CHAPTER 222

Variations in rheological properties of muds in the Gironde estuary

Pascal Galichon*, Alain Feral**,
Jérôme Granboulan**, Jacques Viguier*

ABSTRACT

In numerous navigation channels, the bed consists of muds. The navigability threshold adopted by many ports is currently that which corresponds to a specific gravity of 1.2. This virtual standard does not fully take into account the rheological characteristics of the muds, which may differ from one site to another.

Investigations were carried out to determine the rheological properties of the Gironde estuary muds. Analyses were carried out in the laboratory on samples taken from different sites and on different dates and in situ, using the SR 10 probe developed by SOGREAH and ultrasonic sedimentometric probe developed by the Bordeaux Port Authority. The results demonstrated the occurrence of major spatial and temporal variations.

The two principal phenomena revealed by the research were that with the same dry sediment content:

. muds were less rigid at the front of the maximum turbidity zone than at the back, by a factor of about 1.6 to 2.5,

. the greater the annual flood, the lower the rigidity.

A proper understanding of the spatial and temporal variations of rigidity is therefore essential to determine and adjust the navigability threshold.

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* SOGREAH Consulting Engineers, 6 Rue de Lorraine, 38130 Echirolles, France

** Port Autonome de Bordeaux, Quai de Bacalan, 33000 Bordeaux, France

INTRODUCTION

The beds of navigation channels consist of muds. Today, the nautical depth is considered to be the depth of water between the unconfined surface and a given level of density (or specific gravity) referred to as the nautical bottom.

A specific gravity value of 1.2, which corresponds to a dry sediment density of around 300 g/l, is currently adopted as navigability threshold by ports such as Rotterdam, Zeebrugge, Nantes-Saint-Nazaire and Bordeaux. However, the establishment of this virtual standard does not fully take into account the rheological behaviour of the muds. With the same concentration levels, muds at different sites may have widely varying rigidity values. Thus, defining the notion of navigability threshold on the basis of a rigidity criterion rather than specific gravity could in some cases result in an increase in the nautical depth.

In order to examine whether this type of procedure would be possible, the Bordeaux Port Authority commissioned SOGREAH to compare the rheological characteristics of muds from the Gironde with those from other ports where the navigability threshold is based on a specific gravity value of 1.2 and where rheological measurements were available. The study consisted of three parts: preliminary investigations, in situ measurements and additional rheological analyses.

1. PRELIMINARY INVESTIGATIONS

Preliminary investigations involved comparing the rheological curves for Gironde mud obtained in the laboratory and dating from before March 1987 with similar curves for muds from the Loire and Mahury.

The same rheological analysis methodology has been used at the Laboratoire Central d'Hydraulique de France and at SOGREAH for nearly 30 years. It enables a comparison to be made between different investigations. Here, the initial rigidity is defined as the torque required to set in motion a rotor immersed in the mud.

This rigidity varies with the dry sediment concentration, following a relation of the type: $\tau_y = aT_z^b$, in which τ_y is the initial rigidity and T_z is the concentration. Two different domains - liquid and plastic - may be defined, where a and b are different (fig. 1). These are separated by what is referred to as critical values, namely critical initial rigidity and critical dry sediment concentration. Determination of these values enables a comparison to be made between muds from different sites.

Figure 2 shows the critical dry sedimentation concentration for different sites. It appears that mud from the Gironde passes from a liquid to a plastic state at higher concentrations (340-620 g/l) than muds from the other sites considered (250-350 g/l).

Figure 3 shows that the initial rigidity for a dry sediment concentration of 300 g/l is less in the Gironde estuary than at the other sites. Seen from another point of view, the initial rigidity of muds from the Gironde at 350 g/l corresponds to that found for concentrations of 300 g/l (i.e. a specific gravity of the order of 1.2) from the other sites.

However, there was a certain spread of the results (figure 4) showing that the trend observed would have to be confirmed by other investigations, namely in situ measurements and additional rheological analyses.

2. IN SITU MEASUREMENTS

The aim of the in situ measurements was:

. to establish an approach for in situ rheological characteristics variations in relation to density,

. to make comparisons with the measurements carried out in other ports.

2.1. CONDITIONS AND MEANS EMPLOYED

The SD 105 ultrasonic densitometric probe, belonging to the Bordeaux Port Authority and the SR 10 probe were mounted on the same structure (fig. 5). This was done in such a way as to ensure that the two probes, separated horizontally by about 20 cm, should remain at the same level as they descended vertically. In this way it was possible to measure, in situ and applied to the same mud, the pair of values for the density (ultrasonic probe) and a rheological characteristic of the mud (SR 10 probe).

2.1.1 PRINCIPLE OF THE SR 10 RHEOLOGICAL PROBE

The probe comprises a cylindrical body, at the end of which a cone rotates at a constant speed (240 rpm). The electrical intensity required to maintain a constant rotating speed is measured. It is then correlated, after laboratory calibration, in relation to the initial rigidity.

2.1.2 SR 10 PROBE LABORATORY CALIBRATION

Two measurements are made for single mud sample:

. on the one hand the initial rigidity using a Brookfield viscometer,

. on the other hand measurement of the electrical intensity using the SR 10 probe.

In this way an initial rigidity-intensity pair is obtained for each sample.

The probe calibration curve is established on the basis of all the pairs (initial rigidity, intensity) obtained using samples of varying concentration.

Figure 6 illustrates the various values obtained on different sites. The low dispersion of values should be noted, and a standard calibration curve may be used for an initial approach, regardless of the site.

Due to the lack of a specific calibration curve, the standard calibration curve was adopted for this investigation.

In this way, it is possible to establish a correspondence between an intensity obtained by the SR 10 probe and a single initial rigidity, which we shall refer to as the "associated initial rigidity".

2.1.3 SD 105 PROBE PRINCIPLE

The SD 105 probe measures attenuation of ultrasonic sound attributable to the mud passing between the transmitter and the receiver. This is proportional to the concentration. Laboratory calibration using Gironde mud made it possible to establish the mud concentration. It should be noted that the probe was used here for vertical measurements, but a version does exist which may be pulled behind a ship. This latter makes it possible to make horizontal density measurements in navigation channels.

2.2 MEASUREMENTS CARRIED OUT

2.2.1 METHODOLOGY

Three vertical investigations were carried out on three different sites, with the probes mounted on the same structure. Subsequently a single vertical investigation was carried out on one site, with the probes separated.

During each of the vertical investigations, pauses in the descent were made. At each pause, a pair of SD 105 attenuation (concentration) and SR 10 intensity (associated initial density) values was noted. Fig. 7 shows an example of a recording.

2.2.2 MEASUREMENT RESULTS

Sites 1, 2 and 3

Figure 8 shows the concentration and associated initial rigidity variations in the axis of the channel, on the basis of the measurements made for the first three sites.

It would appear that in the area of site 3, the furthest downstream, one pass was filled by density currents coming from upstream. In the light of measurements made elsewhere, the slope of approximately 0.4% between sites 1 and 2 appears to be sufficient to produce a flow of this type carrying with it a higher proportion of sandy matter. In addition the vertical rigidity and density gradients show that, in all probability, the uppermost layer on site 3, over approximately 30 cm, is a recent arrival which has not yet had the time to solidify.

Site 4

On this site the two probes were separated.

As is shown in figure 7, the two probes detected a superficial layer, about 20 cm thick, with a higher density and rigidity than the layer immediately below. The measurements, carried out at the end of the ebb-tide, indicate a contribution from upstream, which supports the previous hypothesis concerning flow from upstream to downstream and in addition the possible existence of a negative density and rigidity gradient (but certainly only temporarily).

2.3 COMPARISON WITH MEASUREMENTS MADE ON THE GIRONDE IN OCTOBER 1984

The circumstances of the two missions, both in terms of space and time, are very different; the two sites are situated about 30 kilometres apart and the first investigations were carried out in the autumn, the second in the spring. However it should be noted, as G. Allen showed (1972), that sites may correspond to the respective positions of the maximum turbidity zone, which is located further downstream in March than in October.

Figure 9 makes it possible to compare the results of the two investigations: it appears that the majority of the points correspond to the range of values noted during the last mission. (The 1984 values nevertheless appear slightly lower, as a whole, than in 1987).

2.4 COMPARISON WITH MEASUREMENTS CARRIED OUT ON OTHER SITES

Comparison with measurements carried out on the Seine and the Loire (cf figure 10) show that in two cases Gironde mud appears in situ to be less rigid than that from other estuaries. For example a concentration of 300 g/l in the Loire corresponds to an associated initial rigidity of 15 N/m2, which would correspond to a 350 g/l concentration in the Gironde.

Consequently, after taking account of the in situ measurements, it appears that in comparison with the other ports and taking account of the hydro-sedimentary conditions encountered during the different investigations, the Gironde muds are less rigid in situ. Consequently this result would justify admitting a navigability threshold situated at a higher density than 1.2. However, to be sure that such steps may be taken, it seems appropriate to acquire increased knowledge on spatio-temporal variability of rigidity levels in situ, for the comparison of different analyses of mud samples collected at different places and times show that significant variations may occur. During this assignment, samples were taken for analysis. The mud proved to be more rigid than that studied previously. It was then decided to carry out rheological analyses on samples in order to show up any spatio-temporal variations in rigidity.

3. SPATIO-TEMPORAL RIGIDITY VARIATION

These analyses were carried out on 10 samples taken between March 1987 and April 1988. They concluded that in general, mud from 1987 was more rigid than that from 1984. In an attempt to explain the cause of initial rigidity value dispersion, the 300 g/l rigidities were entered in a graph. This was done for all the samples collected in the Gironde, whose date and place of collection was known. The position of the maximum turbidity zone, as observed by G. Allen in 1970-71 (figure 11) was also entered on the same graph.

It should be noted that movement of the mud zone may vary in time. It depends on variations in river flow.

It has been established that in general mud collected to the rear of the mud zone, in relation to the direction in which it is moving, appears more rigid than mud collected to the front of the zone. The ratio varies between 1.6 and 2.5. It seems probable that the age of the mud partly explains the phenomenon, but there may exist other factors such as grain sizes or changes in the mineral composition.

3.1 VARIATION IN RIGIDITY WITH RIVER FLOW

In addition, taking the samples collected between March and April and tracing the 300 g/l initial rigidity variations in relation to river flow in February (the month in 1984, '87 and 88 when flow was highest - cf. figure 12), it is clear that at PK 72 (the only PK for which measurements are available for three different years) the 300 g/l initial rigidity drops at the same time as the flow.

A relation of this sort deserves confirmation on the basis of other measurements.

The high rigidity values observed in 1987 seem to be accounted for by the absence of significant flood flow that year, and inversely, the low values obtained in 1984, in particular in May, seem to be attributable to the heavy flooding in February 1984.

4. CONCLUSIONS

The results of the 1987 measurements did not confirm that Gironde mud is systematically less rigid than that from the other sites. Because of this, in the present state of information, no decision can be reached with respect to the systematic adoption of a navigability threshold corresponding to a specific gravity of more than 1.2. However, it is likely that this would be possible in certain cases.

Indeed, the study showed that at a given spot, the rheological properties of the Gironde muds appear to be in relation to the hydrosedimentary conditions (and more particularly the river discharge).

In particular, it would appear that the rigidity of a mud is lower when the deposit is the result of suspended sediment introduced recently into the estuary. In the lower reaches of the river, fluid mud generally forms after the initial floods. Consequently, under these circumstances, the rigidity of the mud in the downstream reaches of the estuary is lower than that at other sites. Hence, a navigability threshold corresponding to a specific gravity higher than 1.2 could be considered.

Far more data is available for the Gironde than for the other sites. More information, obtained under varying hydrosedimentary conditions, will be needed for these sites before statistically valid comparisons can be made.

REFERENCES

G.P. Allen: Etude des processus sédimentaires dans l'estuaire de la Gironde. Doctoral thesis, University of Bordeaux I, 1972.

J. Grandboulan and M. Chaumet-Lagrange: Un nouvel instrument pour optimiser l'entretien des chenaux d'accès portuaires: la sonde sédimentométrique à ultrasons. Revue Technique des Phares et Balises N° 71, 1986.

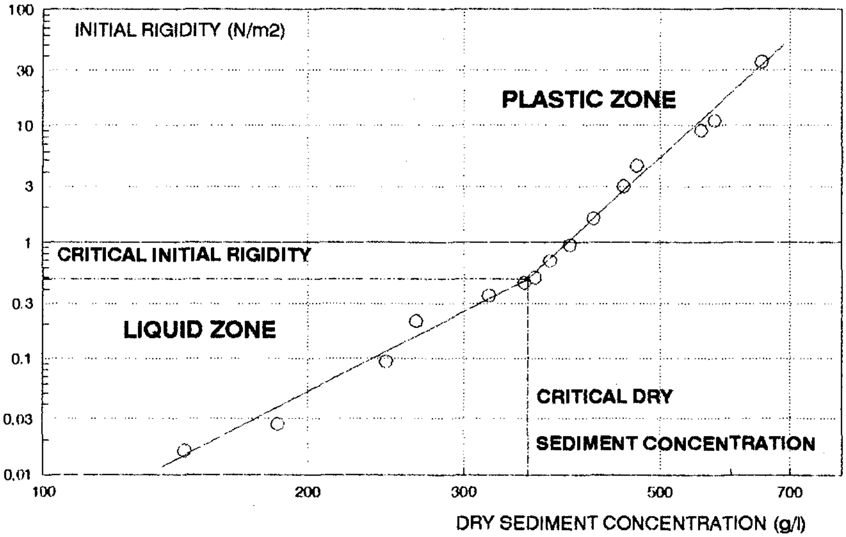


FIG 1:INITIAL RIGIDITY IN RELATION TO THE DRY SEDIMENT CONCENTRATION

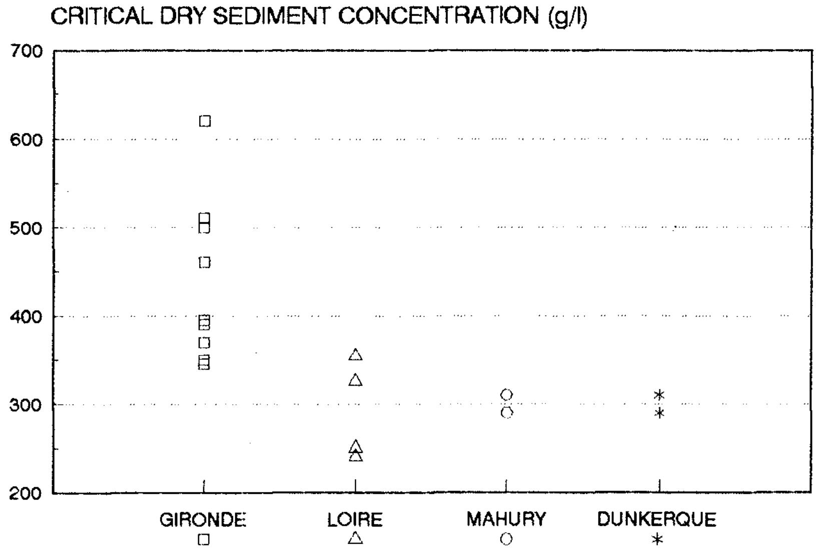


fig 2: CRITICAL DRY SEDIMENT CONCENTRATION FOR DIFFERENT SITES

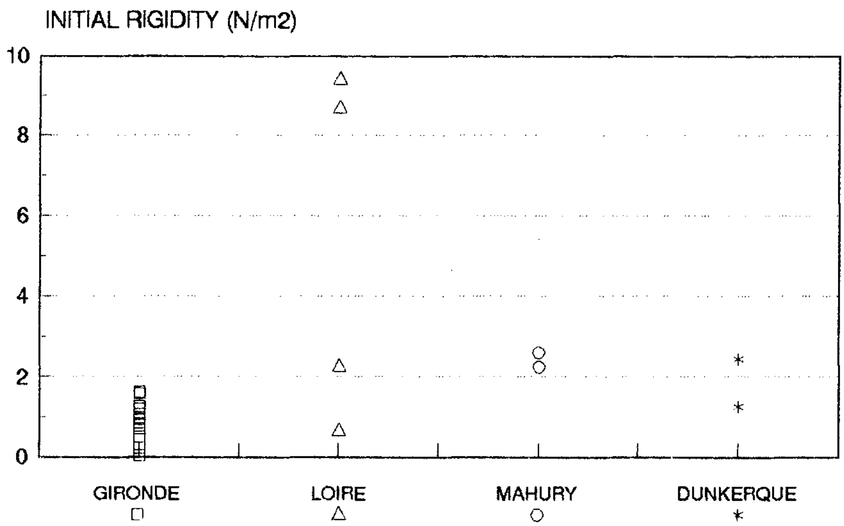


FIG 3: INITIAL RIGIDITY FOR DIFFERENT SITES
FOR A DRY SEDIMENT CONCENTRATION OF 300 g/l

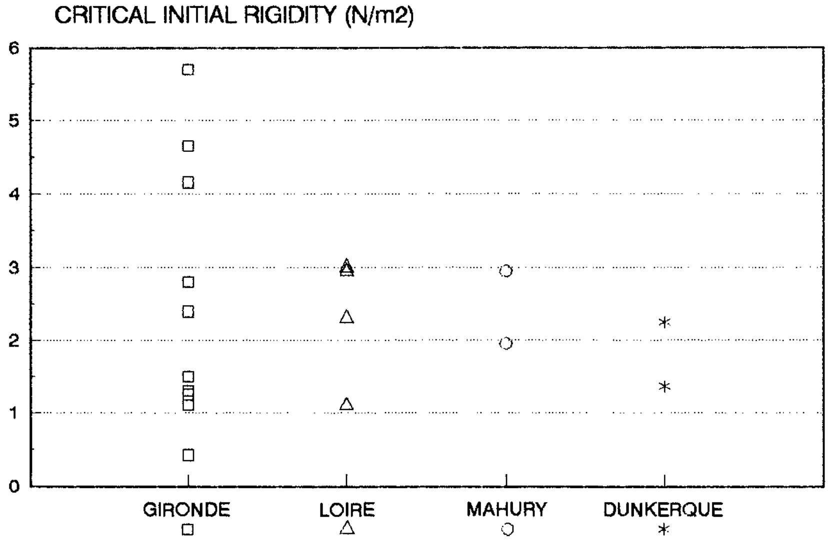


FIG 4: CRITICAL INITIAL RIGITY FOR DIFFERENT SITES

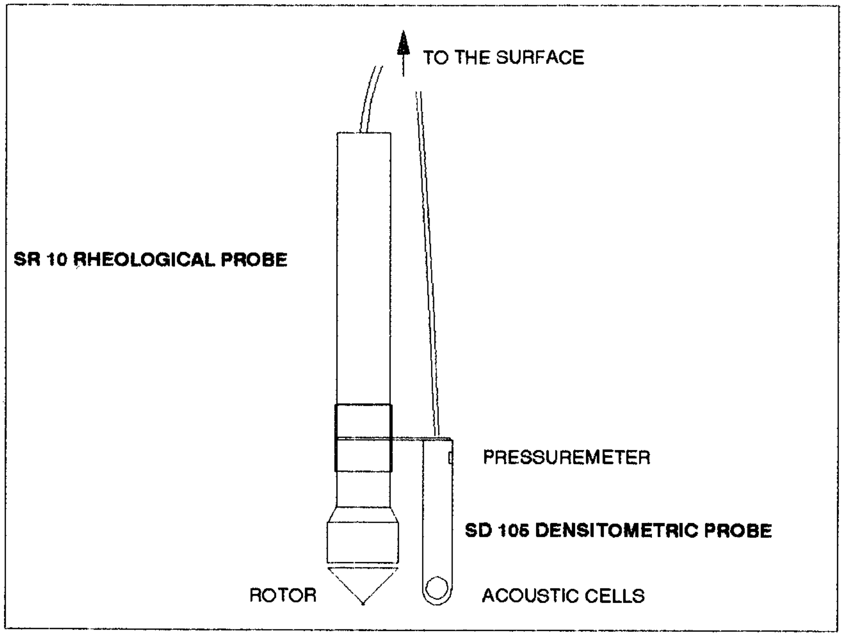


FIG 5: SCHEME OF THE COUPLING OF THE DENSITOMETRIC AND RHEOLOGICAL PROBES

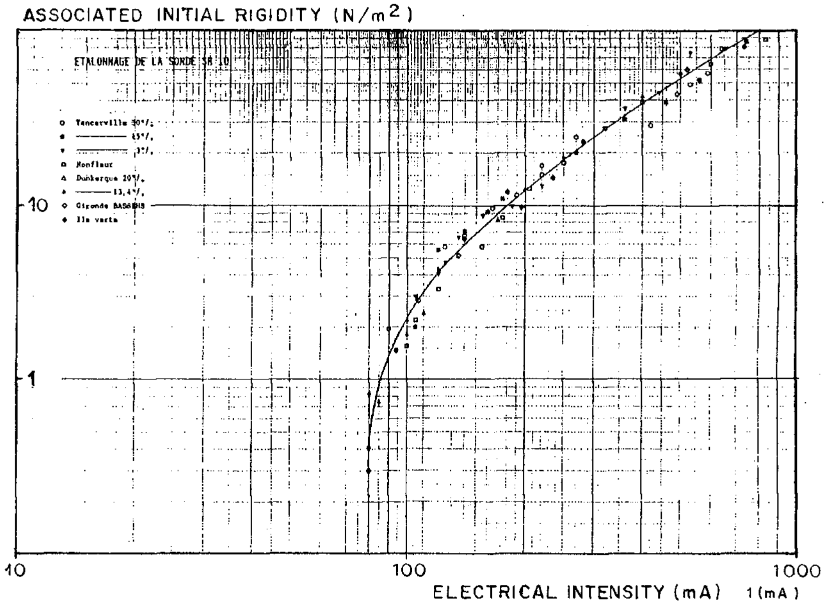


Fig. 6 - SR 10 RHEOLOGICAL PROBE CALIBRATION

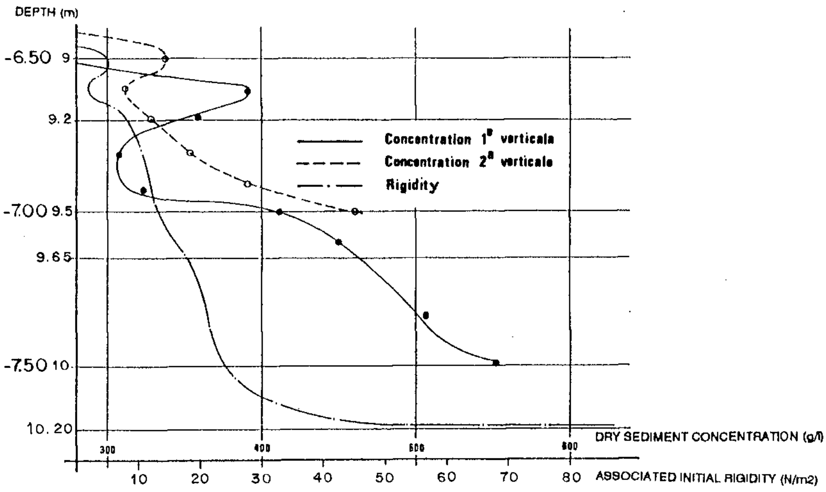


Fig. 7 - VARIATION OF THE CONCENTRATION AND THE RIGIDITY WITH THE DEPTH (SD 105 AND SR 10 SEPARATED)

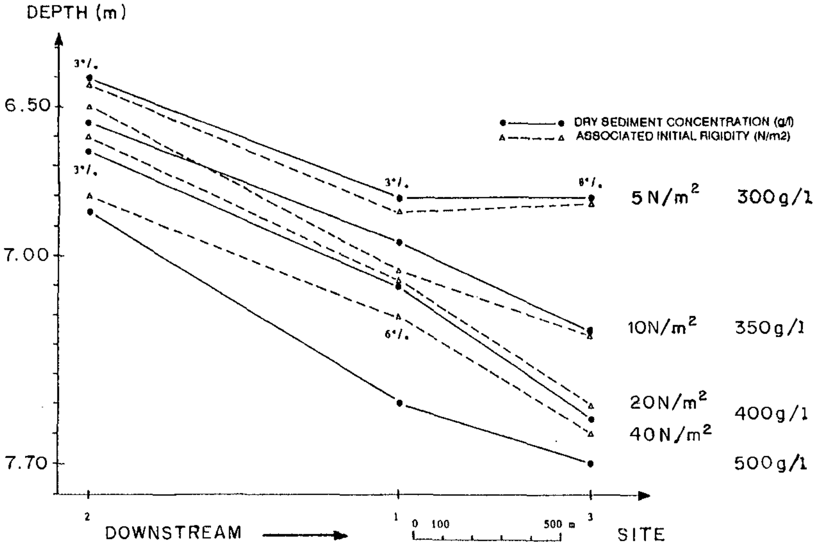


Fig.8 - SPATIAL VARIATION OF DRY SEDIMENT CONCENTRATION AND ASSOCIATED INITIAL RIGIDITY

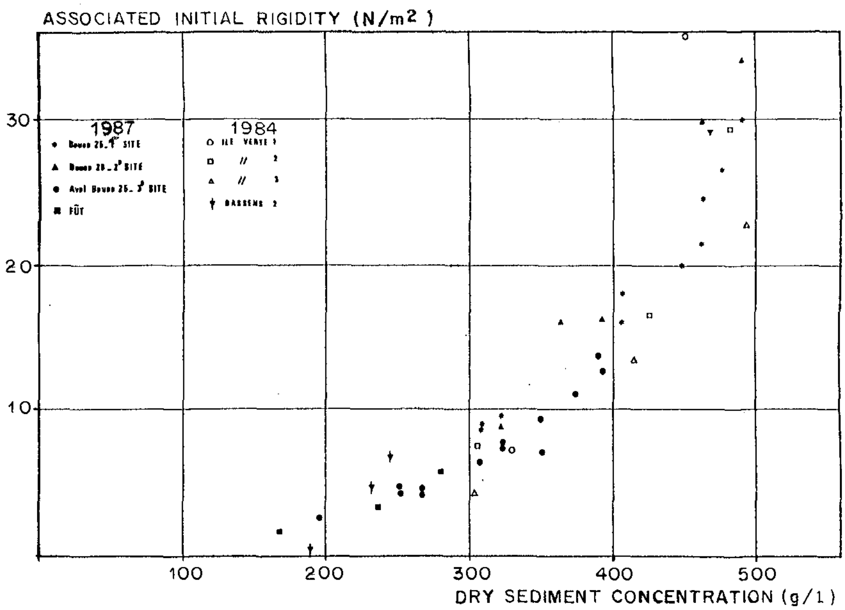


Fig. 9 - RELATION BETWEEN DRY SEDIMENT CONCENTRATION AND ASSOCIATED INITIAL RIGIDITY IN SITU FOR GIRONDE

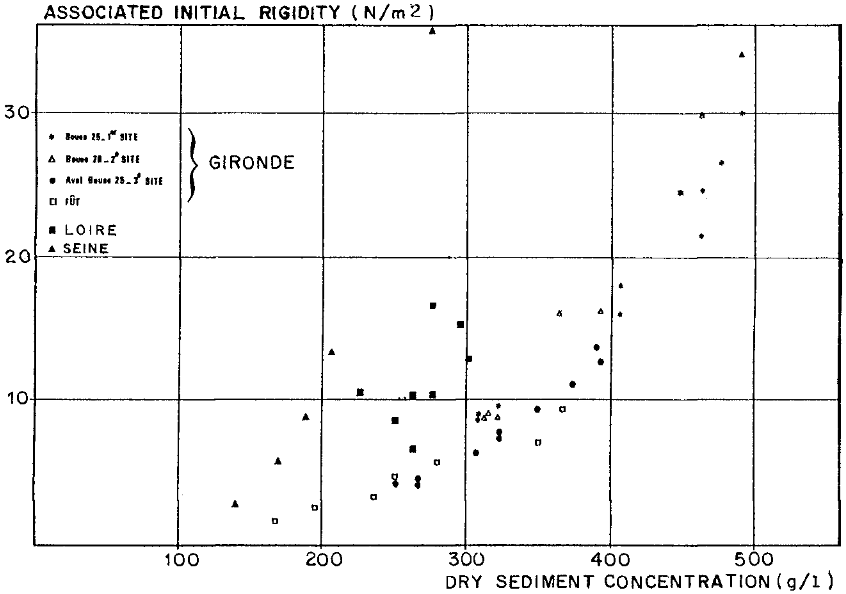
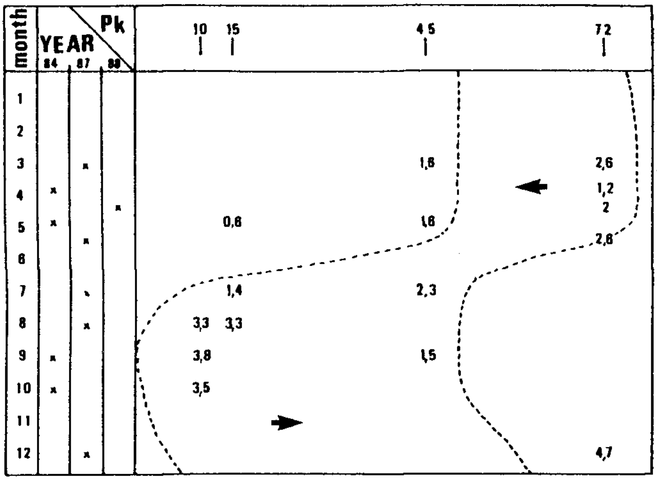


Fig. 10 – RELATION BETWEEN DRY SEDIMENT CONCENTRATION AND ASSOCIATED INITIAL RIGIDITY IN SITU FOR DIFFERENT SITES



----- mud limits in 1971 (G. P. ALLEN 1972)

➔ Direction of movement the mud

Fig.11 – Initial rigidy variations at concentration of 300g/l (Pa)

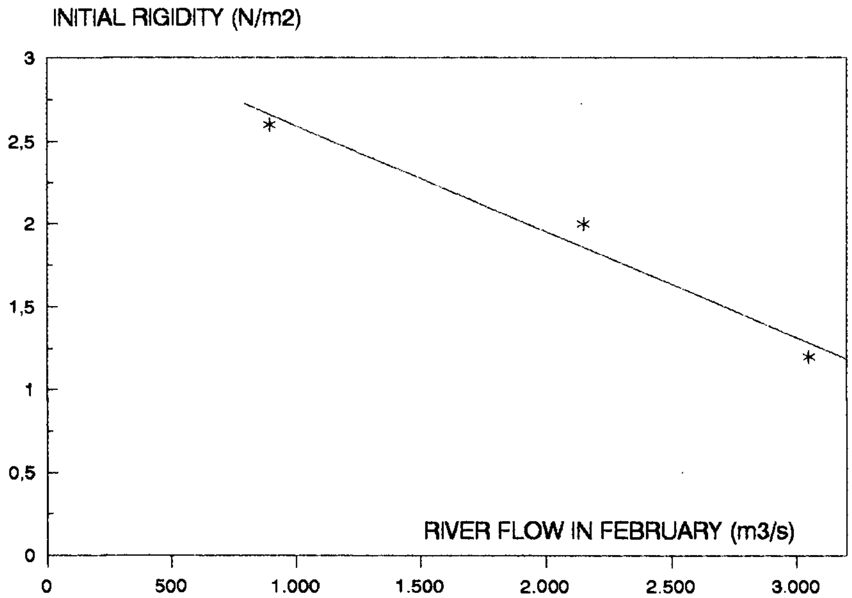


FIG 12: VARIATION AT Pk 72 OF THE INITIAL RIGIDITY FOR A DRY SEDIMENT CONCENTRATION OF 300 g/l IN RELATION TO THE RIVER FLOW IN FEBRUARY (annual maximum)