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<<BEHAVIOUR OF OFF-SHORE STRUCTURES>>
The Norwegian Institute of Technology

ASPECTS OF THE INSTRUMENTATION AND MEASUREMENT PERFORMANCE OF THE RESEARCH PLATFORM NORDSEE

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ABSTRACT

Since the beginning of 1975 data may be obtained from a fixed structure in the Nort Sea, position 54° 42’ 06’’ N, 7° 10’ 00’’ E. The Research Platform NORDSEE has started to operate in its three main tasks:

- permanent measuring station for meteorological and oceanographical data
- manned control station for a marine test field
- research object for investigations of the interaction of marine environment and the behavior of the structure

Investigation of the first and third point has already begun. Within the scope of various programmes, some still belonging to the construction, some to the research plans and others to current measurement programmess, extensive data material has already been gathered.

Deformations and movements of the construction can be determined at several hundred measuring points, by means of strain gauges and accelerometers.

At the same time, data concerning sea state, current and wind as well as additional meterological and oceanographical data can be recorded and related to the measurements of the structural behaviour.

Particular measurements are extracted and used for permanent supervision of the behaviour and safety of the construction.

Measurements of tide level, wind and sea have considerable references value regarding the storm flood forecast for the German North Sea coastal area.

Certain features of the conception of the platform and of its instrumentation and some first results are described.

1. Introduction

In design and dimensioning offshore structures it becomes obvious that there is a lack of sufficient exact parameters
Wave loads on tubular structures for example, are generally calculated on the basis of an approximate formula (1) involving values for orbital velocity and acceleration which are heavily dependent on the applied wave theory. The required drag and mass coefficients are difficult to confine. (2)(3).
Model tests give little help as transcritical Reynolds numbers of the natural flow conditions are nearly impossible to accomplish in model scale.(4)(5)
The range of possible calculations of horizontal wave loads, recognised by classification rules (6), can easily be ascertained.
Similar problems occur in the determination of wind loads. The presence of spray just above the water surface during high winds may lead to much higher loads than normally calculated. (7)
Other difficulties arise in the determination of the effects of cyclic wave loads on the foundation soil below gravity structures.
The numerous scientific and engineering questions provide good reason to demand more extensive measurements on full scale offshore structures.
The possibility of simultaneously measuring the origins of the environmental loads such as wind and waves, as well as the response of a typical, if also unconventional offshore structure, has been materialized in a rather unique manner with the Research Platform “Nordsee”.

- the large space of laboratories and accommodation allow long term ressearch on location
- the position in the North Sea represents at times extremly hostile, but for offshore industry relevant, environmental conditions
- the hybrid structure offers both the properties of “classic” tubular structures as well as of new gravity based concrete structures
- the research facilities are flexible so as to be adaptable for new formulated tasks.

However, investigations on the interaction of an offshore structure with the marine environment represent only one task.
The objectives and functions of the research platform are diverse.
With the platform as a base, extensive data is scheduled to be collected on physical, chemical and biological topics of oceanography and marine biology. Continuous measurements related to the sea and weather conditions are carried out.
The platform will serve as a testing site for automatic sea data acquisition systems. The measuring instruments for the determination of the oceanographic parameters, as well as large buoys designed as carriers for the instruments, may be tested here under operational conditions.
Finally, the platform will function as a basis for research into the behaviour of sound in the sea under natural contitions.
The project was financed by the Germany Ministry of Research and Technology and supervised by the Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt mbH (GKSS.) The platform was designed by the Ingenieurgemeinschaft Meerestechnik + Seebau GmbH (IMS), who also acted as general contractor.

2. Some general features of the Research Platform

The overall design of the platform configuration reflects the basic requirement that the natural hydrodynamic conditions of the sea should be affected as little as possible, especially in the vicinity of the waterline. This lead to a rather unusual design of the tubular supporting structure, with four heavy corner legs, only two diagonal braces on each side above the waterline and a more complex bracing structure below. The deck house with a main deck and two decks for laboratories, conference rooms and living quarters below, has dimensions of 26.4 by 26.4 meters and is located 20 meters above the sea surface. An overall view of the platform can be seen in Fig. 1. A more detailed description of the design can be found in (9),(10) and(11).
The design and layout of the decks are determined by the functional requirements. The main deck provides space for work requiring large working area.
A central opening of 3 meters by 3 meters (comparable to a moon pool) is fitted in all decks to facilitate research work. A winch to serve the opening is installed on the main deck. In addition the central opening can also be served by two cranes .
The opening can be closed by hatch covers at each deck level. Helicopter landing facilities, life saving equipment as well as a work boat are, of course, provided. Engine rooms and workshops are situated on the upper deck, just below the main deck
Excellent sound proofing was considered of greatest importance here.
All living quarters are, on principle, provided as single rooms in the lower deck; they may, however, be used by two people if necessary. As a maximum 14 scientists may be accommodated. A crew of 7 people will, in addition, be responsible for the operation of the platform. Fuel and lubricating material, as well as fresh and waste water, are stored in double bottom tanks below the lower deck. As the study of the marine fauna and flora must not be affected, the waste water is purified. Nine laboratories are installed, one for chemical purposes, eight for physical research. These laboratories have supplies of fresh and sea water, compressed air and stabilized current of 380/220 V 50 Hz, 440/220 V 400Hz and 24 V DC.

A data distribution system is provided for the transfer of data from various points on deck to and between the laboratories. This system is capable of transferring DC signals down to 15µ V as well as high frequency AM and FM signals.

3. Conceptional evaluations for instrumentation of the platform as research object

As starting point for measurements on the platform, a concept was developed which, under step by step realisation, should make the following main investigations possible:

1. Recording relevant environmental data (in particular wind and waves)
2. Recording stress in the tubular structure to determine loads, (normal force and bending moment) according to size and distribution.
3. Determination of strains at the hot spots on some standard nodes.
4. Determination of the vibration behaviour of the structure.
5. Observation of the bearing conditions of the gravity foundation.
6. Investigation of wave loads at chosen points.
7. Observation of particular parts of the tubular structure of extreme stresses and / or magnitude and number of occurrence of alternating stresses, as information on the safety of the structure.

These results should justify comparison with analytically obtained values in order to arrive if possible, at generally valid statements regarding loads and strains on similar structures.

An instrumentation system, aimed at approaching the above mentioned targets was designed and built as can be seen in fig. 2 and 3, the priority of underwater equipment as against installations above water being stressed. The possibility of expansion for later tasks is as far as possible taken into account: underwater equipment holders and cable laying

facilities in trenches and ladders are provided.
Measurement of the distribution of loads in the sections of the tubular structure can be practically obtained by means of strain gauges. In order to keep the sensors within a reasonable number, these must be concentrated on characteristic parts of the structure.
Four tripods (NW, NE, SW, SE corner) may be considered as principal load bearers. They are connected by the deck, annular beams and the gravity base.
It can be admitted that the maximum wave load on the platform is to be expected from north westerly direction. Calculation has shown that with such waves, and considering one symmetrical half of the platform, mainly the members of the south west tripod will have the highest stresses. Consequently the SW-corner was intensively instrumentated and equipped to have at least 3 measuring planes per member.
One node for each node type is equipped with strain gauge rosettes to record strains in the highly stressed areas. At the same time the forces and moments going into the nodes should be measured at the connecting members.
For experimental recording of the vibration behaviour and response to excitation from wind and wave, wide ranged accelerometers are provided. The SW-tripod is once again more extensively equipped to record detailed movements. The strain gauges, naturally also give information about vibrations.
All strain and vibration measurements only take on reasonable meaning when they can be correlated with environmental data i.e. in particular, wind, sea and current.
In order to record the sea state at the affect of the prevailing wave direction with as little disturbance as possible, two complimentary sensor systems were planned on the northern, western and southern horizontal annular beams, at approximately 11 meter depth of water:
Pressure sensors for constant notation of the course of pressure which can be converted to wave energy spectra as well as echo sounding sensor, allowing a direct statement on the actual wave height.
Flow measurement of the orbital velocity close to the wave measurement instruments allow assumption of the wave direction.
Analysis of the basic current is made through an additional current meter on the foundation body.
Through pressure measurements around a tubular (not represented in fig.2, and 3) in connection with flow measurements, statements should be made about local wave loads, their distribution and correlation to wave motion, without having to resort to possible doubtful, wave theories.
Observation of bearing conditions can be achieved by strain measurements in the statically important parts of the foundation body.
Tidal and meteorological measurements should of course, be made.

The concept was established in close-operation between GKSS, Bundesanstalt für Wasserbau (BAW). Leichtweiß-Institut (LWI) of the TU Braunschweig, Germanischer Lloyd (GL), Deutsches Hydrographisches Institut (DHI) and IMS.
The assembly of the strain gauges and their wiring was carried out by the BAW.
The wave measuring instruments, partly projected by DHI, current meters and pressure transducer rings were installed by the LWI. IMS acted as co-ordinator and carried out the work for the remaining measuring instruments and the recording device.

4. Instrumentation for measuring the behaviour of the structure and the environment

4.1 Strain gauges in the tubular members

In order to limit the number of gauges and cables, strain measurements in the tubular members are based on uniaxial strain gauges measuring lengthwise along the pipe wall. Determination of torsional moment was therefore dispensed with.
Nearly all measuring planes were equipped with 4 gauges, each being staggered at 90° angles. Since the ideal planes which can be placed through the strain values around the pipe, are determined by 3 points, normal force and bending moment can be calculated with 3 measuring values. The fourth value serves for redundancy and control.
These measuring planes lie in the middle of the member and approximately one meter away from the welds of the adjoining nodes.
Certain members which are of interest simply because of their normal force properties, are equipped with two opposite lying strain gauges which enable elimination of bending strain when parallel connected.
The strain gauges are spot welded and well protected by compound filled cases. To exclude sea affects, wiring and gauges lie on the inside of the pipes.
Types of strain gauges and the other gauges are summarized in Table 1.

4.2 Strain gauge rosettes in the nodes

Also for reasons of protection, the strain gauge rosettes were attached to the inside pipe wall of the nodes, although the absolute maximum stresses are to be expected on the outside. The spot was chosen from the finite element calculation of the corresponding node to be where maximum strain caused by the various load condition on the inside if the node, could be expected. It can be expected to receive statements on the maximum tensions on the outside of the node after comparison between experimental and theoretical results.

4.3. Strain gauges in the foundation body

The foundation body is equipped with 32 uni-axial stain gauges which work on the Principe of vibrating wires. They are arranged tangentially to the boxlike ring bearing the foundation body and lie next to the joints connecting tubular structure to the foundation and half way between the foot joints, one sensor each in the top and the bottom slab.

4.4. Wave and current measurements

Fig. 4 shows one of the units for wave measurements before assembly on the horizontal annular member (compare Fig.5).
On the left side, immediately next to the one meter high standard, the pressure sensor is to be seen. It works on the principle of a vibrating wire.
Outside of the left is the echo sounding transmitter/receiver. A generator on the deck of the platform delivers impulses of 0,75 millisecs in a sequence of 7 Hz. The acoustic signals of approximately 120 kHz are sent to the water surface by a crystal vibrator. The scattering angle amounts to +/- 1° so that wave lengths of approximately 55 cm are resolved.
On the right side of the sensor unit both the horizontal and vertical standing discs of the current velocity meters can be seen. Each disc has two measuring directions parallel to its surfaces so that all three directions in space can be measured.
The measurement is based in the principle of electromagnetic induction.
An additional current sensor is attached to the foundation body. (Fig.6).

4.5. Tidal measurements

Measurements of the water level are taken on the pressure principle. The column of water, standing above an outlet 9 meter below the water surface, at the SW-corner and kept balanced pneumatically using the method of streaming air bubbles, is measured and recorded. The tide level refers at this time to an internal gauge zero.

4.6. Water and steel temperature

The water temperatures between –4 and –19 meter chart zero are indirectly measured. The actual measurement is taken from the inside of the steel pipe to which the thermocouple elements are attached. This temperature, accurate to one tenth degree, can be approximately equated with the outside temperature, keeping in mind the preconditions that the water temperature variations are relatively long term. Another thermo-element is positioned at +15,5 meter in the same leg.

4.7. Other instrumentation

Additional instrumentation for meteorological measurements such as windspeed and direction, air pressure, air temperature and air humidity is of course provided.
Measurements of tank volumes may give information about the actual vertical loading conditions.
The visual range measurements are used as information for the arriving helicopters.

5. Data acquisition system

The data acquisition system is designed to meet the requirements of the safety observation and reseach activities. It was designed in prefabricated parts in order to cope more easily with later demands. An outline of the functional contents is given in Fig. 7.
The equipment is accommodatated in 19” racks.
The approximately 450 sensors end in a cross-connection field. From here electronic evaluating units, amplifiers and recording instruments are chosen. The signals are standardized for a +/- 5V range.
Two magnetic tape systems are available:
The first system, prepared for the observation of the platform, contains

- an analog 14 track magnetic tape unit using pulse code modulation for the recording of 32 channels
- one play back channel
- four FM channels
- one comment channel

At a recording frequency of 37 Hz the total recording time per tape is seven and a half hours. The values are coded in 10 Bits (binary).
The second PCM-system with a transportable tape recorder, enables simultaneous recording of 120 measurements for research purposes (not shown in sketch 7).
In the data centre the connection to the data distribution system enables the measurements either directly or after processing to be transferred to the laboratories.
The constant observation of environment and structure is carried out in the following manner:
Particular values are continuously measured, amplified and compared with certain threshold values. If these threshold values are exceeded, an alarm warns the responsible electronic engineer and starts the automatic registration of these values. In this first phase of development the observed values are wave height, wind velocity and the normal force in a typical, maximum stressed member.
In addition, the normal forces on some other members, as also acceleration of the deck and of one node above the water level are recorded.

6. First experience and results

The final installation of the measuring system was prepared on land in such a way that only the connection between the terminal boxes in the lower and upper part of the tubular structure remained to be made after the upper section was set down.
This task, which could only begin after the final welding work had been carried out, was finished in autumn 1975. Towards the end of this process GKSS, BAW, LWI, DHI and IMS had already started with the first investigations with the scope of a preliminary scientific programme which was intended to introduce the measuring and safety observation systems and prepare these for further expansion.
Only then could an overall impression be obtained regarding the actual operational functioning of the sensors, their wiring, as well as the appertaining operational electronics and recording units.
Numerically, the larger proportion of the sensors functioned from the start efficiently. Concerning the remaining sensors: the following problems emerged and were successively investigated for each of the sensors involved:

1. insulation leakage on some cables due to dampness
2. corrosive effects
3. influence from fields of electro-magnetic interference
4. susceptibility of outside positioned sensors to damage during irregular supply manoeuvres

The instruments operating on the system of frequency transferral (concrete strain gauges and pressure sensors for wave measurements) have proved to be decidedly robust and stable against certain insulation leakage.
Redundancies in the layout have proved advantageous, since in spite of all protective measures during the winter period 1974/75 when the substructure was already on position, some dampness penetrated the wiring either from the sensor side or from the wiring boxes and some of the strain gauges which react sensitively to insulation leakage, were affected.
Appearances of corrosion were noticed on pressure and current sensors and are now the object of thorough investigations.
Accelerometers and current velocity sensors were affected by fields of electro-magnetic interference. By filtering or eliminating the cause of interference, the disturbances could be suppressed and straightforward measurements carried out.
Statements concerning measurement results, analysis of specific questions and experiences with the preliminary scientific programme are described in (12) and (13).
In order to check the mathematical assumptions and methods for determining the vibratioinal behaviour on the actual object, an experimental vibration analysis was carried out. The platform was periodically excited using a mechanical exciter producing horizontal loads up to 19,6 Mp in frequencies of up to almost 20 Hz.
These tests confirmed the calculation and proved that the lowest natural frequencies of the platform lie in a field where energetic excitation from the sea is not expected.
As test also, the exciting sea and the response of the platform were measured with a strain gauge near the foundation body and spectrally analysed. Fig. 8 shows the resonances of the tubular structure.
The extensive data material obtained from these tests can be evaluated from the actual analysis. It forms a basis for achieving deeper knowledge of the dynamic behaviour of the construction. Tests, evaluation and some results are described in (14).
The storm floods of 3rd and 22nd January, 1976 were among the prominent events in the course of observation of the weather conditions in the German Bight. Some recordings of the first January storm flood are represented in (15). Fig. 9 shows as example, a wave spectrum of 3rd January, 1976, 16:30 h which was measured by an OAR pressure sensor and mathematically corrected. The calculated maximum wave height amounted at this time, approximately four and a half hours after the climax of the storm, to 9.33 m, the significant wave height 5.27 meter.
The highest water level up til now was recorded on 21st January, 1976, 02:00h with +3.70 m above gauge level zero, as against normal high tides of approximately +1.4 meter.

7. Conclusion

Since the initial operation of the scientific measuring installations on the research platform “Nordsee”, an extensive amount of data has already been accrued within the scope of different programmes, some of which belong to the construction and others to the research plans as well as to current measurements. The first results are under consideration.
Within the frame of future scientific research programmes, further interpretation of these data, new field measurements and extensive comparisons with results of calculations, will need to follow. The range of tasks will be expanded and supplementary equipment may be required.
Previous results, have, however, confirmed that the platform is an excellent research object.

8. Acknowledgement

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References:

(1) J.R. Morision, O'Brian, M.., Johnson, J.W. and Schaaf, S.A.:
The Forces Exerted by Ocean Waves on Piles. Petrl. Trans. Of AIMME, Vol. 198, Paper 2846, 1950 p. 149-154.

(2) Wiegel, R.L: Waves and their Effects on Pile-Supported Structures. General Lecture Symposium "Reseach on Wave Action" Delft Hydraulics Laboratory, 1969 Delft, The Netherlands

(3) O. Burkhardt: Über Wellendruck auf senkrechte Kreiszylinder Mitteilungen des Franzius- Instiutes, Hannover, Heft 19, p.58-201.

(4) G.H. Keulegan, L.H. Carpenter:
Forces on Cylinders and Plates in an Oscillating Fluid.
Journ. of Research of the National Bureau of Standards, Paper 2857 Vol. 60, No.5, 1985, p. 423-440.

(5) W.-D. Longrée: Etude experimentale du spectre des forces hydrodynamiques d'un element cylindrique immergé en mouvement oscillatoire, Thèse, Université Paul Sabatier, Toulouse 1972.

(6) Rules for the Design, Construction and Inspection at Fixed Offshore Structures, Det Norske Veritas, Oslo 1972

(7) A. Führböter: Eine Bemerkung über den Einfluß des Gischtanteils in der Luft auf die Windbelastung von Seebauten. Heft 40 Mitteilungen des Leichtweiß-Institutes der TU-Braunschweig 1974

(8) L. Bjerrum: Geotechnical problems involved in foundation of structures in the North Sea Geotechnique 23 (1973), Nr. 3, p. 319-358.

(9) St. Knabe, W.-D. Longrée, K. Jungk, Forschungsplattform vor Helgoland mit "Meerestechnik" Bd 5 (1974) Nr. 3

(10) H. Slazmann, St. Knabe, W.-D. Longrée, P. Burmeister, W. Jennrich, U.Meins, J. Vieregge, W. Kirchhoff, H.Victor: Meß-und Erprobungsstation im deutschen Nordseeschelf. Mit "Meerestechnik" Bd 6 (1975) Nr. 5.

(11) H.G. Payer, W.-D. Longrée: Design, Analysis and Construction of the Research Platform "Nordsee". Offshore Technology Conference, Houston Nr. 2168, 1975

(12) Abschlußbericht zum Vorlaufsprogramm zum ingenieurwissenschaftlichen Forschungsprogramm auf der Forschungsplattform Nordsee, März 1976.

(13) G. Witte, T.E. Schellin, P. Relotius: Analyse der Standsicherheit einer Meeresplatform mit Flächengründung. Interocean 1976, Düsseldorf Nr. 10-76-217

(14) W.-D. Longrée, Mr. Kolb, H.G. Payer: Messungen von Eigenschwingungen der Forschungsplattform der Nordsee bei periodischer Anregung, Interocean 1976, Düsseldorf, Nr. 10-76-233.

(15) W.-Dr. Longrée, K. Richter: Auf der Forschungsplattform Nordsee gemessene Umweltdaten während der Sturmflut 3./4. Januar 1976, in Vorbereitung.

Fig. 1 Research Platform NORDSEE in autumn1975

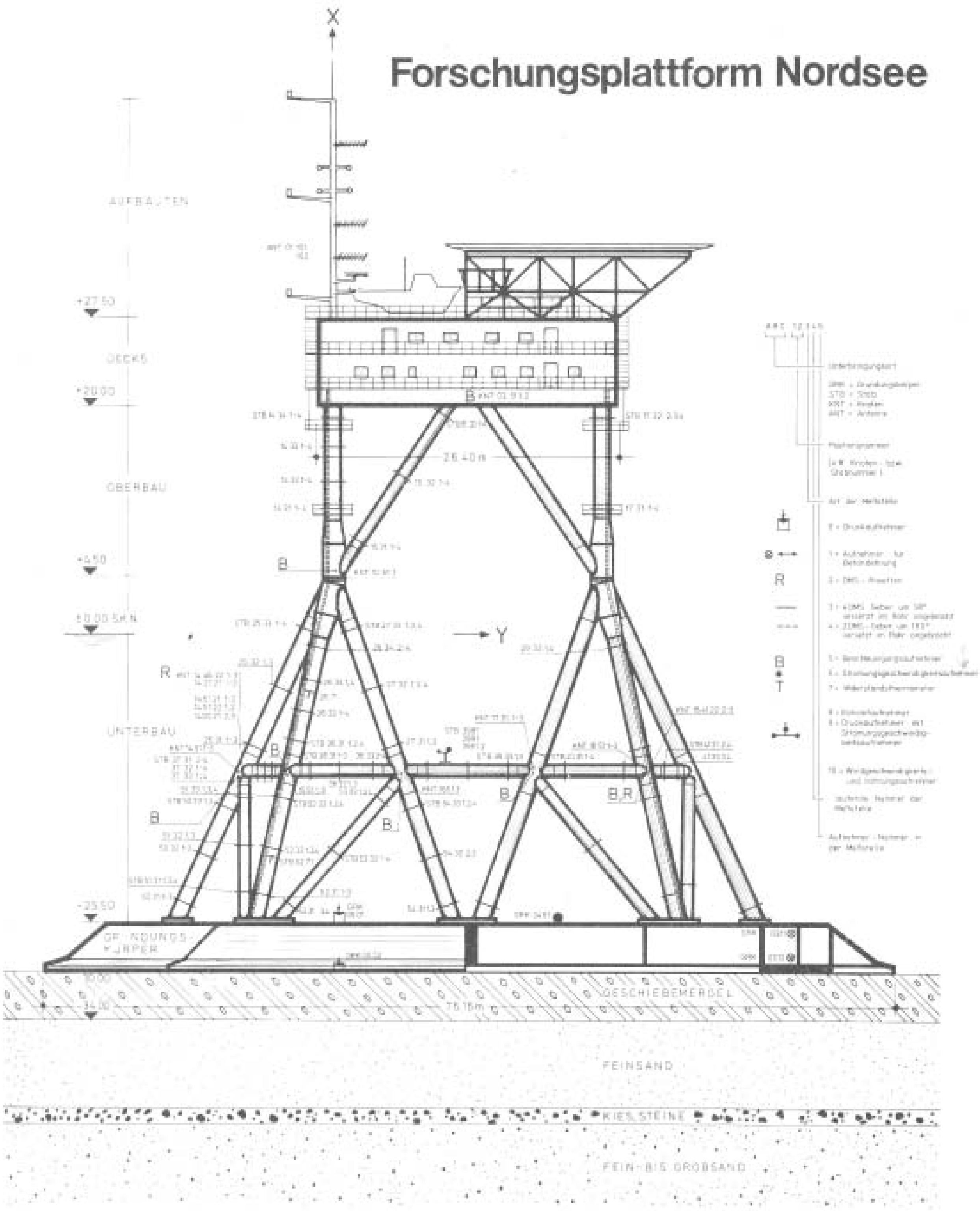

Fig. 2 Instrumentation (view from south)

Explanation of the instrumentation code, (reading from top to bottom)

GRK:		foundation body
STB:		member
KNT:		joint
ANT:		antenna
(12)		position number (member or joint number)
0	:	pressure transducer
1	:	strain gauge for concrete
2	:	strain gauge rosette
3	:	4 strain gauges in member staggered at 90°
4	:	2 strain gauges in member staggered at 180°

5	:	accelerometer
6	:	current meter
7	:	thermo resistance
8	:	echo sound transducer
9	:	pressure transducer with current meter
10	:	wind meter
(4)		number of gauge plane
(5)		number of gauge at the gauge plane

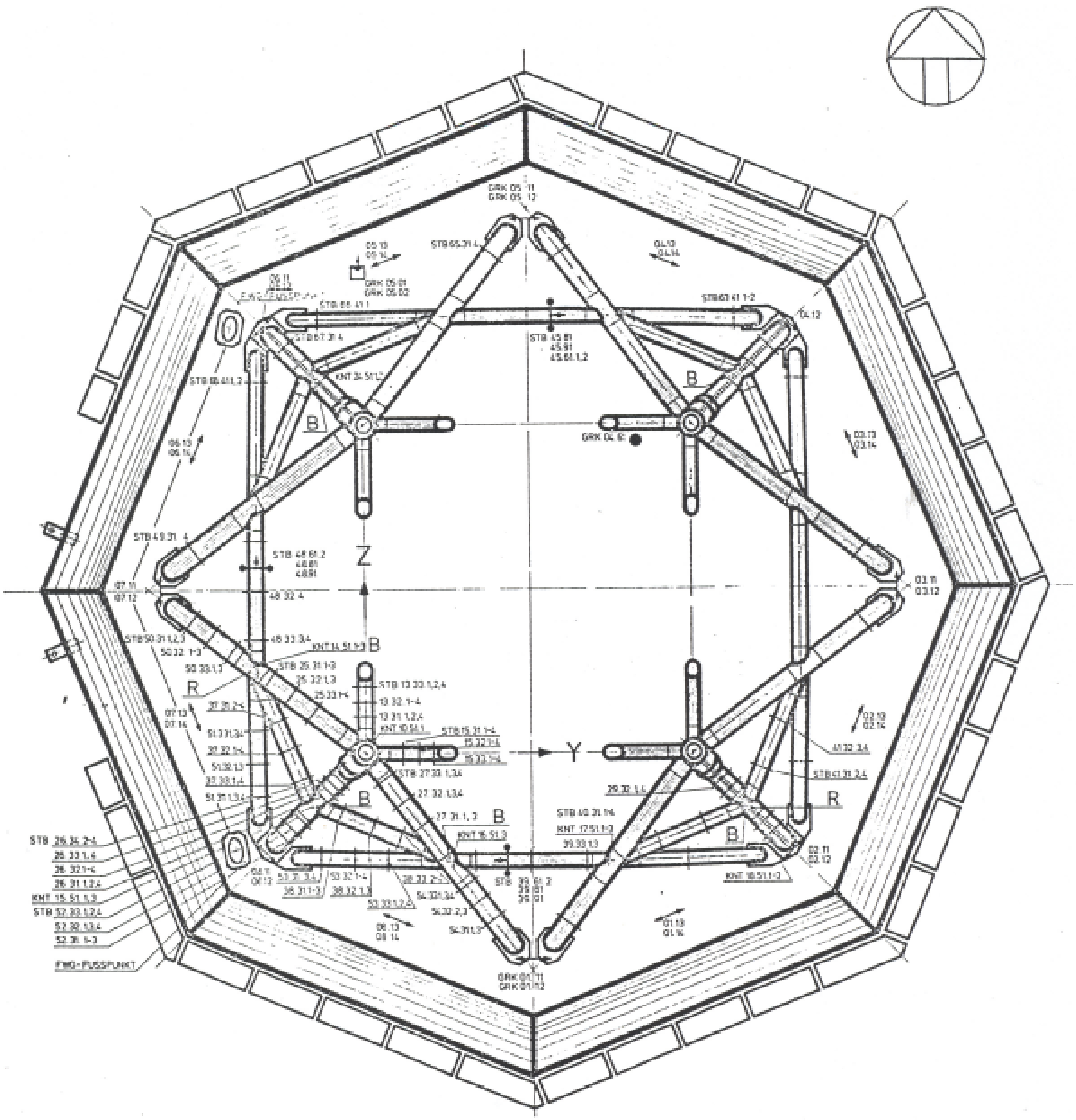

Fig. 3 Instrumentation (horizontal section at 13.5 m)

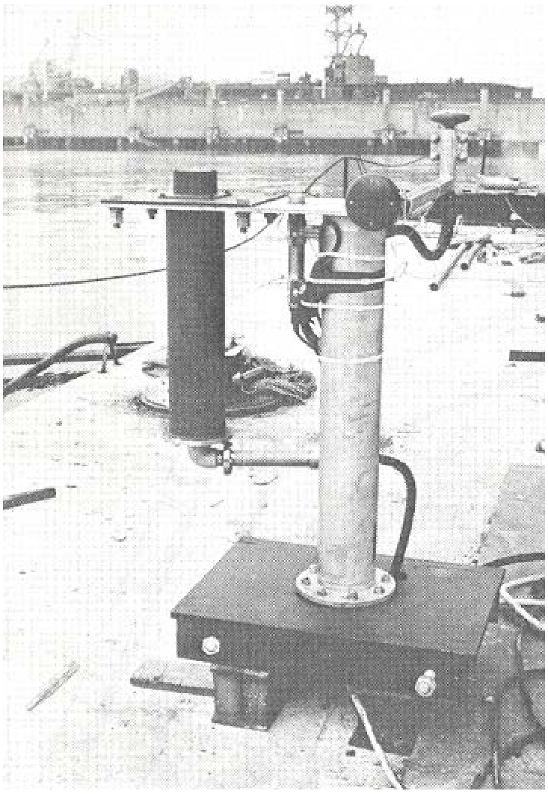

Fig. 4 Wave measuring unit with sonic sensor, pressure transmitter and current meter

Fig. 6 Current meter on the gravity base

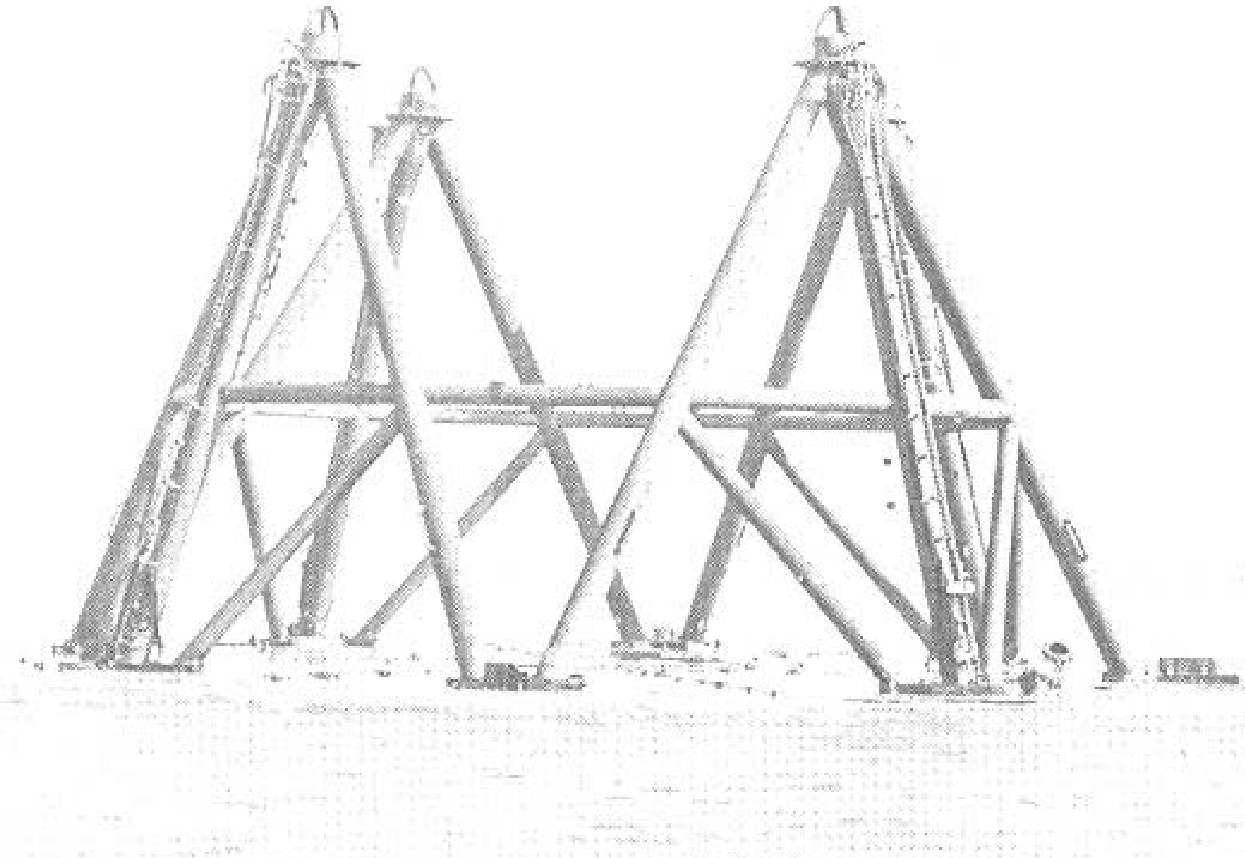

Fig. 5 Substructure of tubular framework and gravity base being towed to position

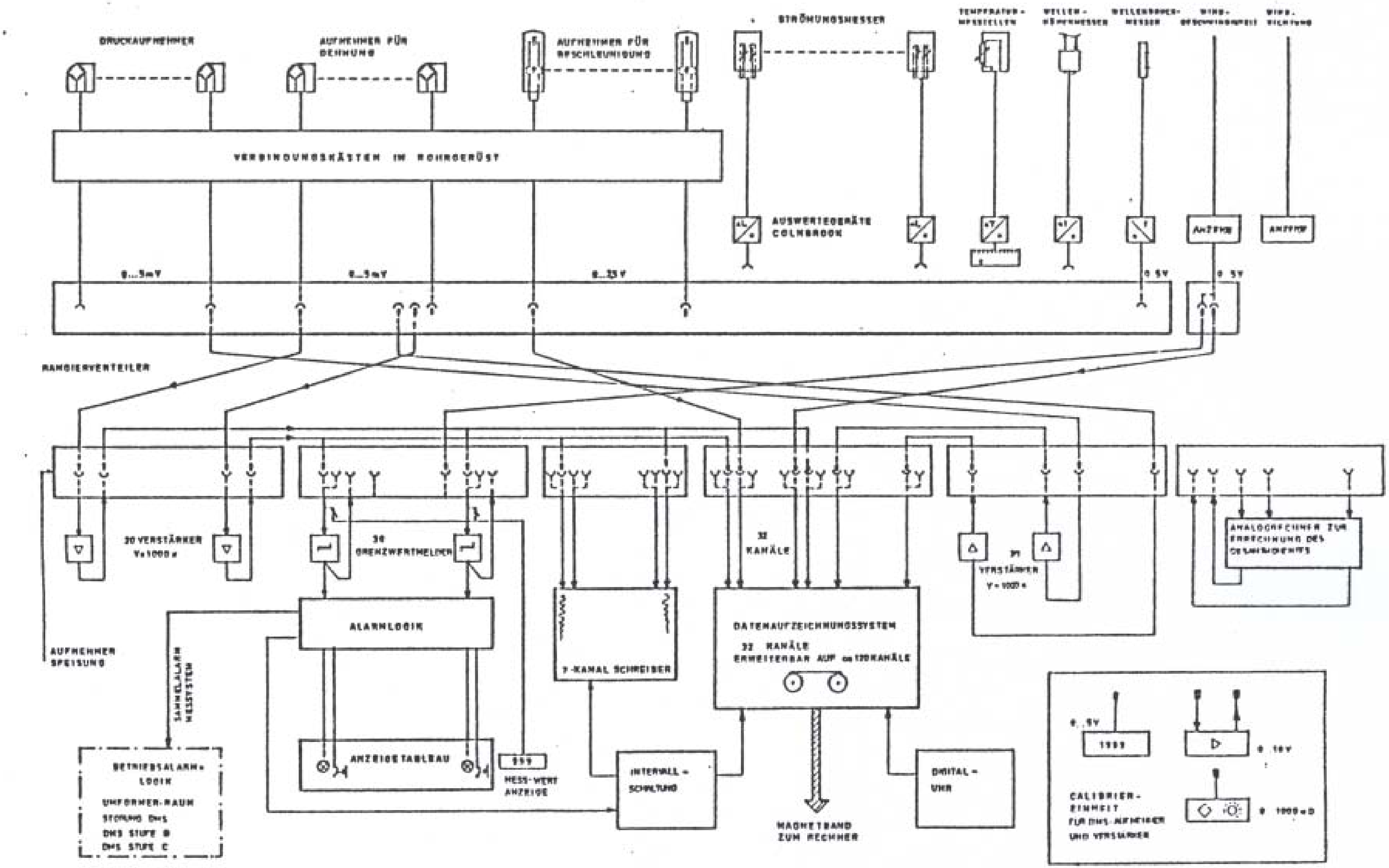

Fig. 7 Layout of the data acquisition system

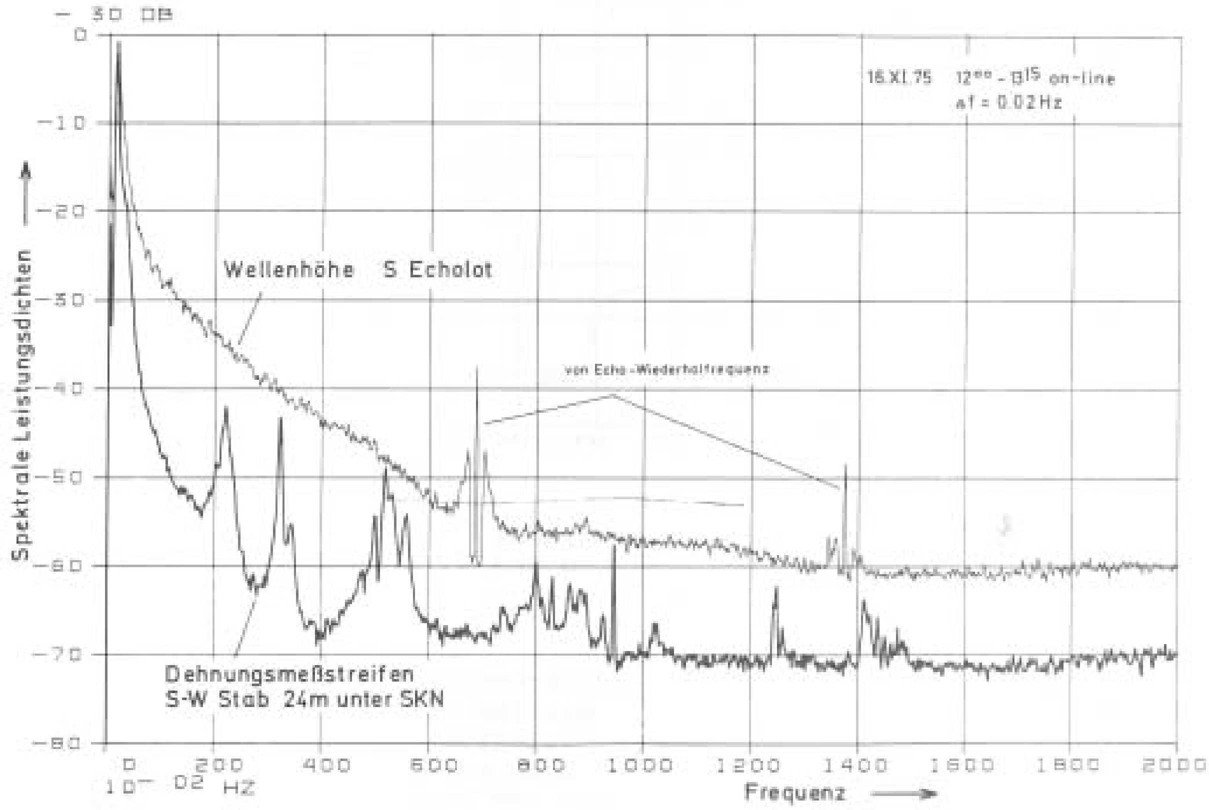

Fig. 8 Example of a strain gauge analysis:
comparison of power densities of wave heights and strains in a tubular member

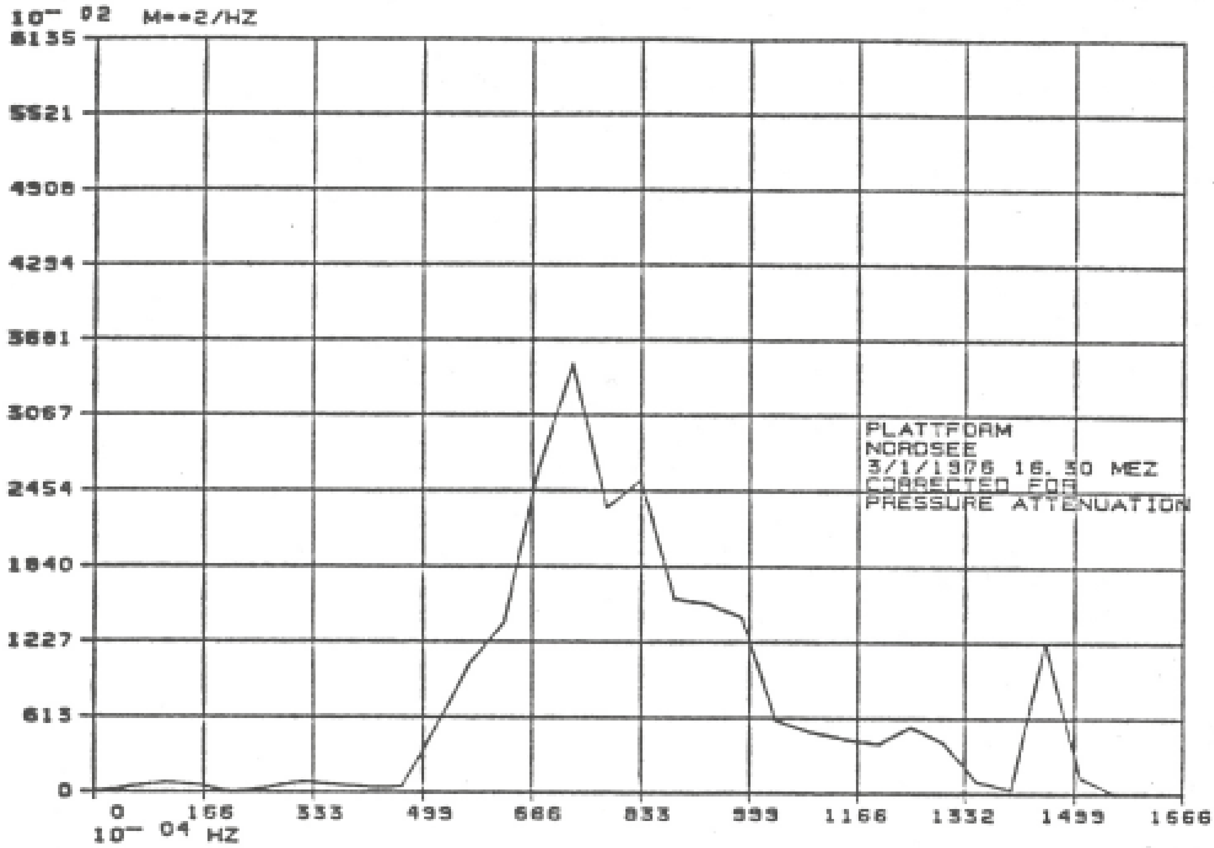

Fig. 9 Example of a wave analysis:
spectraldensity ofthe sea January 3, 1976, 16:30h

	MEASUREMENT	INSTRUMENTATION	RECORDINGFACILITIES
Instrumentation for the measurement of the Environmental conditions	- air pressure	Barometer	1)
	- air temperature	Thermometer	1)
	- humidity	Hygrometer	1)
	- wind velocity	Cup-type anemometer with measuring generator- Type 4011 of Fa. Friedrichs	1) 3) 4)
	- wind direction	Wind indicator with ring potentiometer Type 4111 of Fa. Friedrichs	1) 2)
	- visual range	Light scattered and recorder (AEG)	2)
	- tide level	Pressure measurements of the column of water using the system of streaming air bubbles. Type Omega of Fa. Seba	2)
	- water / steel temperature at –4 and –19 m chart 0 steel temperature taken at +15,5m)	Resistance thermometer PT 100 With digital indication, Type NUR of Fa. CoreciNumecor	1) 4)
	- wave height	a) Sonic method-oscillator Type C of Fa. Fahrenholz b) Pressure sensor:principle of vibrating wire, Modell WS-704 of Fa. Ocea Applied Research	2) 3) 4) 2) 4)
	- Current velocity	Electro-magnetic 2 component sensors Fa. Colnbrook	3) 4)
	- pressure	Pressure sensor BAW with 240 ….strain gauges, full bridged, measuring range 50 mW	3) 4)
Instrumentation for the measurement of the structural behaviour	- Strains in the members of the Tubular structure	Spot welded, uniaxial strain gauge bridges Type HBM 360.01-2001 of Fa. Hottinger	4) 4)
	- Strains at chosen points in the joints	Adhesive strain gauge rosettes Type 1520 Ry 11-Fa. Hottinger	2) 4)
	- Strains in the reinforced concrete foundation body	Strain gauges, principle of vibrating wire, Type MDS 53a of Fa. Maihak, measuring length 250mm	1) 2)
	- Acceleration of deck and joints	Servo-accelerometer - Horizontal direction: Systron Donner system 4310A-1X33 Measuring range +/-1g - Vertical direction: System Endevco QA-116-17, measuring range +/-10g	3) 4)
	Recording facilities	1) Notation 2) integrated recorder or printer	3) separate analog recorder 4) PGM-magnetic tape recorder

Tab. 1. Instrumentation according to method of measurement, type of sensor and recording facilities