

COMPUTER CODE DEVELOPMENT AND TEST OF STRUCTURAL ANALYSIS FOR DOUBLE WALL PIPING OF FBR PRIMARY COOLANT SYSTEMS

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SUMMARY

Double wall piping structures are to be adopted for the main and auxiliary primary coolant systems of the Japanese Fast Breeder Reactor "MONJU".

The double wall piping structures consist of inner piping and outer piping. Through the inner piping flows the sodium coolant and through the annulus between them passages pre-heating gas. In case of sodium leakage through small cracks on the inner piping wall, the outer piping must act as a containment structure. Since there were few data available on mechanical and structural behaviors for double wall piping design, attention has been concentrated on two objects:

- (1) to study experimentally mechanical and structural behaviors on double wall piping, and
- (2) to develop a computer code for static analysis, and vibration and earthquake response analysis of the structures.

The models of double wall piping with the pad-connections, the welded flange connections and bellow structures were erected. The inner piping should have the mechanisms so as not to be constrained by the outer one, and the difference of expansion and contraction between them can be absorbed by bellow structures. These models break down into four kinds; the straight model, the curved model, the bellow model and the simulated loop model.

A computer code for numerical solutions on these experimental models was developed. In this computer code the modified Choleski decomposition method, the power method and other useful methods were employed.

The computed results on the vibration and static analysis for the experimental models have shown good agreements with the experimental results.

Thus it was indicated that this code can be provided for practical use of double wall piping analysis.

This work was performed as a part in a series of the research and development programs of Japanese Prototype Fast Breeder Reactor "MONJU" under the contract between Power Reactor and Nuclear Fuel Development Corporation and a group of Mitsubishi.

1. Introduction

The double wall piping structures are to be adopted for the main and auxiliary primary coolant systems of the Japanese Fast Breeder Reactors. The double wall piping structures consist of inner piping and outer one. Through the inner piping flows the sodium coolant and through the annulus between them passages preheating gas. In case of sodium leakage through small cracks on the inner piping wall, the outer piping must act as a containment structure. Since there were few data available on mechanical and structural behaviors for double wall piping design, attention has been concentrated on two objects in this work;

- (1) to learn experimentally mechanical and structural behaviors on double wall piping, and
- (2) To develop a computer code for static analysis, and vibration and earthquake response analysis of the structures.

2. Experiment

2.1 Experimental models

Models of double wall piping with the pad connections, the welded-flange connections and with the bellow structures were erected. The inner piping should have the mechanisms so as not to be constrained by outer one, and the difference of expansion and contraction between them due to temperature change can be absorbed by bellow structures. These models break down into four kinds; the straight pipe model (S1), the curved pipe model (C2), the bellow model (B3) and the simulated loop model (Z4). S1, C2, B3 and Z4 are shown schematically in Figs. 1, 2, 3 and 4 respectively. These models have a reduced scale of about one-fourth of life module.

The material, the outer diameter and the wall thickness of the inner piping and the outer piping of S1, C2 and Z4 are as follows.

Inner piping: material - steel, outer dia. $D = 241.8$ mm, and wall thickness $t = 6.2$ mm

Outer piping: material - austenitic stainless steel (JIS SUS304), outer dia.
 $D = 267.4$ mm, and wall thickness $t = 3.5$ mm

The bellow model B3 and the bellow members of S1, C2 and Z4 are made of austenitic stainless steel (JIS SUS304).

2.2 Experimental procedure

(1) Static testing

One end of models, S1 and C2, was rigidly connected to the horizontal test floor in vertical direction. Concentrated load perpendicular to the vertical axis were applied to the other free end with an oil jack. Ends of Z4 were rigidly connected to the horizontal test floor and to the vertical plane respectively. Concentrated loads were applied to the two points of the inner piping from the vertical and horizontal directions within a plane which contained the axes of the piping. One end of B3 was fixed on the horizontal test floor and load was applied to the other free end.

Fig.5 shows the procedure of the static and dynamic test of S1.

The deflections of 9 points of S1, 11 points of C2, and 24 points of Z4 were measured with dial gauges. Measurements were performed on two connecting conditions between the outer piping and inner piping; the pad-touching and pad-free conditions.

The bellow model (B3) was tested to obtain stiffness of bending, rotation, expansion and shearing about the model axis. Stiffness constants obtained here were used as input data for numerical analysis.

(2) Dynamic testing

Dynamic (natural vibration frequency) tests were conducted with the use of an electro-dynamic shaker attached to the free end of S1, C2 and two points of Z4. Natural vibration frequencies were measured with the mechanical impedance method. Vibration mode as an acceleration mode was measured with the use of mode analyser at the same time. The measurements were also conducted on two connecting conditions; pad-touching and pad-free conditions.

2.3 Experimental results

Experimental cases of two testings are shown in Table .

(1) Static

Table shows the free end deflections of S1 and C2 due to static loads.

(2) Dynamic

Table shows the natural vibration frequencies of the models (S1, C2 and Z4).

Fig. 6 shows the 1st natural vibration mode of C2.

2.4 Discussion

(1) Static

As the bellow of the outer piping has extremely low stiffness than that of the other model structural members, the large deflection of the outer piping appeared at the bellow member. Therefore the deflection of the inner piping is considerably different from that of the outer one.

(a) Stiffness contribution ratio of the outer piping to the whole structures of the models. Stiffness contribution ratio of the models calculated from the experimental results have varied from about 5 to 15%. This variation is due to the pad connecting condition between the inner piping and the outer piping. The stiffness contribution ratio resulted in very low value, because the inner piping had adopted the mechanisms so as not to be constrained by the outer one.

(2) Dynamic

The natural vibration frequency of the experimental results for S1 has agreed with the numerical values from the computer code. The influence of the connecting condition between the inner piping and the outer one with a pad structure was concluded as described below. The pad structure has little influence on the vibration mode and natural frequency in the case of the 1st vibration mode, but a great influence has been observed in the case of the higher mode due to the dominance of the local vibrations of the models.

3. Computer code

3.1 Computer code development

Computer code was developed in order to compare the experimental results with the theory. In this computer code, the double wall piping is considered as coaxial double tube with finite stiffness. The static and dynamic equations for a structure are expressed as:

$$[K] \{X\} = \{F\} \tag{1}$$

$$[M] \ddot{\{X\}} + [C] \dot{\{X\}} + [K] \{X\} = \{F(t)\} \tag{2}$$

respectively, where

[K] : stiffness matrix for the structure

[M] : mass matrix for the structure

[C] : damping matrix for the structure

- $[X]$: displacement column matrix for the structure
- $[F]$: static load column matrix for the structure
- $[F(t)]$: dynamic load column matrix for the structure
- t : time
- $\ddot{[X]}$ = $d^2[X] / dt^2$
- $\dot{[X]}$ = $d[X] / dt$

In these equations the stiffness matrix for the structure is obtained from the displacement method with elastic beam theory, whereas the mass matrix is obtained with energy method. Matrices for the double wall piping with the pad connection have been derived by numerical method.

The earthquake response analysis for the structure is also available in this code with the use of the modal vibration analysis method based upon the earthquake response spectral method.

The modified Choleski decomposition method, power method and other familiar useful methods were adopted for the numerical solutions of eqs. (1) and (2).

The computer code was constructed with the FortranIV programming language.

Fig.7 shows a schematic of the flow diagram of the code.

3.2 The description of the computer code

This code adopted the double precision processing for higher accuracy.

The numerical data were processed with IBM System 370 Model 165IJ at the Mitsubishi Computing Center.

The piping members which can be dealt in this code are as follows :

- (a) Straight piping (with shearing stiffness, end fixing rigidity)
- (b) Curved piping (with shearing stiffness)
- (c) Bellow member

The connecting conditions between inner piping and outer piping and supporting conditions in this code are listed (see Fig.8). In this code, pipings are divided into several pieces with appropriate lengths and their end is called "Joint". Inner pipings are assigned even Joint number, and outer pipings are assigned odd Joint number.

- (a) Joint 2 is rigidly connected to Joint 1.
- (b) Joints 3 and 4 are spaced through a spacer which is rigidly connected to Joint 3. ~~This spacer has a dimension larger than the width of annulus, so that these Joints act as if they were connected by a spring.~~
- (c) Joint 6 is elastically supported by a hanger and is not connected to Joint 5.
- (d) Joint 8 is rigidly supported by a damper and is not connected to Joint 7.
- (e) Joint 9 is elastically supported by a hanger, but is not connected to Joint 10.
- (f) Joint 11 is rigidly supported by a damper, but is not connected to Joint 12.
- (g) Joint 14 is rigidly connected to Joint 13, and further Joint 13 is supported by a damper.
- (h) Joint 16 is rigidly connected to Joint 15, and Joint 15 is supported by a hanger.
- (i) Joints 17 and 18 are independent each other.
- (j) In the annulus between Joints 19 and 20, there is a pad mechanism. This pad mechanism is freely movable for axial direction but constrained for radial direction. Following items can also be put in the form of input data.

Lumped mass, distributed mass, concentrated load, deflection type load, distributed load, mass of insulating materials enclosing outer piping, mass of fluid flowing through inner piping, rigid or elastic type piping support.

3.3 Analytical results on the experimental models

Some examples of analytical results on this experiment are listed below.

(1) Results

An analysis on a single piping simply supported at the both ends conducted in order to compare to the theoretical value from Mechanical Handbook. Table IV shows the numerical solutions of this piping (Fig.9) in static analysis. The theoretical values are also listed in the same table. The comparison of these values has found to be in fairly good agreement. Table II shows the solutions of static analysis, and the experimental results are also listed in the same table. Figs.10, 11 and 12 show the analytical models of S1, C2 and Z4 respectively. Table III shows the results of dynamic analysis and the experimental results. There is a good agreement between numerical solutions and experimental results. Table V shows an example of input and output data list.

(2) Discussion

Previously, fairly good agreement with strict solution has known in the numerical solution for the single piping simply supported at the both ends. This time, the numerical solutions of static and dynamic analyses on S1 has agreed with the experimental results with only a little error. This error has been caused by the evaluation difference of the boundary conditions.

The comparison of numerical solutions with experimental results in Table II has revealed a difference. The authors have the following reason for this difference. In numerical analysis of C2, the value of the flexibility factor of the elbow element of the model was calculated from the equation of ASME Code Sec.III NB-3687.2. As the ASME Code equation is a design equation, the calculated value of flexibility factor of the model is supposed to be more conservative than the actual value. The following alteration of the flexibility factor in the numerical analysis led to closer agreement: for instance, $k = 6.5$ resulted in a free and deflection of 0.3985 cm in static analysis under a loading of 2 ton, and 60.27 Hz in dynamic analysis. The experimental values are 0.402 cm and 59 Hz respectively.

The experimental and numerical values of Z4 showed a good agreement with each other.

4. Conclusion

The static and dynamic experiments on the straight pipe model, the curved pipe model, bellow model and the simulated loop model revealed the structural and mechanical behaviors of the double wall piping structure. The structural mechanisms adopted here has shown that the static and dynamic influence of outer piping on the entire piping structure is little, so that the computer code developed in this work has found to be available in the double wall piping analysis. Thus, it was concluded that this can be provided for practical use of double wall piping structure analysis of the Japanese Prototype Fast Breeder Reactor.

This work was performed as part in a series of the research and development programs of Japanese Fast Breeder Reactors under the contract between the Power Reactor and Nuclear Fuel Development Corporation (PNC) and a group of Mitsubishi from Nov. 1971 to Sept. 1972.

Part of the experiments was performed at Obayashi-Gumi Technical Research Institute, Tokyo.

5. Acknowledgement

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Table I Experimental cases

Items	Case No. (Static)	Case No. (Dynamic)
S1 pad-free	1	11
pad-touching	2	12
C2 pad-free	3	13
pad-touching	4	14
B3	5	-
Z4 pad-free	-	16
pad-touching	-	17

Table II Free end deflection of S1 and C2 due to the static load of 2 ton

Item	Exp. Case No.	Deflections (Experiment) (cm)	Deflections (analysis) (cm)
S1 pad-free	1	0.167	0.162
pad-touching	2	0.165	0.160
C2 pad-free	3	0.432	0.626
pad-touching	4	0.402	0.531

Table III The natural vibration frequencies of S1, C2, and Z4

Item	Exp. Case No.	Frequency (Experiment) (Hz)	Frequency (Analysis) (Hz)
S1 pad-free	11	94	97.8
pad-touching	12	94	98.0
C2 pad-free	13	57	45.8
pad-touching	14	59	50.9
Z4	pad-free	20.7 (1st)	18.38 (1st)
		27.8 (2nd)	25.66 (2nd)
		36 (3rd)	34.55 (3rd)
	pad-touching	21.3 (1st)	21.28 (1st)
		28.5 (2nd)	29.12 (2nd)
		37.6 (3rd)	38.38 (3rd)

Table IV Deflection of the single piping simply supported at the both ends

Joint	Deflection (Numerical results) (cm)	Deflection (Theoretical value) (cm)
1	0.0	0.0
2	-0.8690	-0.8685
3	-1.2196	-1.2191
4	-0.8690	-0.8685
5	0.0	0.0

Table V Example of input data list
DATA LIST

1	2	3	4	5	6	7	8
1	1						
2	500	6	1.-3	1.-3			
3	EIGENVALUE PROBLEM OF Z-SHAPED MODEL						
4	JOINT						
5	J1NT11	1	212.0	251.0	181.0		111111
6	J1NT11	3	212.0	243.2	181.0		
7	J1NT11	5	212.0	185.4	181.0		
8	J1NT11	7	212.0	147.6	181.0		
9	J1NT11	9	212.0	95.8	181.0		
10	J1NT11	9	1.11-23.68821.845			1.845	MASS
11	J1NT11	11	212.0	71.0	181.0		
12	J1NT11	11	1.11-23.68821.845			1.845	MASS
13	J1NT11	13	212.0	34.1	181.0		
14	J1NT11	15	202.0	10.0	181.0		
15	J1NT11	17	177.9	0.0	181.0		
16	J1NT11	17	109.9	0.0	181.0		
17	J1NT11	19	1.11-23.68821.845			1.845	MASS
18	J1NT11	21	141.0	0.0	181.0		
19	J1NT11	21	1.11-23.68821.845			1.845	MASS
20	J1NT11	23	120.4	0.0	181.0		
21	J1NT11	25	106.0	0.0	181.0		
22	J1NT11	27	99.8	0.0	181.0		
23	J1NT11	27	1.11-23.68821.845			1.845	MASS
24	J1NT11	27	71.0	0.0	181.0		
25	J1NT11	29	1.11-23.68821.845			1.845	MASS
26	J1NT11	31	34.2	0.0	181.0		
27	J1NT11	33	10.0	0.0	171.0		
28	J1NT11	35	0.0	0.0	146.8		
29	J1NT11	37	0.0	0.0	136.6		
30	J1NT11	37	1.11-23.68821.845			1.845	MASS
31	J1NT11	39	0.0	0.0	110.2		
32	J1NT11	39	1.11-23.68821.845			1.845	MASS
33	J1NT11	41	0.0	0.0	85.9		
34	J1NT11	43	0.0	0.0	69.6		
35	J1NT11	45	0.0	0.0	49.3		
36	J1NT11	47	0.0	0.0	28.9		
37	J1NT11	47	1.11-23.68821.845			1.845	MASS
38	J1NT11	49	0.0	0.0	0.0		111111
39	J1NT11	49	1.11-23.68821.845			1.845	MASS
40	J1NT2	2	212.0	251.0	181.0		111111
41	J1NT2	4	212.0	241.2	181.0		
42	J1NT2	6	212.0	195.4	181.0		
43	J1NT2	8	212.0	147.6	181.0		
44	J1NT2	10	202.0	95.8	181.0		
45	J1NT2	12	112.0	71.0	181.0		111111
46	J1NT2	14	212.0	34.1	181.0		
47	J1NT2	16	202.0	10.0	181.0		
48	J1NT2	18	177.9	0.0	181.0		
49	J1NT2	20	109.9	0.0	181.0		
50	J1NT2	22	2141.0	0.0	181.0		111111

MODE = 1 FREQUENCY = 21.387

JOINT	D-X	C-Y	D-Z	R-X	R-Y	R-Z
1 1	0.0	0.0	0.0	0.0	0.0	0.0
2 2	0.0	0.0	0.0	0.0	0.0	0.0
1 3	0.236720-01	-0.431660-07	-0.519440-01	0.186120-02	0.360320-04	0.448070-03
2 4	0.207240-01	-0.574410-04	-0.449070-01	0.171240-02	0.378880-03	0.746670-03
3 5	0.810360-01	-0.863240-07	-0.17959	0.317040-02	0.726490-04	0.144440-02
2 6	0.751070-01	-0.115810-03	-0.16346	0.308390-02	0.737610-03	0.140950-02
1 7	0.14250	-0.129470-06	-0.35666	0.393810-02	0.160300-03	0.179390-02
2 8	0.15535	-0.173790-03	-0.33948	0.412560-02	0.113600-02	0.147280-02
1 9	0.25403	-0.172590-06	-0.55763	0.418880-02	0.143970-03	0.140750-02
2 10	0.25403	-0.231670-03	-0.55763	0.486490-02	0.151400-02	0.119940-02
1 11	0.31998	-0.264530-03	-0.70447	0.512740-02	0.174140-02	0.229310-02
2 12	0.31998	-0.264530-03	-0.70447	0.512740-02	0.174140-02	0.229310-02
1 13	0.40610	-0.133150-03	-0.89186	0.505100-02	0.181780-02	0.231420-02
2 14	0.40536	-0.390680-03	-0.89970	0.526970-02	0.195120-02	0.229220-02
1 15	0.45718	-0.201950-01	-0.97821	0.392120-02	0.243850-02	0.140250-02
2 16	0.45714	-0.212100-01	-1.0300	0.447350-02	0.255370-02	0.188920-02
1 17	0.47320	-0.562410-01	-0.94351	0.351750-02	0.330960-02	0.111580-02
2 18	0.47303	-0.576640-01	-0.95485	0.354700-02	0.477110-02	0.108940-02
1 14	0.47322	-0.666080-01	-0.91673	0.351730-02	0.331290-02	0.131450-02
2 20	0.47384	-0.666080-01	-0.91673	0.349390-02	0.484890-02	0.106080-02
1 21	0.47385	-0.857300-01	-0.77237	0.330180-02	0.514910-02	0.444650-03
2 24	0.47385	-0.957390-01	-0.77237	0.330180-02	0.514910-02	0.444650-03
1 23	0.47391	-0.11437	-0.66421	0.329910-02	0.523290-02	0.412340-03
2 24	0.47376	-0.11489	-0.66511	0.318390-02	0.549270-02	0.480120-03
1 23	0.47393	-0.12709	-0.58777	0.329700-02	0.525900-02	0.402560-03
2 26	0.47370	-0.12740	-0.58835	0.306740-02	0.540290-02	0.482610-03
1 27	0.47396	-0.13253	-0.55476	0.329810-02	0.546250-02	0.401340-03
2 28	0.47367	-0.13253	-0.55476	0.302580-02	0.549220-02	0.449440-03
1 29	0.47351	-0.15372	-0.39369	0.283230-02	0.566040-02	0.407740-03
2 30	0.47351	-0.15372	-0.39369	0.283230-02	0.566040-02	0.407740-03
1 31	0.47370	-0.18661	-0.18750	0.270040-02	0.557430-02	0.418860-03

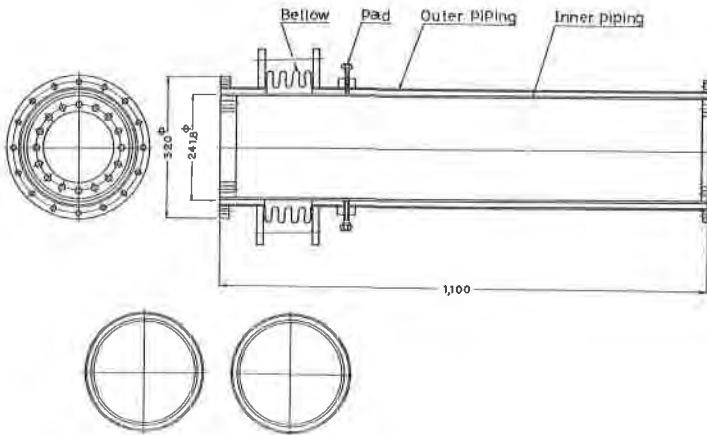


Fig.1 Straight pipe model (S1)

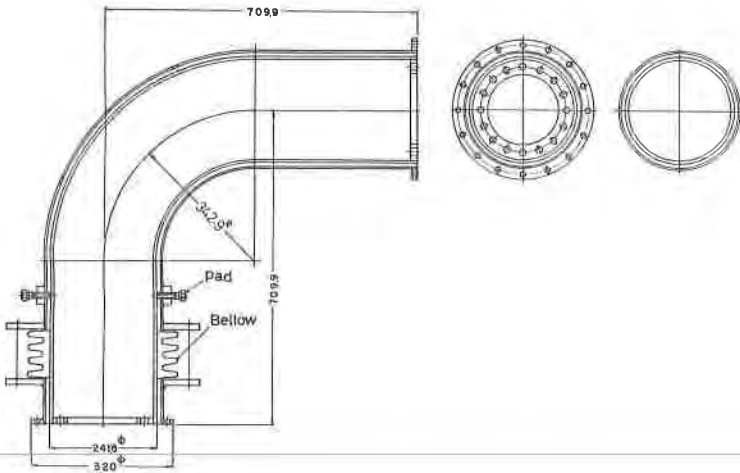


Fig.2 Curved pipe model (G2)

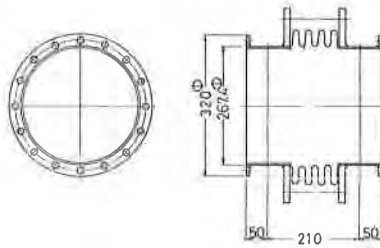


Fig.3 Bellow model (B3)

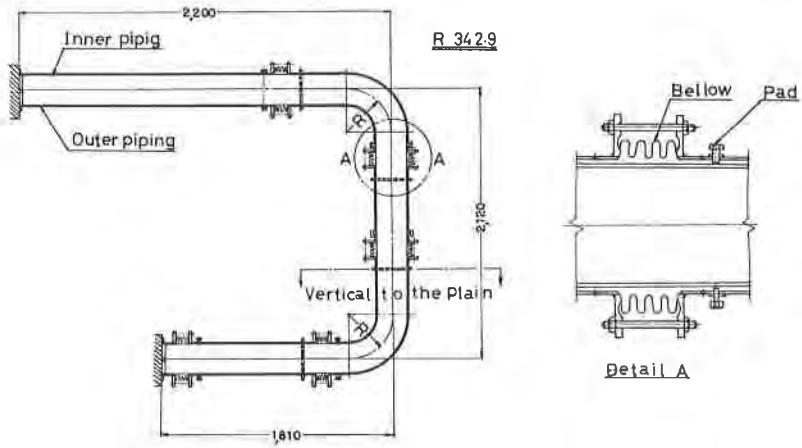


Fig. 4 Simulated loop model (Z4)

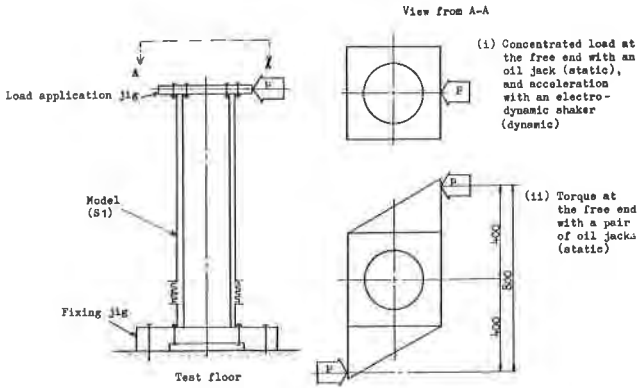


Fig. 5 Procedure of static load application (and dynamic vibration test)

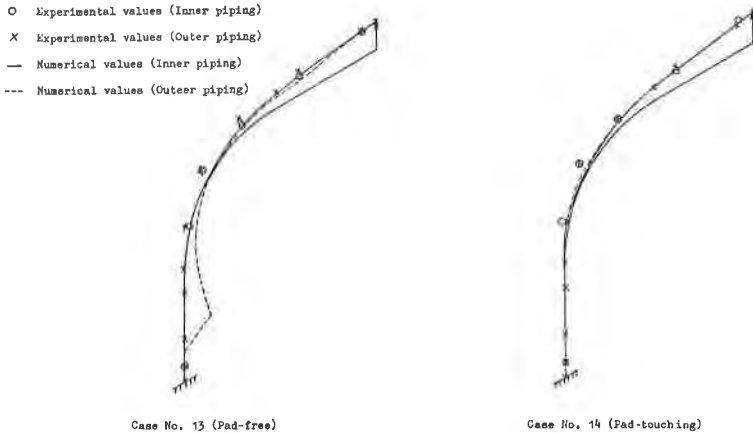


Fig. 6 Natural vibration mode (1st) of C2

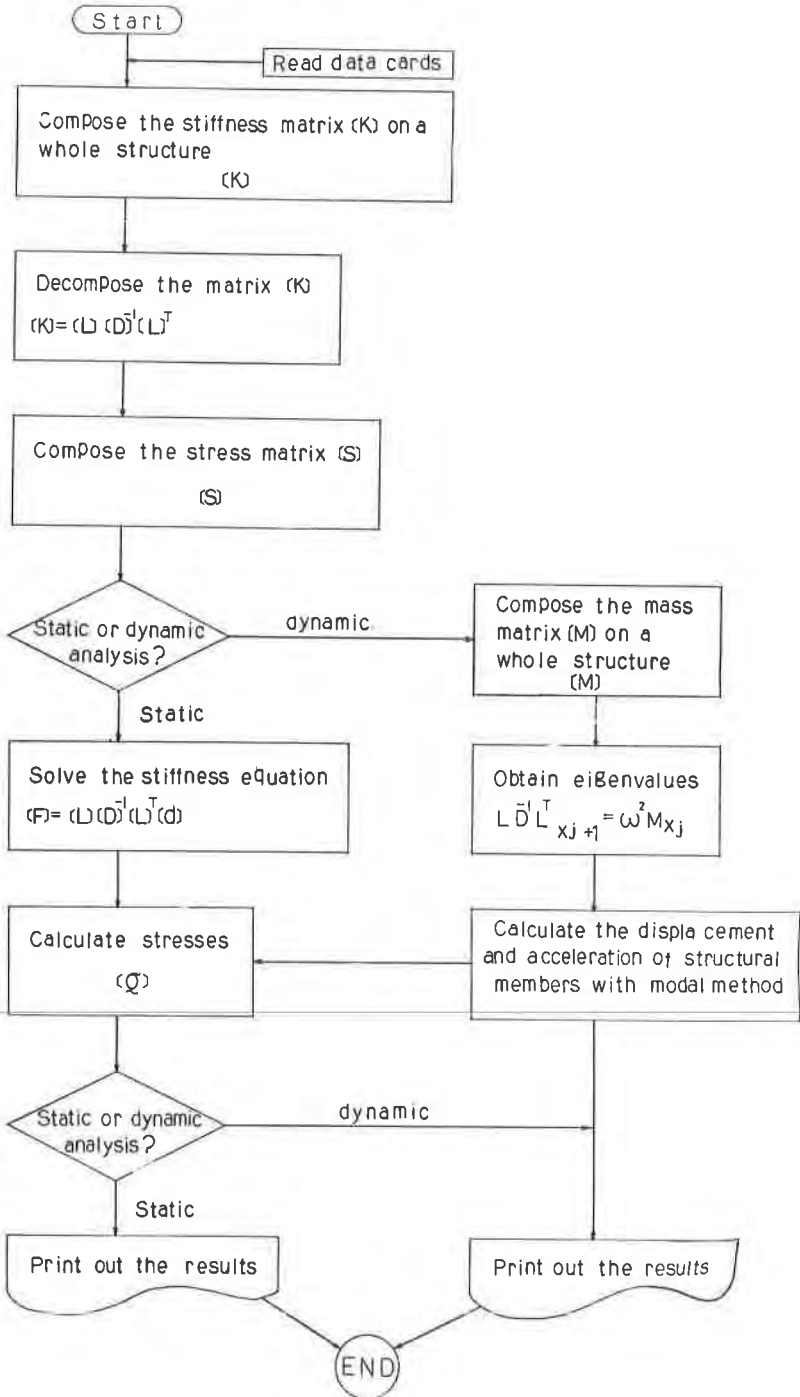


Fig.7 Schematic of the flow-diagram of the code

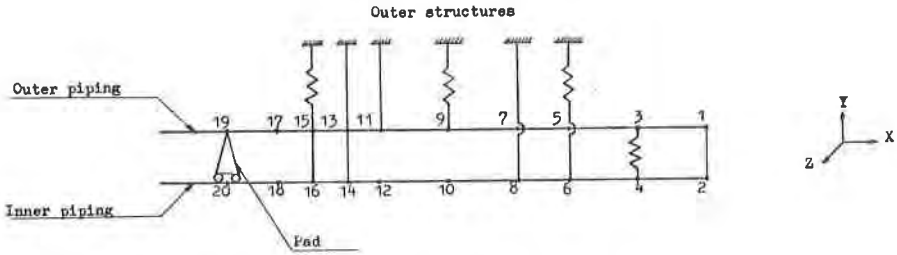
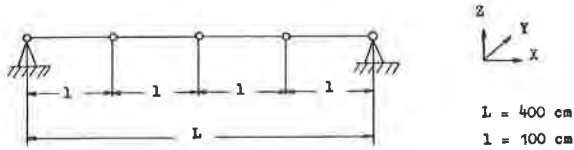


Fig.8 The description of the connecting conditions between inner piping and outer piping, and to the outer structures



Outer dia. = 4.0 cm

Thickness of piping wall = 0.5 cm

Specific weight of piping material = 12 gr/cm³

Young's modulus $E = 2.1 \times 10^6 \text{ Kg/cm}^2$

Moment of inertia $I = 8.59 \text{ cm}^4$

Fig.9 Analytical model of the single piping simply supported at the both ends

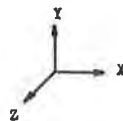
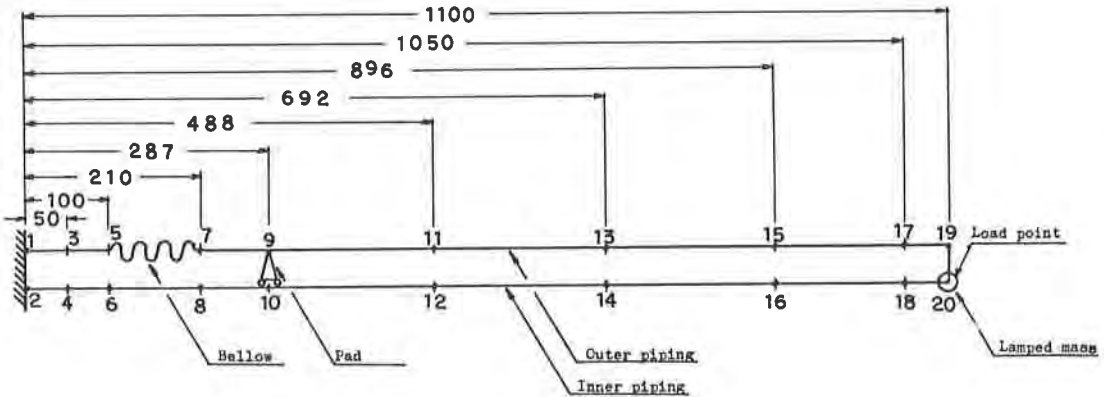


Fig.10 Analytical model of S1

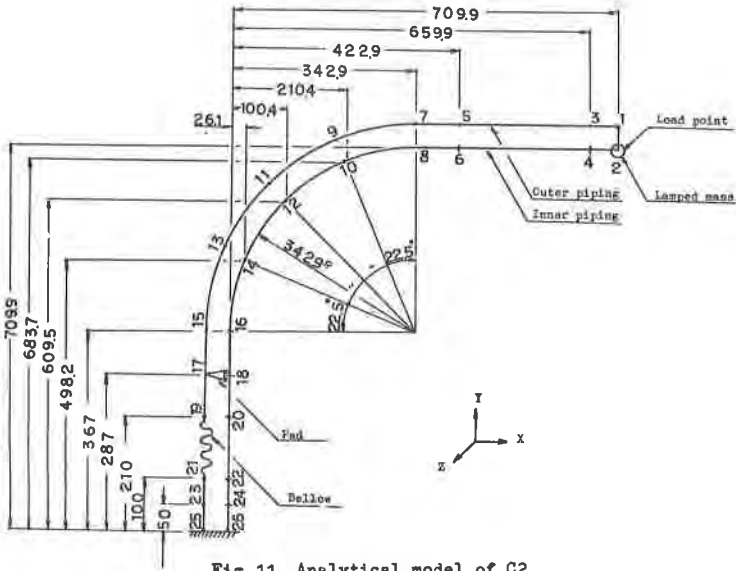


Fig.11 Analytical model of C2

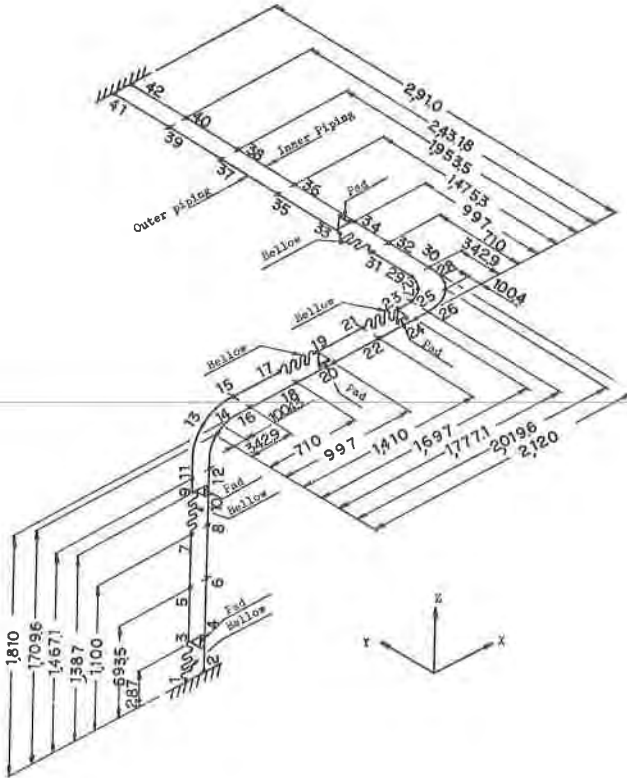


Fig.12 Analytical model of Z4