APPLICATIONS OF FERRANTI COMPUTERS

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Computing Stresses in Pipe Systems

Introduction

This document gives a brief description of a programme for the Ferranti Pegasus Computer, which is of the utmost importance in connection with the computation of stresses in three-dimensional, multi-anchor pipe systems (or, of course, two anchor systems as a particular case). It may be used for steam or hydraulic pipe layouts in marine or industrial installations, power-stations, chemical plant and in oil refineries.

The programme uses the method of pipe stress analysis developed by Mr. H. M. Gemmell of Yarrow & Co. Ltd., Scotstoun, Glasgow, and adapted for automatic computation by Ferranti Ltd. It is available as part of the Ferranti Computing Service; those who wish to have this type of calculation carried out should request further details.

The programme is capable of dealing with any multi-anchor system of pipe layout, up to a maximum of nine anchors. Each branch of the system (i.e. run of piping without intermediate off-shoots) is assumed to consist of a number of sections which are either straight lengths of pipe, or plane circular arcs, with any orientation in space. The physical constants of the pipe may vary in any desired manner from section to section.

The basis of the calculation is to assume that one of the anchors remains fixed in space, while given deflections are applied to the remaining anchors, which may now be regarded as 'free ends'. The deflections will ordinarily consist of those due to thermal expansion reversed in sign, with allowances made for cold pull-up etc. The programme will then compute the forces and moments which have to be applied at these free ends in order to produce the given deflections there.

Brief Description of Method

The analysis falls naturally into two parts. The first part consists of the analysis of a single branch assumed fixed at one end, that is, the computation of a flexibility matrix of order six which relates the deflections produced at the free end to the corresponding loading. (There are six components of deflection – three linear and three angular, and six components of loading – three forces and three moments.)

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Pxyz relative to the standard axes is specified by the rotations that the standard axes would have to undergo in order to coincide ultimately with the local axes Pxyz. A typical chain of rotations might run: 90° about the x-axis, 30° about the new y-axis, 5° about the new z-axis. They would be punched simply as 90/1 30/2 5/3.

If the section is rigid, the shape is irrelevant, and for such a section the letter R is punched.

As the machine reads in this tape, for each section it works out, and adds in, one more contribution to the branch flexibility matrix.

The above will give a general idea of the manner in which the geometry of the pipe system is fed into the Computer.

Presentation of Results

The final stage of the calculation is the reading in of the deflection tape, during which the forces and moments at the free-ends are calculated. Then, the three forces and three moments for the first free-end are printed out in an orderly array, followed by those for all the other free-ends in turn.

The whole calculation can be carried out in any consistent set of units; in general, pounds and inches are used.

The times for doing this calculation are very dependent on the complexity and configuration of the pipe system. They are in all cases very short in comparison with previous methods; for example a pipe consisting of a single branch with 20 sections would only take about 3 minutes, and it would be a very complicated multi-anchor system which took as long as an hour.

Conclusion

When using the previous hand methods it might have taken several months to stress a three-dimensional system with three anchors, this representing something like the practical limit. More complex systems often had to be simplified, by introducing, for example, further anchors which partitioned the complete system into manageable portions. With this programme, capable of tackling up to nine anchor points directly, the designer is given a new degree of freedom.

The input of deflection data and the calculation of the stresses comprise the final stage of the calculation, and very little extra time is required to put in a whole series of sets of deflections, thus readily stressing the whole system under a wide range of physical conditions.

In consequence of the short time for the whole calculation, it may easily be repeated whenever the designer finds it necessary to alter the pipe system, either by changing the layout, or by adding a pipe, or by changing a pipe cross-section.

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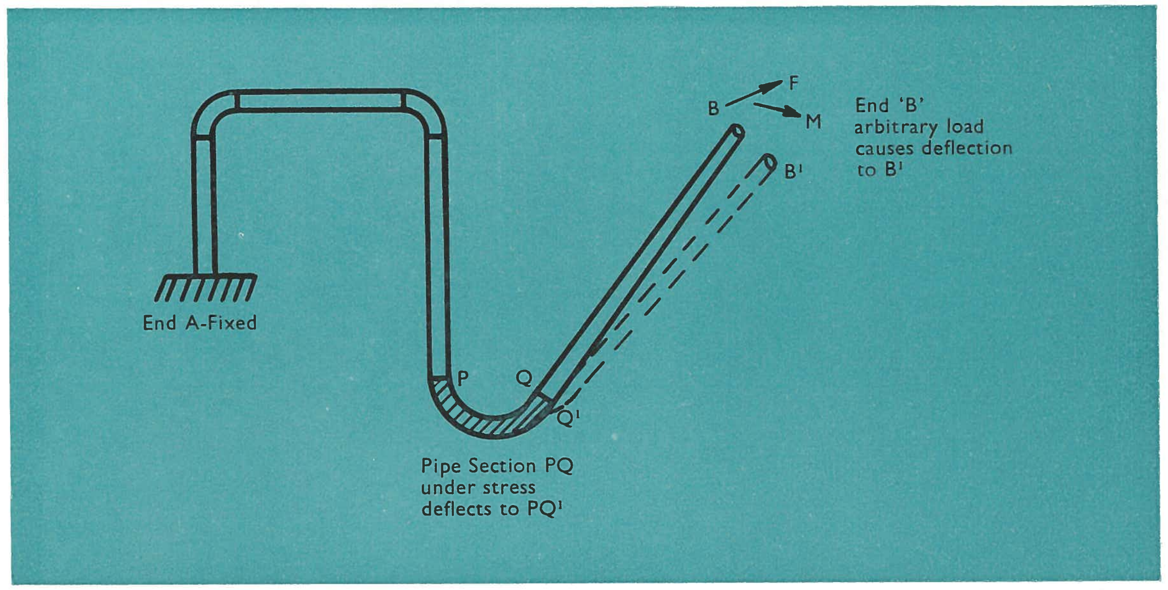

Figure 1

Consider the branch AB in Figure 1, in which end A is fixed. Suppose an arbitrary force and moment are applied to end B of the pipe. Each pipe section will, in general, bend, and thus there will be a deflection at end B. This deflection may be regarded as the sum of contributions from the individual pipe sections, due allowance being made for the geometry of the system. An individual pipe section PQ (P being nearer to A) is considered as having a certain loading applied at Q, this loading being equivalent to the given loading at B, when transferred to Q. Now the deflection of Q, relative to P, due to a known loading at Q may be expressed in terms of a square symmetrical flexibility matrix of order six (since there are six components of load and six of deflection). The elements of this matrix may be computed from the physical properties of the section PQ. When this relative deflection is known, it may be transferred to B, thus giving the contribution from section PQ to the deflection at B, due to an arbitrary loading applied at B. What is actually calculated, of course, is a flexibility matrix. This is done for each section in turn, and the sum of these matrices gives the flexibility matrix for loads and deflections at end B.

This calculation is carried out for every branch of the given pipe system.

The second part of the analysis consists of utilising these flexibility matrices, multiplied by certain geometrical matrices, to build up the final flexibility matrix of order 6m, where m is the number of free-ends. Since the deflections at the free-ends are given, it only remains for the computer to solve the set of 6m equations to give the loads that are produced at these ends.

The Multi-anchor Flexibility Matrix

If there are m free-ends in the system, the complete flexibility matrix L will be of order 6m, and may be regarded as m^2 matrices L_{hk} of order 6 by 6. The matrix L_{hk} is the flexibility matrix of the free-end h with respect to the free-end k. That is, given a load vector F_k (of six components) applied at k, then the deflection produced at h is $L_{hk}\ F_k$. The free-end labels h, k range from 0 to m-1.

Figure 2 represents a pipe system with five free ends, numbered from 0 to 4. The various branches are lettered *a*, *b*, . . . *i* for convenience. It will be seen that the flexibility of any one branch causes contributions to be made to a number of matrices L_{hk}.

Thus, in particular, section *e* will cause contributions to the matrices L_{11}, L_{12}, L_{13}, L_{22},

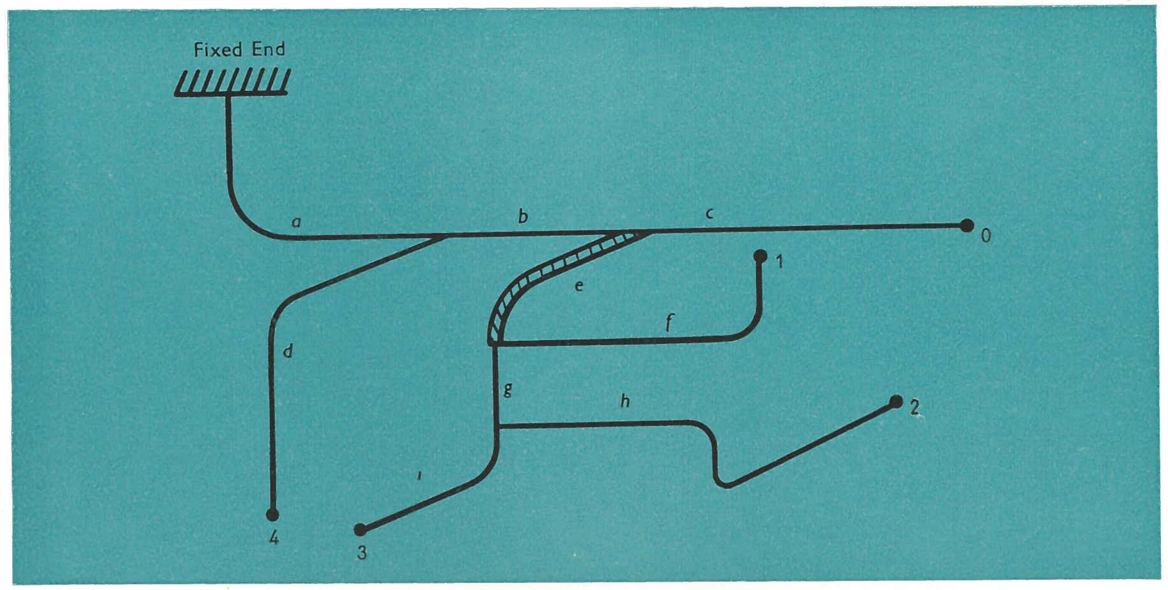

Figure 2

L_{23}, L_{33}. The actual contributions depend on the flexibility of section *e* itself, and the relative coordinates of ends 1, 2 and 3 with respect to the end of branch *e*. The flexibility matrix of branch *e* has to be pre- and post-multiplied by certain geometrical matrices in very much the same way as the flexibility matrices of the sections of branch *e* itself are treated. This is the basis of the multi-anchor programme. Each branch *a*, . . . *i* is computed in turn, and at the end of the computation for each branch, the machine works out contributions to the various matrices L_{hk}. The values of h and k to be taken depend simply on the indices of the 'downstream' free-ends, i.e. those free-ends on the side of the present branch remote from the fixed end. For branch *e* say, the numbers given to the machine would be simply 1, 2 and 3, from which the machine would compose the six combinations given above.

The matrix L is set to zero initially, and when every branch has been treated as above (so that the machine has now computed the final flexibility matrix L), a further data tape is read in on which the given deflections at the free-ends are punched. The set of equations, formed by the flexibility matrix L and the vector of deflections as the right-hand side, is now solved to give the loads at the free-ends.

Preparation of Data Tapes

Full details of the manner in which data tapes are punched will be found in another document 'Preparation of Data Tapes for the Multi-anchor Pipe Stressing Programme'.

Apart from the input of various sets of coordinates, the main item is the specification of the branch details. All the sections of any one branch are treated in turn, starting at the 'upstream' end. First of all, the letter S or C is punched according to whether the section is straight or curved. This letter is followed by other letters and numbers giving information about Young's modulus, stiffness, length (for a straight section), and radius, angle of arc, and Karman's constant for a curved section. Where several consecutive sections have a common value for some parameter (Young's modulus for example), this parameter need be punched only once. In the case of a curved section, information has also to be given about the orientation of the curve in space. This is done by taking a local set of right-handed axes Px, Py, Pz at the beginning of the section P in the above notation. These axes are such that Px is tangential to the arc (pointing 'downstream') and Py is along the inward-drawn radius. The orientation of