FLUID ELEMENT IN SAP IV

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SUMMARY

In previous studies a fluid element is incorporated in the widely used general purpose finite element program SAPIV. This type of problem is of interest in the design of nuclear components involving geometric complexities and nonlinearities. The elasticity matrix of a general-purpose finite element program is modified in such a way that it becomes possible to idealize fluid as a structural finite element with zero shear modulus and a given bulk modules. Using the modified version of SAPIV, several solid-fluid interaction problems are solved. The numerical solutions are compared with the available analytical solutions. They are shown to be in reasonable aggrement. It is also shown that by solving an exterior-fluid interaction problem, the pressure wave propagation in the acoustic medium can be solved with the same approach.

In this study, two of the problem not studied in the previous work will be presented. These problems are namely the effects of the link elements used at solid-fluid interfaces and of the concentrated loads on the response of the fluid medium. Truss elements are used as the link elements.

After these investigations, it is decided that general purpose finite element programs with slight modifications can be used in the safety analysis of nuclear reactor plants. By this procedure it is possible to handle two-dimensional plane strain and tridimensional axisymmetric problems of this type.

1. Introduction

In the analysis of nuclear reactors, there are many situations in which fluid-solid interaction should be considered. Especially, in the safety analysis of nuclear reactor plants the response of a structure enclosing or embedded within a fluid with significant energy content will be important. Among such problems are : (1) energy releases due to hypothetical accidents in which the integrity of the primary containment must be insured; (2) local energy releases at the subassembly level where the integrity of adjacent subassemblies must be quaranteed so that the event does not propagate {1}.

As indicated by Belytschko {1}, the analyses of such hydraulic-structural problems have often been performed by an uncoupled two step procedure : (1) the fluid response has been studied by hydrodynamic models that omit the structural behaviour, usually by treating the structural walls as rigid; and (2) the pressure predicted on the rigid walls by the hydrodynamic program are then applied to a model of the structure to determine its response. It is agreed that this type of uncoupled analysis is very conservative. To overcome that drawback and in fact, in same cases unsound designs, studies started on coupled fluid-structure programs in late 1960's. Algorithms for fluid and structure are being developed and they are coupled to obtain the response of fluid on structure. All these efforts directed on development of new computer programs and algorithms.

In this study a fluid element is incorporated in the widely used general purpose finite element program SAPIV {2} to analyze solid-fluid interaction problems. The elasticity matrix of the general purpose finite element program is modified in such away that it becomes possible to idealize fluid as a structural finite element with zero shear modulus and a given bulk modulus. Using the modified version of SAPIV, several solid-fluid interaction problems are solved. The numerical solutions are compared with the available analytical solutions {3}, {4}. They are shown to be in reasonable agreement. It is also shown that by solving on exterior-fluid interaction problem, the pressure wave propagation in the acoustic medium can be solved with the same approach {5}.

2. Formulation

The fluid medium is treated as on elastic medium with shear modulus equal to zero and, in this case, the Lamé equations govern the behavior of both the fluid and the solid media. For the fluid medium, of the Lamé coefficients, μ, is zero and the other is equal to the bulk modulus of the fluid ($\lambda = K$). This formulation will be called the "pseudo-elastic formulation", {3}. This method requires minor modifications to the existing general purpose computer programs and the resulting matrices are symmetric.

The necessary modifications for the pseudo-elastic method are introduced in a version of SAPIV which is available at the Middle East Technical University. Only the plane and axisymmetric elements are modified at the present. Also an option is added to the program for the use of one-point integration rule in addition to the usual two-point integration rule.

If, in a general purpose program, the Lamé coefficients (λ,μ) are required as data, instead of Young's modulus E and Poisson ratio ν, then no modification is necessary in the program itself. Otherwise, the elasticity matrix in the program has to be modified. Once this is done, it is not necessary to add fluid elements in the Library of the program. An additional consideration is needed to model the slip condition at the solid-fluid interface. A special joint element can be incorporated into the program, {6}, or short truss elements with large stiffness can be used as link elements at the interface.

In this study, two of the problems not studied in the previous work, {3}, {4}, will be presented. These problems are namely the effects of the link elements used at solid-fluid interfaces and of the concentrated loads on the response of the fluid medium. Truss elements are used as the link elements.

3. Link Elements

The size, length and rigidity of the truss elements have been investigated at the core support of a nuclear reactor plant, the lower portion of the primary containment , the skirt and the fluid below the core support structure. A schematic of the support structure and the finite element mesh is indicated in Fig. 1. This model is somewhat similar to the model given in reference {7}. In the problem there are 83 nodal points, 50 fluid elements, 10 solid elements and 11 link elements. Fluid and solid elements are modelled as axisymmetric shell elements with the following properties solid section is assumed to be concrete with Young's modulus of 100000 kg/cm^2 and Poisson's ratio of 0.1667. Interior is modelled as hydrodynamic, and properties of water are used, bulk modulus being $2.0x10^5$ kg/cm^2 and specific gravity 1 gr/cm^3 and mass density $1x10^{-6}$ kg. sec^2/cm^4.

Truss elements are used as the link elements. Purpose of the link elements is to model behavior of fluid and solid points at the interface. The length of the truss elements kept at a minimum since in reality two ends of the truss member correspond to the same point. The imaginary rigidity of the link elements are arranged through the specification of either modulus of elasticity or the cross sectional area. The link elements assumed to be rigid enough when, for all truss elements, the displacements two ends of, the trusses are identical. In this manner slip at the interface can be modelled. Fluid and solid are free to more in tangential direction but will have the same displacement in perpendicular direction of the interface.

In the problem solved in this study, the length of the truss elements are taken as 0.001 cm. Since the problem solved is an axisymmetric one, the actual cross sectional ereas in the teritory of each truss member are used so that the resulting link element stresses will correspond to actual hydrodynamic pressure at link element locations. The rigidity of the truss elements effects the overall behavior of the fluid-structure system. The rigidity should be as high as possible and can be arranged through Young's modulus E. If E increased without any limit it might cause numerical instability problems due to ill-conditioning of the system stiffness matrix containing elements corresponding to "very stiff" truss members. For the problem solved E value has been changed from 1.0 to 10^{25}. When $E = 10^5$ kg/cm^2 enough rigidity is provided. When E exceeds 10^{15} numerical instability problems has started. The optimum rigidity can be obtained through trial and error and it should be as high as possible before numerical problems. The stress distribution in some of the truss members are given in Fig.2 and Fig.3.

4. Effect of Loading

Two types of loading is being investigated. In the first one uniform time dependent load with 100 kg/cm^2 is applied from the top surface in negative z direction. In the second case a concentrated load equivalent to total force resulting due to 100 kg/cm^2 load from the top centroid in negative z direction. Both types of load are applied as constant step loading for infinite duration. Concentrated and uniform loading created no special problem. Results for typical deflections are given for both types of loading in Fig.4.

5. Results and Conclusion

After these investigations, it is decided that general purpose finite element programs with slight modifications can be used in the safety analysis of nuclear reactor plants.

It is anticipated that modifications explained here can be easily extended to other general purpose finite element computer programs such as the nonlinear code NONSAP {8}, at least for nonlinear solid-linear fluid interaction problems. This will also enable one to model the link elements nonlinearly so that the separation between solid and fluid can be allowed.

References

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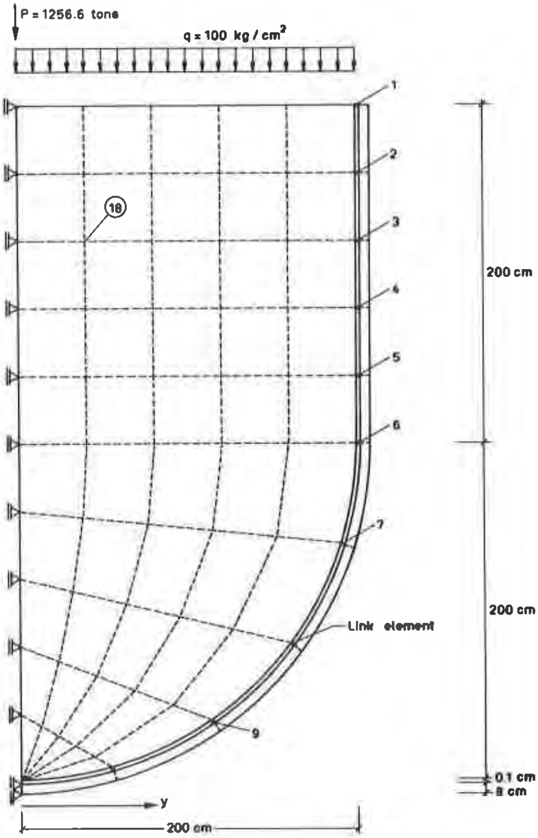

Fig. 1 Simple model of primary containment

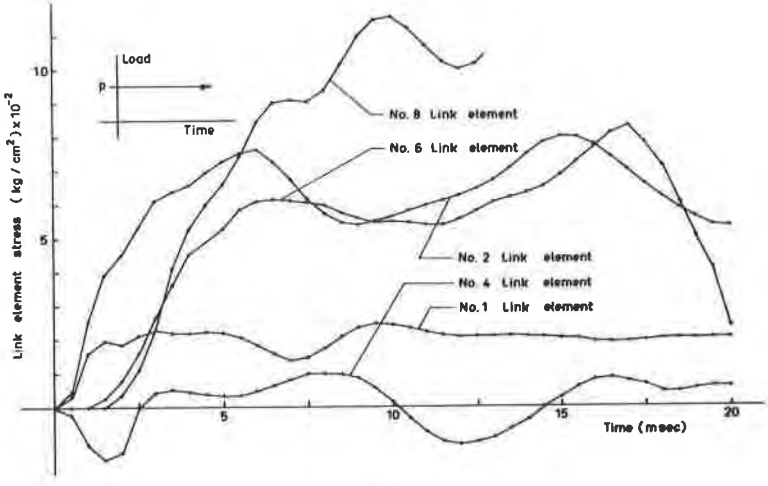

Fig. 2 Link element stresses under uniform loading

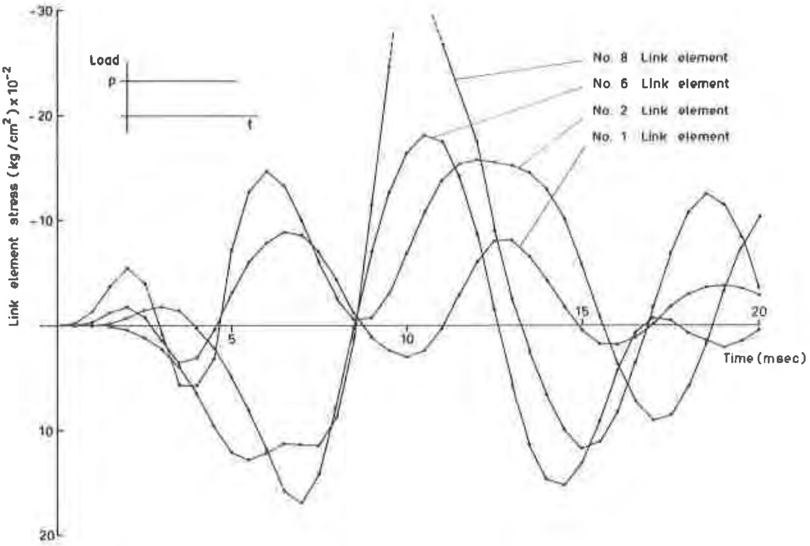

Fig. 3 Link element stresses under concentrated load

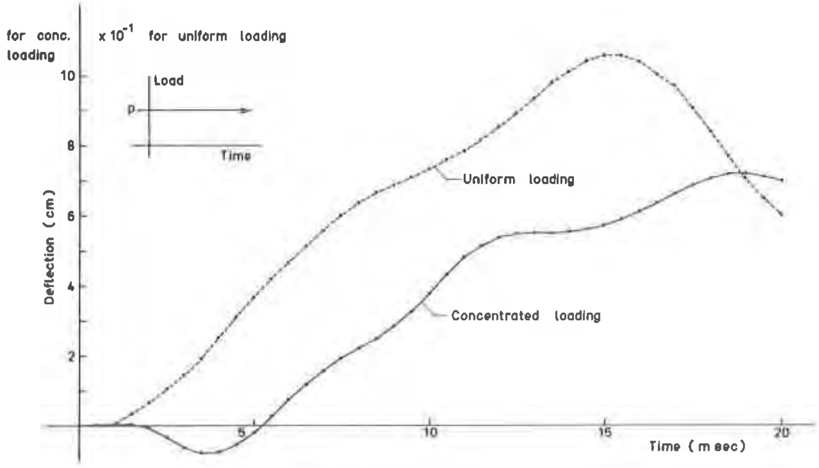

Fig. 4 Vertical deflection of point 18 due to concentrated and uniform loading