Development of an Analysis Code for Pressure Wave Propagation (I)

—Analyses of Experiment—

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Development of an Analysis Code for Pressure Wave Propagation (1)

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Abstract

We analyzed the propagation of the pressure-wave in the piping system of SWAT-1B rig by using SWAC-5 Code.
We carried out analyses on the following parts.

1) A straight pipe
2) Branches
3) A piping system

The results obtained in these analyses are as follows.

1) The present our model simulates well the straight pipe and the branch with the same diameters.

2) The present our model simulates approximately the branch with the different diameters and the piping system.

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* Work performed by Kawasaki Heavy Industries, Ltd. under contract with Power Reactor and Nuclear Fuel Development Corp.

** Kawasaki Heavy Industries, Ltd.

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-- Analyses of Experiment --

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1. Preface

The sodium-water reaction pressure generated at the time of a SG tube rupture accident propagates to the inside of SG itself, secondary piping, circulation pump, IHX and valves. These devices are required to be designed so as to stand said propagation pressure. Consequently, the code designed to analyze the propagation of pressure-wave is needed and this code is required to be evaluated.

Studies on propagation of pressure wave have been performed in various ways for the purpose of analyzing the water hammer phenomenon.[1),2)] Since the survey of the studies in this field are dealt with in detail in the reference literature[2)], we omit describing the same in this report. The study in the past shows a good coincidence between the results of analyses of propagation of pressure wave and the result of tests with a linear piping system of simple form. But the studies using the piping systems having complex forms including SG and IHX are yet to be made.

Described below are the results of analyses by means of SWAC-5 which is an improvement of SOWACS[3)], Calculation Code for Sodium-Water Reaction in Compressible Sodium.

The experiments were performed by the Power Reactor and Nuclear Fuel Development Corporation (hereinafter abbreviated as PNC) using the Corporation's SWAT-1B.

2. Outline of the Experiments

For the purpose of smoothly describing the analyses of the experiments, an outline of the experiments conducted by the PNC using the Corporation's SWAT-1B is presented below.

2.1 Items of Experiments

The propagation of pressure wave in the piping system was measured.

By properly selecting the layout of pressure sensors, propagation of the pressure wave in each of the following component was measured independently.

1) Straight pipe
2) 3-branch parts

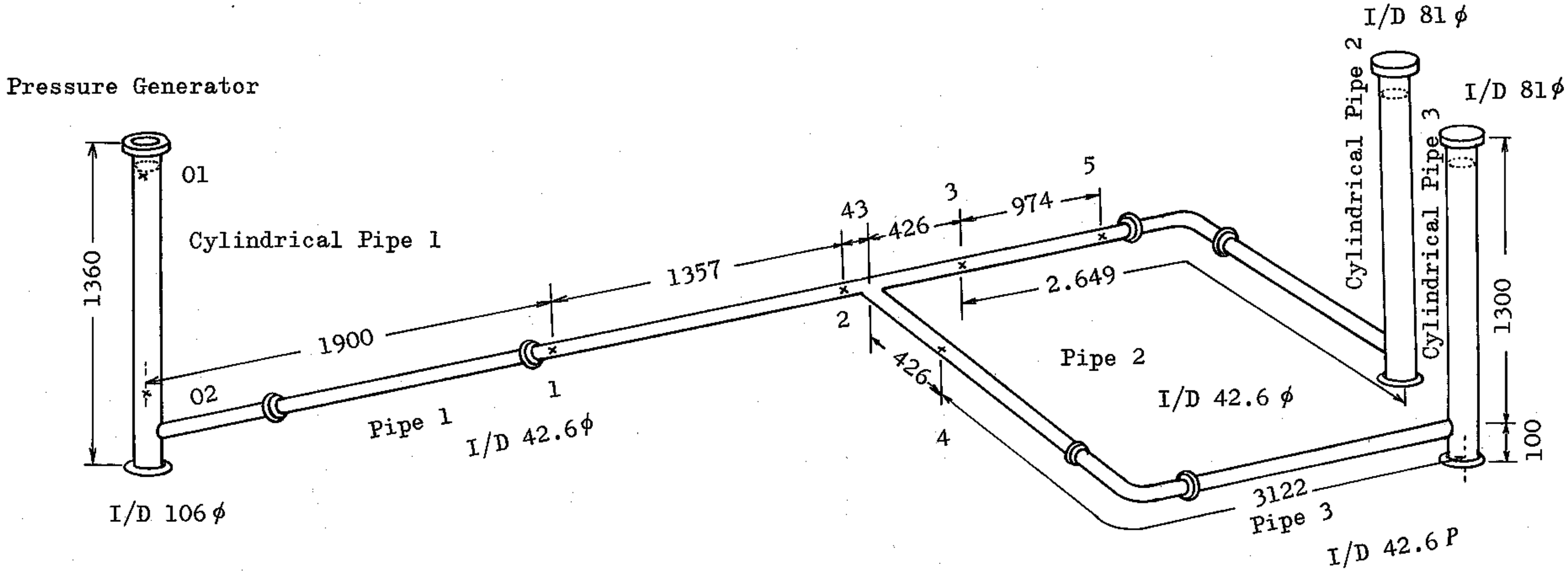
There are two kinds, i.e. Branches of the same diameter and the branches of different diameters.

3) Piping system

2.2 Apparatus and Conditions for Experiments

The SWAT-1B can have the modles of SG, IHX and pump incorporated in it, but the apparatus used in this report is composed of stainless steel pipes only. The apparatus is illustrated in Fig. 2.1. Water is used as the fluid.

The upper part of the cylindrical tube is pressurized momentarily by a pressure generator. The propagated pressures measured at the points 01, 02, 1, 2, 3, 4 and 5 are made the objects for this experiment. The pipes connecting the cylindrical pipes 1, 2 and 3 are installed horizontally. The cylindrical pipes 2 and 3 have free liquid surfaces.



Note: 01 through 5: Pressure measuring points

Fig. 2.1 Apparatus for Experiments

3. Analyses of Experiments

3.1 Calculation Model

A model of the apparatus as shown in Fig. 2.1 is prepared as illustrated in Fig. 3.1.

The pressure measuring points, 01, 02, 1, 2, 3, 4 and 5 correspond to joints 1, 2, 5, 6, 8, 15 and 9 respectively.

The joints 4, 13 and 19 represents 1-branch points, 3, 7, 12 and 18 3-branch points and 14 and 20 free liquid surfaces respectively.

3.2 Assumptions and conditions for Calculation

1) It is assumed that water flows in conformity with the equation of water hammer.

2) The method for calculation on each boundary is as described in the Section for Pressure-Wave Propagation Co e in this Study.

3) The data used in the calculation including the shape and physical property values are shown in Table 3.1.
(For sonic values refer to the appended Table 2.)

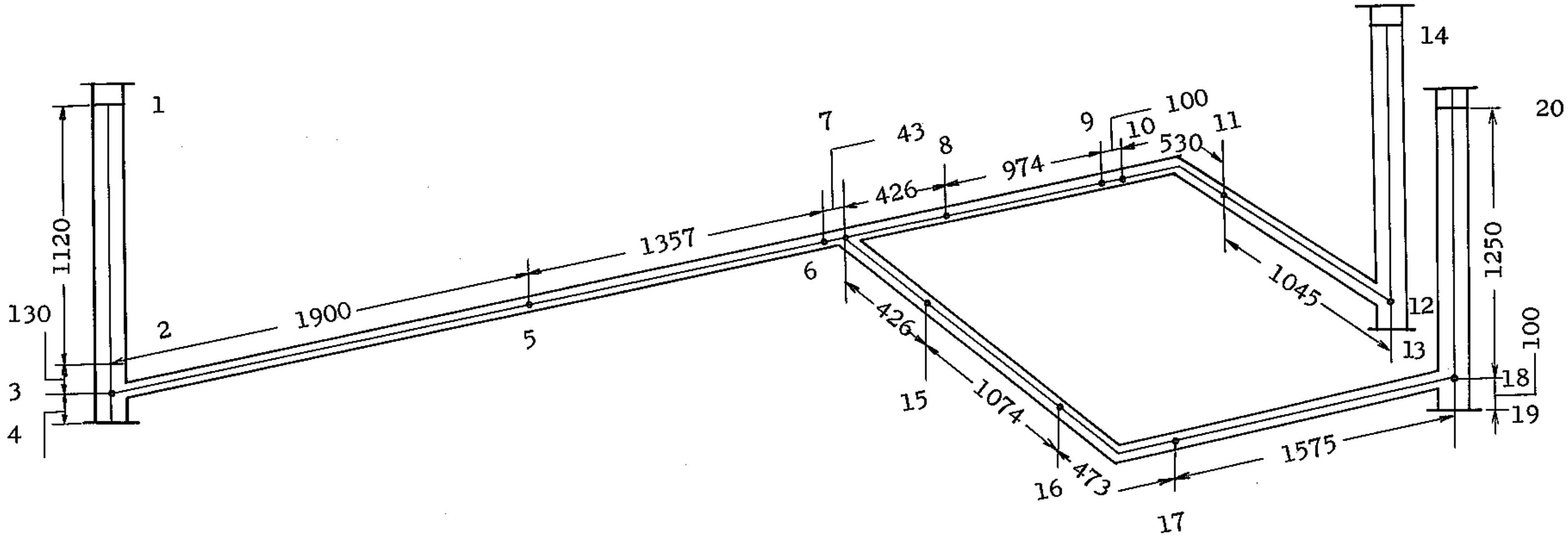
3.3 Analysis of Each Part

3.3.1 Propagation of Pressure-Wave in Straight Pipe

Propagation of pressure-wave in straight pipe is analyzed using the measured value for joints 8 and 9. The measured pressure (Channel 5 in the appended diagram 7) is input to joint 8 in Fig. 3.1 and the calculated value is compared with the measured value for joint 9 (Channel 6 in the appended diagram 7).

The pressure-wave passing through joint 8 reaches the entrance of cylindrical pipe 2 about 1.9 msec later, where it is reflected and reaches joint 9 about 1.2 msec later (See the appended diagram 1). Consequently, for a period of 3.1 msec the measured value for joint 9 has the effect of only a straight pipe. The experiment data used for the comparison is BD-93 (See the appended diagram 7). The result of the analyses is illustrated in Fig. 3.2.

There can be seen a good coincidence between the analytical value and the test value for the pulse rising time for the start of response at joint 9. The analytical value for the peak pressure shows about 10% higher than the test value. This may be ascribed to the effect of the bending part, but it is yet to be verified. As regards the straight pipe, it may well be thought that the present model simulated it almost accurately.



Note: Bending part; 10 11 16 17

Free liquid surface; 1 , 14 , 20

Measuring point; 1 , 2 , 5 , 6 , 8 , 9 , 15

Fig. 3.1 Calculation Model

Table 3.1 Calculation Conditions

a. Conditions on Form

Member	Name	Length (m)	Sectional area (m^2)	Effective dia. (m)	Sonic speed (m/s)
Connecting pt. 1 - 2	Cylindrical tube .1	1.120	$8.87x10^{-3}$	0.1063	1302
2 - 3	"	0.130	"	"	"
3 - 4	"	0.100	"	"	"
3 - 5	Pipe .1	1.90	$1.42x10^{-3}$	0.0426	1383
5 - 6	"	1.357	"	"	"
6 - 7	"	0.043	"	"	"
7 - 8	Pipe .1	0.426	"	"	"
8 - 9	"	0.974	"	"	"
9 - 10	"	0.100	"	"	"
10 - 11	Pipe .2 (bend)	0.530	"	"	"
11 - 12	Pipe .2	1.045	"	"	"
12 - 13	Cylindrical tube .2	0.100	$5.16x10^{-3}$	0.0811	1343
12 - 14	"	1.250	"	"	"
7 - 15	Pipe .3	0.426	$1.42x10^{-3}$	0.0426	1383
15 - 16	"	1.074	"	"	"
16 - 17	Pipe .3 (bend)	0.473	"	"	"
17 - 18	Pipe .3	1.575	"	"	"
18 - 19	Cylindrical tube .3	0.100	$5.16x10^{-3}$	0.0811	1343
18 - 20	"	1.250	"	"	"

b. Constant

Specific weight of water	1000 kg/m^2	Parameter for coefficient of friction (C_1)	0.3164
Kinematic Coefficient of viscosity	0.101 x $10^{-5} m^2/s$	(C_2)	-0.25
		where $f = C1Re^{C_2}$	

c. Others

Width of space mesh	0.0426 m	Analysis time	~15.3 msec

3.3.2 3-Branch Part

1) Pressure wave propagation in 3-branch tubes of same diameters. The 3-branch part is shown as joint 7 in Fig. 3.1, and the measured pressure (Channel 3 in the appended diagram 6) is input to joint 5 and the calculated value is compared with the measured value for joints 8 and 15. The pressure wave passing through joint 5 reaches the 3-branch part about 1 msec later, where it is reflected and reaches joint 5 again about 1 msec later. (Refer to Appended Diagram 1) Consequently, the measured value at joint 5 is the pressure free of any effect of the 3-branch part during a period of about 2 msec. So, the pressure value during the period may be used as the input wave for the analysis.

The wave pressure having passed joint 5 reaches joints 8 and 15 simultaneously about 1.32 msec later. For the period of about 2 msec after that, the pressure wave is free of any effect of any boundary condition. So, from the response made by joints 8 and 15 during said period of 2 msec, an analysis of the 3-branch part is performed.

The experiment data used for the comparison is BD-22 (Refer to Appended Diagram 6.) The result of the analysis is illustrated in Fig. 3.3. The part up to the period for about 3.34 msec is the period during which comparison is available. Up to the period of about 2.86 msec, a good coincidence is seen between the test value and the analytical value for joints 8 and 15 respectively.

After the period of 2.86 msec, the measured value at joint 8 is about 10% higher than the analytical value and the test value at joint 15 is about 10% lower.

Since the distance from the branch point to joint 8 is equal to the distance from the branch point to joint 15, the same value is calculated by the analysis. It can be thought that the difference between the test values for joints 8 and 15 is ascribed to the effect of the bending part.

The bend in the lower stream of joint 8 and the bend in the lower stream of joint 15 have different bending radius and tube length, which are 210 mm and 530 mm for the former and 250 mm and 473 mm for the latter. The time at which a difference between the analytical value and the test value starts appearing some time after about 2.86 msec is the time at which the reflected waves from the bends start reaching joint 8 and 15 respectively.

2) Pressure Wave Propagation in 3-Branch Tubes of Different Diameters

In Fig. 3.1, joint 12 is a 3-branch point at which a tube of 42.6 mm in diameter crosses at right angles with a tube of 81.8 mm in diameter.

The measured pressure (Channel 5 in Appended Diagram 7) is input to joint 8 and the pressure wave having passed joint 8 passes joint 9 and reaches joint 12 about 1.9 msec later. And the reflected wave reaches joint 9 about 1.2 msec later. And about 0.7 msec later, it reaches joint 8. Consequently, the pressure for 3.1 msec through 4.5 msec at joint 9 is affected by only the reflection of joint 12. So, comparison is made between the measured value (Channel 6 in Appended Diagram 7) and the analytical value at joint 9 for said period.

The experiment data used in the comparison is BD-93 (Refer to Appended Diagram 7.)

The result of analysis is illustrated in Fig. 3.4.

For the initial period, the pressure of the result of analysis is larger than the experiment result and later, this relation is reversed.

3.3.3 1-Branch Part and Free Liquid Surface Part

As regards the 1-branch part and the free liquid surface, there is available no measured value which is not affected by any other boundary condition, so that no analysis was made.

3.4 Analysis of the Whole System

The calculation model is illustrated in Fig. 3.1.

3.4.1 In case Joint 1 is the Pressure Source Point

The propagation of the pressure wave for the system as a whole was analyzed using the measured pressure value at the pressure source point (joint 1) as illustrated in Fig. 3.5.

A comparison between the measured value (Channel 2 in Appended Diagram 6) and the calculated value is illustrated in Fig. 3.6. It is seen that the calculated pressure value is higher than the measured value by 25% approximately.

There is a great difference in pressure variation between the measured values and calculated values. Siad difference can be thought ascribed to the following.

(1) It is likely that there is a large measuring error in the measured value at the pressure source point.

(2) It is likely that the 1-branch boundary condition for joint 4 is different from the calculated condition.

Comparison between the measured values and the calculated values at joints 5, 6, 8 and 15 are illustrated in Appended Diagram 2 through 5.

As described above, when a measured pressure value at joint 1 is used as an input wave, there occurs a great difference in the pressure wave propagation phenomenon in the system as a whole between the measured value and the calculated value.

On the other hand, since cylindrical tube 1 as illustrated in Fig. 2.1 has the section area about 6 times as large as that of tube 1, the phenomena in the cylindrical tube are little affected by tube 1.

In addition to this, assuming that there is no error in the conditions for analysis as described in (2) above, the measured value at joint 2 is not so much affected by any boundary condition until the reflected waves from cylindrical tubes 2 and 3 reach joint 2.

Consequently, in such a case as this, it is possible to analyze the propagation of the pressure wave in the system as a whole by using the measured pressure value at joint 2 as an input value.

3.4.2 In Case Joint 2 is the Pressure Source Point

A comparison between the result of analysis of the system as a whole in which the measured value at joint 2 (Channel 2 in Appended Diagram 6) is used as an input value and the result of experiment is described below.

The measured values at joints 5, 6, 8 and 15 (Channels 3 through 6 in Appended Diagram 6) and the result of analyses are illustrated in Fig. 3.7 through Fig. 3.10.

Each diagram shows a good coincidence between the measured value and the analytical value up to the time when the effects from the free liquid surfaces of cylindrical tube 2 and 3 start appearing. However, nothing definite can be said as to the cause, since no experiment has ever been made with respect to the free liquid surfaces.

Similarly, a comparison was made between the measured values and analytical values using the Experiment Data BD-16 (Refer to Appended Diagram 8).

The measured values at joints 5, 8 and 15 (Channels 3, 5 and 6 in Appended Diagram) and the result of analyses are illustrated in Fig. 3.11 through Fig. 3.13. They show the tendency approximately same as the Experiment Data BD-22.

Then, with the sonic velocity in each part of the whole system arranged to 1302 m/s using the Experiment Data BD-22, comparison was made between the measured values and the result of analyses.

The measured values at joint 5 (Channel 3 in Appended Diagram 6) and the result of analysis are illustrated in Fig. 3.14.

The measured values at joints 6, 8 and 15 (Channels 4, 5 and 6 in Appended Diagram) and the result of analyses are illustrated in Appended Diagram 9 through 11.

Each diagram shows that the difference between the experiment value and the result of analysis is a little larger than the case in which the sonic velocity in each part of the whole system is given independently, but the tendency of the wave form is almost identical. Consequently, in the range in which the sonic velocity has the difference of several per cent, no phenomenal difference was seen between the analytical value and the experiment value with respect to the whole system.

3.4.3 Effect of Sonic Velocity at Bend

Due to the difference in shape between the bend of tube 2 and that of tube 3 in Fig. 3.1, it can be thought that the pressure wave propagation is different between the two. (Refer to Fig. 3.3). In this experiment, calculation was made to find what is the difference between the analytical values of the two in the system as a whole, in case the sonic velocity at the bend is changed from 1383 m/s to 1483 m/s. The comparison at joint 5 is illustrated in Fig. 3.15 and the comparison at joint 8 in Appended Diagram 12. Almost no difference was seen between the analytical value of 1383 m/s and the analytical value of 1483 m/s. Consequently, with this apparatus for experiment, there is little change in the analytical value of the system as a whole if the difference in sonic velocity at the bend is about 100 m/s.

3.4.4 Effect of Model at 3-Branch Part of Different Diameters

The result of comparison of the analyses of the system as a whole at joint 5, in case a test is performed by changing the model of the 3-branch part of different diameters at joint 12 and joint 18 in Fig. 3.1 is illustrated in Fig. 3.15.

Case 2 in the diagram is the result of analysis using a model short of the branching part toward the lower part of the entrances of the cylindrical tubes 2 and 3 (short of the section between joints 12 and 13 and the section between joints 18 and 19).

Case 3 is the result of analysis using a model (same as that in Fig. 3.1) in which the entrances of the cylindrical tubes 2 and 3 are handled as 3-branch parts.
Case 4 is the result of analysis of a system in which the diameters of cylindrical tubes 2 and 3 are made 1.2 times as large as the actual one after removing the section between joints 12 and 13 and the section between joints 18 and 19 in the same manner as Case 2.

In Fig. 3.14 there is observed no phenomenal change quantitatively in the comparison in each of the three cases, although a little change can be observed quantitatively. Consequently, the analytical value of the system as a whole will not be changed much by a change in the model to this degree.

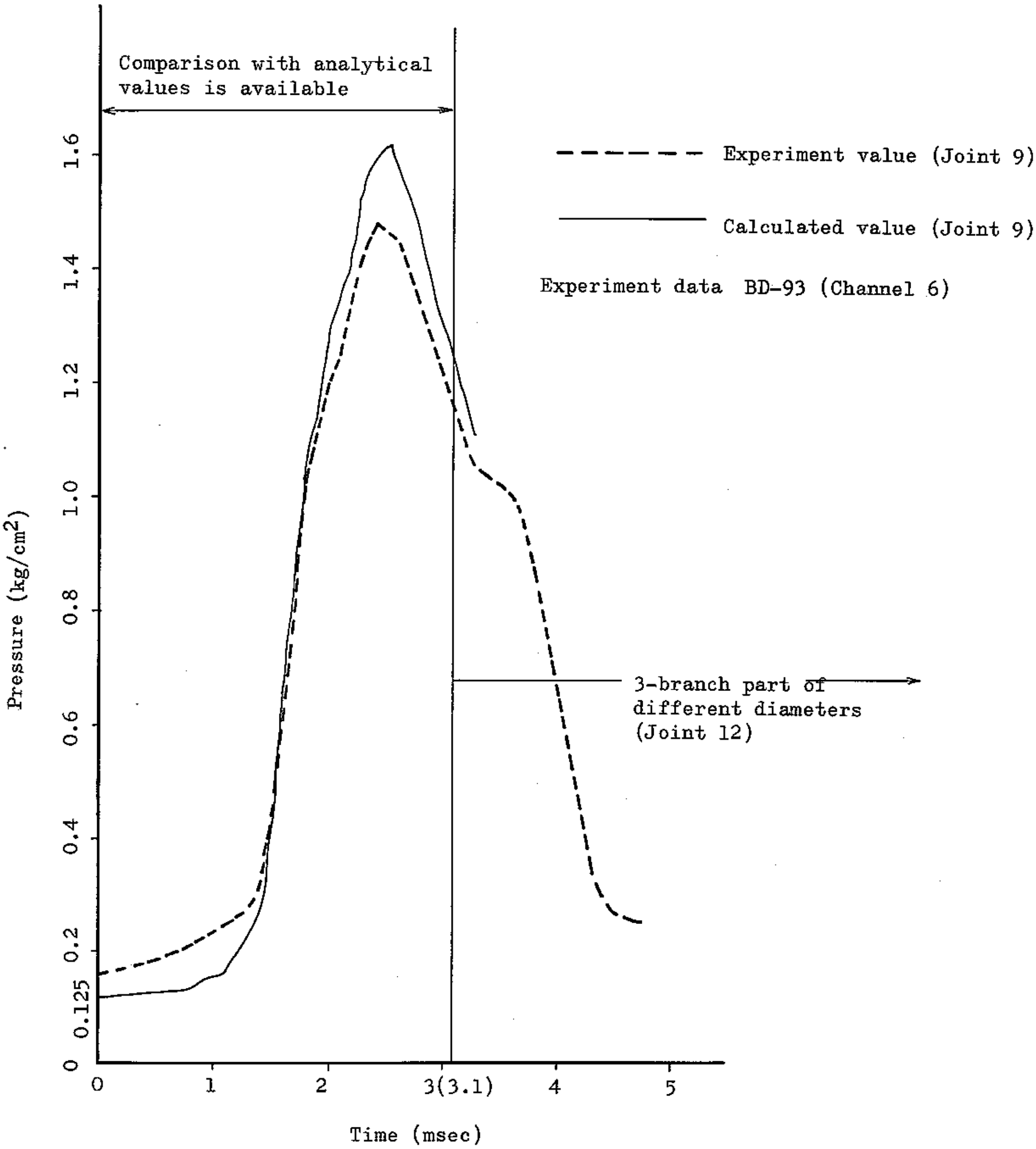


Fig. 3.2 Pressure Wave Propagation in Straight pipe

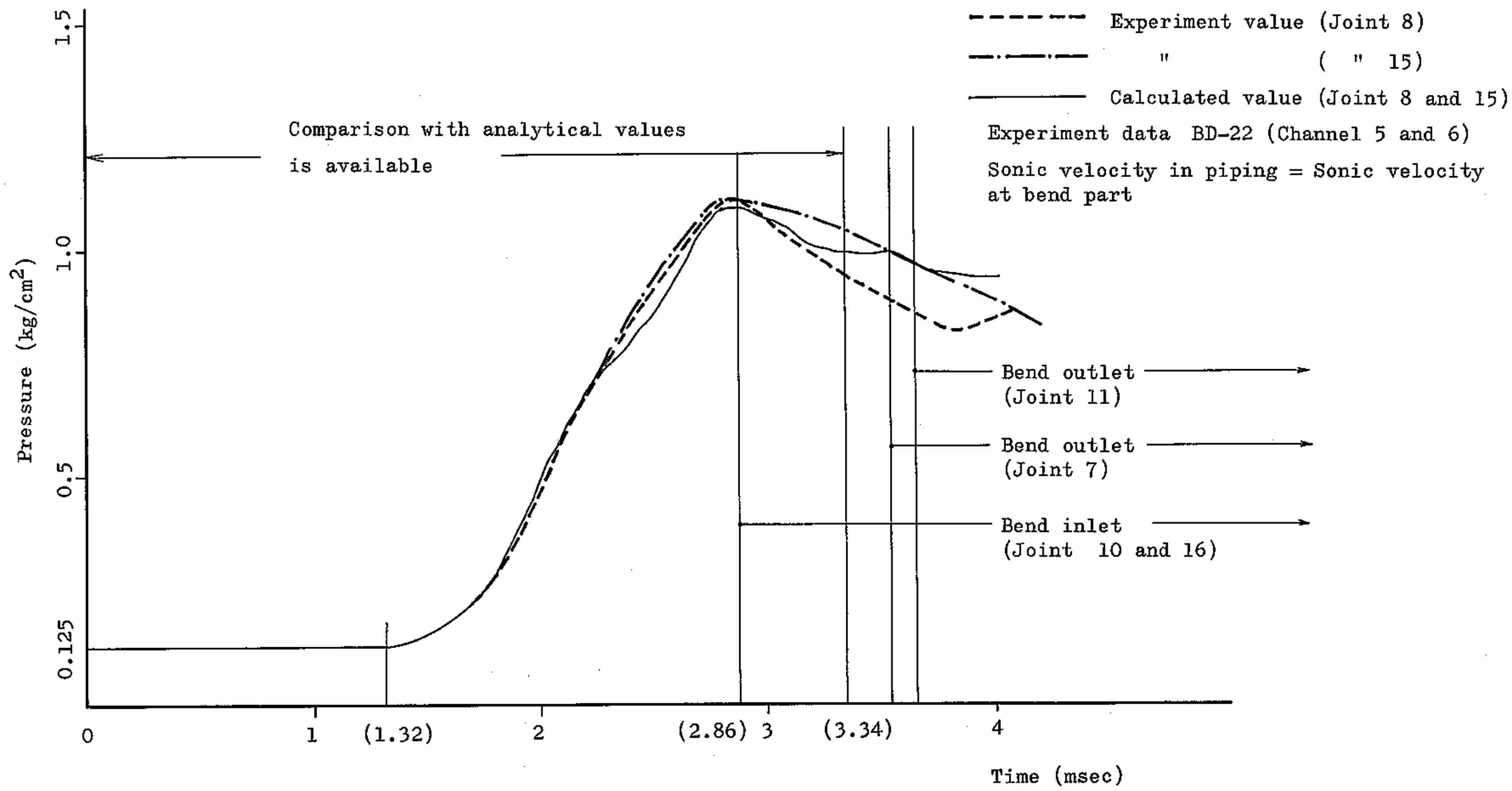


Fig. 3.3 Pressure-Wave Propagation in 3-Branch Tubes of Same Diameter

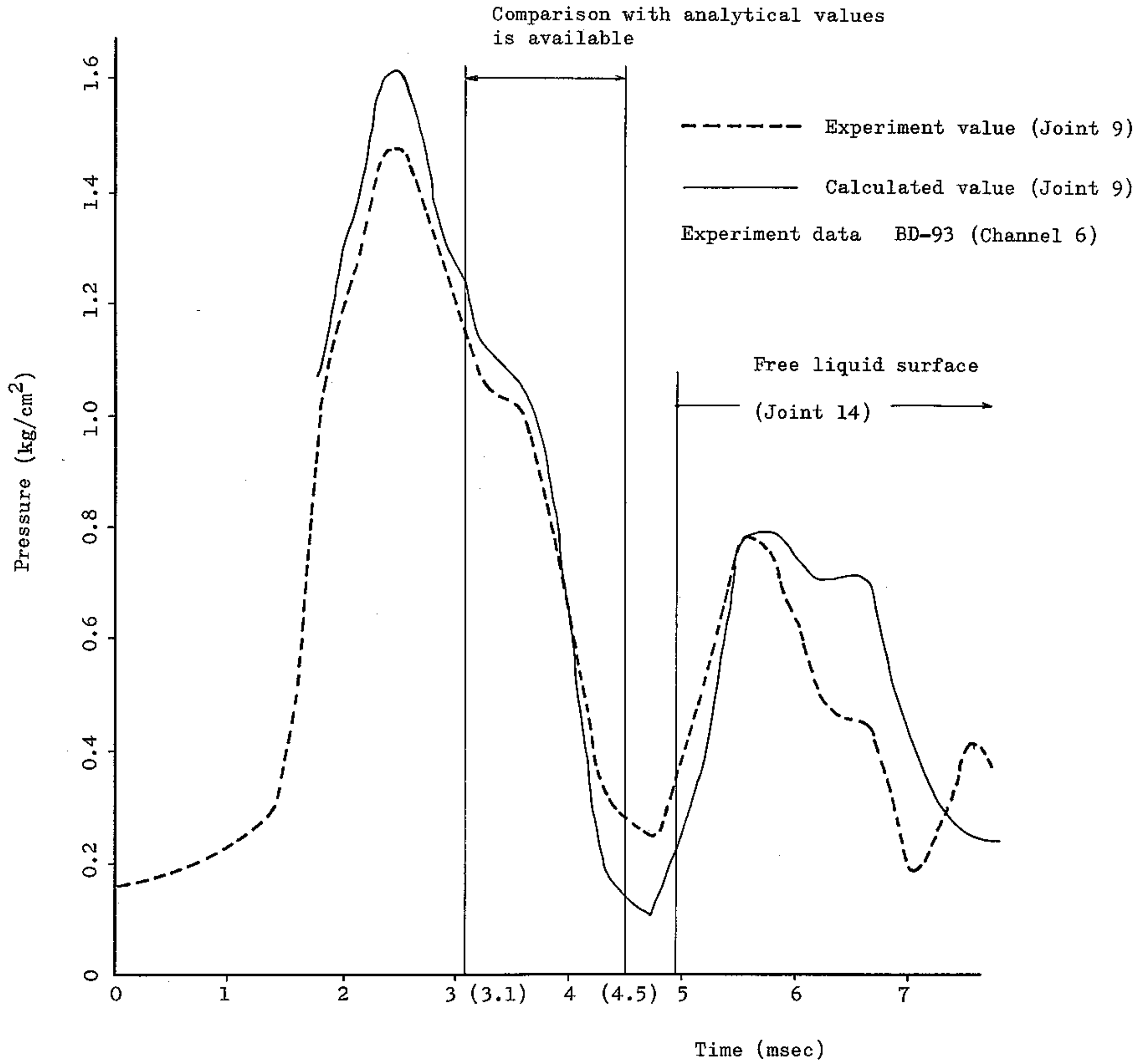
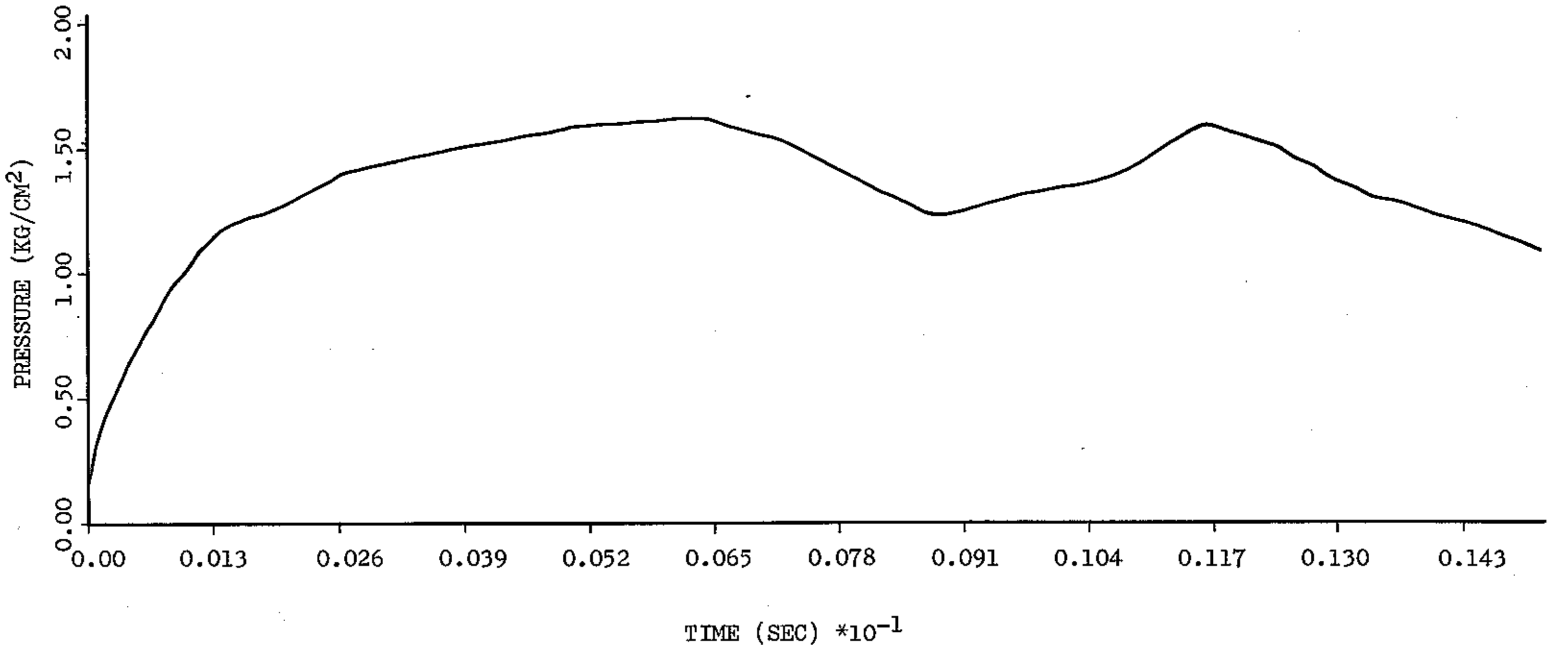


Fig. 3.4 Pressure-Wave Propagation in 3-Branch Tubes of Different Diameters

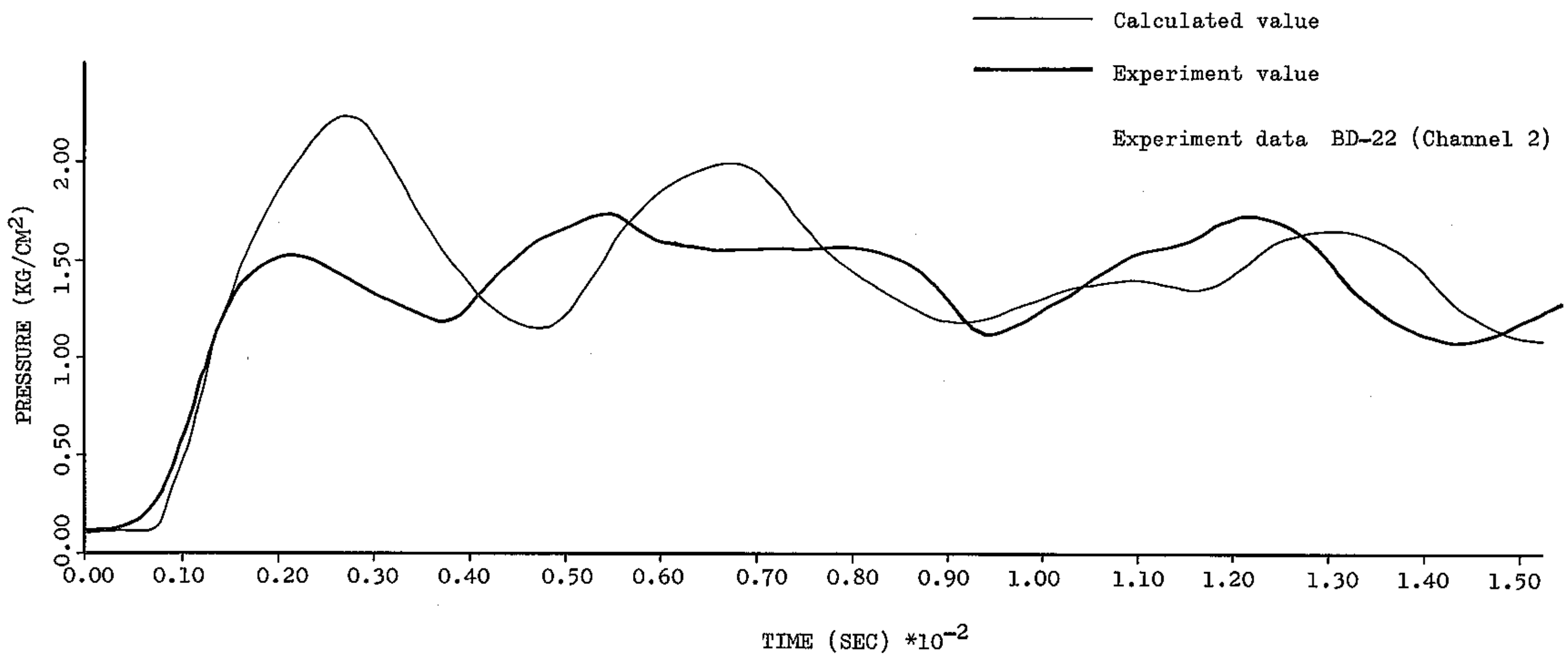
Experiment data BD-22 (Channel 1)



PRESSURE, LEFT OF MEMBER 1.

PRESSURE-WAVE PROPAGATION CASE1

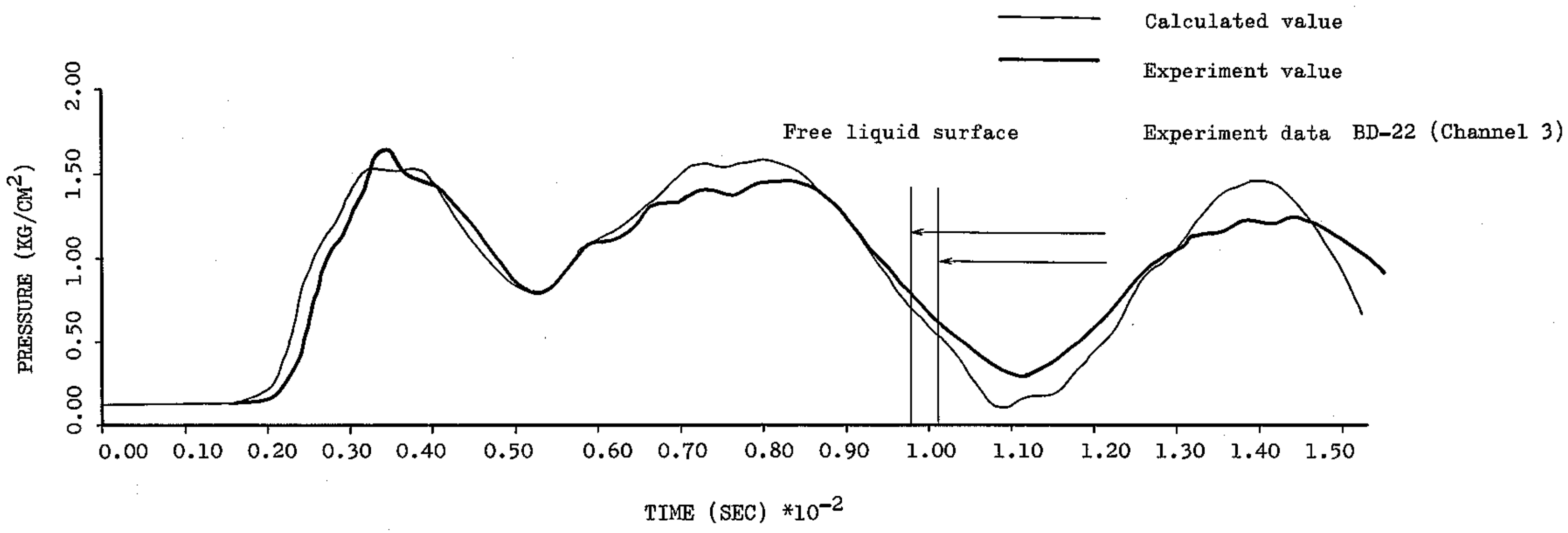
Fig. 3.5 Pressure at Pressure Source Point (Joint 1)



PRESSURE, LEFT OF MEMBER 2.

RESSURE-WAVE PROPAGATION INPUT JOINT 1 CASE 14

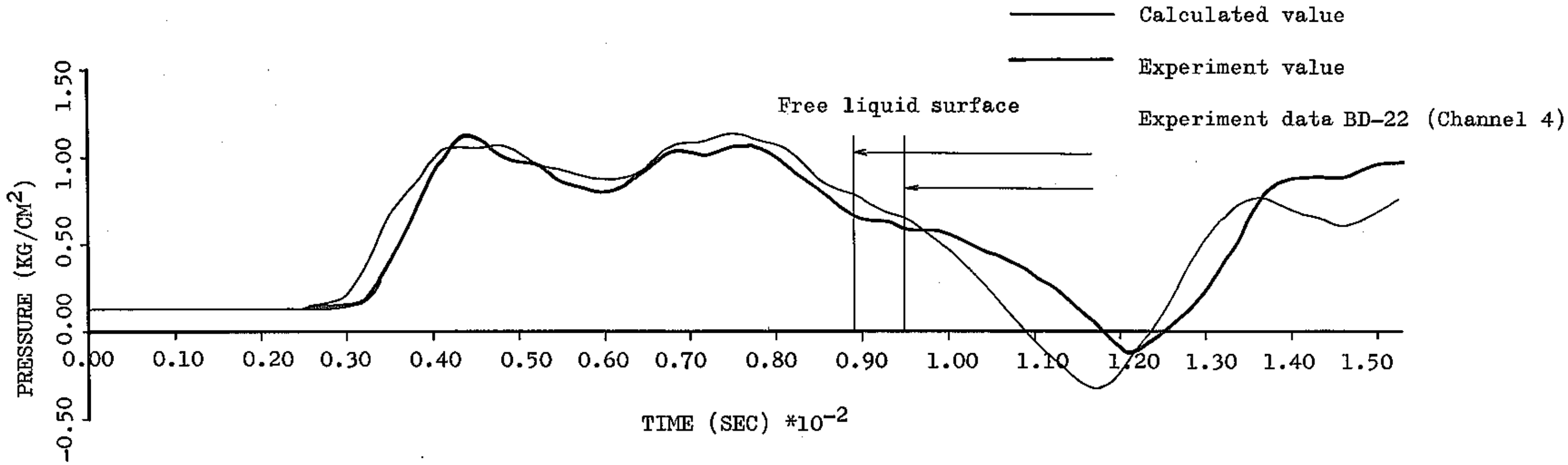
Fig. 3.6 Pressure Variation at Joint 2



PRESSURE, LEFT OF MEMBER 5.

PRESSURE-WAVE PROPAGATION INPUT JOINT 2. CASE 12

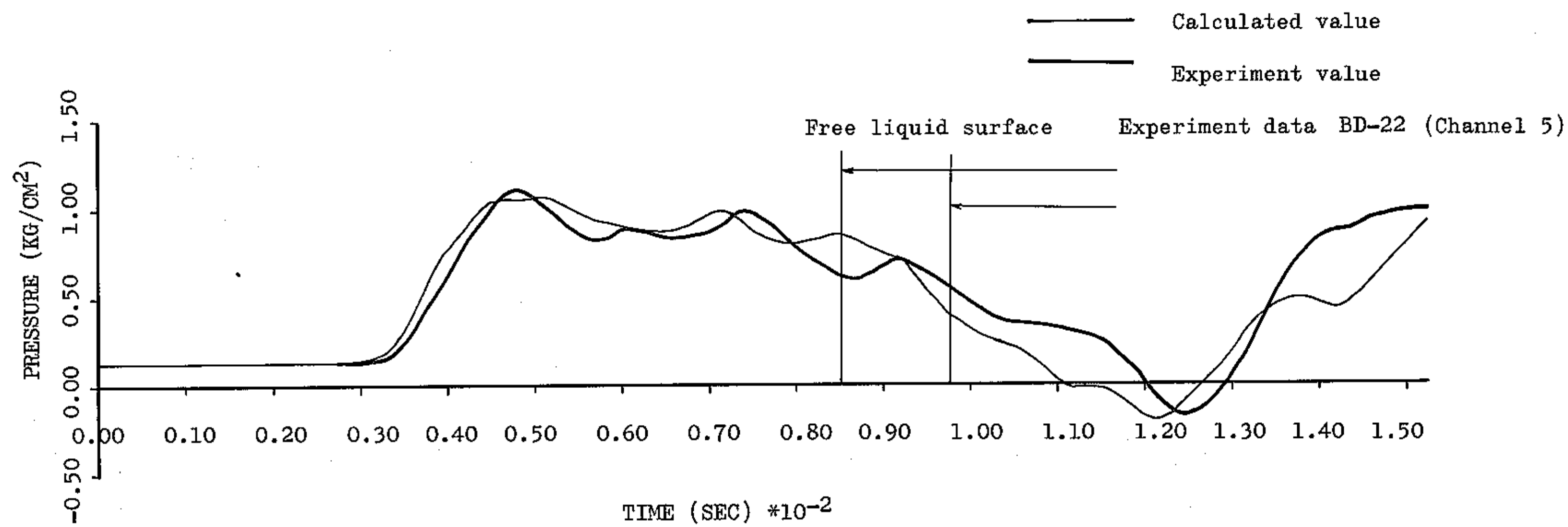
Fig. 3.7 Pressure Variation at Joint 5



PRESSURE, LEFT OF MEMBER 6.

PRESSURE-WAVE PROPAGATION INPUT JOINT 2. CASE 12

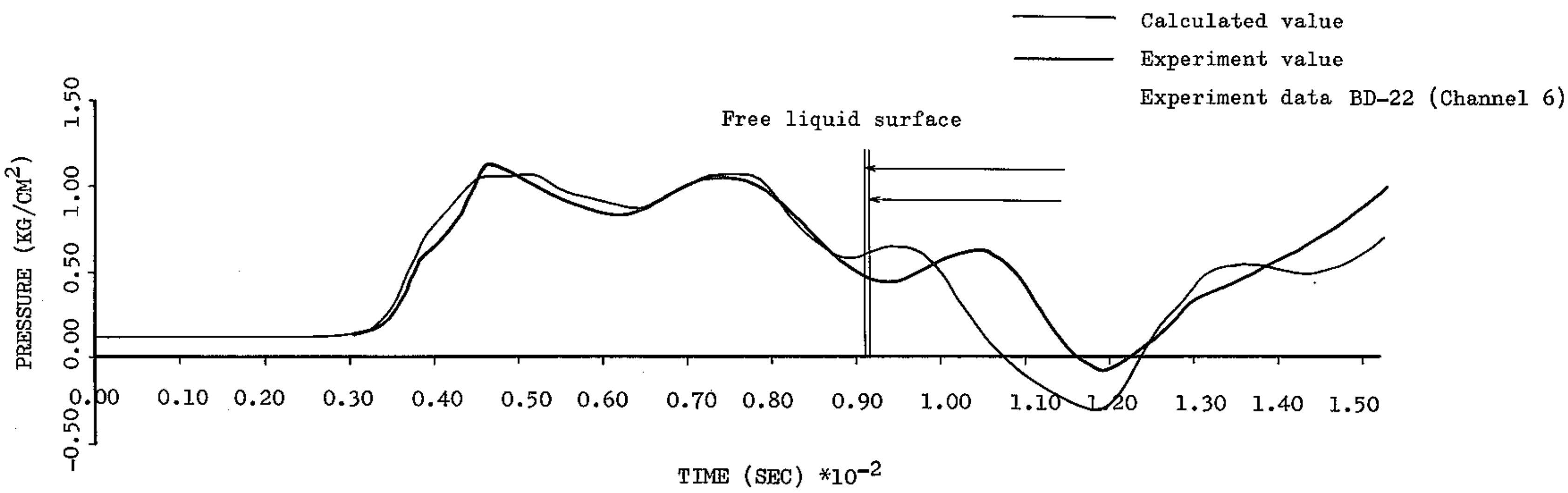
Fig. 3.8 Pressure Variation at Joint 6



PRESSURE, LEFT OF MEMBER 8.

PRESSURE-WAVE PROPAGATION INPUT JOINT 2. CASE 12

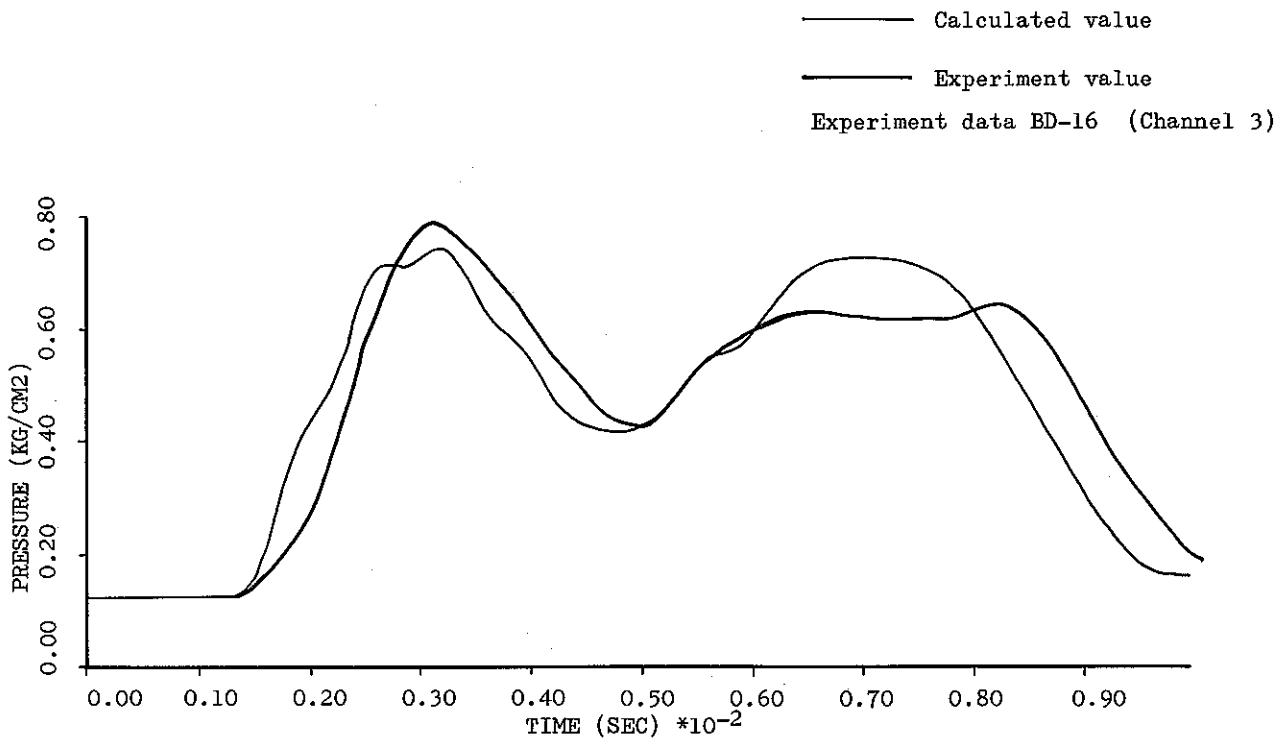
Fig. 3.9 Pressure Variation at Joint 8



PRESSURE, LEFT OF MEMBER 15

PRESSURE-WAVE PROPAGATION INPUT JOINT 2. CASE12

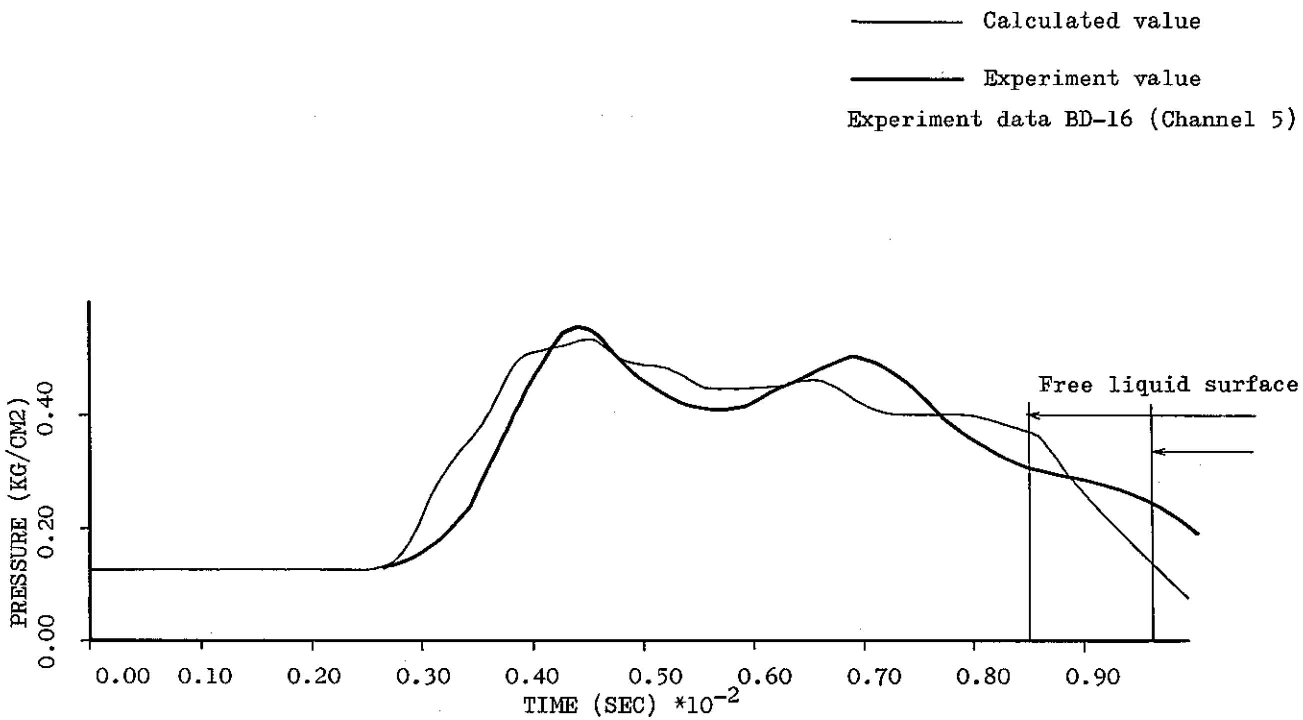
Fig.3 10 Pressure Variation at Joint 15



PRESSURE, LEFT OF MEMBER 5.

Fig. 3.11 Pressure Variation at Joint 5

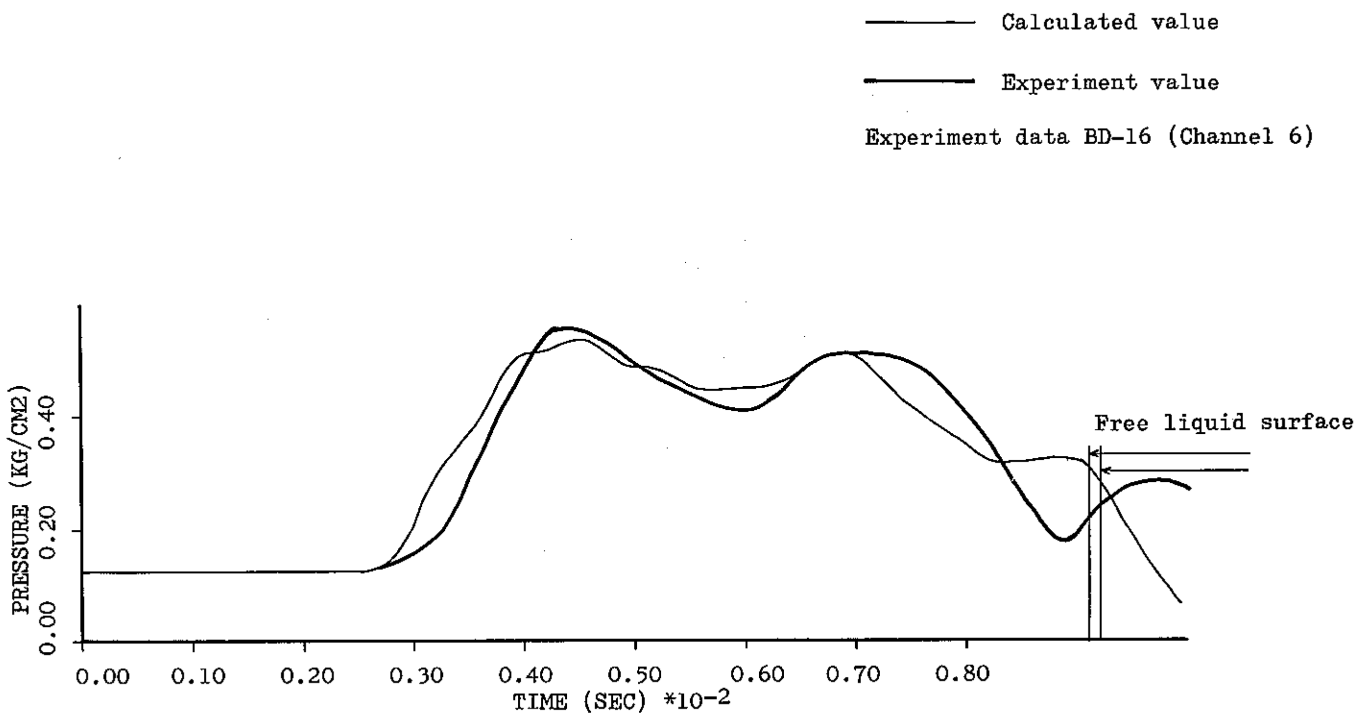
PRESSURE-WAVE PROPAGATION INPUT JOINT 2. CASE 8



PRESSURE, LEFT OF MEMBER 8.

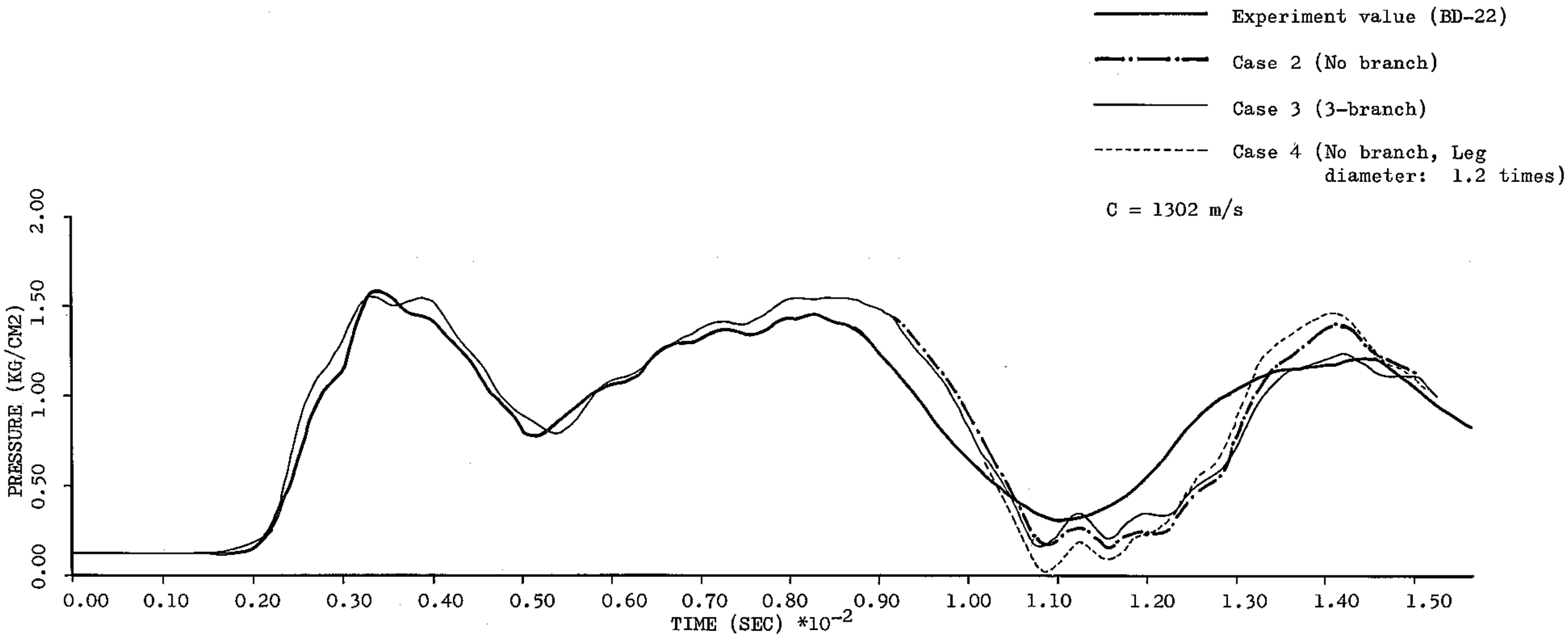
Fig. 3.12 Pressure Variation at Joint 8

PRESSURE-WAVE PROPAGATION INPUT JOINT 2. CASE 8



PRESSURE, LEFT OF MEMBER 15.　　　Fig. 3.13 Pressure Variation at Joint 15

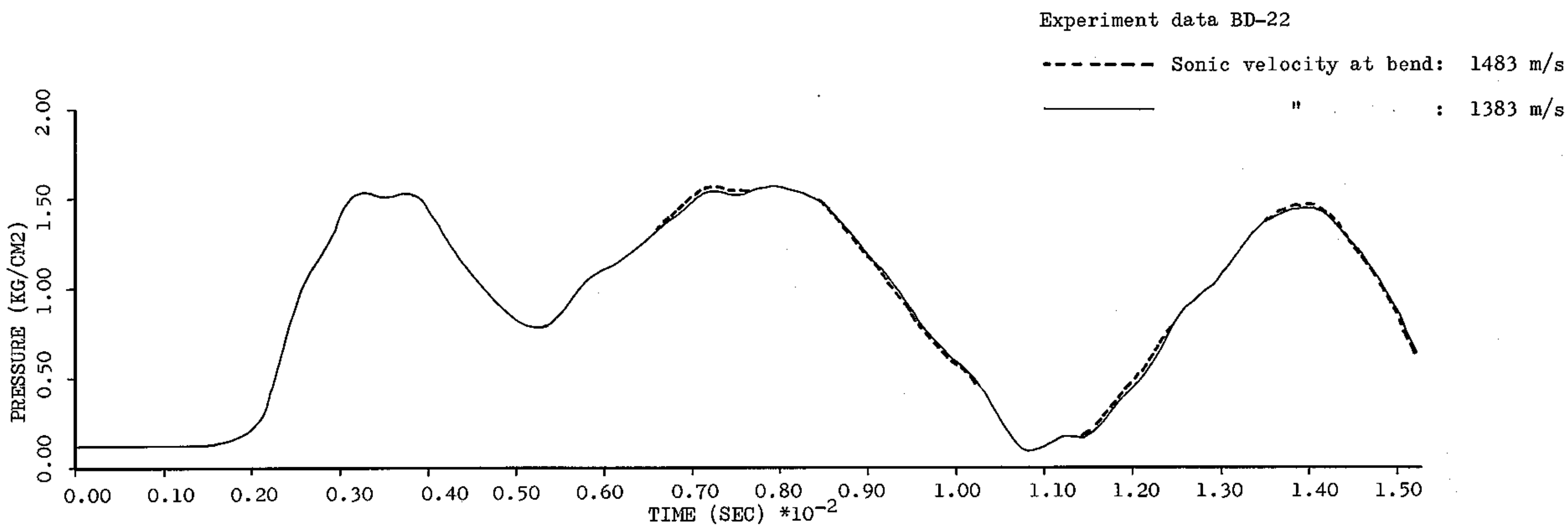
PRESSURE-WAVE PROPAGATION INPUT JOINT 2.　　CASE 8



PRESSURE, RIGHT OF MEMBER 5.

PRESSURE-WAVE PROPAGATION INPUT JOINT 2.

Fig. 3.14 Pressure at Joint 5



PRESSURE, LEFT OF MEMBER 5.

Fig. 3.15 Effect of Sonic Velocity at Bend Part (Joint 5)

PRESSURE-WAVE PROPAGATION INPUT JOINT 2. CASE 11, 12

4. Conclusion

The following conclusions have been arrived at concerning the characteristics of each piping element.

1) Our present model can simulate the straight pipe.

2) Our present model can simulate the 3-way branches with the same diameter.

3) Our present model cannot perfectly simulate the 3-way branches with different diameters.

4) Our present model can almost simulate the pressure wave propagation in the piping system.

5. Postscript

We analyzed the propagation of pressure wave using the results of experiments with SWAT-1B, but as the data for studying the response of each piping element, they cannot be said sufficient for the purpose of analyses, since the data are for short periods. So, we hope that further experiments available for a long period are performed. Moreover, since it is important to properly grasp the boundary conditions at the lower part of cylindrical pipe 1 in performing an analysis of the piping system as a whole, we hope experiments be performed intended to analyze the lower boundary.

Since the characteristics of the bend part are yet to be verified, they need to be verified through experiments.

We have described our requests concerning experiments as above.

As to analyses, we think it is necessary to consider a model designed to solve the problem of handling the branch pipes with different diameters.

6. Acknowledgement

We would like to express our appreciation to Mr. Masao Hori, Head of Fast Reactor Safety Laboratory in Power Reactor & Nuclear Fuel Development Corporation and Mr. Makoto Hishida of the same Laboratory for their valuable suggestions in executing our study and also for permitting us to refer to the experimental data with SWAT-1B.

7. References

1) G.R. Rich : Hydraulic Transients, Mcgraw Hill Book Company, Inc., 1951

2) F.E. Perkins, A.C. Tedrow, & P.S. Eagleson : Trans, ASCE, 128 (1963), 1538

3) Kosuke Sakano & Yoshihisa Tanaka : Analyses of $Na-H_2O$ Reaction by one-dimensional method with compressibility of sodium and water taken into consideration, Sectional Committee Meeting for Reactor Physics & Reactor Engineering of Japan Atomic Energy Society for 1970. D36

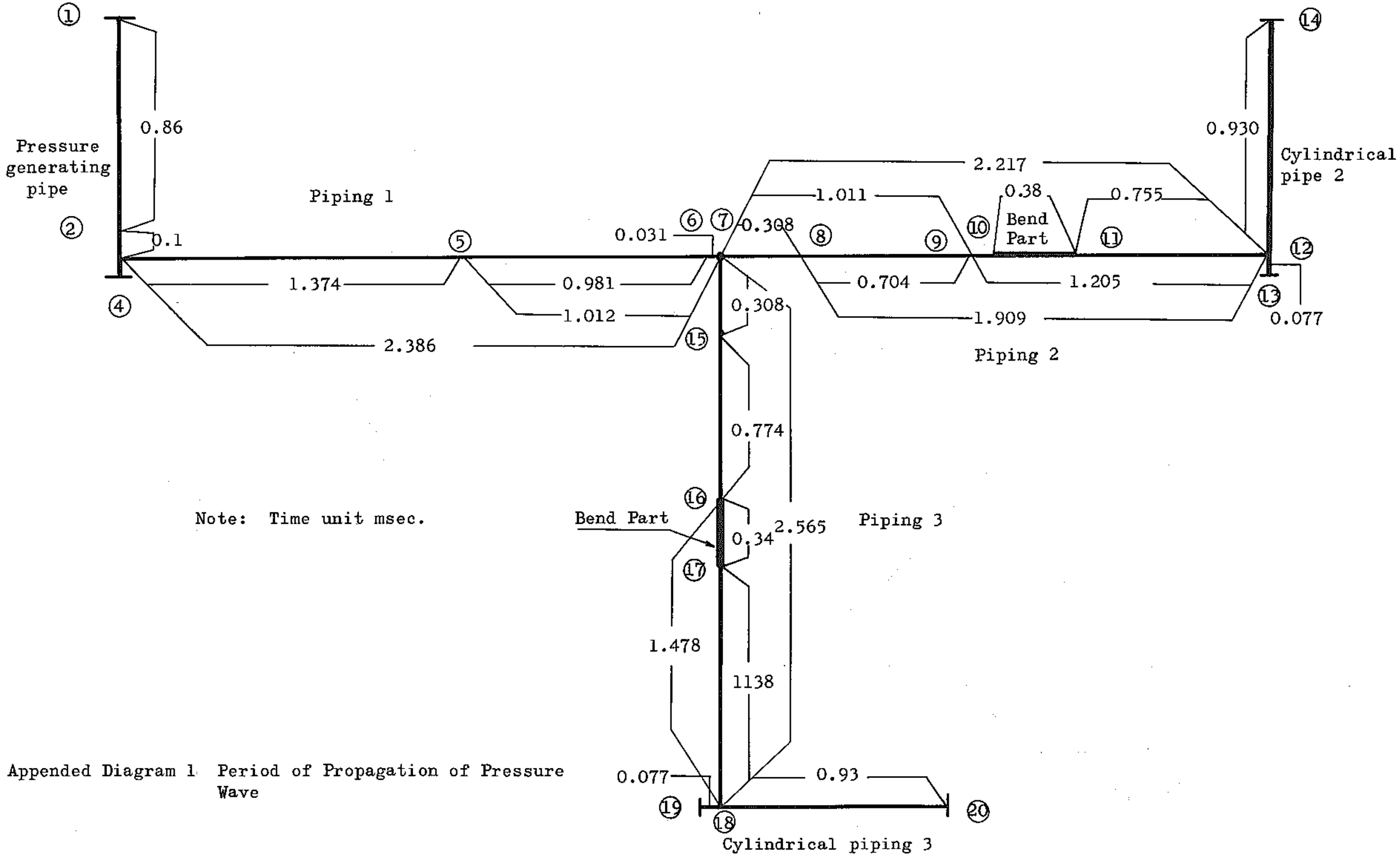
Appended Diagrams and Tables

List of Appended Diagrams

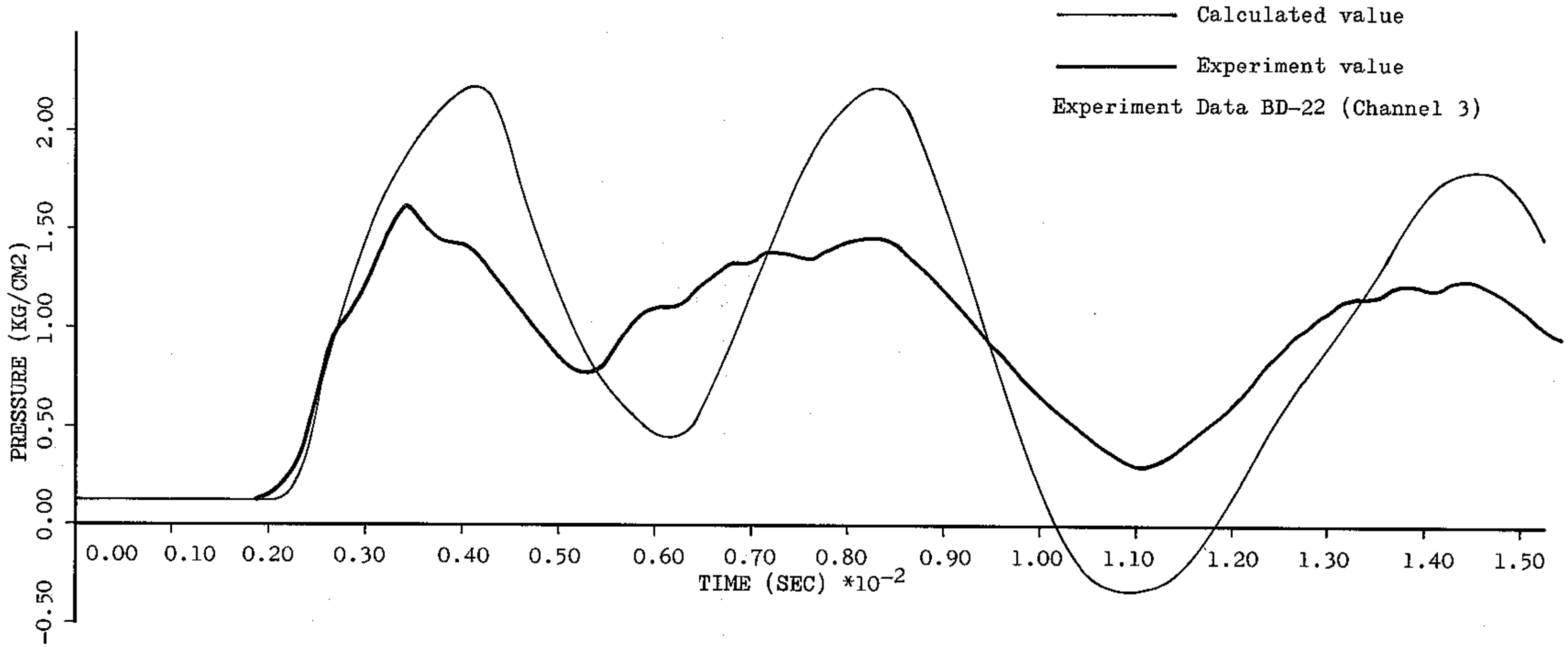
Diagram No.	Subject
1	Period of Propagation of pressure wave
2	Pressure at Joint 5 (Input of pressure source point)
3	Pressure at Joint 6 (- do -)
4	Pressure at Joint 8 (- do -)
5	Pressure at Joint 15 (- do -)
6	Experiment Data BD-22
7	Experiment Data BD-93
8	Experiment Data BD-16
9	Pressure at Joint 6 (Sonic velocity: 1302 m/s)
10	Pressure at Joint 8 (- do -)
11	Pressure at Joint 15 (- do -)
12	Pressure at Joint 8 (Effect of sonic velocity at bend)

List of Appended Tables

Table No.	Subject
1	Input Data for the Straight Pipe Calculation
2	Regarding Sonic Velocity
3	Experiment Data Scale

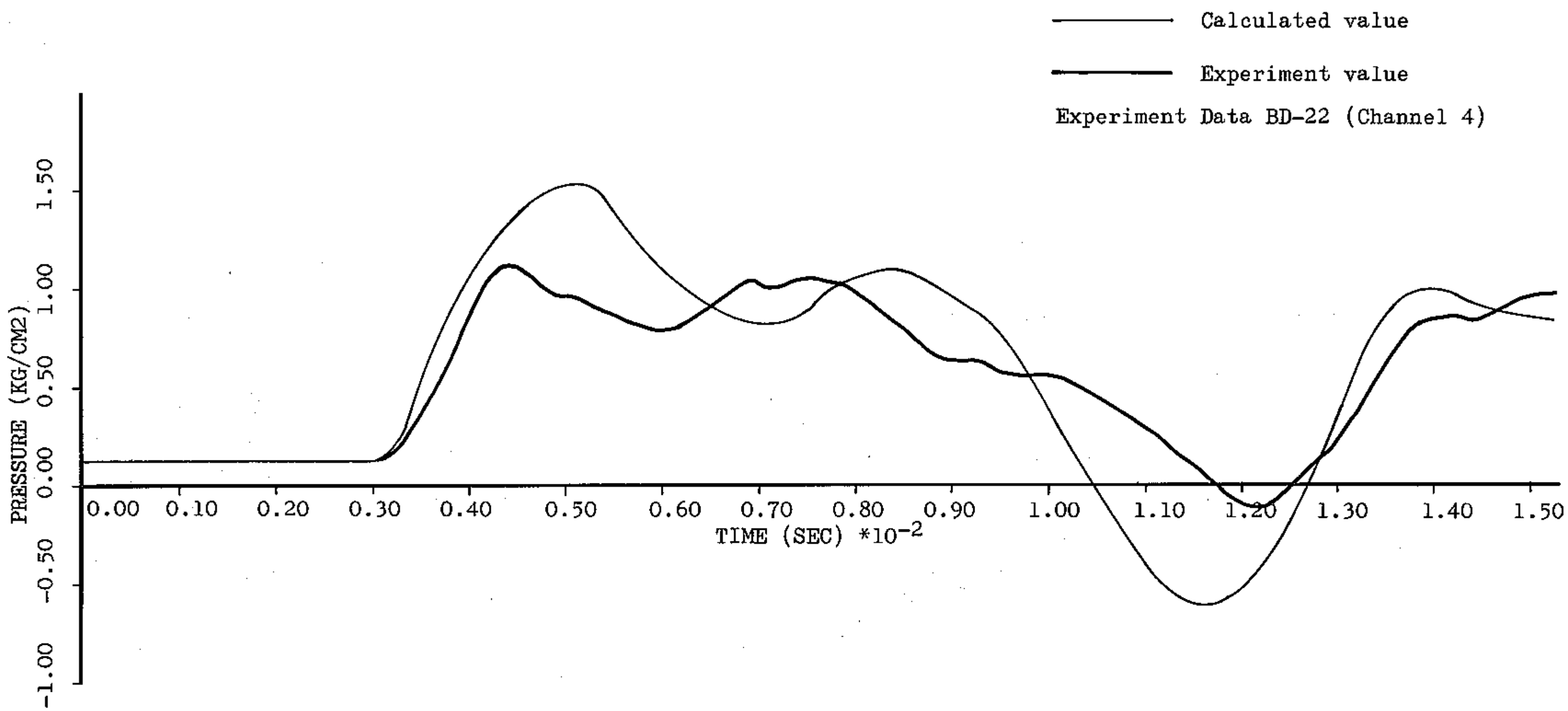


Appended Diagram 1 Period of Propagation of Pressure Wave



PRESSURE, LEFT OF MEMBER 5. Appended Diagram 2 Pressure Variation at Joint 5

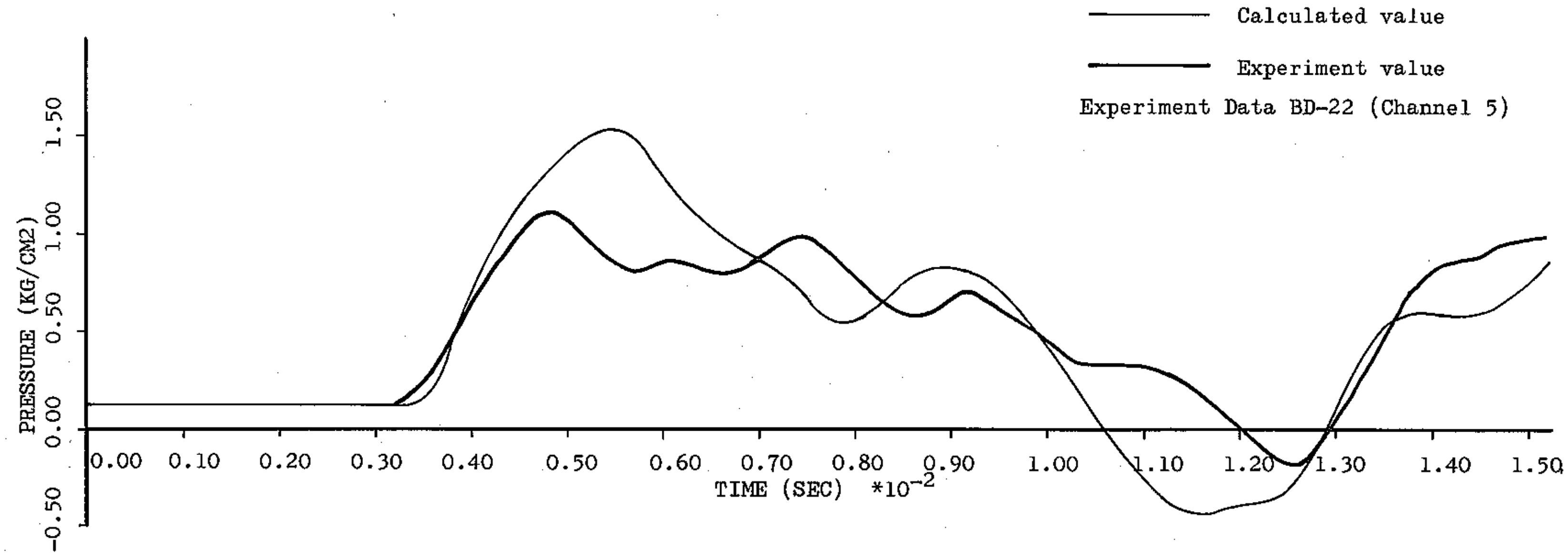
RESSURE-WAVE PROPAGATION INPUT JOINT 1 CASE 14



PRESSURE, LEFT OF MEMBER 6.

Appended Diagram 3 Pressure Variation at Joint 6

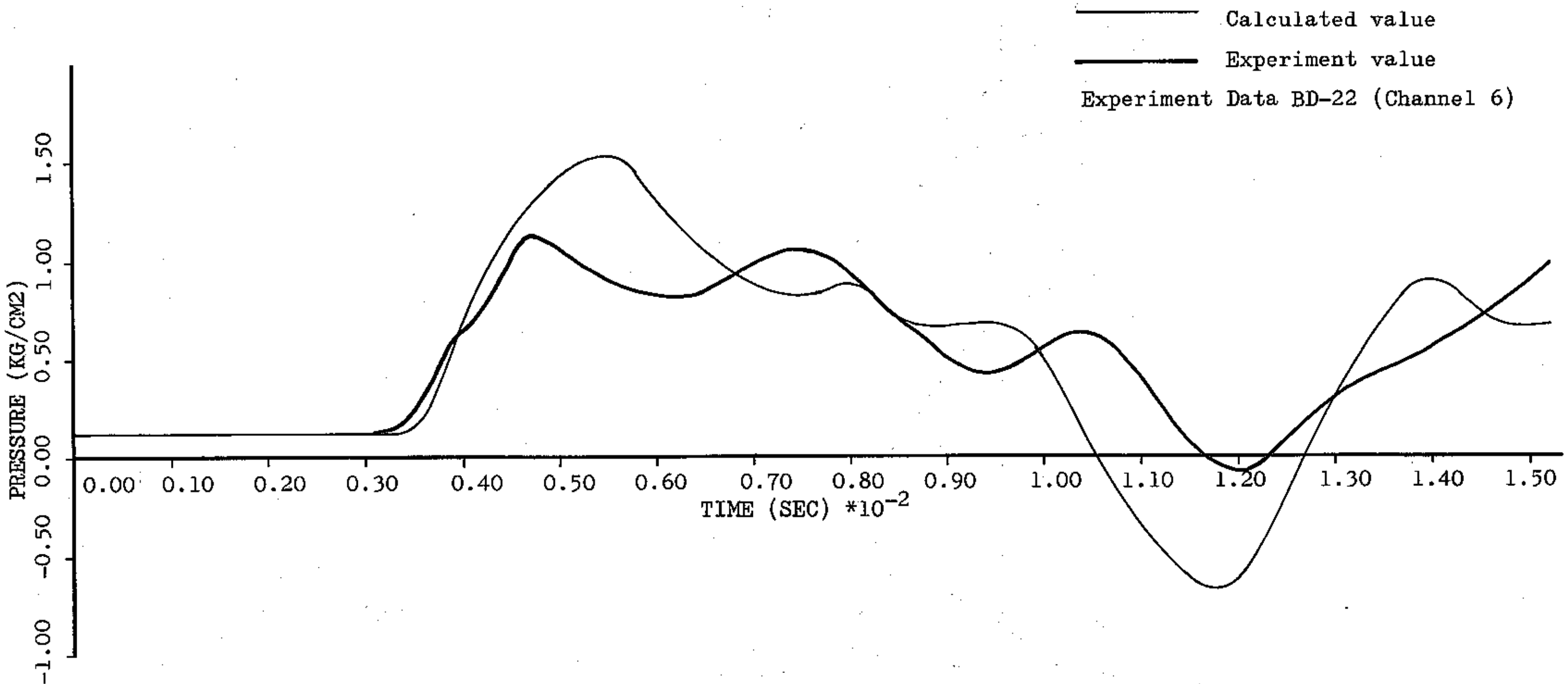
RESSURE-WAVE PROPAGATION INPUT JOINT 1 CASE 14



PRESSURE, LEFT OF MEMBER 8.

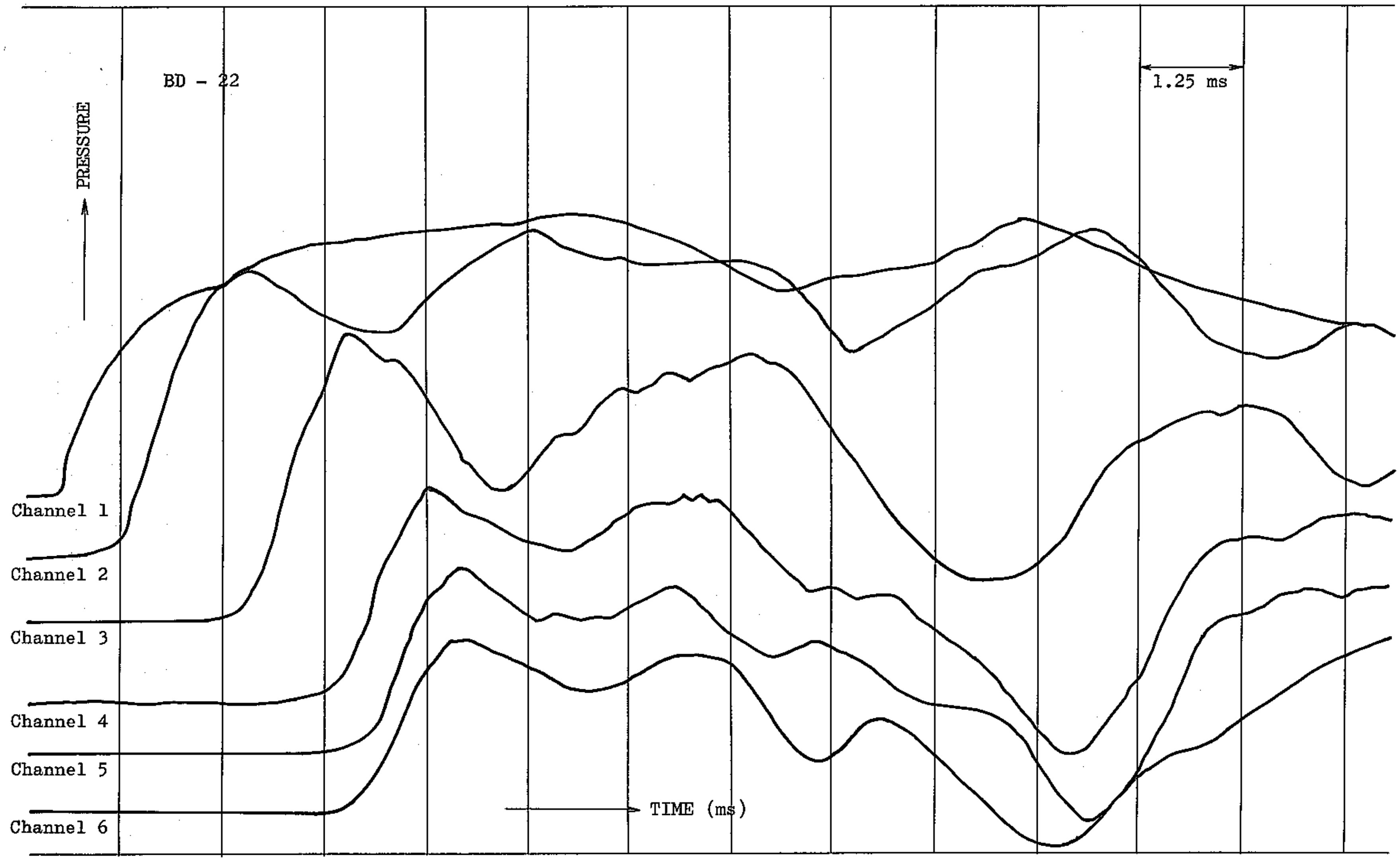
Appended Diagram 4 Pressure Variation at Joint 8

RESSURE-WAVE PROPAGATION INPUT JOINT 1 CAST 14

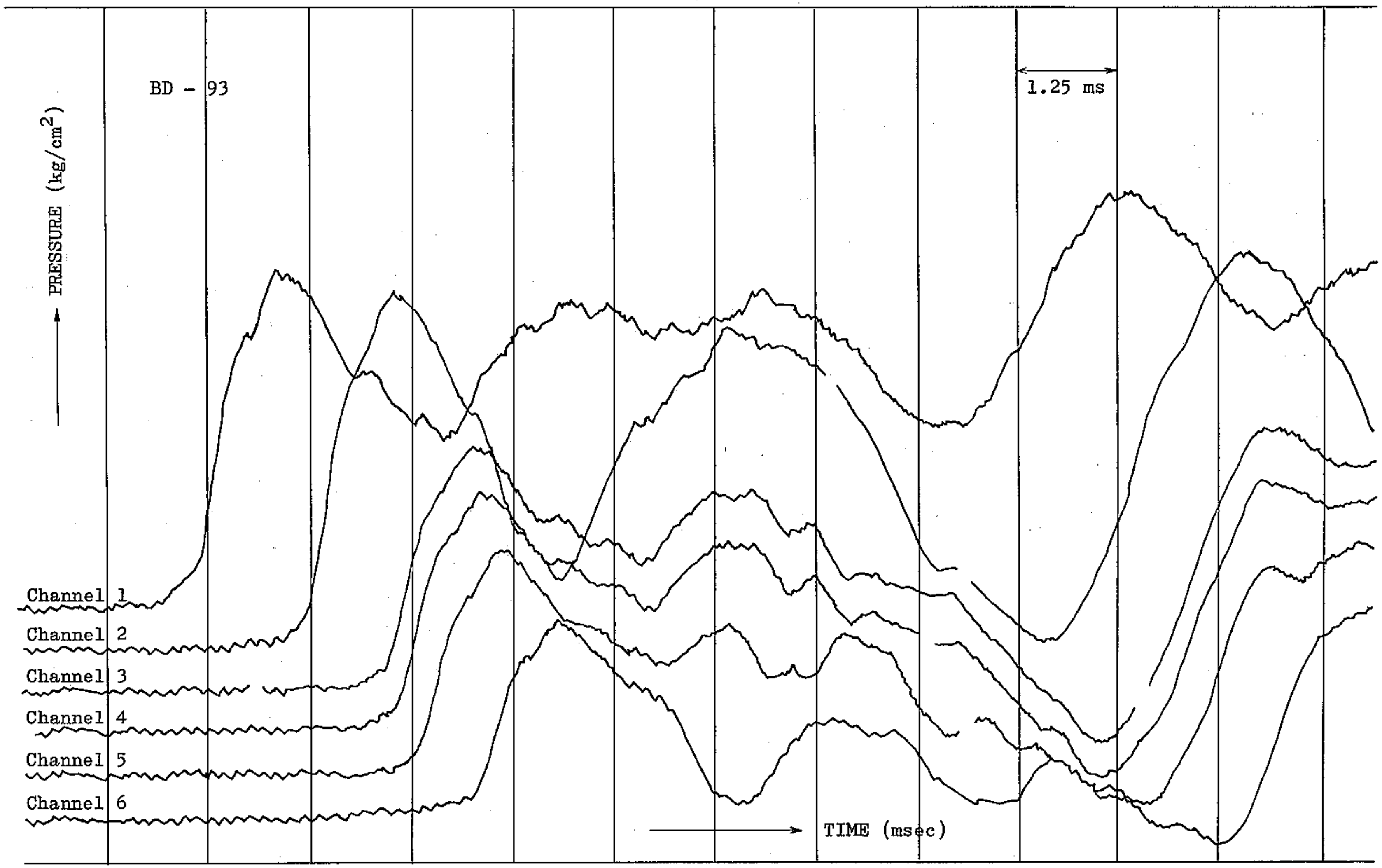


PRESSURE, LEFT OF MEMBER 15. Appended Diagram 5 Pressure Variation at Joint 15

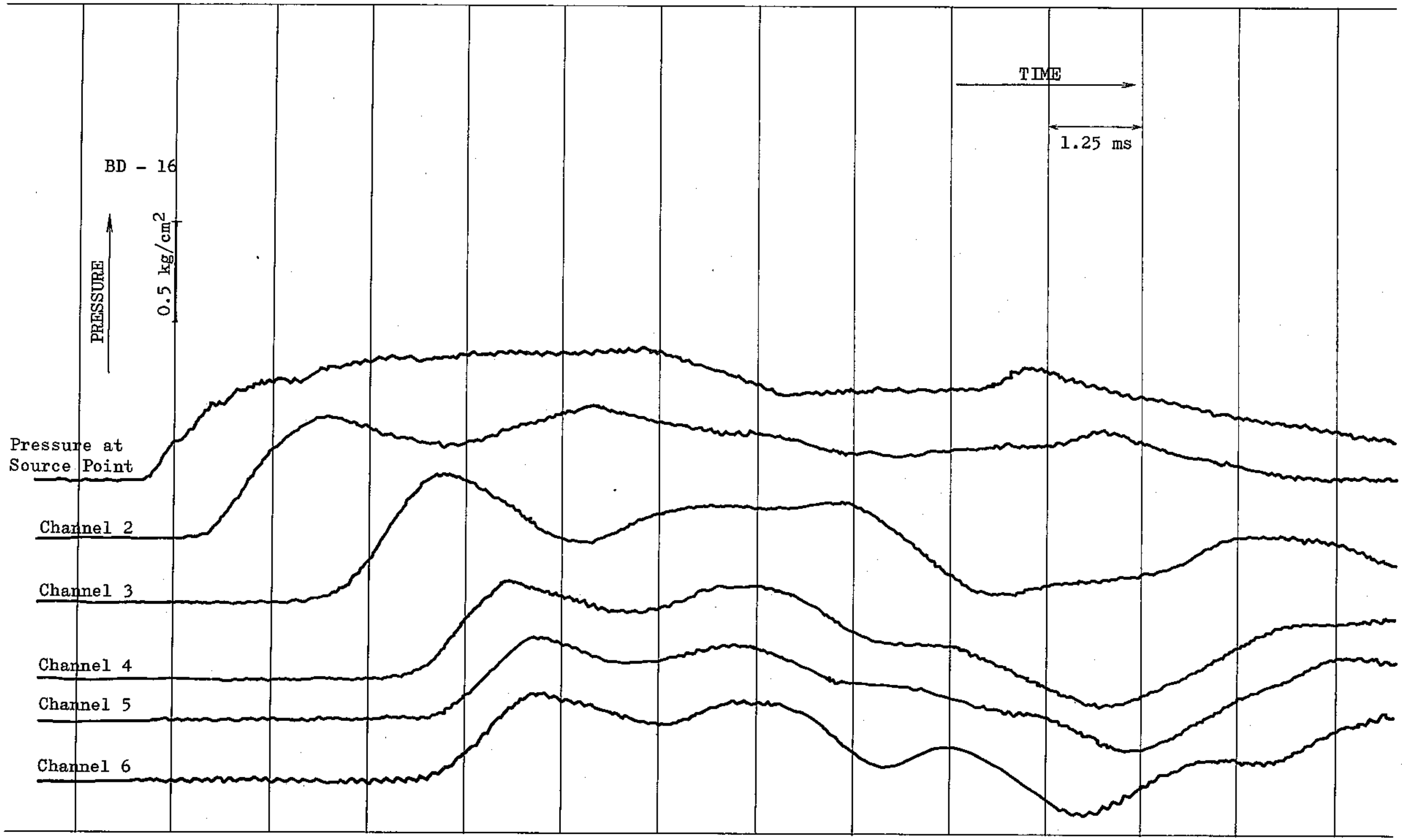
RESSURE-WAVE PROPAGATION INPUT JOINT 1 CASE 14



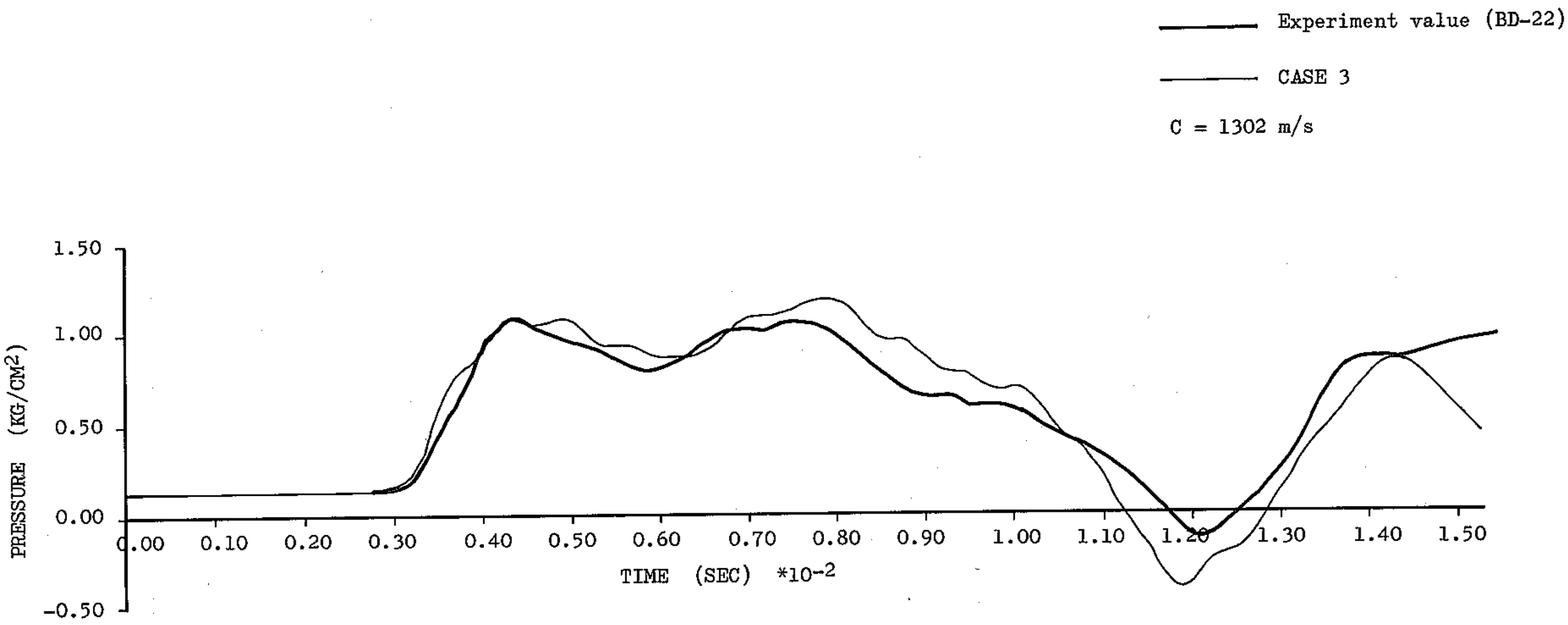
Appended Diagram 6 Experiment Data BD-22



Appended Diagram 7 Experiment Data BD-93



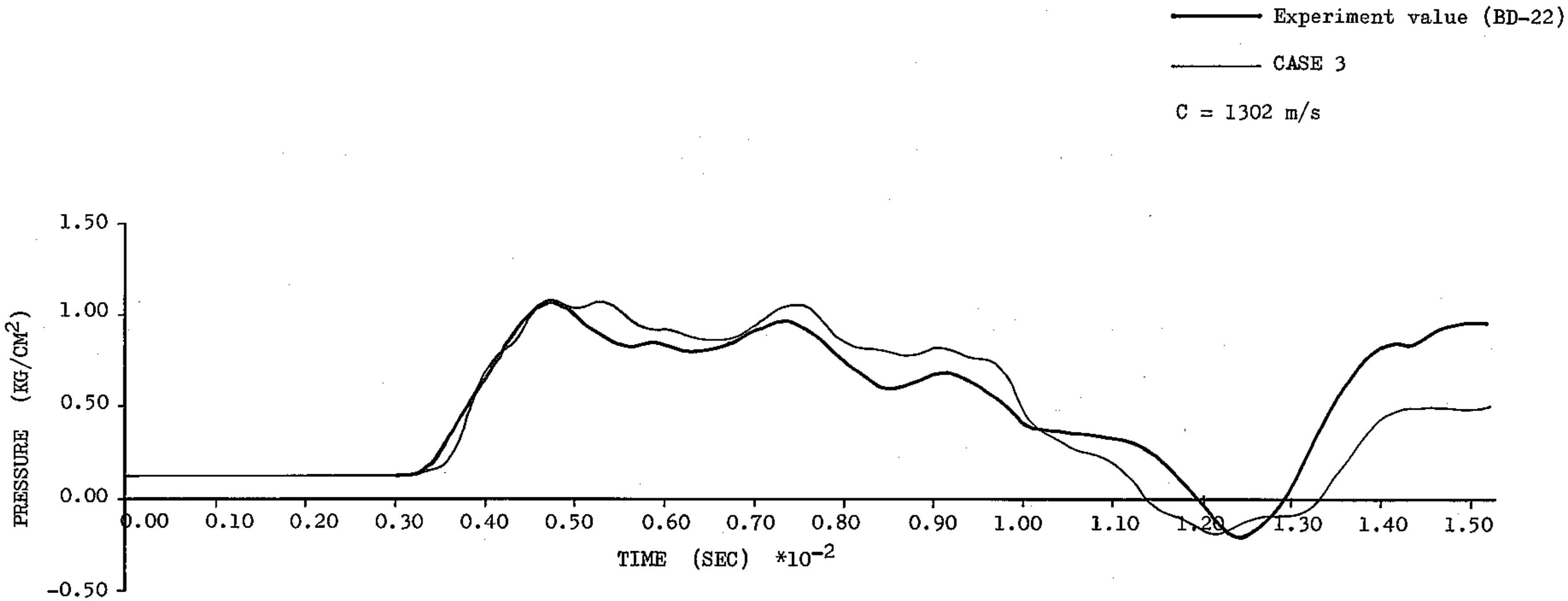
Appended Diagram 8 Experiment Data BD-16



PRESSURE. RIGHT OF MEMBER 6.

PRESSURE-WAVE PROPAGATION INPUT JOINT 2.

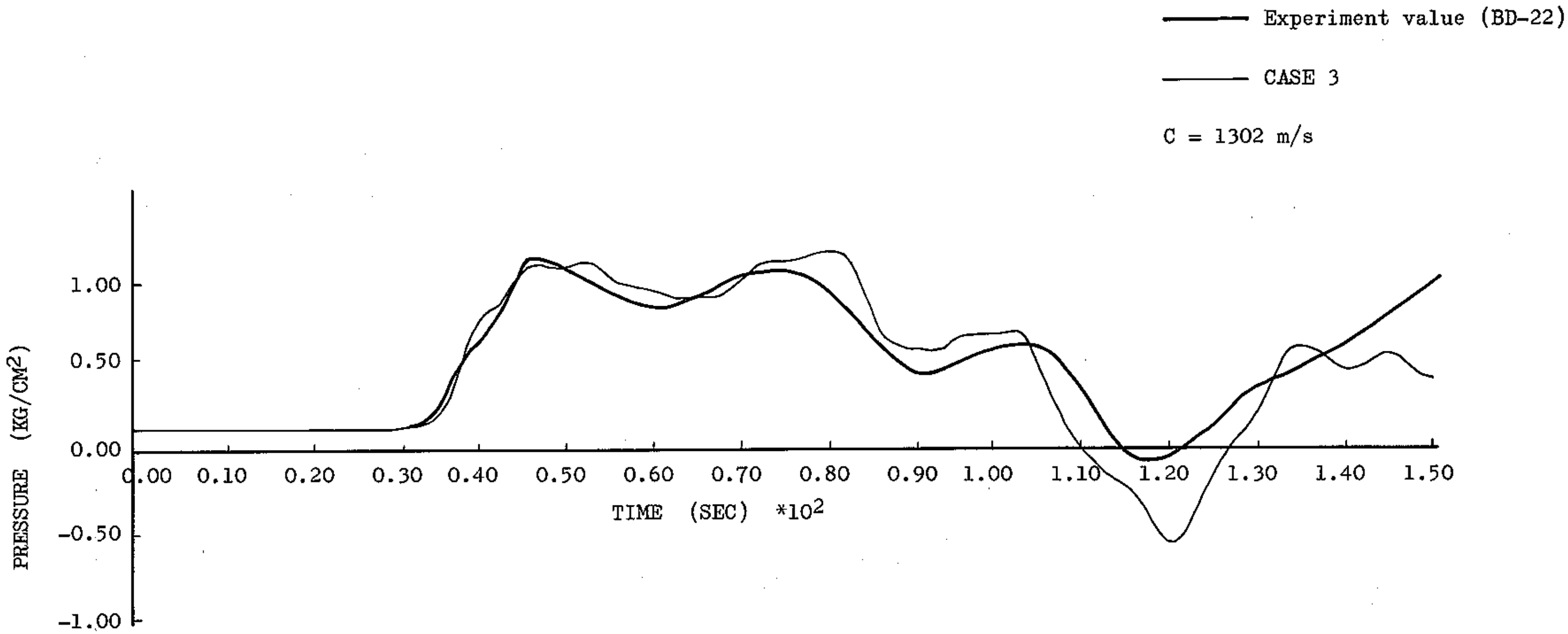
Appended Diagram 9 Pressure at Joint 6



PRESSURE. RIGHT OF MEMBER 8.

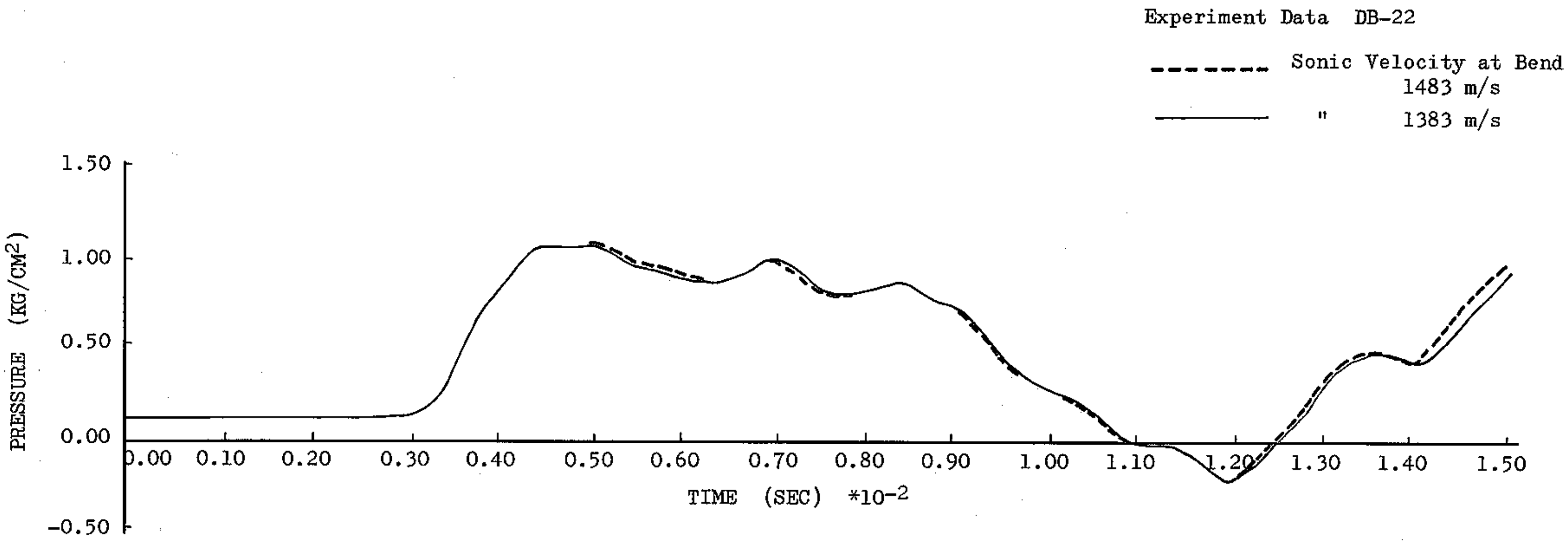
PRESSURE-WAVE PROPAGATION INPUT JOINT 2.

Appended Diagram 10 Pressure at Joint 8



PRESSURE. RIGHT OF MEMBER 12. Appended Diagram 11 Pressure at Joint 15

PRESSURE-WAVE PROPAGATION INPUT JOINT 2.



PRESSURE. LEFT OF MEMBER 8.

PRESSURE-WAVE PROPAGATION INPUT JOINT 2. CASE 11, 12

Appended Diagram 12 Effect of Sonic Velocity at Bend (Joint 8)

Appended Table 1   Input Data for the straight pipe calculation

Pressure Wave Source BD-93 Input Joint 8. Case 13

	1		3		1						
	2		2		1		1				
	22		1003		3004		3005				
	42		1002		2003		3004		3005		
	92		23		39		2		29		
	162		1								
	164		4								
	174		1000								
	175		0		1		1		150		2
	187		1								
	201		1								
	202		5								
	212		1								
	213		5								
	223		1								
	237		1		1						
	240		44								
1	1										
	1	0.974		1.678		0.10		1.25			
	51	1.383	+3	1.383	+3	1.343	+3	1.343	+3		
	101	1.42	-3	1.42	-3	5.16	-3	5.16	-3		
	151	0.042		0.042		0.0811		0.0811			
	202	1.0	+3	0.101	-5						
	250	1.25									
	255	0.3164		-0.25							
	307	0.		0.		0.		-0.1		1.25	
	369	8.0	-3								
	391	0.05									
	401	1.402									
	402	50.									
	426	0.0		2.5	-4	3.75	-4	6.25	-4	7.5	-4
	431	8.4375	-4	9.0625	-4	10.0	-4	10.9375	-4	13.125	-4
	436	14.0625	-4	15.0	-4	16.5625	-4	18.4375	-4	19.275	-4
	441	25.3125	-4	27.1875	-4	29.6875	-4	31.25	-4	33.125	-4
	446	34.0625	-4	36.5625	-4	38.75	-4	42.50	-4	43.75	-4
	451	45.625	-4	47.8125	-4	49.0625	-4	50.625	-4	52.50	-4
	456	53.75	-4	54.37	-4	56.25	-4	5.875	-3	6.0	-3
	461	6.156	-3	6.281	-3	6.562	-3	7.0	-3	7.25	-3
	466	7.375	-3	7.625	-3	7.812	-3	8.0	-3		
	476	0.125		0.1580		0.1589		0.2098		0.2947	
	481	0.4645		0.6342		0.8719		1.0756		1.3132	
	486	1.3132		1.4151		1.584		1.6188		1.5509	
	491	1.1435		1.10955		1.0756		1.0077		0.9398	
	596	0.95677		0.8549		0.8549		1.0416		1.0416	
	501	1.10955		1.0077		0.8549		0.75307		0.77005	
	506	0.8209		0.770		0.770		1.0077		1.0416	
	511	1.0077		0.9567		0.9058		0.4984		0.3626	
	516	0.3626		0.4645		0.4475		0.3117			
1	1										

Appended Table 2 Regarding Sonic Velocity

Equation for Claculation

$a = \sqrt{kg/\gamma} / \sqrt{1 + (K/E)\ D/S}$ (Alliévi)

Place	Sonic Velocity (m/s)
Cylindrical pipe at pressure source (I/D 106 mm dia.)	1302
Pressure propagation pipe (I/D 42.6 mm dia.)	1343
Cylindrical pipe at the end of piping (I/D 81 mm dia.)	1434

Where, $g = 9.81\ (m/S^2)$ $\gamma = 1000\ (kg/m^3)$

E = Modulus of longitudinal elasticity of piping wall $= 2.0 \times 10^{10}\ (kg/m^2)$

K = Bulk modulus of water = 2.279 (kg/m^2)
(Reactor Handbook Vol IV p.18 John Wiley & Sons 1964)

Comparative Table of Sonic Velocity of Water (Reference)

No.	Author	Experimental Formula	Sonic Velocity in Water at 25.6°C
1	Allievi	$\sqrt{kg/\gamma}$	1496.8
2	Greenspan-Tshiegg	$1402.736 + 5.03358T - 0.0579T^2 + 3.3163 \times 10^{-4}T^3 - 1.45262 \times 10^{-6}T^4 + 3.0449 \times 10^{-9}T^5$	1499.2
3	McConnel-Mruk	$1554 - 0.0305\ (68.4 - T)^2 + 10^{-4}\ (T - 20) \times (T - 40) \times (T - 60)$	1498.4
4	Willard	$1557 - 0.0245\ (74 - T)^2$	1499.6
5	Randall	$1404.4 + 4.8215T - 0.047562T^2 + 0.0001354T^3$	1498.9

Appended Table 3 Scaling of the Experiment Data

Axis	Data Name	BD - 22		BD - 93		BD - 16	
	Channel No.	Joint No.	Pressure per mm	Joint No.	Pressure per mm	Joint No.	Pressure per mm
Ordinate (Pressure)	1 Channel	1	kg/cm^2 0.02779	-	kg/cm^2 0.03423	1	kg/cm^2 0.02399
	2 Channel	2	0.02588	5	0.03206	2	0.02547
	3 Channel	5	0.02637	6	0.03087	5	0.02544
	4 Channel	6	0.02359	-	0.03180	6	0.02215
	5 Channel	8	0.02678	8	0.03395	8	0.02557
	6 Channel	15	0.02944	9	0.03476	15	0.02511
Abscissa	Time Scales	0.625 msec/cm		0.625 msec/cm		0.625 msec/cm	

Table 2.1 Input Format of SWAC-5

I	Title Card		(10A8)
II	Integer Data		(i1, i11, 5i12)
	Address	Symbol	Description
	1	NS	Number of sections* ≦ 20
	2	NR (i=1, 20)	Number of members in each section (NS(i) 50)
	22	JS (i=1, 20)	Joint No. at both ends of each section (4 ~ 6 digits)
	42	JN (i=1, 50)	Joint No. at both ends of each member (4 ~ 6 digits) (Write in the direction of coordinate axis in series from Section 1.)
	92	NN (i=1, 50)	Number of divisions of each member ≦ 99 (Write in the same manner as JN(i).)
	144	MT	Number of surge tanks ≦ 5
	145	MR	Number of rupture discs ≦ 10
	146	JT (i=1, 5)	Joint No. of surge tank
	151	JR (i=1, 10)	Joint No. of rupture disc
	162	IC	= 0 Sonic velocity in each member is all same as RDATA (51). = 1 Sonic velocity in each member is all different.
	163	IV	= 0 V0 = 0
	164	JB (i=1, 10)	Joint No. of 1-branch boundary (Invariably the end of a section)
	174	NST	Number of time steps
	175	NOUT (i=1, 10)	= 0 OUTPUT Option = 1 Yes (Write) NOUT (1) Write P and V for each point. NOUT (2) Write P and V at both ends and at the place of maximum pressure of each member. NOUT (3) Output step (= 0; each time, = 1; every other time, = 2; every 2 times)