FROM ACOUSTIC AND DYNAMIC PROPERTIES OF SATURATED SEABEDS TC GEOTECHNICAL CHARACTERIZATIONS AND PREDICTIONS

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ABSTRACT:

It is of major importance to know for sandy and silty or clayed seabeds the eventual short or long term natural capacity of burying or undermining artifacts like pipes, piles, foundations. Several theoretical modelizations are necessary for the various encountered physical situations: scour and liquefaction in sands, burying in plastic sediments.

A modelization of saturated sediments provides, together with experimental data, links between microscopical and macroscopical behaviours, and between acousto-dynamical and geotechnical behaviours.

1. INTRODUCTION

Main phenomena arising at short or long term are: sinking into plastic sediments, liquefaction of sand due to pore pressure under heavy swell, sand transport by current or wave effects at sea floor. Specific models are able to make predictive computations. But some parameters are necessary for feeding the models: density, cohesion, permeability, granulometry (firstly the mean size of grains), sometimes the friction angle. Most of them can be obtained from acoustical *in situ* measurements, with the help of modelization and empirical statistical relations.

2. CHARACTERIZATION

2.1. Empirical relations

Although a firm theoretical basis is still lacking, one states some relations between purely geotechnical parameters and dynamical behaviour parameters. The sound speed is statistically related to physical basic properties: mean grain size, density, porosity (Fig. 1a according to BACHMAN [1], Fig. 1b according to BACHMAN and AVALLET [2]).

In cohesive sediments, the cohesion is related to the shear modulus. For example, one sees on Fig. 3 the values of shear modulus and cohesive shear strength in the first meters of depth of a clayed floor.

The authors suggest the relation $G \cong 200$ C. It is worth noting that the sound speed offers a quick way to characterize the sediments. MOUSSIESSIE [4] (Fig. 4) shows the relationship between sound speed and internal friction angle, therefore sediment type. It is practically the same correlation one found on Fig. 1 between sound speed and mean grain size.

2.2 Models

A modelization of propagation in porous media can be built. It provides celerity and attenuation of compressional, shear and Rayleigh waves. It explains a part of empirical previous results. With frequency dependence of parameters, it offers a supplementary information for identifying the sediment.

The model is obtained by an homogeneization technique. It provides a generalized Darcy coefficient, dependent on frequency. It is able to explain the variation of sound speed with porosity: Fig. 1b, from AVALLET [2]. For different waves, it was possible to compare favourably model predictions and experiments with frequency variations. One retains two facts:

- with sound attenuation versus frequency, it is possible to recognize the sediments, Fig. 5, according to AVALLET;
- for any sediment, the dispersion curves of the Rayleigh wave are similar, if they are plotted versus a dimensionless frequency: F/F_0, where $F_0 = n/(8\ \pi K r)$.

n = porosity
K = quasi-static (low frequency) permeability
ρ = specific mass of water.

The shapes of curves are shown on Fig. 6, according to LARCHER [5]. They are correct for sands as for clays. $F_0 \cong 100$ Hz in sands; $F_0 \cong 50$ kHz in clays.

The turning point of attenuation is roughly near $10^{-4}\ F_0^2$ dB/m. The Rayleigh wave celerity is very near shear wave celerity. It is a mean for obtaining the G modulus value.

In conclusion, it must be stressed that we have at our disposal a set of relationships, issued from experiments and from models. The following table shows how to use the previous results:

geotechnical parameters	goal (model to feed)	most correlated acoustical parameters to measure	see Fig. n°
class of sediment	choice of the models	sound speed sound attenuation others	4; 5
density	all	impedance	2
mean grain size	liquefaction and sand transport	sound speed sound attenuation	1a; 5
porosity ———— permeability	liquefaction	impedance, sound speed ———— shear wave speed and attenuation	1b; 2 ———— 6
cohesive shear strength	burying in silted and clayed sediments	shear wave speed	3; 6

In fact there is no one-to-one correspondence between geotechnical and acoustical parameters; the nature of sediments interacts with physical properties; the results we are looking for are better obtained by crossing several laws.

Therefore it should be interesting to do at the same time identification and characterization of the sediment. An artificial intelligence tool, for example based upon Neural Network technique, should be useful for this task. It would integrate geo-acoustical model and statistical correlations. The Neural networks have shown their ability to synthetize heterogeneous data (PAROT [6]) with eventually redundancy and a need to extrapolate.

3. BURYING IN PLASTIC SEDIMENTS

It is a short term phenomenon. A plasticity Finite Element modelling of the cohesive soil provides burying predictions, under a theoretical framework of limit analysis: Fig. 7 (according to PASTOR [7]). This modelling method was developed by IMG, University of Grenoble. Specific calculations were made for cylindrical objects, and compared with *in situ* experiments: Fig. 8, and with laboratory experiments: Fig. 9 (from PASTOR). It was shown that better results can be obtained when the kinetic energy is taken into account, even for a deposition on the floor with zero initial velocity. The bearing capacity of sea floors is computed from the same model. It is only necessary to know density and cohesion. The vertical variations of these parameters are important. Typical profiles probably exist. They are issued from consolidation law of the material.

4. LIQUEFACTION

It eventually occurs in sands under the swell. Generally it happens during storm swells; it is therefore a random phenomenon, dependent on meteorological conditions, but very severe when it occurs. With an analytical swell model and a very simple diffusion model in the sediment, it is easy to predict conditions for liquefaction: Fig. 10 (from THIRARD [8]).

It appears that the phenomenon must be suspected to occur in fine sands only. With usual swells, the maximum probability occurs for breaking waves at depth of 10 meters or less, therefore in shore regions. More precise computations giving the seepage forces due to interstitial pressures on buried structures show that uplift can be observed (CHENG [9]). It is remarkable to stress that in the simplest model, valid in not too fine sands, no sediment parameter is necessary except the density.

5. SEDIMENT TRANSPORT

The sand transport is able to bury objects by scour and deposit, but also by incident sand waves. This is in general a long term phenomenon but the extent of time scale is in fact very large. The current velocity is of considerable influence.

5.1. Current

Under periodic (tide) or stable current, the characteristic time for tansport is given by L/<C>, where L is the dimension of the object and <C> is the time averaged sediment wave celerity.
The case <C> = 0 is not considered here. A typical asymptotic formula is:

$$\langle C\rangle \equiv \lim_{T\to\infty} \frac{a}{T} \int_0^T |u|^4 \, \mathrm{sgn}\, u \, dt$$

(a = constant depending on the sand,
u = flow velocity).

The influence of velocity peaks is clear in this formula. A computer model has been established. It provides scenarii of time evolution: Fig. 11 from PAROT [10] shows 4 typical dimensionless time evolutions of scour A obtained with different values of the parameters for a constant stream. Every case is close to a logarithmic evolution. More realistic results are obtained with Finite Element 3-D models. But scale model experiments in a laboratory channel are in accordance with a theoretical formula: Fig. 12. A chart of time scales is presented on Fig. 13 (THIRARD). For $u = 0.5$ m/s, $d = 0.5\ 10^{-3}$ m, the time scale is a few days. Low currents and fine granulometry are associated with very long time scales, tending to geological ones.

5.2 Swell

From a swell model and a sediment transport model, it is also possible to give the conditions for swell transport threshold. Very usual swells are in the transport domain. Large depths are concerned: down to 200 m (PINOT [11]).

5.3. Sand waves

Many sandy floors are covered with sand waves. They progress under current and swell. The celerity is approximately given by the graph (Fig. 14, THIRARD).

Since the current velocity appears with exponent 3, the averaged wave celerity is controlled by the peaks of velocity; for high celerities, the mean grain size d is without influence on celerity of waves. It is interesting to note that after a perturbation model coupling turbulent flow and sand transport, the wave formation occurs for k (wave number) such that $ky \equiv 10^{-2}$, where y is the roughness scale of the floor. So the ripple formation is a prelude to metric wave formation, itself preceding the building of giant waves (hectometric in wavelength).

6. CONCLUSION

This paper demonstrates the strong correlation between the acoustical properties (longitudinal and shear propagation characteristics) of the seabed with its major engineering characteristics (underwater embankment stability, loading capacity and risks of scour around foundations of any kind). As a consequence, when an engineering project must be conducted, an acoustical recognition of the sea floor, combined, if possible, with data base exploitation and Rayleigh wave measurements, has the capacity of giving sufficient information about the sediment physical properties. Theoretical and semi-empirical models, simple or sophisticated, give an estimation of possible scenarii of risk for the structure. To achieve the direct usefulness of this approach in typical projects, some additional work is suggested to simplify the sediment identification and the subsequent numerical tools. Another important development is a standard experimental set-up for the *in situ* propagation measurements.

ACKNOWLEDGEMENTS

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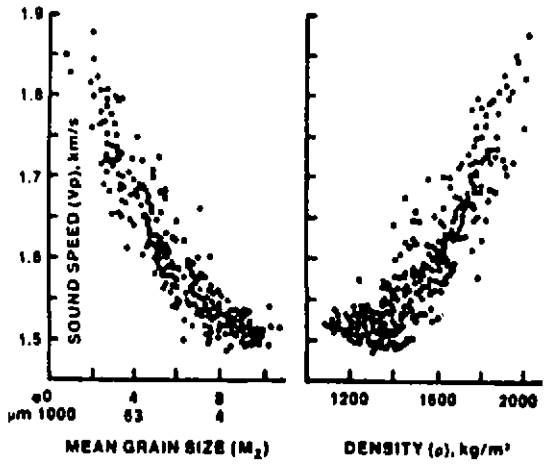

Fig. 1a: Sound speed versus mean grain size and density; all environments.

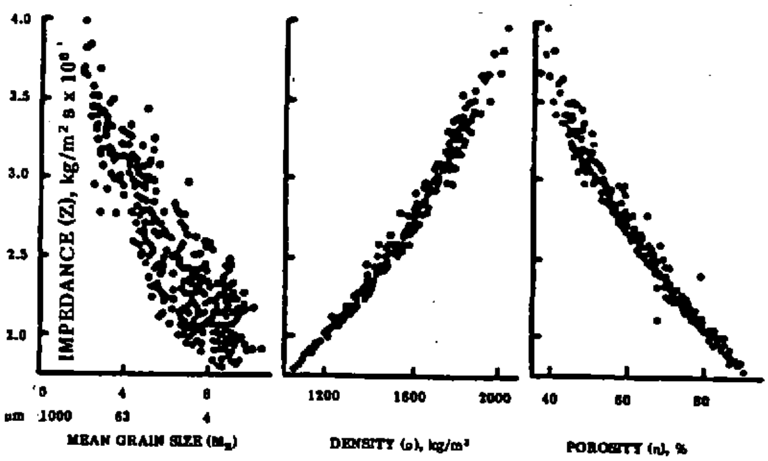

Fig. 2: Impedance versus mean grain size, density and porosity; all environments.

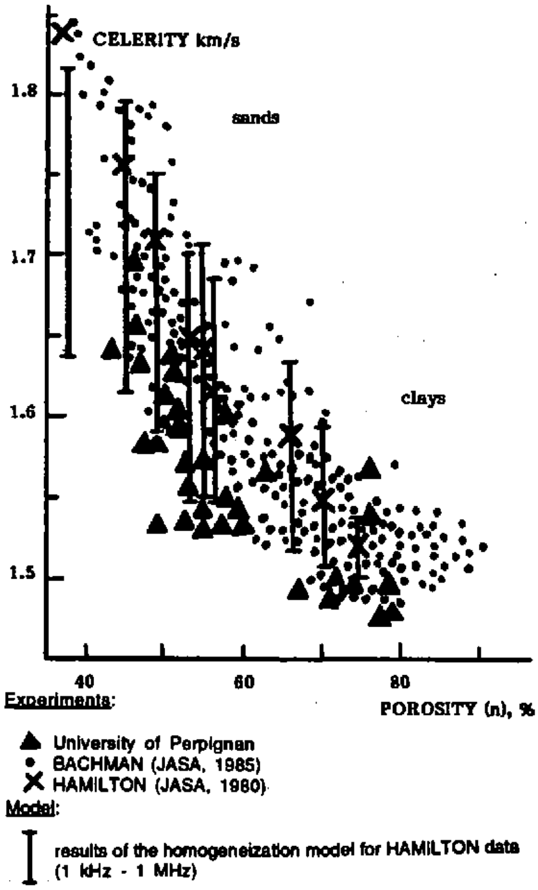

Fig. 1b: Sound speed versus porosity; all environments

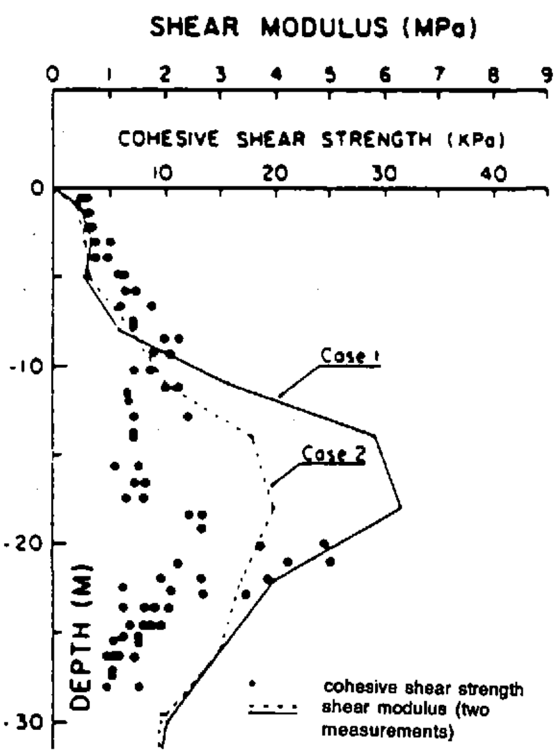

Fig. 3: Shear modulus G and cohesive shear strength C versus depth in a clayed sediment (according to YAMAMOTO [3])

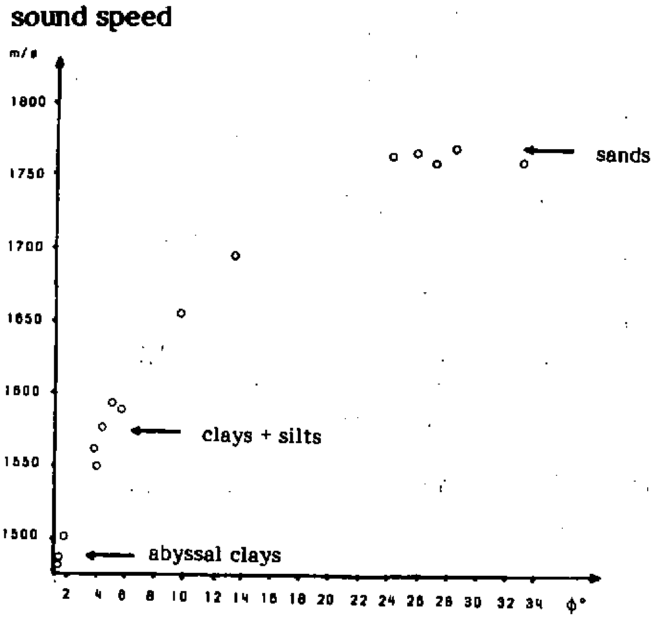

Fig. 4: Sound speed versus internal friction angle for various sediments (according to MOUSSIESSIE)

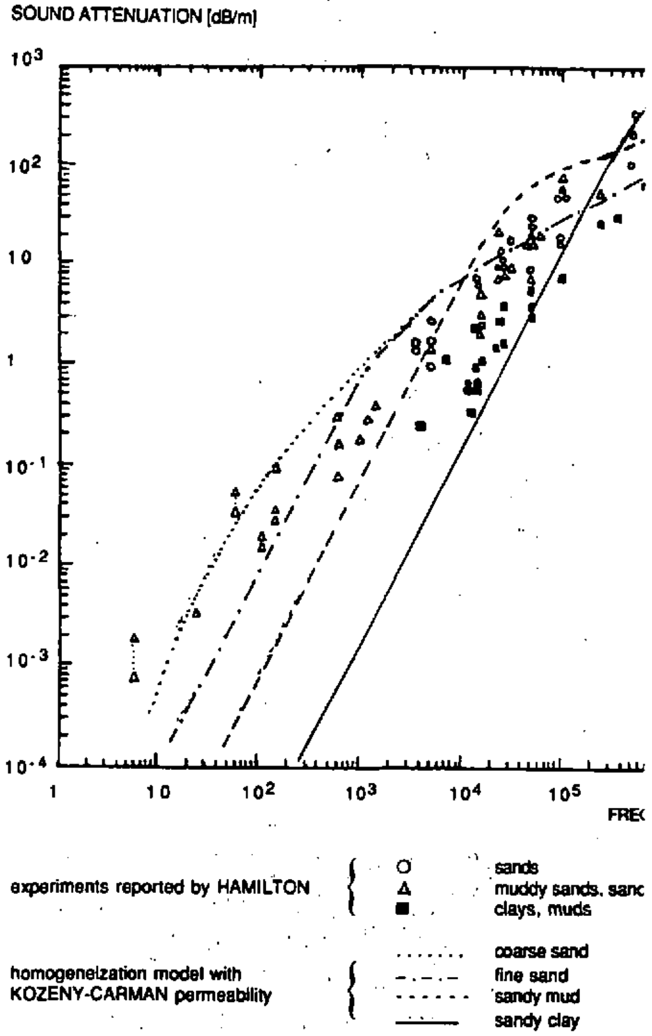

Fig. 5: Sound attenuation versus frequency

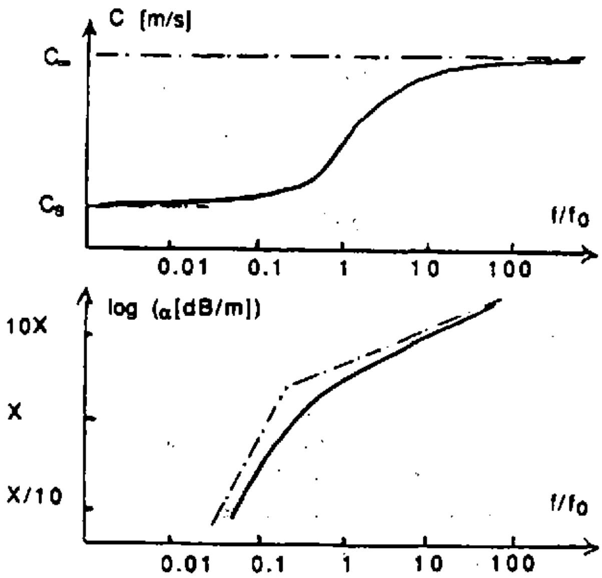

Fig. 6: Characteristics of Rayleigh wave. Generally, C_S and C_∞ are comprised between 10 m/s and 50 m/s.

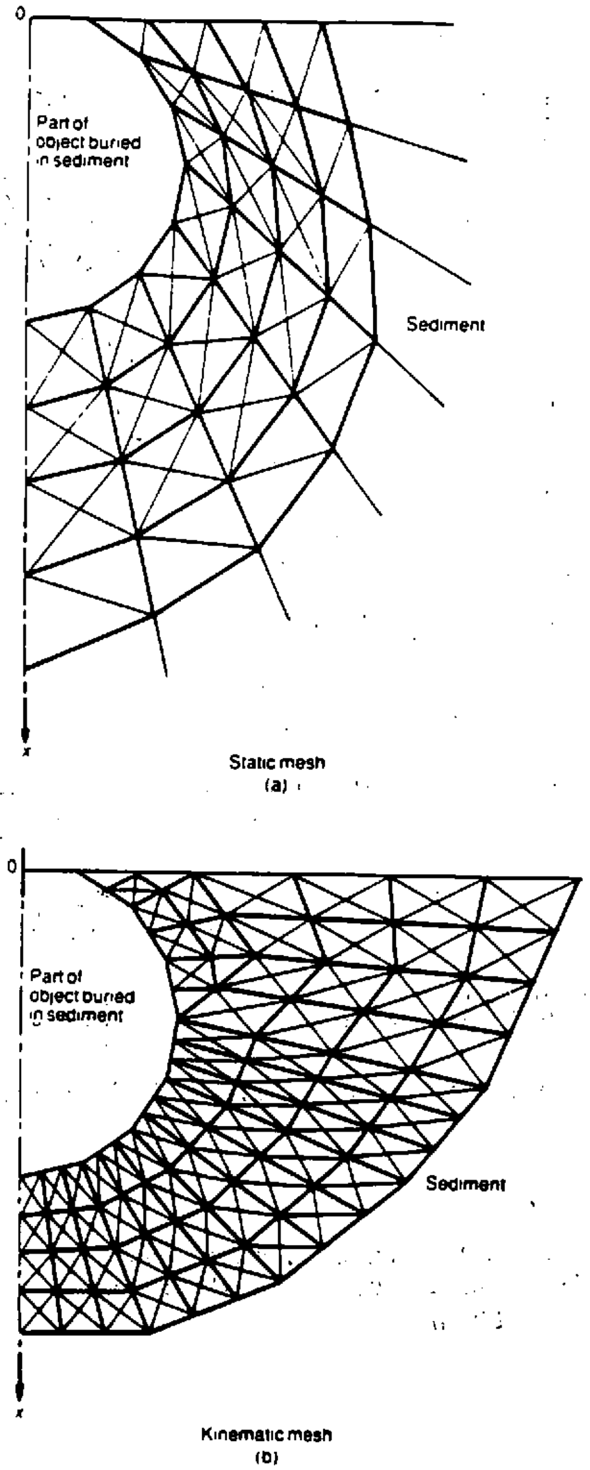

Fig. 7: Examples of finite element mesh used: (a) in static programs; (b) kinematic programs

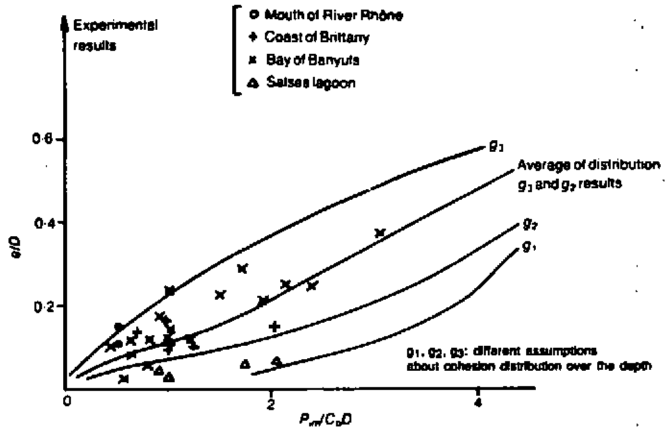

Fig. 8: Comparison of calculations and in situ experiments

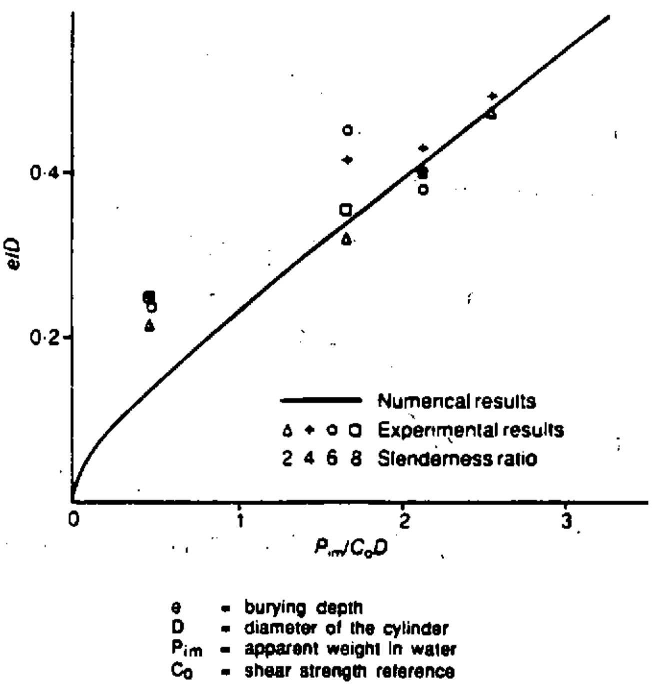

Fig. 9: Comparison of calculations and laboratory experiments

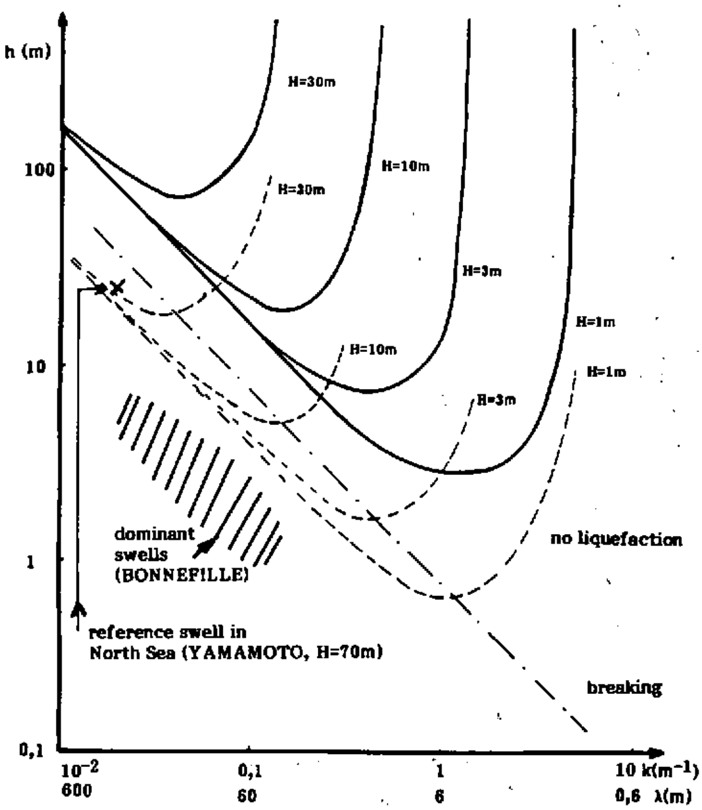

Fig. 10: Liquefaction and swell domains in the "wave number/amplitude" plane

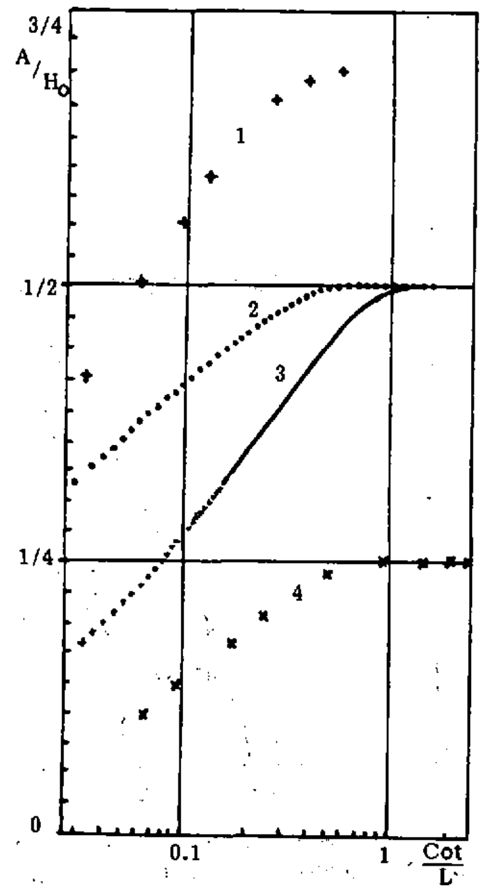

Fig. 11: Time evolution of scour in typical situations (L = characteristic dimension of the object)

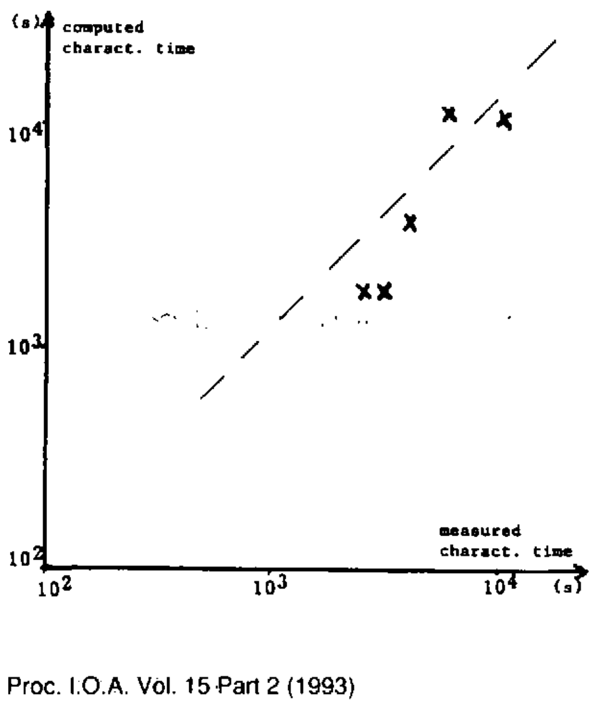

Fig. 12: Time scale (time to steady state) for scour around cylinders on a sandy floor: correlation between experiments in channel at laboratory and computation results

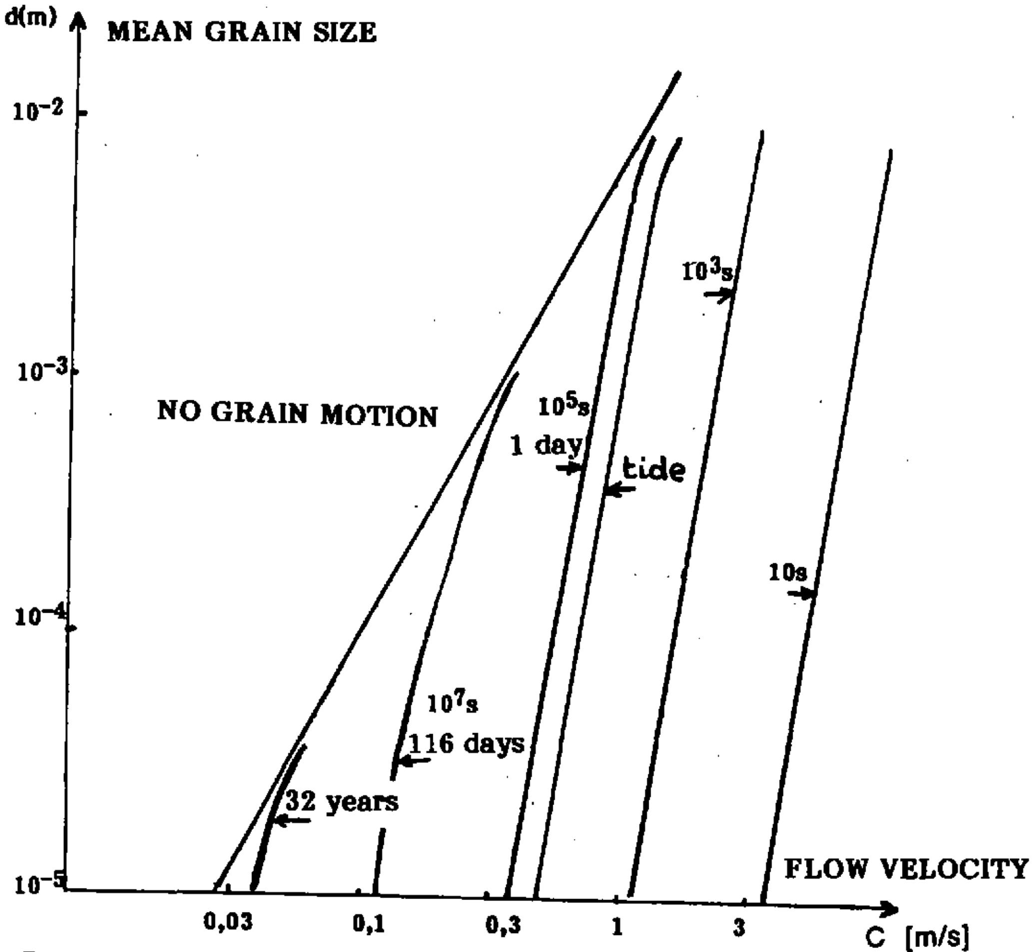

Fig. 13: Graphs of equal time scale for an object of dimension 0.6 m under steady flow (in the "flow velocity/mean grain size" plane)

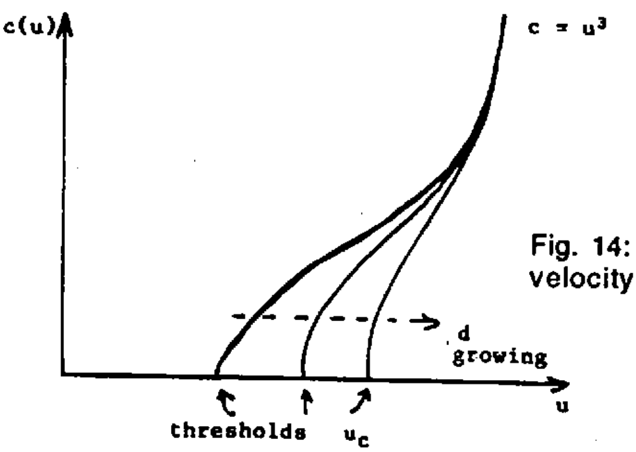

Fig. 14: Celerity of sand waves versus flow velocity