HYDRO-ELASTIC STUDY OF INSTABILITY OF THE COOLING CIRCUIT OF SUPERPHENIX

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Summary : To deal with problems of hydro-elastic vibrations encountered during the start up of SUPERPHENIX, the L.N.H. has designed an approch which combines a physical scale model and in parallel a hydro-elastic analitical study.

Very low frequency vibrations whose intensity exceeded that forecast were detected during the initial sodium tests of the SUPERPHENIX reactor, the appearance of these phenomena was linked to loading the wier of the cooling circuit of the main wessel.

The studies started by the L.N.H. had a twofold aim : on the one hand, to confirm the origin of the phenomena observed on the reactor and find ways to eliminate the vibrations and on the other hand, to understand the phenomenon and determine the threshold values of the parameters which trigger instability, two courses were followed simultaneously for this purpose :

- the construction of a physical mode, scale : 1/4 (E.P.O.C) and,
- analitical study of the hydro-elastic coupling, putting the phenomenon into equation form and then solving them numerically.

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E.D.F. L.N.H.

CONTENTS:

SIMILITUDES :

HYDRAULICS

→ Reynolds number (turbulent flow)
→ Froude number (gravity waves)

⇒ → geometrical scale $\hat{L} = 1/4$ (to have turbulent flow)
→ $F_r = \frac{V}{\sqrt{gL}}$ → $\hat{V} = \hat{L}^{1/2}$
→ $\hat{Q} = \frac{1}{32}$ $\hat{t} = \frac{1}{2}$

HYDRO-ELASTICS

→ $\frac{E}{\rho_e V^2}$ E = Young Elasticity number
$\rho_e V^2$ = cinetic energy of the flow

→ $\frac{\rho_s}{\rho_e}$

⇒ → find a material with an Young elasticity number around 4000 kg/mm²
→ Tin is quite adequate but not for all of the shell.
→ The shell is therefore built in two part.

– The discharging crest is made of tin without distorsion in thickness (for hydraulics reasons)

$$\frac{\hat{E}}{\hat{\rho}_e \hat{L}} = 1{,}01$$

– The shell is made of aluminium with a slight distortion of its thickness to respect a simplified similitude

$$\frac{\hat{E}\,\hat{k}^3}{\hat{\rho}_e\,\hat{L}^4} = 1$$ (membrane phenomena are negligible)

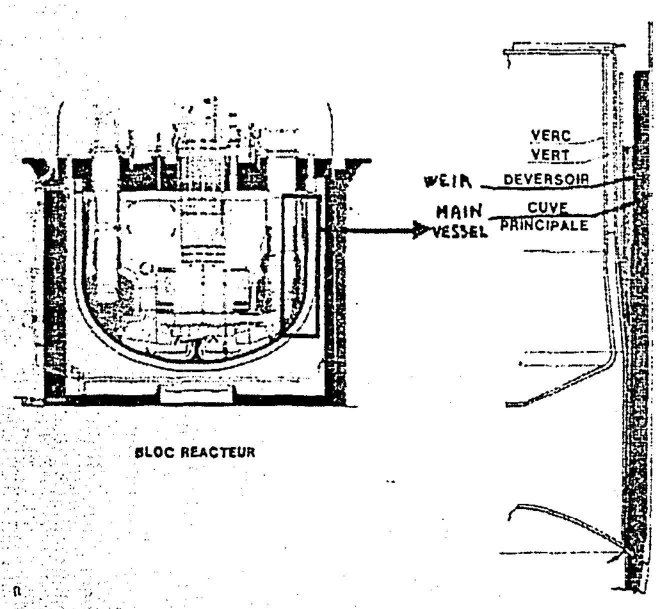
k = thickness of the shell

SUPERPHENIX

Detection of hydro-elastic vibrations

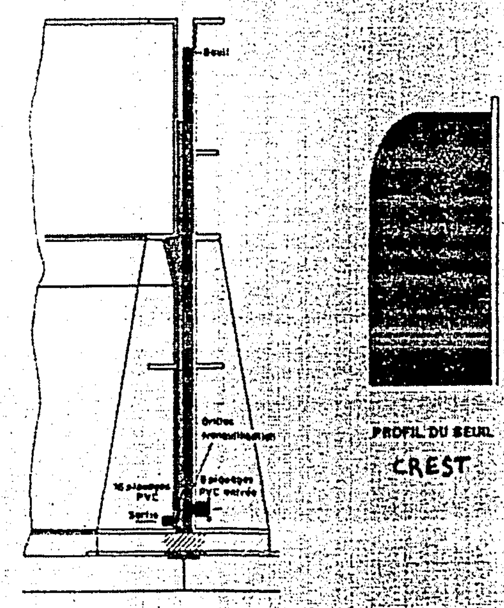
physical scale-model	Analytical study
E.P.O.C. 1/4	of the coupling
- confirm the origin	- understand the phenomena
- find ways to deal with vibrations	- study the parameters

E.D.F. STUDIES ON THE COOLING CIRCUIT OF SUPERPHENIX



REACTEUR SUPERPHENIX

SITUATION DU CIRCUIT DE REFROIDISSEMENT DE LA CUVE PRINCIPALE



MODELE E.P.O.C.

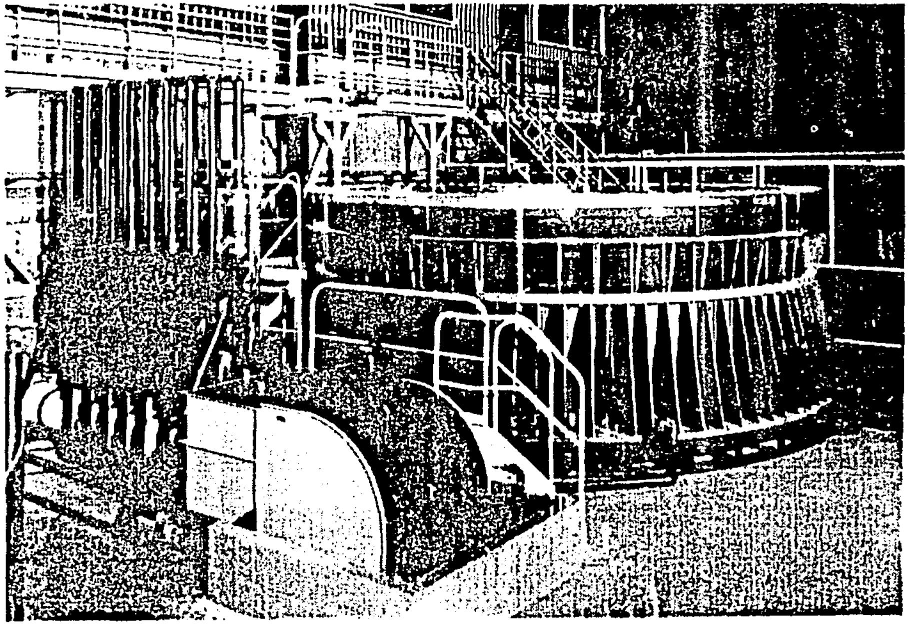
E.P.O.C. MODEL

SCALE 1/4

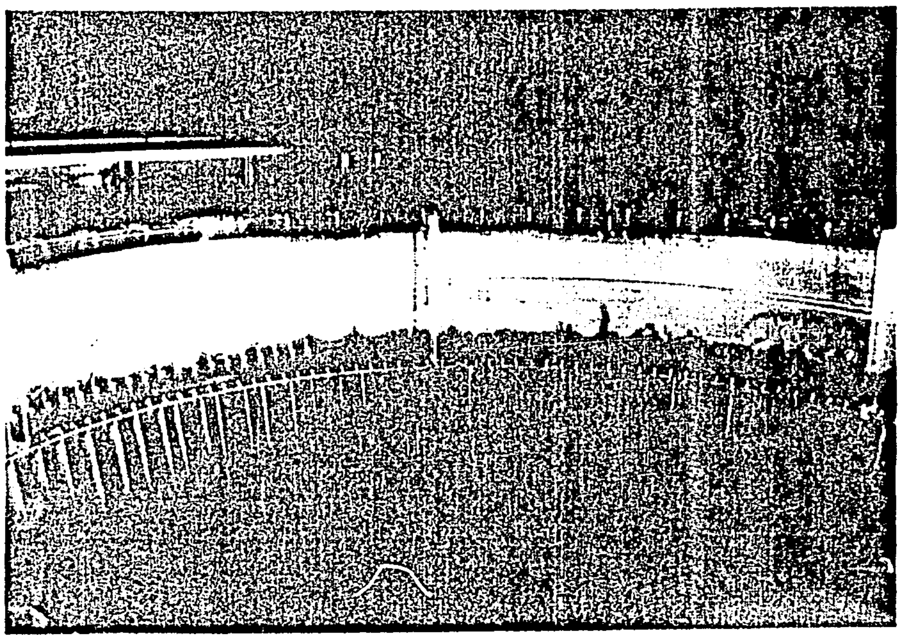
ETUDE DES PHENOMENES ONDULATOIRES DANS LES COLLECTEURS DE SUPERPHENIX (MODELE E.P.O.C.)

MODELLING THE GEOMETRY OF THE REACTOR FOR THE EPOC MODEL

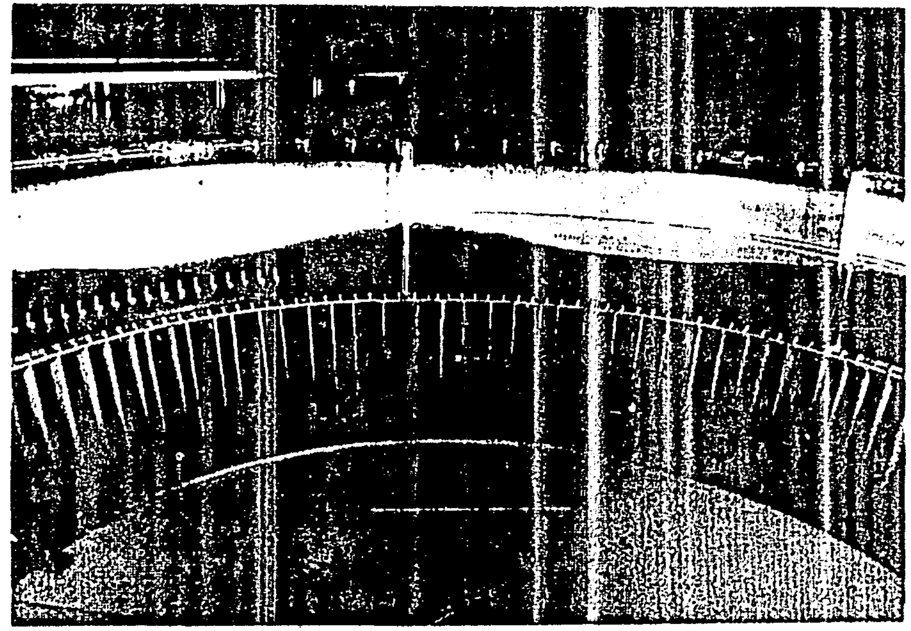
DER LNH



GENERAL VIEW OF THE EPOC SCALE MODEL

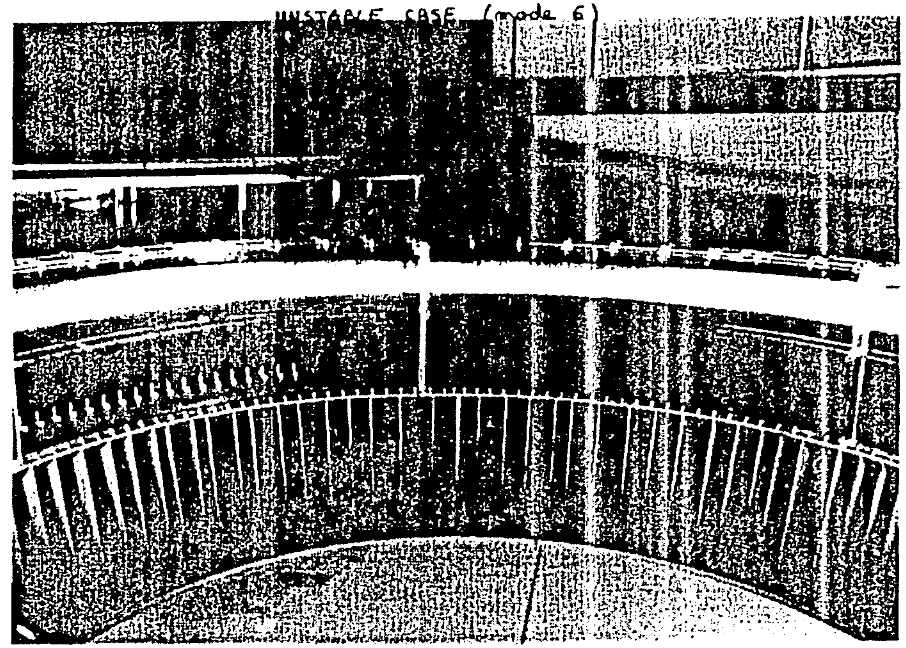


UNSTABLE CASE (fast mode)



Cas instable 20 l/s, 45 cm de hauteur de chute

UNSTABLE CASE (mode 6)



STABLE CASE

Cas stable 30 l/s, 15 cm de hauteur de chute

VISUALISATION DES SURFACES LIBRES MODELE EPOC (2ème phase d'essais)

DISPLAY OF FREE SURFACES EPOC SCALE MODEL

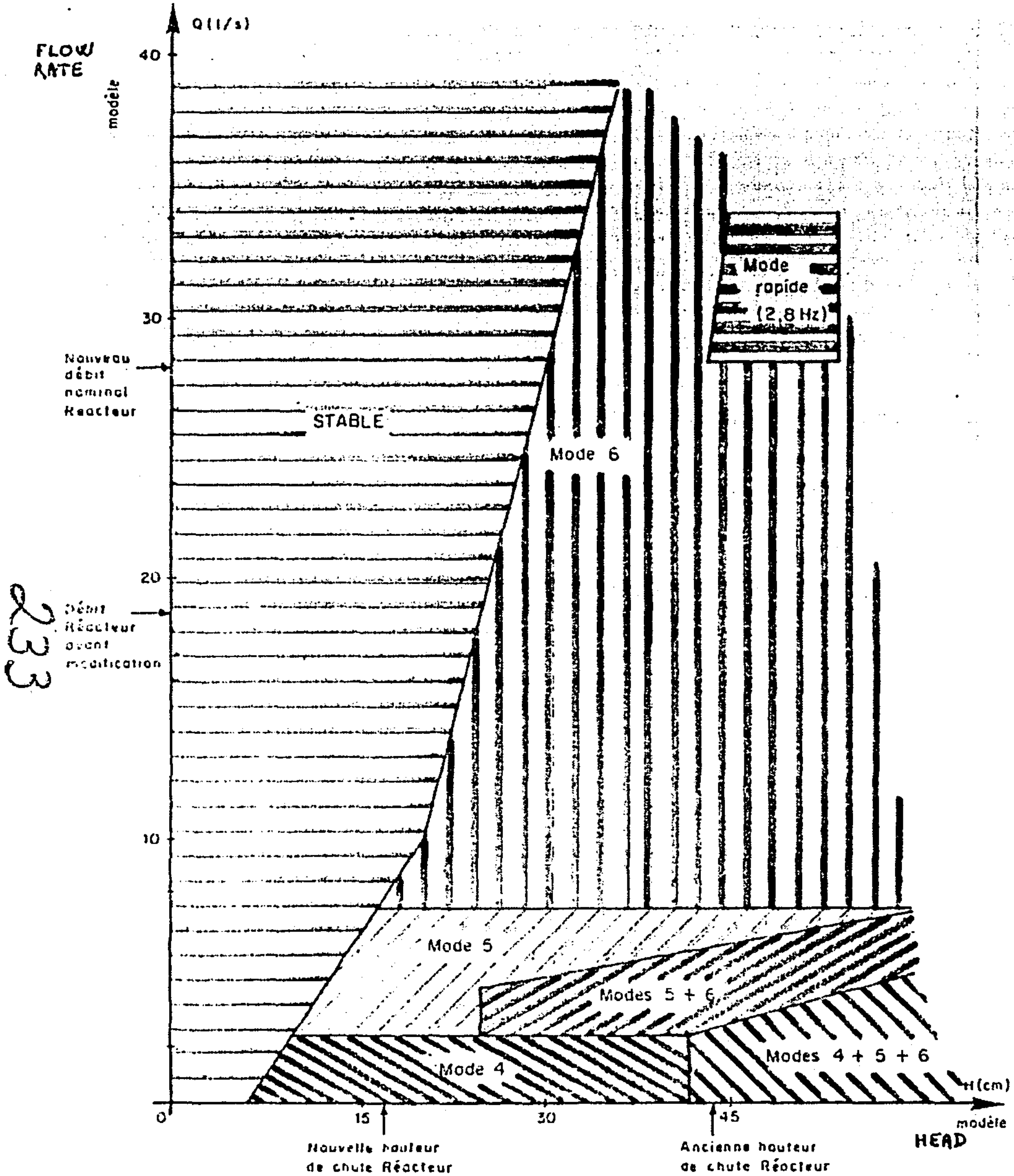


Figure 9 : Zones de stabilité et d'accrochage des différents modes (2eme phase d'essais)

STABILITY AND ESTABLISHMENT ZONES OF THE DIFFERENT MODES

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$$\frac{d^2 \varepsilon_{1n}}{dt^2} a_1 + \frac{d\varepsilon_{1n}}{dt}\left(\frac{3}{2} g^{1/2} h_1^{1/2} + q_0 \frac{n}{L} x_1\right)$$

$$+ \varepsilon_{1n}\left(\frac{3}{2} g^{1/2} h_1^{1/2} \frac{q_0}{a_1} \frac{n}{L} x_1 + a_1 g \frac{n}{L} x_1\right)$$

$$= \frac{d^2 \omega_n}{dt^2}\left(h_2 + \frac{L}{n} x_1\right)$$

$$+ \frac{d\omega_n}{dt}\left(h_2 \frac{q_0}{a_1} \frac{n}{L} x_1\right) \qquad (22)$$

avec $x_1 = \text{th}\left(\frac{n}{L} H_0\right)$

UPSTREAM LEVEL

$$\frac{d^2 \varepsilon_{2n}}{dt^2} a_2 + \frac{d\varepsilon_{2n}}{dt}\left(q_0 \frac{n}{L} x_2\right)$$

$$+ \varepsilon_{2n}\left(a_2 g \frac{n}{L} x_2\right)$$

$$= \frac{d^2 \bar{\omega}_n}{dt^2} h_1 - \frac{d^2 \omega_n}{dt^2} \frac{L}{n} x_2 \qquad (23)$$

$$+ \frac{d\bar{\omega}_n}{dt}\left(h_1 \frac{q_0}{a_2} \frac{n}{L} x_2\right)$$

$$+ \frac{d\tilde{\varepsilon}_{1n}}{dt}\left(\frac{3}{2} g^{1/2} h_1^{1/2}\right)$$

$$- \tilde{\varepsilon}_{1n} \frac{3}{2} \frac{q_0}{a_2} g^{1/2} h_1^{1/2} \frac{n}{L} x_2$$

avec $x_2 = \text{th}\left(\frac{n}{L} H\right)$

DOWNSTREAM LEVEL

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$$\frac{d^2 w_n}{dt^2}\left[\frac{a}{\rho} + \frac{L^2}{n^2}\left(\frac{H}{T_2} + \frac{d_3}{e_1}\right) - \frac{L}{n}\left(\frac{f_1}{e_1} + \frac{f_2}{e_2}\right)\right] =$$

$$-\frac{dw_n}{dt}\left(n_1 d_3 \frac{L}{n}\frac{T_1}{e_1^2} + a\sqrt{\frac{\pi s}{\rho}}\right)$$

(amortissement) (absorption)

$$-\frac{d\bar{w}_n}{dt}\left(n_1 d_3 \frac{L}{n}\frac{T_2}{e_2^2}\right)$$

(amortissement déphasé) (dephased absorption)

$$- w_n \frac{K}{\rho}$$

(raideur) (rigidity

$$-\frac{d\mathcal{E}_{1n}}{dt}\frac{L}{n}\frac{d_3}{e_1}T_1$$

$$-\mathcal{E}_{1n}\frac{L}{n}\left(g\,T_1 + \frac{1}{2} d_3\, g^{1/2} n_1^{1/2}\frac{T_1}{e_1^2}\right)$$

$$+\bar{\mathcal{E}}_{1n}\frac{L}{n}\frac{1}{2} d_3\, g^{1/2} n_1^{1/2}\frac{T_2}{e_2^2}$$

$$-\frac{d\mathcal{E}_{2n}}{dt}\frac{L}{n}\frac{d_3}{e_2}T_2$$

$$+\mathcal{E}_{2n}\frac{L}{n} g\, T_2$$

avec $T_1 = \dfrac{ch(\frac{n}{L}H_1) - 1}{sh(\frac{n}{L}H_1)\cdot ch(\frac{n}{L}H_1)}$

et $T_2 = \dfrac{ch(\frac{n}{L}H) - 1}{sh(\frac{n}{L}H)\cdot ch(\frac{n}{L}H)}$

Equation of the shell movement.

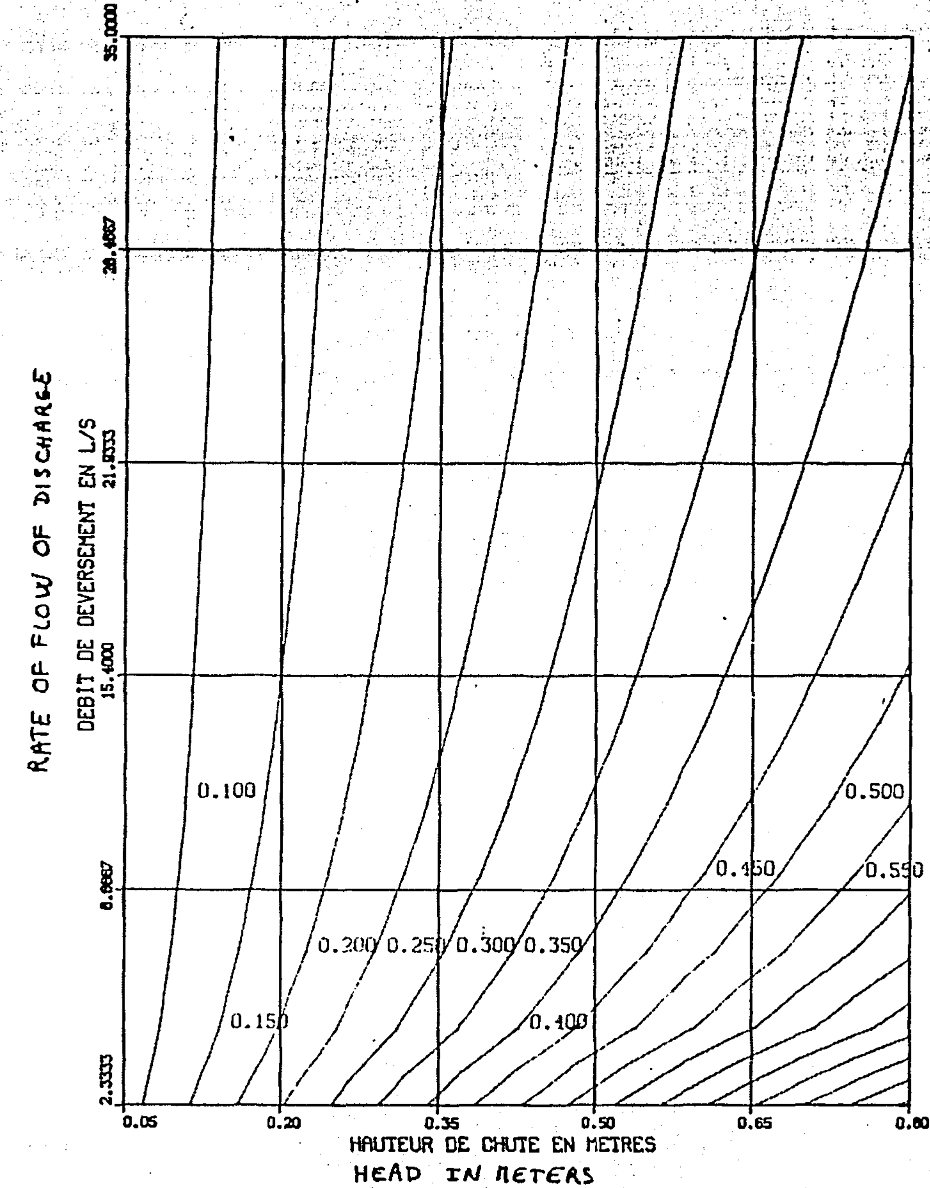

Fig:14 CALCUL ANALYTIQUE DU MODELE EPOC

ISO-TEMPS DE CHUTE EN SECONDES

ANALYTICAL COMPUTATION OF THE EPOC MODEL

ISO-FALL TIME IN SECONDS

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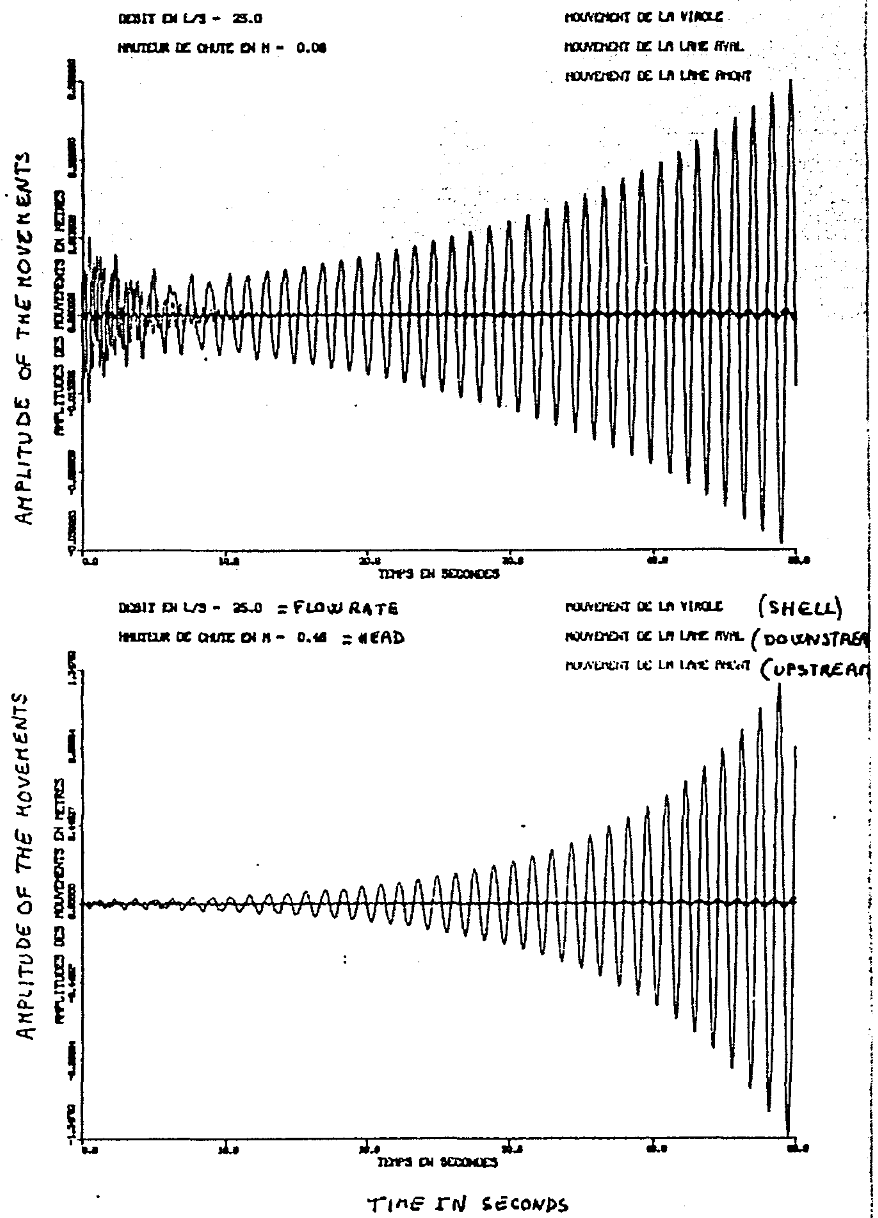

Fig :15 AMPLITUDES DES MOUVEMENTS

CALCUL SEMI-ANALYTIQUE SANS AMORTISSEMENT

AMPLITUDE OF MOVEMENTS

SEMI-ANALYTICAL COMPUTATION WITHOUT ABSORPTION

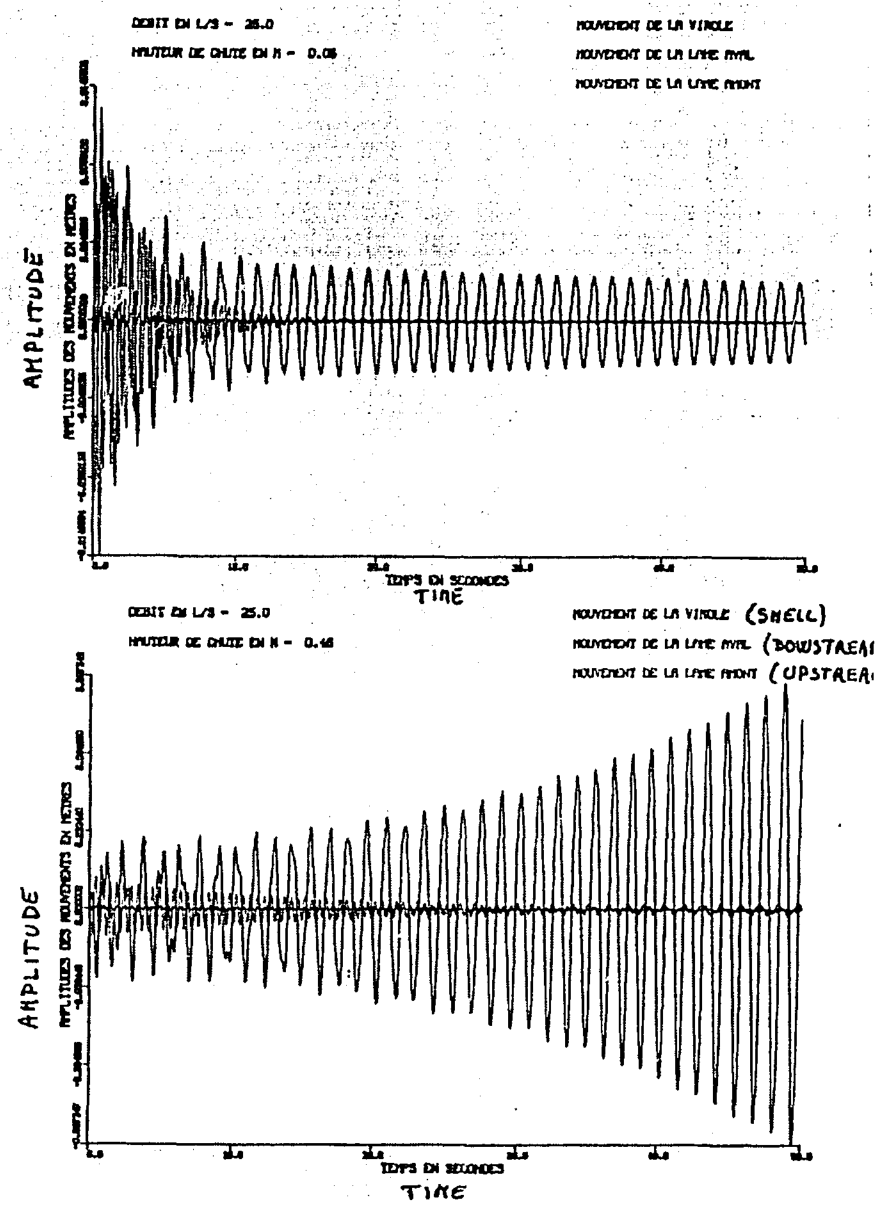

Fig :16 AMPLITUDES DES MOUVEMENTS

CALCUL SEMI-ANALYTIQUE AVEC AMORTISSEMENT

AMPLITUDE OF MOVEMENTS

SEMI_ANALYTICAL COMPUTATION WITH ABSORPTION

CONCLUSIONS:

THE **EPOC** PHYSICAL SCALE MODEL IN HYDRO-ELASTIC SIMILITUDE WITH THE RELEVANT ZONE OF **SUPERPHENIX** HAS UNCOVERED A PHENOMENON OF CLOSE COUPLING BETWEEN FLUID AND STRUCTURE, AND HAS ENABLED THE MAIN HYDRO-ELASTIC CHARACTERISTICS OF THE PROBLEM TO BE GRASPED.

SIMPLIFIED **SEMI-ANALYTICAL MODEL** IS USED AS A THEORITICAL APPROACH OF THE PROBLEM. THE MODEL CLEARLY PROVES THE EXISTENCE OF HYDRO.ELASTIC INSTABILITY, AND DETERMINES THE THRESHOLD VALUES OF THE PARAMETERS WHICH TRIGGER INSTABILITY.