8005150547

TPIPE FREQUENCY ANALYSIS ALGORITHM

DESCRIPTION

NCR DETERMINATION

During the use of large structural analysis packages, such as TPIPE, there is always a possibility of finding errors. TVA continually works to minimize this possibility. TVA maintains a large set of verification benchmark problems which have been formulated to check all aspects of TPIPE's logic and calculations. Each time that TPIPE is modified for any reason, all the benchmarks are run and the results are compared, item by item, with previously accepted results. No version of TPIPE is allowed to be used for production until it can run all verification benchmarks successfully. The set of benchmarks are continually updated as TPIPE is modified.

When an error is found in the TPIPE results, the error is evaluated immediately to determine if an NCR is required. The following procedure is used to make that determination:

1. The cause of the error is determined. If the cause cannot be determined immediately, an NCR is filed.

2. The error and the cause are evaluated to determine if TPIPE could produce erroneous results which would not have been caught using standard checking procedures. If the error could have resulted in the issuance of incorrect design data, an NCR is filed. If it is determined that the erroneous results would be caught during standard checking procedures, then no NCR is filed.

FREQUENCY ANALYSIS

A frequency analysis is required in piping analysis to determine the response of a piping system to dynamic loads. The frequency analysis is used to determine the natural frequencies and mode shapes of a piping system from the piping system's equations of motion. The frequencies and mode shapes are required when calculating the piping system's response using response spectra and time history, modal super-position techniques. A complete description of the frequency analysis formulation in terms of an eigenvalue problem are given in reference 1.

FREQUENCY ANALYSIS IN THE ORIGINAL TPIPE

TPIPE is a derivative of the SAPIV structural analysis program from the University of California at Berkeley. A description of the SAPIV program can be found in reference 2. The frequency analysis algorithm in SAPIV was used in an unmodified form in TPIPE. The subspace iteration method for determining frequencies and mode shapes was the frequency analysis technique used. Some of the relevant characteristics of the subspace iteration method as found in the SAPIV and TPIPE codes are as follows:

1. The method always produces highly orthogonal modes which result in a near perfect diagonal generalized mass matrix.

2. The method iterates to a frequency tolerance of 1.0×10^{-5} and/or 16 iterations, whichever comes first.

3. The method converges to the lower frequencies and mode shapes first while the higher frequencies were not calculated to as high a degree of accuracy. The method calculates all required frequencies and mode shapes simultaneously.

A complete description of the subspace iteration method as found in the SAPIV and TPIPE codes is given in reference 3. The subspace iteration method was used in its original form for all TPIPE versions up through 3.10.

MODIFIED TPIPE FREQUENCY ANALYZER - STEP 1

The modified subspace iteration method was developed during 1977-1978. The modified method was implemented in the spring of 1979 in TPIPE version 4.0 and has been used in all subsequent versions of TPIPE.

The modified subspace iteration method uses a frequency shifting technique. As noted in section C of this report, the unmodified subspace iteration converges fastest to the lowest frequencies, i.e., the frequencies closest to the zero frequency.

It was determined that by numerically shifting the apparent zero frequency of the piping system and calculating the frequencies in small groups around each shift point, a significant reduction in the cost of a frequency analysis could be obtained (see reference 4). A 50 percent reduction in cost was realized in TPIPE version 4.0 over any previous version. Some of the relevant characteristics of the modified subspace iteration method are as follows:

1. Since the mode shapes are calculated in groups instead of all at once, all modes are sufficiently orthogonal, but the degree of orthogonality can vary slightly from one group of modes to the next.

2. Each group of frequencies and modes iterates to a frequency tolerance of 1.0×10^{-5} and/or 16 iterations, whichever comes first. After 16 iterations, if the group has not converged, then it is assumed that the results are close enough and the calculations proceed with the next group. Subspace iteration produces uniform accuracy throughout all frequencies.

MODIFIED TPIPE FREQUENCY ANALYZER - STEP 2

The modified subspace iteration method was enhanced further by code optimization performed by the OPCODE Company of Houston, Texas. The modifications did not change the algorithm's method or calculation sequences. They consisted of input/output and calculation subprograms which take advantage of the CDC machine architecture. A cost savings of over 50 percent was realized from these modifications. The OPCODE modifications were implemented in TPIPE version 4.2C in January 1980.

BROWNS FERRY RBCCW

Irregularities in the results of an analysis on the RBCCW at Browns Ferry initiated a detailed inspection of the results of that problem and an evaluation of the implications of the results. A detailed description of the inspection and the resulting conclusions was presented in reference 5.

Additional information relevant to this problem is presented in the last two sections of this report.

NCR's CEB 80-14 (SQN), CEB 80-15 (WBN), AND CEB 80-16 (BLN)

It became apparent after the Browns Ferry RBCCW problem that the generalized mass matrix and the frequency analysis output was not being properly reviewed. This resulted in a series of NCR's regarding the review of the TPIPE output. The corrective action outlined by the NCR's was as follows:

All piping problems run on TPIPE versions 4.0 through 4.2D from which design data had been issued would be reviewed. The frequency analysis output and the generalized mass matrix would be checked for acceptability. Also, the TPIPE program would be modified to perform the checking internally in all future versions.

In performing the review of the outputs as defined by the NCR, another problem was found to have the same error in the generalized mass matrix as the Browns Ferry RBCCW problem, i.e., the diagonal terms of the generalized mass matrix were other than unity. A close inspection revealed that an error existed in the modifications implemented into the subspace iteration algorithm in version 4.2C. The error, which rarely occurred, resulted in the diagonal terms of the generalized mass matrix being calculated wrong. The closely spaced modes found in the Browns Ferry RBCCW problem were symptom of the problem, but were not the problem. Since all piping analysis personnel had been directed to review the generalized mass matrix for correctness in accordance with the related NCR's, any incorrect runs generating by this error would have been found and not used. A new NCR regarding this pr[illegible] therefore was not filed.

The error described above was corrected in TPIPE version 4.2E (April 1980) at the same time that the modifications described in the last section of this report were implemented.

CONCLUSIONS AND CORRECTIVE ACTION

1. The frequency analysis output and the generalized mass matrix are being reviewed for all problems run on versions 4.0 through 4.2D for which TVA has issued design data. All problems with inconsistent generalized mass terms are being evaluated for accuracy of results.

2. To eliminate any possibility of recurrence of the situation addressed by this report, the following improvements are being implemented into TPIPE version 4.2E and all subsequent versions.

   a. All diagonal terms of the generalized mass matrix are being internally checked for unity. Any values not close to unity will cause the program to stop.

   b. All off-diagonal terms of the generalized mass matrix are being checked to be smaller than a threshold value. Any values not less than the threshold will cause the program to stop.

   c. If the program iterates on one group of modes for more than 32 iterations, the program stops.

   d. The frequencies are calculated to a tolerance of 1.0×10^{-7} instead of 1.0×10^{-5}.

   e. The residual of each mode and frequency will be calculated and printed as a mode tolerance. This number gives an indication of the level of accuracy in the stresses and anchor loads (see reference 6).

   f. A condition number will be calculated and output with comments to give indications of any ill-conditioning of the equations of motion for the piping system (see reference 7).

REFERENCES

1. Bathe, Klaus-Jürgen and Wilson, Edward L.; Numerical Methods in Finite Element Analysis, Prentice-Hall, Incorporated, New Jersey, 1976, pp. 363-371.

2. Bathe, Klaus-Jürgen, Wilson, Edward L., and Peterson, Fred E.; SAPIV - A Structural Analysis Program for Static and Dynamic Response of Linear Systems, Report No. EERC 73-11, June 1973, revised 1974, College of Engineering, University of California, Berkeley, California.

3. Bathe, Klaus-Jürgen and Wilson, Edward L.; Numerical Methods in Finite Element Analysis, Prentice-Hall, Incorporated, New Jersey, 1976, pp. 494-520.

4. Taylor, Robert L. and Rollins, James M.; Modified Subspace Computation for Eigenvalues and Eigenvectors. A copy of this report is attached.

5. CEB Memorandum dated March 14, 1980, "TPIPE Frequency Algorithm" (CEB 800314 001).

6. Bathe, Klaus-Jürgen and Wilson, Edward L.; Numerical Methods in Finite Element Analysis, Prentice-Hall, Incorporated, New Jersey, 1976, p. 413.

7. Ibid, pp. 299-300.