CHAPTER 96

EXPERIMENTAL INVESTIGATION OF TURBULENCE NEAR CYLINDERS

by

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ABSTRACT

Model tests with locally generated turbulence near horizontal and vertical cylinders are reported.

Turbulence is measured with newly developed ultra-sonic probes, and spectral density functions and auto-correlation functions are given.

Tests are carried out in uniform currents, in sinusoidal waves, and in combinations of current and waves.

Results are given for a viscous laminar boundary layer corresponding to a very fine sediment, and for a turbulent boundary layer corresponding to a hydraulically rough bottom.

In Norway recent scour research, initiated by the North Sea oil operations, has been guided in three directions:

1) Scour around big gravity structures
2) Distribution of pore pressures in the ground under wave loads.
3) Local scour near unburied pipelines.

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The unburied pipeline and therefore an extensive research work on possibilities for scour, and forces on the pipeline during different scour stages has been carried out.

This has been reported by KJELDSEN, GJØRSVIK, BRINGAKER, JACOBSEN 1973 (1), and as a result of this a practical relation has been given from which scour depths near unburied pipelines can be estimated.

With E as a scour Euler number and F as a pipeline Froude number the scour depth can be found from the equation

$$E = 4/5 \cdot F^{4/5} \qquad (1)$$

This equation is based on tests in uniform currents with pipeline Reynolds numbers in the interval:

$$1 \cdot 10^4 \leq R \leq 2 \cdot 10^5 \qquad (2)$$

15 tests were carried out and a regression analysis gave a correlation coefficient 0,98 to eq. (1).

From this investigation it was clear that it was the energy in the locally generated turbulence that was responsible both for the scour and for the forces on the pipelines.

The conclusion was drawn that no more knowledge about scour and pressure distributions around cylinders could be obtained using "all over parameters".

Therefore the investigation reported here with observations and analysis of locally generated turbulence, was initiated.

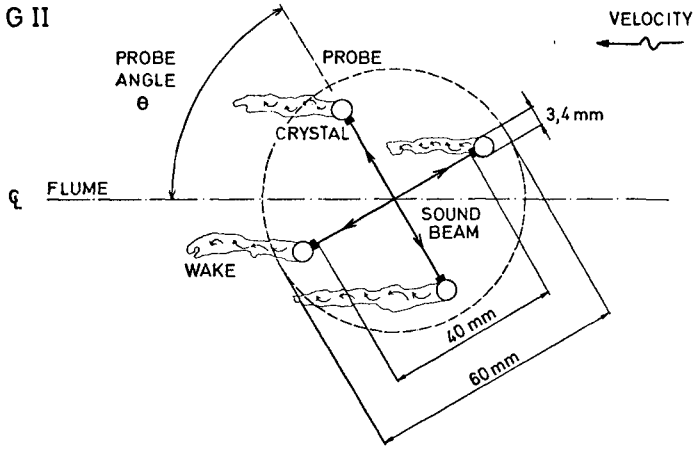
EXPERIMENTAL SET-UP

Two ultra-sonic probes were available for the turbulence measurements.

These are "transit time difference velocity meters".

The instruments are shown in Figure 1. The first one has four piezo-electrical crystals and uses two ultrasonic sound beams. The frequency used in the sound beams is 300 Hz.

ULTRA - SONIC PROBES



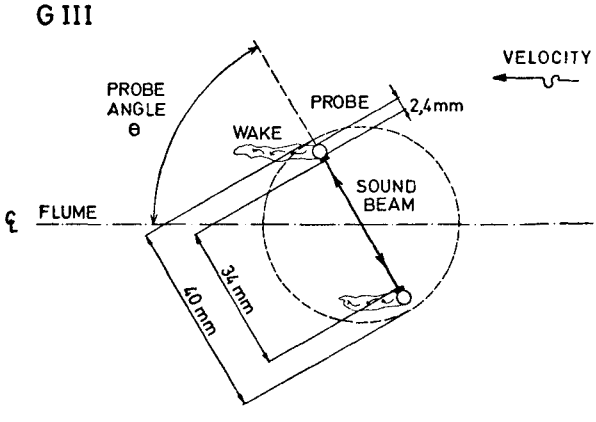


Fig. 1

The second one has two crystals and uses one ultrasonic sound beam. From recorded time differences of the sound beams travelling through the water, the flow velocity can be evaluated.

The first probe gives the velocity vector in a (horizontal or vertical) plane, while the other gives one component of the velocity vector only.

One particular advantage is, that the probes are very efficient in two phase-flow with heavy sediment transport.

A comprehensive description of the instruments and the calibration procedure is given by AUDUNSON, GYTRE, LAUKHOLM (2).

The probes were placed immediately upstream and downstream of the actual structures.

Two series of tests were performed, as shown in table 1.

In the first test series, no scour action took place and only turbulence was recorded.

The tests were performed in a 26 m long, 0.75 m wide and 0.60 m deep flume with a bottom of shingles with a mean grain diameter d_{50}=16 mm giving a hydraulically rough bottom and a very strong turbulence, which was extremely useful for the testing and calibration of the signal from the probes.

For verification of the results runs with uniform currents on a plane bottom, and different water depths were performed.

The probes were placed on different positions along the flume to check the growth of the boundary layer and to give the position of the fully developed velocity profile.

After this, the same verifications were done with sinusoidal waves and combinations of waves and currents.

After turbulence recordings were taken for all these situations, a horizontal cylinder with a diameterof 6 cm was placed on the bottom and the turbulence recorded just ahead and just behind.

Similarly a vertical cylinder with the same diamter were placed on the bottom and the turbulence near it was recorded.

For comparison another test series was performed. Here the "clear water scour case" was examined, where no grain movement takes place on an undisturbed bottom while scour action starts ahead of an unburied pipeline.

These tests were performed in a 33 m long, 0.5 m wide and 2 m deep flume, with a silty bottom, with a material with a mean grain diameter d_{50}=0.074 mm which is very similar to bottom materials found in the North Sea.

TEST TABLE 1

RUN No.	Flume	Structure	Diameter	Bottom	Flow	Mean flow velocities	Waves	Water depth	Scour	Probe
-	(m)	-	(cm)	(mm)	-	(m/s)	(m)(sec)	(m)	-	-
1-22	Length:26 Width:0.6 Depth:0.75	Unburied pipeline Vertical pile	6.0 6.0	Shingles d_{50}=16	Uniform current Sinusoidal waves Current and waves	0.10 0.20	T=1.0-2.5 H=0.015 - 13.2	0.20 0.30 0.50	No scour. Turbulence recordings only.	G III Ultrasonic current meter One channel
52-56	Length:33 Width:0.5 Depth:2.0	Unburied pipeline	50.0 22.5 6.0	Silt d_{50} = 0.074	Uniform current	0.20 0.25	-	1.50	Start of "Clear water scour" observed	G II Ultrasonic current meter Two channels

The viscous boundary layer in this flume was laminar, and tests were performed with pipelines with diameters 50 cm, 22.5 cm and 6 cm.

Only tests in uniform currents were performed in this flume.

The scour action was recorded and some results from the test series will be given, but further work has to be carried out, as correct turbulence recordings on a hydraulically smooth bottom are very difficult to obtain.

Possibilities for a digital as well as for an analogue analysis of the recorded turbulent signal existed.

The measuring period was 3 - 6 minutes.

Modification of the signal from the probe was done by a specially designed box ("ULTRA-GYTRE"). From there the signal was taken to a tape recorder (TANDBERG 100) and to a plotter (SANBORN).

From the tape recordings the measured signal was converted to digital form with a frequency of 10 Hz, giving a Nyquist frequency of 5 Hz, and anlysed on a computer.

Further the signal was taken to a wave analyser (NORTRONIC) and an xy-plotter (GÖERZ), which allowed us to make an analogue analysis of the frequency distribution in the measured signal.

As the noise level from the probe for higher frequencies was quite high, it was decided to base the analysis on the digital signal only.

From the converted data, a turbulent data base was obtained.

A fast Fourier analysis gave spectral density functions as well as autocorrelation functions.

SPECTRAL DENSITY FUNCTIONS

Spectral density functions were obtained for all tests mentioned in table 1, and as an example fig. 2 is given.

The measuring period varied in the different tests from 3 - 6 minutes.

To get more confidence in the obtained spectral density function, the signal was divided into 4 blocks overlapping each other, and each consisting of a measuring period of 102.4 sec.

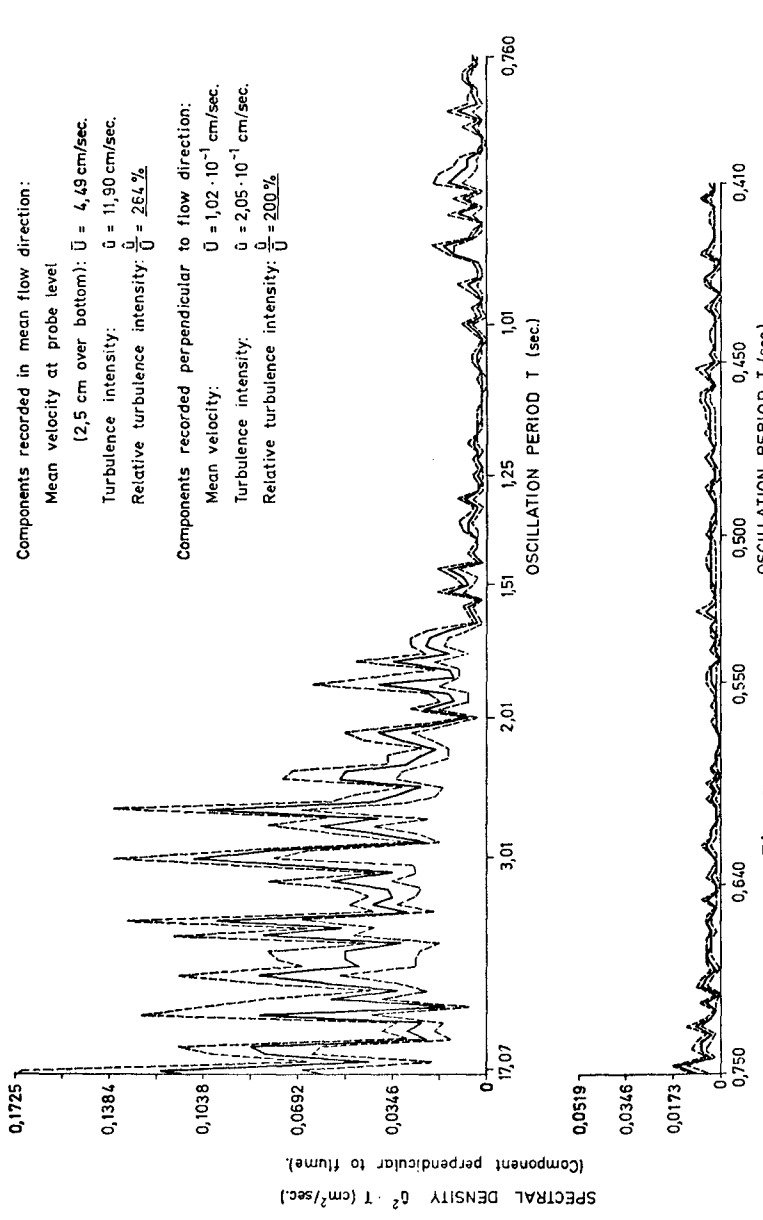

SERIES: G II RUN 52
PROBE AHEAD OF PIPELINE
PIPELINE DIAMETER: D = 0,50 m
MEAN FLOW VELOCITY: V = 0,20 m/sec.
Components recorded in mean flow direction:
Mean velocity at probe level
(2,5 cm over bottom): Ū = 4,49 cm/sec.
Turbulence intensity: û = 11,90 cm/sec.
Relative turbulence intensity: û/Ū = 264 %
Components recorded perpendicular to flow direction:
Mean velocity: V̄ = 1,02 · 10⁻¹ cm/sec.
Turbulence intensity: v̂ = 2,05 · 10⁻¹ cm/sec.
Relative turbulence intensity: v̂/Ū = 200 %
SPECTRAL DENSITY 0² · T (cm²/sec.)
(Component perpendicular to flume).
0,1725
0,1384
0,1038
0,0692
0,0346
0
12,07
3,01
2,01
1,51
1,25
1,01
0,760
OSCILLATION PERIOD T (sec.)
0,0519
0,0346
0,0173
0
0,750
0,640
0,550
0,500
0,450
0,410
OSCILLATION PERIOD T (sec.)

Fig. 2

The Fourier analysis was made on each block, and the mean values of the spectral density from the four blocks was calculated for each oscillation period and drawn as a full curve in fig. 2.

In addition the variance in the mean value for each oscillation period was calculated. The variance is added to and subtracted from the mean value, and shown in fig. 2 as dotted lines.

The lower limit for oscillations that could be recorded is given by the measuring period for the blocks, 102.4 sec, but to get confidence in the curve the lowest oscillations were omitted, and the lowest oscillation given in fig. 2 is the sixth harmonic, corresponding to period T=17.07 sec.

It is obvious from the results given in fig. 2, that the turbulence is clearly anisotrop, with a component perpendicular to the flume wall, that is negligible, compared with the component along the mean flow direction.

The turbulence is thus "two-dimensional", however, we were only able to measure the horizontal component.

Fig. 1 shows that in the "two-dimensional" case the distance in the mean flow direction between the probes on the current meter can be reduced, if the current meter makes an angle with the mean flow direction. The measurements can be obtained with a probe with one channel only, as shown in fig. 1. In the test series with G III the probe angle was 60^{o}, thus giving a probe distance of 17 mm in the mean flow direction and a theoretical cut-off of turbulence at 8 Hz in a flow with a mean flow velocity of 0.20 m/sec.

A good deal of noise occurred in the signal, so in practice we got an upper limit of 2.5 Hz corresponding to an oscillation period of 0.4 sec.

The digital technique gives a reliable value up to this limit, since 2.5 Hz is half the Nyquist frequency.

The bandwidth actually obtained with the instrumentation and analysis used thus became

$$17.07 \leq T \leq 0.41 \text{ sec.} \qquad (3)$$

AUTOCORRELATION FUNCTIONS

The difference in the turbulence between the various tests performed, is best illustrated by the obtained autocorrelation functions.

Fig. 3 illustrates the situation in a uniform current with a mean flow velocity of 0.20 m/sec.

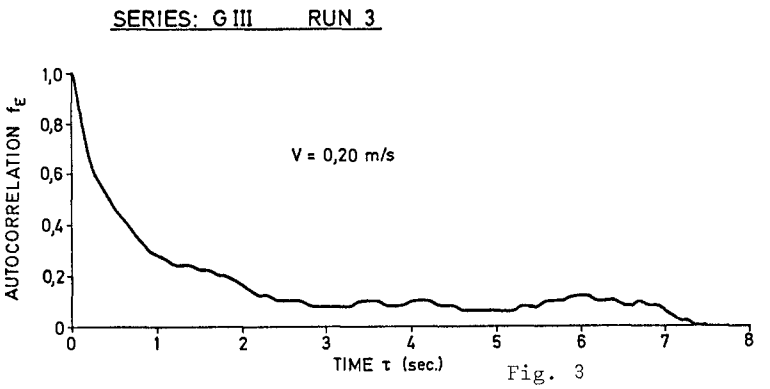


Fig. 3

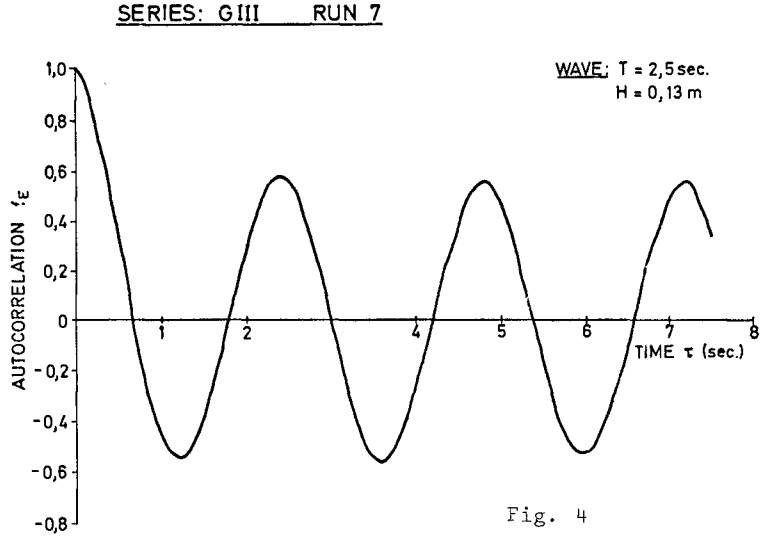


Fig. 4

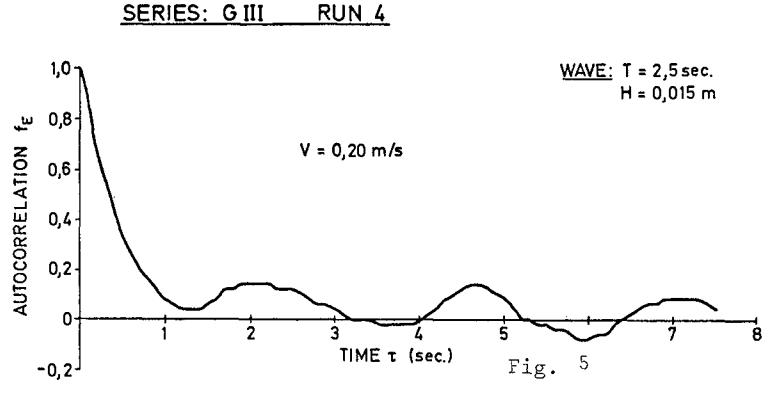


Fig. 5

The curve has an obvious negative exponential form, and thus gives another verification of the obtained data.

Fig. 4 illustrates the situation for a wave with period 2.5 sec and height 0.13 m.

Fig. 5 illustrates the situation with a combined flow of a current with mean velocity 0.20 m/sec and a wave with period 2.5 sec and height 0.015 m.

In fig. 6 the effect of an obstruction is shown. Here the probe is placed just ahead of a pipeline in a wave with a period 1.75 sec and a height 0.12 m, and it is observed, that the autocorrelation function is changed significantly.

Fig. 7 shows the autocorrelation function for the probe placed behind the pipeline in a uniform current with mean flow velocity 0.20 m/s.

Fig. 8 shows the function obtained with the probe behind the pipeline in a combined action of a current with mean flow velocity 0.10 m/s and a wave with period 2.5 sec and height 0.12 m, propagating in the same direction as the current.

Fig. 9 gives the autocorrelation function near a vertical cylindrical pile for comparison. Here the current was 0.20 m/sec and the wave had a period of 2.5 sec and a height of 0.12 m. The locally generated turbulence was in this case much less than in the former case with the horizontal pipeline.

All curves were obtained on a hydraulically rough bottom with a water depth 0.50 m.

For the uniform current case, curves were obtained with the probes in several different positions along the flume, and good agreement was found between the individual correlation functions, which is another verification of the obtained data.

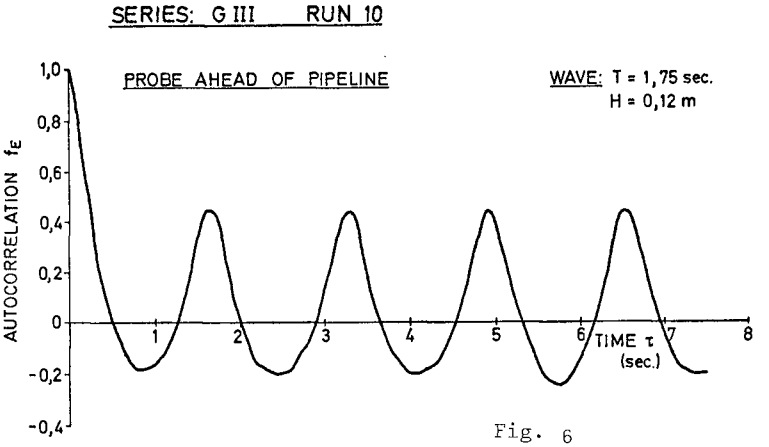


Fig. 6

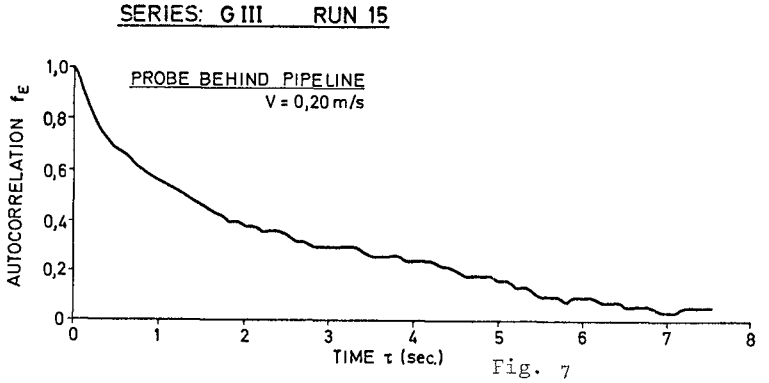


Fig. 7

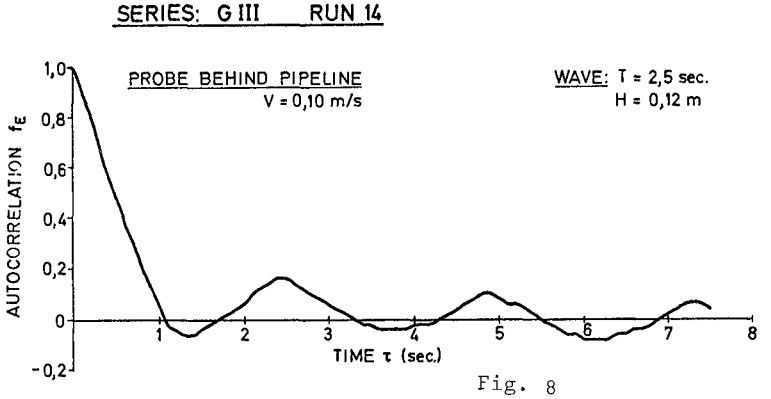


Fig. 8

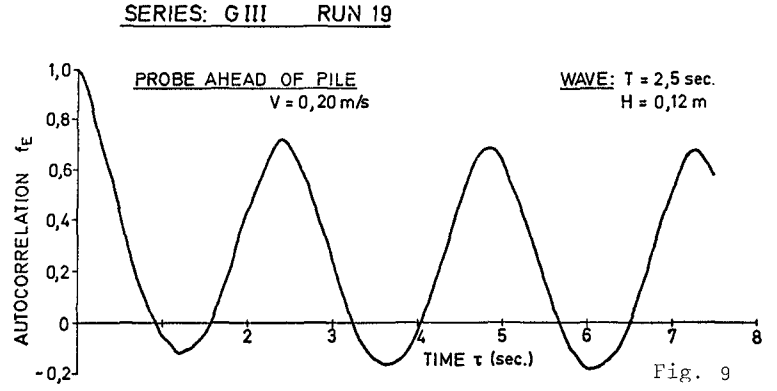


Fig. 9

CONCLUSIONS

From this investigation it can be concluded that the new ultrasonic velocity meter delivers a reliable signal, and thus gives very good opportunities for measurement of turbulence characteristics.

A very clear demonstration is given of the modification of autocorrelation functions for the recorded velocity, compared with autocorrelation functions for undisturbed flows due to uniform currents, sinusoidal waves, and combinations of waves and currents.

Applications of the new instrument, other than in scour research, may well include important problems of fluid loading on cylinders.

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