JAERI-M
83-020

PIPE RUPTURE TEST RESULTS; 6 IN. PIPE WHIP TEST UNDER BWR LOCA CONDITIONS —— OVERHANG LENGTH PARAMETER

February 1983

Ryoichi KURIHARA, Toshikazu YANO, Shuzo UEDA,
Toshikuni ISOZAKI, Noriyuki MIYAZAKI, Rokuro KATO
and Shohachiro MIYAZONO

日本原子力研究所
Japan Atomic Energy Research Institute

JAERI-M レポートは，日本原子力研究所が不定期に公刊している研究報告書です。
入手の問合わせは，日本原子力研究所技術情報部情報資料課（〒319-11茨城県那珂郡東海村）あて，お申しこしください。なお，このほかに財団法人原子力弘済会資料センター（〒319-11 茨城県那珂郡東海村日本原子力研究所内）で複写による実費頒布をおこなっております。

JAERI-M reports are issued irregularly.
Inquiries about availability of the reports should be addressed to Information Section, Division of Technical Information, Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken 319-11, Japan.

編集兼発行　日本原子力研究所
印　　刷　㈱高野高速印刷

Pipe Rupture Test Results; 6 in. Pipe Whip Test under BWR LOCA Conditions — Overhang Length Parameter

Ryoichi KURIHARA, Toshikazu YANO, Shuzo UEDA,
Toshikuni ISOZAKI, Noriyuki MIYAZAKI, Rokuro KATO
and Shohachiro MIYAZONO

Division of Nuclear Safety Research,
Tokai Research Establishment, JAERI

(Received January 27, 1983)

A series of pipe rupture tests has been performed in JAERI to demonstrate the safety of the primary coolant circuits in the event of pipe rupture, in nuclear power plants. The present report summarizes the results of 6 in. pipe whip tests (RUN 5605, 5606), under BWR LOCA conditions (285°C, 6.8 MPa), which were performed in August, 1981. The test pipe is made of Type 304 stainless steel and its outer diameter is 6 in. and its thickness is 11.1 mm. The restraints are made of Type 304 stainless steel and its diameter is 16.0 mm. Two restraints were set on the restraint support with clearance of 100 mm. Overhang length was varied as the parameter in these tests and was 300 mm or 700 mm.

The following results are obtained. (1) The deformations of a pipe and restraints are limited effectively by shorter overhang length of 300. However, they become larger when the overhang length is 700 mm, and the pipe deforms especially at the setting point of restraints. (2) Velocity at the free end of pipe becomes about 30 m/sec just after the break. However, velocity at the setting point of restraint becomes about only 4 m/sec just after the break. (3) It seems from the comparison between the 4 in. tests and 6 in. tests that the maximum restraint force of 6 in. tests is about two times as large as that of 4 in. tests.

Keywords: Pipe Whip, 6 In. Pipe, Restraint, Clearance, Overhang Length, BWR LOCA Condition, Rupture Disk

---

This work was performed under the contact between the Science and Technology Agency of Japan and JAERI to demonstrate the safety against pipe rupture of the primary coolant circuits in nuclear power plants.

配管破断試験：ＢＷＲ・ＬＯＣＡ条件6インチ口径パイプホイップ試験結果――オーバーハング長さの効果

日本原子力研究所東海研究所安全工学部
栗原 良一・矢野 歳和・植田 脩三・磯崎 敏邦
宮崎 則幸・加藤 六郎・宮園昭八郎

（１９８３年1月２７日受理）

軽水炉一次冷却系配管の瞬時破断に対する健全性を実証するために，日本原子力研究所では一連の配管破断試験が実施されている。本報は昭和５６年８月に実施したＢＷＲ・ＬＯＣＡ条件（２８５℃，6.8 MPa ）下の６インチ口径パイプホイップ試験（ＲＵＮ　５６０５，５６０６）の結果をまとめたものである。配管試験体はＳＵＳ ３０４ステンレス鋼製６Ｂ，sch ８０ の配管から製作した。レストレントはＳＵＳ ３０４ステンレス鋼製１６mm径を２本使用し，クリアランスを１００mmで一定にして，オーバーハング長さを３００mmと７００mmに変えた。

試験から次の結果を得た。

(1) オーバーハング長さを３００mmにした場合，配管試験体およびレストレントの変形は有効に抑制される。

(2) 配管先端の速度は破断直後約３０ｍ／secであり，レストレント設置点における配管の速度は破断直後約４ｍ／secである。

(3) 前報の４インチ口径パイプホイップ試験結果と比較して，レストレント反力は約２倍になる。

本報は電源開発促進対策特別会計施行令に基づき，科学技術庁から日本原子力研究所への委託研究，配管信頼性実証試験の内，配管破断試験；BWR・ＬＯＣＡ条件６インチ口径パイプホイップ試験結果をまとめたものである。

目　　次

CONTENTS

1. INTRODUCTION

Pipe rupture tests[(1)] have been performed using FRPC-II* in JAERI to demonstrate the safety against pipe rupture of the primary coolant circuits in nuclear power plants. Pipe whip tests are part of pipe rupture tests, and have been performed under BWR (285°C, 6.8 MPa) or PWR (320°C, 15.6 MPa) LOCA conditions using test pipes of diameter in 4, 6 and 8 in. 4 in. pipe whip tests under BWR and PWR LOCA conditions[(2),(3)] had been performed already, and we obtained some results.

The present report summarizes the results of 6 in. pipe whip tests (RUN 5605, 5606), under BWR LOCA conditions, which were performed in August, 1981. Clearance is the distance between a pipe and restraints, and is kept constant at the value of 100 mm in these tests. Overhang length is the distance from a setting point of the restraints to the free end of the pipe, and varies from 300 mm to 700 mm in both tests.

---

* FRPC-II: Facilities for Reliability Study of Pressure Boundary Components-II

2. TEST PROCEDURE

2.1 Test Condition

The profile of the testing system is shown in Fig. 2.1. Test pit and plant room are divided by a wall. An auxiliary connecting pipe which reduces the diameter of the 8 in. nozzle to the diameter of the 4 in. test pipe is attached to the nozzle of the pressure vessel. An electric heater and a pressure vessel are used to heat up a water to BWR LOCA conditions, which are kept constant in a system by a circulating pump. The water level is set at the height in 4 m from the bottom of the pressure vessel just before the blowdown. A pressurizer is used to the tests under only PWR LOCA conditions, and is nothing but a storing place of steam.

The test equipment is shown in Fig. 2.2. The test pipe is connected to the auxiliary connecting pipe and is 4500 mm in length and is fixed by the pipe support so that the length of the test section is 3000 mm. A tracing plate is set next to the test pipe to trace the loci of whipping pipe. We attached to the test pipe high temperature strain gages, pressure transducers, thermocouples, displacement meters and accelometers.

Test conditions are summarized in Table 2.1. Two runs of test were performed under BWR LOCA conditions, varying overhang length from 300 mm to 700 mm. The test pipe was made of Type 304 stainless steel, and its outer diameter was 165.2 mm and its thickness was 11.0 mm. The restraints were made of Type 304 stainless steel, and its diameter was 16.0 mm. Two restraints were set on the restraint support with clearance of 100 mm.

The chemical composition and mechanical properties of a pipe and restraints are summarized in Table 2.2. The view of the test system before the test in RUN 5606 is shown in Photo. 1. Hot water is circulated through the warming-up line which is attached to the free end of the test pipe to keep the temperature of the test system uniform. A flexible tube is used as a part of the warming-up line to reduce its restriction to pipe whip motion.

2.2 Test Equipment

The configuration of the welded type of rupture disk is shown in Fig. 2.3. This rupture disk is butt-welded at the tip of the test pipe.

This assembly was developed especially for the pipe whip test. A rupture disk was placed and welded between two segments of pipes. The weight of this assembly is lighter than a flange jointed type of rupture disk. Instantaneous pipe rupture is simulated by breaking this rupture disk using the electric arc method. The short nozzle for the warming up line and the seat for the pressure transducer are attached to the pipe end.

The details of the restraint are shown in Fig. 2.4. The restraint is composed of a U-bar, bearing plate, clevis, bracket and pin. The clevis is screwed to the end of the U-bar and is used for fine adjustment of clearance. The bearing plate made of carbon steel is attached to the inner side of the circular part of the U-bar. The purpose of this plate is to wrap around the test pipe to mininize pipe rebounds. Restraint assemblies are pinned to the bracket which is set on the restraint support.

2.3 Measuring Items and Devices

The locations of measuring devices on the test pipe are shown in fig. 2.5. High temperature strain gages (XU 111 ∿ XU 122) were used and attached to the surface of the pipe by welding. Displacement meter of XU 201 was the eddy current type and measured the transient displacement of the whipping pipe. The accelerometers of XU 301 and XU 302 were piezo type and attached to the locations shown in fig. 2.5.

The locations of strain gages attached to the restraints are shown in Fig. 2.6. These strain gages were ordinary ones used at room temperature. The strain gages attached to the clevises of restraint were utilized to measure the restraint force.

Measuring items for each test are summarized in Table 2.3.1 and Table 2.3.2. The symbols XU, PU, WU and TU are mainly the strain gages, pressure transducers, load cells and thermocouples, respectively. The symbols L, M and H in the columns of Record Device mean that the outputs were amplified through the low, middle and high speed type of dynamic strain amplifier. The symbol ON means that the amplified outputs were recorded into the disk of the computer in on-line mode, and no symbol means that the outputs were recorded into the analog data recorder.

Table 2.1 Test Condition

Run Number		5605	5606
Test Number		6BW1	6BW2
Date		'81.7.27	'81.8.6
Pressure (MPa)		6.76	6.76
Temperature (℃)	Vessel	284.7	284.7
	Test Section	283.5	282.9
Diameter of Test Pipe		6B, sch 80	
Length of Test Section		3000 mm	
Restraint	Type	U – bar	
	Overhang (mm)	300	700
	Clearance (mm)	100	
	Diameter (mm)	16	
	Number	2	

Table 2.2 Chemical Composition and Mechanical Properties

(a) Test Pipe (Room Temperature)

%

C	Si	Mn	P	S	Ni	Cr
0.05	0.47	1.50	0.029	0.005	9.30	18.40

Yield Strength	Tensile Strength	Elongation
264.6MPa	597.8MPa	66%

(b) Restraint (Room Temperature)

%

C	Si	Mn	P	S	Ni	Cr
0.04	0.46	0.89	0.032	0.025	8.10	18.30

Yield Strength	Tensile Strength	Elongation
287.1MPa	649.7MPa	61.8%

Table 2.3.1 List of Measuring Items

TAG No.	LOCATION	SPECIFICATION	MANUFACTURER TYPE	RECORD DEVICE	
XU111				DR	M
112				↑	L
113		HIGH TEMP			L
114		SPOT WELDED			L
115	PIPE	PLASTIC	AILTECH		L
116	SEE FIG. 2.5	STRAIN GAGE	SG-125-01F(4)		L
117			-4-304SS		M
118					M
119					M
120					M
121					M
122				↓	M
126			BLH	DR	M
XU131				DR	M
132				↑	M
133					M
134					M
135					M
136	RESTRAINT No.1	PLASTIC	TOKYO SOKKI		M
137		STRAIN GAGE	YL-5		M
138	SEE FIG. 2.6				M
139					M
140					M
141					M
142				↓	M
143				DR	L
XU151				DR	M
152				↑	M
153					M
154					M
155					M
156	RESTRAINT No.2	PLASTIC	TOKYO SOKKI		M
157		STRAIN GAGE	YL-5		M
158	SEE FIG. 2.6				M
159					M
160					M
161					M
162				↓	M
163				DR	L
WU131				DR	M
132	CLEVIS	ELASTIC	KYOWA	↑	M
151	SEE FIG. 2.6	STRAIN GAGE	KFD-2-D16-11Z	↓	M
152			-100-3	DR	M

Table 2.3.2 List of Measuring Items

TAG No.	LOCATION	SPECIFICATION	MANUFACTURER TYPE	RECORD DIVICE	
PU101	SEE FIG. 2.1	PRESSURE STRAIN GAGE TYPE	BLH GP－H	ON	H
103				ON	H
105				ON	H
111			SHINKO－K	ON	H
112				ON	H
113				ON	H
114				ON	H
115				ON	H
116			TOYOTA PMS－10K TMN	ON	S
TU101	SEE FIG. 2.1	TEMPERATURE C－A SHEATH TYPE	OKAZAKI T－35	ON	B
102				ON	↑
104				ON	│
130			SUKEGAWA	ON	│
131				ON	│
132				ON	↓
133				ON	B
XU200	SEE FIG. 2.5	DISPLACEMENT	KYOWA, INDUCTANCE	DR	M
201			KAMAN, EDDY	DR	
202			TOKYO SOKKI, DIAL	XY	L
203				XY	L
XU301	SEE FIG. 2.5	ACCELERATION PIEZO ELECTRIC	ENDEVCO 2273A	DR	C
302				DR	C
XU401	SEE FIG. 2.2	BUBBLE METER		DR	
402		VELOCITY		DR	
WU101	SEE FIG. 2.1	LOAD CELL	BLH T2G－1	DR	M
115		WATER LEVEL	FUJI FEC－3－4－N3－1	DR	

H : High Freq. Amp. (50 KHz) ………… SHINKO DA－4007－F
M : Medium Freq. Amp. (10 KHz) ………… SHINKO DA－4006－F
L : Low Freq. Amp. (2 KHz) ………… SHINKO DA－6005－F
B : DC Amp. ………… BLH BLH－5300
C : Charge Amp. ………… ENDEVCO MODEL 2735
S : Multi Purpose Amp. (20KHz) ………… SAN－EI 6M72V
PR : Analog Data Recorder ………… AMPEX PR－2200
ON : Temporally Digital Memory
XY : XY－Recorder

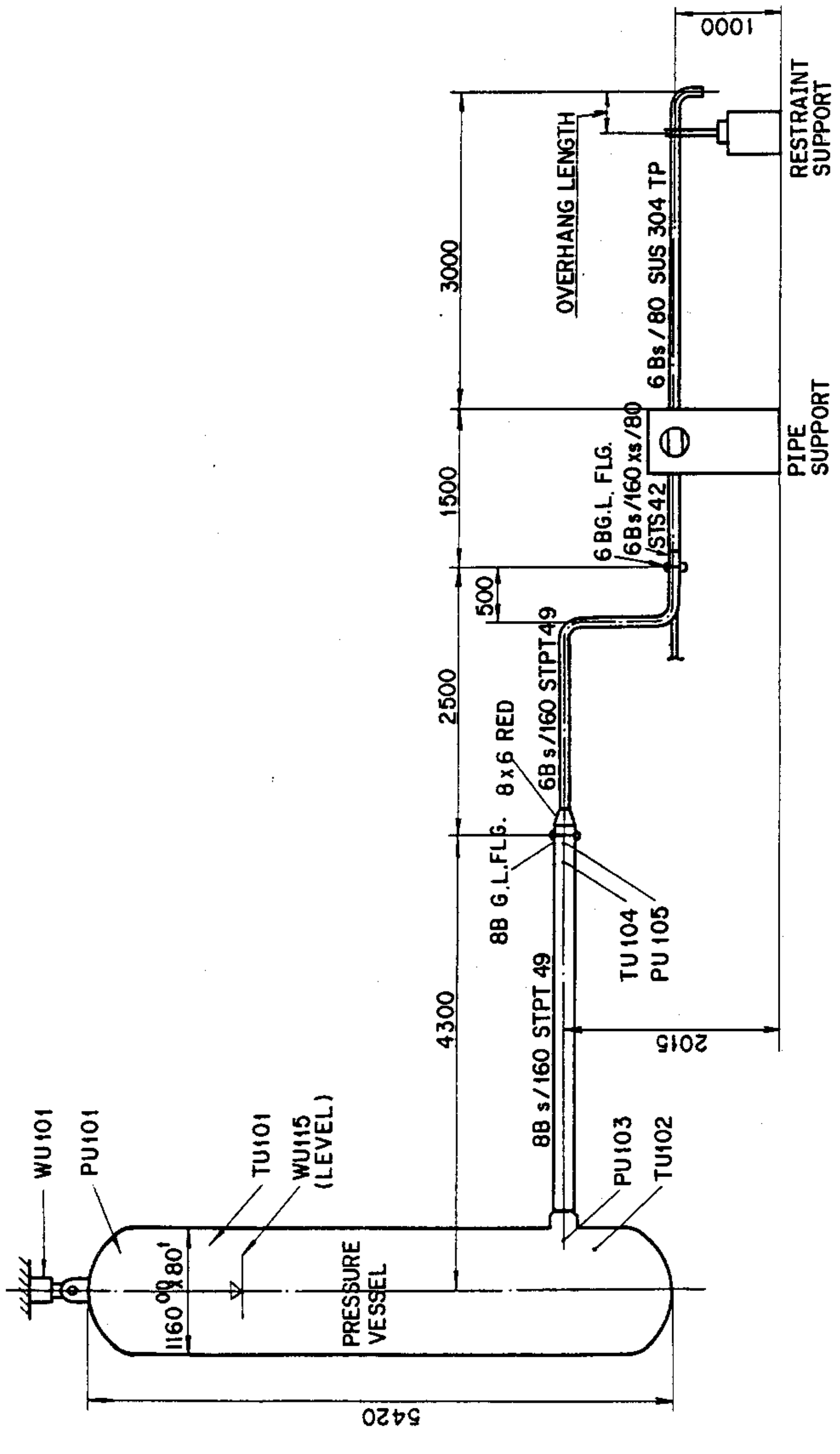


Fig.2.1 Pipe Line Layout of Pipe Whip Test

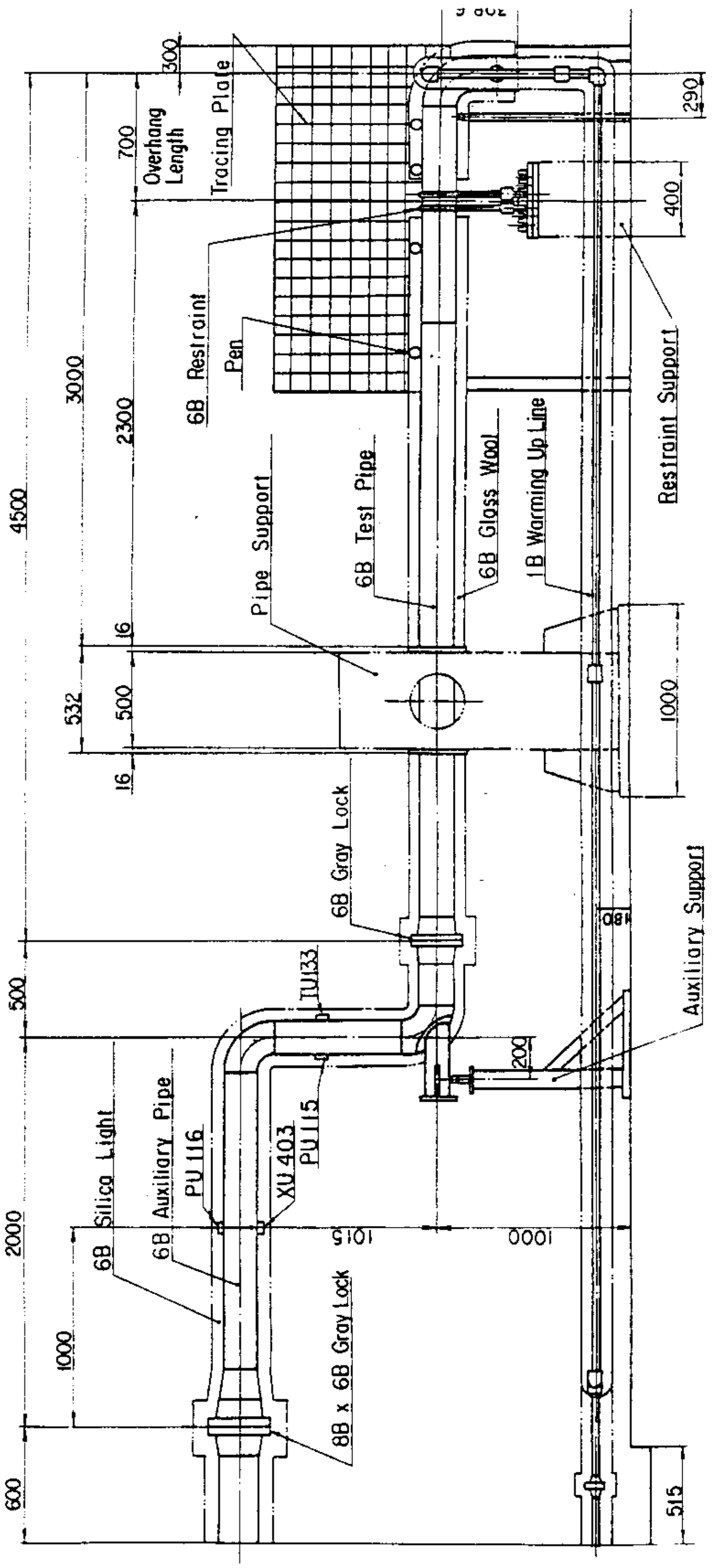


Fig.2.2 Arrangement of Test Section

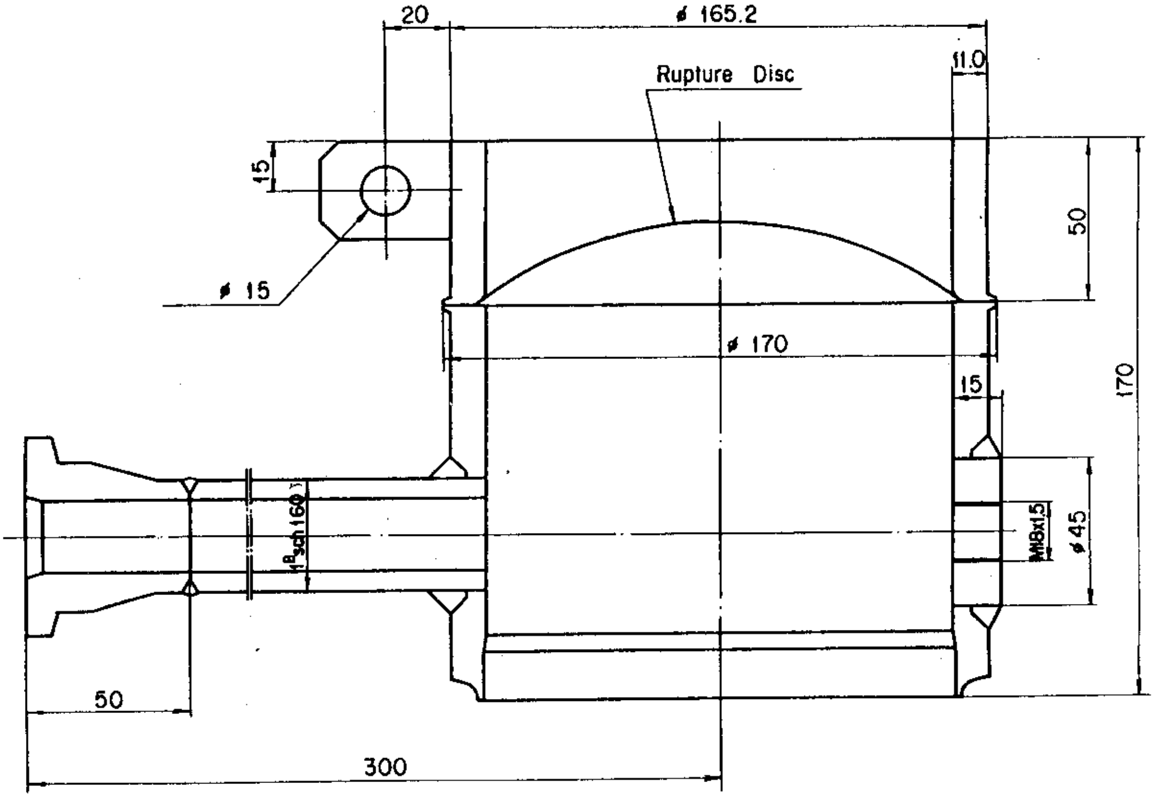


Fig.2.3 Details of Pipe End

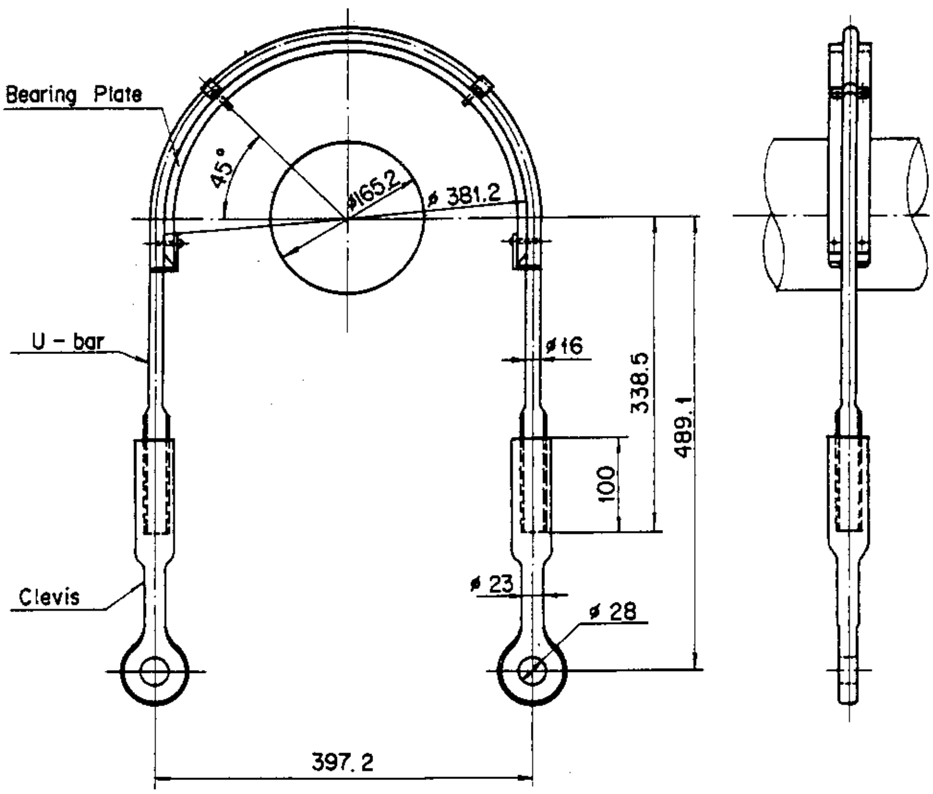
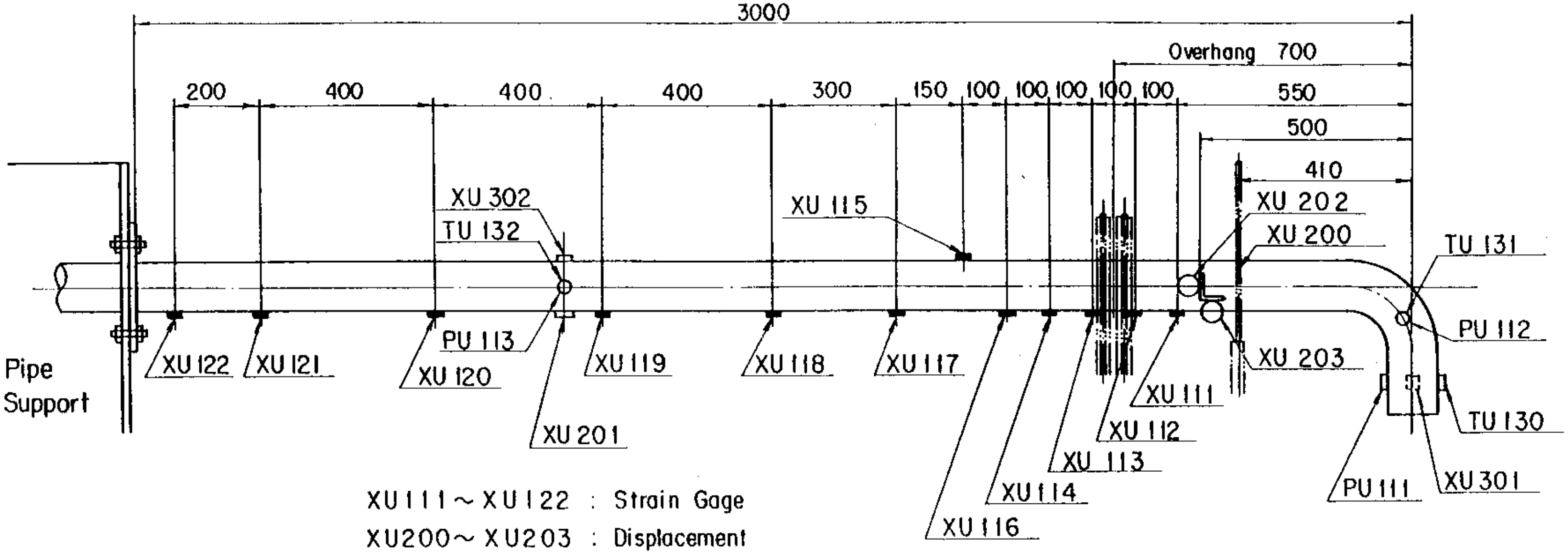
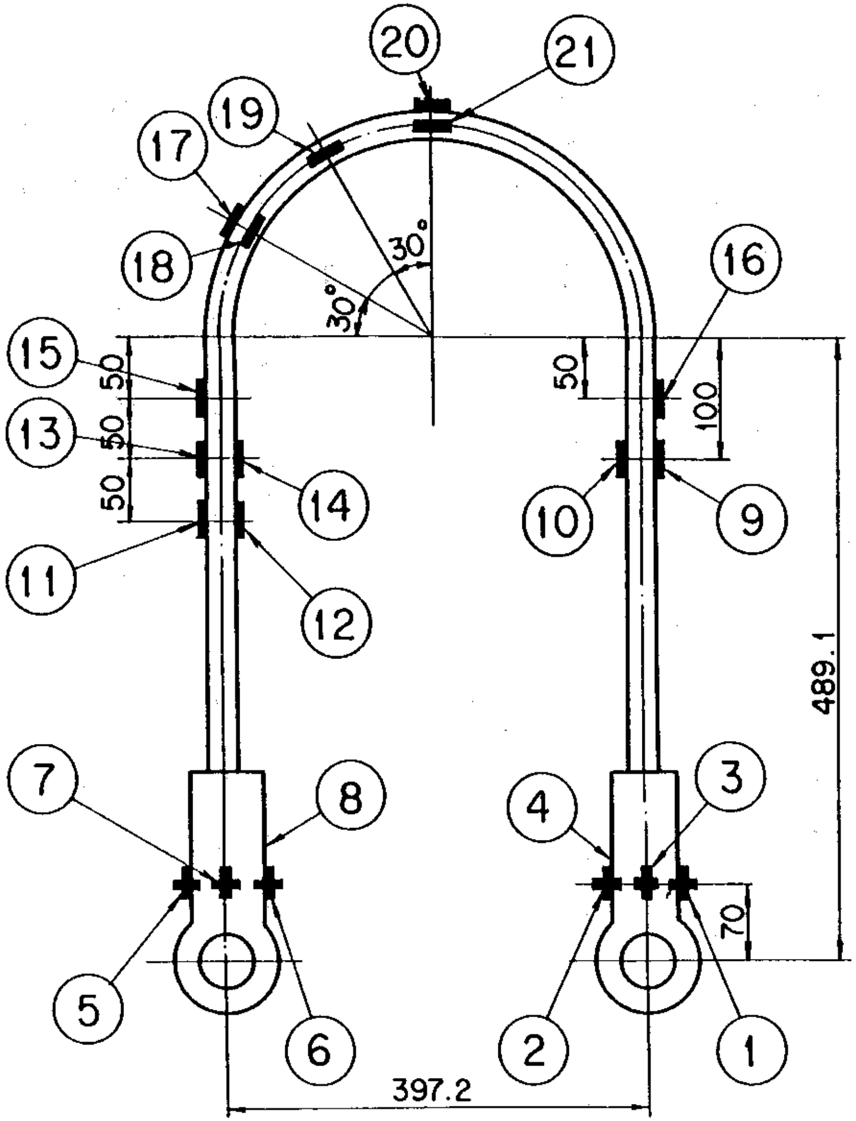


Fig.2.4 Details of Restraint



XU111 ～ XU122 : Strain Gage
XU200 ～ XU203 : Displacement
XU301 ～ XU302 : Accelerometer
PU111 ～ PU113 : Pressure Transducer
TU130 ～ TU132 : Thermocouple

Fig.2.5 Location of Detectors attached to Pipe



	Tag Number	
	Restraint 1	Restraint 2
1 ~ 4	WU 131	WU 151
5 ~ 8	WU 132	WU 152
9	XU 131	XU 151
10	XU 132	XU 152
11	XU 133	XU 153
12	XU 134	XU 154
13	XU 135	XU 155
14	XU 136	XU 156
15	XU 137	XU 157
16	XU 138	XU 158
17	XU 139	XU 159
18	XU 140	XU 160
19	XU 141	XU 161
20	XU 143	XU 163
21	XU 142	XU 162

Fig.2.6 Location of Detectors attached to Restraint

3. TEST RESULTS

3.1 Electrical Measurement

The results of electrical measurement, that is to say, pressure, temperature, strain, acceleration and load etc. were obtained according to Table 2.3.1 and Table 2.3.2. These results will be shown in the next chapter 4.

3.2 Residual Deformation Measurement

(1) Residual strains of the test pipe

Results in RUN 5606 are summarized in Table 3.1 and their distribution along pipe axis are shown in Fig. 3.1.

(2) Measurement of outerdiameter of the test pipe

Results in RUN 5606 are summarized in Table 3.2 and their distributions along pipe axis are shown in Fig. 3.2.

(3) Residual deformations of the test pipe

Results in RUN 5606 are summarized in Table 3.3 and their distributions along pipe axis are shown in Fig. 3.3. Peak deformations are also shown in Fig. 3.3, which are obtained from the loci on the board set next to the test pipe.

(4) Residual strains of restraints

Results in RUN 5606 are summarized in Table 3.4 and their distributions are shown in Fig. 3.4. The measuring results of outputs of strain gages before and after the tests are summarized in Table 3.5.

3.3 Observation of Pipe Whip Phenomenon by High Speed Camera

Photographs taken by the high speed camera are shown in Photo. 3. Only local views near restraints in RUN 5606 could be observed in the tests. Frame intervals is 2.5 msec/frame.

Restraints slided along the pipe axis after the impact between the pipe and the restraints, and it seemed to increase the upward movement of the test pipe. View of the test system after the test in RUN 5606 is shown in Photo. 2.

3.4 Photographs after Tests

Photographs of the situations before and after the test in RUN 5606 are comparatively shown as follows.

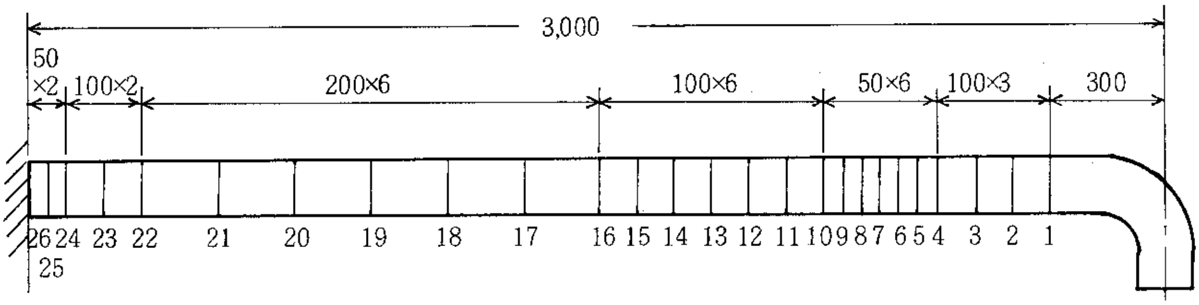
Front views of the test system before and after the test are shown in Photos. 4 and 5.

Side views of the pipe and restraints before and after the test are shown in Photos. 6 and 7.

Deformations of the pipe and restraints at the setting point of restraints are shown in Photos. 8 and 9.

Front and side views of the restraints before and after the test in RUN 5606 are shown in Photos. 10 to 13.

Table 3.1 Results of Dimensional Measurements of Test Pipe along Axis

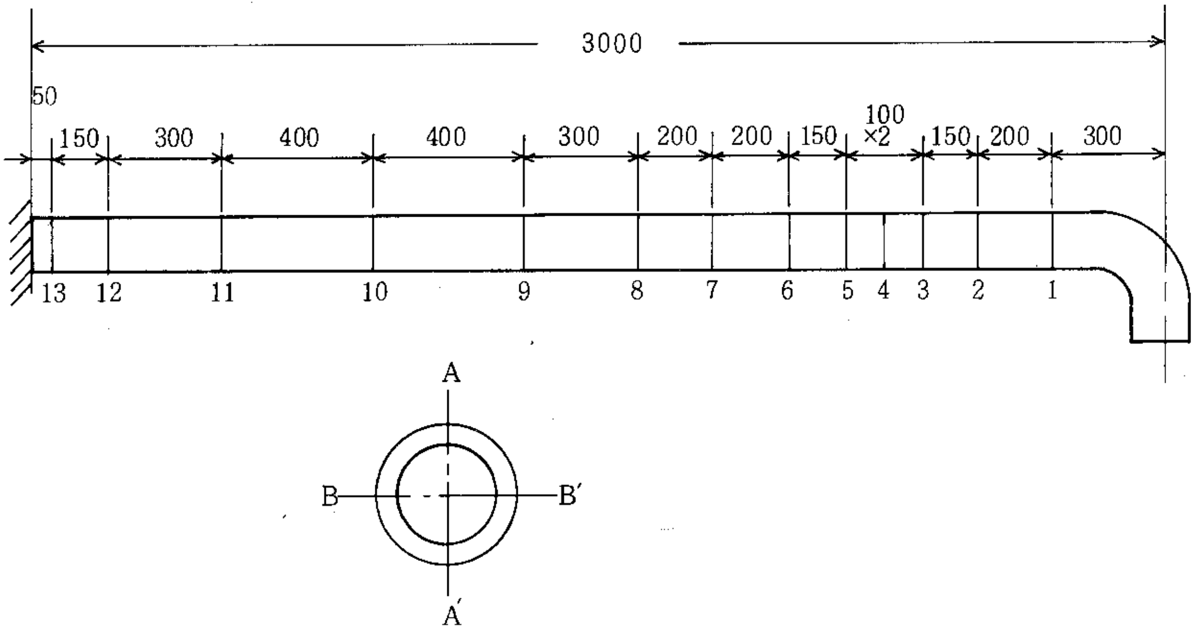


		1−2	2−3	3−4	4−5	5−6	6−7	7−8	8−9	9−10
Upper Side	Elongation	−0.10	0.35	−1.25	−2.05	−3.15	−4.10	−4.65	−4.20	−4.95
	Strain	−0.10	0.35	−1.25	−4.08	−6.28	−8.19	−9.38	−8.45	−9.90
Lower Side	Elongation	0.15	0.75	3.05	2.30	3.00	3.70	4.55	5.00	5.30
	Strain	0.15	0.75	3.05	4.63	6.03	7.41	9.08	10.08	10.58

		10−11	11−12	12−13	13−14	14−15	15−16	16−17	17−18	18−19
Upper Side	Elongation	−10.00	−6.35	−5.50	−3.80	−2.25	−1.00	−0.60	−0.20	0.45
	Strain	−10.02	−6.38	−5.50	−3.80	−2.25	−1.00	−0.30	−0.10	0.23
Lower Side	Elongation	9.40	7.60	6.10	4.20	2.50	1.25	0.80	0.35	0.10
	Strain	9.41	7.62	6.11	4.20	2.51	1.25	0.40	0.18	0.05

		19−20	20−21	21−22	22−23	23−24	24−25	25−26	
Upper Side	Elongation	−0.25	−0.40	−0.35	−0.30	−0.30	−0.30	−0.25	
	Strain	−0.13	−0.20	−0.18	−0.30	−0.30	−0.60	−0.50	
Lower Side	Elongation	0.40	0.45	0.55	0.30	0.30	0.10	0.15	(mm)
	Strain	0.20	0.23	0.28	0.30	0.30	0.20	0.30	(%)

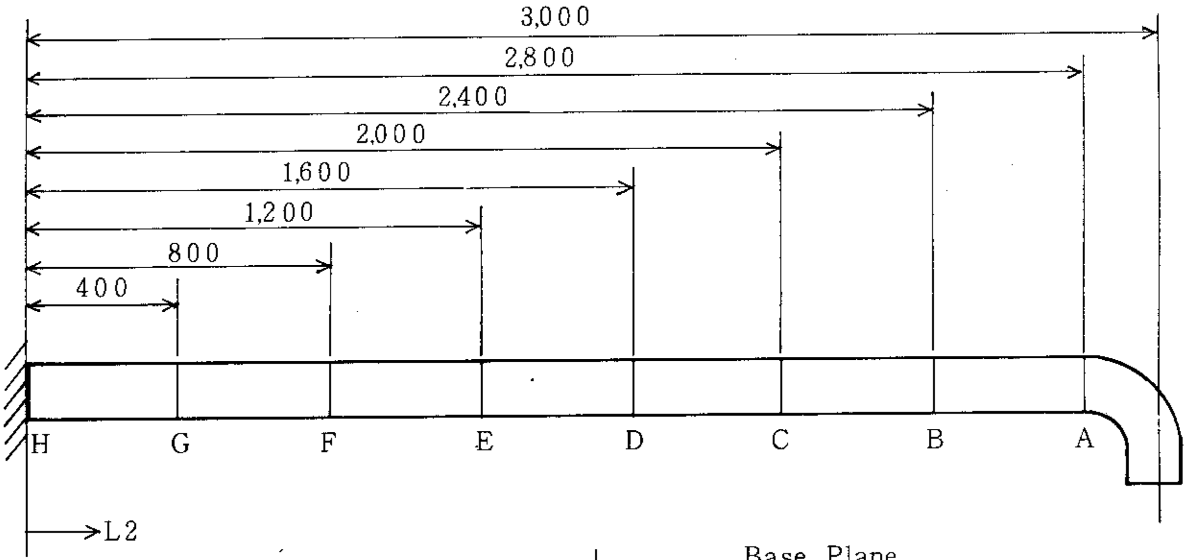
Table 3.2 Results of Dimensional Measurements in Diameter of Test Pipe

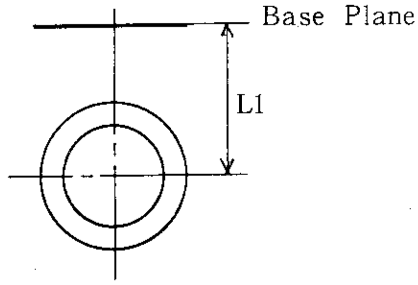


		1	2	3	4	5	6	7	8
A–A′	Expansion	0.08	−0.44	−10.635	−11.57	−14.11	−12.13	−4.18	−0.74
	Strain	0.05	−0.27	−6.445	−7.01	−8.49	−7.35	−2.53	−0.45
B–B′	Expansion	−0.06	0.22	6.14	11.73	13.54	11.67	5.70	0.83
	Strain	−0.03	0.13	3.72	7.10	8.20	7.07	3.45	0.50

		9	10	11	12	13	
A–A′	Expansion	0.27	0.12	0.21	−0.87	−0.05	
	Strain	0.16	0.07	0.13	−0.52	−0.03	
B–B′	Expansion	−0.08	0.04	0.04	−0.05	0.39	(mm)
	Strain	−0.05	0.02	0.02	−0.03	0.24	(%)

Table 3.3 Results of Residual Deformation of Test Pipe

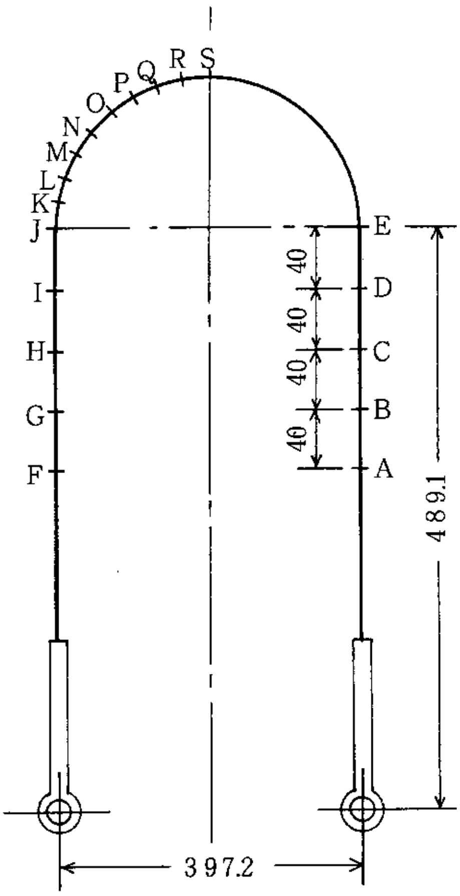




	L 1		L 2	
	Before Test	After Test	Before Test	After Test
A	247.7	−297.3	2800.5	2630.1
B	248.2	− 22.3	2400.2	2340.3
C	248.0	182.7	2000.0	1992.5
D	248.3	234.7	1600.0	1599.8
E	247.5	243.4	1200.0	1200.0
F	247.4	249.1	800.0	800.0
G	247.5	253.1	400.0	400.0
H	248.0	252.2	0	0

(mm)

Table 3.4 Results of Dimensional Measurements



	R 1		R 2	
	Elongation	Strain	Elongation	Strain
A − B	0	0	0.05	0.13
B − C	0	0	0.10	0.25
C − D	0.10	0.25	−0.10	−0.25
D − E	0.10	0.25	−0.15	−0.38
A − E	0.30	0.19	0	0
A′− C′	0.10	0.13	0.15	0.19
F − J	0.10	0.06	−0.05	−0.03
F′− M′	0.10	0.13	0.20	0.25
F − G	0	0	0.10	0.25
G − H	0	0	0.10	0.25
H − I	0.05	0.13	0.25	0.63
I − J	0.05	0.12	0	0
J − K	−0.55 (0.35)	−1.53 (1.01)	−0.65 (0.20)	−1.82 (0.58)
K − L	−0.65 (0.45)	−1.83 (1.30)	−0.85 (0.15)	−2.36 (0.43)
L − M	−0.65 (0.6)	−1.81 (1.73)	−0.65 (0.30)	−1.82 (0.87)
M − N	−0.25 (0.55)	−0.69 (1.60)	−0.20 (0.10)	−0.56 (0.29)
N − O	0.35 (0.55)	0.97 (1.58)	−0.10 (0.10)	−0.28 (0.29)
O − P	1.25 (0.8)	3.48 (2.32)	1.20 (0.05)	3.37 (0.14)
P − Q	1.85 (0.65)	5.17 (1.87)	1.15 (0.30)	3.23 (0.87)
Q − R	1.75 (0.5)	4.92 (1.44)	1.40 (0.35)	3.86 (1.00)
R − S	1.55 (0.2)	4.32 (0.58)	1.55 (0.25)	4.35 (0.72)

mm %

( ) : Side of U− bar

Table 3.5 Residual Strain of Test Pipe and Restraint

Tag No.	Residual Strain	Tag No.	Residual Strain
XU111	25682	XU136	1602
XU112		XU137	−379
XU113		XU138	−607
XU114		XU139	−18491
XU115		XU140	12294
XU116		XU141	12945
XU117		XU142	7845
XU118	7435	XU143	10328
XU119	594	XU151	−1525
XU120	1117	XU152	1565
XU121	1905	XU153	−360
XU122	2243	XU154	968
WU131	1953	XU155	−805
WU132	1046	XU156	1269
WU133		XU157	−1345
WU134	1011	XU158	−1576
XU131	−83	XU159	−15585
XU132	1650	XU160	1622
XU133	530	XU161	2258
XU134	1308	XU162	6974
XU135	105	XU163	12774

(μ)

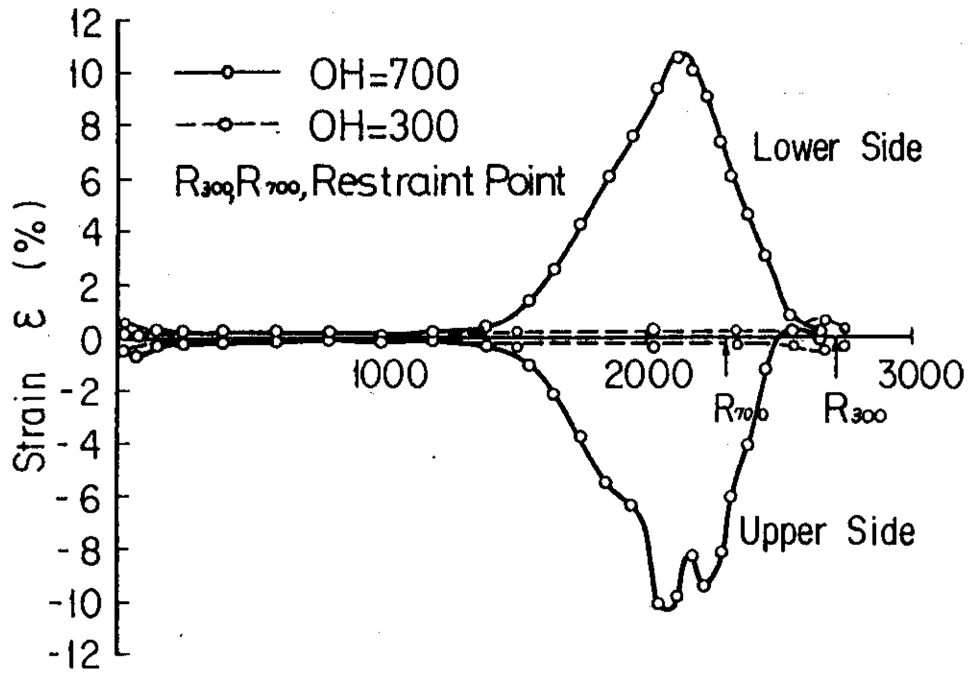


Fig.3.1 Axial Distribution of Residual Strain of Test Pipe

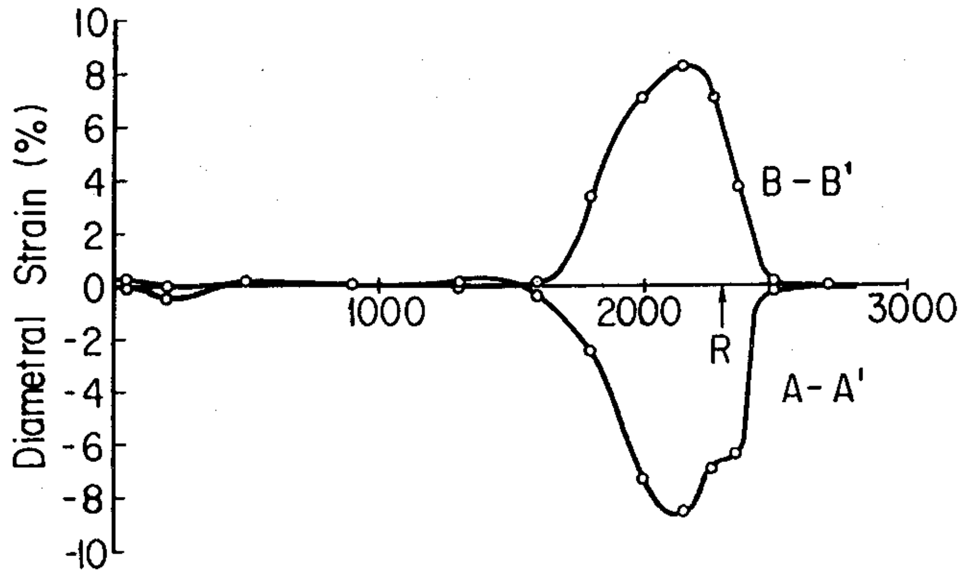


Fig.3.2 Oval Deformation of Test Pipe

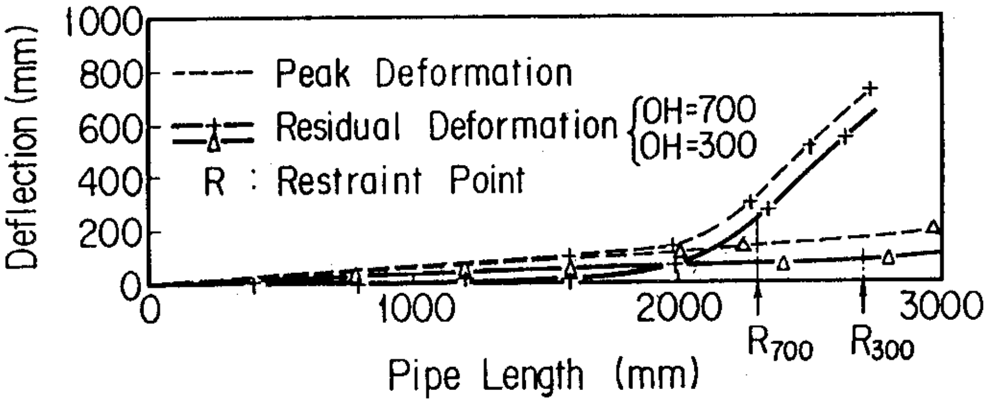


Fig.3.3 Residual Deformation of Test Pipe

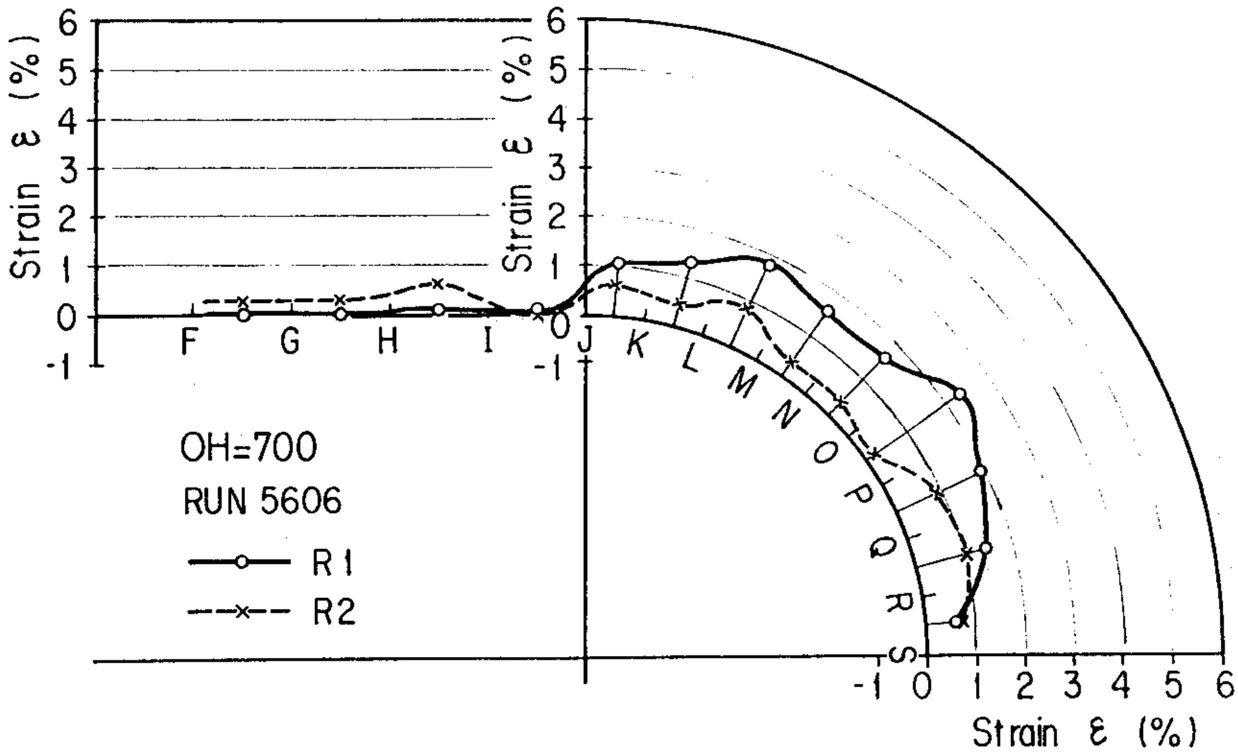


Fig.3.4 Residual Strain of Restraint

4. DISCUSSION

4.1 Time Sequence of Typical Detectors

Output signals from each detector were recorded into an analog tape. These time histories were drawn across the paper of the X-Y plotter. A code generating system made it possible to search the tape automatically and initializing the time axis. Starting point, Time=0, in the output-time histories does not mean the moving instant of the test pipe but the instant when the electrode discharged sparks.

The time sequence of major events is shown in Fig. 4.1. Time=0 is the starting point in the output-time histories. XU 301 is the accelerometer attached to the free end of the test pipe. The starting time of the output of XU 301 means the moving instant of the test pipe. XU 143 and XU 163 are the strain gages attacked to the top of the restraints R1 and R2, respectively. The starting time of these outputs means the instant of impact between the test pipe and the restraint. Impact time is defined as the elapsed time from the rising time of the accelerometer XU 301 to that of the straing gage XU 143. This value is also shown in Fig. 4.1.

4.2 Pressure in Vessel and Pipe

The initial conditions of pressure and temperature have already been shown in Table 2.1. Pressure and level histories (PU 111, PU101, WU 115) in RUN 5606 are shown in Fig. 4.2. The output of the pressure transducer PU 111 at the free end of the test pipe decreases more rapidly than PU 101 at the pressure vessel just after the break. In the case of PU 101, the knee where the discharging jet changes from hot water into steam one appears at about 9 sec after the rupture. Thereafter pressure drops rapidly for discharging a high quality saturated steam. The falling rate of the water level is 0.36 m/sec, which is about two times as fast as that 0.2 m/sec of 4 in. test results in RUN 5603[3].

The comparison of pressure histories along the test pipe is shown in Fig. 4.3. Pressures drop in stepwise manner just after the initiation of the blowdown, and become to drop later and smaller with increasing distance from the free end of the test pipe. Velocity of the pressure wave propagating in the fluid becomes about 1150 m/sec as shown in Fig. 4.4, which is almost equal to the velocity of sound, 985 m/sec, in the saturated fluid with 6.86 MPa pressure.

4.3 Fluid Temperature in Vessel and Pipe

Temperature histories, TU 102, 130, in the vessel and pipe are shown in Fig. 4.5. The fluid temperature, TU 102, in the vessel decreases slowly after the initiation of the blowdown. From 2 second to 30 second temperatures followed a saturation curve. The fluid temperature, TU 130, in the test pipe decreases rapidly just after the initiation of the blow-down. After 30 second, temperature rised over the saturation point because of heating by vessel wall.

4.4 Deformation of Test Pipe

(1) Residual Deformation

Residual deformation of the test pipe is small when the overhang length is 300 mm, since the restraints limit the pipe movement as shown in Photo. 4. However, it is larger in the case of OH* =700 mm, and the pipe deforms especially at the setting point of restraints as shown in Photo. 5. Residual deformations of the test pipe are comparatively shown in Fig. 3.3. The free end of the test pipe deflects about 700 mm upwards in RUN 5606.

Distribution of the residual strains along pipe axis is shown in Fig. 3.1. Distribution of the outer diameters along pipe axis is shown in Fig. 3.2.

(2) Dynamic Deformation

Strain histories of the test pipe in RUN 5606 are shown in Fig. 4.6. XU 111, XU 113, XU 116, XU 118 and XU 122 are the strain gages attached at the points of 550 mm, 750 mm, 950 mm, 1500 mm and 2900 mm, respectively. The rising of stain in XU 122 appears in the earliest time of these outputs. This means that the test pipe near the pipe support deforms in the earliest time till the impact between the test pipe and restraints.

Dynamic strain distributions of the test pipe are shown in Fig. 4.7. The first plastic strain of the pipe appears at the point near the pipe support before the impact. The second plastic strain of the pipe appears

---

* CL: Clearance, OH: Overhang length

at the setting point of restraints after the impact, and increases with time. This moves to the pipe support at 70 msec after the break, because of the inclination of the restraints.

4.5 Deformation of Restraint

(1) Residual Deformation

Deformed restraints after the tests are shown in Photos. 18 and 19. the restraints incline toward the pipe support, and is bent at the part of the clevis. The flaw scratched by the restraints in observed at the surface of the test pipe.

Front and side views of the restraints R1 and R2 after the tests are shown in Photos. 20 through 24. The deformation of the restraint R1 is larger than that of R2. The bearing plate inside of the U-bar includes the test pipe. In the case of OH=700 mm, the part of the clevis which is thined to attach the strain gage is bent toward the test pipe. However, in the restraints with ordinary clevis of the real plants, the inclination of the restraints seems to be small. The clevis should be designed strongly in order to prevent the plastic deformation. The residual strain distribution of each restraint is shown in Fig. 3.4. The restraint R1 deforms more than the restraint R2, since the test pipe bends steeply at the setting point of restraints.

(2) Dynamic Deformation

Strain histories of the restraints R1 and R2 in RUN 5606 are shown in Fig. 4.8 and Fig. 4.9. Strain of the restraint R1 is larger than that of the restraint R2. Output phase of the strain gage attached at the inner side of the U-bar is inverse with that at the outer side of the U-bar. This phenomenon seems to be caused by the bending vibration of the U-bar. The first maximum restraint strains are summarized in Table 4.1.

4.6 Restraint Force

Restraint force histories in RUN 5606 are shown in Fig. 4.10. Perfect restraint force could not be measured, since the strain gages were snapped because of large plastic strain. However, the first maximum restraint forces can be obtained, and are summarized in Table 4.2.

4.7 Deflection of Test Pipe

The output result of the pipe velocity meter XU 402 is shown in Fig. 4.11. The output voltage changes in a stepwise manner, since a scratching pen cut a several electric paints on the board.

Displacements at the free end of pipe and the setting point of restraints versus time are shown in Fig. 4.12. The former was obtained by the velocity meter XU 402 and the latter was obtained by the results of high speed camera. Velocity at the free end of pipe is about 30 m/sec just after the break, and decreases to about 4 m/sec. However, velocity at the setting point of restraint is about 4 m/sec just after the break, and decreases to about 1 m/sec. From these results, we can imagine that the test pipe already bends like a bow according to the bending moment before the impact between the pipe and the restraints.

4.8 Comparison between 4 in. and 6 in. Tests

4 in. pipe whip tests under BWR LOCA conditions were summarized in the previous report.(3) Comparison of test conditions between 4 in. and 6 in. pipe whip tests is summarized in Table 4.3. Sectional area of 6 in. pipe is about two times as wide as that of 4 in. pipe.

Comparison of test results between 4 in. and 6 in. pipe whip tests is summarized in Table 4.4. 4 in. tests in the cases of OH=250 mm and OH=550 mm are represented, since these cases resemble to those of 6 in. tests. The maximum restraint force of 6 in. test is about two times as large as that of 4 in. test. However, the maximum restraint strain does not change so much, since the sectional area of restraints of 6 in. test is also two times as large as that of 4 in. test.

Out-of-plane angle of restraint means the inclination of the restraints from the original position, and increases with increasing overhang length. Total deflection of pipe end is measured from the loci scratched on the board next to the test pipe, and also increases with increasing overhang length.

Impact time means the elapsed time from the instant of break to the instant of contact between the pipe and the restraints, and is not so different between 4 in. test and 6 in. test. Time to maximum restraint force is measured from the restraint force history, and does not change with increasing overhang length.

Table 4.1 Maximum Restraint Strain

	R 1	R 2	Total Ave.
XU 1－1	－2000	－2500	
XU 1－2	4000	4000	
XU 1－3	－2000	－2000	
XU 1－4	4000	4000	
XU 1－5	－2000	－2500	
XU 1－6	4000	4000	
Average	1000	833	917

μ

Table 4.2 Maximum Restraint Force

	R 1	R 2	Total
WU 1－1	38.2 (3.9)	17.2 (1.75)	
WU 1－2	34.3 (3.5)	16.7 (1.70)	
WU 1－1 + WU 1－2	72.5 (7.4)	33.8 (3.45)	106.3 (10.85)

kN
(ton)

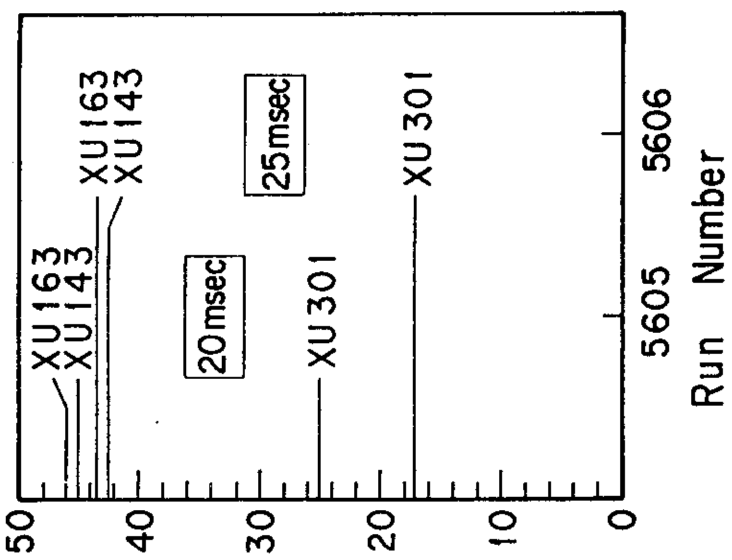


Fig.4.1 Time sequence of Typical Detectors

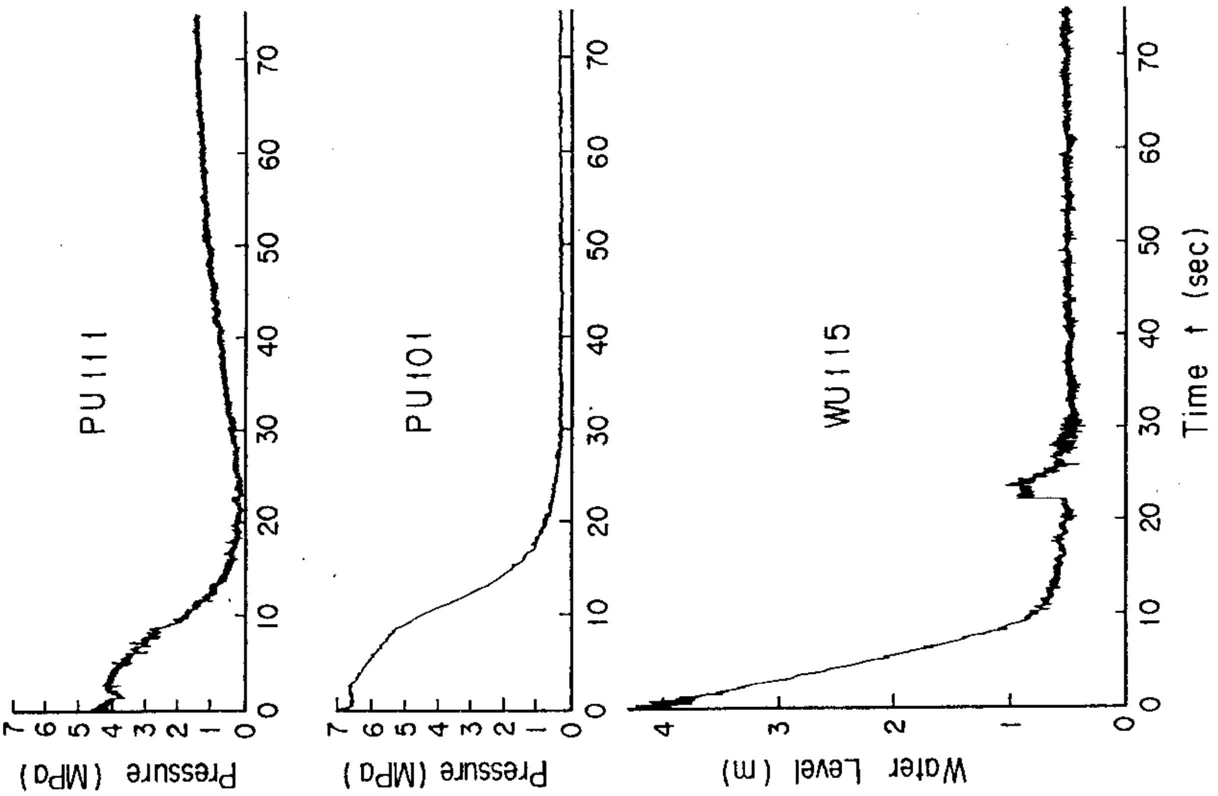


Fig.4.2 Pressure and Level Histories of RUN 5605

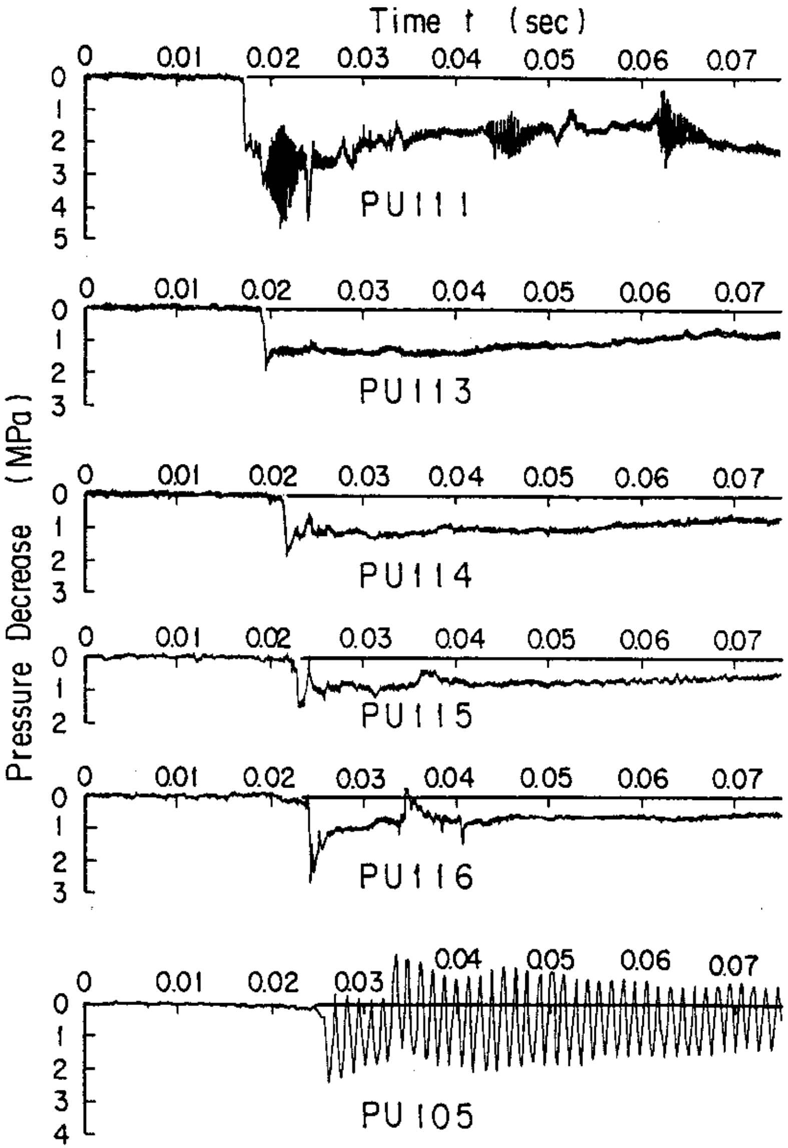


Fig.4.3 Pressure Histories in Various Locations of Pipe

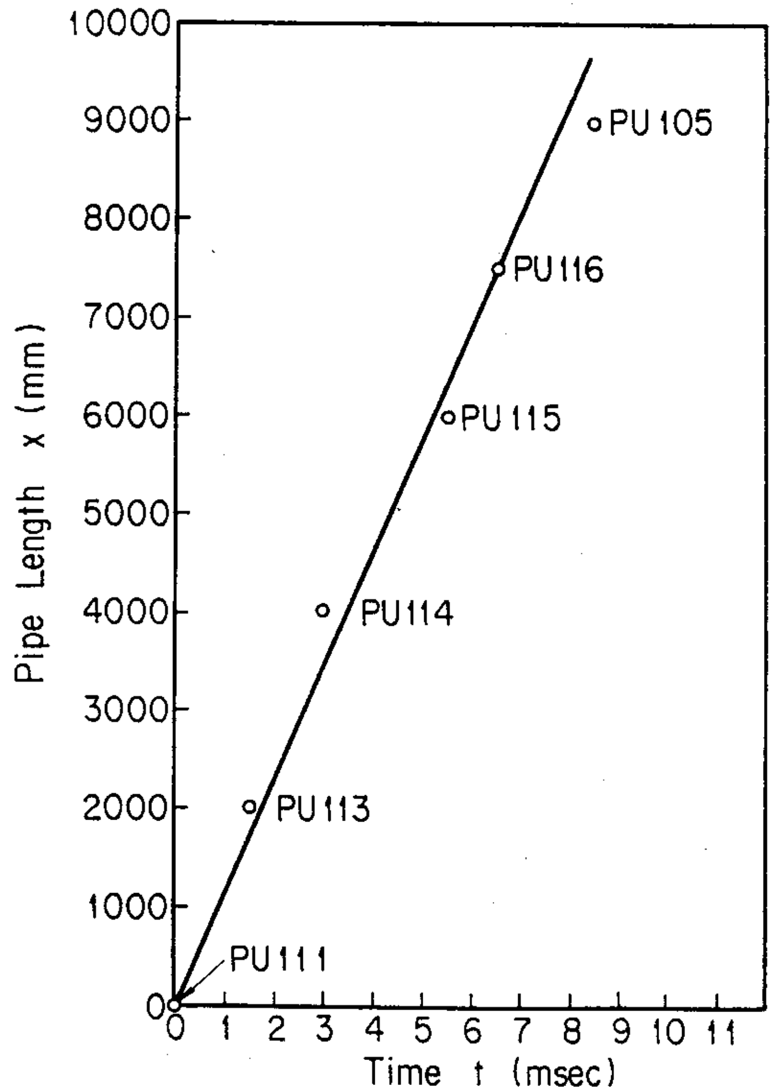


Fig.4.4 Speed of Pressure Wave Propagation in Pipe

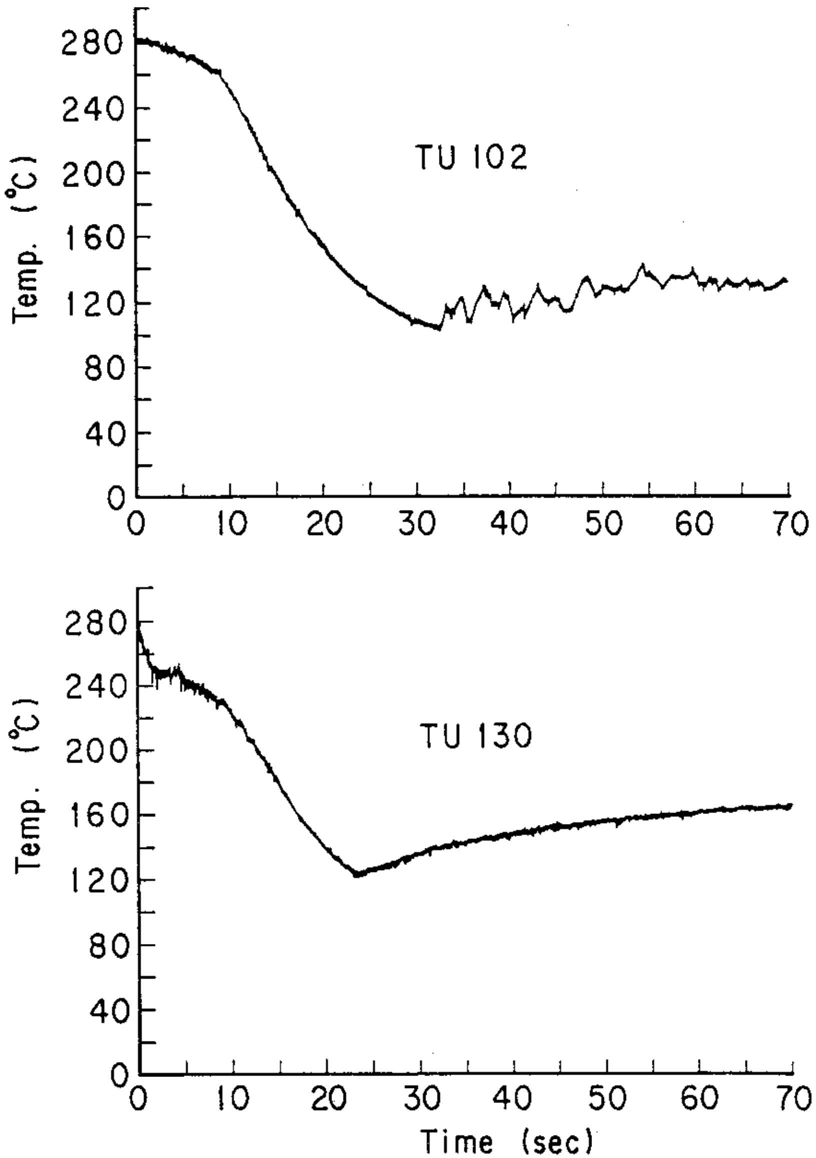


Fig.4.5 Fluid Temperature Histories of RUN 5606

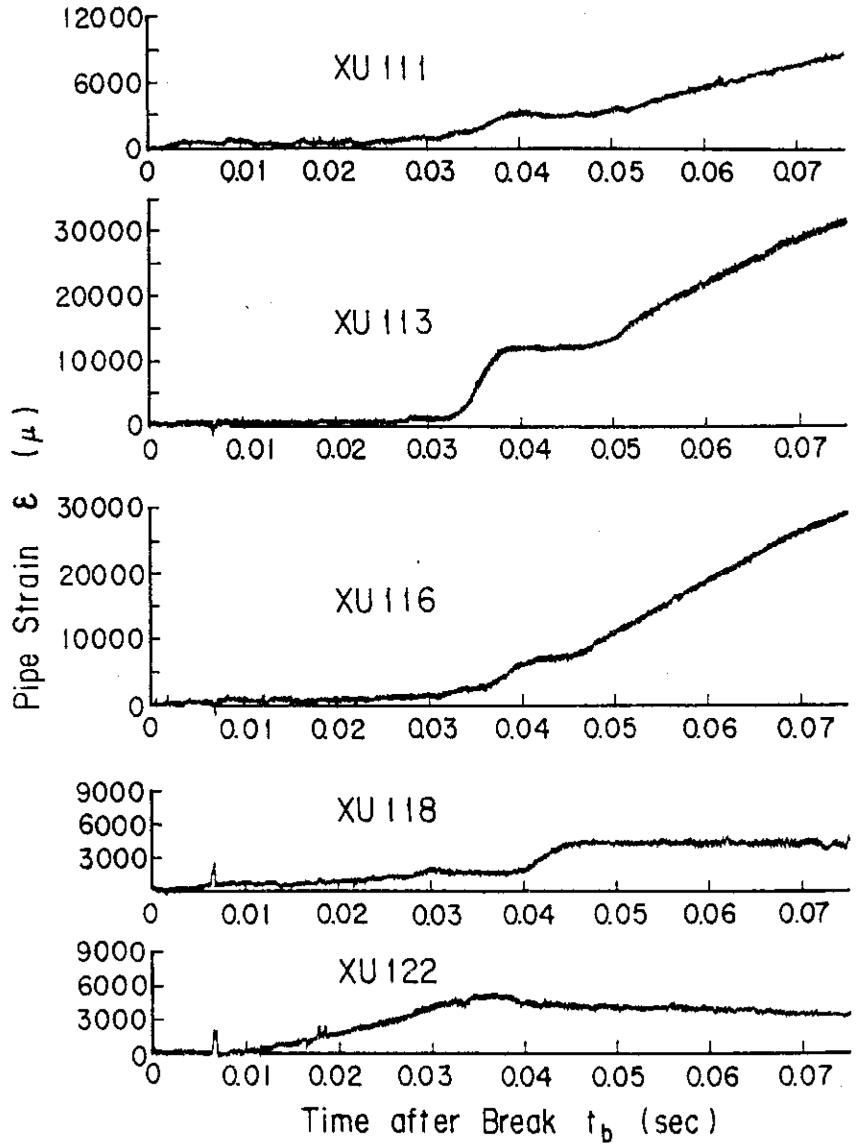


Fig.4.6 Strain Histories of the Gage attached to the Pipe

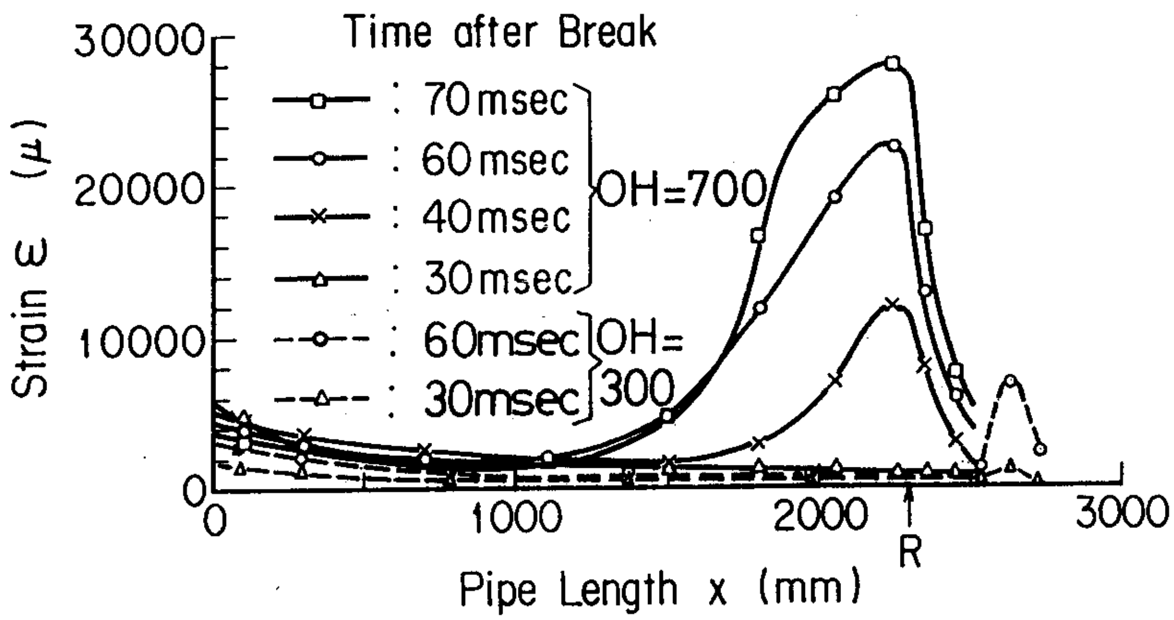


Fig.4.7 Dynamic Strain Distribution along Pipe Axis

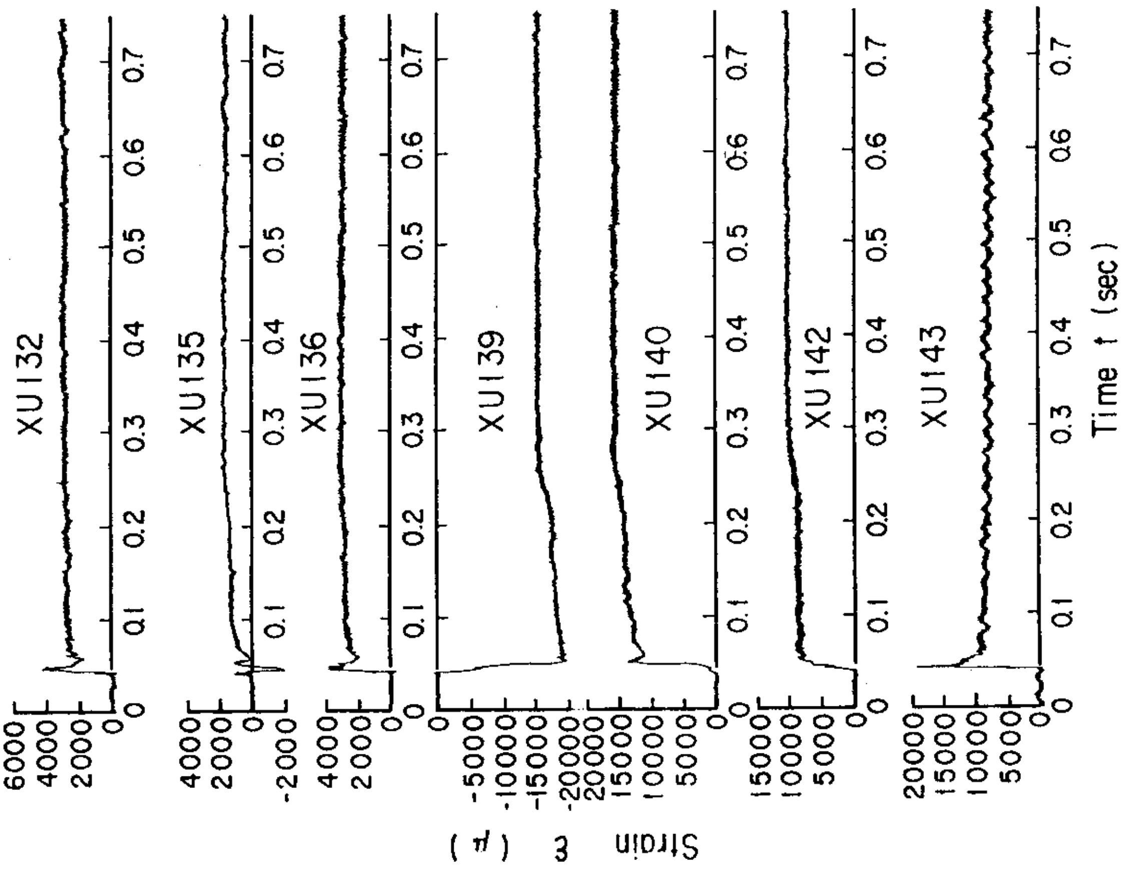


Fig.4.8 Strain Histories of Restraint R1 (0-0.7 sec)

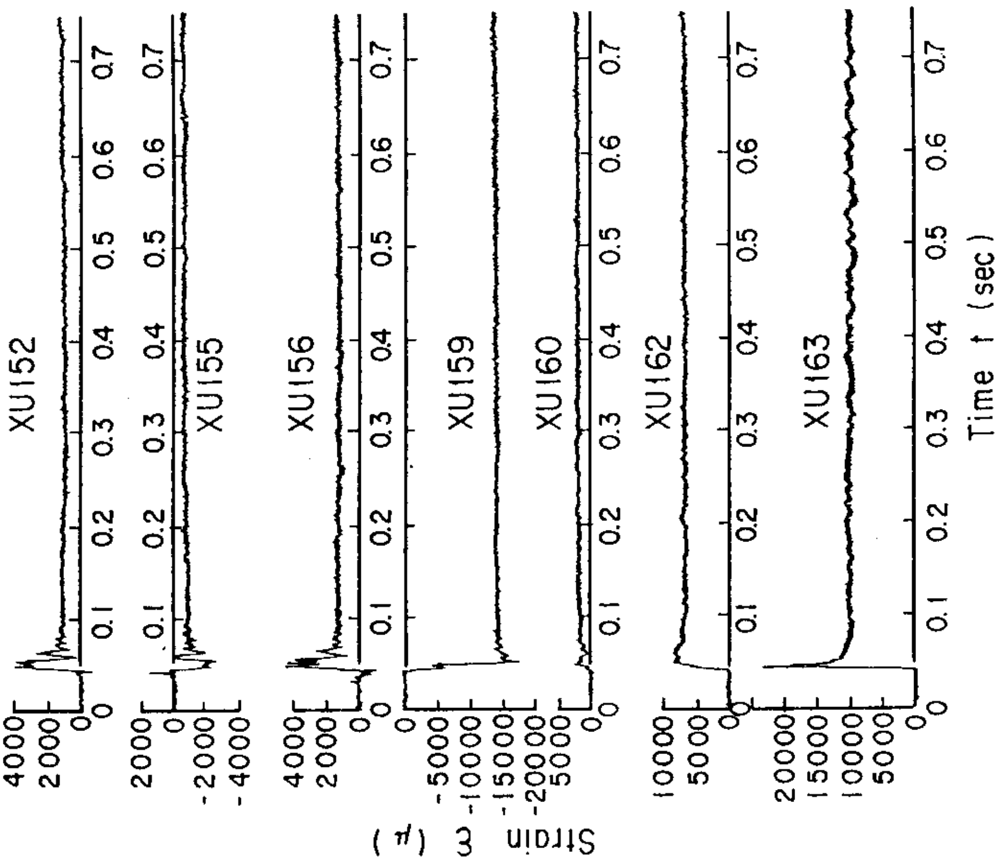


Fig.4.9 Strain Histories of Restraint R2 (0-0.7 sec)

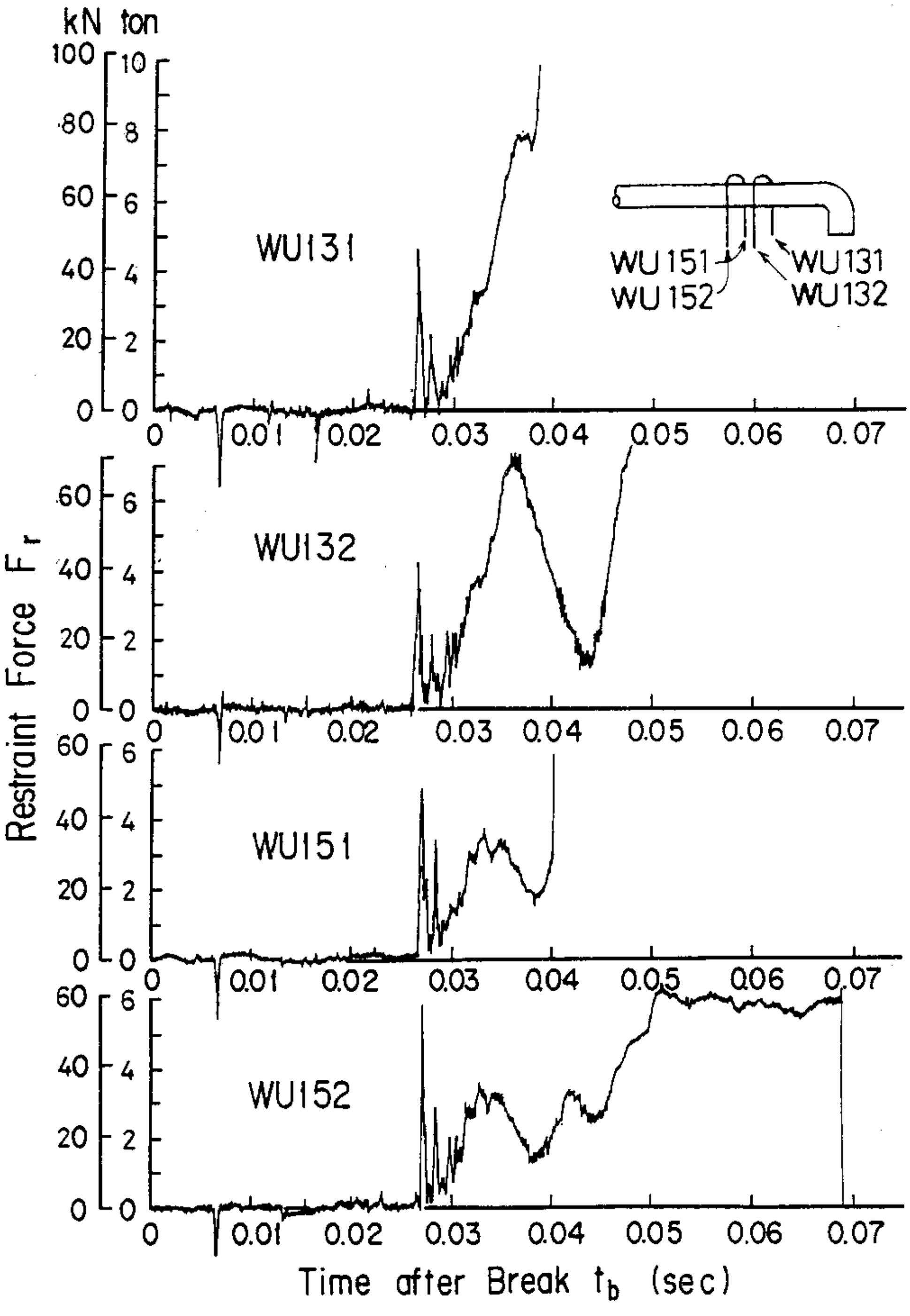


Fig.4.10 Restraint Force Histories (0-0.07 sec)

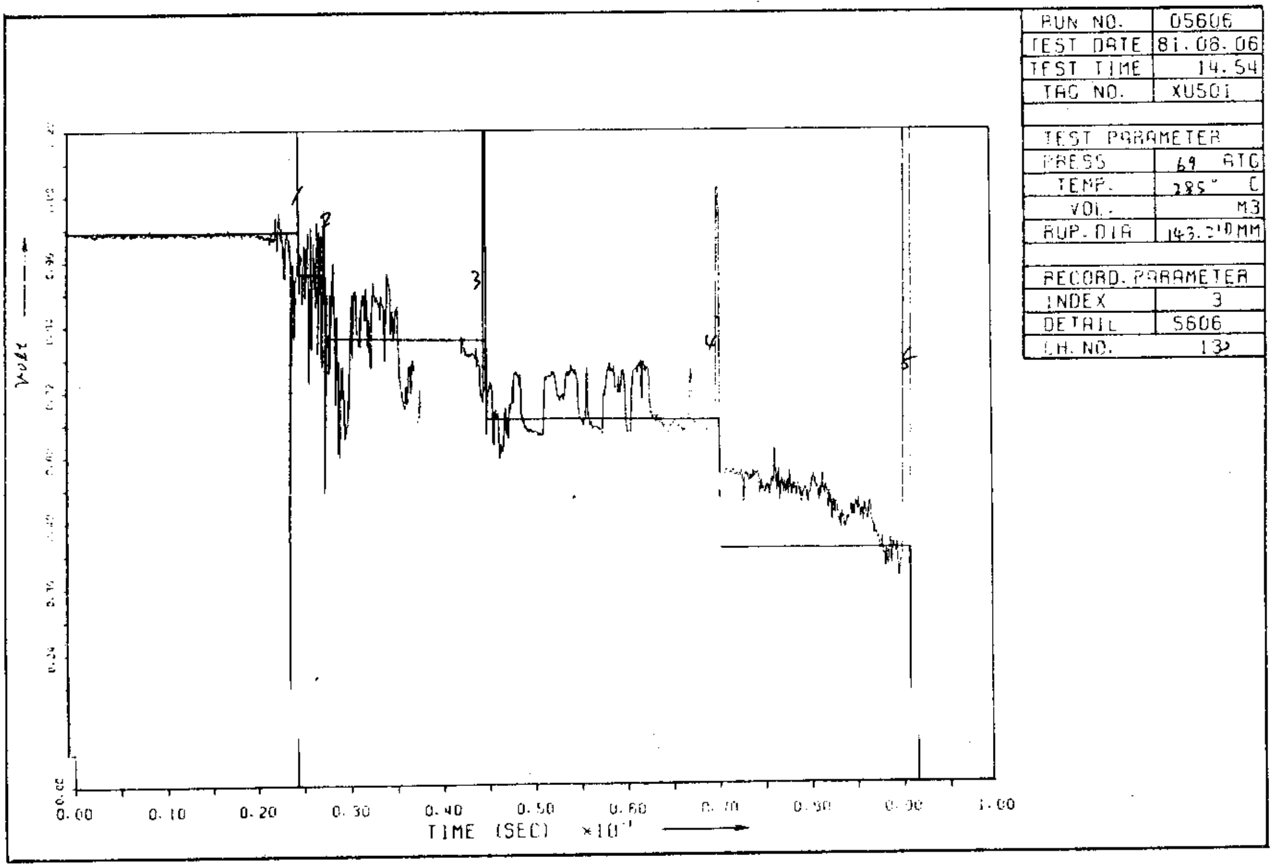


Fig.4.11 Time Histories of Velosity Meter

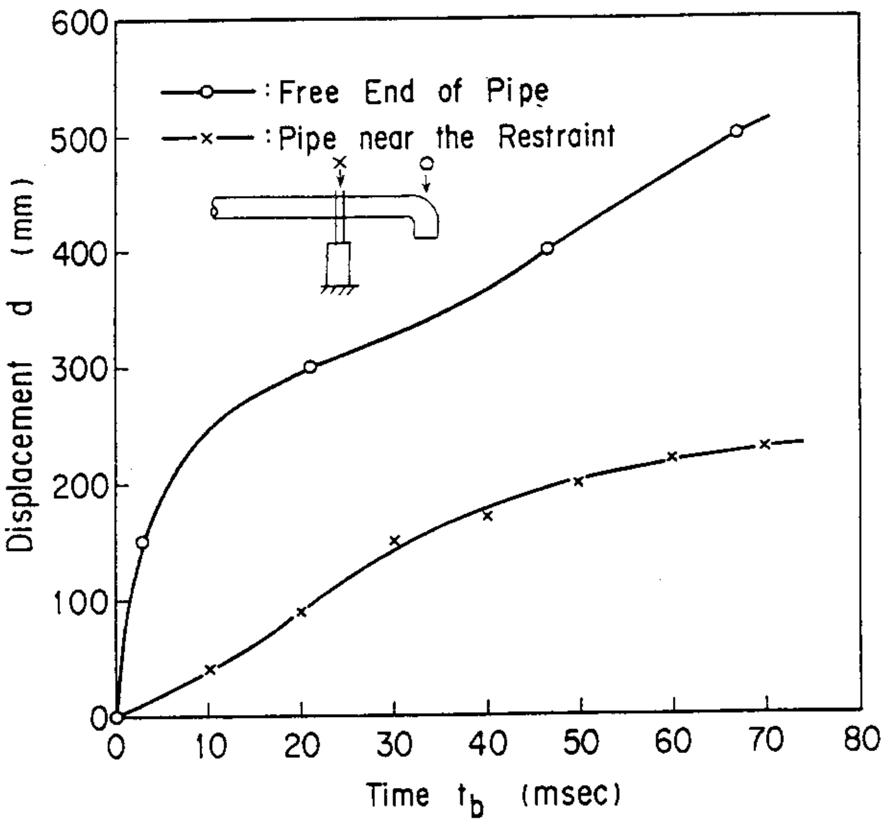


Fig.4.12 Displacement of Pipe versus Time

5. CONCLUDING REMARKS

6 in. pipe whip tests (RUN 5605, 5606) under BWR LOCA conditions (285°C, 69 kg/cm^2) were performed with FRPC-II. Two restraints were set with clearance of 100 mm and overhange lengths of 300 mm and 700 mm. The following results are obtained.

(1) Velocity of the pressure wave propagating in the fluid becomes about 1000 m/sec, which is almost equal to the velocity of sound, 985 m/sec, in the saturated fluid with 6.86 MPa pressure.

(2) Residual deformation of the test pipe is small when the overhang length is 300 mm, since the restraints limit the pipe movement effectively. However, it becomes larger when the overhang length is 700 mm, and the pipe deforms especially at the setting point of restraints.

(3) The restraint R1 deforms more than the restraint R2 in both cases of RUN 5605 and 5606. Out-of-plane angle of restraint increases with increasing overhang length, and is about 18° in the case of OH=700 mm.

(4) Output phase of the strain gage attached at the inner side of the U-bar is inverse with that at the outer side of the U-bar. This phenomenon seems to be caused by the bending vibration of the U-bar.

(5) Velocity at the free end of pipe becomes about 30 m/sec just after the break, and decreases to about 4 m/sec. However, velocity at the setting point of restraint is about 4 m/sec just after the break, and decreases to about 1 m/sec.

(6) The maximum restraint force of 6 in. test is about two times as large as that of 4 in. test. However, the maximum restraint strain does not change so much, since the sectional area of restraints of 6 in. test is also two times as large as that of 4 in. test.

(7) Out-of-plane angle of restraint and total deflection of pipe end increase with increasing overhang length in both cases of 4 in. and 6 in. test.

ACKNOWLEDGEMENTS

The authors wish to make their grateful acknowledgement to Dr. M. Nozawa, Center Director of the nuclear safety research center in JAERI, for this valuable advices. Acknowledgement is also due to the members of committee on the assessment of Safety Research for Nuclear Reactor Structural Components in JAERI (Chairman: Prof. Dr. Y. Ando, University of Tokyo) for their fruitful comments.

REFERENCES

(1) N. Miyazaki, Y. Kannoto and R. Kurihara "The effect of various parameters on pipe whip phenomena" Vol.21 No.6 Journal of JNS 1979.

(2) S. Ueda, etc. "Pipe rupture test results; 4 inch pipe whip tests under BWR operational condition —— clearance parameter experiments (RUN 5405, 5406, 5407) JAERI-M 9496

(3) R. Kurihara, etc. "Pipe rupture test results; 4 inch pipe whip test under BWR LOCA conditions —— overhang length parameter tests (RUN 5407, 5501, 5504, 5603) JAERI-M 82-022

ACKNOWLEDGEMENTS

The authors wish to make their grateful acknowledgement to Dr. M. Nozawa, Center Director of the nuclear safety research center in JAERI, for this valuable advices. Acknowledgement is also due to the members of committee on the assessment of Safety Research for Nuclear Reactor Structural Components in JAERI (Chairman: Prof. Dr. Y. Ando, University of Tokyo) for their fruitful comments.

REFERENCES

(1) N. Miyazaki, Y. Kannoto and R. Kurihara "The effect of various parameters on pipe whip phenomena" Vol.21 No.6 Journal of JNS 1979.

(2) S. Ueda, etc. "Pipe rupture test results; 4 inch pipe whip tests under BWR operational condition —— clearance parameter experiments (RUN 5405, 5406, 5407) JAERI-M 9496

(3) R. Kurihara, etc. "Pipe rupture test results; 4 inch pipe whip test under BWR LOCA conditions —— overhang length parameter tests (RUN 5407, 5501, 5504, 5603) JAERI-M 82-022

APPENDIX A Material Property

The tensile test specimen of pipe and restraint material is shown in Fig. A.1. Pipe material specimens were manufactured from the section along pipe axis. Restraint material specimens were manufactured from the straight portion of the U-bar. Tensile test were conducted with Instron Model 1123 Universal Instrument.

The tensile test results of pipe and restraint materials are shown in Fig. A.2 to Fig. A.4. Proof stress $\sigma_{0.2}$ and strain hardening modulus E_T are obtained from these stress-strain curves. These tensile test results are summarized in Table A.1.

Table A. 1 Conditions and results of tensile test

No.	Material	Temp.	$\sigma_{0.2}$	σ_u	ϕ	E_T
1	Restraint	R. T.	30.2	75.0	60.9	162.5
2	Pipe	R. T.	23.0	62.6	57.0	242.5
3	Pipe	285℃	17.7	46.4	35.9	282.5

$\sigma_{0.2}$: Proof stress Kg/mm^2

σ_u : Tensile strength Kg/mm^2

ϕ : Elongation %

E_T : Strain hardening modulus Kg/mm^2

Material is Type 304 stainless steel

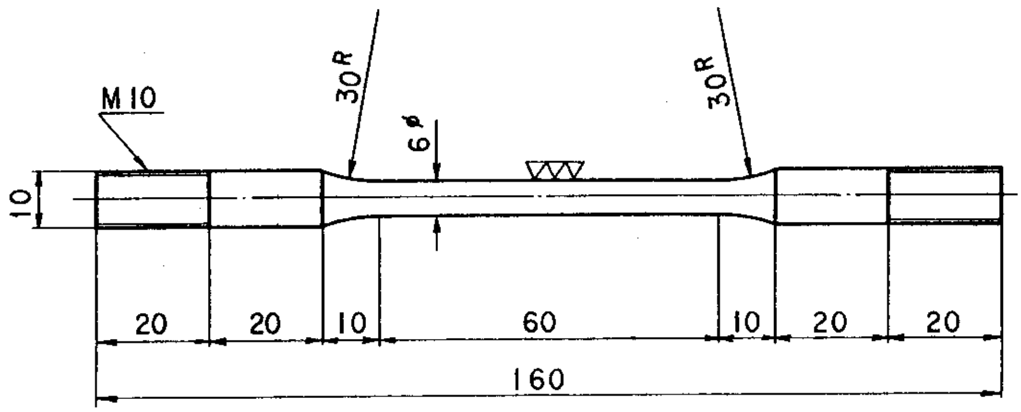


Fig.A.1 Tensile Test Specimen of 6 in. Pipe and Restraint Material

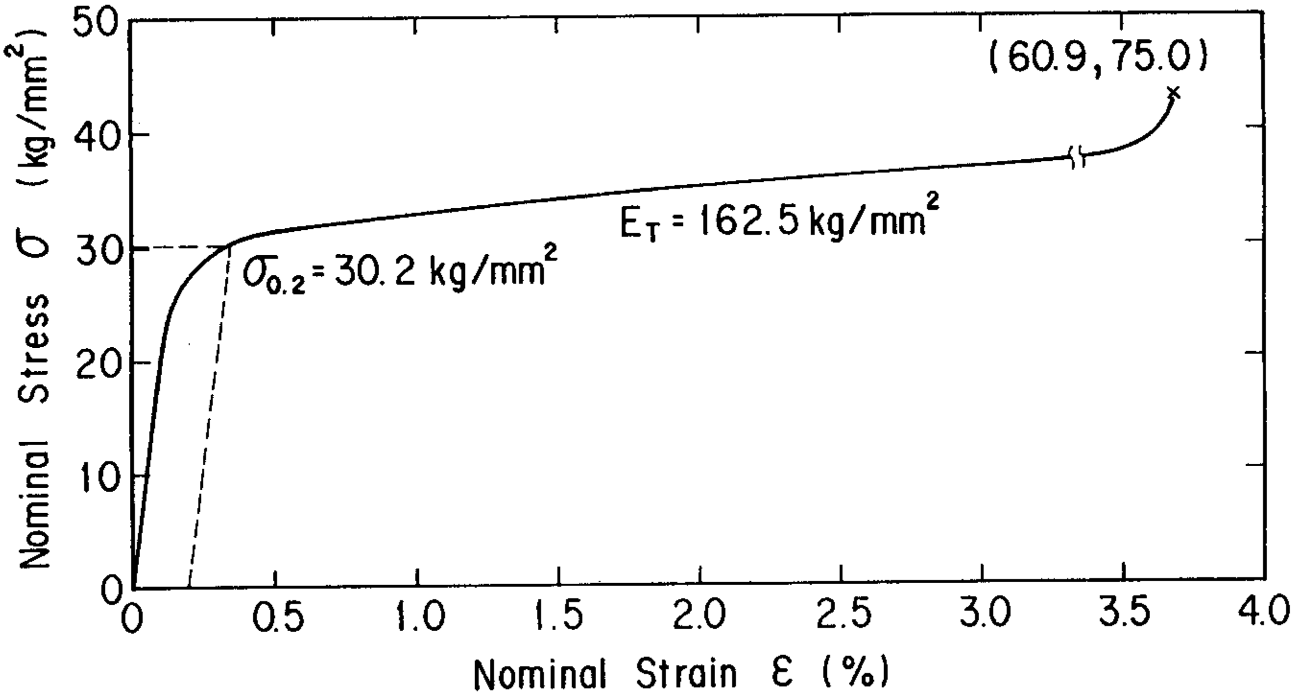


Fig.A.2 Tensile Test Result of Restraint Material's Specimen of R.T.

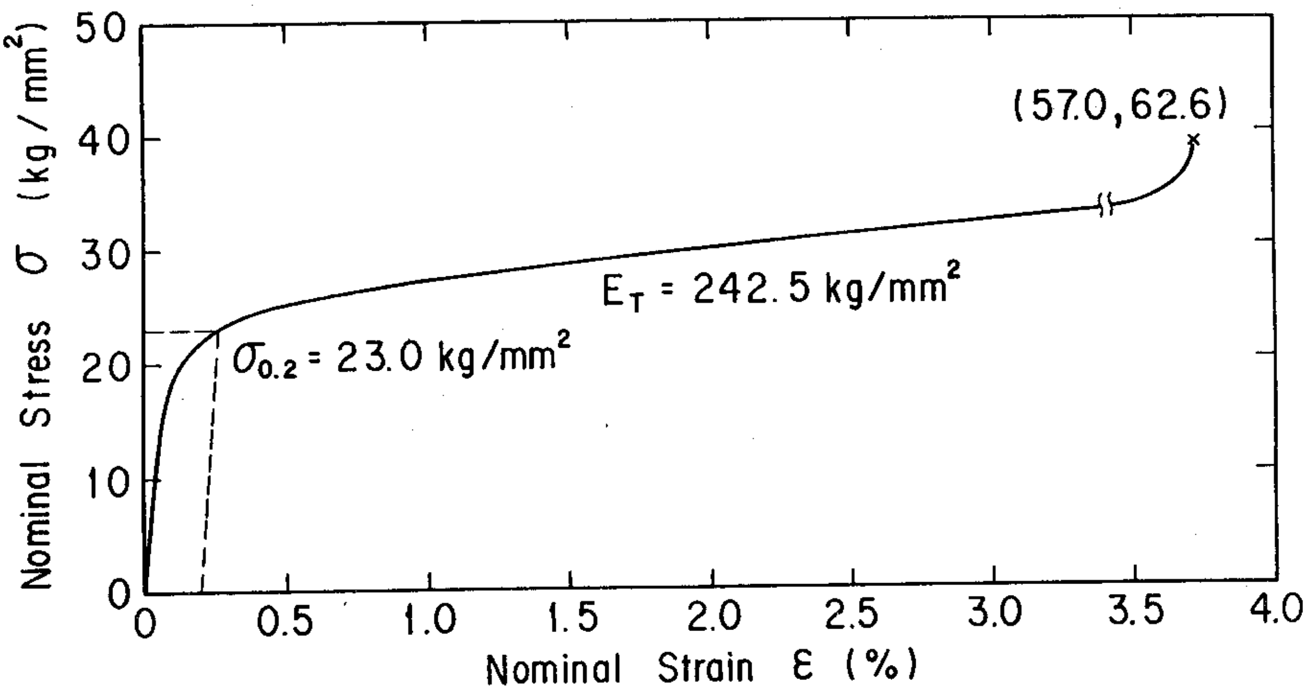


Fig.A.3 Tensile Test Result of 6 in. Pipe Material's Specimen at R.T.

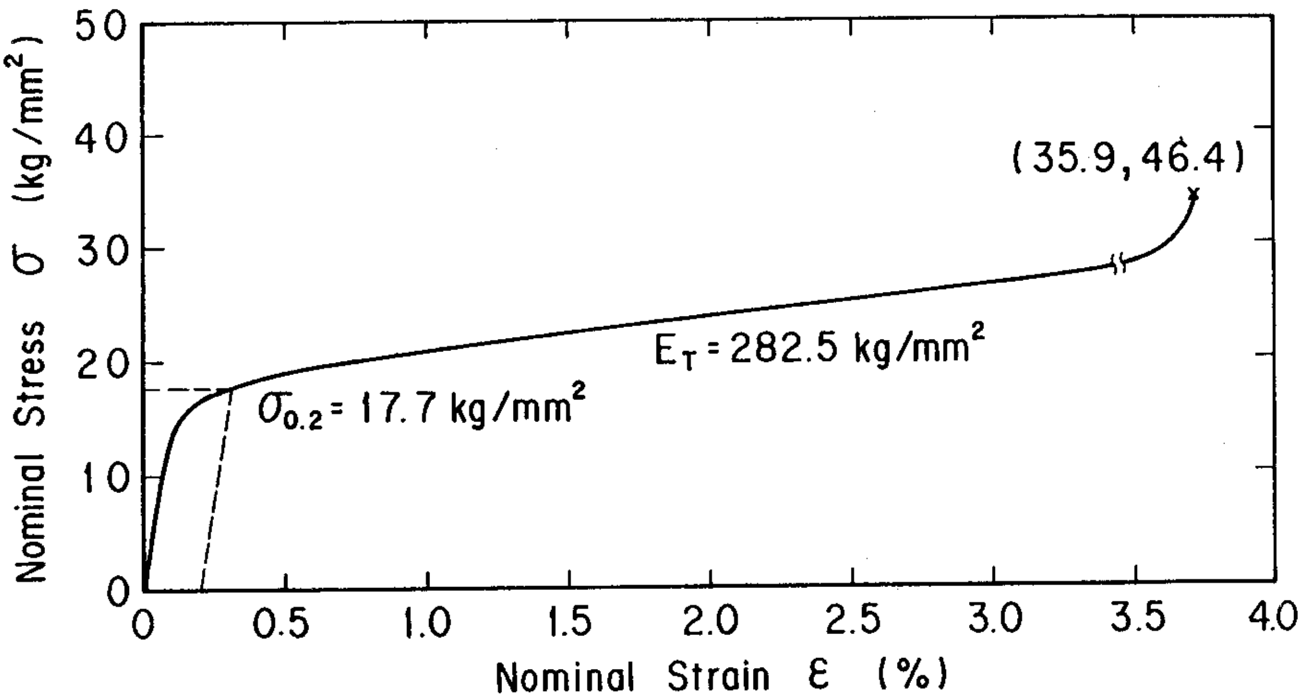


Fig.A.4 Tensile Test Result of 6 in. Pipe Material's Specimen at 285°C

APPENDIX B Natural Frequency

Mechanical impedance of test pipe is shown in Fig. B.1. It is obvious from this figure that the first natural frequency of pipe is about 10.5 Hz. The vibrator with a impedance head was attached at the free end of pipe. The test pipe was clamped at 3000 mm from the free end of pipe. The fluid was not filled in this pipe and the temperature of pipe is about 15°C.

Mechanical impedance of the restraint is shown in Fig. B.2. It is obvious from this figure that the first natural frequency of restraint is about 74.0 Hz. The vibrator with a impedance head was attached to the top of the U-bar. Natural frequencies of the pipe and the restraint are summarized in Table B.1. Calculated natural frequency of the test pipe is also summarized in Table B.1.

Table B. 1 Natural Frequency of Pipe and Restraint

	1	2	3	4
Restraint (Exp.)	10.5	74.0	235.0	630.0
Pipe (Exp.)	10.5	74.0	188.0	372.0
Pipe (Exp.)	16.8	105.8	294.9	578.0

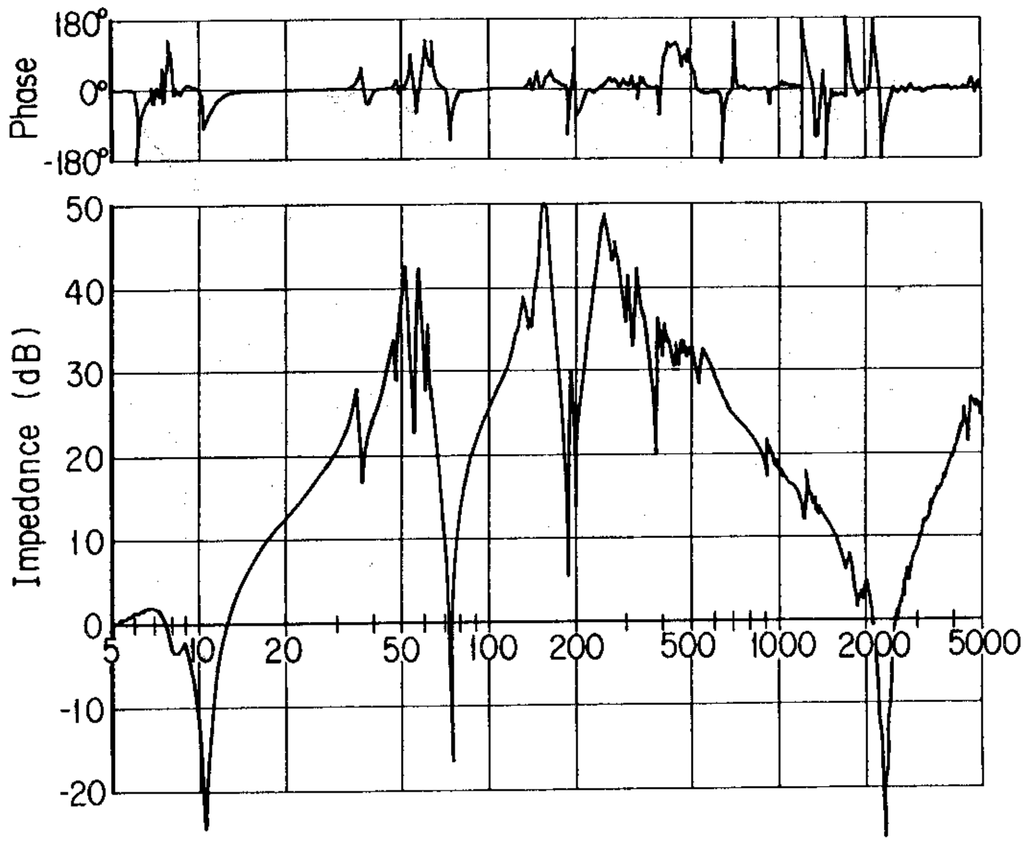


Fig.B.1 Mechanical Impedance of Test Pipe

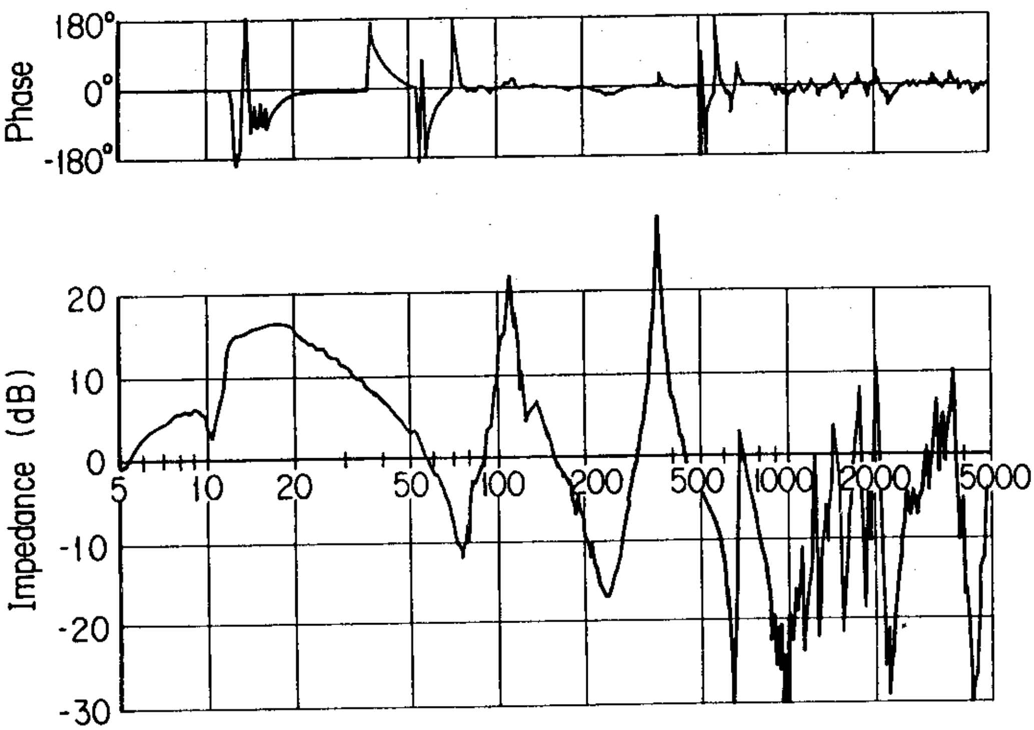


Fig.B.2 Mechanical Impedance of Restraint

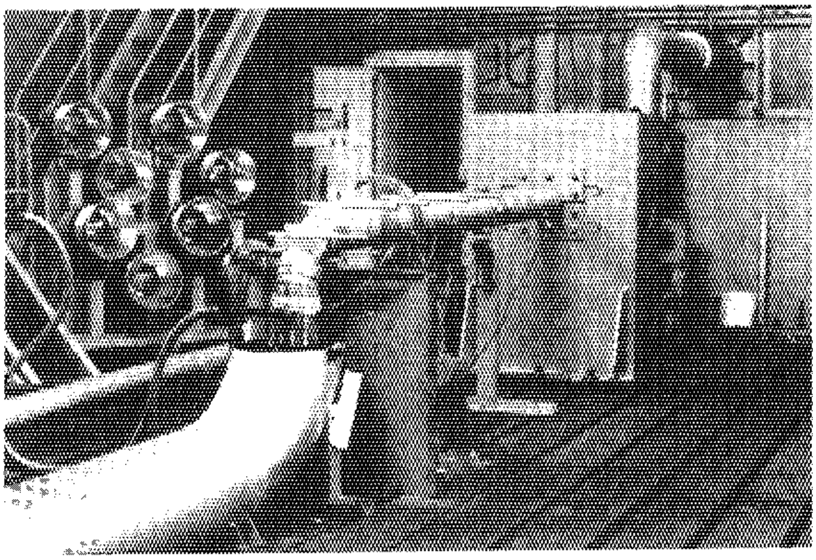


Photo.1 View of Test System before Test

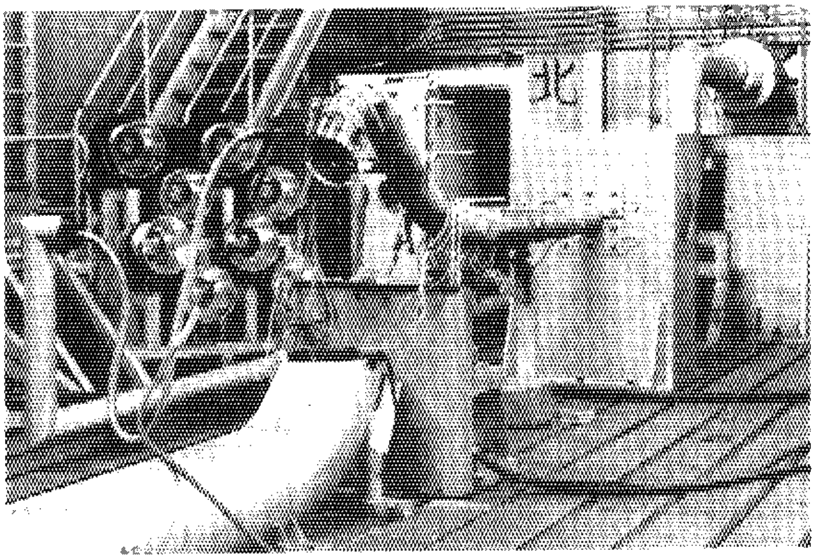


Photo.2 View of Test System After Test

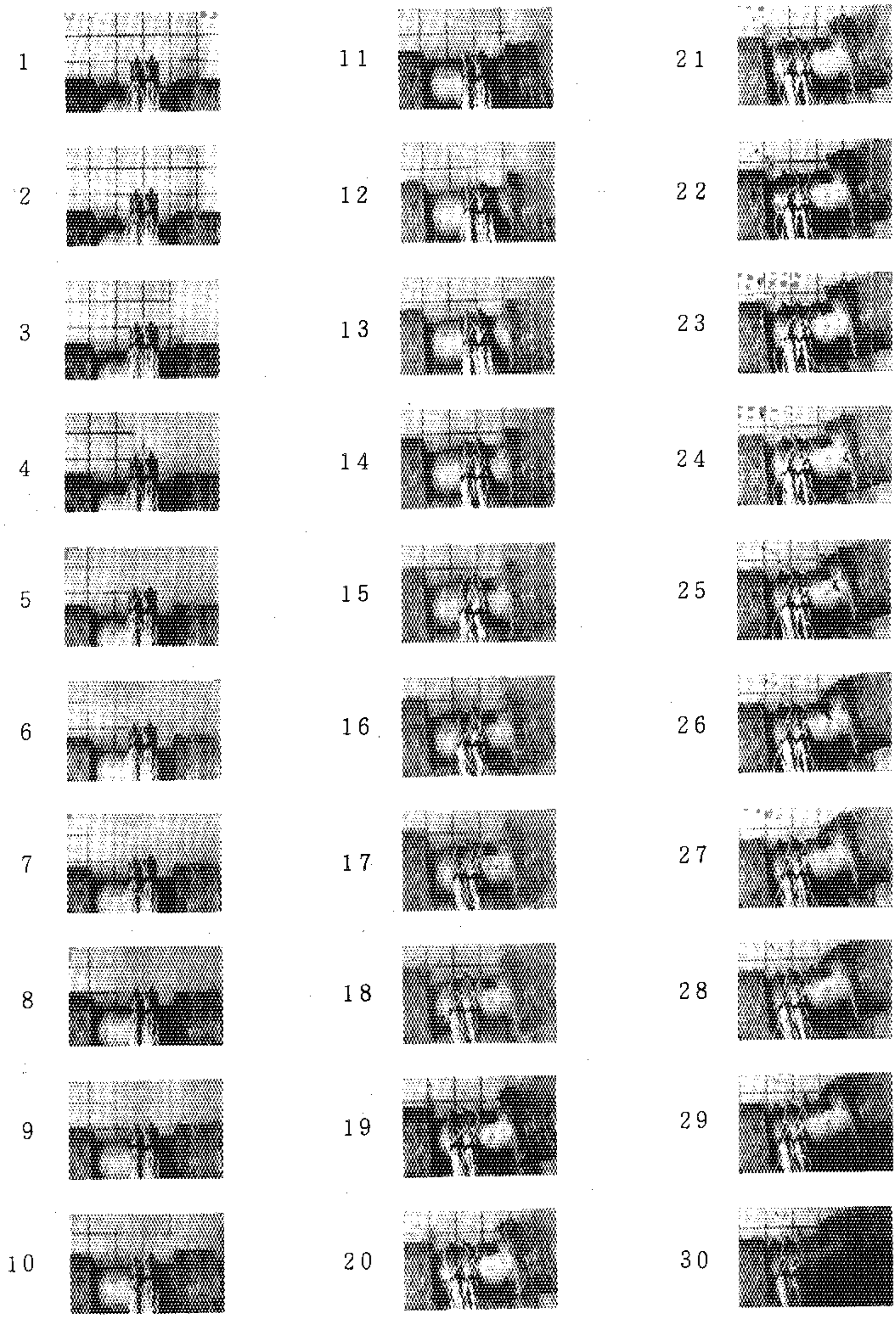


Photo.3 Selected Frames of High Speed Camera (RUN 5606)
2.5 msec/frame

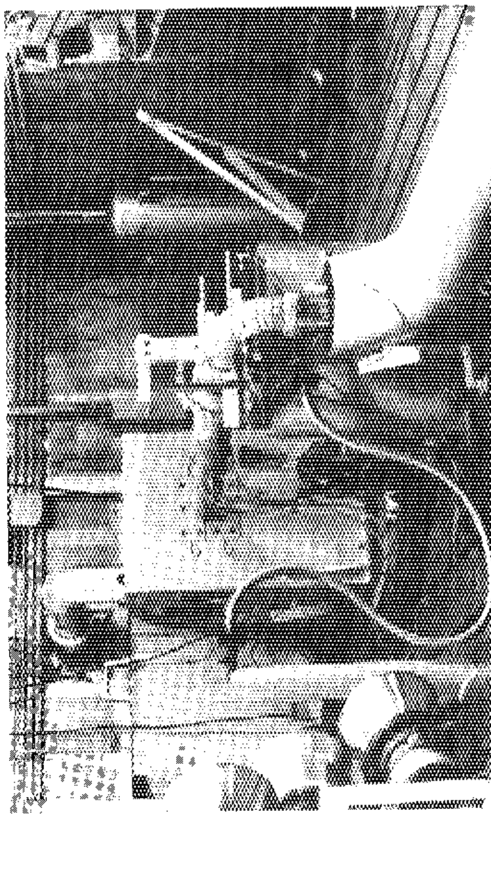


Photo.4 Front View of Test System before Test

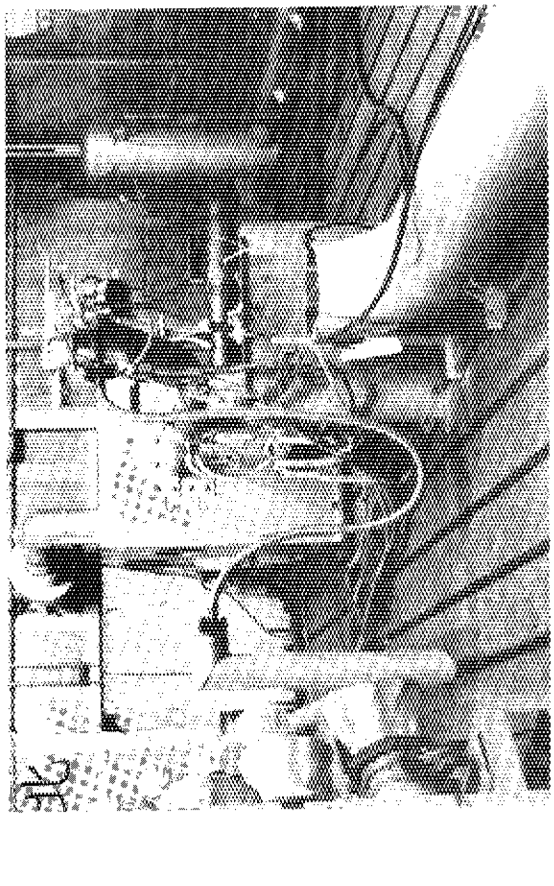


Photo.5 Front View of Test System after Test

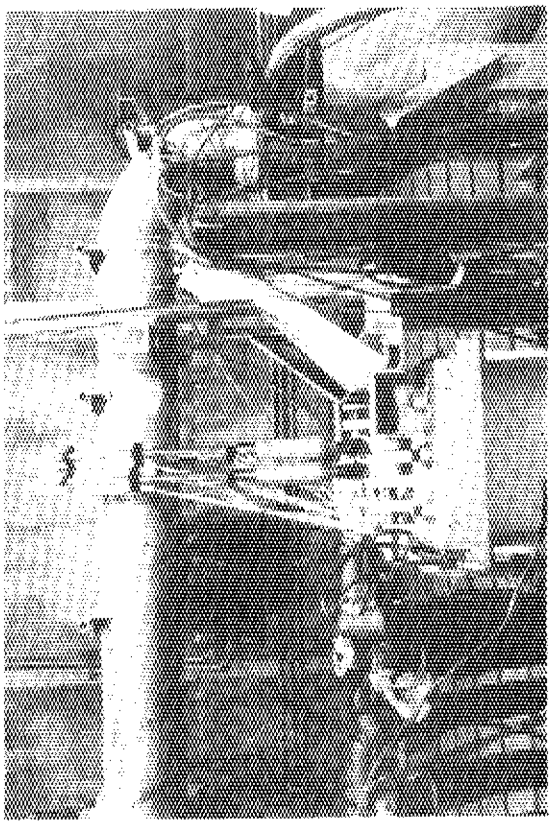


Photo.6 Side View of Test System before Test

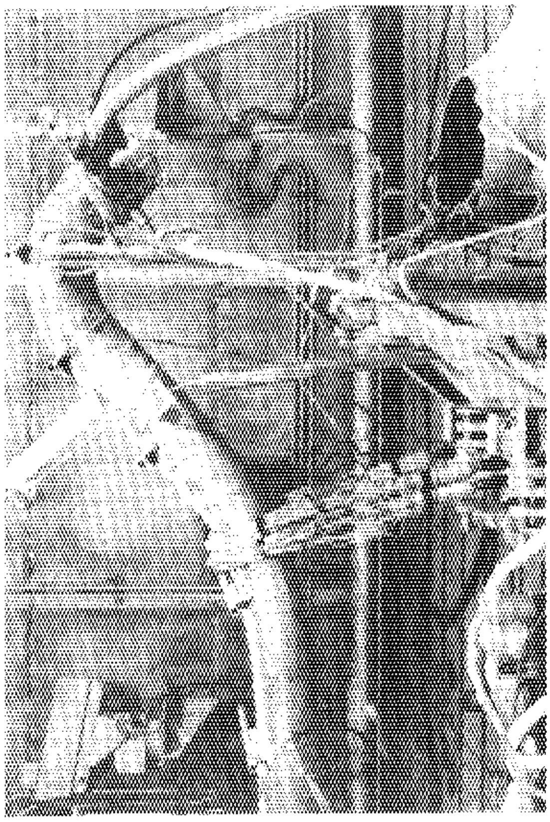


Photo.7 Side View of Test System after Test

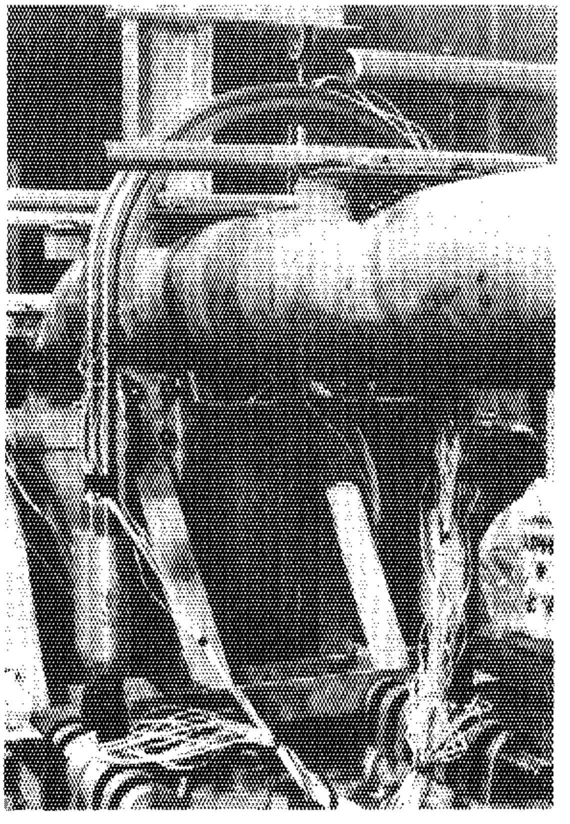


Photo.8 Pipe and Restraints before Test

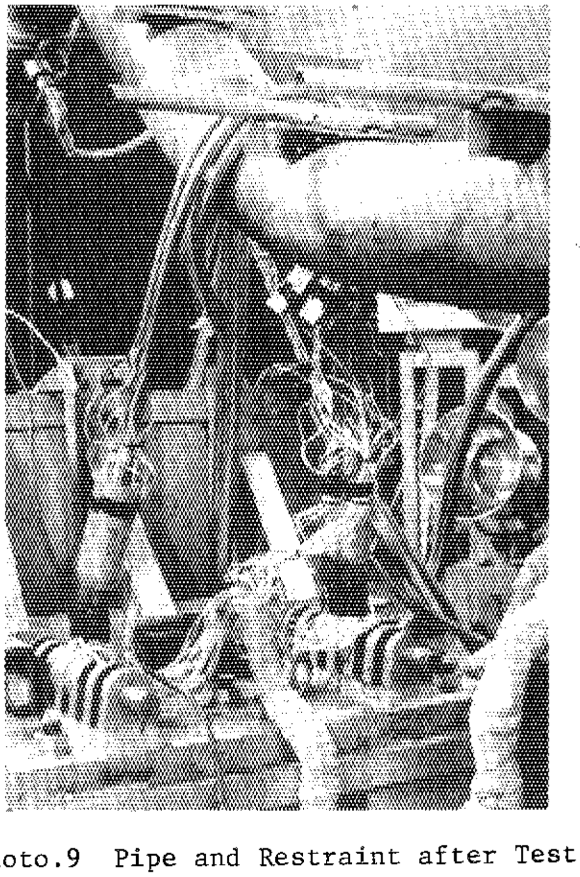


Photo.9 Pipe and Restraint after Test

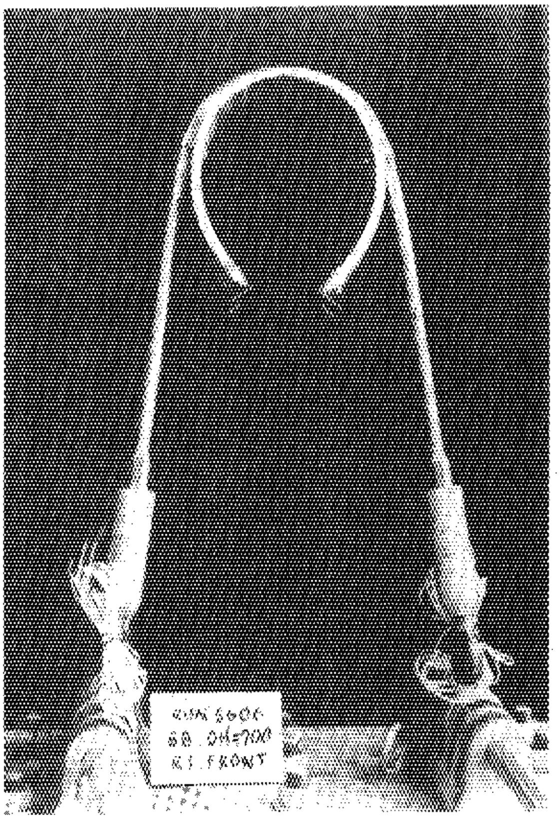


Photo.10 Front View of R1

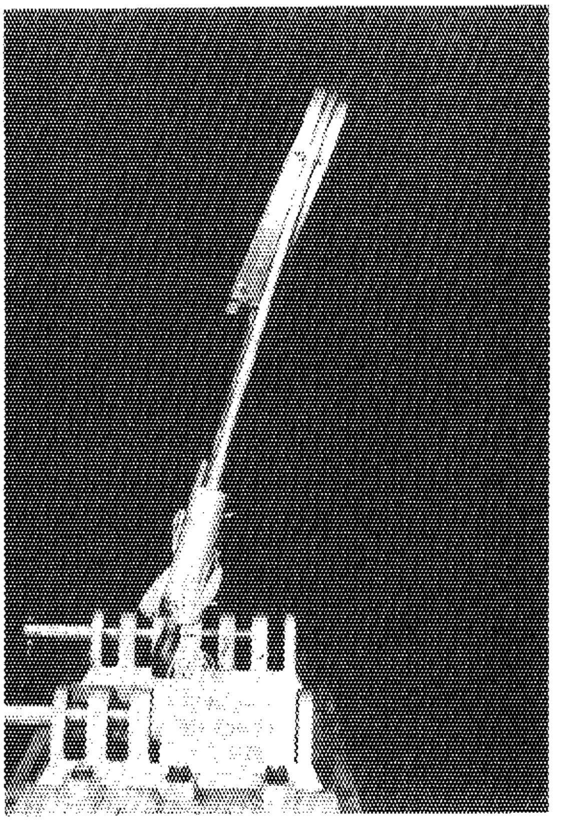


Photo.11 Side View of R1

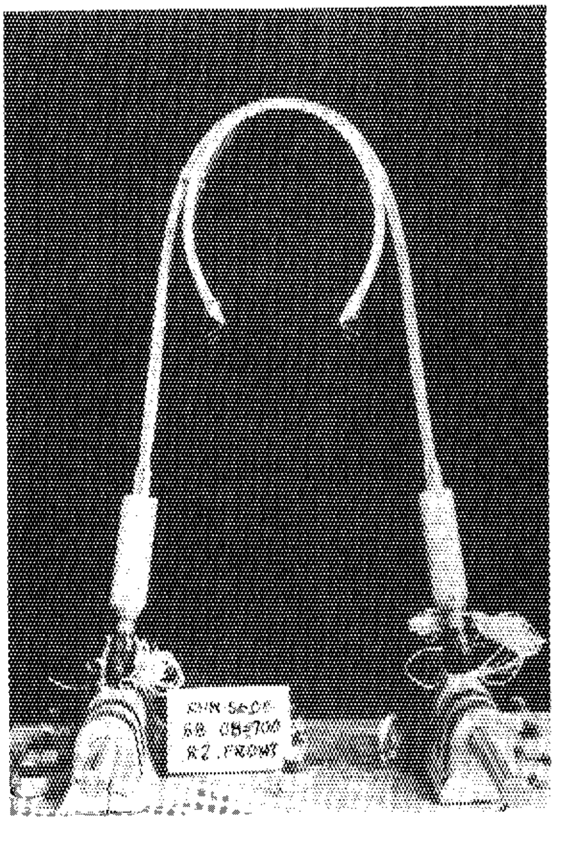


Photo.12 Front View of R2

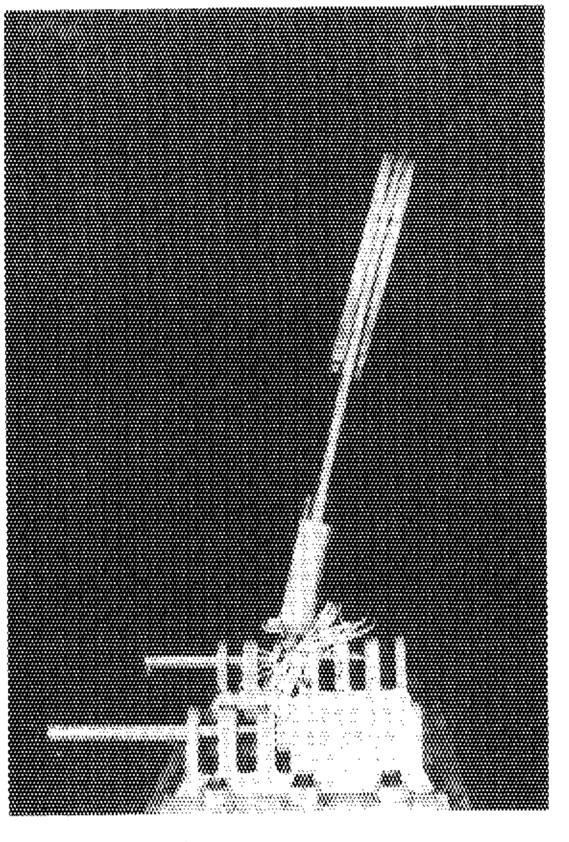


Photo.13 Front View of R2