AN APPROACH TO THE ASSESSMENT OF DOUBLE CONTAINMENT RLG STORAGE TANKS UNDER ABNORMAL LIQUID LOADS

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In assessing the integrity and safety of double containment RLG storage tanks it is necessary to investigate the loads and the behaviour of the outer tank if the inner containment were to fail. This paper provides an overview of the current state-of-the-art in this type of coupled fluid-structure interaction problem and its feasibility is illustrated by reference to some of the results from an actual tank assessment.

INTRODUCTION

Refrigerated liquid gas (RLG) is often stored in large double containment tanks, a typical example of which is shown in Figure 1. Economy of scale dictates that typically large tanks are constructed with a volume of approximately 50,000 m^3. In the event of an accident the consequences of such large volumes of gas being released and the devastating results of fire and explosion are such that the probabilities of failure or release are required to be very low. The provision of guard and bunds walls alone may not be able to provide the necessary protection, especially as plants tend to be located close to populated areas. There has developed therefore a philosophy of integrated secondary containment to provide extra safety. The need to assess the overall integrity of the system therefore becomes important.

There is clearly a diversity of views about the types of credible accident that should be considered in the design which could lead to a release of liquid from the primary to the secondary containment. A scenario that is considered as a possibility is the rapid propagation of cracks in the inner containment, leading to rapid dynamic liquid loads being applied to the outer containment. The problem for the designer is often how best to estimate the loading on the outer containment in such an event.

Considerable work has been carried out into investigating these loads [1]. The need for a high degree of confidence in the design, balanced against construction cost, needs a more rigorous approach order to quantify these loads.

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In this paper some of the numerical approaches available for solving this problem are outlined and reviewed- including results from a study [2]. It is shown that the use of complex numerical methods can be crucial in obtaining a true understanding of the system behaviour and the design objectives that are to be met.

FORMULATION OF THE PROBLEM

The outer tank of an RLG double containment storage system, typically constructed with pre-stressed concrete, provides, amongst other benefits, secondary containment should the inner tank rupture. An assumed pattern of rupture states that a crack propagates vertically in the inner shell and also circumferentially along its base. Considerable disagreement exists as to the speeds at which cracks will actually propagate in the inner tank. Our approach is to conduct a sensitivity analysis to determine a pattern of crack propagation that will result in a 'worst case' design condition. Clearly, the inner shell will move with the liquid in some way and may impact along with the liquid on the outer tank. From some work already carried out it is clear that this is not a simple problem to solve [1]. In many ways an experimental solution is practically the most satisfactory approach.

Experimental work unfortunately takes a long time to set up- is expensive and often lacks flexibility in variation of design parameter changes. If it can be shown that numerical tests compare well with a well-designed experiment. the continued use of analysis becomes inefficient.

The problem under consideration in the event of a tank rupture is a highly complex interaction between fracture propagation and the flow of a fluid with a free surface. In order to understand the physics of the problem two simpler boundary conditions were considered.

The first problem considered is an axisymmetric shell where horizontal and vertical cracks are assumed to propagate at a much higher velocity than that of the fluid so that in effect the whole of the inner tank is instantaneously removed (Figure 2). The second problem addressed is when a specified section of the inner tank is removed (Figure 3) and the liquid is allowed to flow throughs the gap and thence into the annular space. The inner tank that remains is not allowed to move and is assumed to be rigid as the fluid moves past it. Taken together these two analyses will give a reasonable first estimate of the forces involved for the true problem. For the purposes of both analyses the outer tank was assumed rigid. Propane with a density of 583 kg/m^3 is used for the fluid. Once the fluid load history has been determined it is applied as a dynamic load *onto the outer tank. The structural calculations are carried out using a non-*linear dynamic program.

PROGRAMS USED IN THE ANALYSES

The finite difference program used for the fluid dynamic problem is based on an Eulerian formulation in conjunction with a finite difference scheme [3]. The volume of fluid technique [4] is incorporated for the treatment of the boundaries. *In an Eulerian representation the grid remains fixed and the* identity of the individual fluid elements is not kept track of and so it is necessary to compute the flow of fluid through the mesh. This calculation requires an averaging of the flow properties of all the fluid elements that find themselves in a given mesh after some period of time. The volume of fluid technique deals with discontinuities and the boundaries can undergo large deformations.

The non-linear structural problem is solved using the explicit finite difference program PR3D [5]. The program deals with both large deformation and plasticity. A better tool for this type of analysis is a non-linear shell program GSHELL [6]. which will be used in calculations to come. Both programs can model reinforcement and prestressing cables.

RESULTS

The axisymmetric problem is represented with the fluid mesh shown in Figure 4 with the fluid contained in the marked area. The fluid is allowed to move and the pressures and velocities computed for a total of 1.2 seconds. Figure 5 shows free-surface plots at different times. Plots of pressure time histories on the outer wall are depicted in Figure 6. An interesting feature is the pressure distribution which is not linear and the maximum pressure of 2.44 times the static head of liquid at the base.

A very coarse mesh (Figure 7) is used for the three-dimensional analysis. Although obviously the results must therefore be treated with caution, this analysis indicates the possibilities of the approach.

Free-surface plots at the outer wall at different times are shown in Figure 8. The pressure contours at the outer wall at different times are shown in Figure 9.

CONCLUSIONS

The axisymmetric analysis carried out can be considered successful for the problem considered, leading to a maximum loading 2.44 times the ratio liquid floor pressure. applied approximately over the lower half of tha tank. This type of information can be used for obtaining the prestressing profile and wall thickness of a tank during design.

Work on the three-dimensional analysis has recently been started and all preliminary indications are that the results will give further insight into the dynamic response of double containment tanks.

It is clear from the work that the modelling of fluid-structure interaction with complex boundaries can be achieved. Detailed validation of the method and comparison with field tests will shed further light on the usefulness of this method to the designer.

ACKNOWLEDGEMENTS

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[2] Baldwin. J.T.. Trbojevic. V.M., 1983, 2nd International Conference on Cryogenic Concrete, October, Amsterdam, Netherlands.

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[5] PML Technical Note No. PR-TN-6, 1984, April, Principia Mechanica Ltd., London.

[6] Trbojevic, V.M., 1983, PML Technical Note No. PR-TN-12, July, Principia Mechanica Ltd., London.

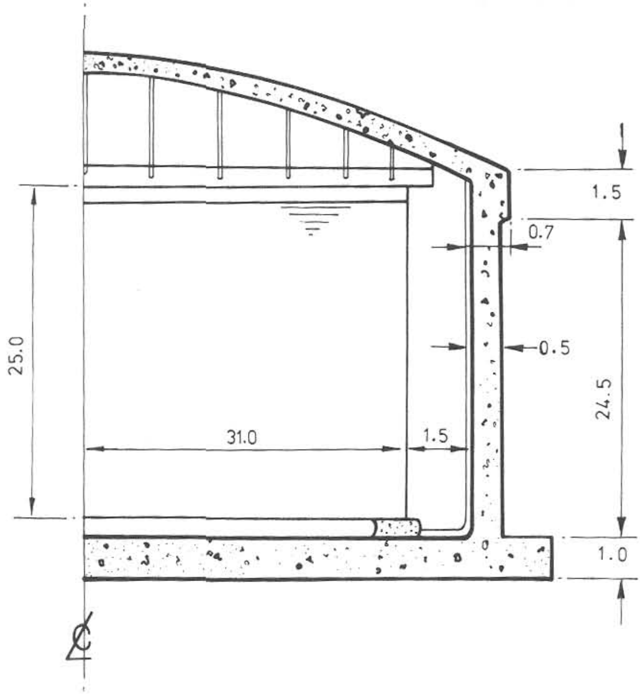


Figure 1 TYPICAL RLG TANK

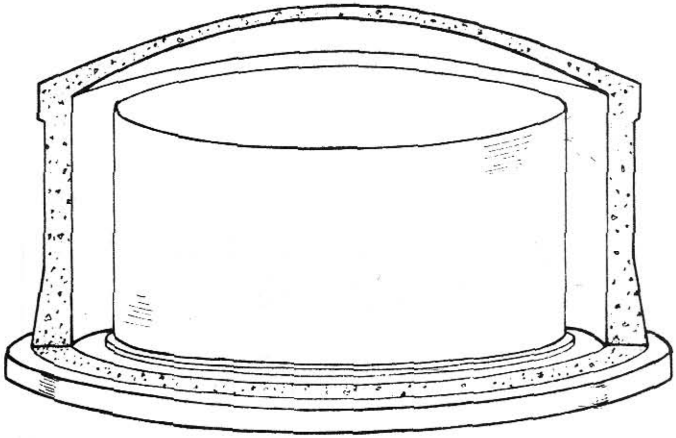


Figure 2 AXISYMMETRIC CASE - THE LIQUID CYLINDRICAL MASS IS SUDDENLY UNRESTRAINED IN THE RADIAL DIRECTION

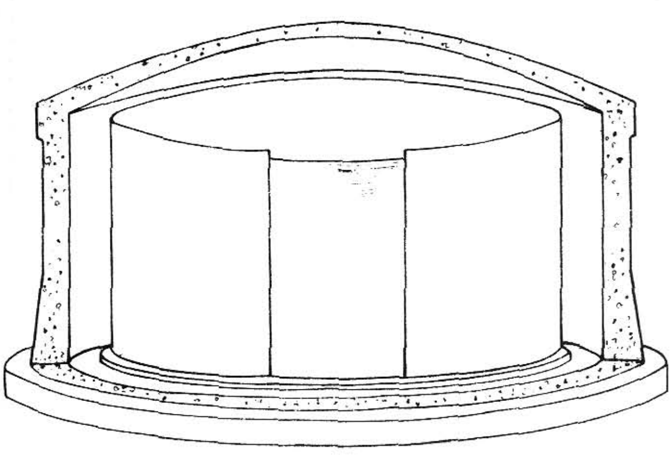


Figure 3 THREE-DIMENSIONAL CASE - THE LIQUID IS SUDDENLY FREE TO FLOW THROUGH AREA BETWEEN TWO GENERATORS

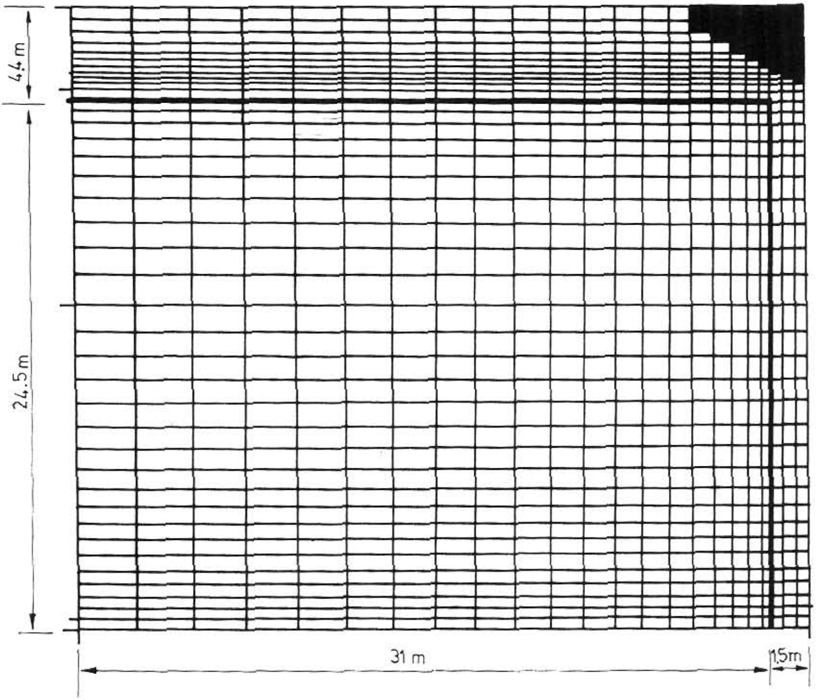
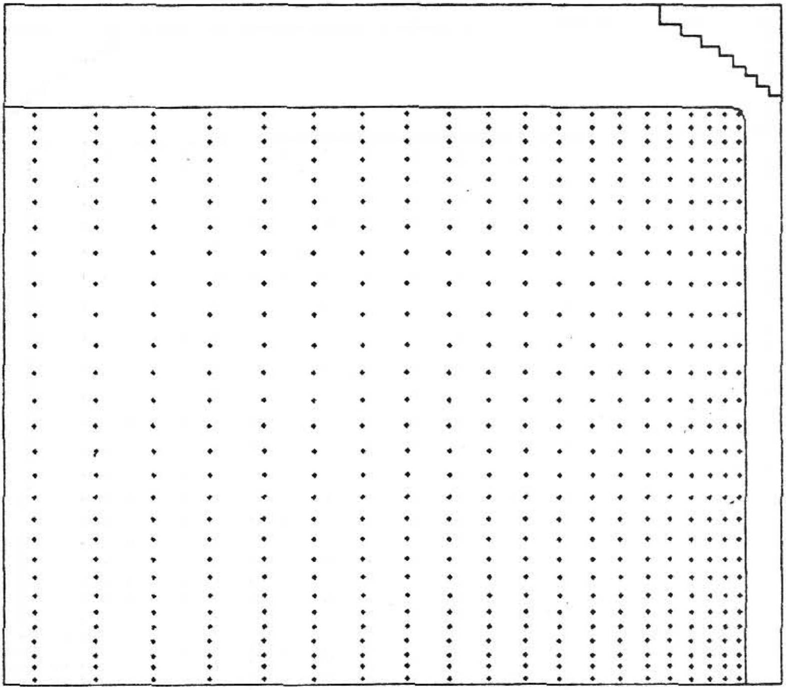
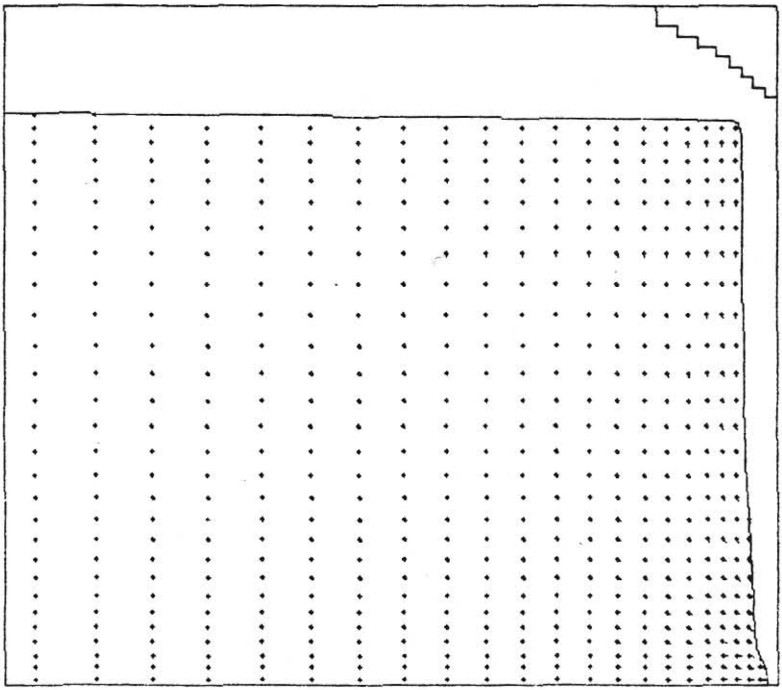


Figure 4 AXISYMMETRIC FLUID MESH - INITIAL FREE SURFACE OF THE LIQUID IS DENOTED BY THICK LINES



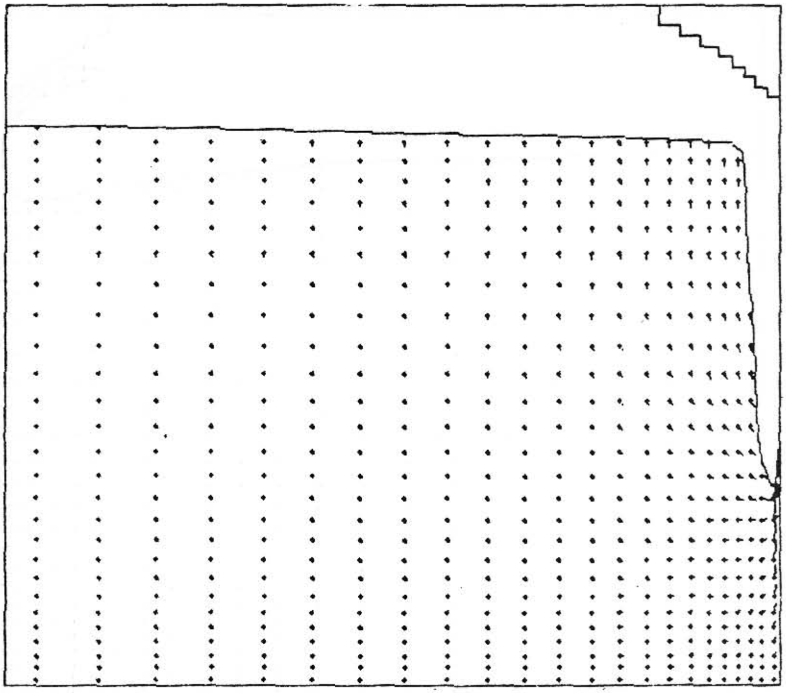
Time = 0.05 seconds

Figure 5 AXISYMMETRIC CASE - FREE SURFACE PLOTS AT DIFFERENT TIMES



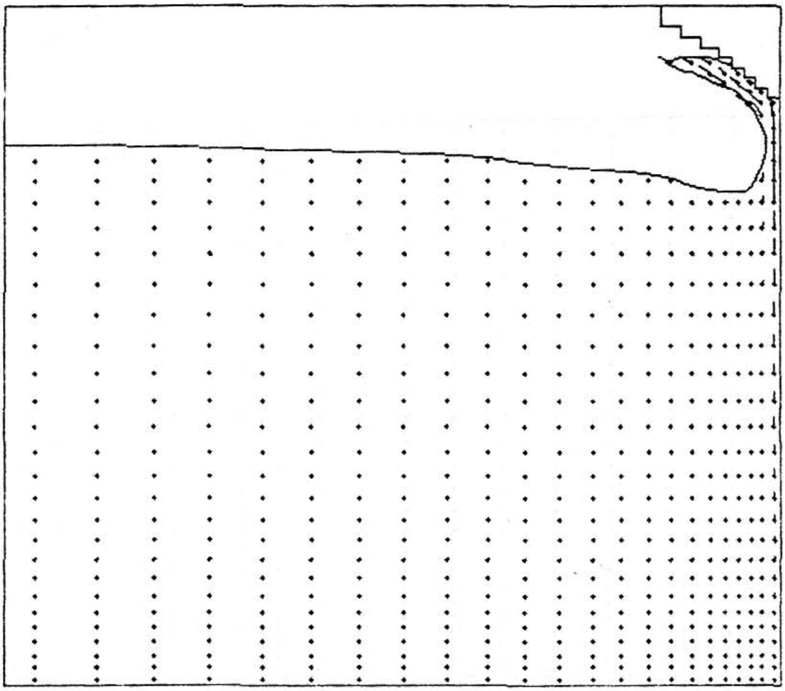
Time = 0.3 seconds

Figure 5 AXISYMMETRIC CASE - FREE SURFACE PLOTS AT DIFFERENT TIMES (Continued)



Time = 0.55 seconds

Figure 5 AXISYMMETRIC CASE - FREE SURFACE PLOTS AT DIFFERENT TIMES (Continued)



Time = 1.10 seconds

Figure 5 AXISYMMETRIC CASE - FREE SURFACE PLOTS AT DIFFERENT TIMES (Continued)

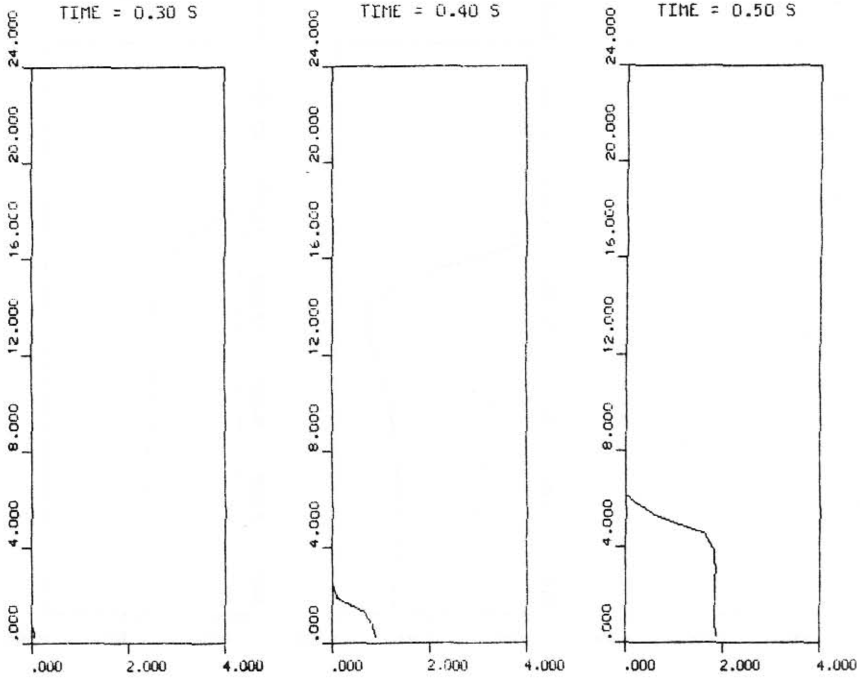


Figure 6 AXISYMMETRIC CASE - WALL PRESSURE DISTRIBUTION AT DIFFERENT TIMES (Continued)

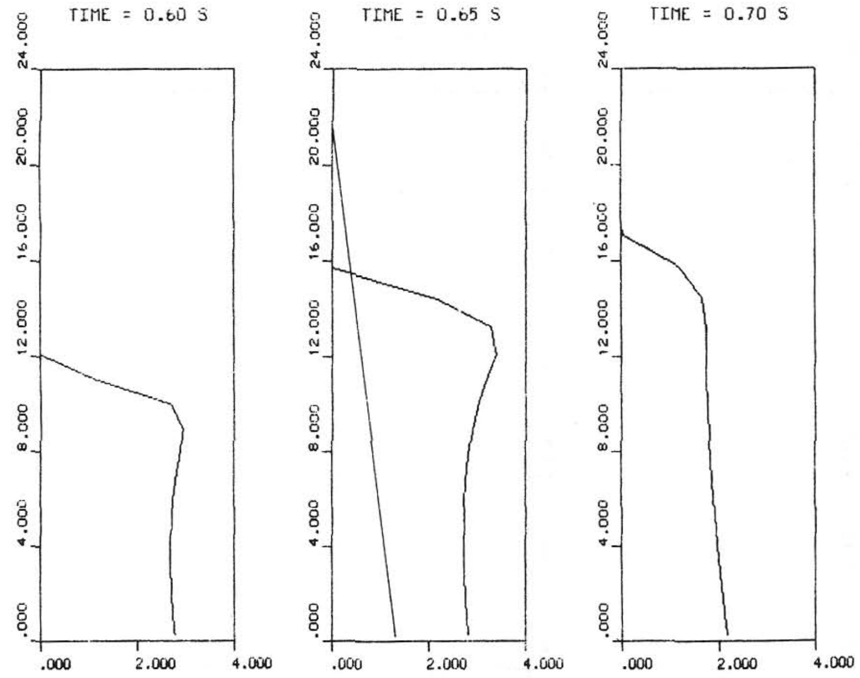


Figure 6 AXISYMMETRIC CASE - WALL PRESSURE DISTRIBUTION AT DIFFERENT TIMES (Continued)

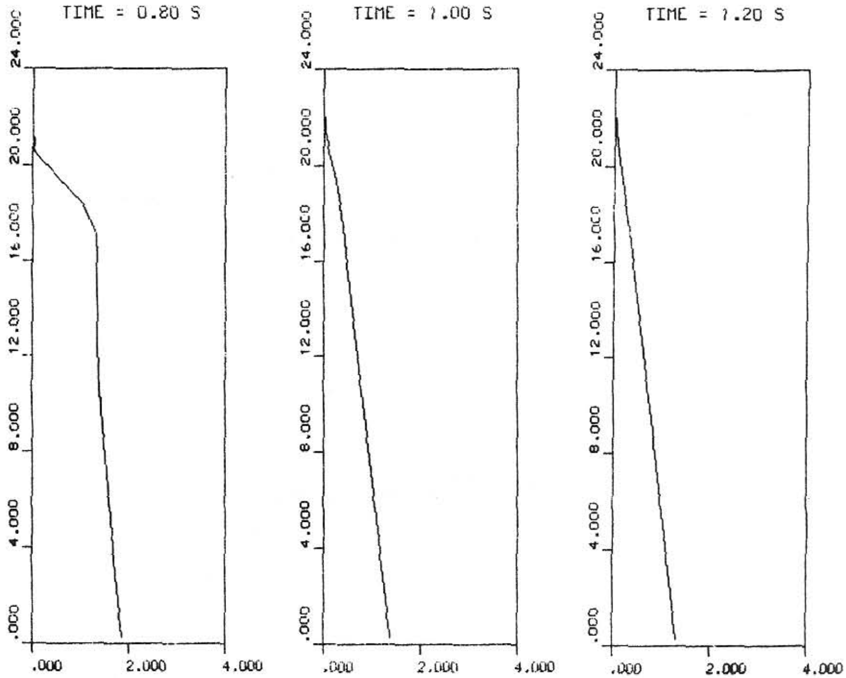
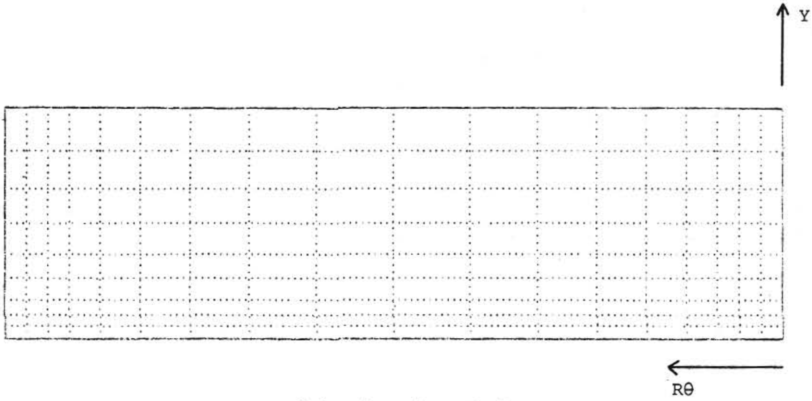
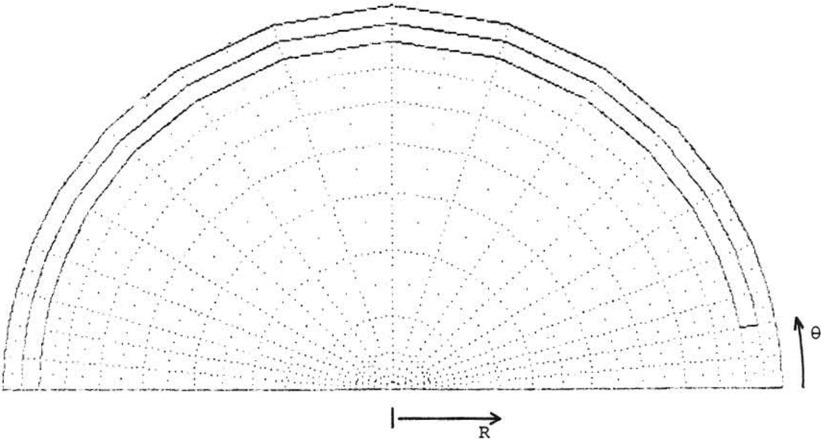


Figure 6 AXISYMMETRIC CASE - WALL PRESSURE DISTRIBUTION AT DIFFERENT TIMES

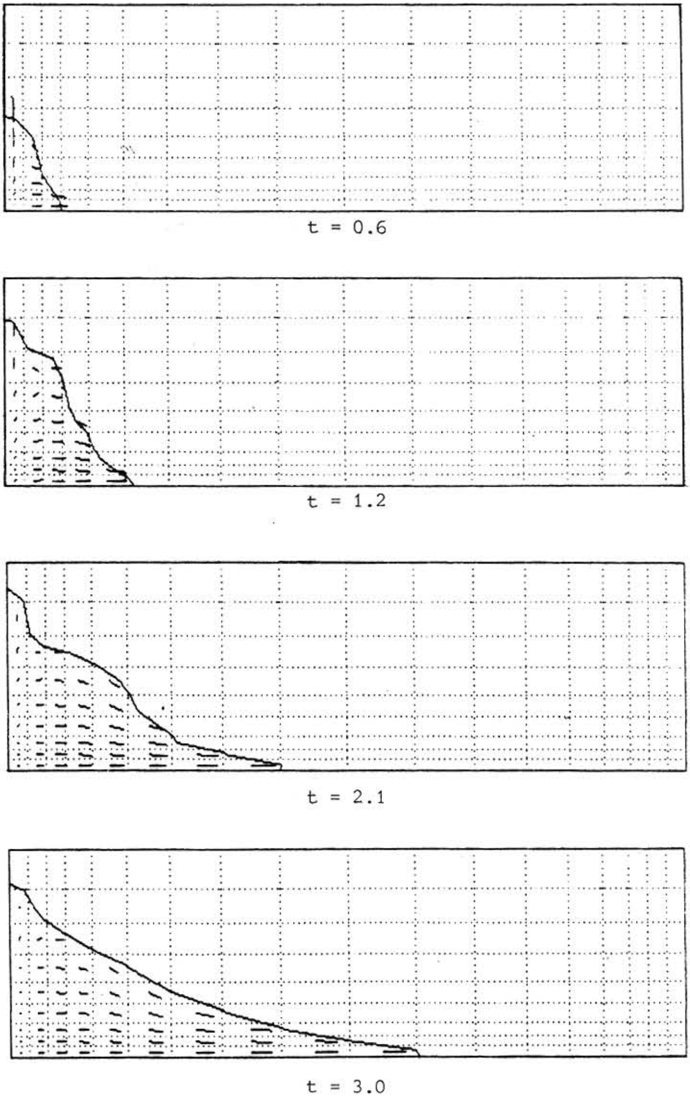


Outer Boundary Mesh



Bottom Boundary Mesh

Figure 7 THREE-DIMENSIONAL FLUID MESH



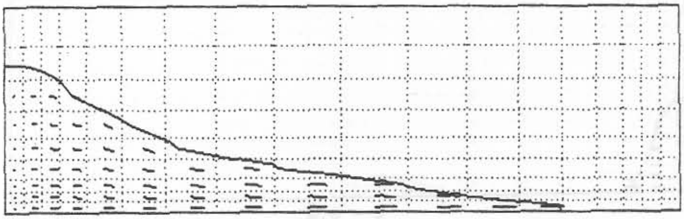
t = 0.6

t = 1.2

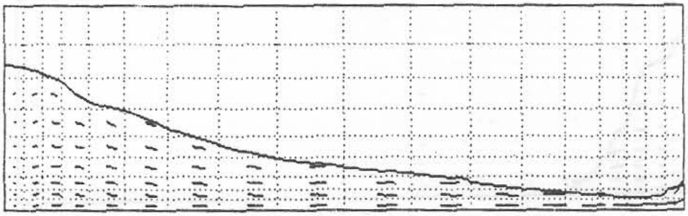
t = 2.1

t = 3.0

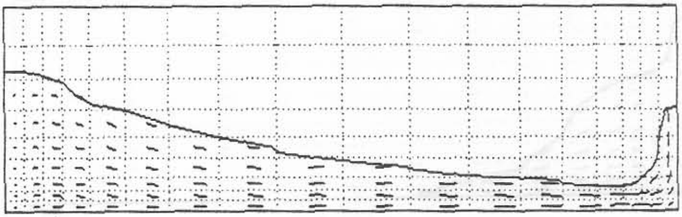
Figure 8 THREE-DIMENSIONAL CASE - FLUID FREE SURFACES AT DIFFERENT TIMES



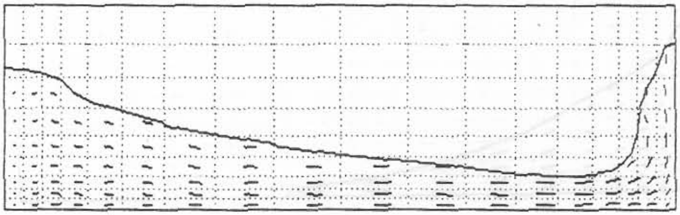
t = 3.9



t = 4.8

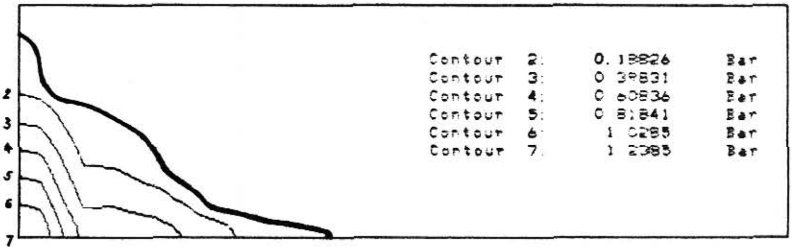


t = 5.7

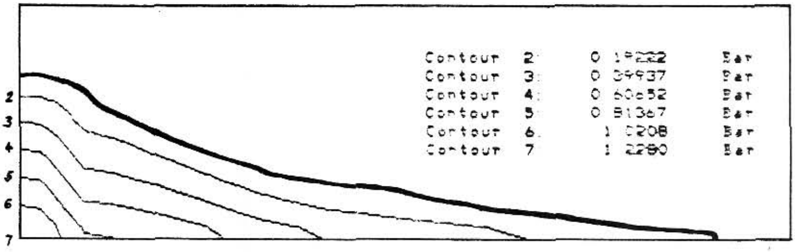


t = 6.6

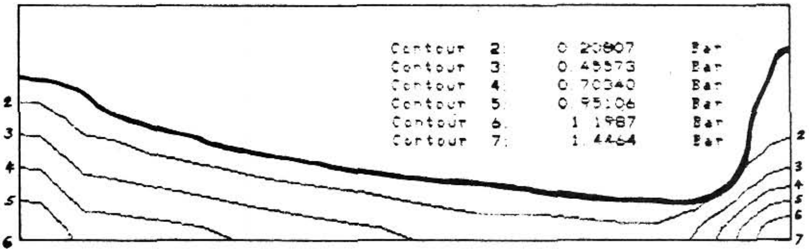
Figure 8 THREE-DIMENSIONAL CASE - FLUID FREE SURFACES AT DIFFERENT TIMES (Continued)



t = 2.1



t = 4.2



t = 6.6

Figure 9 PRESSURE CONTOURS AT OUTER MESH BOUNDARY (FREE SURFACE IS DENOTED BY EMBOLDENED LINES)