Thermal Load on Overall Structural Stability

The difference between a strain-induced load (e.g. thermal load) and a mechanical (follower) load can be further demonstrated by the example presented in attachment 1.6. Figure (a) shows a beam subjected to an imposed displacement of δ_1 which generates a lateral load equal to the beam collapse load (calculated to be 13.7 kips for this example). Figure (b) shows the same beam subjected to a mechanical load equal to the collapse load. Since the strain-induced load is self-limiting, the beam in Figure (a) will not collapse. The beam will stay in equilibrium with a maximum deflection equal to the imposed displacement δ_1. In contrast, the beam in Figure (b) will collapse and the maximum deflection δ_2 will increase without limit when a mechanical load is applied. This is illustrated in the force-deflection curve as shown in Figure (c). It demonstrates that the energy due to the strain-induced load is limited.

Due to its self-limiting nature, the strain-induced load will be relieved when the structure deforms due to other mechanical loads. Figure (d) shows a beam loaded under the combination of a strain-induced load and a mechanical load. Similar to Figure (a), the beam is first subjected to an imposed displacement of δ_1 . Then the beam is loaded with a mechanical load W_1. As the lateral load W_1 increases, the strain-induced load is relieved and reduced to (13.7^k - W_1). The total load at the point of load application remains constant (equal to 13.7^k). The deflection increase will be insignificant if the stiffness of the strain-induced mechanism (e.g. hydraulic jack) is relatively higher than the stiffness of the beam. The structure remains in the stable configuration as long as the applied mechanical load is below the collapse load.

The allowable stresses used for the design of steel structures at Watts Bar for all applicable loads, except thermal loads, are based on AISC allowables with an upper limit of 0.9Fy. This ensures that the WBN structures under the mechanical loads are well below the collapse loads and the structures remain in a stable configuration under the combination of thermal and mechanical loads.

8. Margin Against Overall Structural Stability

The study performed in enclosure 1 reference 1 demonstrates structural stability under thermal axial load. In order to evaluate margin of safety the analysis was performed to a temperature of 700 degrees. This temperature is more than twice the maximum temperature documented on the TVA environmental drawing (47E235-41) to exist inside containment. This temperature also represents the point at which material properties begin to change significantly. At the 700 degree temperature the displacement ductility ratio is 5.1. This represents a margin of safety for overall structural stability of 1.7 (5.1/3) against an allowable ductility ratio of 3.

ATTACHMENT 1.1

COMPARISON OF LOAD - DEFLECTION DATA FOR ANSYS AND TEST

SHEET 1 OF 1

EBASCO SERVICES INCORPORATED
BRANCH/PROJECT ID: WCG-1-811

By C Wu Date 4-3-91 Sheet 39 of 55
Chkd. by Y Chen Date 4-4-91 OFS No. - Dept. No. -
Client TVA
Project WBNP Unit 1
Subject Test Correlation Study for Thermal Use of Ductility Ratio

Rev 1 PREPARED BY: SAL DATE 8/6/91
CHECKED BY: WKB DATE 8/6/91

11.6.1 (Continued)

Figure 11.6.1A

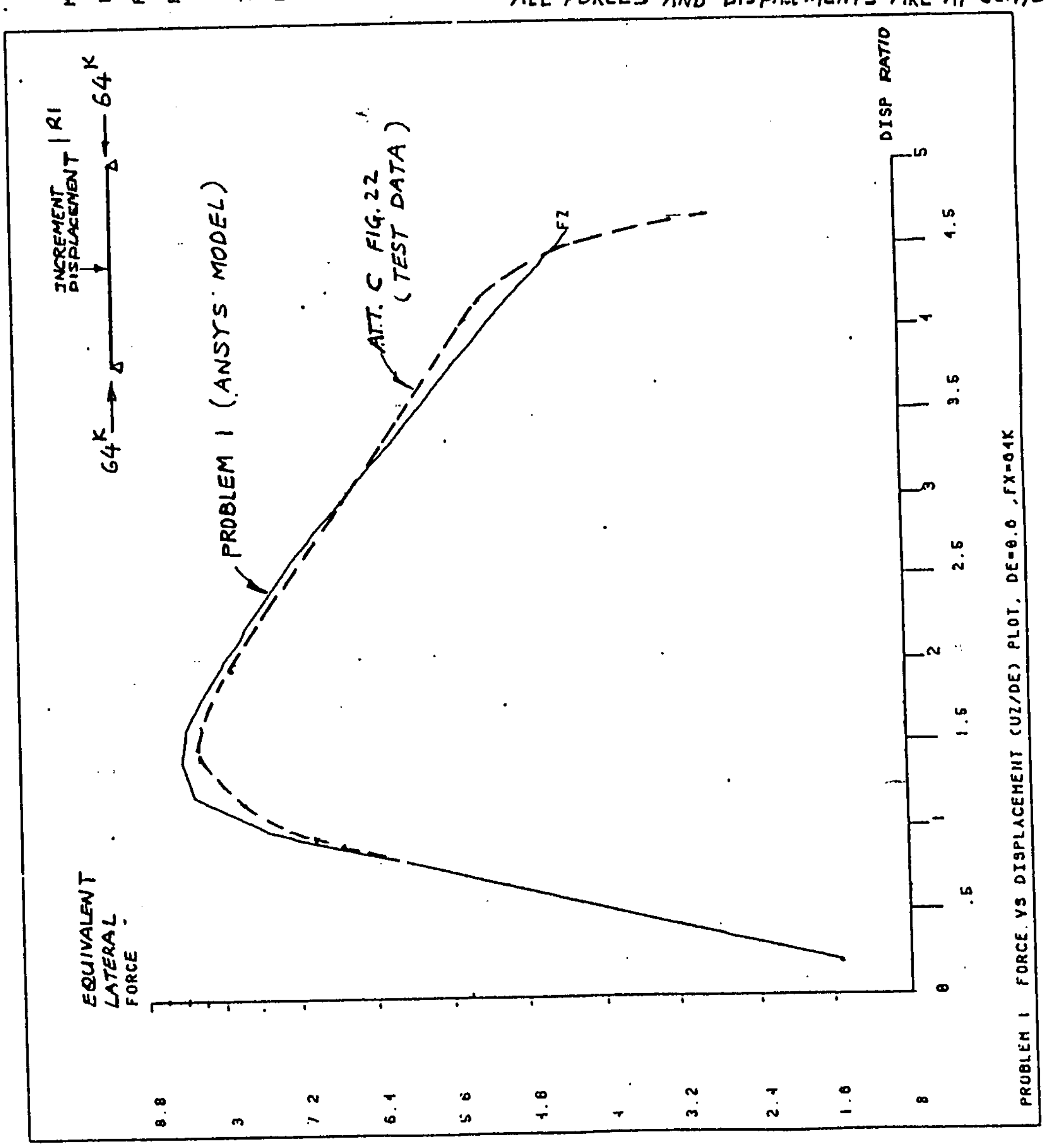
LATERAL FORCE VS DISPLACEMENT RATIO - HOWLAND NEWMARK TEST MODEL

ANSYS 4.3A
MAR 29 1991
15 58 11
PLOT NO. 1
POST26
ZV =1
DIST=.6668
XF =.5
YF =.5
ZF =.5

APPLIED CONSTAN F_x(AXIAL) = 64^K

$$\text{DISP RATIO} = \frac{\text{ACTUAL LATERAL DISP. (UZ)}}{\text{LATERAL DISP. @ STRESS YIELD (DE)}}$$

ALL FORCES AND DISPACEMENTS ARE AT CENTER SPAN



ATTACHMENT 1.2

PLOT OF ANSYS RESULTS

SHEET 1 OF 2

EBASCO SERVICES INCORPORATED

BRANCH/PROJECT ID: WCG-1- 811

By C-Wu Date 4-3-91 Sheet 42 of 55

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Client TVA

Project WBNP Unit 1

Subject Test Correlation Study for Thermal Use of Ductility Ratio

11.6.2 (Continued)

Figure 11.6.2A

DISPLACEMENT RATIO VS TEMPERATURE – HOWLAND NEWMARK THERMAL MODEL

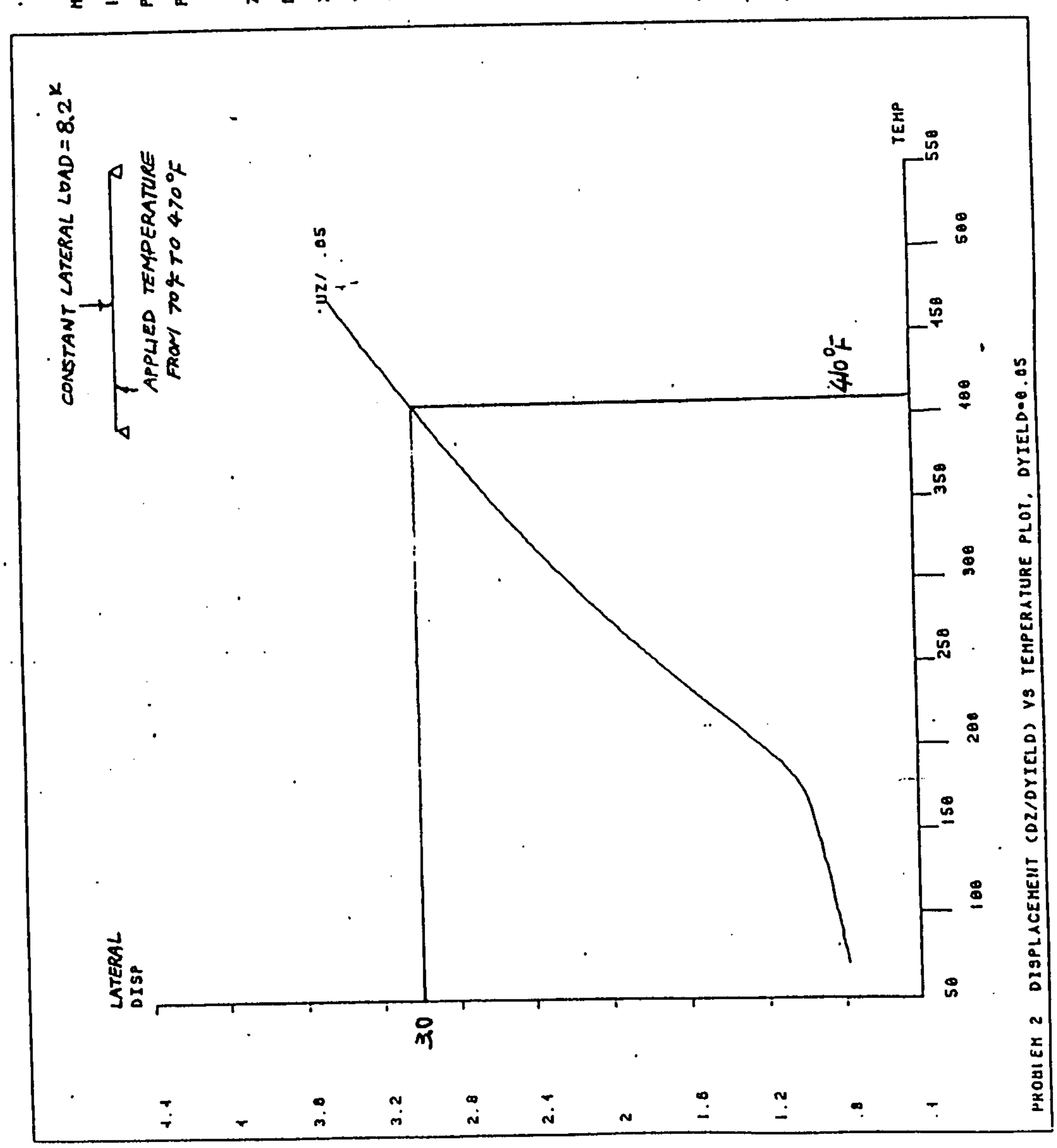
APPLIED CONSTANT LATERAL LOAD ($F_z = 8.2^K$)

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

ALL DISPLACEMENTS ARE AT CENTER SPAN

ANSYS 4.3A
MAR 28 1991
14 48 33
PLOT NO. 1
POST26

ZV =1
DIST=.6868
XF =.5
YF =.5
ZF =.5



ATTACHMENT 1.2

PLOT OF ANSYS RESULTS

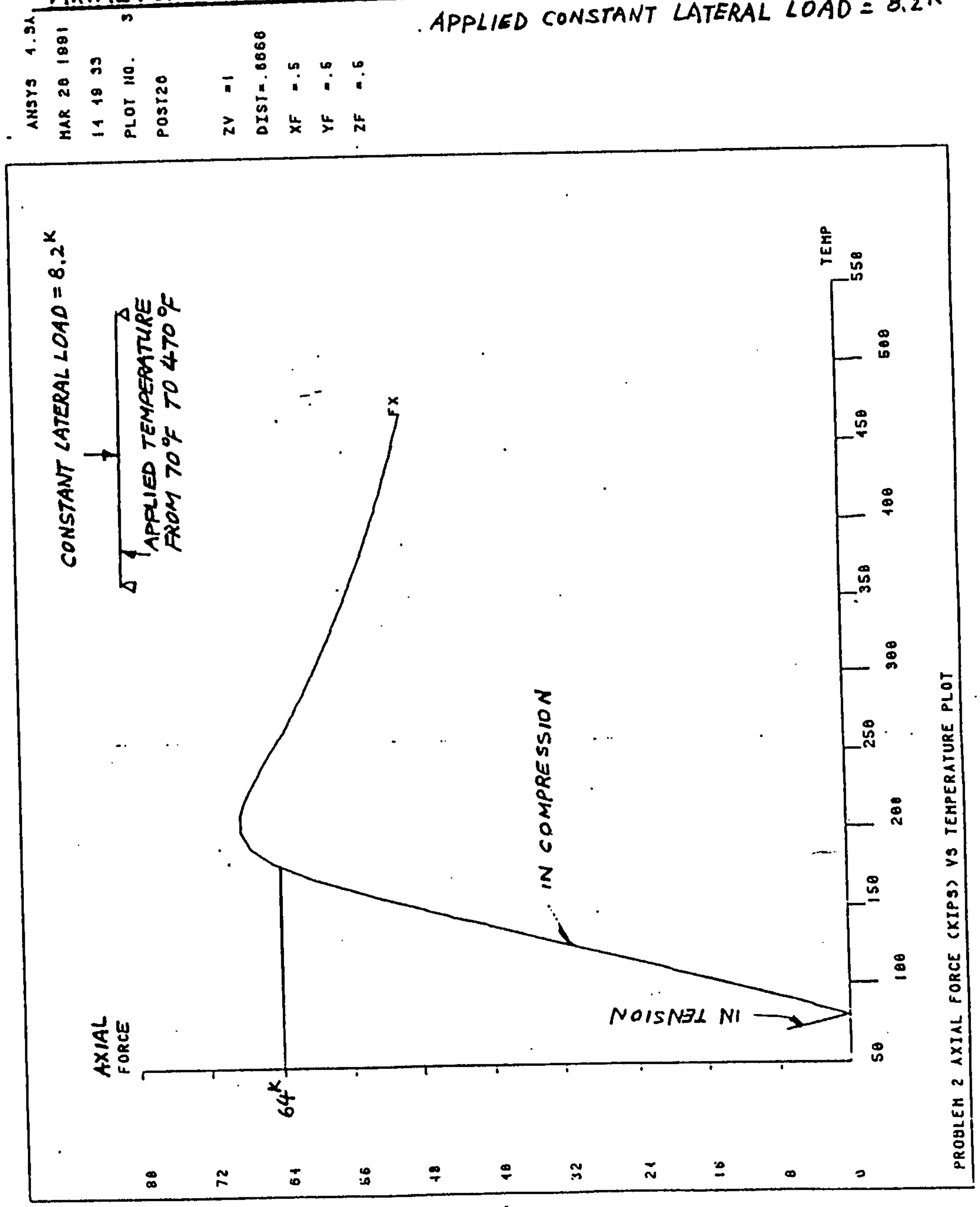
EBASCO SERVICES INCORPORATED
BRANCH/PROJECT ID: WCG-1-811

By C Wu Date 4-3-91
Chkd. by Y Chen Date 4-4-91 OFS No. - Dept. No. -
Client TVA
Project WBNP Unit 1
Subject Test Correlation Study for Thermal Use of Ductility Ratio

11.6.2 (Continued)

Figure 11.6.2C

AXIAL FORCE VS TEMPERATURE - HOWLAND NEWMARK THERMAL MODEL
APPLIED CONSTANT LATERAL LOAD = 8.2K

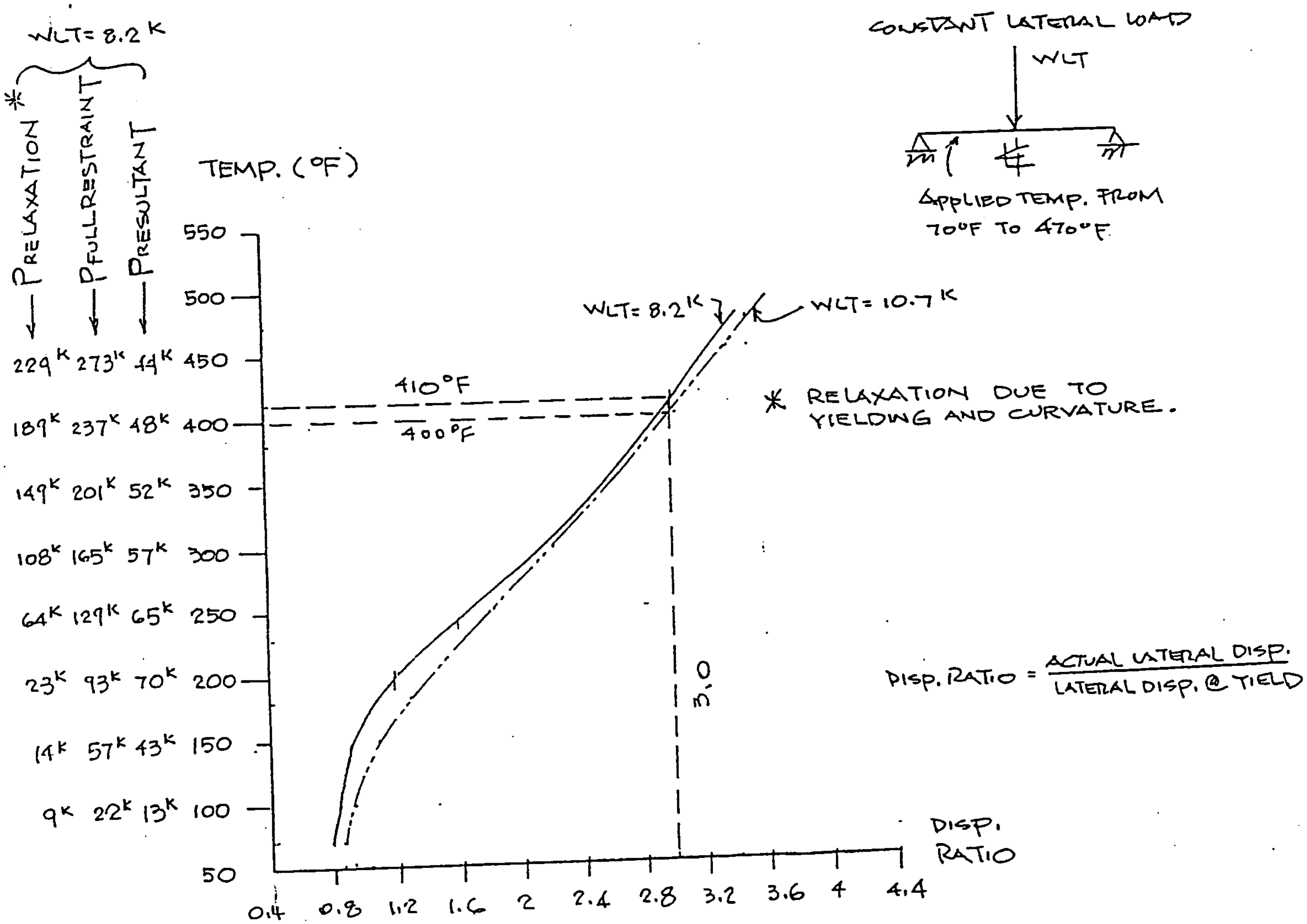


ATTACHMENT 1.3

COMPARISON OF RESULTS
USING MECHANICAL LOADS OF 8.2 AND 10.7 KIPS.

SHEET 1 OF 3

EBASCO SERVICES INCORPORATED



$P_{resultant}$ = Axial force in beam-column from ANSYS

$P_{full\ restraint}$ = Thermal axial load under fully restrained condition

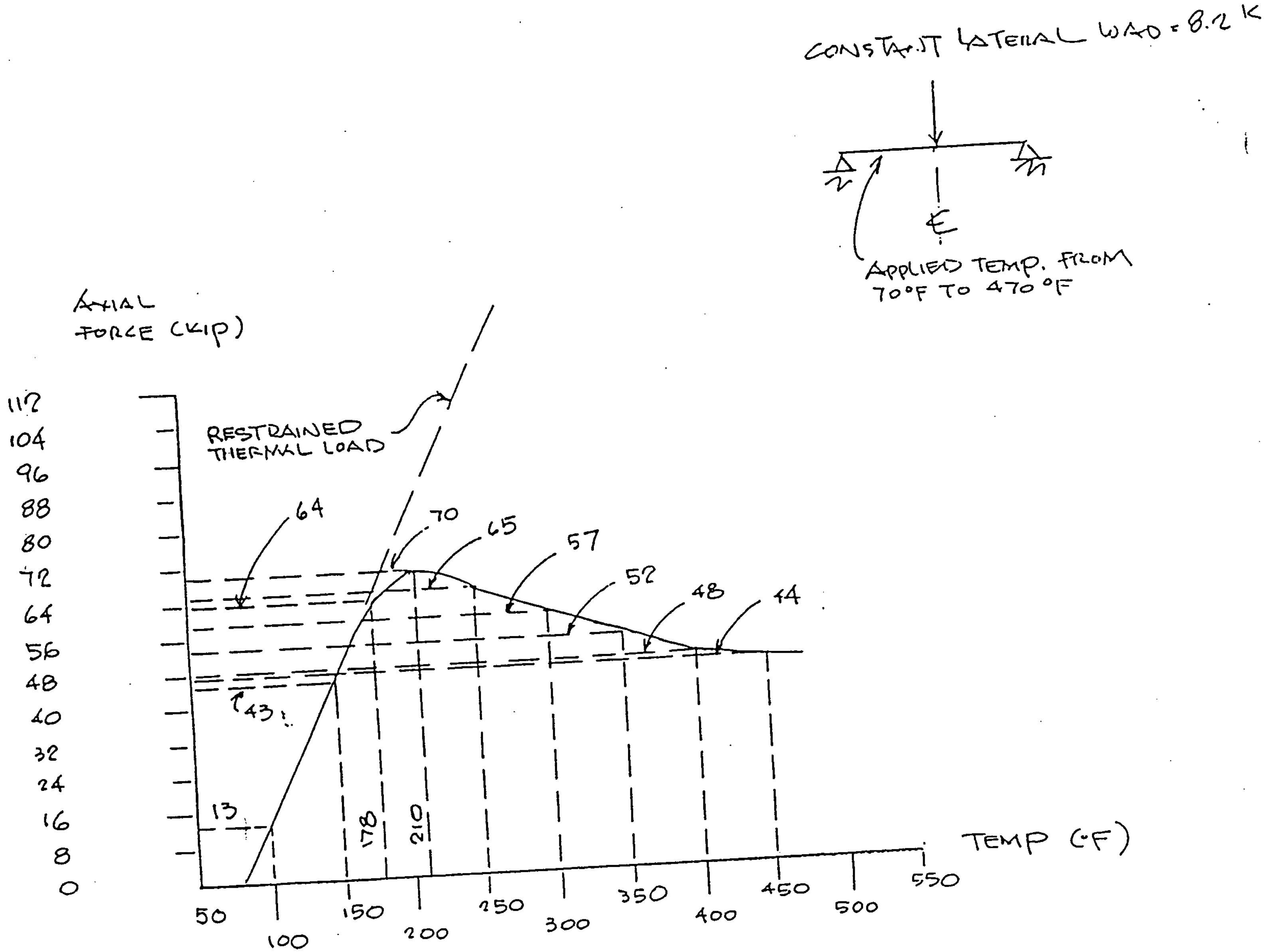
$P_{relaxation}$ = $P_{full\ restraint}$ - $P_{resultant}$

ATTACHMENT 1.3

EBASCO SERVICES INCORPORATED

RESULTS USING MECHANICAL LOAD OF 8.2 KIPS

SHEET 2 OF 3



ATTACHMENT 1.3

RESULTS USING MECHANICAL LOAD OF 10.7 KIPS

EBASCO SERVICES INCORPORATED

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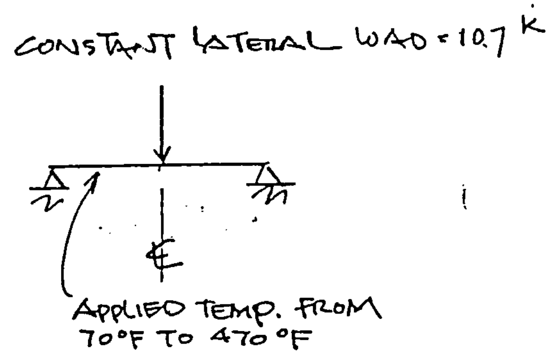

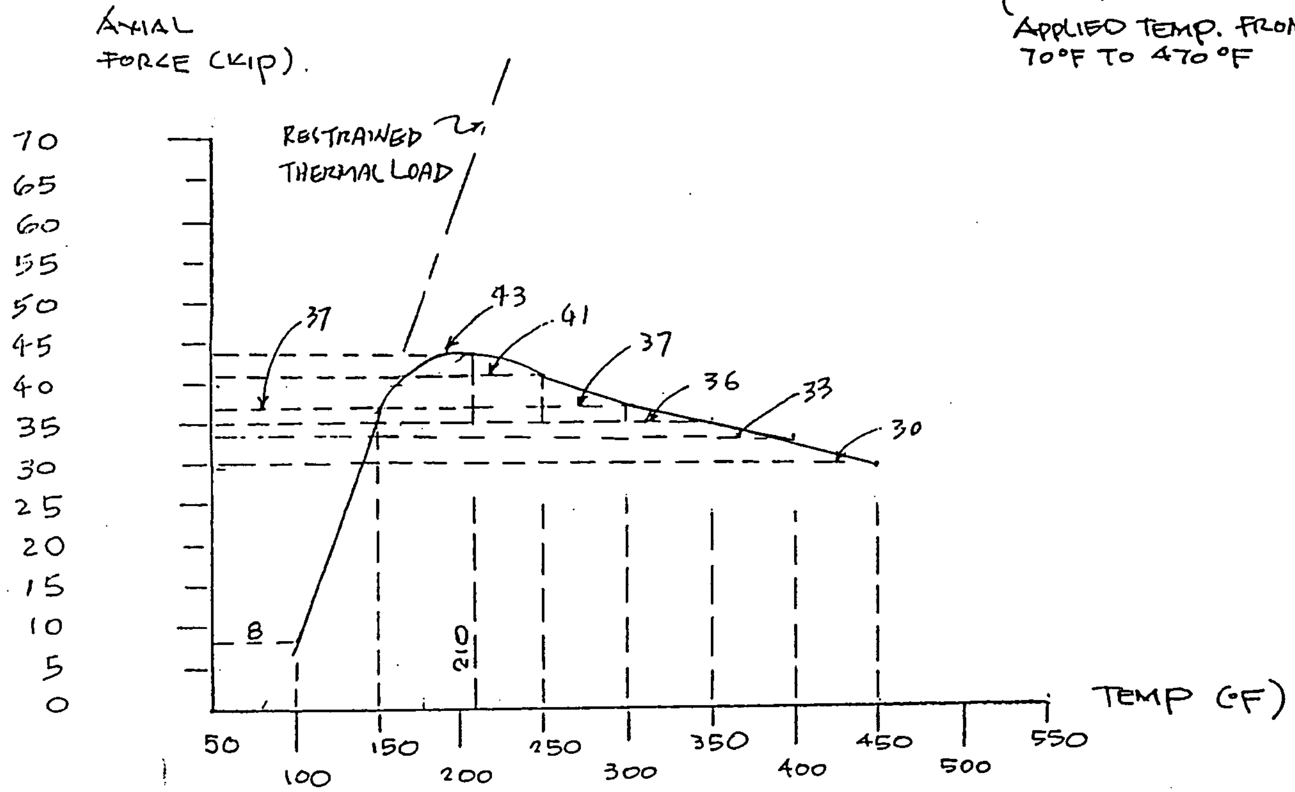

ATTACHMENT 1.4

TABLE OF STRAINS

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EBASCO SERVICES INCORPORATED

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Chkd. by JOU Date 8/30/91 OFS No. NR Dept. No. NR

Client TVA

Project WBNP Unit 1

Subject Study on the Effect of Repeated Load & Load Sequence for Thermal Eval.

Table 11.3.4.11 Comparison of Strains between SSE Cycles at Node 19 (Segment Point 1) (Analysis AX28T)

	EE01	Diff. per Cycle	EP01	Diff. per Cycle
SSE+THERMAL	0.001358		0.008021	
Cycle 1	0.001359	0.04%	0.008125	1.30%
Cycle 2	0.001359	0.02%	0.008176	0.63%
Cycle 3	0.001359	0.01%	0.008207	0.38%
Cycle 4	0.001359	0.01%	0.008225	0.22%
Cycle 5	0.001359	0.01%	0.008236	0.13%
Cycle 6	0.001359	-0.04%	0.008244	0.10%
Cycle 7	0.001358	-0.05%	0.008249	0.06%
Cycle 8	0.001357	-0.06%	0.008253	0.05%
Cycle 9	0.001357	-0.04%	0.008257	0.05%
Cycle 10	0.001356	-0.03%	0.008259	0.02%

Note:

1. EE01 and EP01 are Elastic and Plastic Strains at Segment Point 1
2. Diff. per Cycle: Increment of strains (Percetage) between current cycle and previous cycle

ATTACHMENT 1.4

TABLE OF STRAINS

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Client TVA

Project WBNP Unit 1

Subject Study on the Effect of Repeated Load & Load Sequence for Thermal Eval.

Table 11.3.4.12 Comparison of Strains between SSE Cycles at Node 19 (Segment Point 5) (Analysis AX28T)

	EE05	Diff. per Cycle	EP05	Diff. per Cycle
SSE+THERMAL	0.001352		0.006841	
Cycle 1	0.001352	0.06%	0.006977	1.99%
Cycle 2	0.001353	0.02%	0.007037	0.86%
Cycle 3	0.001353	0.01%	0.007069	0.45%
Cycle 4	0.001353	0.01%	0.007088	0.27%
Cycle 5	0.001353	0.00%	0.007099	0.16%
Cycle 6	0.001353	0.01%	0.007107	0.11%
Cycle 7	0.001353	0.00%	0.007112	0.07%
Cycle 8	0.001353	0.00%	0.007116	0.06%
Cycle 9	0.001353	0.00%	0.007119	0.04%
Cycle 10	0.001353	-0.01%	0.007121	0.03%

Note:

1. EE05 and EP05 are Elastic and Plastic Strains at Segment Point 5
2. Diff. per Cycle: Increment of strains (Percetage) between current cycle and previous cycle

ATTACHMENT 1.4

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Client TVA

Project WBNP Unit 1

Subject Study on the Effect of Repeated Load & Load Sequence for Thermal Eval.

Table 11.3.4.13 Comparison of Strains between SSE Cycles at Node 19 (Segment Point 11) (Analysis AX28T)

	EE11	Diff. per Cycle	EP11	Diff. per Cycle
SSE+THERMAL	0.001354		0.007258	
Cycle 1	0.001354	0.04%	0.007345	1.20%
Cycle 2	0.001355	0.02%	0.007393	0.65%
Cycle 3	0.001355	0.01%	0.007423	0.41%
Cycle 4	0.001355	0.01%	0.007441	0.24%
Cycle 5	0.001355	0.01%	0.007453	0.16%
Cycle 6	0.001355	0.00%	0.007460	0.09%
Cycle 7	0.001355	0.00%	0.007465	0.07%
Cycle 8	0.001355	-0.03%	0.007470	0.07%
Cycle 9	0.001354	-0.03%	0.007473	0.04%
Cycle 10	0.001354	-0.02%	0.007476	0.04%

Note:

1. EE11 and EP11 are Elastic and Plastic Strains at Segment Point 11

2. Diff. per Cycle: Increment of strains (Percetage) between current cycle and previous cycle

ATTACHMENT 1.4

TABLE OF STRAINS

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Client TVA

Project WBNP Unit 1

Subject Study on the Effect of Repeated Load & Load Sequence for Thermal Eval.

Table 11.3.4.14 Comparison of Strains between SSE Cycles at Node 19 (Segment Point 15) (Analysis AX28T)

	EE15	Diff. per Cycle	EP15	Diff. per Cycle
SSE+THERMAL	0.001356		0.007604	
Cycle 1	0.001339	-1.25%	0.007775	2.25%
Cycle 2	0.001317	-1.65%	0.007860	1.09%
Cycle 3	0.001307	-0.72%	0.007902	0.53%
Cycle 4	0.001302	-0.36%	0.007926	0.30%
Cycle 5	0.001300	-0.17%	0.007939	0.16%
Cycle 6	0.001299	-0.09%	0.007948	0.11%
Cycle 7	0.001298	-0.06%	0.007955	0.09%
Cycle 8	0.001298	-0.04%	0.007958	0.04%
Cycle 9	0.001297	-0.02%	0.007961	0.04%
Cycle 10	0.001297	-0.02%	0.007963	0.03%

Note:

1. EE15 and EP15 are Elastic and Plastic Strains at Segment Point 15
2. Diff. per Cycle: Increment of strains (Percetage) between current cycle and previous cycle

ATTACHMENT 1.4

TABLE OF STRAINS

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Client TVA

Project WBNP Unit 1

Subject Study on the Effect of Repeated Load & Load Sequence for Thermal Eval.

Table 11.3.4.16 Comparison of Strains between SSE Cycles at Node 51 (Segment Point 1) (Analysis PR9CT)

	EE01	Diff. per Cycle	EP01	Diff. per Cycle
SSE+THERMAL	0.001324		0.001782	
Cycle 1	0.001246	-5.87%	0.001984	11.34%
Cycle 2	0.001241	-0.43%	0.002001	0.86%
Cycle 3	0.001235	-0.44%	0.002012	0.55%
Cycle 4	0.001233	-0.22%	0.002018	0.30%
Cycle 5	0.001231	-0.14%	0.002021	0.15%
Cycle 6	0.001230	-0.06%	0.002022	0.05%
Cycle 7	0.001230	-0.02%	0.002023	0.05%
Cycle 8	0.001230	-0.01%	0.002023	0.00%
Cycle 9	0.001230	-0.01%	0.002023	0.00%
Cycle 10	0.001230	0.00%	0.002023	0.00%

Note:

1. EE01 and EP01 are Elastic and Plastic Strains at Segment Point 1
2. Diff. per Cycle: Increment of strains (Percetage) between current cycle and previous cycle

ATTACHMENT 1.4

TABLE OF STRAINS

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Client TVA

Project WBNP Unit 1

Subject Study on the Effect of Repeated Load & Load Sequence for Thermal Eval.

Table 11.3.4.17 Comparison of Strains between SSE Cycles at Node 51 (Segment Point 5) (Analysis PR9CT)

	EE05	Diff. per Cycle	EP05	Diff. per Cycle
SSE+THERMAL	0.001335		0.003740	
Cycle 1	0.001335	0.00%	0.003766	0.68%
Cycle 2	0.001329	-0.38%	0.003773	0.21%
Cycle 3	0.001327	-0.17%	0.003776	0.06%
Cycle 4	0.001326	-0.09%	0.003776	0.01%
Cycle 5	0.001325	-0.06%	0.003776	0.00%
Cycle 6	0.001324	-0.05%	0.003776	0.00%
Cycle 7	0.001324	-0.05%	0.003776	0.00%
Cycle 8	0.001323	-0.04%	0.003776	0.00%
Cycle 9	0.001323	-0.02%	0.003776	0.00%
Cycle 10	0.001323	-0.02%	0.003776	0.00%

Note:

1. EE05 and EP05 are Elastic and Plastic Strains at Segment Point 5

2. Diff. per Cycle: Increment of strains (Percetage) between current cycle and previous cycle

ATTACHMENT 1.4

TABLE OF STRAINS

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EBASCO SERVICES INCORPORATED

BRANCH/PROJECT ID: WCG-1-1047

By SAL Date 8/29/91 Sheet 68 of 139

Chkd. by J OU Date 8/30/91 OFS No. NR Dept. No. NR

Client TVA

Project WBNP Unit 1

Subject Study on the Effect of Repeated Load & Load Sequence for Thermal Eval.

Table 11.3.4.18 Comparison of Strains between SSE Cycles at Node 51 (Segment Point 9) (Analysis PR9CT)

	EE09	Diff. per Cycle	EP09	Diff. per Cycle
SSE+THERMAL	0.001331		0.003185	
Cycle 1	0.001188	-10.79%	0.003494	9.71%
Cycle 2	0.001178	-0.84%	0.003514	0.58%
Cycle 3	0.001173	-0.42%	0.003523	0.25%
Cycle 4	0.001170	-0.24%	0.003527	0.12%
Cycle 5	0.001169	-0.13%	0.003528	0.04%
Cycle 6	0.001168	-0.06%	0.003528	0.00%
Cycle 7	0.001167	-0.05%	0.003528	0.00%
Cycle 8	0.001167	-0.03%	0.003528	0.00%
Cycle 9	0.001166	-0.03%	0.003528	0.00%
Cycle 10	0.001166	-0.03%	0.003528	0.00%

Note:

1. EE09 and EP09 are Elastic and Plastic Strains at Segment Point 9
2. Diff. per Cycle: Increment of strains (Percetage) between current cycle and previous cycle

ATTACHMENT 1.4

TABLE OF STRAINS

SHEET 8 OF 8

EBASCO SERVICES INCORPORATED
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Client TVA
Project WBNP Unit 1
Subject Study on the Effect of Repeated Load & Load Sequence for Thermal Eval.

Table 11.3.4.19 Comparison of Strains between SSE Cycles at Node 51 (Segment Point 13) (Analysis PR9CT)

	EE13	Diff. per Cycle	EP13	Diff. per Cycle
SSE+THERMAL	0.001327		0.002338	
Cycle 1	0.001311	-1.18%	0.002338	0.00%
Cycle 2	0.001315	0.31%	0.002338	0.00%
Cycle 3	0.001317	0.14%	0.002338	0.00%
Cycle 4	0.001318	0.06%	0.002338	0.00%
Cycle 5	0.001318	0.05%	0.002338	0.00%
Cycle 6	0.001319	0.03%	0.002338	0.00%
Cycle 7	0.001319	0.02%	0.002338	0.00%
Cycle 8	0.001319	0.02%	0.002338	0.00%
Cycle 9	0.001320	0.02%	0.002338	0.00%
Cycle 10	0.001320	0.02%	0.002338	0.00%

Note:

1. EE13 and EP13 are Elastic and Plastic Strains at Segment Point 13

2. Diff. per Cycle: Increment of strains (Percetage) between current cycle and previous cycle

ATTACHMENT 1.5

TABLE OF DISPLACEMENTS

SHEET 1 OF 2

EBASCO SERVICES INCORPORATED

BRANCH/PROJECT ID: WCG-1-1047

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Client TVA

Project WBNP Unit 1

Subject Study on the Effect of Repeated Load & Load Sequence for Thermal Eval.

Table 11.3.4.15 Comparison of Displacements between SSE Cycles at Node 19 (Analysis AX28T)

	Displ. (SRSS)	Diff. per Cycle
SSE+THERMAL	5.311	
Cycle 1	5.318	0.13%
Cycle 2	5.321	0.06%
Cycle 3	5.323	0.03%
Cycle 4	5.324	0.02%
Cycle 5	5.325	0.01%
Cycle 6	5.325	0.01%
Cycle 7	5.325	0.01%
Cycle 8	5.326	0.01%
Cycle 9	5.326	0.00%
Cycle 10	5.326	0.00%

Note:

1. Disp. (SRSS): SRSS displacement, $SQRT(UX^2+UY^2+UZ^2)$, at node 19
2. Diff. per Cycle: Increment of displacements (Percetage) between current cycle and previous cycle

ATTACHMENT 1.5

TABLE OF DISPLACEMENTS

SHEET 2 OF 2

EBASCO SERVICES INCORPORATED

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Project WBNP Unit 1

Subject Study on the Effect of Repeated Load & Load Sequence for Thermal Eval.

Table 11.3.4.20 Comparison of Displacements between SSE Cycles at Node 51 (Analysis PR9CT)

	Displ. (SRSS)	Diff. per Cycle
SSE+THERMAL	1.124	
Cycle 1	1.140	1.47%
Cycle 2	1.143	0.25%
Cycle 3	1.145	0.12%
Cycle 4	1.146	0.08%
Cycle 5	1.146	0.05%
Cycle 6	1.147	0.03%
Cycle 7	1.147	0.03%
Cycle 8	1.147	0.03%
Cycle 9	1.147	0.02%
Cycle 10	1.148	0.02%

Note:

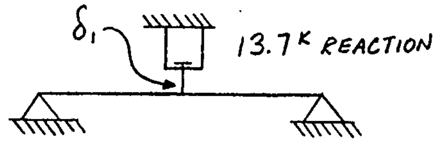
1. Disp. (SRSS): SRSS displacement, $SQRT(UX^2+UY^2+UZ^2)$, at node 51

2. Diff. per Cycle: Increment of displacements (Percetage) between current cycle and previous cycle

ATTACHMENT 1.6

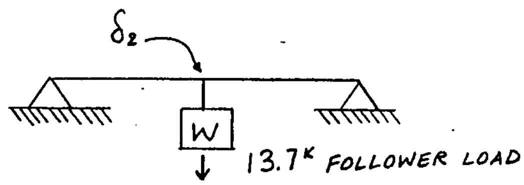
SHEET 1 OF 1

STRAIN INDUCED LOAD

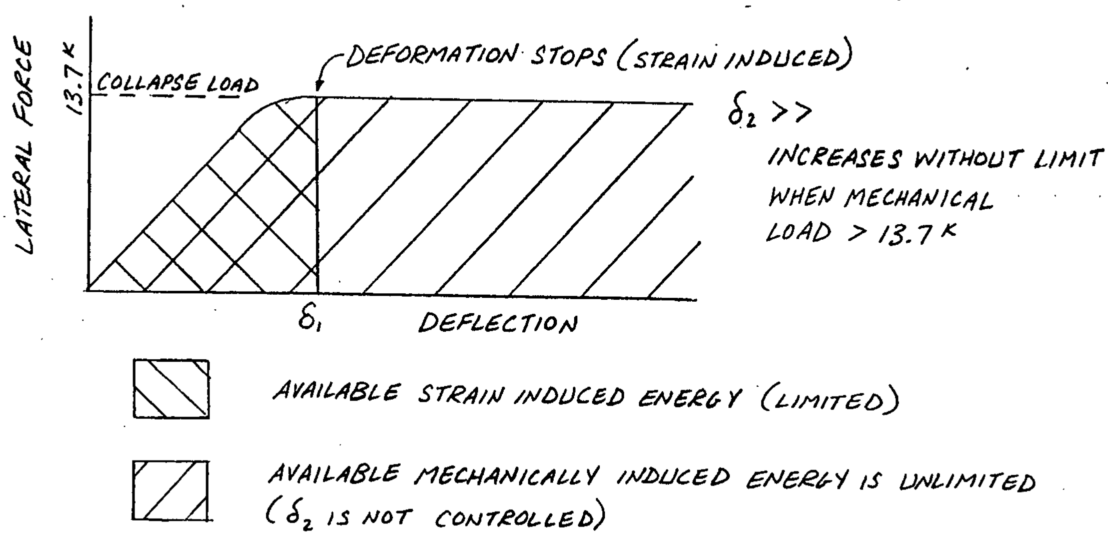


(a)

MECHANICALLY INDUCED LOAD

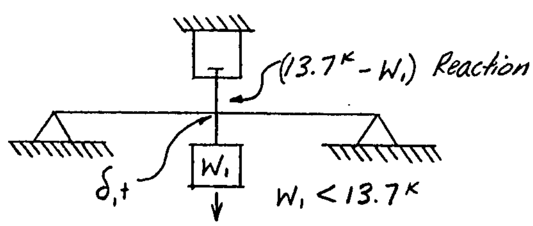


(b)



(c)

STRAIN INDUCED LOAD PLUS MECHANICAL LOAD



(d)

Supplemental Information on Thermal Evaluation
Criteria for Structural Steel Members

ENCLOSURE 2

CONCERN 2

Since ANSYS code is the primary tool to calculate the ductility of a member as well as the extent of the thermal axial load relaxation, there should be a verification of the code based on applicable experiments in an inelastic region. This should include comparison of the ANSYS results with experiments performed in Concern 1, as well as numerical studies regarding error estimate and instability associated with the calculations.

RESPONSE

1. Introduction

The ANSYS program is a general purpose finite element computer program. It has been widely used in the industry for structural analysis, especially nonlinear analysis.

The ANSYS program is used to determine the ductility ratio for the Watts Bar thermally restrained structures. The ANSYS program considers geometric nonlinearity (large deflection) and material nonlinearity to account for the P-delta and plasticity effects. By using the large deflection analysis option, the ANSYS program can predict the buckling load. Both mechanical (follower) loads and thermal loads are accepted by the ANSYS program. The capabilities, applications and program verification of the ANSYS program are well summarized in enclosure 2 reference 3, section 8.3.3.

2. Enclosure 2 References

   1. Calculation WCG-1-811, "Test Correlation Study for Thermal Use of Ductility Ratio." This calculation was provided by letter dated June 6, 1991 and during the NRC audit of September 9-13, 1991.

   2. NRC Inspection Item TT-7(c). This item was identified and resolved during the NRC audit of September 9-13, 1991.

   3. Welding Research Council Bulletin 365, "Recommended Practices in Elevated Temperatures Design: A Compendium of Breeder Reactor Experiences (1970-1987) Volume III-Inelastic Analysis," July 1991.

3. Verification And Validation of ANSYS

As owner of the ANSYS program, Swanson Analysis Systems Incorporated maintains the quality assurance for the program. Verification problems related to the Watts Bar applications are maintained by the owner, but are proprietary. Arrangements can be made for the problems to be reviewed. The applicable verification problems are:

- Large Displacement Analysis of an Elastic Truss/Spring System (Spring-damper element)

- Dynamic Analysis of a Spring-mass-dashpot System (Combination element)

- Static Plastic Hinge in Beam (Combination element)
- Creep Verification for STIF24, 3-D Thin Walled Plastic Beam Element
- Dynamic Large Deflection Plastic Pipe Whip (STIF24)
- Plastic Large Rotation (STIF24)
- Plastic Bending of a Clamped I-Beam (STIF24)
- Plastic Large Deflection Beam with Shear Deflection (STIF24)
- Pipe Plastic Test (STIF24)
- Check User Swelling (STIF24)

4. Verification by Experiment

TVA has performed a test correlation study utilizing the test data for a beam-column subjected to lateral and axial mechanical loads. This study was documented in enclosure 2 reference 1. The objective of this study was to correlate ANSYS analysis results with test data presented in the report "Static Load Deflection Tests of Beam - Columns" by Howland and Newmark, University of Illinois. Based on the comparison of load-deflection data, the ANSYS analysis results match very well with the test data. See Concern 1 for additional discussion.

5. Buckling Analysis Capability of ANSYS Program

The ANSYS program utilizes the large deflection analysis to predict the buckling load. In a large deflection analysis, the change in displacements between interactions will decrease as the structure converges to a stable configuration. If the structure is loaded beyond its stability limit, incremental displacements will increase from iteration to iteration (i.e., the solution diverges). The buckling load is the point at which the solution begins to diverge. To demonstrate ANSYS capability in predicting the buckling loads, TVA has performed buckling analyses for a column subjected to an axial load and a beam subjected to a lateral load for the lateral torsional buckling.

The ability of the ANSYS program to predict the column buckling load was discussed during the NRC audit on Civil Calculations on September 9-13, 1991. This discussion is documented in enclosure 2 reference 2. An analysis made during the audit demonstrated that the ANSYS program can predict the axial buckling load very well. A copy of enclosure 2 reference 2 is provided in attachment 2.1.

The capability of ANSYS to estimate lateral torsional buckling is further demonstrated by comparing the ANSYS analysis results with hand calculation results. The member used and results are provided in attachment 2.2. The comparison results indicate that lateral torsional buckling is adequately calculated in the ANSYS analysis.

6. Comparison Of ANSYS Results By The ABAQUS Code

To demonstrate independently that the ANSYS program is capable of determining the structural responses for the Watts Bar thermally restrained structures, a nonlinear analysis was performed using the ABAQUS program. The ABAQUS program is also a general purpose finite element computer program capable of solving linear and nonlinear problems. This program was developed by Hibbit, Karlsson & Sorensen, Inc. with support from EPRI. The problem chosen for this analysis is a simple supported beam subjected to a lateral mechanical load and followed by a temperature increase. This problem was previously analyzed by using the ANSYS program and documented in enclosure 2 reference 1.

The analysis results obtained from the ABAQUS run were compared with those from the ANSYS analysis. Attachment 2.3 shows the plots of the displacement ductility vs. temperature and beam axial force vs. temperature for results obtained from ANSYS and ABAQUS programs. The ABAQUS results match very well with the ANSYS results.

ATTACHMENT 2.1
SHEET 1 OF 8

T30 910924 804

Date: 9/23/91
Item No: TT 7(c) R1

NRC Inspection
Civil Calculations
9 - 13 September 1991

Program Element: Thermal

NRC Reviewer(s): Tom Tsai

TVA Responsible Person: John Hughes/Bob James

ESI Contact Alan Lin

Issues Discussed/Information Presented:

The ability of ANSYS to predict Euler buckling was discussed.

Open Issue(s)/Request(s):

Provide example confirming buckling capacity by ANSYS large deflection capability to AISC formula for a column. | R1

TVA Planned Action/Position:

See attached calculation

Prepared By: [signature]
Reviewed By: [signature] for J Hughes per telecon 9/23/91
Approved By: [signature] 9/24/91

WBEP - 3113M

ATTACHMENT 2.1

SHEET 2 OF 8

EBASCO SERVICES INCORPORATED

BY SAL DATE 9-12-91 SHEET 1 OF 7

CHKD. BY AJChe DATE 9/12/91 OFS NO. NR DEPT. NO. NR

CLIENT TVA

PROJECT WBNP Unit #1

SUBJECT Comparison of Buckling Load from ANSYS VS AISC Formula

The member used in Prob # 1 of WCG-1-811 (Test Correlation Study for Thermal Use of Ductility Ratio) is adopted in this calculation. (Length of 180" is used)

The member is Axially loaded (20 Kip) and followed by incremental load step (1^{K} per Load step). A Lateral force of 0.1^{K} is applied at mid-span of the member in the directions of both strong & weak axes to simulate initial curvatures.

ANSYS analysis indicates BUCKLING occurs at Axial Force = 33^{K} (See sheet 2)

The computation of buckling Load per DG-C1.6.12 results in the Buckling Load = 33.3^{K} (See Sheet 3)

The ANSYS input file is attached in sheets 4 through 7.

ATTACHMENT 2.1

SHEET 3 OF 8

EBASCO SERVICES INCORPORATED

BY SAL DATE 9/12/91 SHEET 2 OF 7

CHKD. BY AJd DATE 9/12/91 OFS NO. NR DEPT. NO. NR

CLIENT TVA

PROJECT WBNP - UNIT #1

SUBJECT Comparison of Buckling Load from ANSYS & AISC Formula

Axial Load

Displacement @ node 16 (mid-span of member)

ANSYS POST26 VARIABLE LISTING

ITER	RFOR 31 FX 31 FX31	DISP 16 UX 16 UX	DISP 16 UY 16 UY	DISP 16 UZ 16 UZ	OPER 28 SQRT SRSS	
12.000	-20.0000	.166952E-01	.273216	.501355E-01	.278280	
19.000	-21.0000	.175872E-01	.294682	.508442E-01	.299553	
27.000	-22.0000	.185040E-01	.320380	.515829E-01	.325033	
36.000	-23.0000	.194526E-01	.350894	.523551E-01	.355311	
46.000	-24.0000	.204471E-01	.387715	.531678E-01	.391878	
57.000	-25.0000	.215098E-01	.433040	.540321E-01	.436927	
70.000	-26.0000	.226844E-01	.491017	.549699E-01	.494605	
85.000	-27.0000	.240379E-01	.566468	.560125E-01	.569738	
104.00	-28.0000	.257260E-01	.670550	.572354E-01	.673480	
124.00	-29.0000	.280293E-01	.817570	.587691E-01	.820159	
144.00	-30.0000	.316317E-01	1.03791	.609332E-01	1.04017	
164.00	-31.0000	.384746E-01	1.40000	.646341E-01	1.40201	
184.00	-32.0000	.551089E-01	2.06739	.728985E-01	2.06941	
204.00	-33.0000	.284202	6.24003	.185217	6.24924	} buckling occurs
224.00	-34.0000	328.185	-50.0891	-164.228	370.385	

EBASCO SERVICES INCORPORATED

BY SAL DATE 9/12/91 SHEET 3 OF 7
CHKD. BY [signature] DATE 9/12/91 OFS NO. DEPT. NO.
CLIENT TVA
PROJECT Watts Bar Unit #1
SUBJECT Comparison of Buckling Load from ANSYS & AISC Formula

Calculation of buckling load based on Paragraph C2.3.2 of Design Criteria DG-C1.6.12

Use same size of beam of the Problem No. 1 in the correlation study WCG-1-811, but with a length of 180 inches.

$A_g = 3.84\ in^2,\quad I_{yy} = 10.6\ in^4,\quad I_{zz} = 3.77\ in^4$

(beam properties from ANSYS output, p. 37 of WCG-1-811)

For the lateral buckling

$$r = \sqrt{\frac{I_{zz}}{A_g}} = \sqrt{\frac{3.77}{3.84}} = 0.991\ in.$$

Use C2.3.2 of DG-C1.6.12 to calculate buckling load:

$$\phi = \frac{Kl}{\pi r}\sqrt{\frac{F_y}{E}} = \frac{1.0 \times 180}{\pi \times 0.991}\sqrt{\frac{36}{29000}}$$

$$= 2.037$$

The buckling load

$$P_u = F_y \times A_g / \phi^2 = 36 \times 3.84 / 2.037^2$$

$$= 33.32\ Kip$$

1

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

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/PREP7
/TITLE,PB1BUK HOWLAND-NEWMARK MODEL, FX= 30-130, BUCKLING TEST
/COM
/COM  FROM PB1AX2
/COM   USE L=180    ---> KL/R > 140
/COM  LATEST REVISION BY SAL  9/11/91
/COM
/COM  JOHN1C3
/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 INPUT:  JOHN1C3
/COM OUTPUT: JOCW1C3
/COM FILE12: JFCW1C3
/COM PLOT FILE: JGCW1C3      *GEOMETRY & BOUNDARY CONDITIONS
/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=180  * SAL 9/12/91          * 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
```

1

```
N,NUM,L
FILL
N,NUM+1,L/2,0,5
E,1,2,NUM+1
RP30,1,1,0                     * RPNNN, NNN=NUM-1
C***
ITER,-20,20
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,16,FY,0.1
F,16,FZ,0.1
C***  F,1,FX,64
C*** DEFINE REPEATING LOADINGS AS MACRO
DE=0.6
*CREAT,TMP
F,1,FX,ARG1
LWRITE
*END
*USE,TMP,20
RP15,,1
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/SHOW
/PNUM,NODE,-1
EPLOT
/PNUM,NODE,1
NRSEL,1,NUM,MID-1
EPLOT
EPLOT
AFWRITE,,1
FINISH
/INPUT,27
FINISH
/POST1
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NLINE,200
*GO,:LA1
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
```



```
:LA1
*CREAT,MAC1
```

```
SET,ARG1
PRRFOR
PRDISP
PLDISP
PLDISP,1
*END
*USE,MAC1,23
FINISH
C***
/POST26
/SHOW
LINE,200
TVAR,1
NUMVAR,50
DISP,2,16,UZ,UZ64
RFORCE,3,31,FX,FX31
NFORCE,4,16,16,MY,MY64
DE=(1)/.6
PE=(1)/9.64
ME=(1)/212
ABS,5,2,,,UZ/,DE,,DE
ABS,6,3,,,FZ/,PE,,PE
ABS,7,4,,,MY/,ME,,ME
C***
*CREAT,DSP
DISP,21,ARG1,UX,UX
DISP,22,ARG1,UY,UY
DISP,23,ARG1,UZ,UZ
PROD,24,21,21,,UXUX
PROD,25,22,22,,UYUY
PROD,26,23,23,,UZUZ
ADD,27,24,25,26,SS
SQRT,28,27,,,SRSS
PRVAR,3,21,22,23,28
*END
*USE,DSP,16
C***
*CREATE,STRN
C***  STORE STRAIN FOR WIDE-FLAGE
ESTR,11,ARG1,215,EE01
ESTR,12,ARG1,216,EP01
ESTR,13,ARG1,239,EE05
ESTR,14,ARG1,240,EP05
ESTR,15,ARG1,275,EE11
ESTR,16,ARG1,276,EP11
ESTR,17,ARG1,299,EE15
ESTR,18,ARG1,300,EP15
PRVAR,3,11,12,13,14
PRVAR,3,15,16,17,18
*END
*USE,STRN,15
C***
PRVAR,1,2,5
PRVAR,1,3,6
PRVAR,1,4,7
C***
C***
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PLVAR,6
PLVAR,6
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ATTACHMENT 2.1

SHEET 8 OF 8

Sheet 7 of 7

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PLVAR,7
/GRAPH,LABY,F&M
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XVAR,2
/GRAPH,LABY,FORC
PLVAR,3
/GRAPH,LABY,MON.
PLVAR,4
/GRAPH,LABY,F&M
PLVAR,3,4
FINISH
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```
1        ANSYS - ENGINEERING ANALYSIS SYSTEM  REVISION 4.3     A 10   CDC-TVA          JAN 1,1987
   ANSYS(R)  COPYRIGHT(C) 1971, 1978, 1982, 1983, 1985, 1987  SWANSON ANALYSIS SYSTEMS, INC. AS AN UNPUBLISHED WORK.
   PROPRIETARY DATA - UNAUTHORIZED USE, DISTRIBUTION OR DUPLICATION IS PROHIBITED.  ALL RIGHTS RESERVED.
   FOR SUPPORT CALL CDC              PHONE                   TWX

 TITLE                                                                  20.9847  SEP 12,1991 CP=      .464

         ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

 NEW TITLE= PB1BUK HOWLAND-NEWMARK MODEL, FX= 30-130, BUCKLING TEST


  FROM PB1AX2
   USE L=180     ---> KL/R > 140
  LATEST REVISION BY SAL  9/11/91

  JOHN1C3

 HOWLAND - NEWMARK MODEL
 REF. NEWMARK LOAD TESTS
 SPECIMEN 415 S 4H13.0
 E=29E3 KSI, FY=55.3 KSI
 INPUT:  JOHN1C3
 OUTPUT: JOCW1C3
 FILE12: JFCW1C3
 PLOT FILE: JGCW1C3      *GEOMETRY & BOUNDARY CONDITIONS


 ANALYSIS TYPE=  0   (STATIC ANALYSIS)

 LARGE DEFLECTION SOLUTION (KAY(6)=1)

 NON-LINEAR ANALYSIS - SUPPLY NON-LINEAR PROPERTIES

 ELEMENT TYPE   1 USES STIF 24
  KEYOPT(1-9)=   0   0   0    0   0   1    0   0   0
  INOTPR= 0  NUMBER OF NODES=   3

 PLASTIC THIN-WALL BEAM, 3-D

 CURRENT NODAL DOF SET IS  UX    UY    UZ    ROTX  ROTY  ROTZ
  THREE-DIMENSIONAL STRUCTURE

 REFERENCE TEMPERATURE=  70.000  (TUNIF=  70.000)

 MATERIAL   1          COEFFICIENTS OF EX   VS. TEMP EQUATION
  CO =    29000.00

 PROPERTY TABLE EX     MAT=   1  NUM. POINTS=  2
       TEMPERATURE      DATA          77 L/POST26/
```

ATTACHMENT 2.2

SHEET 1 OF 13

EBASCO SERVICES INCORPORATED

BY ___ DATE 11-20-91 SHEET 1 OF ___

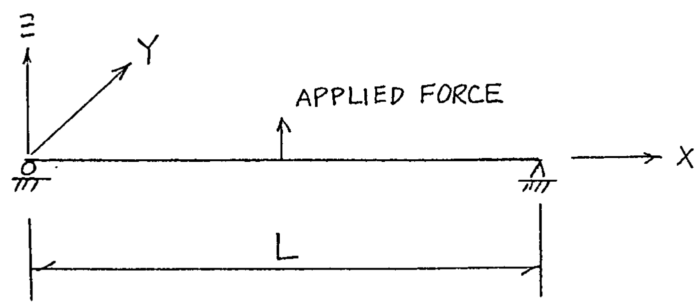
CHKD. BY ___ DATE 11/21/91 OFS NO. NR DEPT. NO. NR

CLIENT TVA

PROJECT WBNP - UNIT 1

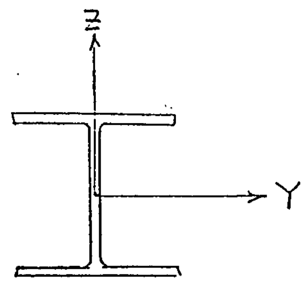
SUBJECT LATERAL / TORSIONAL BUCKLING - ANSYS VS HAND CALC.

Problem Description



ELEVATION

W 4 x 13



SECTION

APPLY FORCES IN Z-DIRECTION TO PREDICT LATERAL BUCKLING.

ATTACHMENT 2.2

SHEET 2 OF 13

EBASCO SERVICES INCORPORATED

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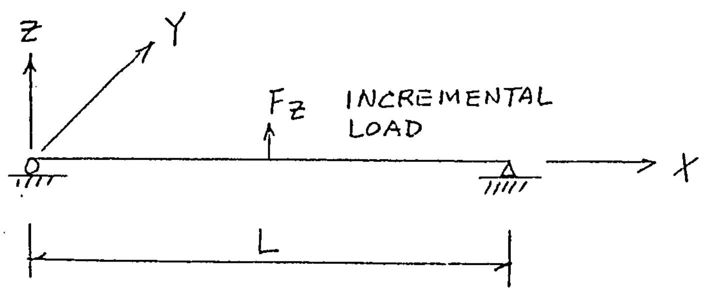
PROJECT WBNP - UNIT 1

SUBJECT LATERAL / TORSIONAL BUCKLING - ANSYS VS HAND CALC.

ANSYS RUNS



ANSYS RUN NO.	L (IN)	Fz (K)	DISPLACEMENT AND ROTATION HISTORY	REMARKS
1	216	4-8	TABLE 4A-1	
2	98	7-15	TABLE 4A-2	

EBASCO SERVICES INCORPORATED

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CLIENT TVA

PROJECT WBNP - UNIT 1

SUBJECT LATERAL / TORSIONAL BUCKLING - ANSYS VS HAND CALC.

Table 4A-1 Displacement and Rotation History at mid-span of member for Run #1 (L=216")

P81LB2 HOWLAND-NEWMARK MODEL,FX=0,FZ=4 - 8 KIP;L=18'; LAT. BUKL TEST

ANSYS POST26 VARIABLE LISTING

NFOR 16 FZ 16 FZ16	DISP 16 UX 16 UX	DISP 16 UY 16 UY	DISP 16 UZ 16 UZ	OPER 28 SQRT SRSS
-2.00000	.411996E-01	.228381E-01	2.72585	2.72626
-2.05000	.432830E-01	.232341E-01	2.79390	2.79434
-2.10000	.454175E-01	.236269E-01	2.86195	2.86241
-2.15000	.476033E-01	.240197E-01	2.93000	2.93048
-2.20000	.498403E-01	.244214E-01	2.99803	2.99854
-2.25000	.521284E-01	.248412E-01	3.06606	3.06660
-2.30000	.544676E-01	.252881E-01	3.13408	3.13466
-2.35000	.568581E-01	.257721E-01	3.20210	3.20270
-2.40000	.592994E-01	.253100E-01	3.27011	3.27074
-2.45000	.617920E-01	.257410E-01	3.33810	3.33878
-2.50000	.643357E-01	.262112E-01	3.40610	3.40681
-2.55000	.669304E-01	.267094E-01	3.47408	3.47483
-2.60000	.695763E-01	.272307E-01	3.54206	3.54285
-2.65000	.722731E-01	.277708E-01	3.61003	3.61086
-2.70000	.750210E-01	.283226E-01	3.67799	3.67886
-2.75000	.778199E-01	.288721E-01	3.74594	3.74686
-2.80000	.806541E-01	-.357895E-02	3.81413	3.81499
-2.85000	.623066E-01	-2.22015	5.20845	5.66223
-2.90000	.533366	-13.9128	32.5651	35.4166
-2.95000	5.78648	-38.3351	76.4872	85.7517
-3.00000	12.6037	-42.2157	86.3739	96.9612
-3.05000	17.2633	-43.3792	90.8616	102.155
-3.10000	20.7498	-43.7542	93.5212	105.315
-3.15000	23.5197	-43.6914	95.2761	107.423
-3.20000	25.8094	-43.4252	96.6254	109.034
-3.25000	27.8403	-43.3889	98.1450	110.861
-3.30000	29.8326	-44.9768	100.805	114.344
-3.35000	31.6294	-51.3506	104.888	120.991
-3.40000	30.1688	-52.0969	95.9983	113.313
-3.45000	28.6430	-5.53789	81.3297	86.4037
-3.50000	34.7173	-102.236	122.950	163.628
-3.55000	30.6961	-44.3818	83.7138	99.5992
-3.60000	32.4208	-51.5686	87.3117	106.460
-3.65000	31.3454	-50.0346	81.3527	100.520
-3.70000	33.4825	-48.3492	83.0428	101.759
-3.75000	35.3895	-49.7123	85.6410	105.158
-3.80000	35.7431	-41.8835	83.2380	99.8016
-3.85000	38.0754	-47.2123	88.1654	107.013
-3.90000	38.0717	-38.5142	84.4453	100.319
-3.95000	39.8360	-42.3421	88.7225	106.073

← LATERAL BUCKLING STARTS (row -2.80000 circled)

$F_z = 2.80 \times 2 = 5.6$ KIPS

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PROJECT WBNP - UNIT 1

SUBJECT LATERAL / TORSIONAL BUCKLING - ANSYS VS HAND CALC.

Table 4A-1 Displacement and Rotation History at mid-span of member for Run #1 (L=216") (Cont'd)

PB1LB2 HOWLAND-NEWMARK MODEL,FX=0,FZ=4 - 8 KIP;L=18'; LAT. BUKL TEST

ANSYS POST26 VARIABLE LISTING

NFOR 16 FZ 16 FZ16	DISP 16 ROTX 16 ROTX	DISP 16 ROTY 16 ROTY	DISP 16 ROTZ 16 ROTZ
-2.00000	.165602E-02	.708813E-12	.107759E-13
-2.05000	.168972E-02	.154941E-11	-.112723E-13
-2.10000	.174077E-02	-.101824E-11	.183266E-13
-2.15000	.180148E-02	.128233E-11	.128292E-13
-2.20000	.186859E-02	.253743E-11	-.128499E-13
-2.25000	.194048E-02	.456573E-12	-.366864E-14
-2.30000	.201622E-02	-.163490E-11	.383115E-14
-2.35000	.209505E-02	.223607E-11	.165939E-13
-2.40000	.232896E-02	-.129002E-11	-.329700E-13
-2.45000	.241368E-02	-.149444E-11	.160648E-14
-2.50000	.251208E-02	-.324945E-11	.150526E-13
-2.55000	.262154E-02	-.264081E-11	.855961E-14
-2.60000	.274154E-02	.173680E-11	.258247E-13
-2.65000	.287266E-02	-.534399E-11	.223443E-14
-2.70000	.301648E-02	.549714E-11	-.140393E-13
-2.75000	.317576E-02	-.819553E-13	.261117E-14
-2.80000	.751948E-02	-.236523E-11	.407239E-14
-2.85000	.320170	.624263E-11	.233000E-11
-2.90000	1.83999	.519601E-10	.125021E-09
-2.95000	2.56806	-.241926E-09	-.174445E-09
-3.00000	2.53580	-.539795E-09	-.492363E-09
-3.05000	2.50260	.688770E-09	-.197616E-09
-3.10000	2.47155	.197468E-10	-.186689E-08
-3.15000	2.44224	.183415E-09	-.262640E-09
-3.20000	2.41736	.445467E-09	-.326446E-09
-3.25000	2.40489	.766207E-09	-.182441E-08
-3.30000	2.42993	-.144069E-09	-.108812E-08
-3.35000	2.53420	.178615E-08	-.594330E-09
-3.40000	2.44539	.151035E-08	-.159361E-08
-3.45000	1.63890	.208271E-08	-.364251E-09
-3.50000	3.30165	.233066E-08	-.270941E-08
-3.55000	2.10255	.205618E-08	-.233998E-08
-3.60000	2.16807	.335190E-08	-.249454E-08
-3.65000	2.02442	.398291E-08	-.312070E-08
-3.70000	1.99411	.574045E-08	-.411880E-08
-3.75000	2.02098	.593134E-08	-.530076E-08
-3.80000	1.85011	.674344E-08	-.524502E-08
-3.85000	1.98460	.437960E-08	-.452782E-08
-3.90000	1.77562	.793383E-08	-.521128E-08
-3.95000	1.90258	.989657E-08	-.979611E-08

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CLIENT TVA

PROJECT WBNP - UNIT 1

SUBJECT LATERAL / TORSIONAL BUCKLING - ANSYS VS HAND CALC.

Table 4A-2 Displacement and Rotation History at mid-span of member for Run #2 (L=98")

PCILB3 HOWLAND-NEWMARK MODEL,FX=0,FZ=7-15 KIP;L=98"; LAT. BUKL TEST

ANSYS POST26 VARIABLE LISTING

NFOR 16 FZ 16 FZ16	DISP 16 UX 16 UX	DISP 16 UY 16 UY	DISP 16 UZ 16 UZ	OPER 28 SQRT SRSS
-3.50000	.241663E-02	.182978E-02	.445754	.445764
-3.60000	.255667E-02	.183349E-02	.458487	.458498
-3.70000	.270066E-02	.183580E-02	.471221	.471232
-3.80000	.284859E-02	.183822E-02	.483954	.483966
-3.90000	.300046E-02	.184072E-02	.496687	.496700
-4.00000	.315627E-02	.184330E-02	.509420	.509433
-4.10000	.331602E-02	.184595E-02	.522152	.522166
-4.20000	.347972E-02	.184868E-02	.534885	.534899
-4.30000	.364735E-02	.185149E-02	.547617	.547632
-4.40000	.381893E-02	.185438E-02	.560349	.560365
-4.50000	.399445E-02	.185735E-02	.573081	.573098
-4.60000	.417391E-02	.186040E-02	.585812	.585830
-4.70000	.435730E-02	.186354E-02	.598543	.598562
-4.80000	.454464E-02	.186676E-02	.611274	.611294
-4.90000	.473592E-02	.187007E-02	.624005	.624026
-5.00000	.493114E-02	.187346E-02	.636735	.636757
-5.10000	.513030E-02	.187694E-02	.649466	.649489
-5.20000	.533339E-02	.188052E-02	.662196	.662220
-5.30000	.554043E-02	.188418E-02	.674925	.674951
-5.40000	.575140E-02	.188794E-02	.687655	.687681
-5.50000	.596631E-02	.189179E-02	.700384	.700412
-5.60000	.618516E-02	.189574E-02	.713112	.713142
-5.70000	.640795E-02	.189978E-02	.725841	.725872
-5.80000	.663467E-02	.190393E-02	.738569	.738601
-5.90000	.686533E-02	.190818E-02	.751297	.751331
-6.00000	.709993E-02	.191253E-02	.764025	.764060
-6.10000	.733846E-02	.191698E-02	.776752	.776789
-6.20000	.758093E-02	.192155E-02	.789479	.789518
-6.30000	.782733E-02	.192622E-02	.802206	.802246
-6.40000	.807767E-02	.193101E-02	.814932	.814974
-6.50000	.833195E-02	.193591E-02	.827658	.827702
-6.60000	.859059E-02	.199578E-02	.840410	.840456
-6.70000	.902611E-02	.559519E-02	.863068	.863133
-6.80000	.956347E-02	.117516E-01	.890691	.890819
-6.90000	.102887E-01	.324518E-01	.926819	.927444
-7.00000	.116671E-01	.876813E-01	.990552	.994494
-7.10000	.150736E-01	.216623	1.12398	1.14476
-7.20000	.268005E-01	.506739	1.46814	1.55337
-7.30000	.768741E-01	1.02827	2.45257	2.66052
-7.40000	.237306	1.52396	4.42205	4.68330
-7.50000	.682061	2.06578	7.62955	7.93365

LATERAL BUCKLING STARTS. (row -6.70000 circled)

$F_z = 6.7 \times 2$
$= 13.4$ KIPS

ATTACHMENT 2.2

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SUBJECT LATERAL / TORSIONAL BUCKLING - ANSYS VS HAND CALC.

Table 4A-2 Displacement and Rotation History at mid-span of member for Run #2 (L=98") (Cont'd)

PB1LB3 HOWLAND-NEWMARK MODEL,FX=0,FZ=7-15 KIP;L=98"; LAT. BUKL TEST

ANSYS POST26 VARIABLE LISTING

NFOR 16 FZ 16 FZ16	DISP 16 ROTX 16 ROTX	DISP 16 ROTY 16 ROTY	DISP 16 ROTZ 16 ROTZ
-3.50000	.846660E-04	-.320951E-12	.192064E-14
-3.60000	.927116E-04	.184282E-12	.160712E-14
-3.70000	.958541E-04	-.462706E-12	-.199833E-14
-3.80000	.986856E-04	.391937E-13	-.217895E-14
-3.90000	.101512E-03	-.547794E-12	-.906875E-15
-4.00000	.104355E-03	.463806E-12	.395969E-14
-4.10000	.107218E-03	-.456769E-12	.229074E-14
-4.20000	.110100E-03	-.214711E-11	.332800E-14
-4.30000	.113004E-03	-.455704E-12	-.272654E-14
-4.40000	.115929E-03	-.135124E-11	.306130E-14
-4.50000	.118876E-03	.175202E-12	-.548108E-15
-4.60000	.121846E-03	-.974407E-13	.130178E-14
-4.70000	.124839E-03	.249197E-13	.149264E-14
-4.80000	.127857E-03	.666237E-12	-.702707E-15
-4.90000	.130899E-03	-.623405E-13	.156722E-14
-5.00000	.133968E-03	.101579E-11	-.314004E-16
-5.10000	.137063E-03	.425136E-12	-.123242E-14
-5.20000	.140185E-03	-.102256E-11	-.109216E-14
-5.30000	.143335E-03	-.171157E-12	-.967540E-16
-5.40000	.146514E-03	-.110424E-11	.195330E-14
-5.50000	.149723E-03	.146391E-11	.162845E-14
-5.60000	.152963E-03	.512233E-13	.287923E-14
-5.70000	.156234E-03	.117017E-11	-.122295E-14
-5.80000	.159538E-03	-.109371E-11	.983148E-15
-5.90000	.162875E-03	-.551316E-12	-.906410E-16
-6.00000	.166246E-03	-.737270E-12	.103794E-14
-6.10000	.169653E-03	-.112118E-11	.112176E-14
-6.20000	.173096E-03	-.858734E-12	.607350E-15
-6.30000	.176576E-03	-.884562E-12	-.269053E-15
-6.40000	.180095E-03	.902566E-12	-.707994E-15
-6.50000	.183653E-03	.406727E-12	.936696E-15
-6.60000	.187253E-03	.180636E-11	.313953E-14
-6.70000	.825848E-03	.110086E-11	.188408E-13
-6.80000	.196539E-02	.135721E-11	.135629E-13
-6.90000	.574736E-02	.656301E-12	.576709E-13
-7.00000	.160399E-01	.867147E-12	.580855E-13
-7.10000	.401780E-01	.490150E-12	.380772E-12
-7.20000	.947157E-01	-.389910E-12	.345501E-12
-7.30000	.195539	.725620E-11	-.250797E-11
-7.40000	.298716	.450195E-12	.384121E-11
-7.50000	.422670	-.809356E-10	.841821E-10

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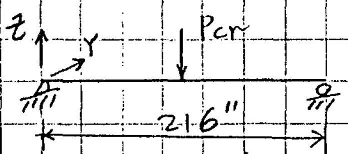
SUBJECT LATERAL / TORSIONAL BUCKLING - ANSYS VS CALCULATION

REF

THEORETICAL CALCULATION

(1) CASE 1 :

W 4 X 13



$L = 216''$

* FROM ANSYS OUTPUT

$I_Y = 3.772 \ IN^4$ *, $I_Z = 10.62 \ IN^4$ *

$J = 0.153 \ IN^4$ *, $E = 29 \times 10^3 \ KSI$

$G = 11.15 \times 10^3 \ KSI$, $C_W = 12.42$ *

$$M_{ocr} = \frac{\pi}{L} \sqrt{E I_Y G J} \cdot \sqrt{1 + W^2}$$

"GUIDE TO STABILITY DESIGN CRITERIA FOR METAL STRUC" BY T. GALAMBOS 4th EDITION PAGE 157

$$W = \frac{\pi}{L} \sqrt{\frac{E C_W}{G J}} = \frac{\pi}{216} \sqrt{\frac{29 \times 10^3 \times 12.42}{11.15 \times 10^3 \times 0.153}}$$

$$= 0.211$$

$$M_{ocr} = \frac{\pi}{216} \sqrt{29 \times 10^3 \times 3.772 \times 11.15 \times 10^3 \times 0.153} \times \sqrt{1 + 0.211^2}$$

$$= 198.7 \times 1.022$$

$$= 203.1 \ ''\text{-}K$$

FOR SIMPLY - SUPPORTED BEAM SUBJECTED TO CONCENTRATED LOAD

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$$M_{cr} = C_b M_{ocr}$$

WHERE $C_b = A = 1.35$

ATTACHMENT 2.2

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PROJECT WBNP - UNIT 1

SUBJECT LATERAL / TORSIONAL BUCKLING - ANSYS VS CALCULATION

REF.

CORRECTION FACTOR (Fa) FOR DISPLACEMENT EFFECTS ON LATERAL BUCKLING STRENGTH.

$$F_a = \frac{1}{\sqrt{\left(1 - \frac{B_1}{B_2}\right)} \times \sqrt{\left(1 - \frac{C}{B_2}\right)}}$$

"EFFECT OF DEFLECTION ON LATERAL BUCKLING STRENGTH" BY CLARK AND KNOLL JOURNAL OF ENGINEERING MECHANICS DIVISION, ASCE, APRIL, 1958

$$B_1 = E \cdot I_Y = 29000 \times 3.772 = 109,388$$

$$B_2 = E \cdot I_Z = 29000 \times 10.62 = 307,980$$

$$C = GJ = 11150 \times 0.153 = 1706.0$$

$$F_a = \frac{1}{\sqrt{1 - \frac{109388}{307980}} \times \sqrt{\left(1 - \frac{1706}{307980}\right)}}$$

$$= \frac{1}{0.804 \times 0.997}$$

$$= \frac{1}{0.8016} = 1.247$$

EBASCO SERVICES INCORPORATED

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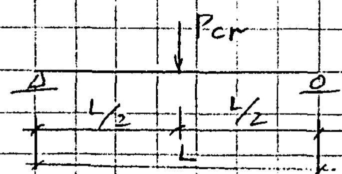
PROJECT: WBNP-UNIT 1

SUBJECT: LATERAL/TORSIONAL BUCKLING - ANSYS VS CALCULATION

REF



$M_{cr} = F_a \cdot C_b \, M_{ocr}$

$= 1.247 \times 1.35 \times 203.1 = 341.9^{\text{''-K}}$

$P_{cr} = \dfrac{4 \cdot M_{cr}}{L} = \dfrac{4 \times 341.9}{216} = 6.33^{\text{KIP}}$

IF WARPING TORSION IS NEGLECTED (CONSERVATIVE)
(ANSYS STIF24 ELEM. DOES NOT INCLDE WARPING EFFECT.)

$C_w = 0$

$M_{ocr} = 198.7^{\text{''-K}}$

$M_{cr} = 1.35 \times 1.247 \times 198.7 = 334.5^{\text{''-K}}$

$P_{cr} = \dfrac{4 \times 334.5}{216} = 6.19^{\text{KIP}}$

ATTACHMENT 2.2

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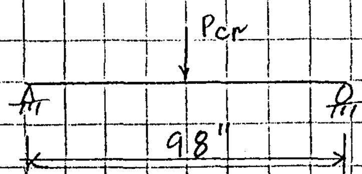
PROJECT WBNP - UNIT 1

SUBJECT LATERAL/TORSIONAL BUCKLING - ANSYS VS CALCULATION

REF

(2) CASE 2 :

M 4 X 13



L = 98"

$$M_{ocr} = \frac{\pi}{L}\sqrt{E I_Y G J} \cdot \sqrt{1 + w^2}$$

$$= \frac{\pi}{98} \times \sqrt{29\times10^3 \times 3.772 \times 11.15\times10^3 \times 0.153} \times \sqrt{1 + 0.211^2}$$

$$= 447.6^{K-''}$$

$$M_{cr} = F_a \cdot C_b \cdot M_{ocr}$$

$$= 1.247 \times 1.35 \times 447.6 = 753.5^{K-''}$$

MOMENT / FORCE AT YIELD

$$\sigma_r = \frac{M_Y \cdot C}{I_z}$$

$$C = \frac{4 - 0.37}{2} = 1.815''$$ ANSYS MODEL

$$M_Y = \frac{\sigma_r I_z}{C}$$

$$= \frac{55.3 \times 10.62}{1.815} = 323.6^{''-K}$$

$$P_Y = \frac{4 M_Y}{L}$$

$$= \frac{4 \times 323.6}{98}$$

= 13.2 KIPS

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REF

SINCE $M_{cr} > M_Y$

THEREFORE, TORSIONAL BUCKLING IN INELASTIC RANGE.

MOMENT/FORCE AT PLASTIC MOMENT

THE PLASTIC SHAPE FACTOR FOR A I-BEAM BENDING ABOUT STRONG AXIS IS 1.15.

THEREFORE, THE PLASTIC MOMENT

$$M_P = 1.15 \cdot M_Y$$

$$= 1.15 \times 323.6 = 372.14^{\prime\prime\text{-}K}$$

$$P_P = \frac{4\,M_P}{L} = 15.18^{K}$$

* FOR PG 12

* REFER TO "INELASTIC LATERAL BUCKLING OF DETERMINATE BEAMS" BY D. NETHERCOT AND N. TRAHALR, JOURNAL OF THE STRUCTURE DIVISION, APRIL 1976

ATTACHMENT 2.2

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REF: * PAGE 705 (SEE PG 11)

FROM FIGURE 2

FOR: $\sqrt{M_P/M_E} = \sqrt{M_P/M_{cr}} = \sqrt{\frac{372.14}{753.5}} = 0.70$

$\gamma = 0.0$ (FOR SIMPLY-SUPPORTED)

$M_c/M_P = 0.91$

∴ INELASTIC BUCKLING LOAD

$M_c = 0.91 \times M_p$

$= 0.91 \times 372.14 = 338.6$ "-K

BUCKLING LOAD

$P_c = \frac{4 M_c}{L} = \frac{4 \times 338.6}{98} = 13.8$ KIPS

Table 4A-3 Comparison between ANSYS Results and Theoretical Resutls for Lateral/Torsional Buckling

Critical Load for Lateral/Torsional Buckling

CASE ID (ANSYS RUN ID)	ANSYS Results (Kips)	Theoretical Results (Kips)	Remarks
1	5.6	6.2	Elastic Buckling
2	13.4	13.8	Inelatic Buckling

ATTACHMENT 2.3

ANSYS versus ABAQUS

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PROJECT WBNP - UNIT 1

SUBJECT ABAQUS VERSUS ANSYS COMPARISON

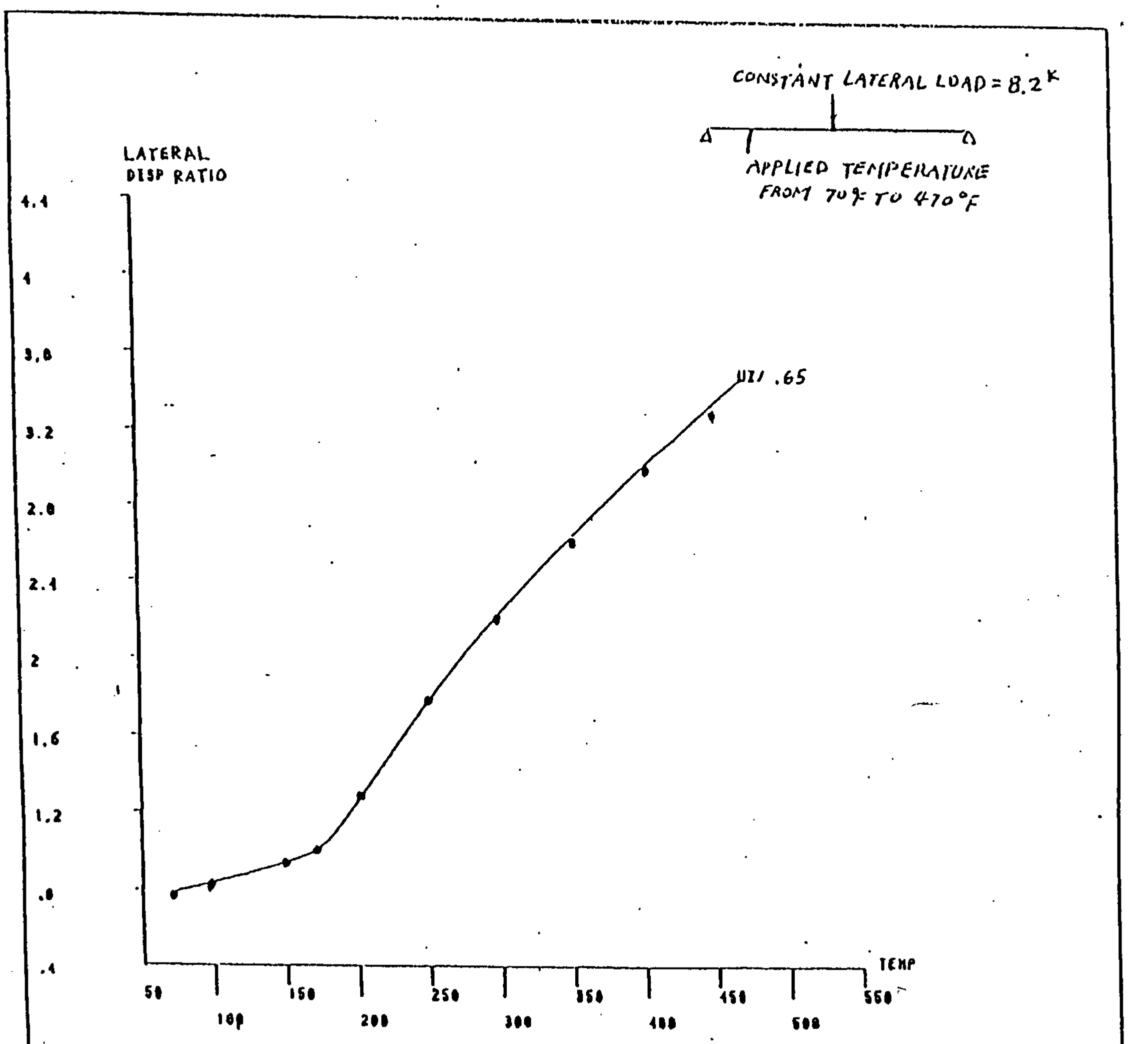
DISPLACEMENT RATIO VERSUS TEMPERATURE

(COMPARISON OF ABAQUS AND ANSYS RESULTS)

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

• ABAQUS RESULTS

— ANSYS RESULTS



PROBLEM 2 DISPLACEMENT (DI/DYIELD) VS TEMPERATURE PLOT, DYIELD=0.65

ATTACHMENT 2.3

ANSYS versus ABAQUS

SHEET 2 OF 2

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PROJECT WBNP - UNIT 1

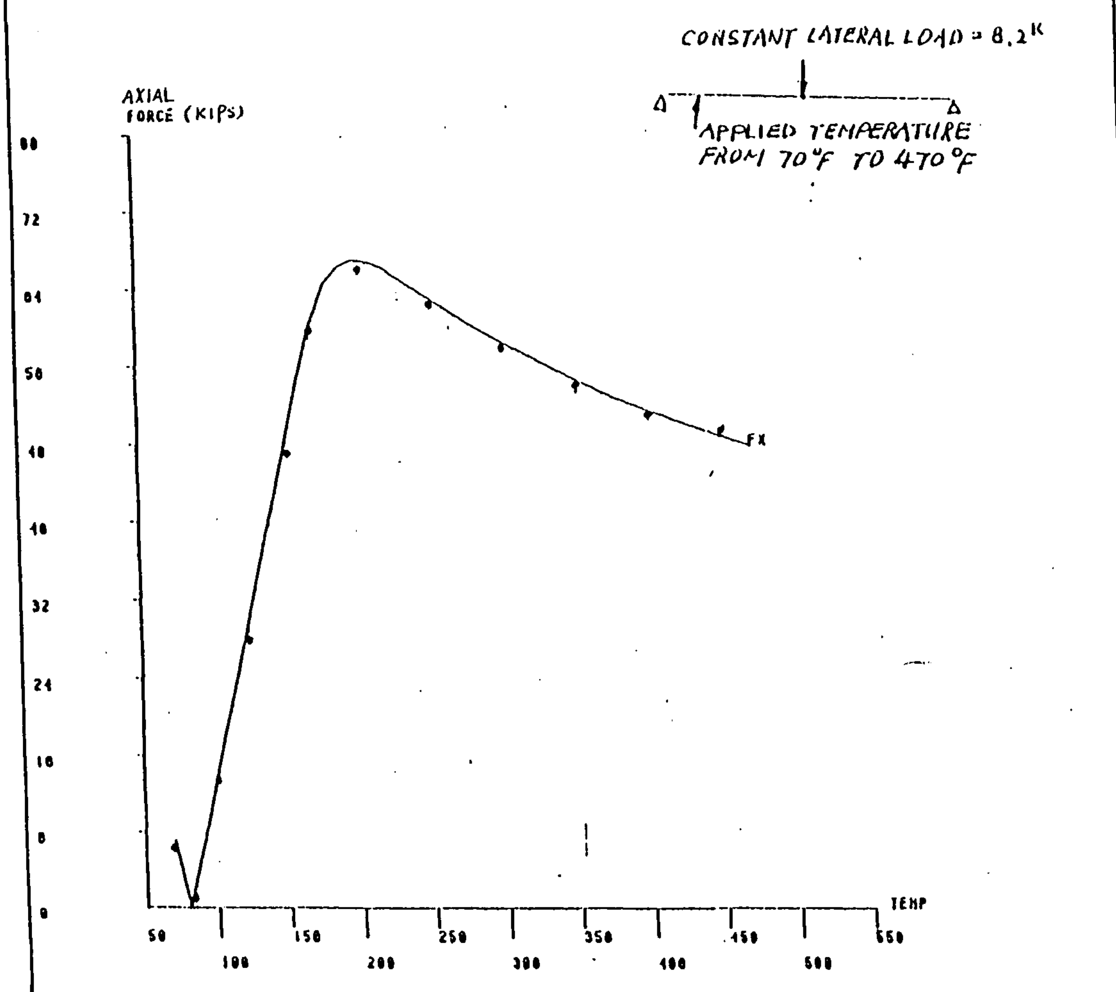
SUBJECT ABAQUS VERSUS ANSYS COMPARISON

AXIAL FORCE VERSUS TEMPERATURE

(COMPARISON OF ABAQUS AND ANSYS RESULTS)

• ABAQUS RESULTS

— ANSYS RESULTS



PROBLEM 2 AXIAL FORCE (KIPS) VS TEMPERATURE PLOT

Supplemental Information on Thermal Evaluation
Criteria for Structural Steel Members

ENCLOSURE 3

Enclosure 3 References

1. Calculation WCG-1-790, "Worst Case Selection of Thermally Restrained Structures." This calculation was provided during the NRC audit of September 9-13, 1991.

2. Calculation WCG-1-969, "Qualification of Worst Cases of Thermally Restrained Structures." This calculation was provided by letter dated October 16, 1991 and during the NRC audit of September 9-13, 1991.

ISSUE

Describe how additional worst cases will be selected.

RESPONSE

For the first fifteen worst case structures which require modification, additional worst case structures will be selected for evaluation. The selection of additional worst case will be based on the same methodology of selection for the first fifteen worst case as documented in Section 11.3 of enclosure 3 reference 1. Section 11.3 is also provided in attachment 3.1.

Also, critical parameters of any of the first fifteen worst cases which require modification will be considered in the selection process. As a minimum, for each of the first fifteen worst cases which do not meet the acceptance criteria and require modification, another worst case structure will be selected. If a group of structures is identified which is similar to a worst case structure that requires modification, then that entire group will be evaluated or modified.

ISSUE

How are actual rotations, deflections and strains considered? A ductility ratio criteria may not be sufficient.

RESPONSE

The maximum displacements and strains for the fifteen worst cases are presented in attachment 3.2. Enclosure 3 reference 2 provides detailed calculation information on these parameters for five worst case members.

Strains, deflection and rotations are inter-related and controlling one will also control the other two. In addition, while deflection of a structure may not affect its structural integrity, it may affect the function of a supported or adjacent system. Therefore, deflections are examined on a case-by-case basis.

The following guidance is included in the design instructions for the evaluation of steel structures with thermal restraint.

1. Maximum strains are maintained below 0.014 in/in.

2. Maximum deflections are evaluated for compatability with supported or adjacent features.

ISSUE

What portion of the population has lateral loads?

RESPONSE

Twenty-five percent of the 204 thermally restrained cases have significant lateral loads induced by direct attachment of system supports or equipment. See enclosure 3 reference 1 for specific member data.

ISSUE

How will provisions for design for thermal loads be incorporated into the FSAR?

RESPONSE

Table 3.8E-2 shown in attachment 3.3 will be included in the FSAR in an upcoming update.

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Project WBNP Unit 1
Subject Worst Case Selection of Thermally Restrained Structures

11.1 Objective

The objective of this calculation is to select the worst cases (enveloping cases) from the thermally restrained structures of Category I structural and miscellaneous steel population.

11.2 Scope

Worst cases are selected from the 204 thermally restrained structures identified in calculation WCG-1-686. The population of structures is limited to those shown on the following series of drawings:

A15	Platforms
A3	Category I Steel Structures
A13	Miscellaneous Steel
C14	Pipe Support Framing

11.3 Methodology

Typical thermal restraints are defined in DG-C1.6.12 and categorized in the following cases:

* Case 1: Axial Restraint
* Case 2&3: Proximity Restraint
* Case 4: Braced Restraint
* Case 5: Header Restraint

These thermal restraint cases are shown in Section 11.4. The selection of the worst cases for each of the thermal restraint configurations is accomplished by the following steps:

Step 1:

For each thermal restraint configuration, relevant data such as reference drawing number, member size and length, connection type and temperatures for operating and accident conditions are tabulated in Tables 11.5.1 through 11.5.4 (Section 11.5) for Restraint Cases 1, 2&3, 4 and 5 respectively. A platform ID is presented in the "COMMENTS" column if the thermally restrained configuration belongs to one of the 20 worst case platforms. Member ID's used in the succeeding sections are also provided in the "COMMENTS" columns.

Step 2:

Field Engineering Assessment is performed for all 204 thermally restrained configurations. Any significant loads on the thermally restrained member, for example, large bore pipe support or heavy equipment are documented. Free edge distance at critical embedded plates and base plates is recorded. Any field conditions that change the thermal behavior of the steel structure as compared to conclusions based on review of drawings are also noted. The completed Field Engineering Assessment Data Sheets are presented in Section 11.6.

Step 3:

The following information is considered for the selection of the worst cases (enveloping cases):

(1) Existence of vulnerable construction configuration details observed from drawing review as well as the Field Engineering Assessment, for example, unusual connection details, expansion concrete anchors (Self-drilling anchors and Wedge Bolt anchors), free edge distance of concrete anchorage, punching shear through concrete wall or slab, etc.

(2) Attachments exhibiting significant lateral loadings on the thermally restrained member (Information obtained from the Field Engineering Assessment).

(3) The "interaction ratio" for the thermally restrained member generated by the screening calculations. Detailed description of the screening calculation is provided in Attachment A.

(4) The maximum stress in the support members (for the Proximity Restraint Case only), see Section 11.4 for identification of the support member.

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The "Enveloping Thermal Structure Selection Spread Sheets" are provided to tabulate the aforementioned information for worst case selection for each thermally restrained configuration for Restraint Cases 1, 2&3, 4 and 5, respectively (See Tables 11.8.1 through 11.8.4 in Section 11.8). For each restraint case, drawing number, member ID, temperatures (operating and accident), member size and the screening calculation are documented. Attributes that need to be considered in the worst case selection process are identified by an "x". For unusual connection details, an "x" is placed on the "connection type" line. For existence of thermally induced lateral forces, an "x" is placed on the "Thermal Lateral Load" line.

The worst cases (enveloping cases) are then selected for Restraint Cases 1, 2&3, 4 and 5, respectively, using the information documented in the "Enveloping Thermal Structure Selection Spread Sheets" in Section 11.8. The results of Selection are presented in Tables 11.9.1 through 11.9.4 in Section 11.9. Sketches of each selected worst cases are shown in Figures 11.10.1 through 11.10.4 in Section 11.10.

Eight (8) configurations are selected as the worst cases for Restraint Case 1 (Axial). Three (3) members with Interaction Ratio greater than 2.0 are first selected as worst cases. Members with Interaction Ratio greater than 1.0 are then taken into account. Five (5) more members are selected by considering altogether the Interaction Ratio and the attributes such as connection details, expansion concrete anchors, significant lateral loads, free edge distance for concrete anchorage, etc. Member 1-11 is selected because of higher Interaction Ratio and existence of significant non-thermal lateral load; Members 1-22 and 1-23 are selected because of higher Interaction Ratio; Member 1-26 is selected because of higher Interaction ratio and connection details (angle column attached to angle member); Member 1-27 is selected because of higher Interaction Ratio, Self-drilling concrete anchors (SSD) and existence of significant thermal lateral load; Member 1-28 is selected because of higher Interaction Ratio, existence of significant thermal lateral load and unusual connection detail (connection with one clip angle); Member 1-37 is selected because of higher Interaction Ratio and existence of significant thermal and non-thermal lateral loads. Member 1-38 is selected because of higher Interacting Ratio, existence of significant non-thermal load and

THIS SHEET ADDED BY REV. 1

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free edge distance for concrete anchorage.

Six (6) Configurations are selected as worst cases for Restraint Case 2&3 (Proximity). Similar to the selection of worst cases for Restraint Case 1, Interaction Ratio in the proximity member, stresses in support member and attributes, such as significant lateral loads, free edge distance for concrete anchorage, are considered altogether in the selection process. Frame 2&3-2(D) is selected because of higher Interaction Ratio, higher stress in support member and existence of significant non-thermal lateral loads; Frame 2&3-5(H) is selected because of higher Interaction Ratio, higher stress in support member, significant non-thermal load and existence of significant free edge distance for concrete anchorage; Frame 2&3-6(J) is selected because of higher stress in support member and existence of significant non-thermal lateral load; Frame 2&3-7(1) is selected because of higher stress in support member and existence of significant thermal and non-thermal lateral loads, Self-drilling concrete anchors, and free edge distance for concrete anchorage; Frame 2&3-8(G) is selected because of higher Interaction Ratio, high stresses in support member and Wedge Bolt concrete anchors; Frame 2&3-9(C) is selected because of higher stress in support member, Self-drilling concrete anchors (SSD) and existence of free edge distance for concrete anchorage.

No configuration is selected as worst case for Restraint Case 4 (Braced) because the thermal effect is negligible for all Case 4 members.

One (1) configuration is selected as worst case for Restraint Case 5 (Header). Members 5-7 is selected because it has the highest Interaction Ratio in the Case 5 population and it is a non-compact section.

Failure due to punching shear through a concrete wall or slab is not a concern, as concluded from concrete drawing review and the Field Engineering Assessment, for all 204 configurations, therefore, no selection is made due to this attribute.

THIS SHEET ADDED BY REV. 1

ATTACHMENT 3.2
Sheet 1 of 1
Deflection and Strain Summary for Worst Case Thermally Restrained Structures

Case ID Model	Case ID Worst Case	Member Length (ft-in)	Max. Displ. (in)	Max. Strain in/in	Mod #
AX11	1-11	7'-9"	0.595	0.0010	
AX22 *	1-22	18'-8"	1.883	0.0152	X
AX23 *	1-23	18'-8"	3.303	0.0115	X
AX26 *	1-26	8'-0"	0.086	0.0022	
AX28 *	1-28	17'-0"	5.105	0.0097	X
PR2D *	2&3-2(D)	6'-3 1/4"	2.145	0.0066	
PR5H *	1-37	22'-11"	---	---	X
	2&3-5(H)	3'-10"	---	---	
PR6J *	1-38	23'-9"	0.672	0.0069	X
	2&3-6(J)	4'-6 1/4"	0.913	0.0086	X
PR7I *	2&3-7(I)	18'-9"	1.328	0.0017	
PR8G	2&3-8(G)	5'-0"	0.018	0.0009	
PR9C	1-27	13'-0"	1.190	0.0056	X
	2&3-9(C)	3'-0"	0.011	0.0001	
HD07	5-7	9'-6"	0.084	0.0009	

* Preliminary Information - calculation in review process

\- Calculations started. Values not yet available

\# Modification planned or anticipated

TABLE 3.8E-2

TYPE MEMBER	TYPE LOAD / TYPE ANALYSIS	TENSION	SHEAR	COMPRESSION # $\phi \le 0.15$	COMPRESSION # $0.15 < \phi \le 0.22$	COMPRESSION # $0.22 < \phi \le 0.4$	COMPRESSION # $0.4 < \phi \le \sqrt{2}$	COMPRESSION # $\sqrt{2} < \phi$	BENDING
PRIMARY MEMBERS	LINEAR +	$\mu_{eb} \le 1.3$	$\mu_{eb} \le 1.3$	Eq. 1	Eq. 2	Eq. 2	Eq. 3	Eq. 4	Eq. 5
	NON-LINEAR +	$\mu_d \le 1.3$ (spans all columns)							
ANCILLARY MEMBERS	LINEAR + (Compression force not present)	$f_a \le F_y$	$f_v \le F_y/\sqrt{3}$	NOT ALLOWED (spans all compression columns)					$f_b \le F_y$
	NON-LINEAR + * (Compression forces is present)	$\mu_d < 0.5 \frac{\varepsilon_u}{\varepsilon_y}$ $\mu_s < 0.5 \frac{\varepsilon_u}{\varepsilon_y}$	$\mu_d \le 1.3$ or $\mu_s \le 1.3$	$\mu_d \le 1.3$ or $\mu_s \le 1.3$ (spans $\phi \le 0.15$ and $0.15 < \phi \le 0.22$)		$\mu_d \le 1$ or $\mu_s \le 1$ (spans $0.22 < \phi \le 0.4$ to $\sqrt{2} < \phi$)			$\mu_d \le 10$ or $\mu_s \le 10$

* OPTIONALLY ACCEPTANCE MAY BE BASED ON PRIMARY MEMBER CRITERIA

+ MEMBER ACCEPTANCE MAY BE BASED ON EITHER NON-LINEAR ANALYSIS AND ACCEPTANCE CRITERIA OR LINEAR ANALYSIS AND ACCEPTANCE CRITERIA.

\# $\phi = Kl/(\pi r) * \sqrt{F_y/E}$

ϕ	Kl/r
0.15	13.4
0.22	19.6
0.4	35.7
$\sqrt{2}$	126.1

NOTE:

1. Maximum strains are to be maintained below 0.014 in/in.
2. Maximum deflections are to be evaluated for compatability with supported or adjacent features.

μ_{eb} = Ductility ratio based on Energy Balance equation

μ_s = Ductility ratio based on strain from non-linear analysis

μ_d = Ductility ratio based on displacement from non-linear analysis

ε_y = Strain at first yield

ε_u = Strain at ultimate stress

ATTACHMENT 3.3

SHEET 2 OF 2

EQUATIONS

Eq. 1

$$Pu = 1.26 * Ag * Fy$$

Eq. 2

$$Pu = 1.06 * (1.34 - \phi) * Ag * Fy$$

Eq. 3

$$Pu = (1 - \phi^2/4) * Ag * Fy$$

Eq. 4

$$Pu = Fy * Ag / \phi^2$$

Eq. 5

$$(Mx/Mucx)^{exp} + (My/Mucy)^{exp} \leq 1.0$$

where Mucx and Mucy are ultimate moment capcities. At brace points, Mucx and Mucy are the plastic moment capacities reduced for the presence of axial load. Between brace points, Mucx and Mucy are the maximum uniform single curvature moment which can be resisted by the member about the respective axis in the presence of the axial load, but in the absence of the other moment. The empirical exponents, exp, establish a parabolic interaction curve.

Pu = Ultimate allowable axial strength

Fy = Specified yield stress

Ag = Gross area of member