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Piping response analysis due to seismic loading

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ABSTRACT: This paper presents the results of analytical investigations in nuclear piping segment seismic behaviour by the application of numerical methods. Two types of finite elements were used for mathematical modelling: the pipe element and the thin shell element. It is our opinion that for global dynamic analysis the application of pipe element is acceptable for modelling, intended for analysis of dynamical characteristics and the level of seismic inertia forces. Nevertheless, stress concentration and deformation monitoring in specific local zones of piping structures can be more adequately implemented by the application of thin shell elements. In case of modelling with the application of thin shell elements, the sub-structure method has been used in order to perform the statical and the dynamical reduction of the total number of system degrees of freedom.

1 STRUCTURE DESCRIPTION

Figure 1 shows a segment of the suction piping the total lenght of which is approximately 25 m on the line between the suction pump and the suction collector. The system is supported at the beginning and the end on the above mentioned units, and lengthwise it is suspended by springs. Table 1 indicates the basic geometrical and material constants of the system. The temperature of the fluid is $t = 285^oC$, and the pressure is $p = 7.15\ N/mm^2$ in operation.

2 MATHEMATICAL MODELLING BY THE APPLICATION OF PIPE ELEMENTS

The mathematical model of the selected system by the application of pipe finite elements is shown by Figure 2. The model consists of 6 elbows and 36 straight pipe elements. The system involves 49 nodal points. Depending on the selection of the number and arrangement of seismic supports, the analysis is made by the application of four dynamical models. Model M01 is without seismic supports, model M02 has seismic support placed in node 17 on X & Z direction of the global axes, model M03 consists of one seismic support in 17 and one in 31 node on Z axis direction, and the M04 model involves three seismic supports, two of which are in node 17 and one in node 31.

Table 1. Geometric and material constants

Lenght of vertical segments	10,65 m
Length of horizontal segments	3,97 m
Lenght of inclined segments	3.19 m
Lenght of elbows	7.26 m
Radius of elbow	1.10 m
I.D.	752 mm
Young's modulus	$2.1x10^5 N/mm^2$
Poisson's ratio	0.3
Wall thickness	42 mm
Dead weight	13.40 kg/cm

3 MATHEMATICAL MODELLING BY THE APPLICATION OF THIN SHELL ELEMENTS AND SUB-STRUCTURE METHOD

Figure 3 shows three adjacent sub-structure of the piping with the designations of internal and external nodal points for each sub-structure. Typical sub-structure is discreted by thin shell finite elements with 20 nodal points. Each nodal point in the elements has three degrees of freedom. The mathematical model of the system consists of 15 sub-structures all together, 6 of which are elbows and 9 straight sections. The number of thin shell finite elements in the sub-structures ranges between 8 and 64 depending on the geometry

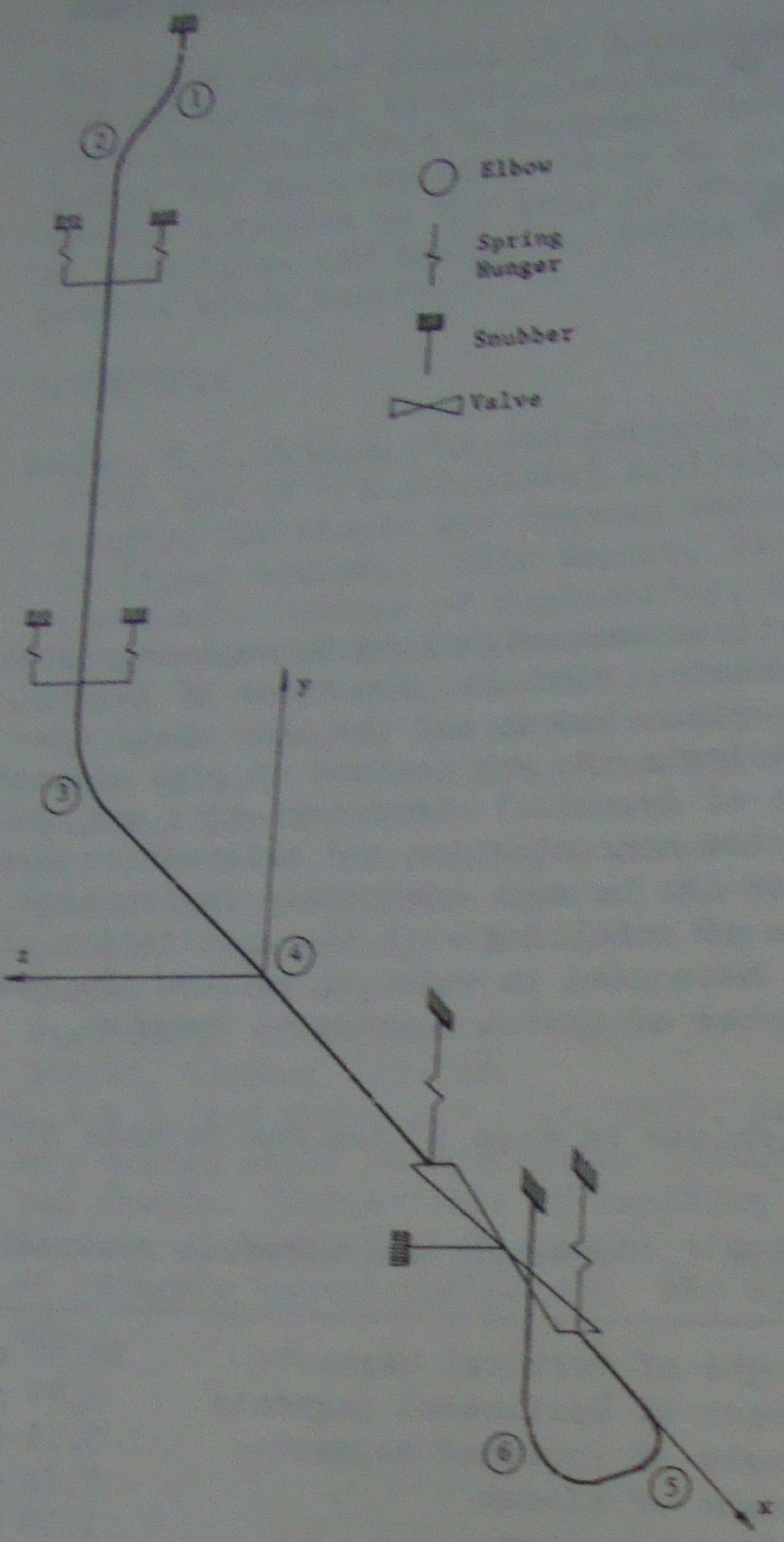

Fig.1 Piping system configuration

of the sub-structure itself. For each substructure the stiffness matrix is given by the following equation

$$K_i = \begin{bmatrix} K_{ii} & K_{ie} \\ K_{ie}^T & K_{ee} \end{bmatrix} , \qquad (1)$$

where

K_{ii} = stiffness matrix associated with the substructural internal degree of freedom

K_{ee} = stiffness matrix associated with external (boundary) degress of freedom

K_{ie} = stiffness matrix associated with inter-activity of the substructure internal and external points.

By the application of statical condensation a stiffness matrix is obtained for the substructure which is associated only to the degree of freedom of external points in the sub-structure. Thus we reduce the total number of the degrees of freedom in a given sub-structure. In case of dynamic analysis the adopted reduction procedure is by the application of Guyan's reduction vector the type of which is

$$U_i = G\ U_e \qquad (2)$$

where

U_i = vector of deformation of the internal degrees of freedom in sub-structure

G = Guyan's reduction vector

U_e = vector of deformation of Guyan's degrees of freedom in the selected nodal points within the sub-structure

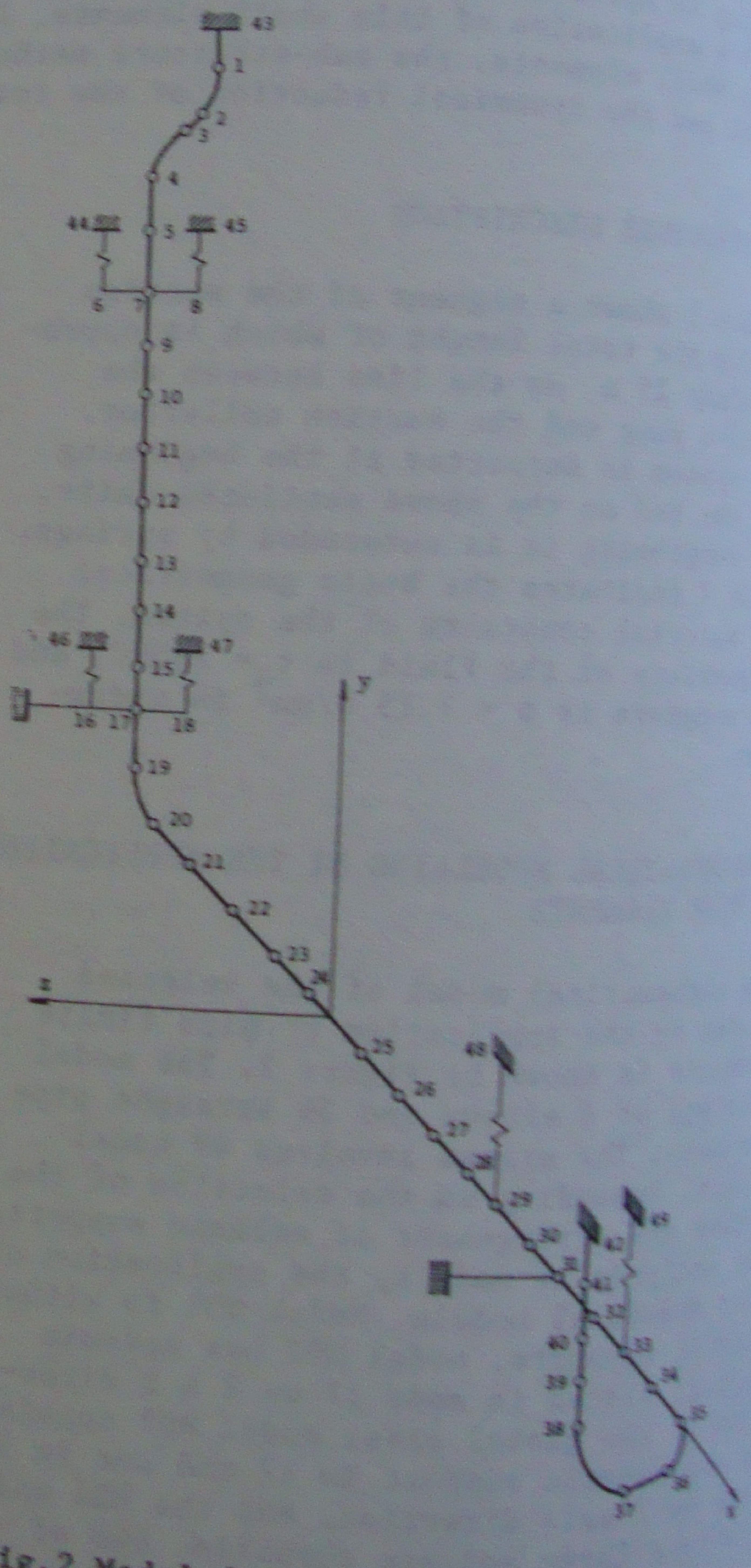

Fig.2 Model for dynamic analysis

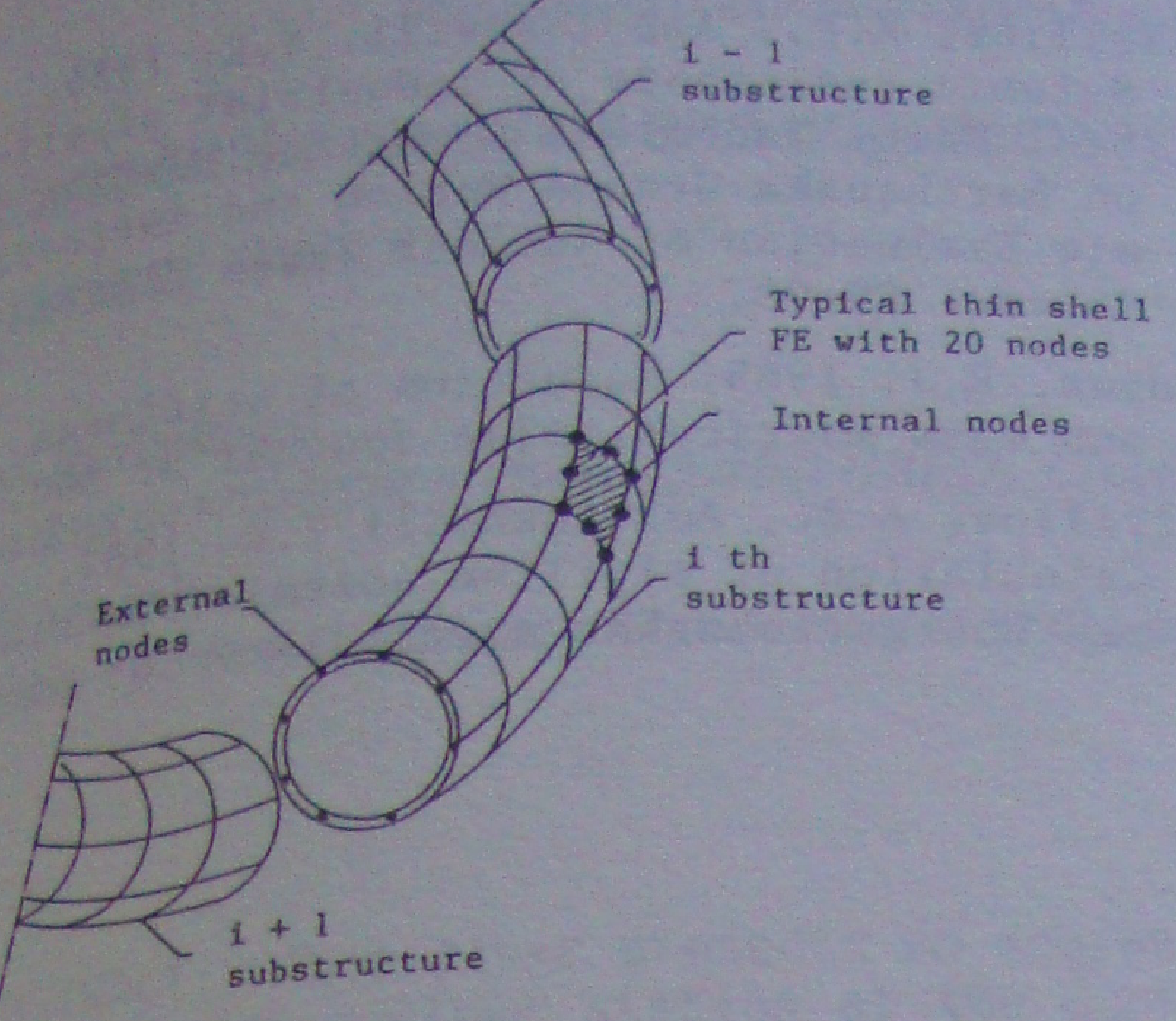

Fig.3 Segment of the mathematical model of thin shell finite elements

Reduced mass, stiffness and damping matrices of a substructure are given by equations:

$$\tilde{U} = G^T M G$$
$$\tilde{K} = G^T K G \qquad (3)$$
$$\tilde{C} = G^T C G$$

or in the developed form

$$\tilde{U} = g_i^T M_{ii} g_i + g_e^T M_{ei} g_i + g_i^T M_{ie} g_e + g_e^T M_{ee} g_e$$
$$\tilde{K} = g_i^T K_{ii} g_i + g_e^T K_{ei} g_i + g_i^T K_{ie} g_e + g_e^T K_{ee} g_e$$
$$\tilde{C} = \alpha \tilde{M} + \beta \tilde{K} \qquad (4)$$

By the application of the given reduction, a comparatively large number of the degrees of freedom in the system decreases considerably because the number of the Guyan's nodal points in each sub-structure is small.

4 ANALYSIS OF THE RESULTS AND CONCLUSIONS

Fundamental periods shown by Table 2 are obtained by the application of mathematical models of pipes finite elements. The same model was used to obtain the sectional forces in piping elements due to seismic effects for the accepted response spectra given by Figure 5. Table 3 shows the calculated stress values due to summary effect of seismic forces, temperature effects, presure and dead load in the critical cross-section of the piping. This procedure enables the assesment of the general state of stresses in the critical cross-sections of the piping structure. It is possible to locate subsequently the critical zones in the piping, and to reanalyze the deformation

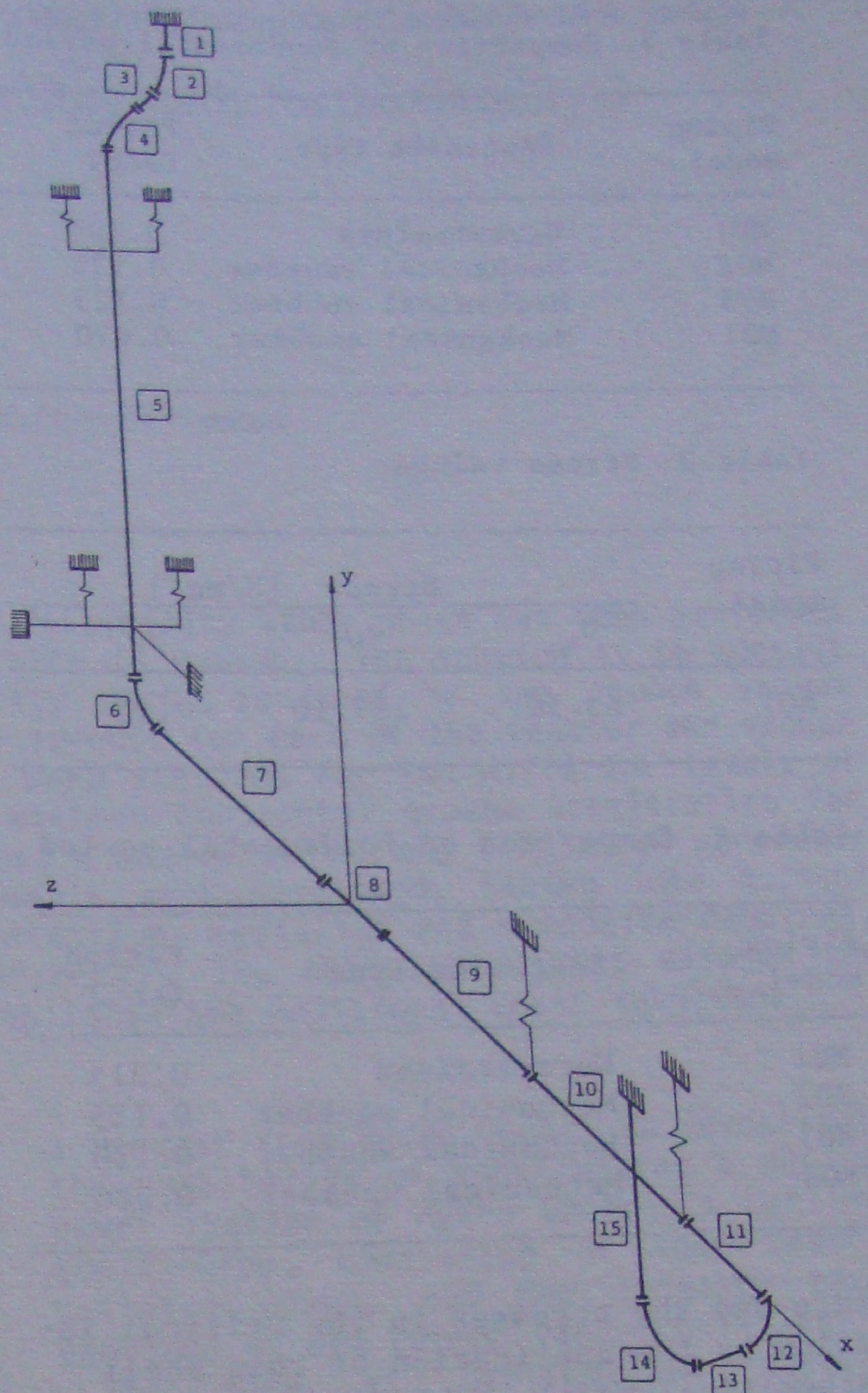

Fig. 4 Substructure numbering

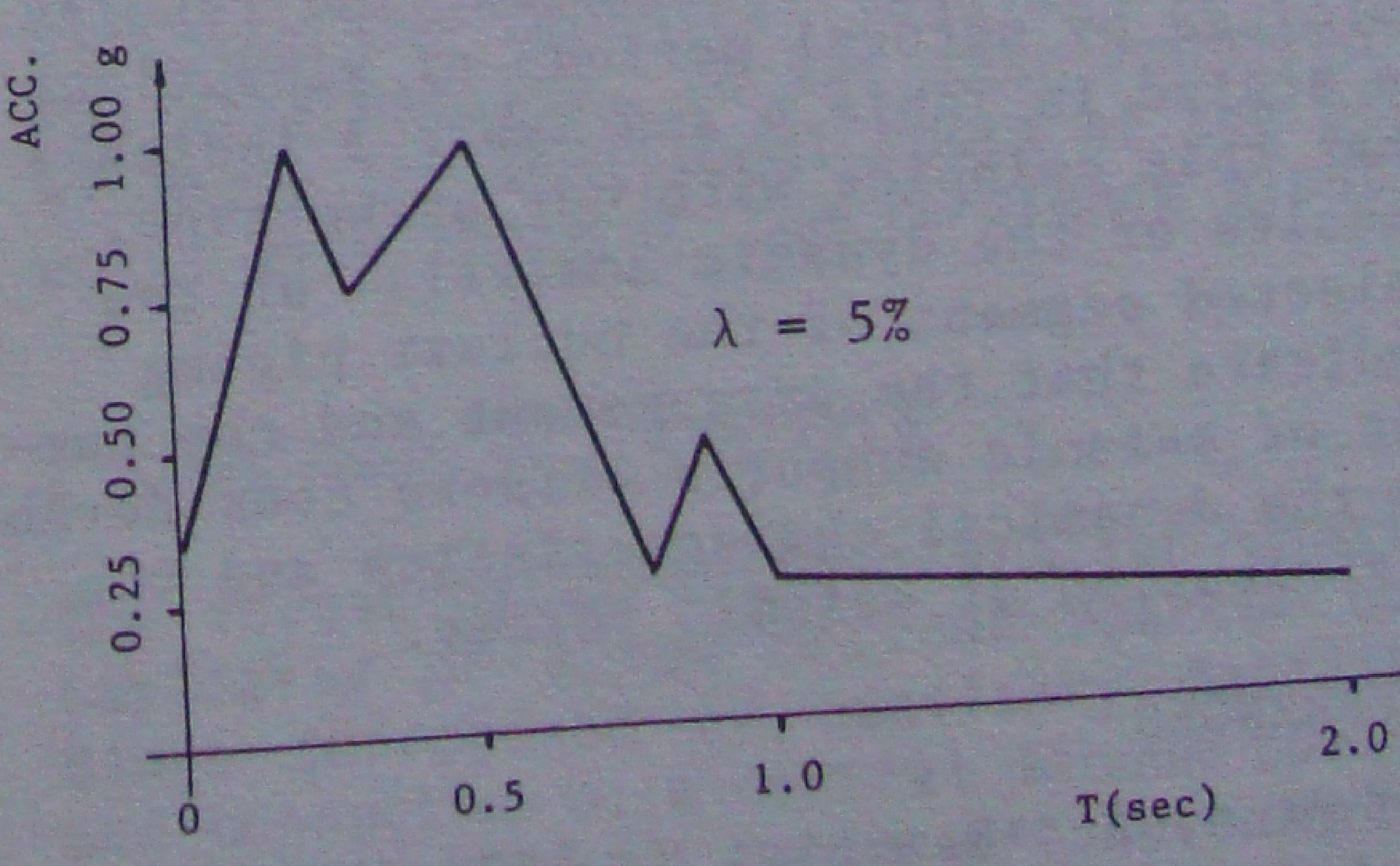

Fig. 5 Response spectra

Table 2. Comparison of fundamental period

Piping model	Restraint type	Period (sec)
M01	Unrestrained	0.303
M02	Mechanical snubber	0.130
M03	Mechanical snubber	0.125
M04	Mechanical snubber	0.070

Table 3. Stress values

Piping model	Stress (N/mm^2)		
	σ_x	σ_y	σ_r
M01	63.56	127.10	-7.15

Table 4. Comparison of fundamental period

Piping model	Restraint type	Period (sec)
M01	Unrestrained	0.315
M02	Mechanical snubber	0.135
M03	Mechanical snubber	0.130
M04	Mechanical snubber	0.080

state and the stresses in the critical location by the application of thin shell mathematical model. Table 4 shows the results of the fundamental vibration periods obtained by thin shell model. In this case, by the application of Gyan's reduction type, the total number of the system degress of freedom is considerably reduced, because 3 Guyan's points at the most were taken in each sub-structure. This brings us to the conclusion that when applying the substructural method it will be possible to use efficiently in analyses this type of mathematical model with a comparatively large number of degrees of freedom. The results obtained by natural periods of vibrations as stated in Table 4 and Table 3 indicate that this coincide with our assumption. Results of the dynamic analysis of the selected segment of the nuclear piping indicate that the arrangement and the number of seismic aupports effects considerably the dynamical characteristics and the distribution of seismic forces.

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