FULL SCALE NEAR SURFACE WATER PARTICLE VELOCITIES AND PRESSURES ACTING ON AN INCLINED TUBULAR MEMBER

by

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ABSTRACT

A field investigation programme on simultaneaus wave force and water particle velocity measurements is decribed with reference to an inclined tubular member subjected to affshore wave kinematics. First measurements at supercritical Reynolds numbers indicate strong irregularities in successively taken pressure distributians on the circumference af the test section as well as in the velocity vectars.
The influence af superimposed tidal currents is obviaus.

I. INTRODUCTION

For want of anything better, MORISON's equation is still used far the calculation of wave forces on circular cylindrical structural members. Mast experiments are based on it both in the labaratary and in the field. However, usually anly water level deflexions and wave forces an a test sectian are measured, and the velocities and accelerations as input ta MORISON's equation are determined using some suitable wave theory. As is well knawn, this pracedure turns out ta be one of the reasans for the wide range of scatter in the reported force caefficients.
Contrary ta the respective investigation technique, DEAN (1976) pointed aut the necessity af also measuring undisturbed flow characteristics down in the fluid. KIM and HIBBARD (1975) measured the local water particle velocities in a full scale experiment and similar measurements are being carried out at present in the Christchurch Bay Tower experiment, see for instance PEARCY and BISHOP (1979) and HOLMES and TICKELL (1979).
High enaugh REYNOLDS's numbers in the laboratory experiments to be applicable ta pratatype were anly obtained by applying special madel techniques for instance SARPKAYA (1976), HOGBEN (1976), YAMAMOTO and NATH (1976).

It remains, however, still a question as to how well the labaratary results apply ta real wave motion, and especially to irregular waves with varying directions of propagation.

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Being also aware of additional uncertainties arising from

a) different roughness characteristics due to marine fouling,
b) the coincident presence of waves and (tidal and wind induced) currents,
c) different shapes of test sections (vertical or inclined),
d) different wave kinematics (deep versus shallow water) etc.

the authors initiated a field wave force investigation programme which is sponsored by the GERMAN MINISTRY OF RESEARCH AND TECHNOLOGY (project number MTK 0053).

The experiments are performed on the GERMAN RESEARCH PLATFORM "Nordsee" about 100 km offshore in a water depth of approx. 30 m. There is also another measuring programme under way on the island of NORDERNEY (German North Sea Coast) involving substantially differing kinematics of shallow waves.
Both investigation programmes are at first restricted to the measurement of near surface wave forces (derived from the measured pressure distribution on the circumference of tubular members), water level deflexions (waves) and to the measurement and analysis of the ambient flow characteristics including tidal, wind and wave induced currents.

In the future the research programmes will be extended by the measurement of directional spectra (from an array of 3 sonar devices) in the offshore programme and the near shore measuring configuration shall be combined with measurements of additional forces exerted by wave spray loadings, see FÜHRBÖTER (1977).
At present the MTK-project deals with the wave loadings exerted on an inclined member of a platform leg, and the nearshore measuring configuration consists of a vertical pile structure for the force measurement with a satellite measuring station for the measurement of water level deflexions and particle velocities.

Because of the lack of space, only the offshore measuring configuration is described in the following including the test structure, the measuring devices, some data processing routines and preliminary evaluations are outlined. Additional remarks on the near shore measuring configuration are contained in BÜSCHING, MARTINI and SPARBOOM (1979).

2. MEASURING CONFIGURATION

The measuring devices of the test section (Fig. 1) consist of a packing ring clamped on a member of a platform leg which is inclined 30.225° with reference to the vertical axis. This tubular structure (5 m long, 1.92 m diameter) containes 24 KISTLER-pressure transducers on its circumference centered about 5 m below mean low water spring (MLWS).

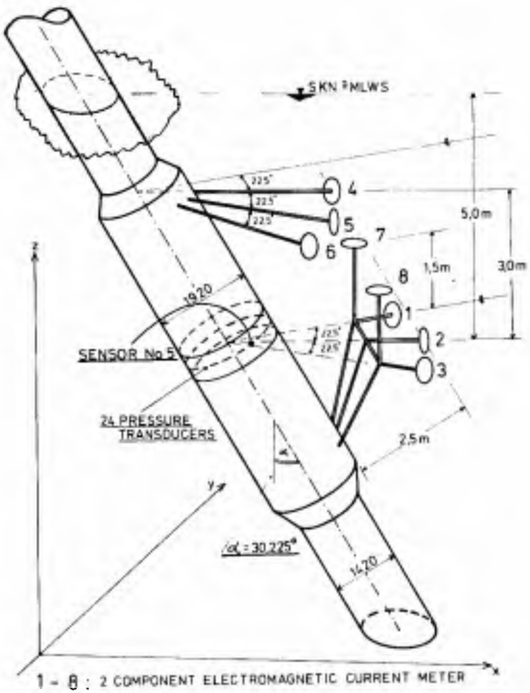


Fig. 1 : Sketch of the measuring configuration

Fig. 2 : Test section clomped on on inclined member of the platform substructure to be seen ot on extremely low tide water level at storm con-ditions. Baylor wave staff on the left hond side.

At the same elevation are located 3 two-component electromagnetic COLN-BROOK-current meters (No. 1 - 3) oriented in such a way (angular spaced 22.5^{a} and 2.5 m distant from the test section) that the particle velocities in certain vertical planes containing the respective main wave propagation direction can be determined from the measurements to a high degree of reliability. For the direct measurement of the wave propagation direction and the phase velocities, the current meters No. 7 and 8 are used, each measuring two velocity components in a horizontal plane 3.5 m below MLWS.

Additionally only 2 m below MLWS, there is a third horizontal measuring plane again containing 3 current meters (No. 4, 5 and 6) for another measurement of the water particle kinematics in vertical planes with reference to the above mentioned current meter positions No. 1, 2 and 3.
The corresponding water level deflexions are measured at a certain distance from the test section by a BAYLOR wave staff, see Fig. 2. Additional wave data can also be received from a set of 3 sonar devices fixed to different members of the platform structure, see LONGREE (1976).

3. MEASUREMENTS

Because of the many interpretation difficulties arrising due to the inclination of the tubular member, superimposed currents and reflexion effects (resulting from the neighbouring platform substructure elements) etc. the authors found it to be reasonable as an initial attempt at data interpretation to consider the simplest loading case in which the main wave propagation direction is in the vertical plane of the inclined member.
As can be seen from Fig. 3, such a configuration accurs when wind and waves come from south westerly directions which unfortunately are not in correspondence with the direction of maximum reliability of current meters 1 — 6 measuring rotating orbital vectors in vertical planes. Hence, the description of actual force creating wave kinematics can only be based on the measurement of

the water level deflexions,
the pressure distribution on the circumference and
the horizontal velocity components (of current meters No. 7 and 8),
which are most reliable for maximum values only.

As an example, such an irregular wave trace measured by the BAYLOR wave staff on November 15th, 1978, 10.11 p.m. at a distance of about 2 m from the test section is shown in the upper part of Fig. 4, and the total set of synchronously taken pressure traces from the circumference of the test section is shown below. Additionally Fig. 5 and 6 contain the corresponding velocity traces of current meters No. 7 and 8 respectively each split into magnitude and direction. All of these traces cover a measuring period of 12.8 sec which are sampled at intervalls of 0.2 sec giving 64 phase points also indicated in the graphs.

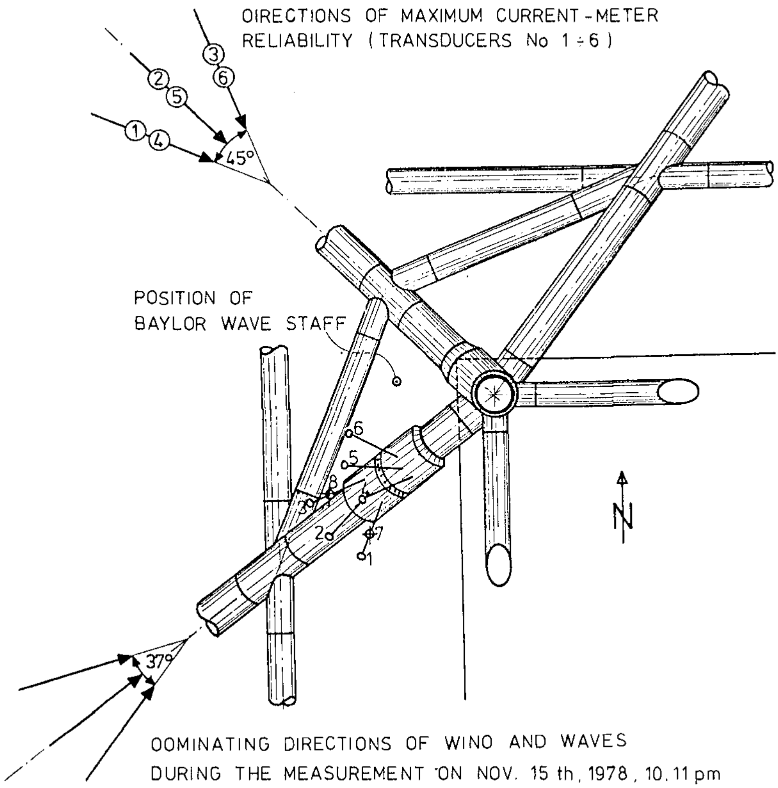


Fig. 3: Orientotion of the test sectian with reference ta different directions of wave propagation

The pressure measurements shawn in Fig. 4 do nat cantoin any different hydrostatic camponents corresponding to their respective locatian below the woter level. Hence, the zero mark shown is arbitrory only. The different behaviour af the curves is due to the processes toking ploce in the boundary layer at specific tronsducer locotions an the circumference and depends on the octuol wave prapagatian directian. This is examined in detoil in Fig. 7 showing the pressure distributions (an the circumference of the test sectian) corresponding

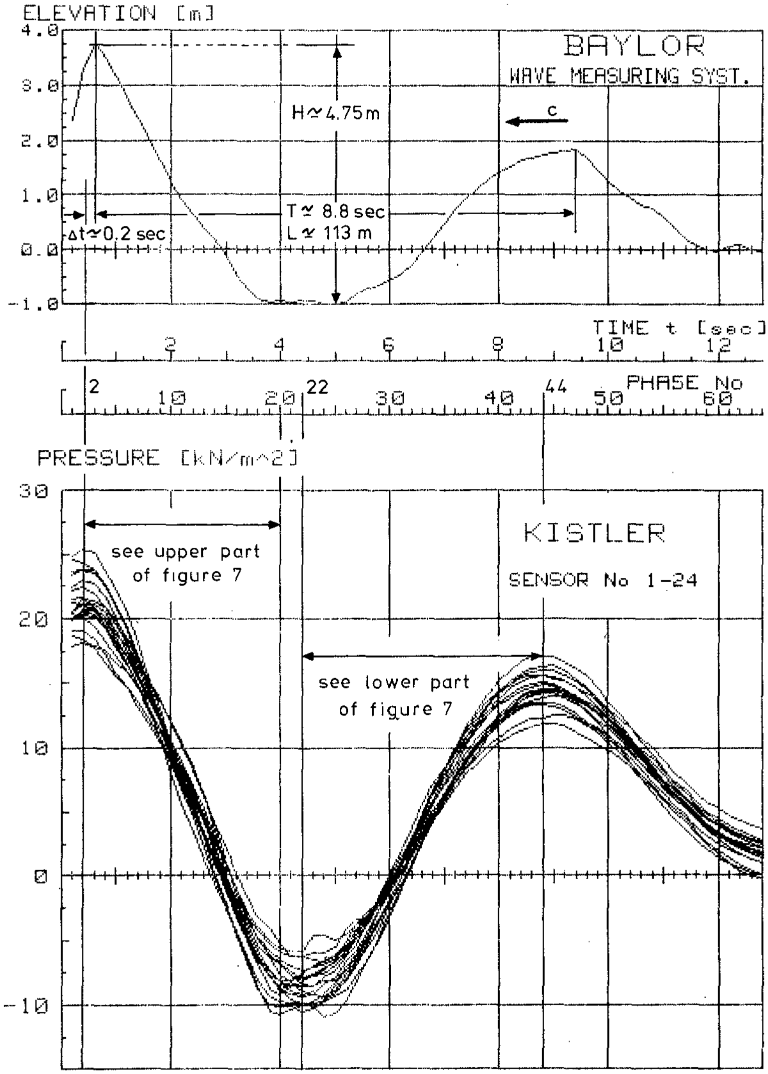


Fig. 4 : Synchronously measured wave trace and pressure traces on the test section circumference on November 15th, 1978, 10.11 pm

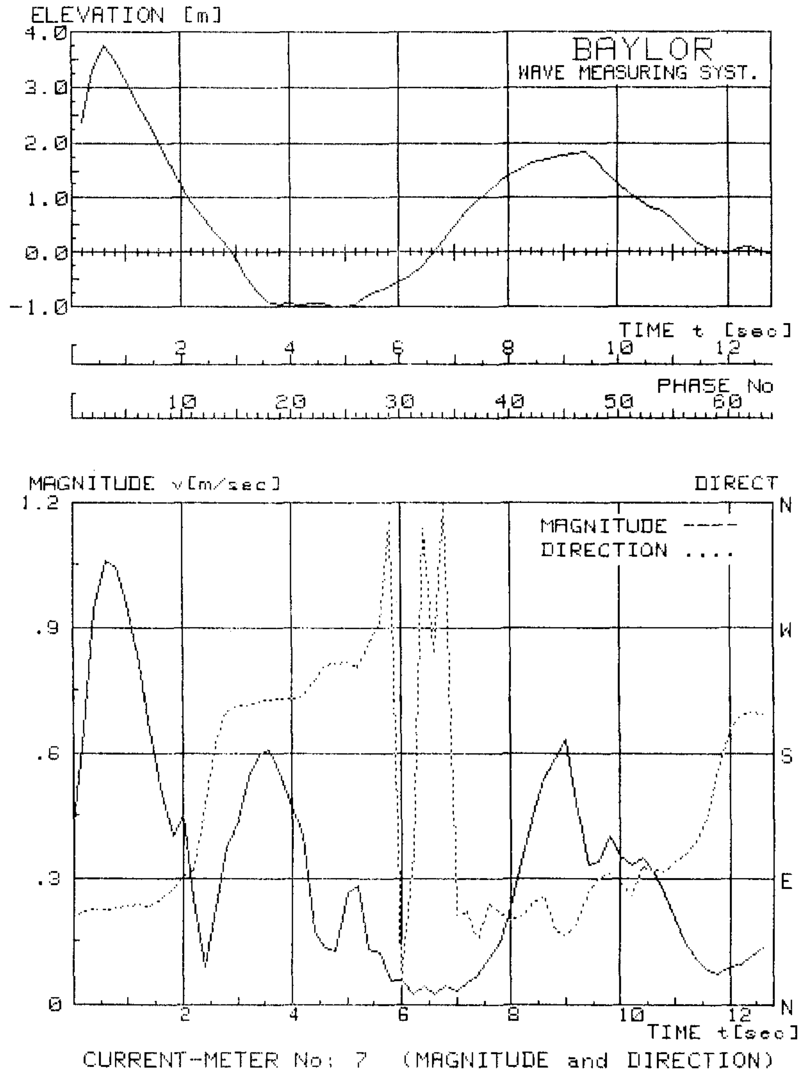


Fig. 5 : Synchronously measured wave and velocity traces on November 15th, 1978, 10.11 pm

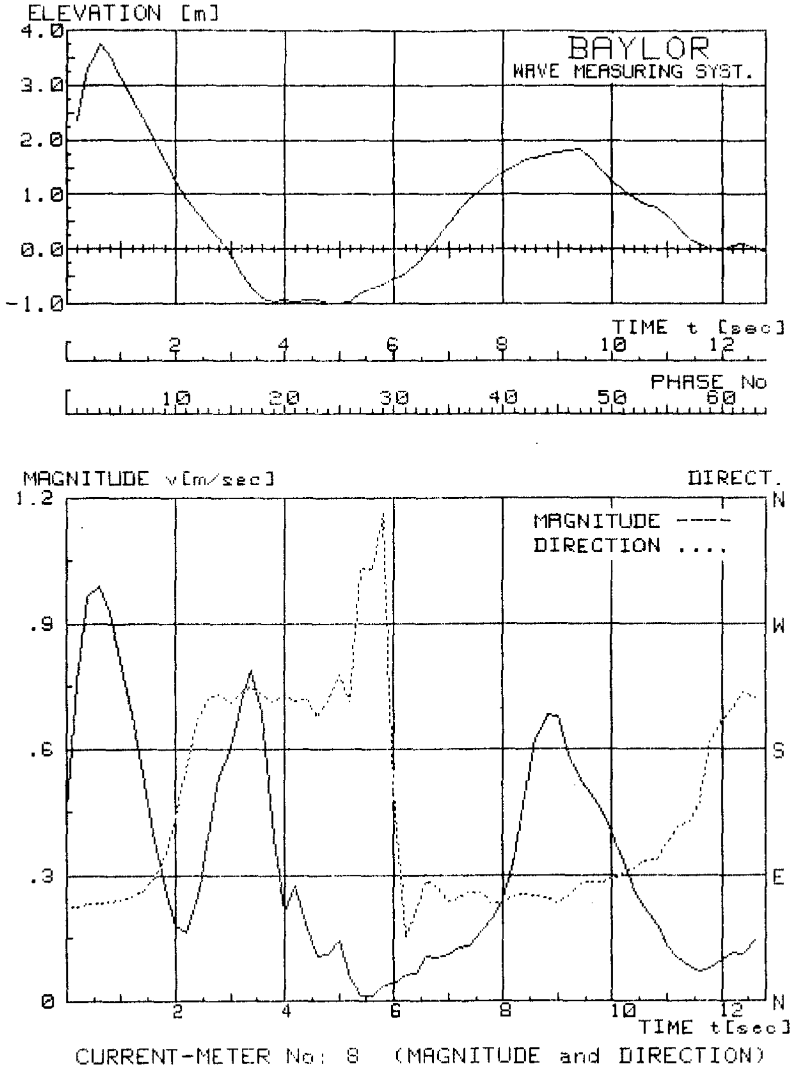


Fig. 6 : Synchranously measured wave and velocity traces on November 15th, 1978, 10.11 pm

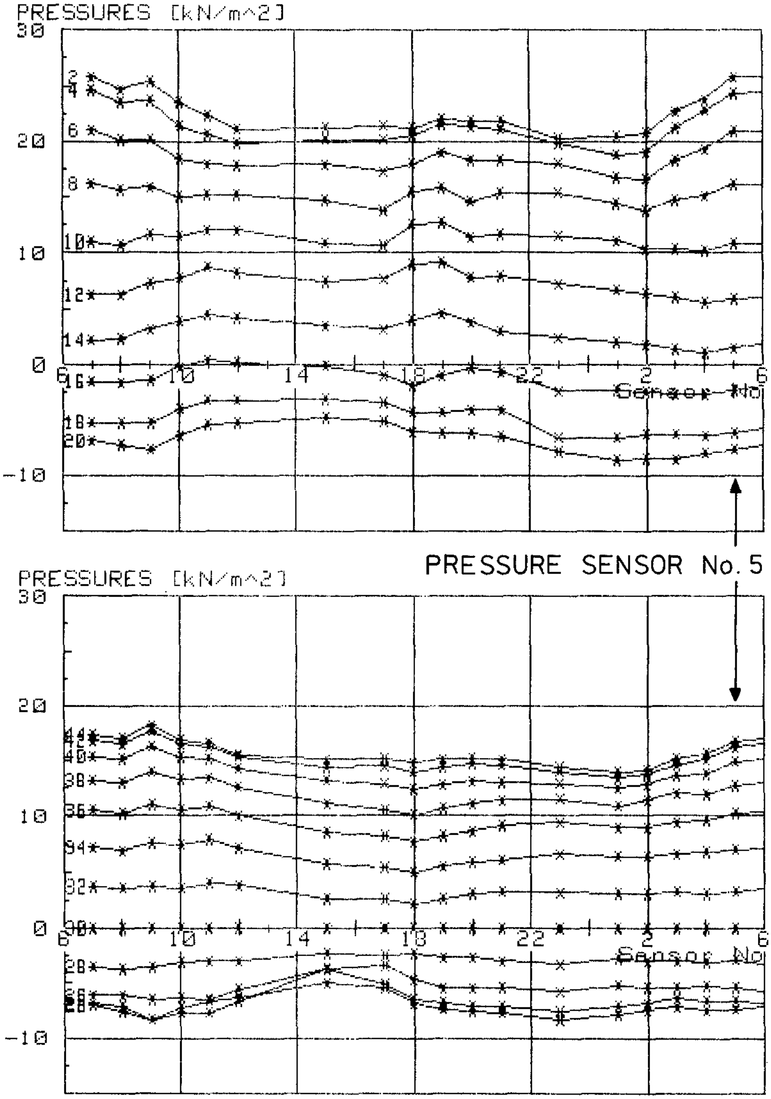


Fig. 7 : Variation of pressure distributions on the circumference of the test section with wave phase

to phase intervalls of 0.4 sec. The respective development from phase No. 2 to No. 20 (marked by numbers on the left hand side), is shown in the upper part of this Fig. and the measurements corresponding to phase numbers 22 to 44 are shown below.

For example, pressure sensor No. 5 (indicated by arrows) located at the highest point on the circumference (see also Fig. 1) shows the absolute maximum pressure value near the first wave crest position (phase No. 2), intermediate values (with respect to other transducers) corresponding to trough phase numbers 18 to 26 and comes back to a relatively high value at the next crest position (phase No. 44).

Because of erroneous offsets in some of the transducer signals in this case all the distributions refer to that of phase no. 30 whose raw data showed minimum deviations from zero. As a consequence in this kind of presentation its pressure values are zero everywhere, cf. lower part of Fig. 7.

4. CONCLUSIONS

With the vertical distance between the first wave crest and the following trough

$$H \simeq 4.75 \text{ m}$$

and the time between the two crests

$$T \simeq 8.8 \text{ sec} \quad \text{corresponding to a wave length}$$
$$L \simeq 113 \text{ m} \quad \text{(at a water depth of about 30 m)}$$

both taken from Fig. 4 and

$$\max.\ u_c \simeq 1 \text{ m/sec}$$

from Fig. 5, the data may be characterized roughly by calculating the following quantities :

REYNOLDS's number

$$R_n = \frac{\max u_c \cdot D}{\nu} \simeq \frac{1 \cdot 1.92}{10^{-6}} = 1.92 \cdot 10^6$$

KEULEGAN-CARPENTER number

$$N_{KC} = \frac{\max u_c \cdot T}{D} \simeq \frac{1 \cdot 8.8}{1.92} = 4.58 \quad \text{and}$$

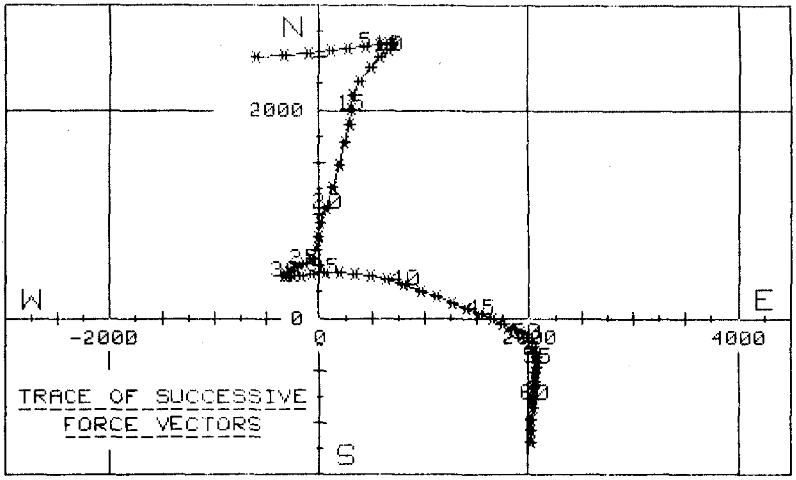
DEANS's reliability ratio (cf. DEAN (1976) Fig. 5)

$$R_D = \frac{F_{D\,max}}{F_{J\,max}} \simeq 0.4$$

Hence, at least at the wave crest position the conditions are well within the rough turbulent flow regime and the data turn out to be more appropriate for extracting C_M rather than C_D. Because of the unsufficient velocity measurement, however, at the present stage the authors do not find it reasonable to apply routines for extracting any force coefficients until the actual flow pattern around the inclined member can be described in general and particularly with reference to varying directions of wave propagation. The following remarks contribute to that aim.

Although there are strong irregularities to be seen from the pressure distributions in Fig. 7, a certain similarity to the well known supercritical stationary flow case is obvious. This is most distinct at the wave crest position (phase no 2) with maximum pressures at the front face and a secondary pressure maximum on the opposite side of the test section circumference. With the flow direction changing the secondary pressure maximum becomes the absolute maximum (near sensor numbers 15 and 17 at phase numbers 22 and 24 respectively) and vice versa, however with its exact location changing from wave to wave.
After integrating the pressure distributions (at phase intervalls of 0.2 sec), the irregular behaviour can also be observed in the resultant force vectors which are plotted with the wave phase in the two alternative presentations of Fig. 8.

The trace of successive force vectors is shown in the upper part and the same data are given below with reference to 0. Both traces are numbered consecutively.
Up to phase number 8 the forces are directed easterly and have south-westerly components at phases 9 to 30.
Maximum forward and backward force vectors differ by angles of $\alpha = 69^{\circ}$ and $\beta = 91^{\circ}$ respectively (see lower part of Fig. 8). A similar change can be seen from the following wave cycle. An inspection of the velocity data is helpful in order to check as to how much these changing force directions are influenced by the inclination of the tubular member.
The respective presentations - similar to that of the resultant forces - are shown in Fig. 9 and 10 respectively. It is apparent from these graphs that there also exist differences in the forward and backward directed flow, but the difference angles between maximum velocities (most reliably measured) are in the range of 13° to 30° only (see upper part of Fig. 9).
A speculation that the deviations are due to superimposed currents can be true, if tidal velocities are considered :
As an example Fig. 11 shows the behaviour of the tidal currents at the same location as during the measuring period from February 15th to 20th, 1977. In particular it can be seen from this graph that maximum tidal velocities (1 hour average values) occur with magnitudes of about $V_T \simeq 0.3$ m/sec setting easterly at increasing water levels and north-westerly with the water level decreasing.
By inserting the vectors U_{CR} and U_{TR} from Fig. 9 into Fig. 11 at a tide phase similar to that of the measurements on November 15th, 1978, the asymmetry between U_{TR} and U_{CR} can be explained by a superimposed tidal current of $V_T \simeq 0.3$ m/sec. The even stronger asymmetry in the force vectors of Fig. 8 than in the velocity vectors (of Fig. 9 and 10) is because an inclined member



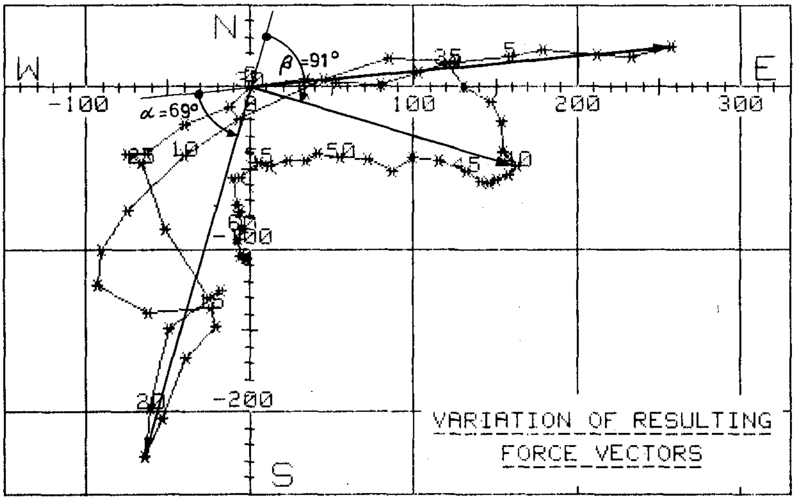
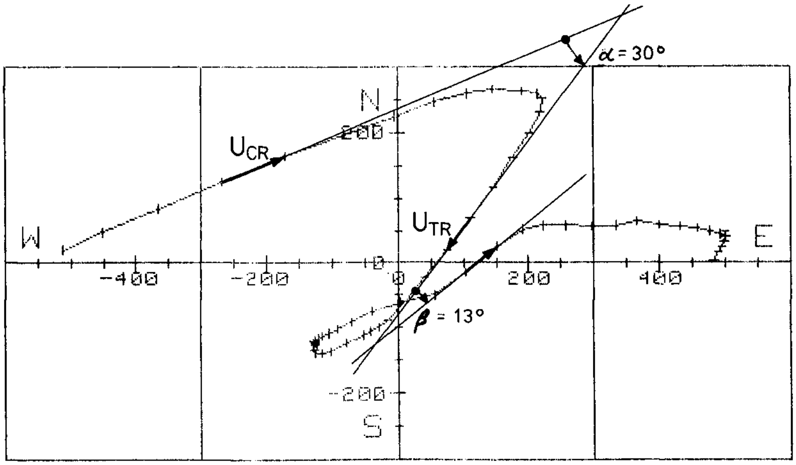
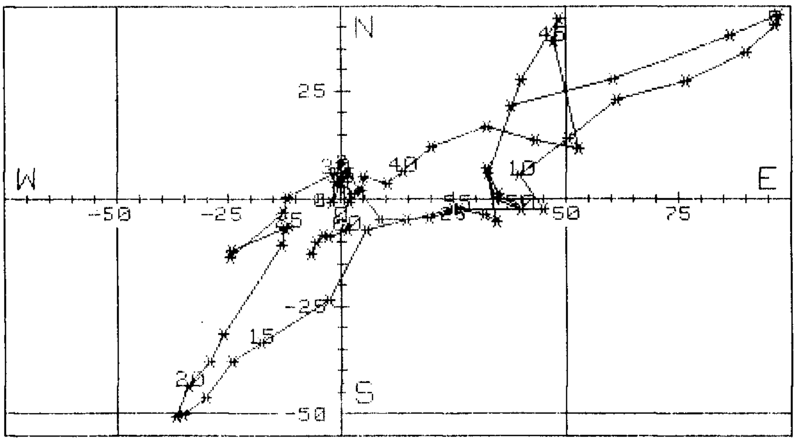


Fig. 8 : Variation ot resultant force vectars with wave phase



TRACE OF SUCCESSIVE VELOCITY VECTORS



VARIATION OF VELOCITY VECTORS

CURRENT-METER No: 7

Fig. 9 : Variation of velocity vectors with wave phase

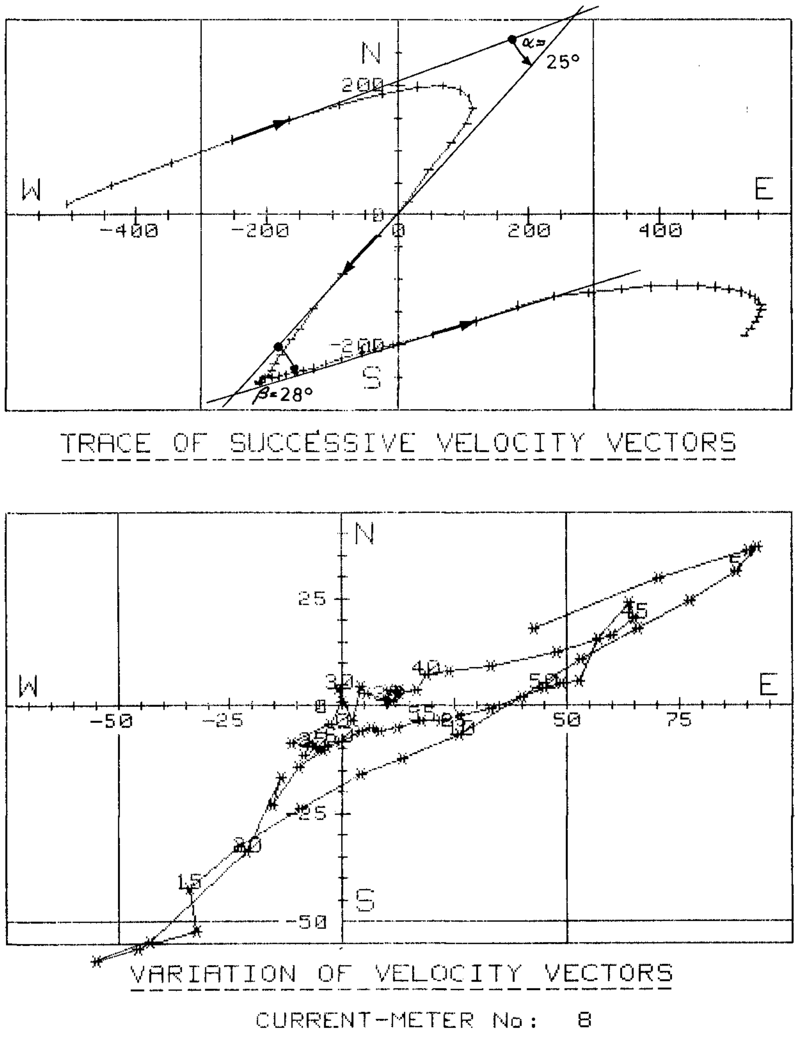


Fig. 10 : Variation of velocity vectors with wave phase

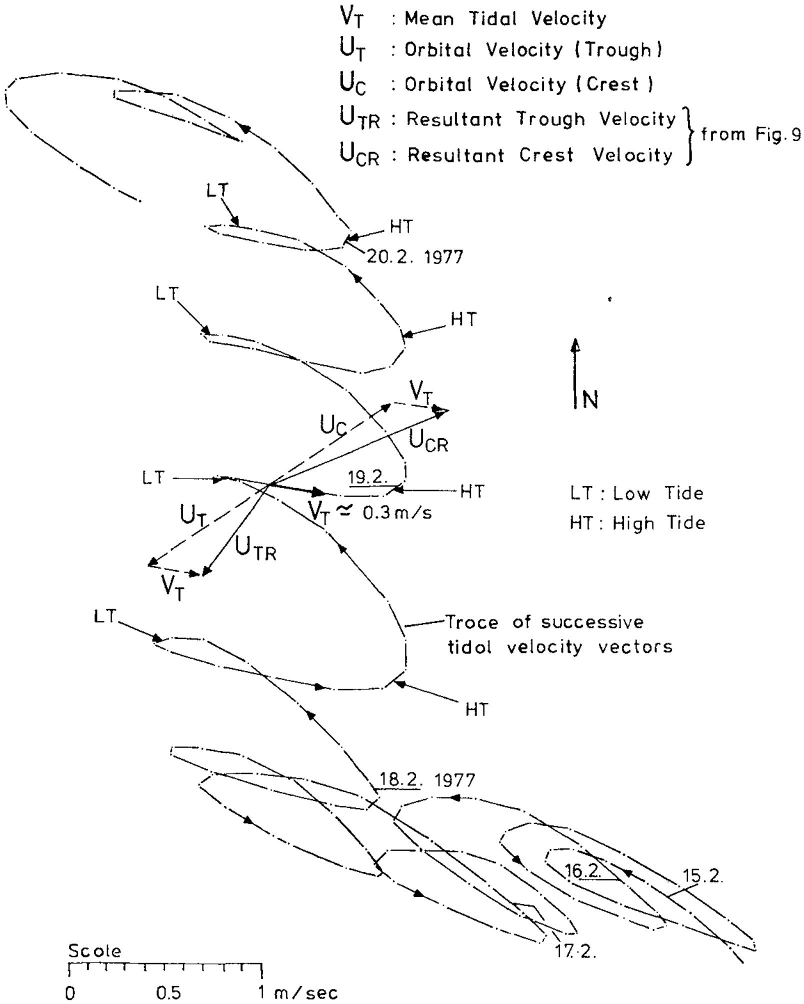


Fig. 11 : Variation of tidal stream vectors from February 15th to 20th, 1977

is (more) sensitive to an asymmetric flow condition resulting in an amplification of the force creating processes.
The evaluations shall be continued in the future. In particular, the synchronous measurements, reported here, shall be compared to the actual tidal velocity as calculated from the long term velocity measurements.

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