

**VELA UNIFORM PROGRAM**

**PROJECT DRIBBLE**

**SALMON EVENT**

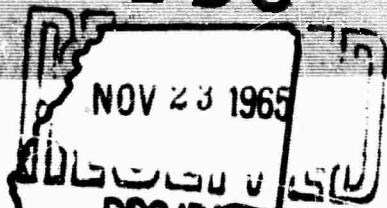
TATUM SALT DOME, MISSISSIPPI

22 OCTOBER 1964

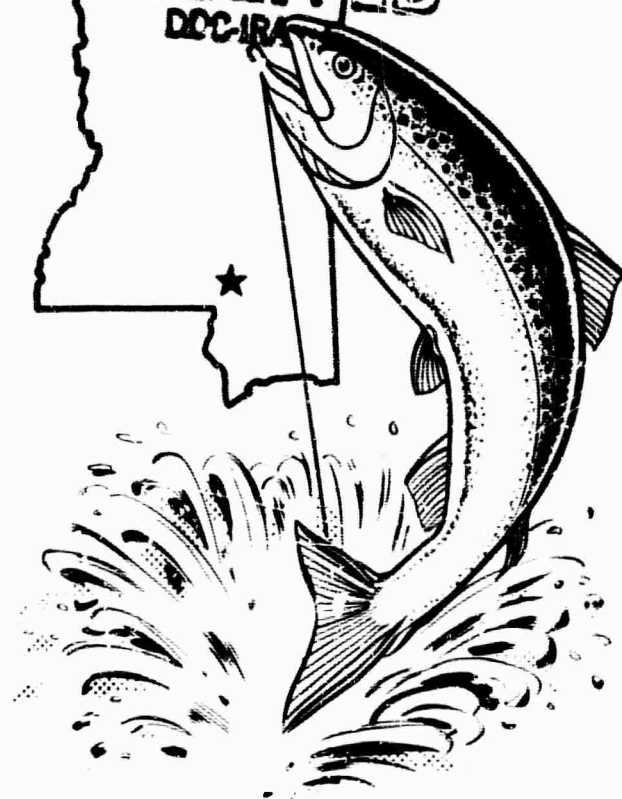
part of an experiment in seismic decoupling at the nuclear level

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OF THE DEPARTMENT OF DEFENSE AND THE U. S. ATOMIC  
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**DDC**



**Structural Response of  
Residential-Type Test  
Structures in close  
Proximity to an  
Underground Nuclear  
Detonation**



JOHN A. BLUME AND ASSOCIATES  
RESEARCH DIVISION

AD629719

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SALMON EVENT

PROJECT DRIBBLE

STRUCTURAL RESPONSE OF RESIDENTIAL-TYPE TEST STRUCTURES  
IN CLOSE PROXIMITY TO AN UNDERGROUND NUCLEAR DETONATION

John A. Blume & Associates Research Division

August 1965

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## ABSTRACT

Response was measured in three one-story simulated residential structures at distances of 2,000, 3,000 and 4,000 meters from Surface Zero for the Salmon event. Statham accelerometers were mounted at roof and floor levels in concrete block and wood frame structures. Peak measured accelerations ranged from about 1.5g (gravity units) at the near structure (concrete block) to about 0.7g at the middle structure (wood frame) to about 0.4g at the most distant structure (wood frame). No damage was observed in any of the instrumented structures; a companion block structure to the wood frame structure at the 4,000-meter distance suffered extension of pre-existing cracks.

## INTRODUCTION

### OBJECTIVES

This report is concerned with the investigation of structural response of a series of one-story test structures which were constructed by the Lawrence Radiation Laboratory (LRL) for the Salmon event, project Dribble. Personnel from this office made a pre-shot and a post-shot survey of these structures, in pursuance of a structural response investigation. The U. S. Coast and Geodetic Survey (USC&GS) instrumented three of the structures with accelerometers. See Figure 1 for structure locations.

Analysis of structural response is limited to a presentation of the general geometries, physical characteristics, and the measured response of the buildings concerned. Further analysis of the response of these structures may be accomplished at an appropriate point in the development of the general structural response investigation for which this firm is under contract to the U. S. Atomic Energy Commission.

### BACKGROUND

The Salmon event involved a 5-kiloton device in a tamped emplacement at the bottom of a bore hole about 325 meters deep, and approximately 365 meters into the Tatum Salt Dome in Lamar

County near Baxterville, Mississippi. Detonation took place at 1600 hours, Greenwich Time October 22, 1964.

A series of test structures was built under the direction of the LRL for the Dribble series. John A. Blume & Associates Research Division did not participate in the design of the structures. These were located as shown in Figure 1. Three of these structures were instrumented by the USC&GS. Representatives of John A. Blume & Associates Research Division made a visual examination of the test structures before and after the event.

All of the test structures have unreinforced concrete block foundation walls on unreinforced concrete strip footings and wood frame floors and gable roofs. The walls are either bare concrete blocks or wood frame with plywood exterior and plaster on mesh or lath interior. Figure 2 shows the general arrangements for both variations.

Static and dynamic tests were made on the wood frame structures at Stations 5 East and 6 East, prior to the Salmon event. These tests were made by United Aircraft for the LRL. As set forth in the interim report of the tests, Flowshare Structural Damage Study, SCR 195, June 15, 1964, the tests included tests of roof-ceiling systems, shear tests of walls, load tests of floors and footings, lateral load tests on footings, roof lift-off tests, and a vibration test series.

## PROCEDURE

### INSTRUMENTATION

The USC&GS instrumented 3E, 4E, and 5E with Statham accelerometers. This system consists of portable pickups which can be widely dispersed. The pickup outputs are recorded simultaneously on a single record. An "area of interest" plot for the Statham accelerometer is included as Figure 3.

A number of USC&GS strong motion accelerograph stations were also manned by the USC&GS for Salmon. One series of interest was dispersed radially easterly from Surface Zero at distances of 1200, 1600, 2000, 3000, 4000, and 6000 meters. These stations were designated 1 East through 6 East, respectively.

The strong motion accelerograph records three mutually perpendicular components of both displacement and acceleration simultaneously on a single record.

"Area of interest" plots for the displacement meters and accelerometers are included in Figures 4 and 5.

In addition to the east line of stations the USC&GS established a south line of strong motion accelerograph stations at distances of 1200, 1600, 2100, 3200, 4100, and 6200. These stations were designated 1 South through 6 South.

Test structures were built by the LRL at stations 0.5 East, 3 East, 4 East, 5 East, and 6 East, and at 2 South and 4 South.

Original records consist of long paper traces which cannot be reproduced in a form suitable for inclusion in this report.

#### DAMAGE SURVEYS

Surveys of the test structures, including photographs, were made by LRL personnel at regular intervals during the period of time prior to the Salmon event. Casual inspections were made by Blume personnel at irregular intervals in the final four weeks before the event.

Post-shot inspections and photographic records of damage were made by LRL personnel, and Blume personnel made detailed inspections of the structures on several occasions after the Salmon event.

## RESULTS

### STRUCTURAL RESPONSE

Tables 1 and 2 present the maximum accelerations recorded at the test structures. The maximum average single amplitudes were used in order to produce the value most suitable for conversion to velocity and displacement by assuming simple harmonic motion and yet give a good representation of the maximum acceleration experienced. In many cases the motion was far from simple harmonic motion, so these values must be used with this in mind.

Table 3 presents the maximum accelerations at the strong motion accelerograph stations, as calculated by the USC&GS and independently by R. F. Beers, Inc. The maximum average single amplitudes from the accelerograph stations, located in instrument shelters adjacent to the test structures, are shown to provide a comparison with those from Statham accelerometer records from the test structures themselves.

### OBSERVED DAMAGE

Pre-shot observations indicated that possibly half of the structures were slightly damaged by Hurricane Hilda, which passed through the Dribble site area on October 4 to 7, about three weeks before the Salmon event. Damage consisted of plaster and block joint cracks. Also, Station 6E, a wood frame structure, was highly stressed during pre-shot strain testing, with damage to exterior area, and some interior cracking.

The only damage in these three test structures attributable to the Salmon event occurred at 4E. The concrete block structure was severely cracked. All the cracks followed the mortar joints. These cracks are generally extensions of and incident to the pre-shot Hurricane Hilda damage. There may also be a continuing settlement problem because the cracking has been observed to extend in the months after the event.

Response spectra for vertical and transverse components of Salmon ground acceleration recorded at Baxterville Oil Field, about 10 kilometers south of Surface Zero, are included in Figures 6 and 7. From these spectra it can be seen that the ground motion acceleration response at the Baxterville Oil Field peaked in the 0.05 to 0.25-second range of periods.

## DISCUSSION

### RECORDED MOTION

Recorded motion, presented in Tables 1 and 2, shows accelerations ranging from a maximum of 1.45g at Station 1 East, to a minimum of 0.02g at Station 5 East. Vertical accelerations were larger than radial accelerations which were in turn larger than transverse accelerations. Periods were generally in the range from 0.10 to 0.20 seconds and showed a tendency to lengthen with distance from Surface Zero.

Velocities and displacements have been calculated using simple harmonic motion assumptions. Because the actual motion was not simple harmonic motion, the values derived are only rough approximations and will not be discussed further.

Table 3 sets forth amplitudes and periods taken from strong motion accelerograph stations in light wooden shelters adjacent to the test structures. These values provide comparison of maximum average single amplitudes of accelerations. Differences are largely caused by the test structure effect on incoming ground motion although some instrumental and interpretative differences are undoubtedly also present. Comparison shows a reasonably close similarity between the sets of values, suggesting that the structural effects and interpretative differences are not large.

## OBSERVED DAMAGE

Damage caused by Salmon event ground motion was observed only in the concrete block test structure at 4E in which existing cracks were extended. Maximum accelerations in the concrete block structure are not known because there were no instruments in that structure. However, because of the similarity between motions recorded at another test structures and at the strong motion stations nearby it can be assumed that the measured values in the adjacent wood frame test structure and at the strong motion station are applicable. Those records show accelerations in the vertical direction of about  $1/2g$ , approaching  $1g$  in the radial direction and about  $1/10$  to  $3/10g$  in the transverse direction.

Station 3E, at which no damage was observed, experienced vertical accelerations of about  $1-1/2g$ , about  $3/4g$  in the radial direction, and about  $1/6g$  in the transverse direction. The absence of any visible damage to the concrete block structures at station 3E at accelerations half again as large as those at 4E suggests that the pre-shot cracking at 4E weakened the structure sufficiently to allow this additional cracking. Figures 5 and 6 show response spectrum peak generally in the 0.05-second to 0.25-second range of periods. The test structures have natural periods of vibration in the range of from 0.02 to 0.05 seconds,

as shown from pull tests on similar test structures (John A. Blume & Associates Research Division Report NVO-99-02 and United Aircraft Report SCR 195). Consequently, the recorded peak accelerations set forth in Tables 1 and 2 with periods ranging generally between 0.10 and 0.20 seconds are probably largely ground motion transmitted to the building and not significantly affected by the response of the structure itself. However, if comparisons are attempted between actual measured peak accelerations in the test structures at Stations 3E, 4E, and 5E with the acceleration response spectrum for Baxterville Oil Field, making adjustments for the various distances from Surface Zero, it is generally the case that the measured accelerations are not greatly different from the adjusted response spectrum accelerations. The adjusted response spectrum would have indicated generally greater accelerations than were actually observed.

## CONCLUSIONS AND RECOMMENDATIONS

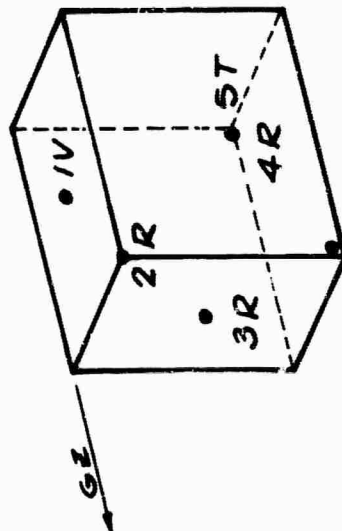
Instrumentation of the test structures was adequate to measure the response of similar structures in the same geologic and soils environment and at similar distances from the shot point. However, the high incidence of damage claims in residential structures at greater distances, with no instrumentation deployed to measure motion in examples of this type of structures, indicates that for future events more attention should be devoted to recording the response of existing residential construction in the range of perceptible motion.

Predictions of structural response using response spectrum techniques for typical construction in areas of clearly perceptible motion should be made in advance of off-site testing because of the possibility of enhanced response and transgression of damage thresholds even when predicted ground motions are below accepted damage threshold levels. Prediction techniques should include consideration of geologic and soil characteristics because of their effect on frequency distributions and more amplification. Additional attention should be devoted to soils of inhabited areas and their dynamic behavior, which may result in structural damage independently of the dynamic behavior of the structure. Surveys should also be made of inhabited areas to delineate regions of existing damage

from foundation problems or other causes, and selected typical structures in these areas should be occupied, instrumented, and monitored during event motion to record actual motion levels and the structural results in order to provide reference data for the evaluation of damage claims and to minimize the submission of unfounded damage claims.

Because of the great variety of existing structures in inhabited areas it is not possible to construct test structures which will represent any great proportion of existing buildings. Measurement of response in test structures provides valuable research data for structural response investigations, but it does not provide acceptable reference data for evaluation of the behavior of existing structures in the same area.

STATION 3E CONC. BLK. ST. THAM	IN.		CM. DISPLACEMENT	T(SEC)	IN./SEC. VELOCITY	CM./SEC. VELOCITY	T(SEC)	g ACCELERATION	T(SEC)
	IN.	DISPLACEMENT							
1 V	0.04 *	0.9 *	0.05 *	0.05	4 *	10 *	0.05	1.45 *	0.05
6 V	0.2 *	0.6 *	0.15 *	0.15	9 *	20 *	0.15	0.98	0.15
2 R	0.1 *	0.3 *	0.12 *	0.12	6 *	10 *	0.12	0.78	0.12
3 R	0.2 *	0.4 *	0.14 *	0.14	6 *	20 *	0.14	0.74	0.14
4 R	0.1 *	0.2 *	0.14 *	0.14	4 *	10 *	0.14	0.45	0.15
8 R	0.07 *	0.2 *	0.15 *	0.15	3 *	7 *	0.15	0.28	0.15
5 T	0.02 *	0.5 *	0.12 *	0.12	1 *	2 *	0.12	0.13	0.12
7 T	0.02 *	0.5 *	0.12 *	0.12	1 *	2 *	0.12	0.13	0.12



6V, 7T, 8R  
3 EAST  
 CONC. BLOCK

\* MAX. AMPLITUDE UNKNOWN.  
 \* DERIVED VALUES, ASSUMING  
 SIMPLE HARMONIC MOTION -  
 OTHERS ARE MEASURED.

## SUMMARY OF PEAK MOTIONS

A. BLUME & ASSOCIATES RESEARCH DIVISION

TABLE 1

	I/N.	CM.		T	IN./SEC.	CM./SEC.		T	ACCELERATION	T	
		DISPLACEMENT				VELOCITY					
STATION 4E											
4	V	MOTION RECORDED NOT BLAST MOTION									
1	R	0.03 *	0.07 *	0.08	2 *	5 *	0.08	0.44 *	0.08		
3	R	0.3 *	0.8 *	0.21	9 *	20 *	0.21	0.69 *	0.21		
5	R	0.02 *	0.06 *	0.09	2 *	4 *	0.09	0.29 *	0.09		
2	T	0.03 *	0.07 *	0.07	2 *	6 *	0.07	0.56 *	0.07		
6	T	0.002 *	0.005 *	0.03	4 *	1 *	0.03	0.24 *	0.03		
7	V	0.06 *	0.1 *	0.11	3 *	8 *	0.11	0.46 *	0.11		
12	V	0.05 *	0.1 *	0.11	3 *	7 *	0.11	0.43	0.11		
8	R	0.2 *	0.5 *	0.24	5 *	10 *	0.24	0.35 *	0.24		
9	R	0.03 *	0.09 *	0.10	2 *	6 *	0.10	0.35 *	0.10		
10	R	0.03 *	0.09 *	0.14	1 *	4 *	0.14	0.16 *	0.14		
14	R	0.1 *	0.3 *	0.19	4 *	10 *	0.19	0.34 †	0.19		
11	T	0.005 *	0.01 *	0.16	2 *	0.5 *	0.16	0.02	0.16		
13	T	0.02 *	0.06 *	0.16	9 *	2 *	0.16	0.09	0.16		
STATION 5E											

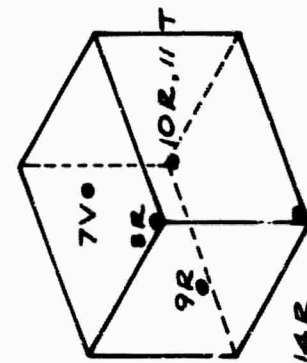
† QUESTIONABLE AMPLITUDE  
UNCERTAIN INSTRUMENT  
MAGNIFICATION.

\* MAX. AMPLITUDE UNKNOWN.

\* DERIVED VALUES, ASSUMING  
SIMPLE HARMONIC MOTION —  
OTHERS ARE MEASURED.

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RESEARCH DIVISION

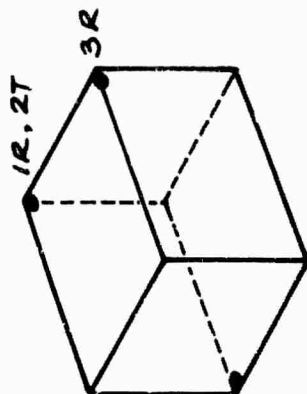
TABLE 2



12V, 13T, 14R

5 EAST

WOOD FRAME



4 EAST

WOOD FRAME

4V, 6T, 5R

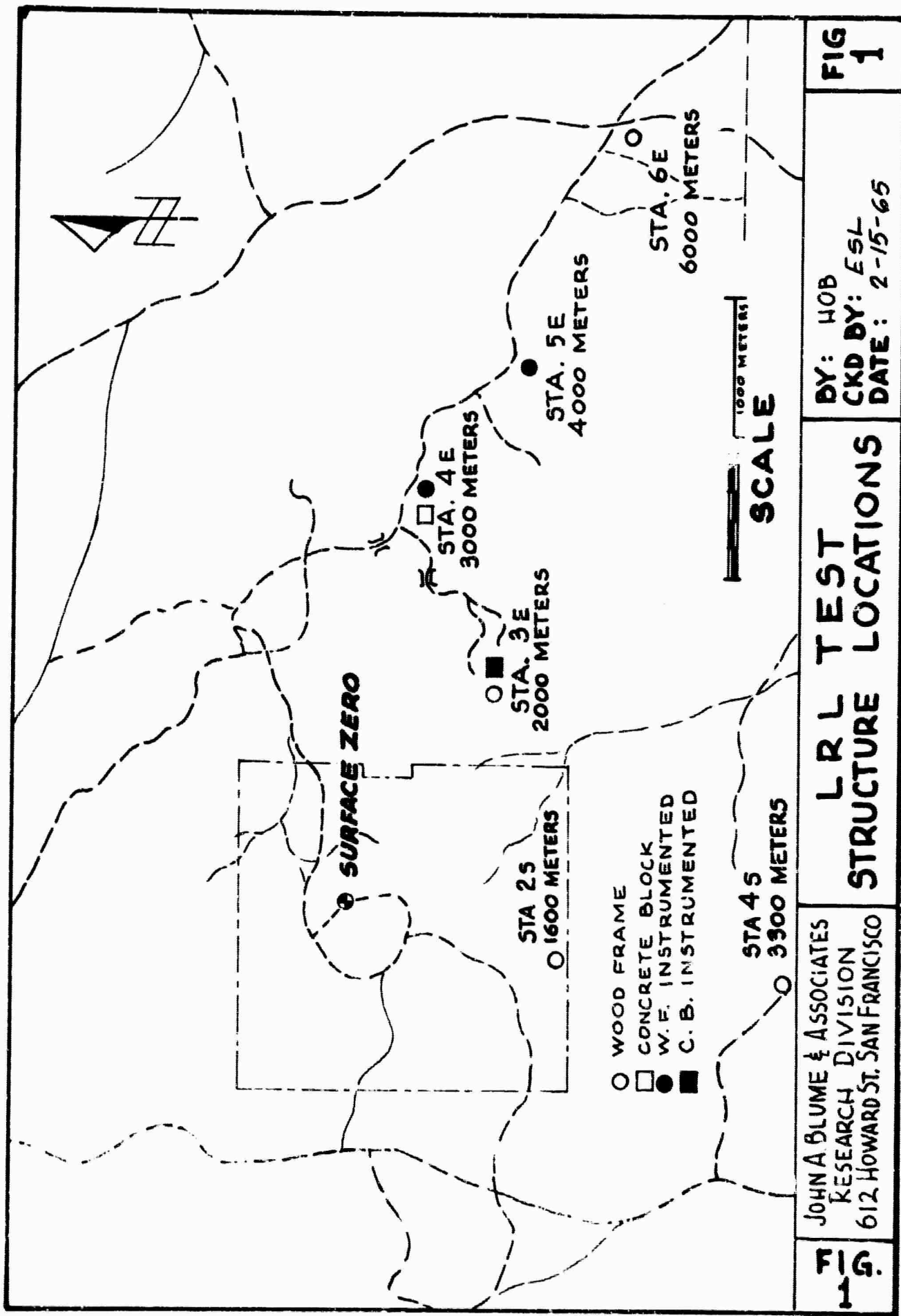
STATION SLANT DISTANCE AND DIRECTION FROM W.P.	INSTRUMENT AND COMPONENT	MEASURED MAXIMUM SINGLE AMPLITUDE ACCELERATION, 10 <sup>-1</sup> g		PERIOD SECONDS	
		USC Ξ GS	R. F. BEERS, INC.	U.S.C Ξ GS	R.F. BEERS, INC.
1 EAST 1.458 KM. S 74.6° E	V USC Ξ GS	28.4	15.00 — *	0.05	0.05
	R ACCELEROMETER	7.6	7.076 7.316 *	0.13	0.06 0.06 *
	T	3.4	3.836 3.269 *	0.03	0.03 0.03 *
2 EAST 1.804 KM. N 88.9° E	V USC Ξ GS	10.6	11.60	0.07	0.05
	R ACCELEROMETER	5.41	5.133	0.11	0.05
	T	1.69	1.793	0.15	0.06
3 EAST 2.118 KM. S 62° E	V USC Ξ GS	15.6	14.63	0.15	0.08
	R ACCELEROMETER	7.11	6.388	0.15	0.06
	T	1.4	1.492	0.13	0.1
4 EAST 3.067 KM. S 81.2° E	V USC Ξ GS	3.80	4.936	0.09	0.05
	R ACCELEROMETER	9.48	11.68	0.17	0.07
	T	1.48	1.727	0.15	0.04
5 EAST 4.140 KM. S 72.5° E	V USC Ξ GS	4.29	3.938	0.11	0.11
	R ACCELEROMETER	3.35	3.156	0.14	0.13
	T	0.63	0.6805	0.16	0.08
6 EAST 5.945 KM. S 70.9° E	V USC Ξ GS	2.88	3.129	0.17	0.12
	R ACCELEROMETER	1.71	1.994	0.19	0.1
	T	0.717	0.8067	0.14	0.11
BAXTERVILLE OIL FIELD 10.104 KM. S 36.3° W	V USC Ξ GS	0.439	—	0.17	—
	R ACCELEROMETER	0.225	—	0.15	—
	T	0.489	—	0.15	—

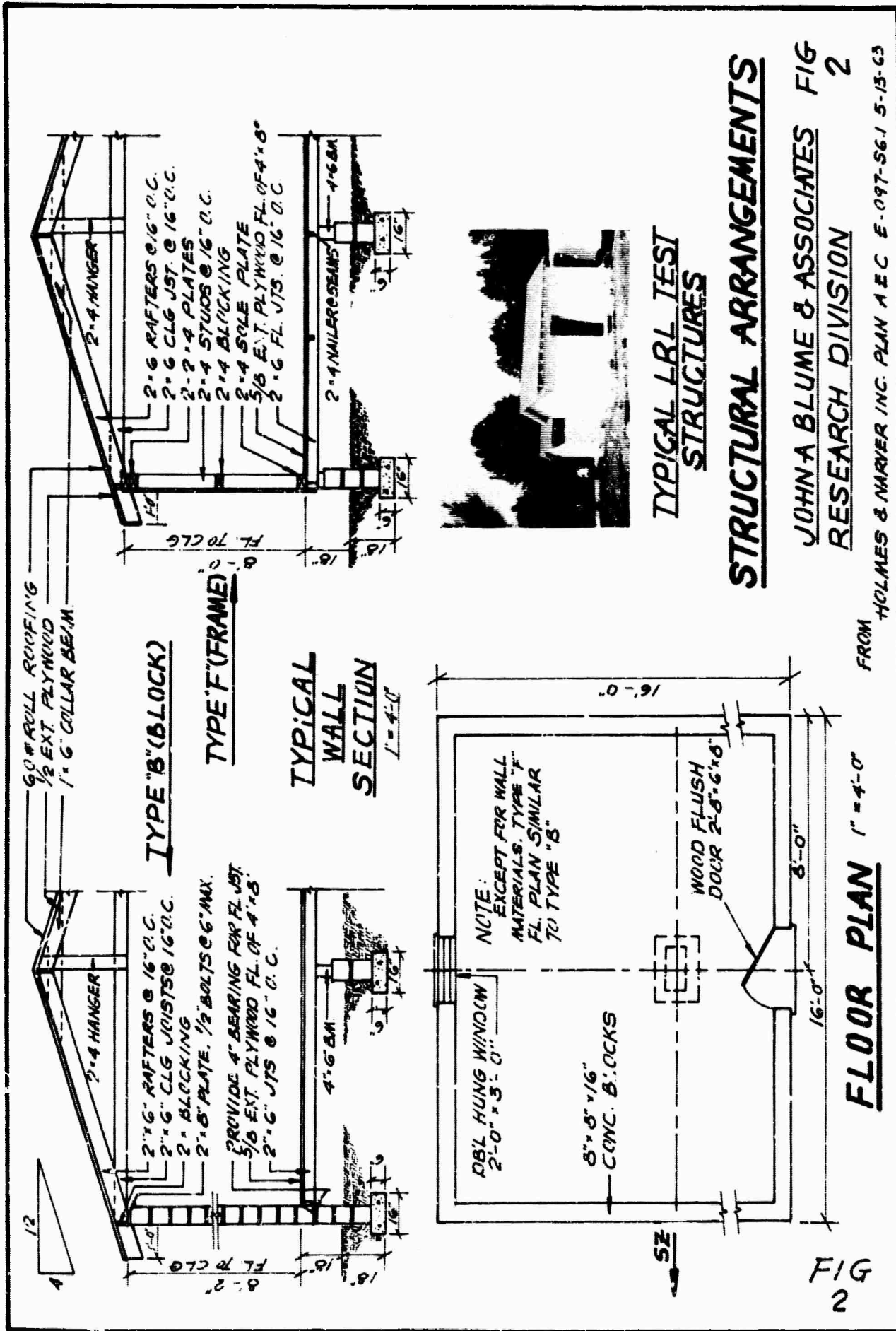
### SUMMARY OF PEAK MOTIONS - STRONG MOTION STATIONS

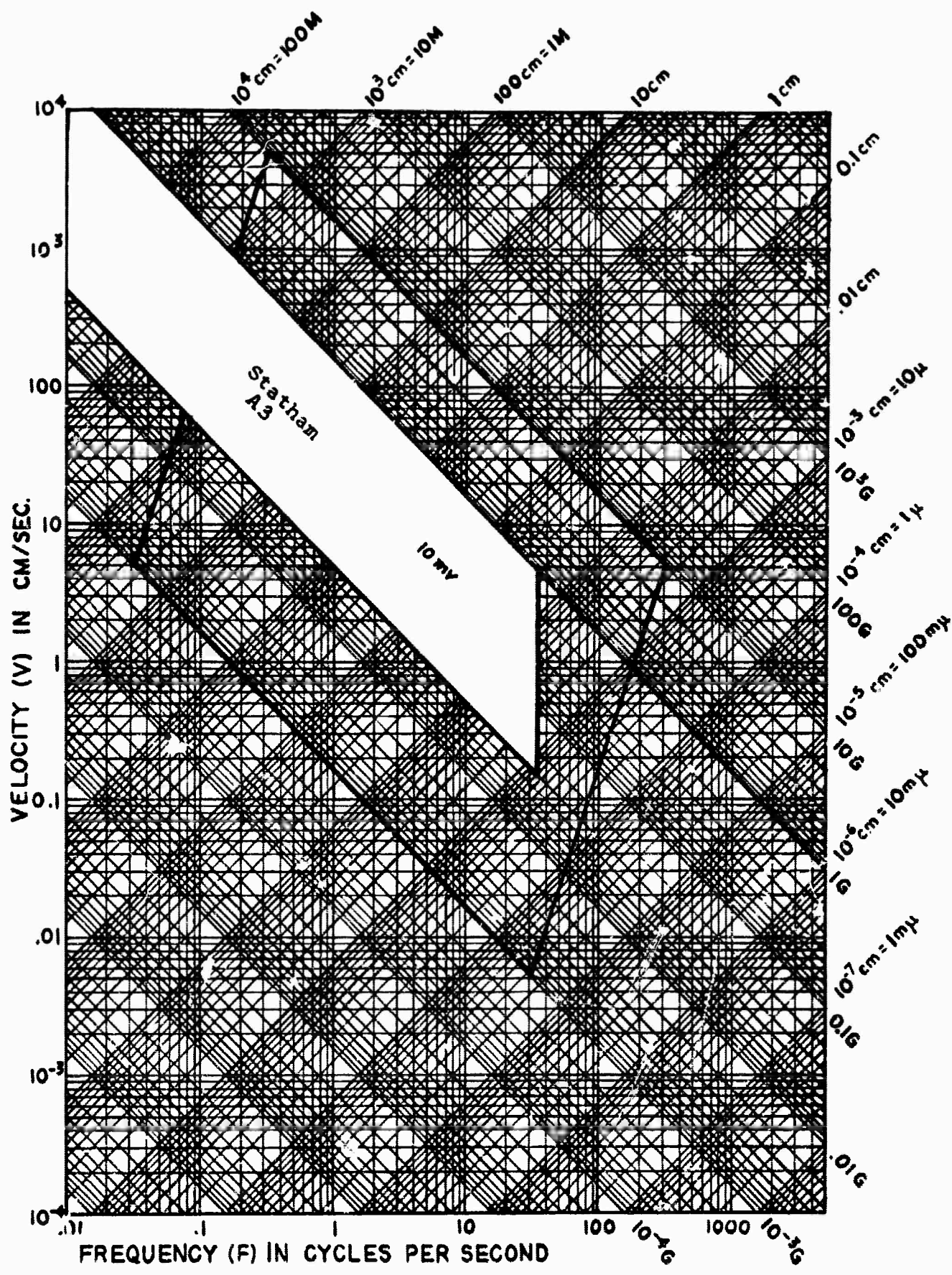
JOHN A. BLUME & ASSOCIATES - RESEARCH DIVISION

TABLE - 3

\* TWO INSTRUMENTS AT THIS STATION







**FIG. 3**

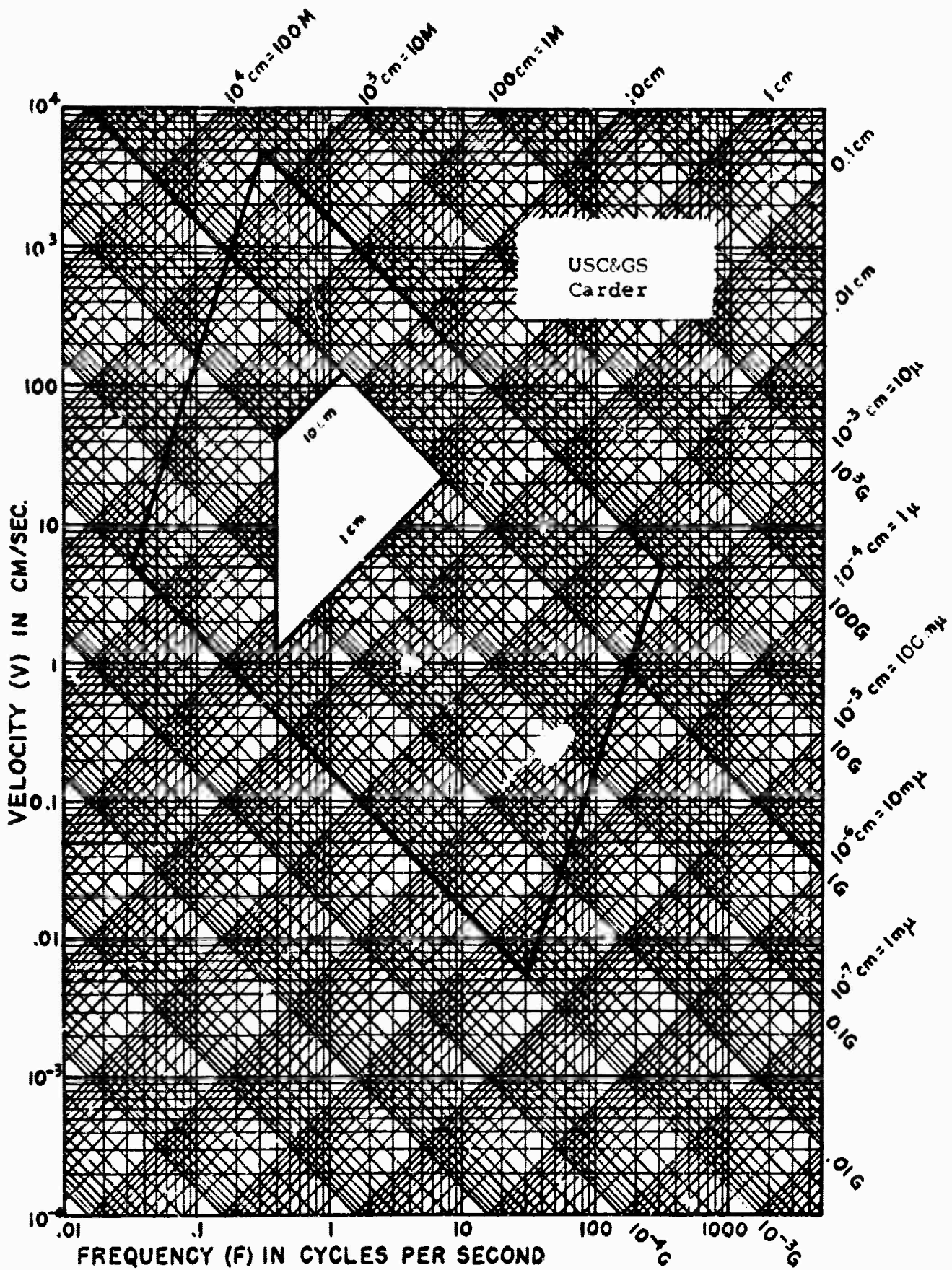
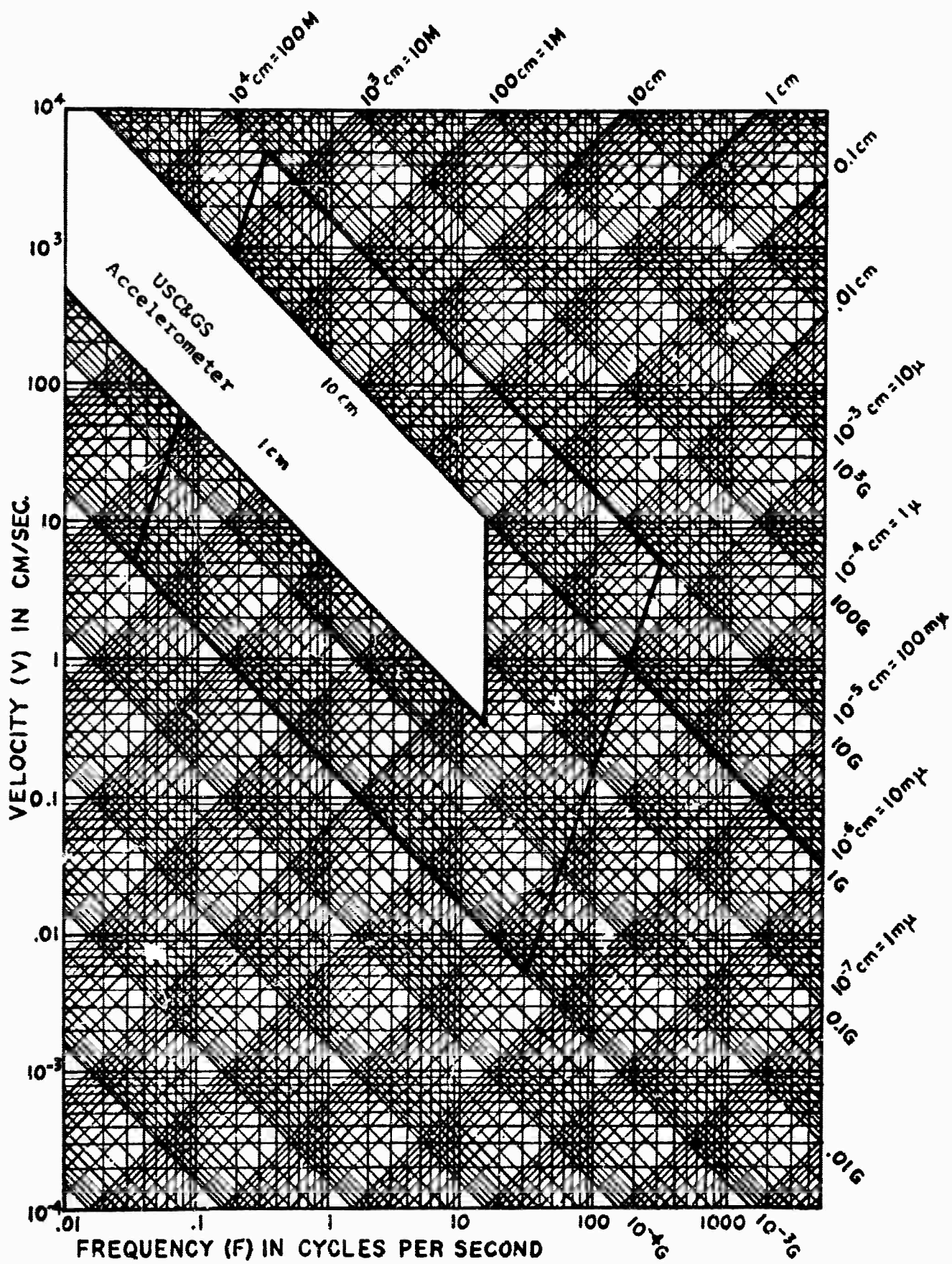
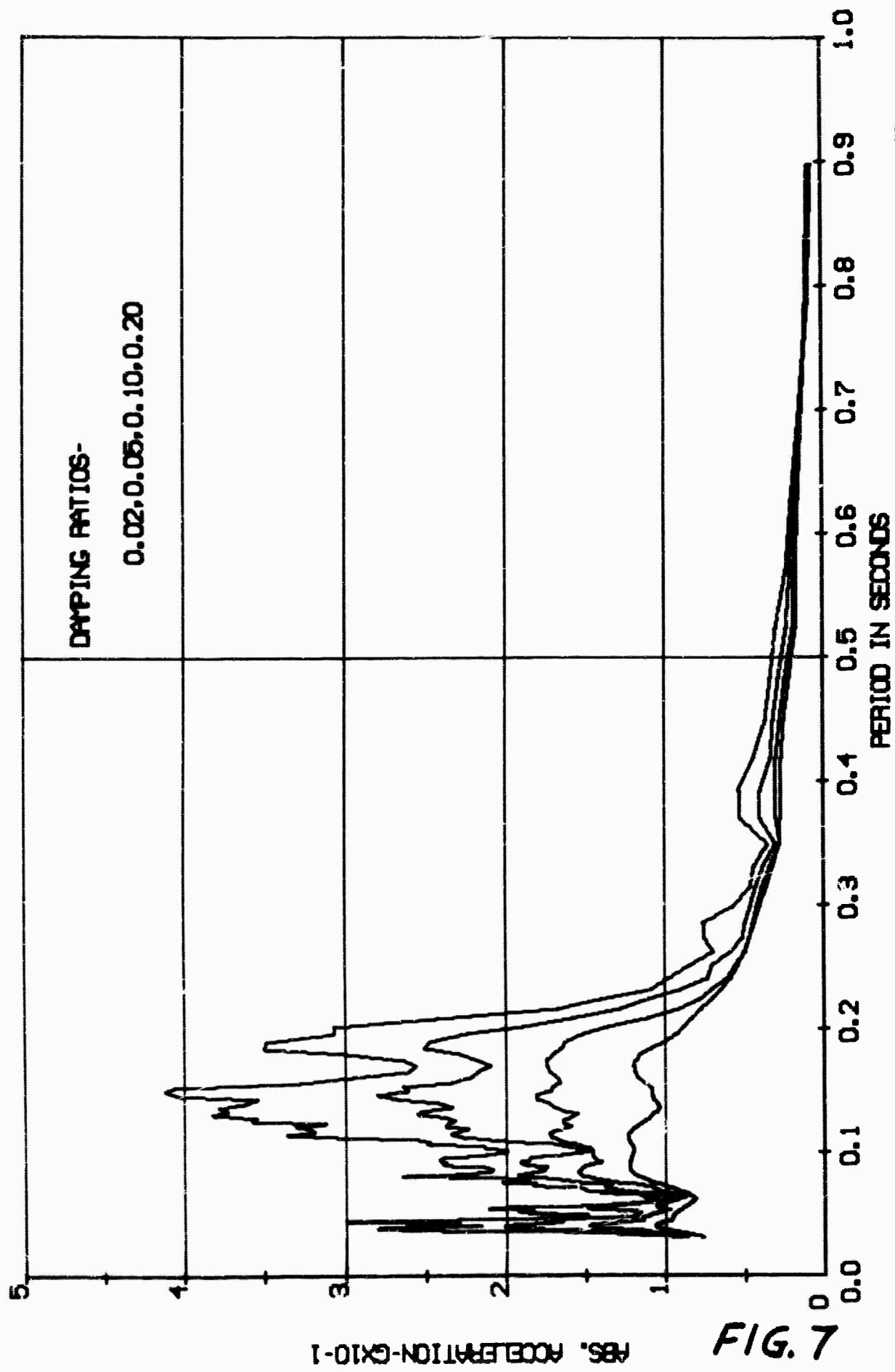


FIG. 4



**FIG. 5**



BAXTERVILLE TRANSVERSE **FIG. 7**

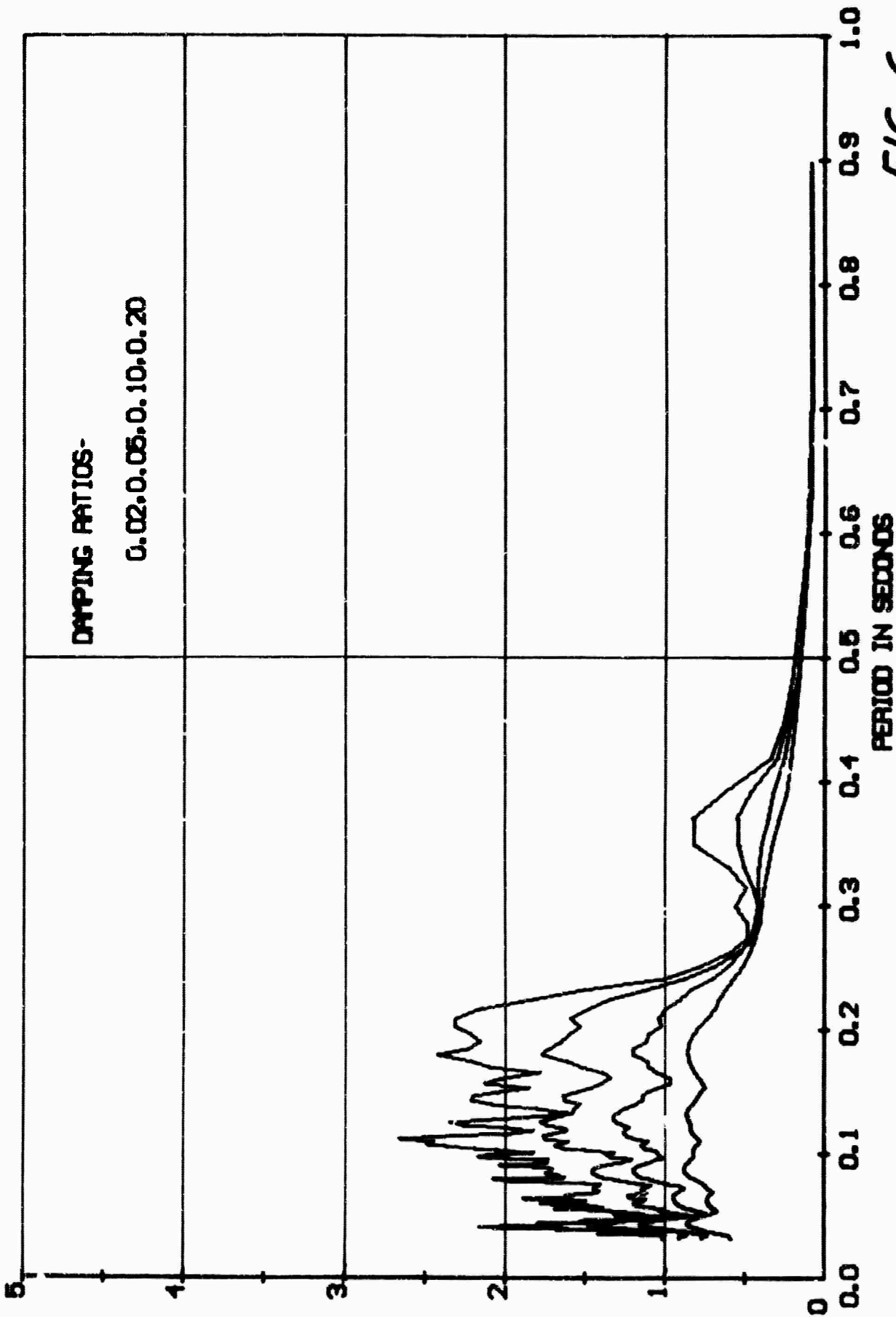


FIG. 6

BAXTERVILLE VERTICAL

FIG. 6

TECHNICAL AND SAFETY PROGRAM REPORTS SCHEDULED FOR ISSUANCE  
BY AGENCIES PARTICIPATING IN PROJECT DRIBBLE

SAFETY REPORTS

<u>Agency</u>	<u>Report No.</u>	<u>Subject or Title</u>
USWB	VUF-1020	Meteorological Documentation and Radiation Protection
USPHS	VUF-1021	Final Report of Off-site Surveillance
USEM	VUF-1022	Pre and Post-Shot Safety Inspection of Oil and Gas Facilities Near Project Dribble
USGS	VUF-1023	Analysis of Geohydrology of Tatum Salt Dome
USGS	VUF-1024	Analysis of Aquifer Response
REECo	VUF-1025	On-Site Health and Safety Report
RFB, Inc.	VUF-1026	Analysis of Dribble Data on Ground Motion and Containment - Safety Program
H-NSC	VUF-1027	Ground Water Supply
FAA	VUF-1028	Federal Aviation Agency Airspace Advisory
H&N	VUF-1029	Summary of Pre and Post-Shot Structural Survey Reports
JAB	VUF-1030	Structural Response of Residential-Type Test Structures in Close Proximity to an Underground Nuclear Detonation
JAB	VUF-1031	Structural Response of Tall Industrial and Residential Structures to an Underground Nuclear Detonation.

NOTE: The Seismic Safety data will be included in the USC&GS Technical Report VUF-3014

TECHNICAL REPORTS

<u>Agency</u>	<u>Report No.</u>	<u>Subject or Title</u>
SL	VUF-3012	Free-Field Particle Motions from a Nuclear Explosion in Salt - Part I
SRI	VUF-3013	Free-Field Particle Motions from a Nuclear Explosion in Salt - Part II
USC&GS	VUF-3014	Earth Vibration from a Nuclear Explosion in a Salt Dome
UED	VUF-3015	Compressional Velocity and Distance Measurements in a Salt Dome

IRL	VUF-3016	Design and Operation of a Chemical Processing Plant for Controlled Release of a Radioactive Gas from the Cavity of a Nuclear Explosion in Salt
IRL	PNE-3002 *	Response of Test Structures to Ground Motion from an Underground Nuclear Explosion
SRI	VUF-3017	Feasibility of Cavity Pressure and Temperature Measurements for a Decoupled Nuclear Explosion
IRL	VUF-3018	Background Engineering Data and Summary of Instrumentation for a Nuclear Test in Salt
WES	VUF-3019	Laboratory Design and Analyses and Field Control of Grouting Mixtures Employed at a Nuclear Test in Salt
IRL	VUF-3020	Geology and Physical and Chemical Properties of the Site for a Nuclear Explosion in Salt
EG&G	VUF-3021	Timing and Firing

\* This report number was assigned by SAN

In addition to the reports listed above as scheduled for issuance by the Project DRIBBLE test organization, a number of papers covering interpretation of the SALMON data are to be submitted to the American Geophysical Union for publication. As of February 1, 1965, the list of these papers consists of the following:

<u>Title</u>	<u>Author(s)</u>	<u>Agency(s)</u>
Shock Wave Calculations of Salmon	L. A. Rogers	IRL
Nuclear Decoupling, Full and Partial	D. W. Patterson	IRL
Calculation of P-Wave Amplitudes for Salmon	D. L. Springer and W. D. Hurdlow	IRL
Travel Times and Amplitudes of Salmon Explosion	J. N. Jordan W. V. Mickey W. Helterbran	USC&GS AFTAC UED
Detection, Analysis and Interpretation of Teleseismic Signals from the Salmon Event	A. Archambeau and E. A. Flinn	SDC
Epicenter Locations of Salmon Event	E. Herrin and J. Taggart	SMU USC&GS
The Post-Explosion Environment Resulting from the Salmon Event	D. E. Rawson and S. M. Hansen	IRL
Measurements of the Crustal Structure in Mississippi	D. H. Warren J. H. Healy W. H. Jackson	USGS

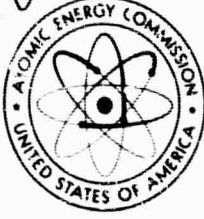
All but the last paper in the above list will be read at the annual meeting of the American Geophysical Union in April 1965.

LIST OF ABBREVIATIONS FOR TECHNICAL AGENCIES

BR LTD	Barringer Research Limited Rexdale, Ontario, Canada	RFB, INC.	R. F. Beers, Inc. Alexandria, Virginia
ERDL	Engineering Research Development Laboratory Fort Belvoir, Virginia	SDC	Seismic Data Center Alexandria, Virginia
FAA	Federal Aviation Agency Los Angeles, California	EG&G	Edgerton, Germeshausen & Grier, Inc. Las Vegas, Nevada
GIMRADA	U. S. Army Geodesy, Intelli- gence and Mapping Research and Development Agency Fort Belvoir, Virginia	SL	Sandia Laboratory Albuquerque, New Mexico
H-NSC	Hazleton-Nuclear Science Corporation Palo Alto, California	SMU	Southern Methodist University Dallas, Texas
H&N, INC	Holmes & Narver, Inc. Los Angeles, California Las Vegas, Nevada	SKI	Stanford Research Institute Menlo Park, California
II	Isotopes, Inc. Westwood, New Jersey	TI	Texas Instruments, Inc. Dallas, Texas
IITEK	Itek Corporation Palo Alto, California	UA	United Aircraft El Segundo, California
JAB	John A. Blume & Associates Research Division San Francisco, California	UED	United Electro Dynamics, Inc. Pasadena, California
IRL	Lawrence Radiation Laboratory Livermore, California	USBM	U. S. Bureau of Mines Washington, 25, D. C.
NRDL	U. S. Naval Radiological Defense Laboratory San Francisco, California	USC&GS	U. S. Coast and Geodetic Survey Las Vegas, Nevada
REECO	Reynolds Electrical & Engineering Co., Inc. Las Vegas, Nevada	USGS	U. S. Geologic Survey Denver, Colorado
		USPHS	U. S. Public Health Service Las Vegas Nevada
		USWB	U. S. Weather Bureau Las Vegas, Nevada

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