COMPUTER AIDED STATIC ANALYSIS OF PIPING SYSTEMS

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Summary

The static analyis program system outlined in the study is used for the static analysis of large complex piping systems (with several hundred network points). With the program system several load cases can be tested simultaneously. The practical use is aided by the data preparation and the plotting programs.

The static analysis program system is prepared to be run on the R32 computer of the Technical University of Budapest. The summary characteristics of the program system are shown in Table 4.

Introduction

During static analysis the basic task is the numerical control of static specifications necessary for the fairly safe operation of a particular piping system developed on the basis of preliminary design considerations. Consequently, the task of the static analysis program system is to determine the deformation, force, moment and stress state of the construction and to compare the resultant reduced stresses rising in certain cross sections with the allowable stress of the material.

The static analysis is based on the finite element method that has its foundations in the displacement method, according to which the piping system has to be divided into members and the connecting points of the pipe members are the so-called network points and the computation results characterize these network points.

The developed static analysis program system has the following characteristics:

— the examined pipeline can be of optional space arrangement and an optional number of branches and/or loops;
— it can join the environment with an optional number of hangers and support (restraints). The hangers can be rigid or flexible;
— the member set to be used for modelling: a straight pipe bend (a pipe with an optional central angle and a curved centerline,) a tee, an expansion joint and valve;

— as a load, concentrated forces and moments, gravity loading (dead weight, coating weight, charge weight), thermal load, internal pressure and displacement loadings (e.g. mounting prestress), and/or their optional combination can be taken into consideration. The program is also suitable for computing wind loadings;
— the program is suitable for the reception of both metric and English unit data, and also the results can be printed out in both unit systems;
— as computation results, the displacement of the typical points of the system with a particular construction and loading, as well as the pipe end and supporting forces are derived. The program computes the forces, moments and stresses at the characteristic points, as well as the resultant stress and the safety factor, in conformity with the ANSI B.31.1, ANSI B.31.3, ANSI B.31.4, ANSI B.31.8 standards or with the HMH theory, according to the designer's choice;
— it is also possible to determine the basic data of the compensating spring hangers.

The static analysis program system consists of three interlinked programs that can also be run independently: the data preparation and check program, the static analysis program and the plotting program. The schematic structure of the program system is illustrated in Fig. 1.

Data set preparation and check program

The data preparation and check program (AELK) has to produce, check and sequence the data set necessary for the static analysis, on the basis of the designer data supply. The data set preparation program—depending on the structure of the pipe line to be examined—is capable for the input and generation of the necessary data in more than one way.

There are five possibilities to determine the location of the characteristic points—the so-called network points—of the pipe:
— according to absolute coordinates in a predetermined global coordinate system;
— according to relative coordinates in relation to another network point;
— pointing out the direction, according to the relative length in relation to another network point;
— the generation of the network point of the curved member by means of the tangent intersection point and the radius of curvature;
— the generation of the network point of the curved member by means of the center of curvature, the radius and the central angle or the projection length of the pipe bend measured on the tangent.

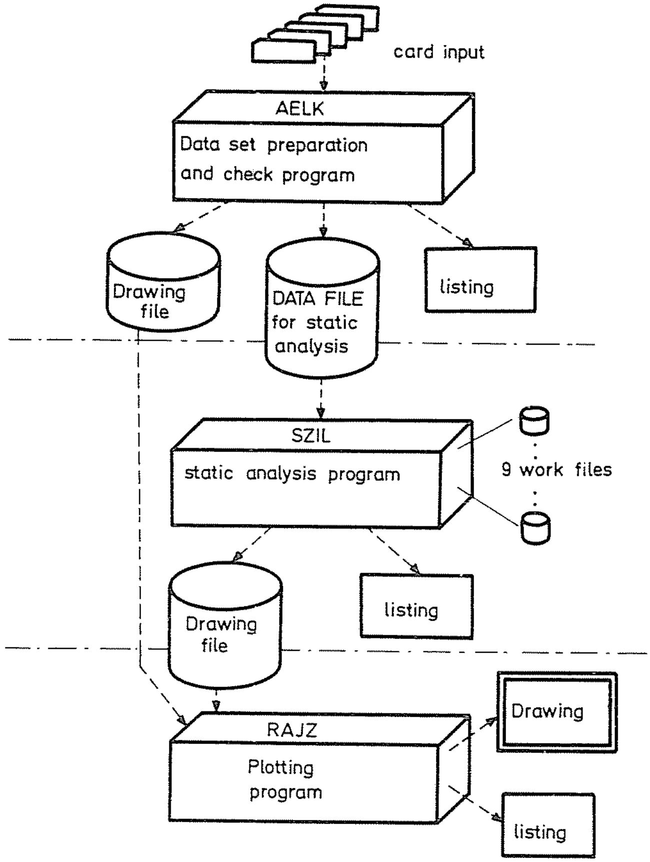


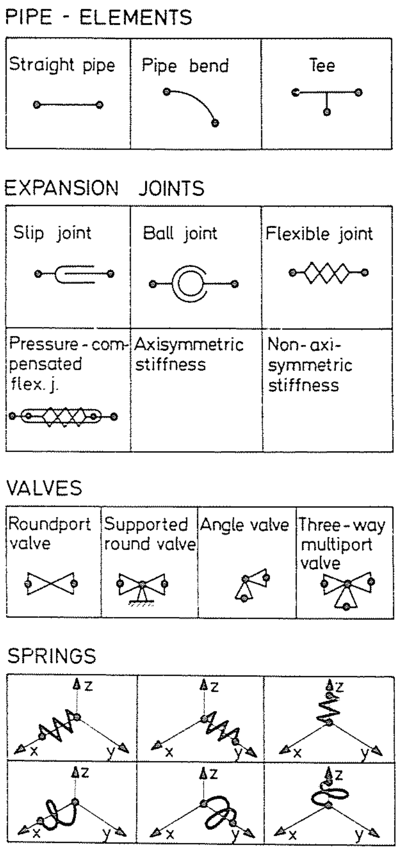
Fig. 1. Schematic structure of the static analysis program system

The temperature of the construction can be characterized by the network point temperatures.

At the supports highly stiff springs are generated by the program; they can be overwritten by the actual spring stiffnesses in case of flexible supports. Also specified displacement loads can be imposed on the construction through the spring members.

The member set to be used for the modelling of the piping system is summed up in Table 1. To describe the particular members, the following quantities can or have to be given:

— in case of piping members the outside diameter, the wall thickness, the reinforcement wall thickness (in case of curved members the medium radius of curvature), and to calculate the deadweight, the densities (the densities of the pipe material, charge and coating) or specific deadweight;



— in case of expansion joints the outside diameter, the mass of the compensator and the characteristic spring stiffnesses;
— in case of valves the characteristic diameter and the mass of the valves.

The material properties for all types of members can be obtained from a given data file. The data file includes the mechanical (modulus of elasticity, Poisson's ratio, linear coefficient of thermal expansion) and static (tensile strength, yield point, duration strength, etc.) characteristics of the most frequently used pipe materials as a function of temperature. In case of materials not included in the data file, it is possible to input these material characteristics.

The data preparation program checks the input data set from a syntactic aspect and there are nearly one hundred types of error messages to help the designer to detect the errors.

The data preparation program is of a batch operation type, its operative storage demand is 130 . . . 140 kB, and the data necessary for the static analysis are put on a low-speed magnetic storage file.

Static analysis program

The core of the static analysis program system is the static analysis program (SZIL) [1] The program—its schematic structure is shown in Fig. 2—calculates the deformation and stress state of the piping system on basis of the displacement method. The principal parts of the program are:
— to set up the member stiffness matrices and member load vectors;
— to set up the stiffness matrix and load vector of the construction;

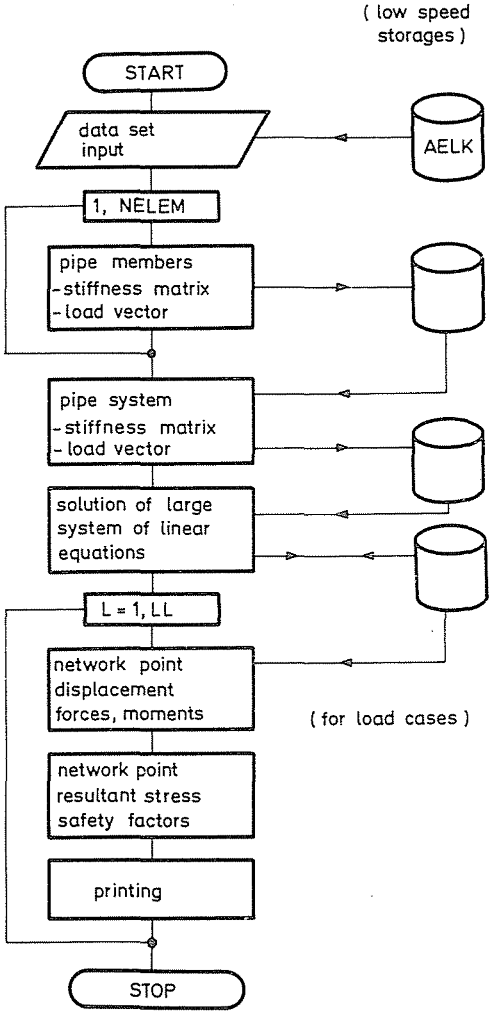


Fig. 2. Flow-chart of the static analysis program

— to solve the system of linear equations, determining the network-point displacements;
— to calculate the forces, moments and stresses in the network points.

In order to generate the member stiffness matrices and load vectors the program has the following characteristics:

— the members in each network point have six freedom degrees with three displacement possibilities and three rotation possibilities. Accordingly, the components of the network point load vector are: axial force, two shear forces, torque and two bending moment components;
— when generating the stiffness matrix of the straight pipe the axial, shear, bending and torsional stresses are defined. When bending the curved member, the change in stiffness resulting from the distortion of the cross section is taken into consideration by the Kármán factor [2];
— the valves are considered as highly stiff members by the program; members which are, nevertheless, characterized by thermal expansion specificities;
— the stiffness matrix of the expansion joint consists of the six stiffness characteristics resulting from the structure of the expansion joint;
— the distributed weight acting on the member (dead weight, wind loading), the thermal load and the internal pressure are reduced to the member network points by the program so that the concentrated substitute loads cause the same deformations in the members as the actual distributed weights.

The setup of the stiffness matrix of the piping system structure corresponds to the current process applied in the finite element method [3].

To solve the large linear equation system the SESOL method, well-known from literature [4], was used. It is a special form of the Gaussian elimination.

As a solution of the algebraical system of linear equations, the network point displacement vectors are derived. They consist of three displacement coordinates and three rotation coordinates for each network point. The supporting and reaction forces, as well as the components of the stress vector working in the particular network point can be determined if the displacement vector is known.

In case of compensating spring hangers, first the compensating hanger loads are determined by the program. Knowing these loads, the detailed static analysis is then performed.

From the network point forces and moments and cross section properties stress components are computed by the program and, according to the designer's choice, resultant stresses are computed in conformity with the ANSI B.31-1, -3, -4, and -8 standards. When determining the resultant stresses—in conformity with the standard specifications—the primary, secondary and occasional loads, as well as the stress concentration factor suggested for the particular pipe members are considered. The calculation of the permissible stresses also corresponds to the different specifications of the particular standards.

In addition to the above, it is possible to generate the resultant stresses according to the Huber–Mises–Henky theory.

The resultant stress is determined by the program in each network point, and a safety factor is calculated on the basis of the permissible stress. In case of a safety factor lower than 1, the designer's attention is drawn to this at the proper place, also through written information.

The static analysis programs have been tested with an example problem in the user manual of the ADLPIPE Static-Thermal-Dynamic Stress Analysis piping design system published in January, 1971.

This example problem is also included in the user manual of the SAP IV finite element program system [5].

The structure of the examined pipe system can be seen in Fig. 3. The outside diameter of the pipes is 10.74 in, the wall thickness is 0.5 in. The elasticity modulus of the pipe material is $E=2.79\times10^7$ psi, the Poisson ratio is $\nu=0.333$, the linear coefficient of thermal expansion is $\alpha=1.226\times10^{-5}$ 1/C°. The network point marked 13 is restrained in the direction of all the six degrees of

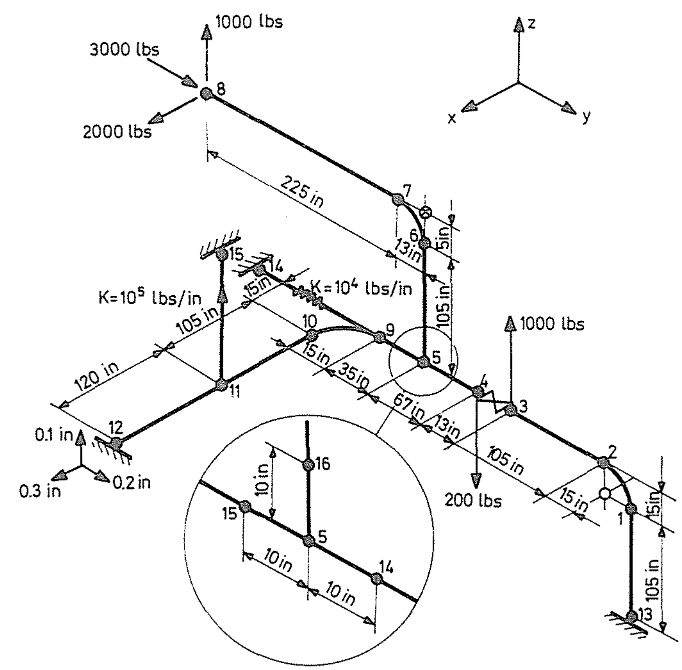


Fig. 3. ADLPIPE sample problem

freedom. At the network point marked 9 there is a spring hanger in direction y, and at the network point marked 11 there is a spring hanger in direction z. The network point marked 12 is restrained in relation to the three rotations, and in direction x, y, and z it has specified displacement components given according to the figure. The difference between the mounting and operating temperatures of the pipe system is uniformly 410 °C. To determine the deadweight of the pipe, 6.61 lb/in weight per unit length was taken into consideration.

The load state of the examined piping system is summed up in Table 2.

Table 2

Reaction forces of tested pipe system

	ADL Pipe and SAP IV			SZIL		
	F_x [1b]	F_y [1b]	F_z [1b]	F_x [1b]	F_y [1b]	F_z [1b]
Network point						
3			1000			1000
4			−200			−200
8	2000	3000	1000	2000	3000	1000
Deadweight			−6284			−6198
Valveweight						−86
$\sum$	2000	3000	−4484	2000	3000	−4484

The results (reaction forces) published in [4], and accordingly those calculated by the authors are given in Table 3. The differences are practically insignificant.

The static analysis program in this present form—in conformity with the data preparation program—is capable to test a maximum 700 network point structure. The high speed storage demand is 240 . . . 250 kB and during operation the program requires 1 . . . 2 MB capacity on low speed storage.

Table 3

Comparison of test results

Network point number	ADL Pipe			SAP IV			SZIL		
	F_x [1b]	F_y [1b]	F_z [1b]	F_x [1b]	F_y [1b]	F_z [1b]	F_x [1b]	F_y [1b]	F_z [1b]
9		5659			5643			5680	
11			−4052			−4045			−4053
12	−4966	2361	4026	−4961	2350	4023	−4964	2359	4027
13	2966	−11021	4509	2961	−10993	4505	2964	−11040	4511
$\sum$	−2000	−3001	4483	−2000	−3000	4483	−2000	−3001	4485

Plotting program

The plotting program package (RAJZ) [6] has two tasks to perform. By plotting the isometric drawing of a pipe system, on the one hand it helps survey the generated data field and detect the sematic errors. On the other hand, based on the plotting data provided by the static analysis program, the deformed state of the pipe network can be drawn in order to help quality decisions concerning the mechanical properties of the system. In conformity with its preceding functions, the network plotting program can be run after both the data preparation and the static analysis program.

The network plotting program is provided with the data necessary for plotting from a magnetic tape, and the instructions concerning the plotting itself (the representation to be applied, deformation enlargement scale, etc.) are input from cards. The drawing can be plotted on a DIGIGRAF plotter in "off-line" operation.

In case of applying the network plotting program, it is possible to choose the dimensions of the sheet and the way of representation is space.

The network plotting is basically isometric, but it is possible to choose Cavalier's axonometry or any other optional axonometry indicated by the designer. In case of the general axonometry, the direction of axes, x, y, z and the desired shortenings in the particular directions of the axes are given by the user.

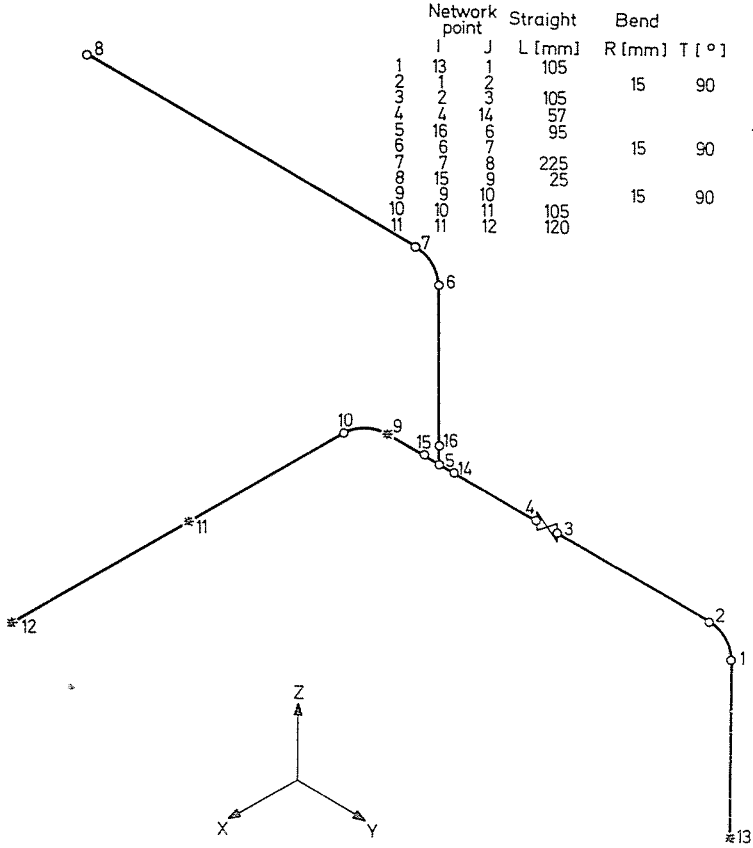
To plot the deformation, three (corresponding to the directions of the three axes) deformation enlargement scales can be given.

The plotter bonders the sheet, draws the text field and fills it in. The scale of the plotting is automatically determined by the program by comparing the useful drawing area with the maximum size of the pipe system. In the plotting, the free network points are marked by a circle, the restrained network points are marked by a star. Beside the network points their sequence number is also plotted. The valves and compensators are represented in the plotting symbolically.

There is also a possibility to write the pipe member lengths (in case of curved members the radius of curvature and the central angle).

In Fig. 4 the computer plotting of the ADL Pipe sample problem shown in Fig. 3 is demonstrated as an example.

The network plotting program requires 110 . . . 120 kB high speed storage capacity, it gets the input data from a magnetic disk and the output is a magnetic tape.



	Network point		Straight	Bend	
	I	J	L [mm]	R [mm]	T [°]
1	13	1	105		
2	1	2		15	90
3	2	3	105		
4	4	14	57		
5	16	6	95		
6	6	7		15	90
7	7	8	225		
8	15	9	25		
9	9	10		15	90
10	10	11	105		
11	11	12	120		

Fig. 4. Computer plotting of the ADLPIPE sample problem

Table 4

Principal characteristics of the static analysis program system

	AELK	SZIL	RAJZ
Programming language	FORTRAN IV	FORTRAN IV	FORTRAN IV
Operating system	OS	OS	OS
Mode of operation	batch	batch	batch
High speed storage	140 kB	250 kB	120 kB
Number of low speed storage files (preserved)	2	2	1
Number of low speed storage files (temporary)	–	9	1
Extent of program	about 2500 FORTRAN lines	about 6000 FORTRAN lines	about 2000 FORTRAN lines
Solution time of test example (16 network points)	4 s CPU	41 s CPU	22 s CPU + plotting
Solution time of a 90 network point example	12 s CPU	170 s CPU	58 s CPU + plotting

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