THE COMPUTER CODE SEURBNUK-2: RECENT DEVELOPMENTS

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The SEURBNUK-2 code is now being developed jointly by AEE Winfrith and JRC Ispra for use in Fast Reactor Containment Studies. To meet the needs of such studies and the needs of the COVA programme, a number of improvements and extensions of the code have been made. A selection of these changes and illustrations of their use are given in this paper.

The structural capability of SEURBNUK-2 was originally limited to the treatment of thin shells, and shell junctions. Although this facility proved surprisingly useful, it was realised that a more versatile and powerful means of calculating the deformation of more complicated structural geometries would be required. The finite element code EURDYN which employs convected coordinates was adapted for the purpose, so that axially symmetric elements of the isoparametric, triangular and thin shell families could be used to model various parts of the reactor structure. The method of coupling this finite element code to the fluid motion is described and the use of this new version of the code is illustrated and the results compared with those obtained by the original code and by experiment.

A feature of many reactor designs which is being modelled in the later COVA experiments is the perforated plate or porous structure. For fixed perforated plates and porous structures, the additional pressure drop and inertia effects can be included in the momentum equations by addition of suitable terms and the original technique of solution is unaltered. Details of the finite difference equations are given in this paper together with the results of check calculations which were performed to ensure the correct functioning of the code.

The extensive use of SEURBNUK-2, particularly in conjunction with COVA, has highlighted a number of code problems which have been successfully resolved. Many of these relate to particular circumstances, and are therefore of limited interest, but a general and quite frequent problem is that of gross bubble distortion which, if untreated, leads to logic problems within the code and consequent failure. Although the basic cause of this distortion is understood, eliminating this problem is not straightforward. A successful palliative is to manually rezone the bubble interface since this then avoids the logical problems in SEURBNUK with little or no effect on the calculation results. A further technique is the damping of the incipient discontinuities by automatic smoothing of the particle velocities. An example of the use of rezoning and smoothing techniques is given.

It is generally recognised that the numerical processes in an Eulerian code such as SEURBNUK introduce spurious diffusion into the solution so that pressure profiles, for example, are smoother than in an equivalent Lagrangian calculation. To give guidance to the calculator on the input parameters which affect these diffusion terms, an analysis of the truncation errors involved in the derivation of the finite difference equations was made. The various diffusion like terms are listed in this paper and their relevance to the calculation is discussed. An example is given which illustrates the changing nature of the solution as the amount of diffusion is modified.

1. Introduction

The development of the SEURENUK-2 code as a tool in containment analysis for fast reactor safety studies has been described at the 4th SMIRT conference (CAMERON et al [1]) and notable features of the code at that time were the implicit calculation of compressible flow, the generalised representation of bounding surfaces, and the computation of the response of thin shell structures. Development of this code has continued jointly by UKAEA and JRC Ispra not only in expanding the capabilities of the code but also correcting shortcomings as revealed by exercises such as COVA (HOSKIN and LANCEFIELD [2]) and APRICOT (HERRMANN and GROSS [3]).

Examples of the expanded capabilities of SEURENUK-2 that are described in this paper are the employment of the Finite Element code EURDYN to enhance the code's capabilities in calculating the deformation of complex structures (Section 2), and the adaption of the fluid motion formulation to permit the modelling of fluid motion through porous materials and perforated plates (Section 3).

Complementing these new developments is the continuing process of turning the code into a reliable computational tool. This is not easily described, being in the main made up of numerous detailed changes to the code, although a small number of problems have been encountered of some substance. One of these, that of spurious distortion of the bubble surface and the treatment devised to overcome this problem is described in Section 4.

The stability of the mathematical solution used in SEURENUK-2 usually gives no cause for concern because of numerical diffusion introduced by the discretisation technique employed. However, in a few circumstances the solutions exhibit non-physical behaviour, so some appreciation of the factors affecting the stability is useful. The diffusion-like terms arising in the SEURENUK-2 are described and their effects are illustrated in a test calculation (Section 5).

2. Development of the Structural Capabilities within the SEURENUK-2 Code

The SEURENUK-2 code is formulated for axial symmetry and thus the earlier structures formulated within the code were axisymmetric thin shells initially restricted to containment vessels but later internal structures were permitted (CAMERON et al [1]). These shells could be subjected to a variety of constraints at the ends, and thin shells could be connected by means of a hinged joint. Thus by approximating the real structure by a number of connected thin shells, SEURENUK-2 could simulate a quite complex structure. Despite the proven usefulness of this thin shell analysis, there was additionally a need for a facility to model both thin shells and massive structures. Any new treatment introduced into the code should preferably be already validated and should be versatile enough for any structural arrangement to be modelled. These considerations led to the decision to use a finite element code rather than a finite difference scheme as used in the existing thin shell formulation. The code finally chosen was EURDYN (DONEA and GUILIANI [4], DONEA, GUILIANI and HALLIEUX [5]) since this was readily available and it was considered that at the present stage the limitations of this convected coordinates code were outweighed by its computational efficiency.

The axisymmetric elements available in the EURDYN code suite are a thin shell element and a constant strain triangular element in EURDYN1, and an isoparametric element in EURDYN2. Details of the formulation of these elements using the convected coordinate scheme are to be

found in Reference [5] (DONEA et al). EURDYN permits a variety of constraints to be placed on the elements, and shells can be connected with either a rigid or a hinged joint. The thin shell could be connected to triangular and isoparametric elements with a hinged joint but in practical applications a rigid connection was more appropriate. To make this junction possible, ideally special transitional elements would be required, but two rather simpler and quite effective alternatives were developed. The first is to introduce an additional section of shell between a node on the structure and a node on the shell, both close to the junction. This effectively stiffens the junction without requiring any changes to the code. The second method is to introduce a rigid, massless triangular element at the junction (OWEN [6]), joining two nodes on the triangular or isoparametric elements to the end node of the shell. The masses at each of these three nodes are redistributed so that each has an equal mass. Then applying the conditions of rigidity and equilibrium to the triangle results in relationships which define the moment applied to the end of the shell and the redistribution of nodal forces such that the junction behaves rigidly.

In the SEURENUK-2 code, the boundary surfaces of the fluid are defined by marker particles and depending on the particular type of surface in question, these particles are fixed, move with the fluid, or move in accord with some prescribed motion or the deflection of a structure. Thus in the latter circumstance if a structure is to be defined by a number of elements, then identifying the marker particles with the nodes on the surface of the structure will provide the necessary physical coupling within the code. The logic used in SEURENUK-2 to determine the pressures along thin shell surfaces enables the appropriate pressures to be applied at any boundary surface, and hence to a structure defined by a finite element mesh. Since the fluid calculation in SEURENUK-2 is implicit (in the ICE sense) whereas EURDYN is explicit, a suitable strategy for coupling the two parts of the calculation is required. In SEURENUK-2 the process employed is to firstly implicitly calculate the new pressure field and then using these pressures explicitly calculate the acceleration of the structure. This acceleration is then used to update the structure velocity and position. In most applications the stability time step for the explicit structure calculation is much less than the time step employed in the fluid calculation so that a subcycling procedure is used. In this, the updated fluid pressure is used throughout the explicit structural calculation.

Although it has been reported that many fluid-structure coupling schemes of the same basic type as described above are in fact unstable, no problems from this source have been experienced, either in the original finite difference thin shell structure or the later EURDYN calculation. This could be due to the high degree of solution damping in the fluid-dynamic calculation (see Section 5).

The version of SEURENUK-2 incorporating the EURDYN finite element code has been applied to a number of problems. An example problem taken from the COVA series of experiments consists of a thin cylindrical vessel supported between a massive roof and floor. The upper end of this vessel is attached rigidly to the roof but the lower end can slide freely in the floor. A simulated diagrid is supported from the vessel by a perforated skirt in the manner shown in Figure 1. In the experiment, this vessel is almost filled with water, and the energy release provided by a low density explosive LDE (HOSKIN and LANCEFIELD [2]). In the SEURENUK-2 simulation of the experiment the vessels are modelled as axisymmetric thin shells and the diagrid as a number of constant strain triangular elements using EURDYN1.

Note that fluid is allowed to flow without resistance through the diagrid support. The pressure from the low density explosive loads the diagrid, stressing the diagrid support member and hence causing an inward deformation of the junction between the diagrid support-member and the containment vessel. These loads also result in longitudinal stresses in the outer tank (Figure 1). At a slightly later time, the pressure on the outer tank causes radial strain away from the rather stiff tank junction region. The pressure wave from the charge is partially reflected at the diagrid and the transmitted wave causes a brief pressurisation of the region below the diagrid.

A second problem, that of the COVA experiment IT8, consists of a thin hemispherically bottomed vessel suspended from a rigid roof as shown in Figure 2. Calculations have been performed with the original SEURBNUK-2 with the finite difference shell representation, and with the SEURBNUK-2 with EURDYN. Figure 2 compares the resulting permanent strains given to the vessel from these calculations with those measured experimentally. It will be seen that both calculations reproduce the main features of the experimental strain distribution, with the SEURBNUK-2 with EURDYN values being rather closer to the experimental values than to those calculated with the original SEURBNUK-2

3. Representation of Rigid Porous Solids and Perforated Plates in SEURBNUK-2

As a first step towards the full representation of porous solids and perforated plates within SEURBNUK-2, the formulation has been revised to permit the modelling of rigid porous solids and perforated plates. To describe the characteristics of these porous structures, it is assumed that the pressure loss due to viscous dissipation in the dynamic state is adequately represented by a steady-state correlation of the form

$$\Delta p = -\zeta \frac{1}{2} \rho v |v| \quad (1)$$

(where the coefficient ζ is constant through a calculation time step)

and that the additional fluid inertia is adequately represented by porosity for a porous solid and by an equivalent length for a perforated plate. The validity of the assumption that a steady-state pressure drop correlation is adequate in the dynamic state will be considered later.

Since the methods of treating porous solids and perforated plates are very similar, only the former will be described in this paper. It can be shown that the appropriate differential equations for flows through a porous solid are

$$\frac{\partial \rho}{\partial t} + \frac{1}{r} \frac{\partial(r\rho u)}{\partial r} + \frac{\partial(\rho v)}{\partial z} = 0 \quad (2)$$

$$\frac{\partial(\rho u)}{\partial t} + \frac{1}{r} \frac{\partial(r\rho u^2)}{\partial r} + \frac{\partial(\rho uv)}{\partial z} = \theta \left[-\frac{\partial P}{\partial r} + S^u \right] \quad (3)$$

$$\frac{\partial(\rho v)}{\partial t} + \frac{1}{r} \frac{\partial(\rho ruv)}{\partial r} + \frac{\partial(\rho v^2)}{\partial z} = \theta \left[-\frac{\partial P}{\partial z} + S^v \right] + \rho g \quad (4)$$

where u and v are the velocities in the material pores in the radial and axial directions respectively; ρ is the bulk average fluid density; θ is the porosity. S^u and S^v are the viscous pressure drop terms in the 'r' and 'z' directions respectively. Equations 2 - 4 are discretised in a similar manner to that described in Reference [1] (CAMERON et al),

using eq. (1) to derive an appropriate expression for S^v , then discretising (as suggested in the work on this topic performed under contract for the UKAEA by Combustion, Heat and Mass Transfer (CHAM) Ltd) gives

$$S^v = -\frac{1}{2} \zeta \frac{1}{\Delta z} |v^n| (2(\tilde{\rho}v)^{n+1} - (\tilde{\rho}v)^n) \quad (5)$$

(neglecting second order terms and using $\tilde{\rho}^n$ and $\tilde{\rho}^{n+1}$ the microscopic densities, interchangeably as convenient). A similar equation is formulated for the 'r' direction.

The additional terms in the momentum equations due to S^u and S^v can be collected with other $(\rho v)^n$ and $(\rho v)^{n+1}$ terms so producing similar equations to those resulting from the standard SEURNUK-2 analysis (CAMERON et al [1]). Substituting these momentum equations into the continuity equation results in the following pressure equation

$$P_{i,j}^{n+1} = A_1 \theta_{i-\frac{1}{2},j} P_{i-1,j}^{n+1} + A_2 \theta_{i,j-\frac{1}{2}} P_{i,j-1}^{n+1} + A_3 \theta_{i+\frac{1}{2},j} P_{i+1,j}^{n+1} + A_4 \theta_{i,j+\frac{1}{2}} P_{i,j+1}^{n+1} + R_{i,j} \quad (6)$$

$$\text{where } A_1 = \alpha_{i-\frac{1}{2},j} r_{i-\frac{1}{2}} / (Dr_i \Delta r^2); \quad A_2 = \beta_{i,j-\frac{1}{2}} / (D \Delta z^2) \quad (7)$$

$$A_3 = \alpha_{i+\frac{1}{2},j} r_{i+\frac{1}{2}} / (Dr_i \Delta r^2); \quad A_4 = \beta_{i,j+\frac{1}{2}} / (D \Delta z^2)$$

$$R_{i,j} = \Delta r \left[A_1 \xi_{i-\frac{1}{2},j}^n - A_3 \xi_{i+\frac{1}{2},j}^n \right] + \Delta z \left[A_2 \xi_{i,j-\frac{1}{2}}^n - A_4 \xi_{i,j+\frac{1}{2}}^n \right] \\ + C_{i,j} \theta_{i,j} P_{i,j}^n / (D \Delta t^2) + \frac{\Delta r}{\Delta t} \left[A_1 (\alpha' \rho u)_{i-\frac{1}{2},j}^n - A_3 (\alpha' \rho u)_{i+\frac{1}{2},j}^n \right] \\ + \frac{\Delta z}{\Delta t} \left[A_2 (\beta' \rho v)_{i,j-\frac{1}{2}}^n - A_4 (\beta' \rho v)_{i,j+\frac{1}{2}}^n \right] \quad (8)$$

$$\text{and } D = [\alpha_{i-\frac{1}{2},j} r_{i-\frac{1}{2}} + \alpha_{i+\frac{1}{2},j} r_{i+\frac{1}{2}}] / (r_i \Delta r^2) + [\beta_{i,j-\frac{1}{2}} + \beta_{i,j+\frac{1}{2}}] / \Delta z^2 + \theta_{i,j} C_{i,j} / \Delta t^2 \quad (9)$$

$$\alpha = 1/[1 + \zeta |u| \Delta t / \Delta r]; \quad \alpha' = 1 + \zeta |u| \Delta t / (2 \Delta r) \\ \beta = 1/[1 + \zeta |v| \Delta t / \Delta z]; \quad \beta' = 1 + \zeta |v| \Delta t / (2 \Delta z) \quad (10)$$

Other terms are as defined by CAMERON et al in Reference [1].

These equations, being of the same form as that in SEURNUK-2, can be solved by the existing procedure.

With perforated plates, the same route is followed except that the porosity θ is unity and an additional fluid inertia due to the presence of the perforated plate is included.

A number of numerical experiments have been performed to confirm that the analysis has been correctly implemented in the code. One of these experiments modelled the motion of an incompressible fluid being displaced by a high pressure gas through a perforated plate in the manner illustrated in Figure 3. This Figure compares the fluid velocity-displacement as obtained using SEURNUK-2 with that obtained by accurate integration of the equation of motion. This test and many others have demonstrated that the code correctly implements the assumed dynamic characteristics of porous solids or perforated plates. Comparison between

experiment and the results of calculations using this developed version of SEURENUK-2 are described elsewhere (KENDALL et al [7]).

It must be reiterated that the analysis just described assumes that the pressure drop across a perforated plate or through a porous solid can be represented adequately by a steady-state pressure loss correlation together with an inertia term. However, there is long-standing evidence that this is not so for rapidly changing flows. Thus for an impulsively moved cylinder quite marked changes occur due to the developing vortex pattern (SCHLICHTING [8]). Similar effects have been noted with impulsively moved plates, but in the main this has been qualitative in nature so that it has not been possible to either quantify the errors involved in the use of a steady-state pressure loss model or evolve a more refined mathematical model. Recent analytic work on the dynamic flow through porous plates (SMOLDEREN et al [9]) has done much to remedy this situation and work is proposed at JRC ISPRA to seek corroborative evidence from experiment. At the present time it would be premature to make a judgement either that such dynamic effects are sizeable and should be included in the analysis or that they are small and can be neglected.

4. CONTROL OF SPURIOUS DEFORMATION AT FREE SURFACES

Although the bulk fluid flow is well described in SEURENUK-2, problems sometimes arise in computing the motion of the massless marker particles which describe the demarcation surface between the bubble and fluid. As mentioned in Reference [1], the velocities of these particles are computed using a complex interpolation between the fluid velocities at neighbouring points, where at least one of these fluid velocities has to be obtained using a linear extrapolation, or using mass continuity (assuming no density change during the time step), or by a mixture of these two methods. Clearly such a procedure is only approximate and can easily lead to systematic errors in particle movement around a bubble. In the initial stages of the bubble expansion when it is expected that the surface would remain perfectly spherical, the fact that the bubble is small and therefore occupies only a few Eulerian cells results in significant errors in the bubble shape which, if uncorrected, can precipitate more severe distortion at a later stage in the calculation. Figure 4a shows an example of this early distortion being the contour of the bubble fluid interface at 400 μ sec after the detonation of a 2 oz IDE charge. This Figure also shows the result of using continuity or extrapolation to extend the velocity field, or a combination of the two (F_c and F_e are the weighting factors for continuity and extrapolation respectively and are input data to SEURENUK-2). It should be noted that the largest deviation from sphericity occurs near the axis, and that sphericity can be maintained by the empirical prescription of $F_c = F_e = 0.5$.

An alternative approach is to force bubble sphericity in the initial stages of expansion by giving all bubble marker particles a common normal velocity equal to the mean of the normal velocities computed as above. Figure 4b shows the results of calculations using the different methods described earlier. It should be noted that the method used to extrapolate the velocity field significantly affects the bubble volume.

Both of the above methods effectively prevent spurious deformations in the early stages of a bubble expansion but because the calculations do not necessarily ensure that the surface velocity or bubble pressure variations are correctly represented, it is desirable that their overall accuracy be checked by comparison with accurate one-dimensional Lagrangian calculations.

At later stages in the calculation, reflected pressure waves cause distortion of the bubble in the manner illustrated in Figure 5. These features become exaggerated by the numerical technique used to calculate the motion of the massless marker particles, leading to an unrealistic bubble shape and eventually logical problems within the code (Figure 6a).

One solution to this problem is to smooth the marker particle velocities by a least squares fitting technique such as provided in the Belgonucleare code SURBOUM. Although this removes the sharp discontinuities in the bubble surface which cause problems within the code logic (Figure 5), this method is computationally expensive.

A successful alternative is to manually reposition the interface marker particles and providing the amount of movement is modest, and the change in nett bubble volume is small, no discontinuity in the overall calculation is apparent. This process is illustrated in Figures 6a and 6b which show the bubble shapes occurring in a calculation of the COVA experiment IT22 shortly before failure in the code due to logic problems, and after a manual rezone, respectively. A facility to permit manual rezoning of marker particles is now provided in the SEURNUK-2 code.

5. EFFECTS OF DISCRETISATION TECHNIQUE ON RESULTS GIVEN BY SEURNUK-2

The numerical method employed in obtaining solutions of complex unsteady flow problems invariably involve approximations to the controlling differential equations: indeed in many instances these approximations are useful in ensuring a stable solution. Although the consequences of the use of a particular numerical method can be determined in a number of ways, it has been found particularly useful in this problem to follow the work of Hirt [10]. In this work, each term in the difference equation is considered to be a continuous function in time and space. If then a Taylor series is used to represent each term in the difference equation, the result is the initial differential equation (before differencing) together with a series of terms representing the truncation error of the particular differencing system used. In SEURNUK-2 the differencing scheme used is virtually the same as that used in ICE where the continuity equation

$$\frac{\partial \rho}{\partial t} + \frac{1}{r} \frac{\partial (r \rho u)}{\partial r} + \frac{\partial (\rho v)}{\partial z} = 0 \quad (11)$$

is differenced as

$$\frac{\rho_{i,j}^{n+1} - \rho_{i,j}^n}{\Delta t} + \frac{(r_{i+\frac{1}{2}}(\rho u)_{i+\frac{1}{2},j}^{n+1} - r_{i-\frac{1}{2}}(\rho u)_{i-\frac{1}{2},j}^{n+1})}{r_i \Delta r} + \frac{((\rho v)_{i,j+\frac{1}{2}}^{n+1} - (\rho v)_{i,j-\frac{1}{2}}^{n+1})}{\Delta z} = 0 \quad (12)$$

and the 'r' momentum

$$\frac{\partial (\rho u)}{\partial t} + \frac{1}{r} \frac{\partial (r \rho u^2)}{\partial r} + \frac{\partial (\rho u v)}{\partial z} = - \frac{\partial p}{\partial r} \quad (13)$$

is differenced as

$$\begin{aligned} & \frac{(\rho u)_{i+\frac{1}{2},j}^{n+1} - (\rho u)_{i+\frac{1}{2},j}^n}{\Delta t} + \frac{(r_{i+\frac{1}{2}}(\rho u^2)_{i+\frac{1}{2},j}^n - r_i(\rho u^2)_{i,j}^n)}{r_{i+\frac{1}{2}} \Delta r} + \frac{((\rho u v)_{i+\frac{1}{2},j+\frac{1}{2}}^n - (\rho u v)_{i+\frac{1}{2},j-\frac{1}{2}}^n)}{\Delta z} \\ & = - \frac{(p_{i+\frac{1}{2},j}^{n+1} - p_{i-\frac{1}{2},j}^{n+1})}{\Delta r} \end{aligned} \quad (14)$$

Similar expressions are derived for the 'z' momentum equations. Note that in eq (12) the convection terms ρu and ρv are spatially centred at time $n+1$ whereas the density differencing is centred at time $n+\frac{1}{2}$. In the momentum equations, the momentum terms are spatially and

temporally centred, but the convection terms and pressure gradient term are centred only in space: temporally these are at n and $n+1$ respectively.

Performing the analysis as outlined above to obtain the discretisation errors results in an infinite series of terms, experience has shown that the diffusion-like terms are the most important in determining the solution behaviour and therefore the following will be limited to a discussion of only these terms. A more comprehensive list of discretisation error terms is given in Reference 11.

The diffusion-like terms in the continuity equation are

$$-\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial \rho}{\partial r} \right) \left[\frac{\Delta t}{2} (c^2 + u^2) - \frac{\Delta r^2}{4} \frac{\partial u}{\partial r} \right] - \frac{\partial^2 \rho}{\partial z^2} \left[\frac{\Delta t}{2} (c^2 + v^2) - \frac{\Delta z^2}{4} \frac{\partial v}{\partial z} \right] + \dots \quad (15)$$

and those in the 'r' momentum equation are

$$-\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial u}{\partial r} \right) \left[\frac{\Delta t}{2} (c^2 - 3u^2) \rho - \frac{\Delta r^2}{2} \frac{\partial (\rho u)}{\partial r} \right] - \frac{\partial^2 u}{\partial z^2} \left[-\frac{\Delta t}{2} \rho v^2 - \frac{\Delta z^2}{4} \frac{\partial (\rho v)}{\partial z} \right] + \dots \quad (16)$$

Similar terms are found in the 'z' direction momentum equation to those given above for the 'r' direction. 'c' in these expressions is roughly the local sound speed.

The above expressions for discretisation errors include terms in Δr^2 and Δz^2 which are second order error terms resulting from the use of centred spatial differencing.

The remaining error terms in the continuity equation result from the use of convection terms which are not time centred. These terms are numerically much larger than the first so that for this discretisation technique the nett diffusion in the continuity equation is always positive. Further, for the sort of velocities occurring in containment analysis, this diffusion is uniform and isotropic because it is dominated by the $\Delta t c^2/2$ term.

Turning to the error terms in the momentum equation, here the terms $\frac{\Delta t c^2}{2}$ and $-\frac{3\Delta t \rho v^2}{2}$ result from the pressure and convection terms respectively being not time centred. The term $\left[\frac{\Delta t}{2} (c^2 - 3u^2) \rho - \frac{\Delta r^2}{2} \frac{\partial (\rho u)}{\partial r} \right]$ represents the numerical diffusion of momentum in the 'r' direction and clearly if the flow velocity is large, so that $u, v > \frac{1}{\sqrt{3}} c$ then the diffusivity will become negative. This is expected to result in an unstable solution [10] and this indeed occurs, for in shock-tube calculations performed using SEURBNUK-2, low shock strengths gave a smooth pressure rise through the shock whereas with strong shocks, an oscillatory behaviour resulted. Hence in calculations involving a high explosive (eg APRICOT Problem 3 [3]) it is expected that the computation will become briefly unstable in the fluid region immediately adjacent to the charge as the strong initial shock propagates into the bulk fluid. However, computations using SEURBNUK-2 have not shown any evidence of such behaviour.

The remaining discretisation error terms in the momentum equations represents momentum diffusion at right angles to the direction under consideration and this term can be either sign but generally quite small in magnitude.

At the velocity levels generally occurring in containment analysis, the diffusion of momentum is dominated by the $\frac{\Delta t c^2}{2}$ term and therefore is for all practical purposes uniform throughout the calculation field. It is interesting to note that a similar sort of effect is produced in Lagrangian codes by the use of a linear pseudoviscous damping term of very much greater magnitude than normally used in such calculations. There is, of course, no direct equivalent of numerically introduced diffusion in the continuity equation with a Lagrangian code.

In principle, numerical diffusion in SEURBNUK-2 can be reduced by inserting into the

difference equations appropriate terms which partially cancel the diffusivity [11]. This technique has been applied to a version of the code but although calculations with this code have demonstrated that diffusion is reduced, problems were experienced with flow instability at the bubble interface even though the nett diffusion was still positive. However there are some indications that reducing the diffusion in the continuity equation alone reduces the smearing effects of diffusion without incurring instability.

In circumstances where the numerical treatment is imprecise in SEURBNUK-2, numerical diffusion tends to smooth out local imperfections in the solution so producing an overall result in general agreement with experiment. This point can be illustrated comparing the results of calculations performed at different degrees of numerical diffusion.

A suitable example for this purpose is that of fluid impact with a rigid surface since an adequate representation of the details of the impact process is clearly not possible in SEURBNUK-2. The amount of diffusion in the code has been shown to be $\frac{\Delta t \cdot c^2}{2}$ so that the diffusion can be changed simply by altering the time step. The impact process was therefore computed for a typical COVA experiment with the time step of about the usual value of $\frac{1}{2}$ the Courant value. It was repeated with the time step increased to $2\frac{1}{2}$ times the Courant value to increase the diffusivity and then with the time step reduced to $1/10$ and then $1/20$ times the Courant time step to illustrate the effect of reduced diffusivity. Figure 7 summarises these results. Clearly diffusion is a necessary ingredient in order to obtain satisfactory results from this sort of calculation: the oscillatory behaviour using short calculation timesteps being non-physical and absent on the corresponding records from experiment.

6. CONCLUDING REMARKS

This paper has described some recent developments to the SEURBNUK-2 code which provide an enhanced structural capability by coupling with the finite element code EURDYN and a treatment of the fluid motion through porous materials and perforated plates. Although these developments greatly increase the code's ability to describe a fast reactor geometry, further improvement is required and typical of these is the current revision of the treatment of thin shells to allow porous shells to be modelled. Investigations are also being made into the modelling of the cavitation behaviour of the coolant, and into a scheme for giving SEURBNUK-2 a two-fluid capability. Following the successful conclusion of these investigations, these features will also be implemented in the code.

A complementary and important task is the testing of these new developments to ensure their correct functioning within the code and finally checking that the important physical processes are being adequately modelled by comparison with experiment. For the latter, the data provided by the COVA series of experiments on models of progressively increasing complexity has an essential role.

Stability of the computational scheme in SEURBNUK-2 gives no cause for concern provided the fluid flow velocities are substantially lower than the corresponding sound velocities, so it is unlikely that instabilities will be experienced when computing fast reactor safety problems. However, some problems remain especially in computing the positions of the bubble/liquid interface and continued improvement of the code logic and formulation is desirable in this area.

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FIG. 1 EXAMPLE OF THE USE OF THE SEURBNUK-2 CODE WITH EURDYN IN CALCULATING THE RESPONSE OF COVA EXPERIMENT WITH A DEFORMABLE DIAGRID.

FIG. 2. COMPARISON BETWEEN CALCULATED AND EXPERIMENTAL STRAINS FOR COVA EXPERIMENT ITB

FIG. 3 SIMPLE ONE DIMENSIONAL TEST PROBLEM INVOLVING A POROUS PLATE.

4a

4b

FIG. 4 EXAMPLES OF DIFFERENT MODELS FOR DETERMINING BUBBLE SURFACE MOVEMENT

FIG. 5 BUBBLE DISTORTION AND ITS CONTROL USING A SMOOTHING TECHNIQUE.

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FIG. 6 EXAMPLE OF REZONING IN SEURBNK 2

(a) TIMESTEP = $\frac{1}{2}$ X COURANT VALUE

(b) TIMESTEP = $\frac{1}{2}$ COURANT VALUE

(c) TIMESTEP = $\frac{1}{10}$ COURANT VALUE

(d) TIMESTEP = $\frac{1}{20}$ COURANT VALUE

FIG. 7 EFFECT OF CHANGING THE TIMESTEP ON THE PRESSURE VARIATION DURING FLUID IMPACT.