# Calculation of the Wall Pressure Field Generated on a Group of Building by an External Explosion

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## ABSTRACT

The aim is to work out a tri-dimensional code calculating the over-pressure distribution on any structure when an air shock waves arrives specially in the case of geometry providing multiples waves reflection. The computer code ZEPHIR was written for the Huyghens-Helmotz (or Kirchhoff) equation with the assumption that the phenomena agrees with the accoustic laws. An integral formulation of this relation leads infinite tridimensionnal problems to a bidimensional one on a surface S limiting the real D. The obtained equation gives the pressure at a point $M_0$ of S and at the time $t_0$ only from the source and the pressures of the other points of S at the past time. The surface S is discretized with triangular elements by means of an automatic computer code COCO of CEASEMT system.

In the first approach the value of the pressure has been taken at nodes of the mesh and a direct resolution of the equation has been done.

Difficulties with computation of curvature radius and singular kernel within the integral lead to replace the S surface by the polyedre constituted by the mesh and to compute the pressure at the gravity center of the triangularelements. But the second approach does not eliminate the time instability in some geometries.

In order to eliminate instability the pressure is calculated with interpolation between several time steps. This solution is efficient and complete qualification obtained.

The ZEPHIR code has been valided against :

- analytic solutions obtained for simple obstacle geometries (cylinder, sphere, dihedral) for a step or decreasing exponential incident pressure pulse.
- pressure traces recorded at a number of points, on small-scale models (cylinder and rectangular building alone, adjacent or separated by a gap) exposed to the blast of external charges.

The aim of the computer code ZEPHYR is to predict overpressure acting on the surface of the structure under waves coming up from a far out source explosion.

## 1. HYPOTHESIS

Alembert's equation describes the physical problem under some more assumptions :

- the overpressure amplitude (≅ 0.1 bar) is small in front of atmospheric pressure and effects of flow are neglectable. It is accoustic waves.
- particulate displacement is small in front of structure dimensions. Fluid-solid interaction is "acoustic".
- a complete reflexion on boundaries is also assumed because they are perfectly rigid and motionless.

With these assumptions we do not take in account explosions with an important blow out effect such as nuclear explosions or closed chemical explosions over small buildings.

Many workers tried to resolve this equation but rapidly difficulties to resolve the problem in an infinite acoustic space arise because of actual means of computation. ZEPHIR code is formulated with boundaries integral equations solved with a technique of time retarded potentials, then infinite 3D problem switchs in a 2D problem over the surface of the structure.

## 2. NUMERIC FORMULATION [1]

The code ZEPHIR computes pressure over the surface of a 3D structure under any incident waves functions of time S(t) coming up from a pin point source situed at finite distance. Under accoustics assumption the equation giving at time $t_0$ pressure at point $M_0$ of the surface is ($\overrightarrow{grad}\, P \cdot \vec{n} = 0$)

$$(1) \quad (4\Pi - A)\, p(M_0 t_0) = \iint_\Sigma \left[ p(M, t_0 - \frac{d}{c})\, \text{grad} \frac{1}{d} - \frac{1}{cd}\, \dot{p}\, (M, t_0 - \frac{d}{c})\, \text{grad}\, d \right] n\, d\sigma + 4\Pi \frac{S(t_0 - \frac{r}{c})}{r}$$

A : solid angle at $M_0$

M : is a point of the surface $\Sigma$

d : distance M $M_0$

c : sound velocity

n : external normal vector to $\Sigma$ at point M

r : distance from $M_0$ to the source of pressure

S(t) : source value at time t

p(M, t) : pressure at point M and time t

$d\sigma$ : surface element at point M

The real structure is replaced by a set of flat triangular elements.

The use fo flat element leads to a great simplification of the initial equation. In fact it is possible to set at the gravity center $M_i$ of each element i.

$$(2) \quad 2\Pi\, p(M_i, t_0) = \iint_\Sigma \left[ p\, (M, t_0 - \frac{d}{c})\, \text{grad} \frac{1}{d} - \frac{1}{cd}\, \dot{p}(M, t_0 - \frac{d}{c})\, \text{grad}\, d \right] n\, d\sigma + 4\Pi \frac{S(t_0 - \frac{r}{c})}{r}$$

because : - solid angle A around $M_i$ is equal to 2 $\Pi$

- $\overrightarrow{grad} \frac{1}{d} \cdot \vec{n}$ and $\overrightarrow{grad}\, d . \vec{n}$ are equal to zero over the i element because $\overrightarrow{grad}\, d$ is included in the plane of the element.

The second part of equation (2) is decomposed over the j element (j ≠ i).

$$(3) \quad 2\Pi\ p\ (M_i,\ t_0) = \sum_{\substack{j\epsilon\Sigma \\ j\neq i}} \iint_j \left[p(M,\ t_0 - \frac{d}{c})\ \text{grad}\ \frac{1}{d} - \frac{1}{cd}\ \dot{p}(M,\ t_0 - \frac{d}{c})\right]\ n\ d\sigma + 4\Pi\ \frac{S(t_0 - \frac{r}{c})}{r}$$

for the two part of the integral of the above equation we assume the pressure is constant over the element during an interval of time.

$$\left.\begin{aligned} A_{ij} &= \iint_j \text{grad}\ \frac{1}{d}\ n\ d\sigma \\ B_{ij} &= \iint_j - \frac{1}{cd}\ \text{grad}\ d.n.d\sigma \end{aligned}\right\} \iint_j \left[p(M,t_0 - \frac{d}{c})\text{grad}\ \frac{1}{d} - \frac{1}{cd}\ \dot{p}(M,t_0 - \frac{d}{c}\right] .n.d\sigma = p\,A_{ij} + \dot{p}\ B_{ij}$$

$A_{ij}$:solid angle issued from the gravity center of i and containing element j. These quantities are computed at the beginning of the run. At that time we have chosen to do an exact computation of theses quantities using spheric trigonometric formulas (Huillier's formula). It is justified to perform such computation because it is important to verify :

$$\sum A_{ij} = 2\ \Pi$$

Which is necessary in order to verify the balance of energy.

$B_{ij}$ term is more difficult to compute, we choose a numerical integration method. Using :

$$\iint_j \frac{\text{grad}\ d}{d}\ .\ n\ d\sigma = \iint_j -\ d\ \text{grad}\ \frac{1}{d}\ n\ d\sigma$$

Let us assume $B_{ij} = -\ d\ A_{ij}$

This last substitution is done on a set of triangles which are integration elements.

Looking closer the equation (3), we can see that p $(M_0 t_0)$ is only dependant on :

- pressure over the structure until the time $t_0 - \Delta t$. $\Delta t$ is the time necessary to the wave to avance a characteristic lenght of the element.
- the derivate of the pressure up to $t_0 - \Delta t$.

Assuming known $\Delta t$ the problem is now to discretize p(M, t) for $0 < t < t_0 - \Delta t$ and for $M \in \Sigma$.

For the spatial problem we assume that the value is constant and equal to the pressure at the gravity center.

Let us assume that the pressure is known at any $\Delta t$ up to $t_0 - \Delta t$.

The equation (3) can be set to (4) :

$$(4) \quad 2\Pi\ p_i(t_0) = \sum_{j\neq i} (A_{ij}\ p_j\ (t_j) + B_{ij}\ \dot{p}_j\ (t_j)) + 4\Pi\ \frac{S(t_0 - \frac{r}{c})}{r_i}$$

with $t_j < t_0 - \Delta t_i$

and where the only problem is the interpolation of :

- $p_j\ (t_j)$ at the different times
- $\dot{p}_j\ (t_j)$

In the Figure 1 the pressure to take in account is the one between C and D limits of j element.

A natural hypothesis is that $p_j(t_j)$ is only dependant of j which lead P to be on line AB.

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In order to have $p_j(t_j)$ we first do a linear interpolation between the closest time of $t_j$ : $t_{j_1}$, $t_{j_2}$.

then, $\dot{p}$ is : $\dot{p}_j = \dfrac{p_j(t_{j_2}) - p_i(t_{j_1})}{t_{j_2} - t_{j_1}}$

This method called method <u>one</u> conducts to time instability.

The instability makes not sure of the precision of results. So a considerable effort has been made in order to obtain a stable method.

It seems better to have a mean value of p during the time step over j. So we did an interpolation between less close times up to A - B

- the closest : option 0 in the code which is in fact the method 1.
- the $i^{th}$ closest : (Figure 2) option i in the code.

A pratical ruse to assure the stability is to choose i function of the ratio R which is equal to the time necessary to cross the element over the time step.

By example, it is recommended to take :

- i = 1 for R = 2
- i = 5 for R = 10

The case of a source outside a tetrahedron (Figures 3 and 4) shows a little instability for i = 2 and good results for i = 4.

## 3. STATE OF THE COMPUTER AND LIMITS OF USE

The code is written in FORTRAN IV and is one modulus fo the structural computation system CASTEM. Mesh generation is done by the modulus COCO or by the new generation advanced mesh generator GIBI.

ZEPHIR code will give out better results for effects of accoustic wave on a structure if the characteristic time of source is of the same order or longer than the characteristic time of the structure. (The characteristic time of wave is the time necessary to divide by two the pressure of the source, and the characteristic time of the structure is the time for the wave to pass over the structure).

This structure must be meshed taking in account in one hand the smallest size and in the other hand the smallest number of elements. Distance between two gravity centers of element must be as constant as possible over all the mesh. Function of speed wave propagation and the size of element we have a time step value $\Delta t$. To this time step a frequency $f_c = \frac{1}{\Delta t}$ is a cutting frequency. For phenomenons existing at a higher frequency than $f_c$, it is necessary to short the time step and to stabilize the numeric computation. When a satisfaying state between these parameters is obtained, results are really good and even sometime better than numerical resolution of analytical solutions. During tests over models of cylindric buildings or parallelepipedic buildings (cylindric building alone spaced buildings or joined buildings) the overpressure due to an explosion has been measured. The input incident wave in computation is smoothed from the real one.

As any explicit computation in time ZEPHIR is under condition $\frac{C\Delta t}{\Delta X} \leqq 1$. Computation cost increases with the ratio, structural dimension versus lengts wave. In fact, this ratio must be smaller than 2 to 5.

## 4. RESULTS

Results have been compared with analytical or pseudo analytical solutions for dihedrons, spheres, cylinders. [2]

Comparison between numerical results and analytical solutions is meaningfull until effect of dihedron top has propagated to computational point. Comparison is done in Figure 5 in case of a rectangular dihedron under rectangular pulse.

Computation for cylinder shows clutters inside shadowed region if incident pressure shows important variations over an element. This enables to treat incident wave with high frequencies in front of the time of propagation accross the structure. (Figure 6).

A narrow rectangular pulse passing over a plane surface is very well simulated (Figure 7).

Results are in good agreement with experiments. Reflexions and diffracted waves running around buildings are well simulated. [3]

Figures show comparison between experiments and computations for :

- pressure at 180° for an incident wave (shadowed region) over a cylinder (Figure 8).
- pressure in the space between two buildings (a parallelepipedic and a cylindric one (Figure 9).
- pressure inside a re-entrant corner between two buildings (Figure 10).

## 5. CONCLUSION

The code ZEPHIR using a polyhedral approximation of 3D structure has permitted to compute diffracted pressure in various cases where an experimental or analytical solution exist ; the flexibility of the code makes it very easy to use ; results are really satisfactory ; they arise the validity of this approach if the ratio of characteristic dimension of the structure versus characteristic lenght of wave stands moderate : at most few units.

ACKNOWLEDGEMENT :

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Note Technique DEMT/SMTS/LAMS/83 à paraître

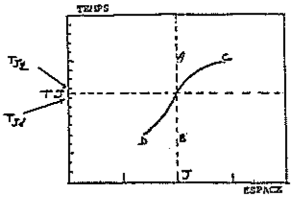

FIGURE 1 : Pressure interpolation -
1st Method

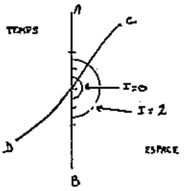

FIGURE 2 : Pressure interpolation -
2nd Method

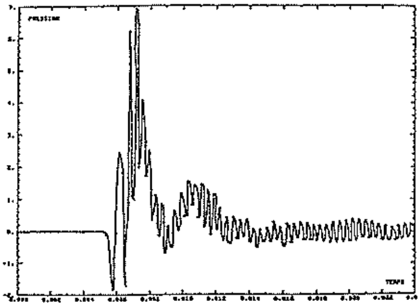

FIGURE 3 : Pressure on a tetrahedron -
i = 2

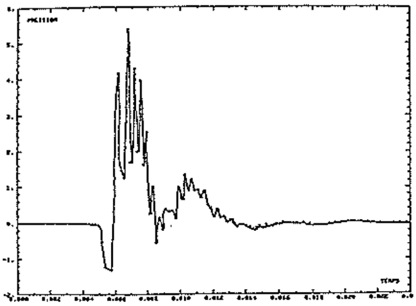

FIGURE 4 : Pressure on a tetrahedron -
i = 4

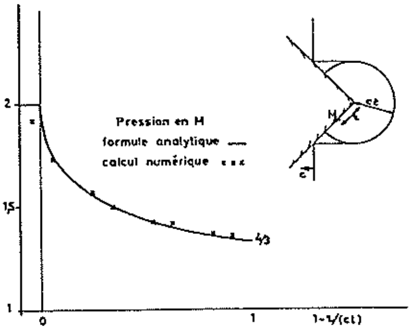

FIGURE 5 : Pressure on a dihedron
(analytic solution)

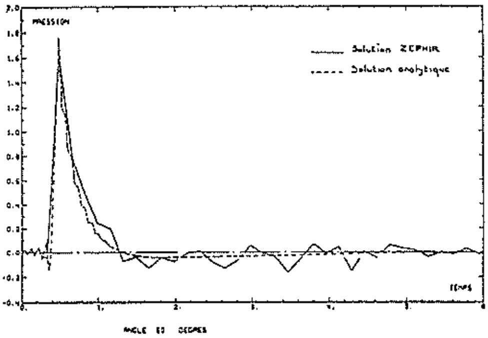

FIGURE 6 : Pressure on a cylinder
(analytic solution)

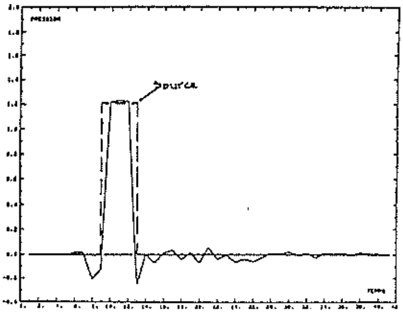

FIGURE 7 : Response to a rectangular pulse

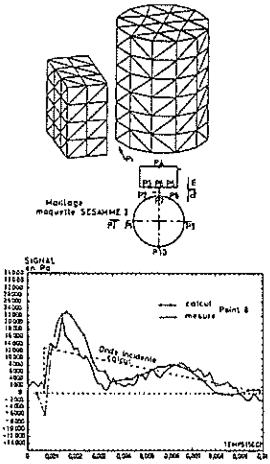

FIGURE 9 : Pressure between two buildings (experiment)

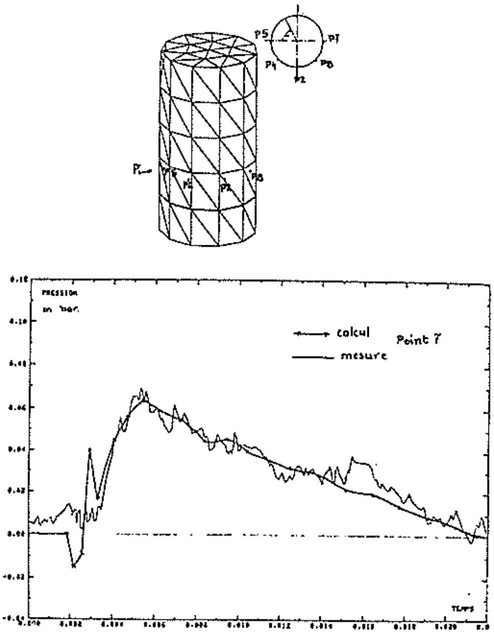

FIGURE 8 : Pressure on a cylinder (experiment)

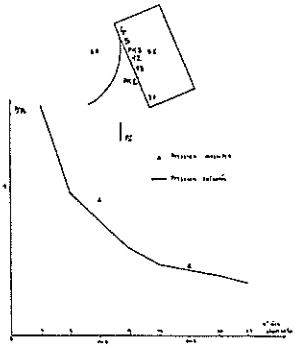

FIGURE 10 : Pressure in a corner (experiment)