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TECHNICAL REPORT

TECHNICAL REPORT TR-5352A-1

EXECUTIVE SUMMARY

WATERHAMMER ANALYSIS FOR SUSQUEHANNA UNITS 1 AND 2 CONTROL ROD DRIVE INSERT AND WITHDRAWAL LINES

MAY 30, 1984

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1.0 INTRODUCTION

Teledyne Engineering Services (TES) has computed the dynamic (force versus time) loadings acting on the insert lines and withdraw lines using the WAVENET computer program (Reference 8). The WAVENET program used here incorporates user subroutines that have been developed by TES under contract to the BWR Owners Group as reported in TES Technical Report TR-5709-2, Rev. 0, "BWR Owners Group CRD Scram Valve Waterhammer Analysis Committee, Generic Control Rod Drive System Study For BWR-2 through BWR-5 Plant Design", dated May 24, 1983. The program with the subroutines has been verified by comparison with actual control rod drive system test data.

The forces from the fluid analysis were used in the structural analysis to determine the integrity of the control rod drive insert and withdraw lines and their support system.

2.0 SUMMARY AND CONCLUSIONS

The analysis indicates that the seismic category 1 I&W piping and supports meet the requirements for Class 2, piping per subsection NC and NF of Section III of the Code (Reference 1 and 2) for scram waterhammer events for operating conditions as specified in the design specifications (References 3, 4 and 5).

The existing support arrangement at the reactor pedestal region was not capable of providing sufficient support for the unbalanced scram waterhammer loads which occur in the pipe that passes through the pedestal opening. Accordingly, a modification was incorporated at this region which provided an acceptable support arrangement.

3.0 METHOD OF APPROACH

The method used to perform the analysis for waterhammer loading and to evaluate the results is described below. The results of the program described below are available for NRC inspection upon request.

3.1 Fluid Analysis

Representative and bounding insert and withdrawal lines were chosen from the Susquehanna Units 1 and 2 piping. The choice of lines was based on consideration of the fluid mechanics loads developed and the structural response of the lines under these loading conditions. For example, lines with long straight runs develop the highest unbalanced fluid dynamics loads and lines with large overhangs in reaction to the waterhammer load will develop highest stresses.

The computer program WAVENET, with the subroutines developed under the BWR Owners Group project, was used to develop the dynamic forcing functions. These forcing functions are the unbalanced loads with respect to time on each pipe segment (straight pipe between elbows). The forcing functions were stored on file for easy access for input to the structural piping program.

3.2 Pipe Stress Evaluation

The forcing functions developed above were applied to the structural piping models using TES program TMRSAP. Lines evaluated were selected to span the selection criteria mentioned above.

Based on the above waterhammer analysis, ability of the piping system to accommodate the waterhammer stresses in combination with other loads was established. Other loads considered were pressure, deadweight, seismic, and safety relief valve (SRV) spectra.

3.3 Support Evaluation

Loads obtained from the piping analysis as described above were used to perform an evaluation of the I&W pipe supports.

3.4 Line Selection

Lines were selected such that the affects of the waterhammer loads on pipe stress and support loads were bounded. The selected lines include the "worst" and representative CRD lines. The fluid models in some cases were hybrid lines which combined characteristics of several lines as required by the structural analysis.

For outside containment, two types of geometries were analyzed. One type was called "STANDARD" and are those lines which have one bend or less between primary containment and the vent valve above the HCU modules. The other type is called "CROSSOVER" and has several bends in the same region and crosses over the reactor centerline.

A list of the fluid analysis models and a tabulation of the structural runs made is shown on Table 1.

3.5 Clamp Testing

A test program was performed to establish the slip capacity of the Unistrut pipe clamps when subjected to static and dynamic axial pipe loads. The dynamic load used in this test program was programmed to simulate a waterhammer impulse which occurs during scram loading.

4.0 PIPING STRUCTURAL ANALYSIS AND EVALUATION

Representative and bounding analyses of CRD piping systems were performed to quantify and bound the CRD waterhammer (W/H) loads for the Susquehanna insert and withdraw line designs. These waterhammer loads are produced by the pressure waves generated from fast actuation of the scram valves. Based on measured valve opening/flow characteristics, the WAVENET program calculates the pressures and velocities versus time along the CRD inlet and outlet lines and provides the force applied to the pipe.

The structural code TMRSAP used these tabulated forces versus time at each elbow location to determine the resulting support loads and pipe stresses. Results of the representative and bounding analysis are presented in terms of maximum support loads and stresses.

4.1 Criteria

4.1.1 Loading Conditions

For this study, the loading conditions considered include:

- Design Pressure (PD)
- Deadweight Loading (DL)
- Thermal Expansion (TH)
- Seismic Loading (OBE, SSE)
- Safety Relief Valve Loading (SRV)
- Waterhammer Loading (Cold Start-up Scram and Normal Operating Scram)
- Seismic Anchor Movements (SAM)

4.1.2 Load Combinations

On Table 2, load combinations are listed for those events which include CRD system scram transients (CSS and NOS) per Reference 4.

The two scram events considered were Cold Start-up Scram (CSS) for those conditions when the reactor is at low pressure and Normal Operating Scram (NOS) for those conditions when the reactor is at operating or elevated pressure. 1% damping was used for the scram loading analysis.

The OBE and SSE spectra are similar because of the specified damping values of 1/2% for OBE and 1% for SSE. The SRV spectra is low. Accordingly, a single spectra was used for the analysis which was an envelope of OBE, SSE and SRV.

The resulting load combinations used for determining pipe stress and support loads are summarized on Tables 3 and 4.

4.2 Analysis Results and Code Evaluation

The evaluation was performed with the aid of a TES postprocessing program PASS. The internal forces, moments and deflections for each load condition are read from magnetic tape. The program then evaluates stresses for Class 2 data points in accordance with the rules of NC-3652.

For the emergency load combination the program conservatively combined the dynamic responses from the dynamic envelope and the waterhammer event by absolute summation. The specification indicates that the SRSS method of combination may be used.

The equation 9 stresses conservatively included an intensification factor (i) of 2.1 at the CRD housing flange instead of the permitted value of 1.0.

The susquehanna CRD support system includes pipe clamps at several locations which provide 3-way support for the pipe. The piping analysis assumed no axial slip at these locations. However, the axial

loads due to the waterhammer loading exceeded the minimum loads as determined by the test program described in paragraph 3.5. Typical axial waterhammer loads and the minimum clamp slip load are shown on Table 5.

The consequence of waterhammer loads in excess of the minimum test load were studied as described in Appendix D. A method was developed to determine the additional pipe stress due to a limited amount of slip at the 3-way clamps and these calculations were performed as part of the evaluation.

These results indicate that the requirements of Section III for Class 2 components are satisfied.

5.0 SUPPORT LOADS AND EVALUATION

Support design loads were derived from the individual PASS results and from hand calculations for the skewed supports.

Loads used the peak Waterhammer loads for each line analyzed. When evaluating support frames and using the total of the insert and withdraw loads consideration of load phasing can be used to reduce the total load on the support. All calculations were performed without considering phasing except where additional design margin was required at support location number 4 inside (riser support) containment.

The outer pedestal support inside containment was modified to include axial restraint at this location.

The results of this evaluation indicate that requirements of Section III for Class 2 supports are satisfied.

6.0 REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section III, 1974 Edition, with Addenda through Winter 1975.
2. ASME Code Cases 1644-6 and 1644-8.
3. Bechtel Specification 8856-M-164, Revision 4, "Design Specification for the Control Rod Drive Hydraulic System for the Susquehanna Steam Electric Station, Units 1 and 2 of the Pennsylvania Power and Light Company, Allentown, PA."
4. Bechtel Specification 8856-G-23, Revision 4, "General Specification for Qualification of the Control Rod Drive Piping System for Seismic and Hydrodynamic Loads for the Susquehanna Steam Electric Station, Units 1 and 2 of the Pennsylvania Power and Light Company, Allentown, PA."
5. Bechtel Specification 8856-G-10, Revision 3, "General Project Requirements for a Seismic Design and Analysis of Class 1 Equipment and Equipment Supports for the Susquehanna Steam Electric Station, Units 1 and 2, Pennsylvania Power and Light Company, Allentown, PA," dated June 25, 1973.
6. TES Technical Report TR-5709-2, Rev. 0, "BWR Owners Group CRD Scram Valve Waterhammer Analysis Committee, Generic Control Rod Drive System Study For BWR-2 through BWR-5 Plant Design", Books 1, 2, and 3, dated May 24, 1983.
7. TES Clamp Test Report TR-5352A-2, "Design Load Test of CRD System Pipe Clamps for Susquehanna Steam Electric Station," dated January 19, 1984.

6.0 REFERENCES (Continued)

8. WAVENET Computer Program, R.T. Bradshaw, Inc., 85 Central Street, Waltham, MA 02154.

9. TMRPIPE Computer Program, including particularly TMRSAP for the static and dynamic stress analysis of the piping system, and PASS for printing the loads and stresses from TMRSAP in technical report format, TES, Waltham, MA.

10. ANSYS Computer Program, Engineering Analysis System, Swanson Analysis Systems, Inc., Elizabeth PA.

11. TES Technical Report TR-5352A, "Waterhammer Analysis for Susquehanna Units 1 and 2 Control Rod Drive Insert and Withdrawal Lines," dated April 13, 1984.

12. TES Technical Report TR-5352-2, Revision 1, "Pipe Stress and Support Analysis and Evaluation for Susquehanna Units 1 and 2 Pedestal Support Modifications," dated March 2, 1984.

TABLE 1 – LIST OF COMPUTER RUNS

LOCATION	LINE TYPE	GEOMETRY	HYDRALIC ANAL		FORCE TIME HISTORY		DW	TH		DYNAMIC ENVELOPE	ANCHOR MOTION	PASS
			CSS	NOS	CSS	NOS						
INSIDE CONTAINMENT	WITHDRAW	3019	X	X	X	X	X	X		X	X	X
		3031	X	X	X	X	X	X		X	X	X
		3059	X	X	X	X	X	X		X	X	X
		5835	X	X	X	X	X	X		X	X	X
		5835 WITH AXIAL ON RISER			X	X	X	X		X	X	X
		3031 " " "			X	X	X	X		X	X	X
	INSERT	3019	X	X	X	X	X	X		X	X	X
		3031	X	X	X	X	X	X		X	X	X
		3059	X	X	X	X	X	X		X	X	X
		5835	X	X	X	X	X	X		X	X	X
OUTSIDE CONTAINMENT NORTH	WITHDRAW	3019 (STANDARD)	X	X	X	X	X	X		X	X	X
NORTH		3059 (STANDARD)	X	X	X	X	X	X		X	X	X
NORTH		5835 (CROSSOVER)	X	X	X	X	X	X		X	X	X
SOUTH		0631 (CROSSOVER)	X	X	X	X	X	X		X	X	X
NORTH		5843 (CROSSOVER)	USED 5835		X	X	X	X		X	X	X
NORTH	INSERT	3415 (STANDARD)	X	X	X	X	X	X		X	X	X
NORTH		3059 (STANDARD)	X	X	X	X	X	X		X	X	X
NORTH		5835 (CROSSOVER)	X	X	X	X	X	X		X	X	X
SOUTH		1831 (CROSSOVER)	X	X	X	X	X	X		X	X	X
NORTH		5843 (CROSSOVER)	USED 5835		X	X	X	X		X	X	X

TABLE 2

CRD HYDRAULIC PIPING
WATER HAMMER LOAD COMBINATION

CASE	P&W	SRV	ADS	OBE	SSE	S/IBA	LBA	CSS	NOS	CATEGORY
1	X							X		Upset
2	X								X	Upset
3	X			X					X	Emergency
4	X	X							X	Faulted
5	X				X				X	Faulted

Notes:

P&W = Pressure plus deadweight
SRV = Pressure actuation of relief valves, as appropriate
ADS = Automatic actuation of relief valves, as appropriate
OBE = Operating basis earthquake
SSE = Safe shutdown earthquake
S/IBA = Small or intermediate LOCA
LBA = Large LOCA
CSS = Cold startup scram
NOS = Normal operating scram

TABLE 3

PIPING LOAD COMBINATIONS

Category	Loading Combinations	Stress Limits
I Upset	PD + DW + CSS	1.2 S_h
II Upset	PD + DW + NOS	1.2 S_h
III Emergency*	PD + DW + OBE + NOS	1.8 S_h
IV Faulted*	PD + DW + SRV + NOS	2.4 S_h
V Faulted*	PD + DW + SSE + NOS	2.4 S_h

* For III, IV, and V Cases, evaluation was performed with Emergency allowables using a conservative load combination as follows:

$$PD + DW + DYN.\ ENV.^{(1)} + NOS \leq 1.8\ S_h$$

TABLE 4

PIPE SUPPORT LOAD COMBINATIONS

Category	Loading Combinations
I Upset	DW + TH + CSS
II Upset	DW + TH + NOS
III Emergency*	DW + TH + NOS + OBE + $E.E._{OBE}$
IV Faulted*	DW + TH + NOS + SRV + $E.E._{SRV}$
V Faulted*	DW + TH + NOS + SSE + $E.E._{SRV}$

* For III, IV, and V Cases, evaluation was performed with Emergency allowables using a conservative load combination as follows:

$$DW + TH + NOS + DYN.\ ENV.^{(1)} + (E.E.)_{Combined}$$

(1) A single spectra was used for the analysis which was an envelope of OBE, SSE and SRV.

TABLE 5

AXIAL SLIP THRU LOADS INSIDE CONTAINMENT

LOCATION 2 - PEDESTAL

	W/H Only		Design		Minimum Slip Test Load
	CSS	NOS	N&U	EMERG.	
3/4" WITHDRAW					
3019W	248	304	329	339	375
3031W	140	271	292	308	
3059W	133	238	297	316	
5835W	211	294	333	344	
1" INSERT					
3019I	351	162	366	209	300
3031I	239	151	256	209	
3059I	261	185	288	257	
5835I	345	170	362	232	

LOCATION 4 - RISER

	W/H Only		Design		Minimum Slip Test Load
	CSS	NOS	N&U	EMERG.	
3/4" WITHDRAW					
3031W	117	277	-	-	375
3059W	169	183	220	250	
5835W	176	157	-	-	
1" INSERT					
3019I	187	98	230	186	300
3031I	224	84	280	188	
3059I	229	160	260	268	
5835I	193	154	230	263	

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APPENDIX A

WATERHAMMER AXIAL LOAD ANALYSIS

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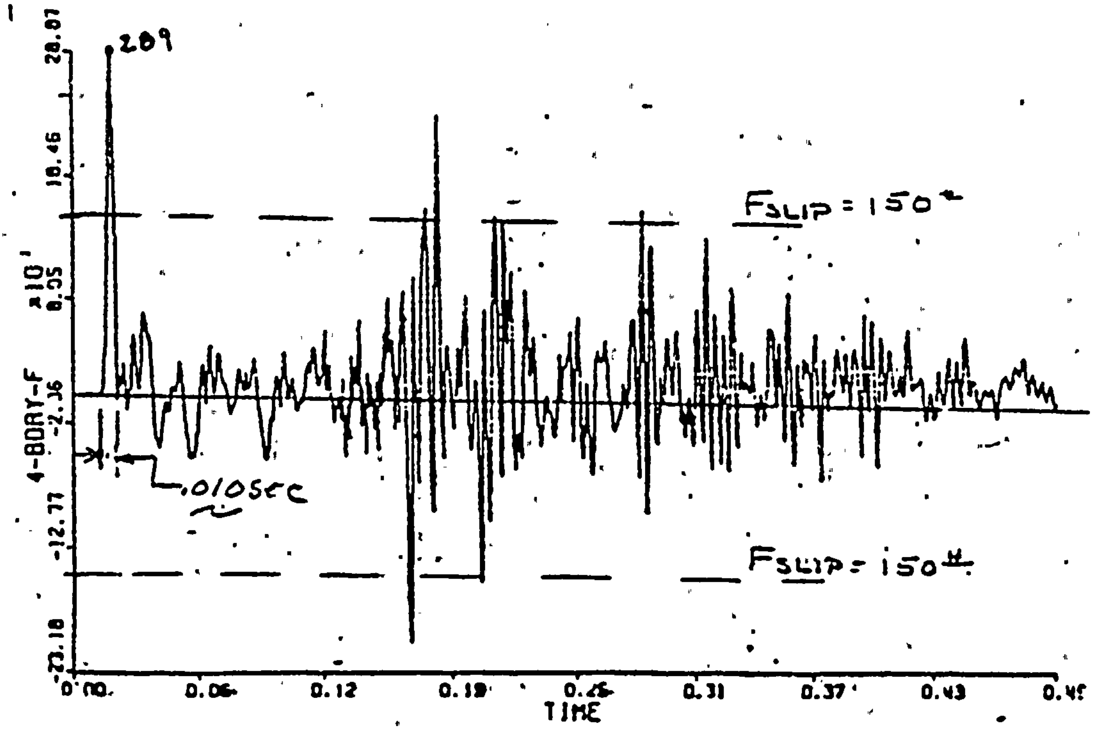
WATERHAMMER AXIAL LOAD ANALYSIS

A typical axial load on a withdraw line clamp in the pedestal for NOS scram is shown below. An arbitrary clamp axial slip design capacity is also indicated.

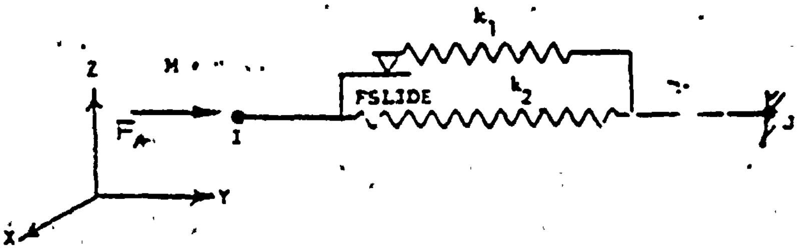
PLOT FOR 5838W INSIDE CONT. (NOS)



To study the behavior of the piping supported by an axial clamp, a single element model from the ANSYS computer program (Reference 10) was used.

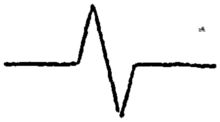
This model is shown below.

SINGLE ELEMENT MODEL



K_1 = Slider Stiffness support and structure
K_2 = Simulated Pipe Stiffness
F_{slide} = Limiting Sliding Force
M = Pipe Mass - For Piping Supported by Clamps
F_A = Applied Load

Impulse loads simular in shape to the waterhammer peaks loads were applied to the single element as follows:

1. Single impulse 
2. Repetitive impulses 
3. Reversed impulse 

Results for the repetitive impulse case are shown on page A-5.

Examination of this data indicated the following:

- Initial deflection is for the pipe/slider spring combination until the slip load is achieved. At this point, the slider spring is inactive and the resistance to slip is provided by the pipe spring.
- Slip continues until the slider load goes below the slip load.
- At the conclusion of the event, the spring has a residual deflection and a residual load opposite in direction to the original load.

From the above review, several conclusions are established:

1. For the second and succeeding similar impulses, above the slip load, the residual load has to be overcome in addition to the slip load. The deflection for each successive load decreased and the residual load increases until a point is reached where the applied load (FA) is equal to or less than the slip capacity (FS) plus the residual load (FR), or in equation form:

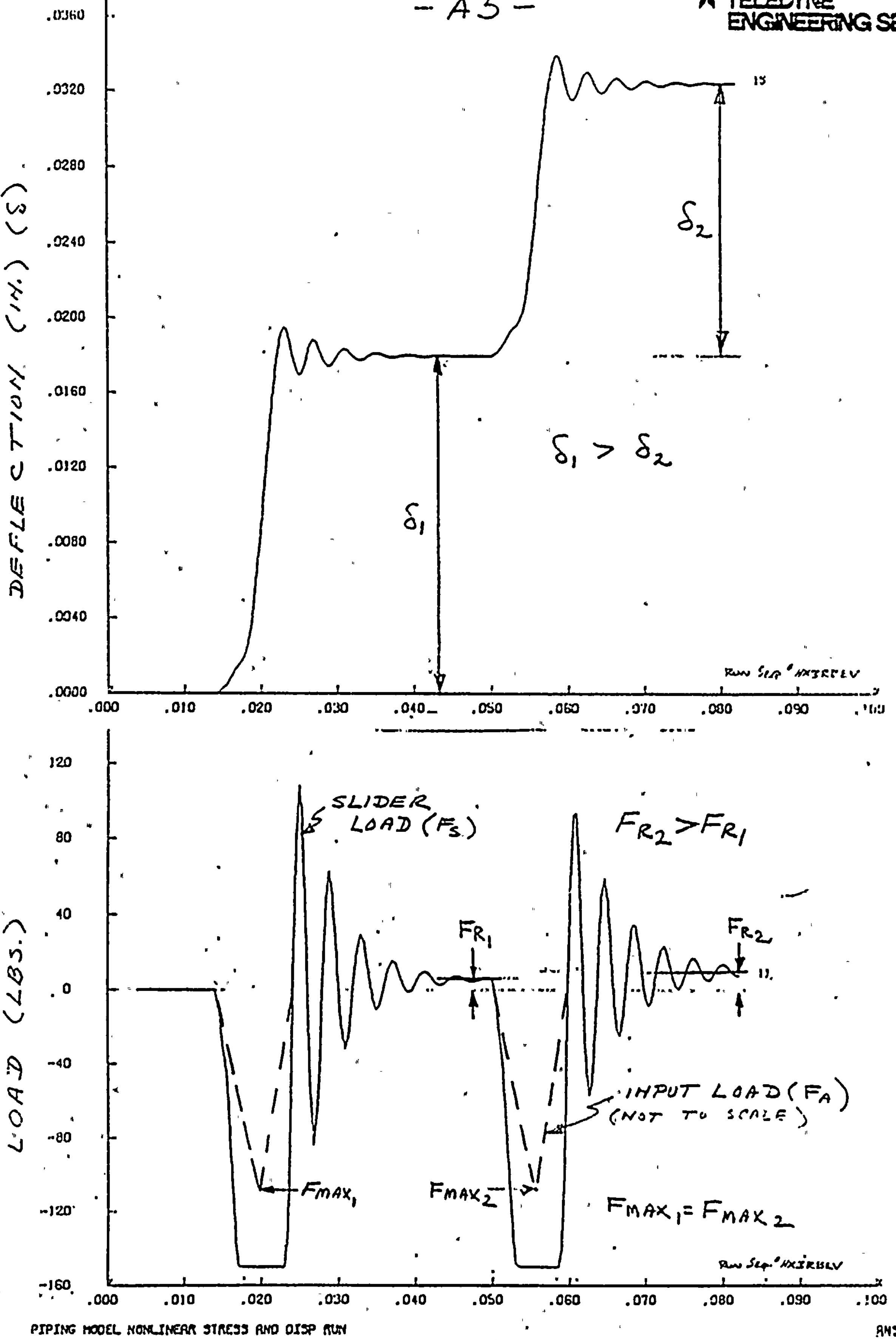
   $$FA \leq FS + FR.$$

   At this point (shakedown), no further slip occurs for any additional like impulses.

2. Further review of other impulse components of the waterhammer event indicate that the peak cycle pulses studied are more critical than the full cycle pulses and faster pulses. Also, as the residual load builds up at the clamp for similar pulses, in

effect, the slip capacity in that direction is increased while the slip capacity in the opposite direction is effectively decreased. Therefore, smaller pulses are able to restore the pipe to its original condition. A situation could be postulated where the pipe cycles between two opposite deflected position which would have low stress magnitude.

3. The above behavior is typical of a secondary type stress which is deflection limited and can be placed in equation 10 or 11 of paragraph NC 3652 of Section III.



RESULTS OF SINGLE ELEMENT MODEL FOR REPETITIVE IMPULSE CASE