SEISMIC PIPE-STRESS CALCULATION TECHNIQUES AND REANALYSIS EFFORT

ACRS Subcommittee Meeting
July 1979

Stone & Webster Engineering Corporation
Boston, Mass.

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May 18, 1979

Mr. Harold Denton, Director
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Sir:

Stone & Webster Engineering Corporation (S&W) and the utility companies involved have been working diligently on the reanalysis required by the NRC Orders to Show Cause of March 13, 1979. We have progressed to the stage where substantial amounts of data are flowing to the NRC and the process of confirming the adequacy of each reanalysis is well under way. The Maine Yankee reanalysis required by the Order to Show Cause has been completed. Work on the other plants is progressing. We have endeavored to do everything necessary to assure full compliance with the Orders, including development and use of special procedures. Concurrently, we have reviewed the evolution and history of our calculational techniques to help establish a clear understanding of them by all concerned.

Given the urgency of the situation, we believe that it would be helpful to both the ACRS and the NRC to have a summary description of our reanalysis activities and procedures and a brief report on our findings with respect to the evolution of our calculational techniques, particularly with respect to satisfaction of the requirements of General Design Criterion 2.

REANALYSIS ACTIVITIES AND PROCEDURES

The reanalysis effort has centered around the fact that certain piping systems were designed by S&W using a computer program (SHOCK II) with a subroute containing an algebraic intramodal force combination in one of the steps. The NRC has contended that the use of algebraic summation in this case was incorrect (we do not agree) and has therefore required that all systems designed with the SHOCK II subroutine be reanalyzed using currently acceptable programs.

In view of the seriousness of the impact of the shutdowns and the extensive effort required to ameliorate the situation, immediate steps were taken upon receipt of the Orders to establish the scope of the reanalysis effort, develop work plans, organize teams for each project, develop procedures to assure a high quality and timely response, and carry out the work expeditiously.

Over 400 people, operating on a two-shift basis, were assembled to gather documentation, perform the analyses, confirm the adequacy of the analyses, and verify current as well as formerly used computer programs. Project teams and review groups were established; administrative and technical procedures were developed; orientations were conducted; and schedules of activities were prepared and tracked.

The basic elements of the reanalysis effort are highlighted below:

1. Establishment of Scope of Effort

   Efforts were made to establish the scope of the reanalysis effort in conjunction with the NRC and the utilities shortly after issuance of the Orders.

2. Development of Work Plans

   A work plan was developed for each of the five units. Each plan consisted of identification of affected systems, determination of reanalysis sequence logic, determination of project manpower requirements and potential sources, and establishment of service priorities including computer use.

3. Retrieval of Documentation and Establishment of Design Basis for Reanalysis

   All available documentation relating to pipe stress and pipe supports was retrieved from archives and/or field records. This documentation included computer and hand calculations, piping design drawings, flow diagrams, piping and support sketches, and project job books. Extensive field verification was performed to assure that the reanalysis effort would reflect the "as-built" configuration of the system being evaluated.

4. Computer Program Verification

   NRC required extensive verification of the calculational techniques to be used in the reanalysis. This consisted primarily of applying the S&W programs PSTRESS/SHOCK III and NUPIPE to standard benchmark problems defined by NRC. Another program (E-PIPE) was verified by NRC itself. S&W

supplied typical problems from each of the affected plants to NRC for confirmation using E-PIPE. The overall verification effort was based on a stringent interpretation of Standard Review Plan 3.9.1 and the application of verification techniques and procedures beyond those generally required of the nuclear industry by the NRC.

5. Reanalysis of Pipe Stresses

Following verification of the "as-built" configuration, the computer model for the system was recoded, if required, and a computer run was made using a verified computer program. If the pipe-stress results were within allowable limits, the evaluation sequence proceeded to review of supports, nozzles, and penetrations (see 6.). If the results indicated a possible stress condition in excess of allowable, the system model was scrutinized in greater detail, revised utilizing current, more sophisticated techniques still consistent with the original licensing bases, and rerun. If the results still indicated a possible stress condition in excess of allowable, the system was analyzed using current methodology, such as amplified response spectra with soil-structure interaction, consistent with the original licensing bases and with current requirements. If this latter rerun does not resolve the problem, additional supports or snubbers are considered.

6. Reevaluation of Pipe Supports, Nozzles, and Penetrations

Following completion of a pipe-stress run where the recalculated loads were within allowable limits, the support and end-reaction loadings were tabulated and compared with the original loadings. If the loadings were equal to or less than the design limits, the supports or nozzles or penetrations involved were considered acceptable. If the loadings were above the original design limits, new calculations or supplements to the original calculations were performed, using techniques licensed for the units. The item was then determined to be either acceptable or in need of modification or replacement. If nozzle reactions exceeded those initially approved, vendors were contacted for approval of the new loadings. The vendor either approved the new reactions or requested reductions. In the latter case, other system modifications were identified and made.

DEVELOPMENT OF SEISMIC PIPE-STRESS CALCULATIONAL TECHNIQUES

The use of algebraic summation for combination of intramodal seismic forces in pipe-stress calculations has been characterized in various ways by government officials and the media. Many of the characterizations have been incorrect or misleading.

From the outset, as stated in public releases, S&W has agreed that the SHOCK II subroutine may not always yield results as

uniformly conservative as procedures used in the nuclear industry today. We believe, however, that the use of algebraic summation was an acceptable, common practice at the time it was used by us, and that the piping systems designed with the use of this method will perform their intended safety functions.

A review of the history of calculational technique development by the nuclear industry confirms that continuous effort was made to better approximate seismic effects since the initial modal combination "rule" was suggested in 1943. This "rule" established an upper bound to maximum seismic response by use of absolute value summation. Because this approach was considered to be unrealistically conservative, alternative techniques have evolved. These include the use of algebraic summation, square root of the sum of the squares, and various combinations of all three (absolute, algebraic, and SRSS).

Through the years we have continually modified our calculational techniques to lead with advances in both the state of the art and regulatory requirements. In 1972 and 1973, we started using new computer programs which introduced a number of changes, including substitution of a modified square-root-of-the-sum-of-the-squares (SRSS) procedures for algebraic summation to combine intramodal forces. In late 1974, NRC formally identified specific acceptable calculational techniques in Regulatory Guide (RG) 1.92. Our modified SRSS technique, then already in use, met the requirements of RG 1.92.

Then, as now, we recognized the evolutionary nature of computer programs and the nature of their use in the overall design process. Therefore, we began to employ the revised techniques on new projects while we continued to use the previous one on certain projects. In our view, the new techniques provided a means for obtaining more uniformly conservative results. That is why we adopted them. This does not imply, of course, that the previous technique was unacceptable. It merely indicates that, consistent with sound professional engineering judgment, we were employing the most advanced calculational tools.

The computer programs developed by us and by others are calculational tools used to predict forces and resultant stresses that may occur during an earthquake. Such predictions are an integral, but not necessarily the most important, part of the total process of establishing design adequacy of piping systems. The present seismic analysis programs utilize more refined calculational techniques, but they still provide only one stress component among several that must be considered, viz., thermal, pressure, deadweight. Furthermore, system modeling and the assumed characteristics of the earthquake used for design has greater impact on the soluation than the method of intramodal force combination. With respect to the trend toward more uniform conservatism, it should be noted that SRSS, which is deemed acceptable and adequately conservative,

is based on statistical concepts and may, in some circumstances, be less conservative than earlier approaches to seismic analysis.

The evolutionary nature of calculational techniques for seismic analysis was similar to the development of other improvements in analytical methodologies, e.g., the change from simple hand calculations to complex computer codes and from static analysis to dynamic analysis. This evolution was accompanied by a parallel development of seismic criteria by the AEC and the NRC starting in the mid-1960s and continuing well into the 1970s. There was no specific ASME code requirement for seismic design during that period.

In response to the recent NRC I&E Bulletin 79-07, additional data have been submitted to the NRC which provide further historical information on the various techniques used in seismic analysis of piping systems. It appears that a number of other responsible organizations have used algebraic summation of intrmodal forces in a seismic pipe-stress analysis for a number of nuclear power plants - perhaps 15 to 20 plants designed by firms other than S&W.

CONCLUSIONS

The efforts we have expended to date have provided results from which some general conclusions may now be drawn. While it is recognized that the algebraic summation of intramodal forces may not always yield results as uniformly conservative as the present-day techniques, it was a widely used technique acceptable to the profession during the evolution of the art of seismic analysis. It is unlikely that major physical changes will be required in the piping systems on which it was used. It appears more likely that any changes that may be required to satisfy current requirements will be confined to pipe supports.

It is a well known and demonstrable fact that piping is not particularly sensitive to seismic events. Such simple, commonly-used design techniques as fastening equipment and restricting the movements of large masses are sufficient to assure a high level of integrity. Further, the various analytical approaches generally show large differences at low stress levels and small differences at high stress levels. In summary, virtually any reasonable design approach or computer program will ensure a high degree of earthquake protection.

During the late 1960s and early 1970s the use of dynamic analysis superseded static analysis and the utilization of computers replaced manual techniques. During the same period, responsible organizations used algebraic summation of intramodal forces in calculational techniques employed to determine values for use in seismic design of piping systems.

Most important is the fact that these changes did not replace design review by knowledgeable engineers. This resulted in designs no less rugged than past designs, which have withstood actual seismic events of great severity. It is noteworthy that a number of knowledgeable individuals have observed that the designs resulting from techniques employing algebraic summation do not appear any less substantial than designs resulting from other techniques.

Our present reanalysis effort has demonstrated that the differences between the earlier techniques and current practice, resulting from gradual improvement typical of high technology developments, do not yield substantially different final designs.

We trust this summary of our reanalysis activity and conclusions are helpful to you.

Yours very truly,

W. J. L. Kennedy
Vice President

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SEISMIC DESIGN REGULATORY GUIDES

RG 1.12	Revision 0 3/71 Revision 1 4/74	Instrumentation for Earthquakes
RG 1.29	Revision 0 6/72 Revision 1 8/73 Revision 2 2/76 Revision 3 9/78	Seismic Design Classification
RG 1.48	Revision 0 5/73	Design Limits and Loading Combinations for Seismic Category I Fluid System Components
RG 1.57	Revision 0 6/73	Design Limits and Loading Combinations for Metal Primary Reactor Containment System Components
RG 1.60	Revision 0 10/73 Revision 1 12/73	Design Response Spectra for Seismic Design of Nuclear Power Plants

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SEISMIC DESIGN REGULATORY GUIDES
(Continued)

RG 1.61	Revision 0 10/73	Damping Values for Seismic Design of Nuclear Power Plants
RG 1.92	Revision 0 12/74 Revision 1 2/76	Combining Modal Response and Spatial Components in Seismic Response Analysis
RG 1.100	Revision 0 3/76 Revision 1 8/77	Seismic Qualification of Electric Equipment for Nuclear Power Plants
RG 1.122	Revision 0 9/76 Revision 1 2/78	Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components
RG 1.132	Revision 0 9/77	Site Investigations for Foundations of Nuclear Power Plants

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SEISMIC DESIGN
AEC REPORTS

TID 7024	Published 8/63	"Nuclear Reactors and Earthquakes", Lockheed and Holmes and Narver, for AEC.
HN-189	Published 3/67 Revised 6/68	"Some Considerations in Earthquake Resistant Design of Nuclear Power Plants", Holmes and Narver, for AEC.
HN-192	Published 4/68	"Antiseismic Design of a PWR Nuclear Power Station", Holmes and Narver, for AEC.

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SEISMIC DESIGN REGULATIONS

10CFR50 Appendix A	Added 5/71 Amended 3/76	General Design Criteria
10CFR100 Appendix A	Added 11/73 Amended 1/77	Seismic and Geologic Siting Criteria

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TECHNICAL DATA

UNIT:	SURRY 1 & 2	MAINE YANKEE	FITZPATRICK	BEAVER VALLEY 1
EARTHQUAKE:				
OBE	.07 g	.05 g	.08 g	.06 g
DBE	.15 g	.10 g	.15 g	.125 g
VERTICAL	2/3 HORIZ.	2/3 HORIZ.	2/3 HORIZ.	2/3 HORIZ.
COMPONENTS	2	2	2	2
DAMPING:				
STRUCTURES			CONCRETE / * / **	CONCRETE / *
OBE	5 %	2 %	2 % / 2% / 1%	2 % / 5 %
DBE	10 %	5 %	5 % / 3% / 1%	2 % / 7 %
PIPING				
OBE	0.5 %	1.0 % *	0.5 %	0.5 %
DBE	1.0 % *	2.0 % *	1.0 %	1.0 %
COMPUTER PROGRAMS USED FOR PIPE DIAMETER:	ALL > 6" SOME < 6"	ALL > 6" SOME < 6"	ALL > 6"	ALL > 6"
	* Verification done with 0.5 % (Ref.: Seismic Design Review Report)	* 0.5/1.0 for welded steel low-stress piping between rigid supports	* Steel frame bolted/riveted ** welded	* Total soil-containment structure system

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PROGRAM COMPARISON

PROGRAM	INTERMODAL	INTRAMODAL
SHOCK I	$R = \lvert R_{im} \rvert + \sqrt{(\sum_{j=1}^{n} R_{ij}^2) - R_{im}^2}$	$F_x = F_{xx} ; F_{xy} = F_{xz} = 0$
SHOCK II	$R = \lvert R_{im} \rvert + \sqrt{(\sum_{j=1}^{n} R_{ij}^2) - R_{im}^2}$	$F_x = F_{xx} + F_{xy} + F_{xz}$ (ALGEBRAICALLY)
SHOCK III	$\sqrt{\sum_{j=1}^{n} R_{ij}^2}$	"MODIFIED SRSS" $F_x = \sqrt{F_{xx}^2 + F_{xz}^2} + \lvert F_{xy} \rvert$
NUPIPE	AVAILABLE OPTIONS: 1. SRSS 2. ABSOLUTE 3. "GROUPING" 4. "10 PERCENT" 5. "DOUBLE SUM"	AVAILABLE OPTIONS: 1. $F_x = (\lvert F_{xx} \rvert + \lvert F_{xy} \rvert) \text{ or } (\lvert F_{xz} \rvert + \lvert F_{xy} \rvert)$ 2. $F_x = \sqrt{F_{xx}^2 + F_{xz}^2} + \lvert F_{xy} \rvert$ 3. $F_x = \sqrt{F_{xx}^2 + F_{xy}^2 + F_{xz}^2}$

Example of nomenclature:

F_{xy} = response in x direction due to y direction earthquake

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79-13,306

SEISMIC DESIGN CONSERVATISMS

1. Selection of low-probability extreme event
2. Wide band ground response spectra
3. Amplification factors
4. Enveloping synthetic time histories
5. Soil-structure interaction
6. Three-component earthquake
7. Elastic dynamic analysis
8. Damping values
9. Multiple application of damping values
10. Load combinations
11. Assumptions of rigid boundaries
12. Analysis at peak value of response

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SEISMIC DESIGN CONSERVATISMS
(Continued)

13. Peak widening of floor response system
14. Envelope response spectra for multiple-supported systems
15. System redundancy
16. Code minimum allowable stresses
17. Material specifications
18. Designer's habits
19. Ductility to failure
20. Seismic stress not always significant fraction of total stress
21. Redundancy of structural elements

SEISMIC REVIEW

Unit:	Surry 1 & 2	Maine Yankee	FitzPatrick	Beaver Valley 1
Reviewer:	NRC Staff	NRC Staff	NRC Staff	NRC Staff
Reviewed:	FSAR to Amendment 32	FSAR to Amendment 34	FSAR + 17 Amendments	FSAR + 11 Amendments
Documented	SER, 2-23-72	SER, 2-25-72	SER, 11-20-72	SER, 10-11-74
Reviewer:	ACRS	ACRS	ACRS	ACRS
Reviewed:	FSAR to Amendment 29	FSAR to Amendment 34	FSAR + 16 Amendments	FSAR + 12 Amendments
Documented:	12-17-71 Letter	1-13-72 Letter	12-15-72 Letter	11-20-74 Letter
Reviewer:	N. Newmark/Hall	J.A. Blume Assoc.	N. Newmark/Hall	
Reviewed:	FSAR to Amendment 25	FSAR to Amendment 25	FSAR + Amendments 1-5 and 8-12	
Documented:	11-4-71 (SER Appendix)	6-18-71 (SER Appendix)	11-3-72 (SER Appendix)	
Reviewer:	ASLB	ASLB	ASLB	ASLB
Reviewed:	(Later)	(Later)	(Later)	(Later)
Documented:				

Note (Surry 1 & 2):
Seismic Design Review Report Amendments 23 and 25

Note (Maine Yankee):
Seismic Design Review Report Amendment 35

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THE REVIEW PROCESS

DATA ACQUISITION
- DWG
- CALCS
- ARS

VERIFICATION

CODING

COMPUTER RUN

STRESS ANALYSIS
- PIPING
- NOZZLES
- PENETRATIONS
- EQUIPMENT

VERIFICATION

HANGER REVIEW

HANGER ANALYSIS

VERIFICATION

ASSEMBLE REVIEW PACKAGE

VERIFICATION

S&W REVIEW

CLIENT REVIEW

NRC REVIEW

▬ Engineering Assurance

▬ Interface with Options Review Committee

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SEISMIC ANALYSIS OF PIPING

INPUT	APPROACH	RESULTS	USAGE
ACCELERATION FACTOR	SIMPLIFIED HAND CALCULATIONS	• UPPER BOUND RESULTS • MOST CONSERVATIVE • MINIMAL DESIGN INFORMATION	• SMALL BORE PIPING
ACCELERATION FACTOR	COMPUTER - STATIC ANALYSIS	• MORE ACCURATE • CONSERVATIVE • BETTER DESIGN INFORMATION	• LESS CRITICAL SMALL & MODERATE SIZE PIPING
AMPLIFIED RESPONSE SPECTRA & DISPLACEMENT PROFILE	COMPUTER - DYNAMIC PLUS STATIC	• QUITE ACCURATE • REASONABLY CONSERVATIVE • GOOD DESIGN INFORMATION	• MOST MODERATE & LARGE POWER PIPING • MODERATE & SEVERE EARTHQUAKES
ACCELERATION OR DISPLACEMENT VERSUS TIME	COMPUTER - DYNAMIC TIME HISTORY	• VERY ACCURATE • MINIMAL CONSERVATISM • EXCELLENT DESIGN INFORMATION	• PRIMARY PIPING • SPECIAL CASES • SEVERE EARTHQUAKES

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COMPUTER PROGRAMS USED FOR DYNAMIC ANALYSIS AT S&W

SHOCK 0 SHOCK 1 SHOCK 2 SHOCK 3	STONE & WEBSTER
NUPIPE-II (CDC)	UTILIZED UNDER ROYALTY AGREEMENT
NUPIPE - SW	PURCHASED FROM NUCLEAR SERVICES CORPORATION

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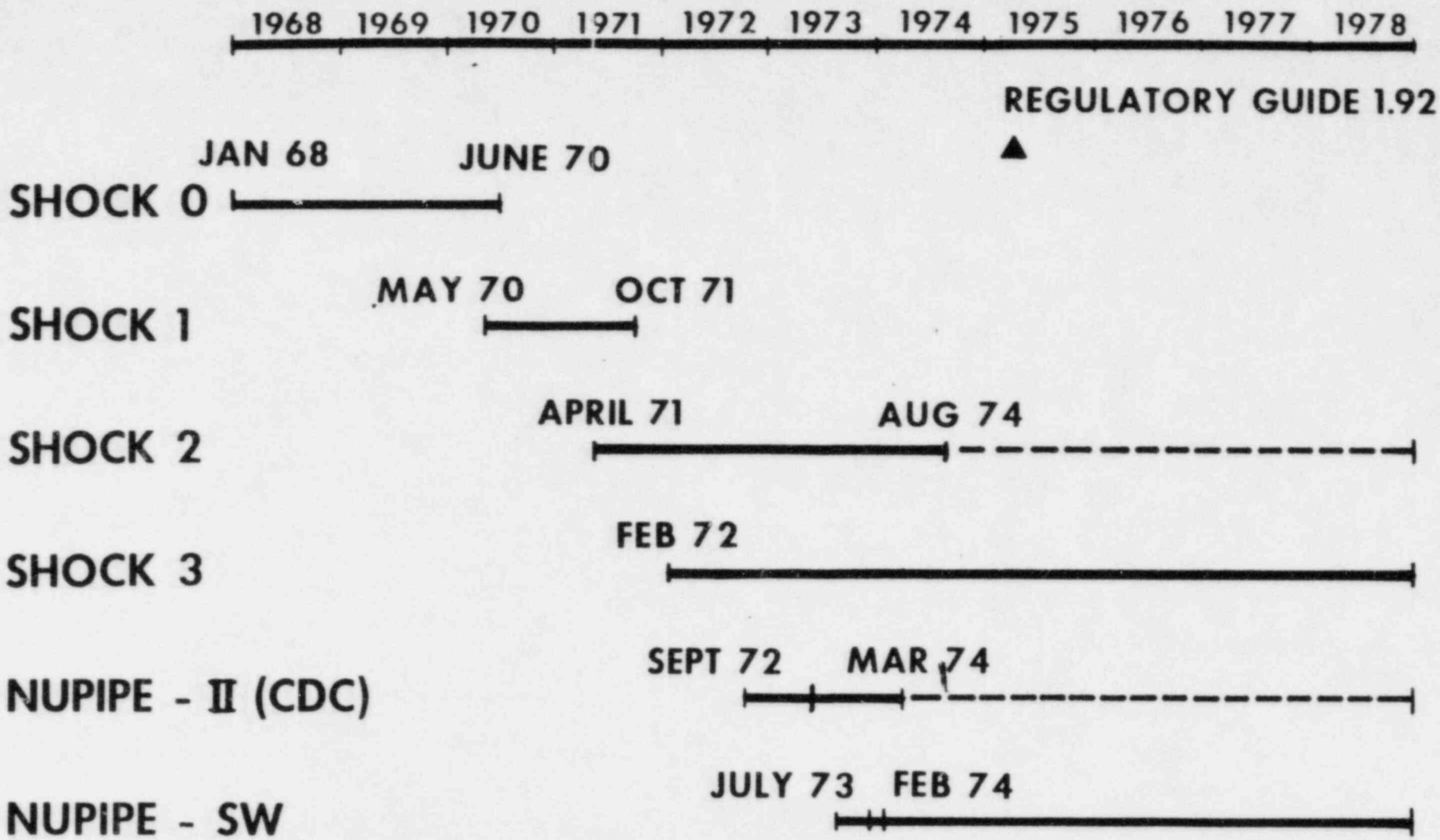
COMPUTER PROGRAM IMPLEMENTATION
DYNAMIC ANALYSIS



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COMPARISON OF PROGRAM METHODS

ITEM	SHOCK 0/ SHOCK 1	SHOCK 2	SHOCK 3	NUPIPE
SPECTRUM INPUT	SINGLE GROUND OR AMPLIFIED SPECTRUM APPLIED IN ALL THREE INPUT DIRECTIONS	UNIQUE, AMPLIFIED SPECTRA APPLIED IN ALL THREE INPUT DIRECTIONS	UNIQUE, AMPLIFIED SPECTRA APPLIED IN ALL THREE INPUT DIRECTIONS	UNIQUE, AMPLIFIED SPECTRA APPLIED IN ALL THREE INPUT DIRECTIONS

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COMPARISON OF PROGRAM METHODS

ITEM	SHOCK 0/ SHOCK 1	SHOCK 2	SHOCK 3	NUPIPE
INTRA-MODAL	INERTIA FORCES CALCULATED IN COORDINATE ASSOCIATED WITH INPUT DIRECTION	INERTIA FORCES CALCULATED IN THREE COORDINATES FOR EACH INPUT DIRECTION ALGEBRAIC SUMMATION	INERTIA FORCES CALCULATED IN THREE COORDINATES FOR EACH INPUT DIRECTION MODIFIED SRSS SUMMATION APPLIED STATICALLY IN EACH MODE TO SOLVE GENERALIZED RESPONSES	INERTIA FORCES CALCULATED IN THREE COORDINATES FOR EACH INPUT DIRECTION MULTIPLE OPTIONS FOR SUMMATION APPLIED STATICALLY IN EACH MODE TO SOLVE GENERALIZED RESPONSES
INTER-MODAL	INERTIA FORCES SUMMED BY "NAVY" METHOD	INERTIA FORCES SUMMED BY "NAVY" METHOD	GENERALIZED RESPONSES SUMMED BY SRSS	MULTIPLE OPTIONS FOR SUMMING GENERALIZED RESPONSES

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COMPARISON OF PROGRAM METHODS

ITEM	SHOCK 0/ SHOCK 1	SHOCK 2	SHOCK 3	NUPIPE
DISPLACEMENT EFFECT	DISPLACEMENTS COMBINED WITH RESULTING INERTIA FORCES - APPLIED TO SYSTEM STATICALLY	DISPLACEMENTS COMBINED WITH RESULTING INERTIA FORCES- APPLIED TO SYSTEM STATICALLY	DISPLACEMENTS INPUT SEPARATELY IN EACH DIRECTION- COMBINED BY SRSS — DISPLACEMENT STRESSES PLUS INERTIA RESPONSES ADDED ABSOLUTELY	DISPLACEMENTS INPUT SEPARATELY IN EACH DIRECTION- COMBINED BY SRSS — DISPLACEMENT STRESSES PLUS INERTIA RESPONSES ADDED ABSOLUTELY

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COMPARISON OF PROGRAM METHODS

ITEM	SHOCK 0/ SHOCK 1	SHOCK 2	SHOCK 3	NUPIPE
OTHER	SHOCK 0 SINGLE PARTICIPATION FACTOR SHOCK 1 DIRECTIONAL PARTICIPATION FACTORS	DIRECTIONAL PARTICIPATION FACTORS	DIRECTIONAL PARTICIPATION FACTORS	DIRECTIONAL PARTICIPATION FACTORS

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SUMMARY

- S&W PROGRAM DEVELOPMENT HAS BEEN RELATED TO A TIME FRAME
- THE RELATIONSHIP FOLLOWS THE "STATE-OF-THE-ART" OF SEISMIC PIPING ANALYSIS
- AVAILABLE TECHNICAL LITERATURE AND USNRC/AEC DOCUMENTATION CONTRIBUTES TO AND HARMONIZES WITH S&W TECHNICAL DEVELOPMENT

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