On Fluid Structure Interaction and Buckling of Thin Shells Under Seismic Loads

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In this paper the classical method used to calculate the buckling of shells filled with fluid submitted to seismic load is criticised.

The main hypothesis done in the classical approach are :
The pressures applied to the structure are the pressures which have been calculated by a fully linear dynamic analysis. The buckling load is then calculated by a quasistatic elastoplastic bifurcation analysis with the "maximum" loads coming from the dynamic analysis.

This paper intends to discuss the validity of such an approach, the discussion is illustrated by the comparison of the classical method applied to the bucking load of two concentric spheres filled with fluid ; and a fully geometric and non linear dynamic analysis of this problem.

Some important effects are quantified :
- effect of loads repetition leading to progressive deformation in certain cases
- effects of the geometric imperfections and their influence of the pressure field
- effects of interaction between dynamic and buckling modes of the structure
- effects of the non linearities in the fluid (cavitation, volumes charges, etc)

Some conclusions are presented on a very simple case to illustrate these effects.

INTRODUCTION

In this paper is presented a numerical study of the dynamic buckling of a system of two concentric spheres separated by a thin fluid layer excitated by a seismic type of loading.

The main physical aspects presented here are the following :

Buckling occurs in this type of structure ; the inertia of the shell being very small in comparison of the added mass of the fluid, there is no benefic effect due to inertial terms. During buckling cavitation could happen in the fluid.

Buckling due to seismical type of load is a progressive type of buckling.

1) PROBLEM AND BASIC STUDIES

1.1. GEOMETRY

Two very thin concentric spheres separated by a thin fluid layer have been studied The geometry is defined on a fig 1. The interior sphere has been choosen with a smaller thickness at the top to force the plastic buckling on this is part of the sphere.

The thickness varies linearly between 0.025 m at the top and 0.04 m.

1.2. MATERIAL PROPERTIES

The fluid is acoustic and has the following properties :

- specific mass $\rho_L = 833$ kgf/m^3
- sound velocity $c = 2172$ m/s^2

The two spheres have the following elastic properties :

- young's modulus $E = 1.6\ 10^{11}$ Pa
- poisson's ration $V = 0.3$
- specific mass $\rho_M = 7.8\ 10^3$ kgf/m^3

The internal sphere has an elastic perfectly plastic material. The yield stress is RE = 8.10^{+} Pa

1.3. MESH

Each shell is represented with thirty axisymetric elements.The fluid layer is represented with 30 axisymetric fluid elements (see fig (2)).

1.4. EIGENFREQUENCIES

The first four eigenfrequencies for axisymetric vibrations with fixed ends and imposed pressure on the free surface of the fluid are 19, 3.6 6.1 and 8hz.

1.5. BUCKLING EULER LOAD (elastic buckling) PE

The elastic linear buckling of the internal sphere has been calculated and compared with the formula given by TIMOSKENKO.

P_E (calculated) $11.7\ 10^5$ Pa

P_a (TIMOSKENKO) $11.5\ 10^5$ Pa

1.6. LIMIT LOAD PL

Taking account of the plastic properties of the internal sphere the pressure leading to plastic static buckling has been calculated ;

$P_L = 4.10^5$ Pa

1.7. IMPERFECTION SENSIVITY

Such a structure for which the ratio P_L/P_E is about 0.3 an interaction between the two types of ruin mode can be expected and an important decrease of the limit load can be expected. The pressure field in the fluid can also be modified by the presence of imperfection as suggested in the paper of AS VELETSOS and JW TUNNER. [4]

2) TRANSIENT ANALYSIS

2.1. LOADINGS

The structure has been prestessed by a static permanent uniform pressure in the fluid Po of 2.10^5Pa. The free surface is at the same pressure. The vertical displacement of point A (of the internal sphere) is forced with the function :

$Uz(A) = \alpha \sin 2\pi Vot$ with Vo = 3hz

2.2. FULLY LINEAR ANALYSIS

Fig 3 shows the vertical displacement of the center of the inner sphere as a function of time for an imposed displacement α = 0.01 m. Fig 4 gives the correlation between the pressure in the fluid and the membrane stress in the inner sphere. This correlation is excellent. From the risult we deduce that the inertia of the shell is negligeable in front of the added mass due to the thin layer of fluid. From the analysis we also find that the maximum pressure in the fluid during the transient linear calculation is $p_{max} = (2 + 1250\alpha)\ 10^5$ Pa (1). We want to know if the inner shell can stand a transient pressure higher than the static limit pressure P_L. From eq(1) we find that if we impose α=0.002 m we have P_{max}/P_L = 1.25. We shall impose that displacement and study if there is buckling or not.

2.3. GEOMETRICAL LINEAR BUT MATERIAL NON-LINEAR ANALYSIS

Fig 5 shows very clearly that there is some progressive deformation during the transient. This phenomenon is due to the permanent pressure po which forces the inner shell to yield only in compression. Anyway the presence of progressive deformation during seismeic loadings is an interesting phenomenon.

2.4. FULLY NON-LINEAR ANALYSIS

Fig 6 shows the vertical displacement of the top of the sphere during the time. We remark very clearly dynamic backling ; at time 0.6 sec the displacement of the top of the sphere is 0.28 m (a linear analysis would give 0.006m). The shell has first yielded at 0.3 sec, but at that moment there has not been excessive deformation in the shell.

It is clear from this remark that we have here a typical case of buckling due to progressive deformation.

From fig 7 on which is drawnthe variation of the dynamic pressure with time we can see that the total pressure becomes negative (-10^5 Pa) during the buckling and that certainly cavitation occurs during buckling.

CONCLUSION

For this type of structure we remark that the buckling due to seismic loads occurs nearly for the same level of pressure that the static elastoplastic buckling. However in this calculation the effects of dynamic amplification have not been studied because the number of cycles that lead to buckling is two small. When there is no permanent pressure (Po) this instability does not necessarily corresponds to large deformations. The level of the loads should be significatively increased to obtain large deformation and buckling. This is a ductility effect.

When there is a permanent pressure Po there is progressive deformation which leads to buckling in a few cycles as soon as the level of the dynamic pressure is over the static limit pressure P_L.

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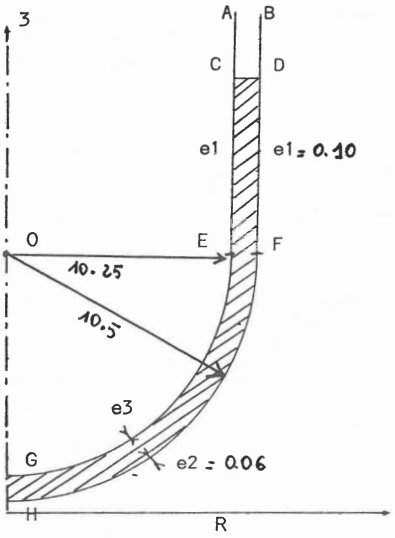

Fig 1 : Geometry of the structure

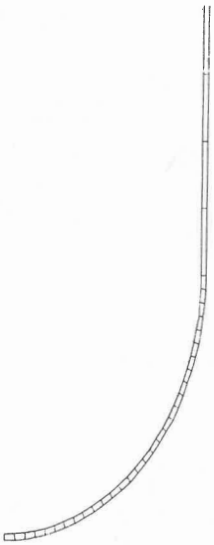

Fig 2 : Mesh

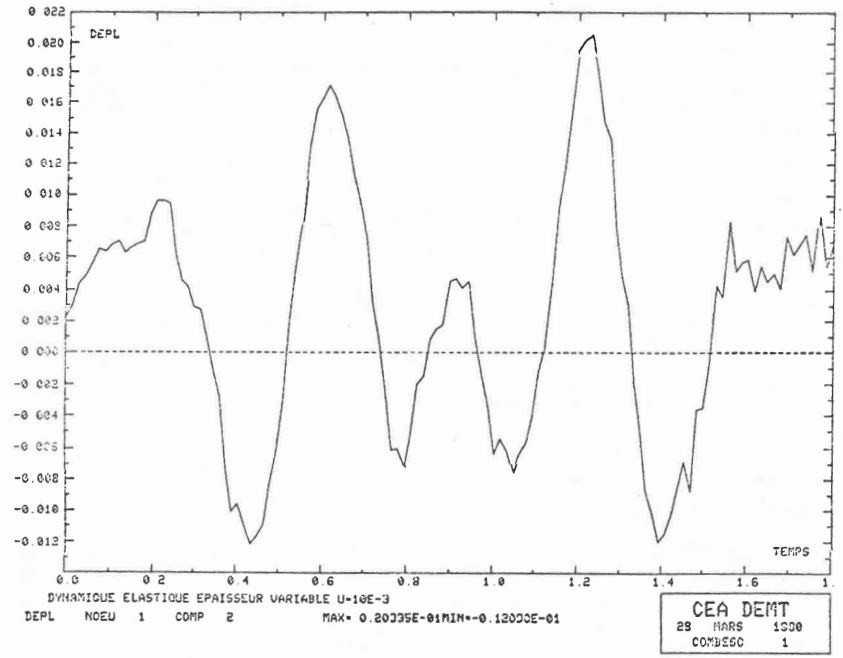

Fig 3 : Elasticity calculation

Vertical displacement of the top in the inner sphère

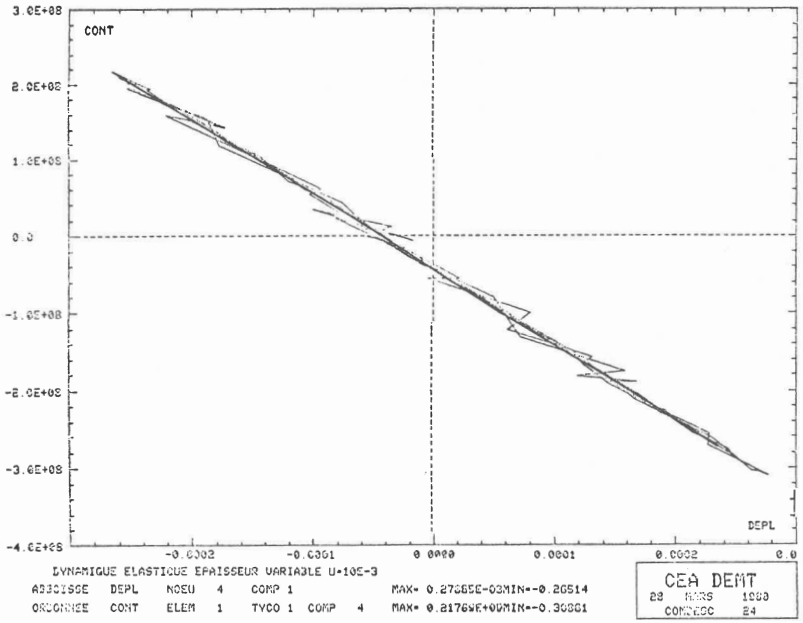

Fig 4 : Correlation between hoop-stress in the shell and pressure in the fluid

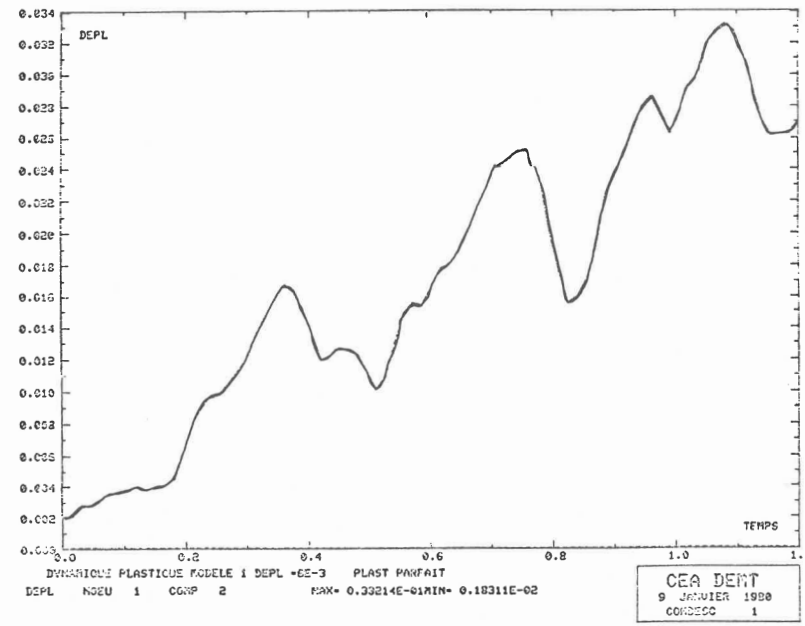

Fig 5 : Plastic calculation

Vertical displacement of the top of the inner sphère

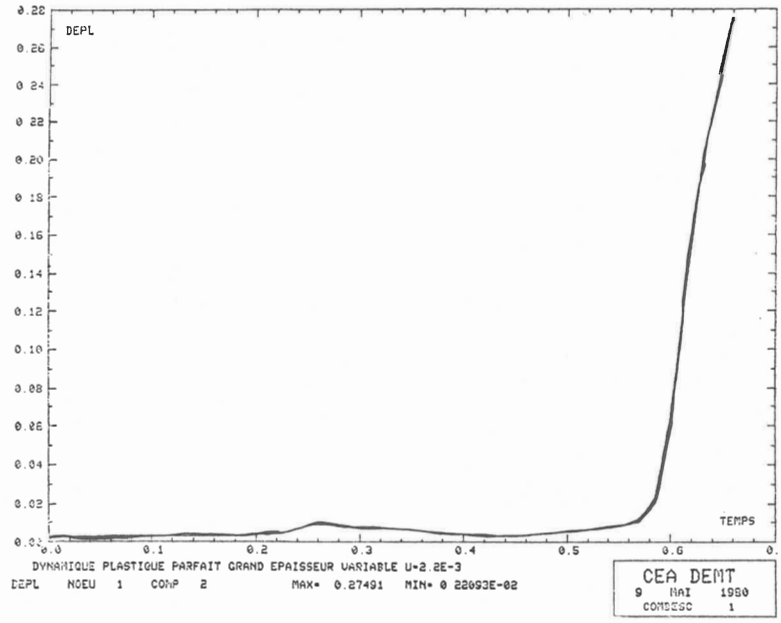

Fig 6 : Fully non-linear analysis $P_{max}/P_L = 1.25$
Vertical displacement of the top of the inner sphère

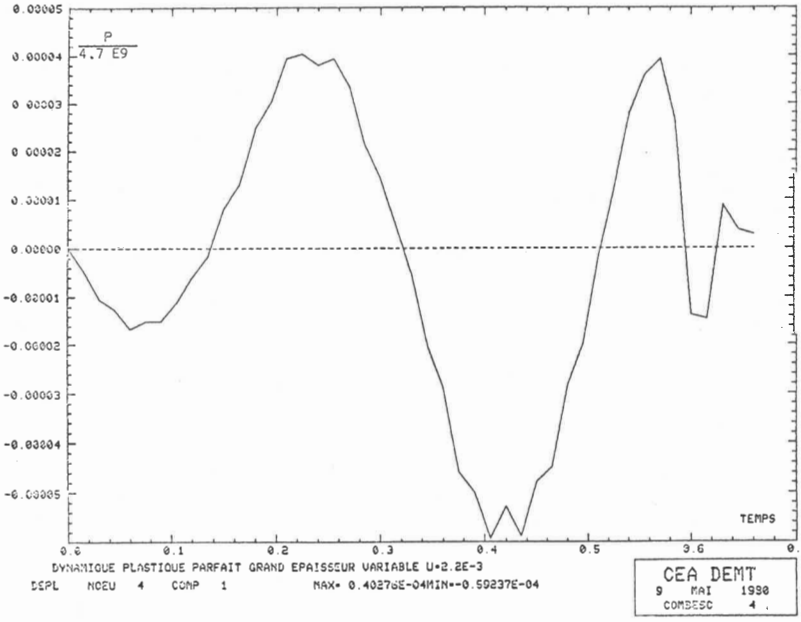

Fig 7 : Fully non-linear analysis $P_{max}/P_L = 1.25$
Dynamic pressure in the fluid