RESIDUAL LOAD METHOD FOR MODAL ANALYSIS OF PIPING SYSTEMS SUBJECTED TO SEISMIC EXCITATION

G. KRAUSE

*Brown, Boveri & Cie AG, Abt. KW/TBI,
Postfach 351, D-6800 Mannheim, Germany*

Nuclear power piping systems are three-dimensional and multi-degree-of-freedom systems. The dynamic response of these systems can be either obtained by the direct time integration of the equations of motion or by the modal analysis method. When this method is used the complete information about natural modes and frequencies has to be available.

Due to the fact that piping systems normally possess a large number of unknowns, the computation of eigenvectors and frequencies is limited. It does not seem to be reasonable to calculate all modes because of the wellknown phenomenon that the accuracy of the higher modes is deteriorating the more the higher the frequency of these eigenforms. This means, the complete response of piping systems subjected for instance to seismic excitation remains unknown.

Two methods which pretend to take the neglected higher modes into account have been proposed simultaneously by different authors in 1975. A comparison of the two methods reveals that they are indeed equivalent to each other. It is called the 'modal-acceleration-method'. This method is based on the principal idea of correcting the incomplete dynamic response to seismic motion by a static residuum.

A static load according to direction and amount of the dynamic forcing function is applied. The static displacements are easily obtained by static analysis. Additionally the same displacements can be expressed again in series of eigenvectors. This series can partially be calculated by means of the known eigenvectors. The difference between the static solution and the incomplete series is the static residuum which is added to the dynamic response.

As will be shown in this work the error of such an approximation can be stated. Furthermore it is concluded from the error investigation that this method yields satisfactory results if the system is rigid relativ to the excitation.

The method that is proposed here - called residual load method - is based on a simple mathematical lemma. From this expression a formula is derived that allows to determine the residual response of all neglected modes. This formula leads to a three-dimensional load applied to the system that depends on the shape of these higher modes and on the direction of excitation. This residual load is really an 'equivalent' one because the total response of the dynamic and residual analysis yields under certain assumptions either the exact solution or a conservative one.

Two examples are presented in which piping systems have been dealt with this method. It seems surprising, that even for branched systems it is sufficient to compute a few eigenvectors and then apply the residual load. It is demonstrated using a constant response spectrum that the sum of the dynamic and residual responses remains at a constant value independent from the number of calculated modes.