MEASUREMENT TECHNIQUES FOR MOORED SHIP DYNAMICS

by

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ABSTRACT

Problems arise during adverse sea conditions with ships moored to the ore loading jetty at Saldanha Bay. Under certain wave conditions moored ships undergo large motions which cause breakage of mooring lines. In order to obtain a quantitative insight into the problem an extensive measurement system was installed at Saldanha Bay. This system comprises instrumentation for the measurement of short and long waves, currents and wind, mooring line and fender forces and the motions of the moored ships. Preliminary results show that during storm conditions long waves with periods between 50 and 150 s occur at the jetty. These periods fall within the same range as the observed natural periods of horizontal oscillation of the moored ships.

1. INTRODUCTION

The increase in the size of tankers and bulk carriers during the last decades has led to a tendency to build cargo-handling jetties for these ships close to deep water in order to reduce the costs of dredging navigation channels. As a result of this development, the mooring locations are, in general, more exposed to wave action. This requires careful design and operation of the mooring equipment to assure the safety of ships and jetty structures and to reduce downtime in loading or unloading of the ships.

A loading jetty has been built in Saldanha Bay, a natural bay on South Africa's west coast, about 150 km north of Cape Town, for the export of iron ore (see Figure 1 and Photograph 1). The main harbour construction, which was completed during 1976, consists of a sand breakwater between Hoedjies Point and Marcus Island, an ore handling plant, a causeway, a jetty and a navigation channel, dredged to a depth of between -23,0 and -23,7 m CD (Chart Datum) in order to allow ships of up to 250 000 dwt to be

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PHOTOGRAPH 1:

General view of ore jetty at Saldanha Bay

PHOTOGRAPH 2:

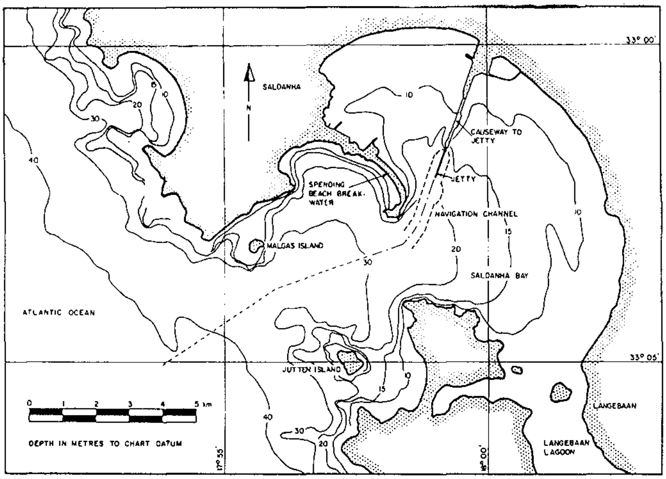
Attachment of strain gauges onto mooring hook (see arrow)

PHOTOGRAPH 3:

Coiled cable connection for fender measurements

PHOTOGRAPH 4:

Digital data acquisition system



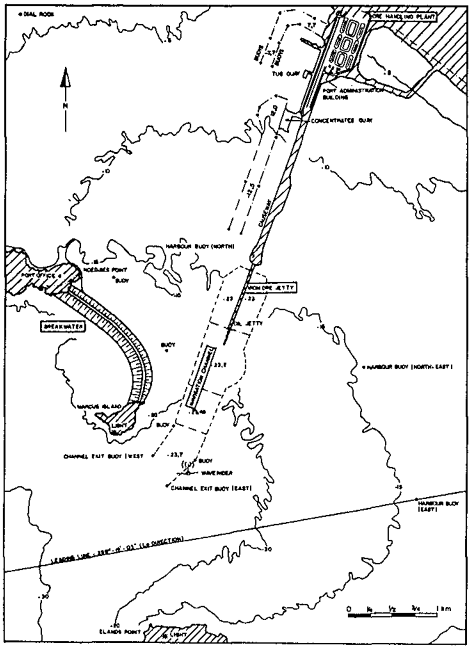


FIGURE 1:

Layout of Saldanha Bay Harbour

FIGURE 2:

Saldanha Bay Harbour Structures

loaded at the jetty (see Figure 2). Since 1977 up to 18 million tons of iron ore have been exported annually.

2. MOORING PROBLEMS

At Saldanha Bay problems have arisen with moored iron ore carriers. Under certain wave conditions, the moored ships undergo large horizontal motions which have, on occasions resulted in the breaking of mooring lines. This in turn has led to interruptions of the loading of iron ore and even necessitated in some isolated instances the removal of ships from the jetty.

The South African Transport Services requested CSIR to assist in investigating these problems and to advise on possible steps to minimize or eliminate their occurrence.

3. STUDY APPROACH

In order to investigate the nature of the problems NRIO initially carried out a feasibility study. This study comprised a literature survey on possible similar problems experienced elsewhere, long-wave measurements at the jetty and discussions with the operational staff at Saldanha Bay on the characteristics of the mooring system, the behaviour of the moored ships and the environmental conditions during the occurrence of problems.

From the literature it was found that similar problems were encountered elsewhere, as reported by Wilson (1954), Keith and Murphy (1970), Bowers (1975) and Nagai et al. (1977). Most problems were caused by the occurrence of relatively long waves with periods between 50 and 150 s, which is in the same range as the natural periods of horizontal oscillation of the moored ships. These long waves may be penetrating into the harbour from the ocean or may be caused by harbour resonance.

During the design of the harbour Wilson was asked to investigate the occurrence of harbour resonance at Saldanha Bay. He concluded (Wilson, 1972) that the natural periods of wave oscillation in the bay would be much larger than the resonance period of the moored ships.

From discussions with the operational staff at Saldanha Bay it appeared that the mooring pattern of the ship is always rather similar, using an average of about 16 mooring lines of various materials and thicknesses (see Figure 3). The jetty consists of a concrete deck supported by caissons and is about 60 per cent open. The jetty is equipped with Yokohama pneumatic fenders with a diameter of 3,3 m and a length of 6,5 or 10,6 m. In almost all cases when problems with moored ships occurred heavy swell was reported. This

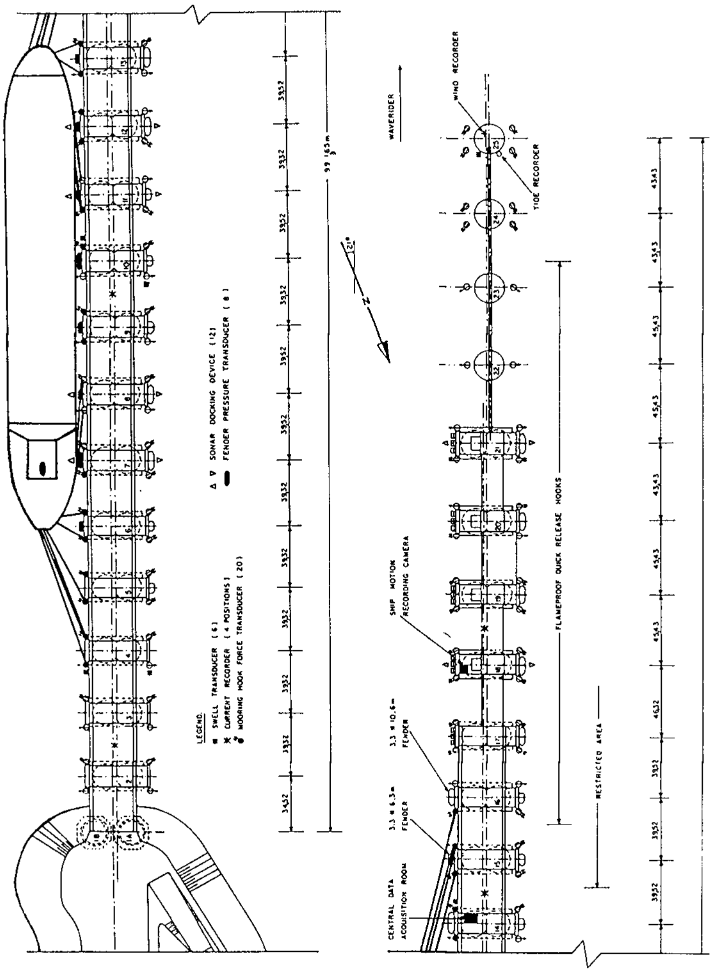


FIGURE 3: Ore jetty, position of instrumentation and typical mooring layout

was determined using a Datawell Waverider, positioned at the entrance of the navigation channel (see Figure 2).

On the basis of this information the first aim of the study was therefore to determine quantitatively the relationship between any low-frequency wave energy and the resulting ship motions and mooring forces. For this purpose an extensive measurement program was undertaken, involving a wide variety of instruments. On the basis of the results of the field measurements preliminary recommendations will be made in order to alleviate the problems. However, physical and mathematical model studies may be necessary to determine the effect of various alternative mooring conditions. These models may be calibrated with prototype data obtained from the field measurements.

4. MEASUREMENT SYSTEM

In order to collect the data required for the investigation, a data-logging system was designed to monitor and record the environmental conditions as well as the motions of the moored ship and of the forces involved. The following were therefore measured:

(a) Long swell at six points along the jetty.

(b) Two components of current from at least one point along the jetty.

(c) Forces in up to 20 mooring lines.

(d) Pressures in eight fenders. The pressure data could be processed to determine forces.

(e) Ship motions.

The above measurements are made only during the presence of a ship in adverse conditions. To obtain general historic data, the following environmental observations are made continuously:

(f) Wind speed.

(g) Wind gust speed.

(h) Wind direction.

(i) Long swell at one point along the jetty.

(j) Waves.

(k) Tides.

For the measurement of the ship motions and of the forces involved it was decided that monitoring the conditions at one of the ore berths would yield sufficient data for the study. The eastern side of the jetty was chosen (see Figure 3), since the largest ships are usually moored at this berth.

5. WAVE MEASUREMENTS

5.1 General

A waverider buoy is anchored at the entrance of the navigation channel (see Figure 2). This buoy can record waves with periods of only between about 1 and 25 s. This is below the range of wave periods expected to be critical for the moored ships, namely, 50 to 150 s. Therefore, long-wave recorders had to be installed to record the waves with periods of between 25 and 150 s.

5.2 Short Waves

To establish a possible relationship between the energies of long and short waves it was decided to use also the waverider data. To facilitate spectral analysis of the data a data logger was installed which sampled the waverider signal at 0,5 s intervals during a period of about 20 min., four times a day. Provision was also made to allow continuous recording during severe ship motions.

5.3 Long Waves

During the feasibility study a pressure recorder was in operation at caisson No 14, east side (see Figure 3) from August 1979 to January 1981, except during the winter months of 1980 when the transducer failed. In order to determine the variation of long-wave energy along and across the jetty it was later decided to deploy six pressure recorders, distributed along the jetty (see Figure 3). To be able to obtain a wave period resolution of between 5 and 500 s the sampling rate of the pressure recorders was set at 2 s while the recording period was about 120 min. The transducers measured the instantaneous water pressures two to five metres below the water surface, where they were fixed onto the caissons by means of stainless steel brackets. One swell recorder (at caisson No 14) was set to record automatically twice a day, while the others could be switched on as required.

5.4 Tides and Very Long Waves

Very long waves with periods of at least 300 s could be determined from the tide recorder installed at caisson No 25 (see Figure 3).

5.5 Wave Correlations

The pressure transducer data were spectrally analysed, and a typical storm sequence is shown in Figures 4a to d.

The spectral analysis is performed for four period ranges, namely, for the wave period ranges 5 to 50 s, 30 to 100 s, 70 to 150 s and 90 to 250 s. Figures 4a to d show that low-frequency energy between 30 and 150 s occurs only during the peak of the storm (Figure 4c). Figures 5a and b show a comparison of characteristic wave heights for the specific wave period ranges. It appears that the low-frequency wave height for both the period ranges 30 to 100 s and 70 to 150 s is about 20 per cent of the wave height in the period range 5 to 50 s.

From visual inspection of the spectral plots such as Figures 4a to d, those plots showing a clear low-frequency energy content, such as in Figure 4c, were selected. These occurrences are related to the observed short-term maximum wave heights H_M at the waverider position, as shown in Figure 6. It can be seen that low-frequency wave energy almost always occurs when the observed wave height H_M at the waverider is larger than 2 m.

6. CURRENT MEASUREMENTS

The most severe motions of the moored ships were reported by the operational staff to be in a horizontal plane, namely, surge, sway and yaw. Therefore, the horizontal water motions are probably a major cause of the problems. These motions can be estimated from the heights and periods of the waves and from the local water depth. In order to provide a check for these estimates as well as to determine a possible existence of cross-currents at the jetty a current meter was installed. Initially only one current meter was used. This could be installed at various positions along the jetty (see Figure 3). In this way possible cross-currents could be measured during various wave conditions, while it was hoped that a correlation with the swell data could be established. A reported strong marine growth at Saldanha Bay prohibited the use of a propeller type current meter, while the large amounts of moving iron ore and steel structures would render an electro-magnetic current meter useless. Therefore, an ultrasonic current meter was used (see Figure 7). The instrument was suspended between two adjacent caissons by means of four stainless steel wires. Because of corrosion problems these were later replaced by polypropylene lines (see Figure 8).

7. WIND MEASUREMENTS

Because wind as well as water motions contribute to ship motions, an Aanderaa anemometer was installed at the top of

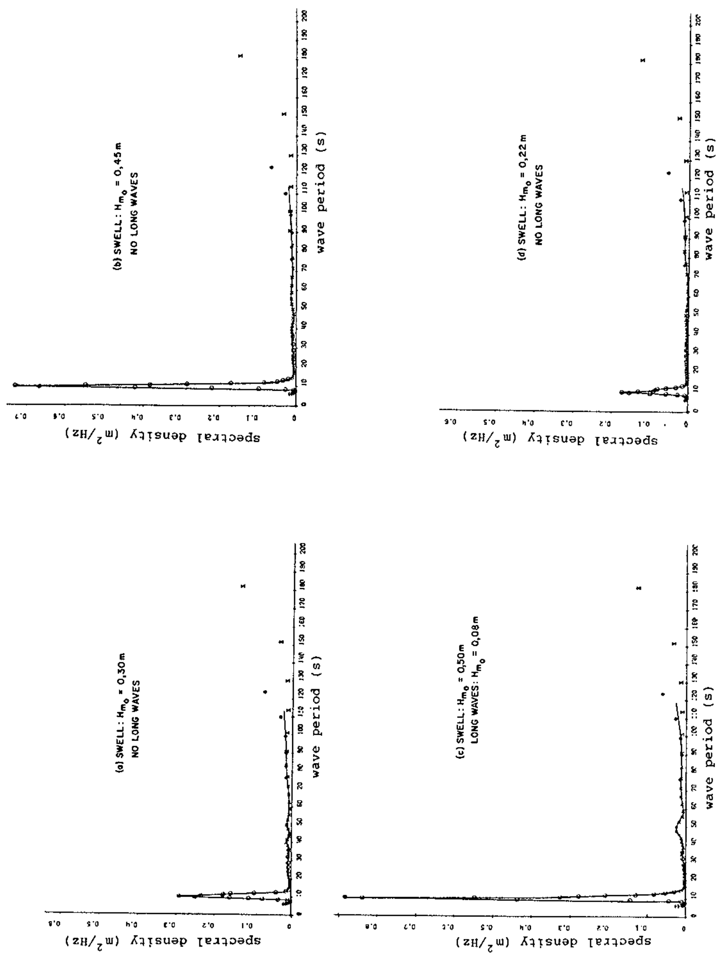


FIGURE 4: Spectral density estimates for a typical storm

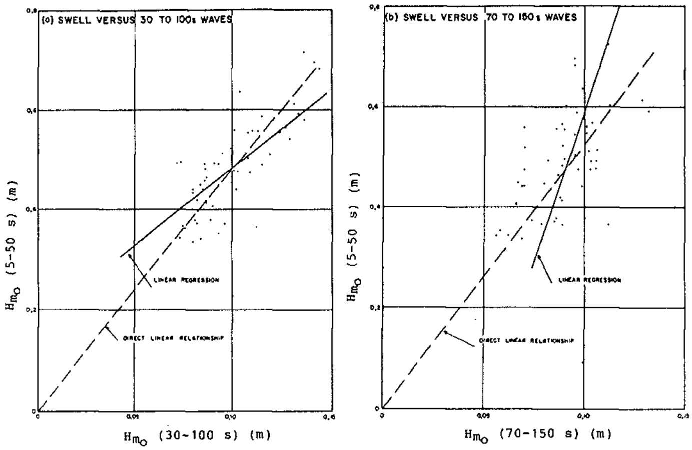


Figure 5: Relationship between characteristic wave heights based on various wave period bands

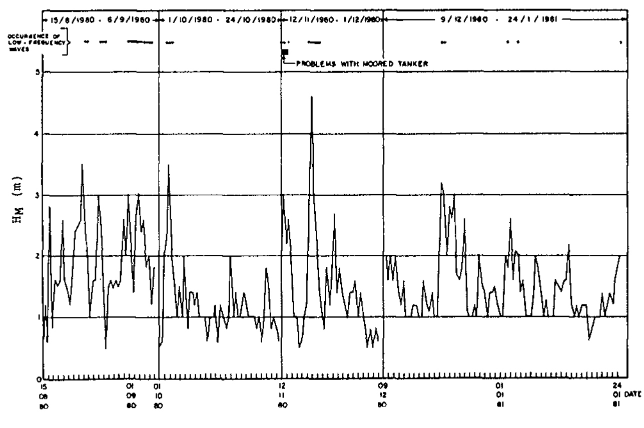


Figure 6: Relationship between short-term maximum wave height H_M and the occurrence of low-frequency waves

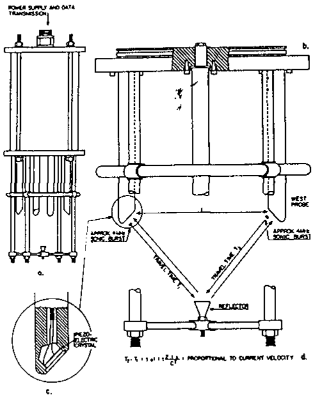


Figure 7: Simrad HC-100 ultrasonic current meter

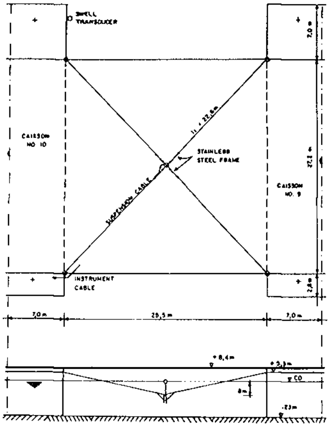


Figure 8: Typical position of current meter

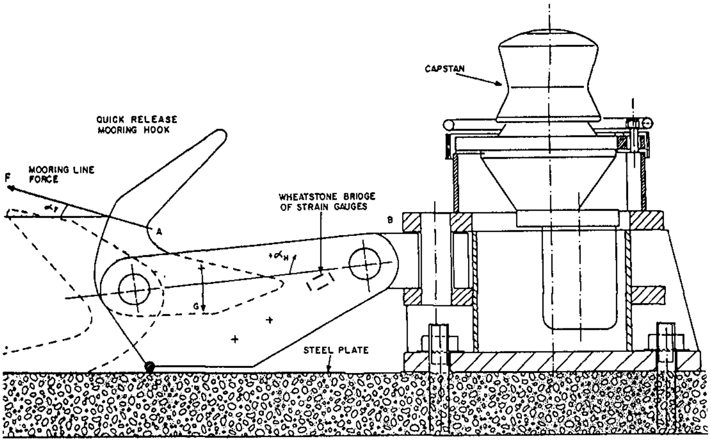


Figure 9: Mooring hook equiped with strain gauges

a light mast at caisson No 25 (see Figure 3). This anemometer monitored continuously wind speed and direction,and every 15 minutes the following data were recorded:

(a) The average wind speed during each 15 min. interval.

(b) The average wind direction during each 15 min. interval.

(c) The maximum wind gust during each 15 min. interval.

8. MOORING LINE FORCE MEASUREMENTS

Forces in the mooring lines can be determined either by monitoring the tensions in the ropes or those in the mooring hooks. Four methods of doing this were considered:

(a) Use of a load cell fitted to the mooring hook and onto which the mooring line could be hooked. The sheer mass of such a device as well as its relative complexity made this impracticable. Its use would also mean the loss of the advantages of the quick-release mechanism of the hook.

(b) Use of a mooring line "forerunner" incorporating a load cell. This offered a technically sound solution but in the given situation would have been difficult to use. The danger of loss of these forerunners, either by their being left attached to the ship's mooring lines or by their falling off the jetty into the water seemed too great to make this method feasible. Further, use of the quick-release mechanism of the hook would almost certainly have resulted in loss of the forerunner. As with method (a) this device would have had to be tested regularly to ensure that mechanical failures did not occur. Further, the long flexible electrical connections would be fairly vulnerable to damage and therefore unreliable.

(c) Monitoring strain in one of the pivot pins of the quick-release mooring hooks, using strain gauges mounted onto these pins. A disadvantage of such a system would have been the complexity of retrofitting such pins in hooks which were in regular use.

(d) Monitoring strain in the mooring hook side plates. This offered a neat solution to the problem, provided that the stability, reproducibility and system inaccuracies were within the required specifications. Also, calculations predicted that the stress in the side plates at the selected point of measurement would have been almost linear with respect to force on the hook (see Figures 9 and 10).

To investigate the feasibility of this method preliminary tests were done on one hook. Strain gauges were fitted to one side plate (see Figure 9) and the hook was taken through a number of load cycles. This test was repeated after three weeks and again after a further two weeks. During these tests the following points were examined:

(a) Reproducibility of observations, both in the short-term and in the long-term.

(b) Temperature stability, particularly with regard to irregular heating of the hook, such as heating up of one side of the hook only by the sun.

(c) Linearity.

The results of these tests showed that the system would meet the required accuracies, namely, that the hooks could be used to monitor forces up to 800 kN (about 80 ton-force) with a resolution and accuracy of 10 kN (about 1 ton-force). Greater inaccuracies would occur at the lower forces but these could be neglected since they were not in the area of interest. At the higher forces the linearity and repeatability improved, giving adequate accuracies.

On the strength of these tests, 20 mooring hooks were instrumented using strain gauges mounted on the side plates of the hooks (see Figure 3 and Photograph 2). The strain gauges are covered with an epoxy-coated aluminium die-cast box which apart from affording protection to the gauges, also houses the local electronics and line drivers.

The hooks are calibrated by means of an hydraulic jack, together with a calibrated load cell, various attachments and spacers. The jack applies a force between the bollard and the curve of the hook (between point A and B as shown in Figure 9). By taking into account the bending moment introduced about the rear pivot axis of the hook, a sufficiently accurate calibration curve was obtained.

9. FENDER FORCE MEASUREMENTS

Since tables are available which give the relationship between pressures in, and forces applied to, the fenders, it seemed that the monitoring of pressure in the fenders would provide the simplest method of determining the forces on the fenders. Tables are also available giving the relationship between fender deflection and force against the fender. Photographic measurements of fender deflection could therefore also be correlated with pressure measurements.

The attachment of the pressure transducer was simple, as a suitable outlet plug was available on the headplate of the fender and required only the insertion of an adaptor and throttle valve. Coupling the transducer to the jetty was a greater problem as the cable had to be flexible enough to allow for the continuous movement of the fender due to wave and swell actions as well as the movement due to tidal variations. The problem was solved by using the coiled flexible cables used between trucks and trailers. Two such lengths joined together provided a sufficient extension to cater for the movements encountered.

The pressure transducer used is a Bell and Howell type with a range of 300 kPa absolute pressure. This provided a range of close to 200 kPa above atmospheric pressure. The fenders are maintained at a pressure of about 75 kPa gauge and the safety release operates at 175 kPa. Eight fenders were equipped with these pressure transducers (see Figure 3 and Photograph 3).

A local pressure transducer amplifier and line driver is mounted on the edge of the jetty in a protective housing. This converts the pressure transducer signal into one suitable for driving down a long line to the recording station. When fenders are being serviced or replaced, it is a relatively simple matter to remove the pressure transducer and the coiled cable from one fender and install it in the replacement fender.

10. SHIP MOTION MEASUREMENTS

10.1 Photographic Technique

Various methods were considered for measuring the motions of the moored ships. This can be done mechanically by attaching an instrument onto the ship, e.g. by a set of lines connected to potentiometers (see Stammers et al., 1977). Another possibility, which was chosen for Saldanha is a remote-sensing method. In this case a camera was installed at a fixed position to take photographs of the ship at 2 s intervals.

A relatively suitahle vantage point for the installation of a camera was found at the top of the chimney at caisson No 18 (see Figure 3). From this position it was possible to determine the most important sway and yaw motions of the ship accurately, as well as the vertical motions of heave, roll and pitch. Only the surge motions could not be determined accurately from this position.

It is necessary to photograph fixed points behind the ship as well as fixed points on the jetty (see Figure 11). Furthermore, the forward mast, bridge and funnel of the ship must be included as target points on the ship. To include all these points for a large ship a lens with a focal length of about 100 mm was required. The large number of photographs to be taken required a camera with a large magazine and an automatic recording system. On the basis of these considerations a Robot Motor Recorder was chosen,

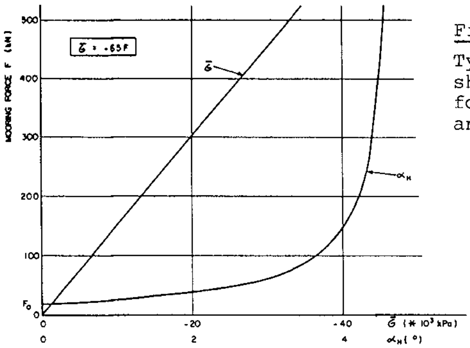


Figure 10: Typical relationship between mooring force F, stress $\bar{\sigma}$ and lift angle α_H

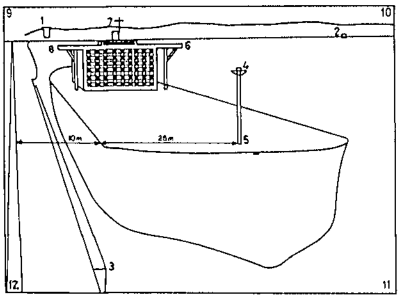


Figure 11: Sketch of photograph of moored ship

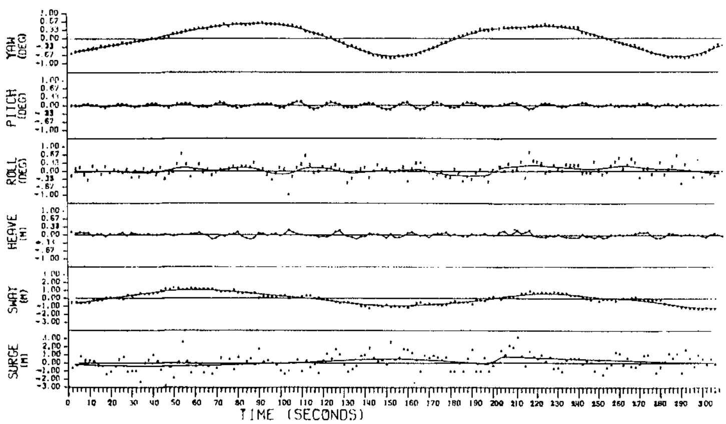


Figure 12: Results of analysis of digital moored ship photographs (run No SM003)

with a lens of 75 mm focal length and a magazine which could contain film for 1 600 frames of 18 by 24 mm.

10.2 Sonar Docking Device

The ore jetty is equipped with an Elac sonar docking device installed by the harbour authority for use by pilots during docking operations. The device makes use of two independent horizontally-looking ultrasonic echo sounders, one for the bow and the other for the stern of the ship. Each system has two transducers mounted in the water on the side of the jetty (see Figure 3). The decision as to which of the two transducers to use, was based on the size of the ship and the position of the ship alongside the jetty.

Measurements of speed of the bow and stern are made as well as of the distance of the bow and stern from the jetty. It was decided that since the device was available, its outputs should be recorded to provide some back-up for and a check on the photographic recording system.

11. DATA ACQUISITION

11.1 Central Data Acquisition System

Most data acquisition is done at the central recording station at caisson No 14 (see Figure 3). This therefore means that all signals have to be transmitted from the various sensors to the recording station. It was decided to use a frequency-modulated system for the transmission of all signals to the recording station and this therefore led to the design of a general-purpose amplifier module to interface the sensors to the cabling system. The module includes an amplifier, voltage-to-frequency convertor and line driver. The amplifier stage can be adjusted to suit the output of the particular sensor, and the voltage-to-frequency convertor is set to suit the range required. Conventional 25-pair telephone cables are installed along the length of the jetty with junction boxes at each caisson. The amplifier modules are installed as close to the sensors as possible and are connected via two-pair telephone cables to the junction boxes on the respective caissons. At the recording station all the frequency modulated signals are fed via phase-locked loops (for filtering and signal conditioning) to the recording system.

The data-acquisition system, DAS (see photograph 4), is an exact copy of the data-acquisition system used in the NRIO coastal engineering model hall (Holroyd, 1980). It is based on the NRIO microcomputer system (Holroyd, 1982) and, in line with the general approach of the Institute, uses digital cassettes as the storage medium. The DAS is split between the continuous monitoring section and the section which operates only when ship monitoring is being done.

The continuous monitor is permanently on power and automatically logs data from the wind sensors and the swell sensor at caisson No. 14. Wind data include the average wind speed, the average wind direction and the highest gust speed for each 15-minute interval. These data are accumulated in the computer's memory over a 12-hour period and are written onto the cassette at 06h00 and 18h00 as a complete data file covering the past 12 hours. At noon and midnight swell data files are recorded for a two-hour period with a two-second sampling interval.

The ship monitoring section of the DAS includes the central control unit, with keyboard and VDU, and five data logging units all connected to and controlled from the central control unit. The central control unit is used to initiate a monitoring run, insert header information, such as the ship's name, and generally acts as a communication link for commands to and prompts from the data-logging units. It was decided to use five data logger units because of the volume of data being collected during a monitoring run. This has the added advantage that the data from each group of sensors are stored on a different cassette, therefore simplifying the subsequent sorting of the data during the analysis stage. All inputs are synchronously sampled at two second intervals and a direct measurement is made of the frequency from the sensor amplifiers.

All data are stored onto digital cassettes in a properly file organised format with headers giving real-time, the type of data, the data format as well as information entered by the operator during initialization. The data are allocated to the logging units as follows:

- Unit 1 - sonar docking device, bow and stern, speed and distance from jetty
- Unit 2 - six long swell sensors
- Unit 3 - X and Y current speed from Simrad HC100 current meter
- Unit 4 - eight fender force sensors plus six mooring hook force sensors
- Unit 5 - fourteen mooring hook force sensors.

The DAS includes a cassette reader and a printer which permits **in situ** checking of the system's performance. Another important built-in maintenance aid permits the display of the sensor line frequencies on the VDU, simplifying checks on sensor performance and calibration.

11.2 Other Data

It was not feasible to store all recorded data at the central data-acquisition system on Memodyne cassettes. The waverider data logger is already an automatic recording system with an accurate time base. Besides graphical recording of the wave history, the signal is sampled every 0,5 s and the values written onto Memodyne cassette four times a day, namely, at 00h00, 06h00, 12h00 and 18h00 GMT. These tapes are spectrally analysed at NRIO using a standard FFT program.

The data from the tide recorder are recorded only graphically. However, any long period oscillations can be easily noticed. Also the actual water levels during the presence of a ship can be read off directly. Both the waverider data logger and the tide recorder are installed at the Port Administration Building (see Figure 2), where they are also used to provide normal harbour operational data.

12. DATA PROCESSING AND ANALYSES

12.1 Digital Data

The in-house data processing system has extensive facilities for reading cassette tapes. Quick look and edit programs are available for checking the data on cassettes, scaling the data according to the calibration values for each sensor and transferring the data onto nine-track magnetic tapes in a standard ASCII-coded file format.

These data are then read from the tape and stored on high-density archive tape at the CDC Cyber 170/750 computer at the Centre for Computing Services of the CSIR. The data from each channel will be spectrally analysed using programs based on the autocovariance method. Directly related spectra can be analysed further using cross-correlation techniques, while also time-history plots of the various signals may show any correlation by visual inspection.

12.2 Photographic Data

12.2.1 Digitizing technique

After the films of the moored ship have been developed, the negatives are projected onto a digitizing tablet where the coordinates of three fixed shore points, of five points on the ship and of the corners of the frame are determined and stored on cassette tape.

The coordinates of the fixed shore points (1 to 3 in Figure 11) relative to those of the corner points of the frame (9 to 12) are used to compute the orientation of the camera and a coordinate system with its origin at the camera position is defined. Also the fixed points 1 to 3 are used to compute the scale of the projection. The projected height of the forward mast (from points 4 and 5) relative to the real height is used to compute the instantaneous distance of the ship relative to the camera, which yields the surge motion of the ship after projecting the distance to the camera to a horizontal plane. The top of the forward mast (point 4), the bridge tip (either point 6 or 8) and the top of the funnel or radar mast (point 7) are used to compute the motions of the ship relative to the camera-based coordinate system. After this system has been transformed to a horizontal coordinate system the instantaneous motions of sway, heave, roll, pitch and yaw can be determined.

The process of digitising is controlled by a Tektronix 4051 desk top calculator. After the digitizing is completed the data files on tapes are transfered to disc storage at NRIO's in-house HP 21 ME minicomputer and from there transformed into ASCII code and written onto nine-track magnetic tape. From here the data are treated in the same way as the digital data described in Section 12.1 are.

12.2.2 Analysis program and ship motion results

A computer analysis program has been developed to compute the motions of the ship in six degrees of freedom, using the coordinates determined with the digitizing tablet. A typical raw result of this analysis is shown in Figure 12. It can be seen that the surge motion has the largest scatter, while sway and yaw show a very smooth variation with periods of about 100 s and almost in phase. Heave and pitch show oscillations with periods of about 16 s, which is slightly above the dominant swell period of about 14 s.

13. PROBLEMS

A number of problems were encountered during the installation period and some are still present. As already mentioned in Section 6 it was known that very active marine growth occurs at Saldanha Bay, especially barnacles, red bait and black mussels. These animals grow so rapidly that they can choke the aperture of pressure gauges. Although copper gauze was used to protect apertures, this toxic metal proved to be ineffective and regular mechanical cleaning by divers has to be performed to keep the instruments functioning.

Another problem is strong corrosion of the metals in the sea water. Initially, copper was used in order to control the marine growth at the instruments. Stainless steel was also used because copper is not a very strong and elastic material. Therefore, initially stainless steel Hilti bolts were used to fasten clamps, brackets and instruments under water. Some instruments were made of stainless steel, such as the Simrad current meter. However, serious galvanic corrosion occurred between copper and stainless steel, as well as mutually between stainless steel when parts of the surface became active due to lack of oxygen. Even the application of zinc anodes did not prevent galvanic corrosion.

The system of sensors along the jetty requires many long lengths of cables which carry signals to the main telephone cables or directly to the recording station. Many of these cables are in fairly vulnerable positions and can easily be damaged during normal mooring operations. Even though cable damage is less than expected, it is still necessary to inspect cables regularly for wear or damage.

Iron ore dust is everywhere and is hostile to electronic circuitry. Keeping the electronic units such as the remote amplifiers clean during installation, repair or calibration is not easy. This task is often made more difficult by unfavourable weather conditions. On some occasions the presence of strong winds, swell and sea spray make repair work impossible.

The scatter of the surge motion results is very large. Attention should be given to determining surge more accurately.

14. CONCLUSIONS

On the basis of the results obtained so far it can be concluded that the various instruments are effective in yielding the required quantitative data for the moored ship investigations. The strain-gauged mooring hooks do not show a significant drift during short periods of measurements; regular recalibration checks are, however, necessary. The flexible coiled cable has also proved to be an adequate connection between the continuously moving fenders and the caissons.

The most important motions of the moored ship, namely, sway and yaw which form the most serious problem, are effectively and accurately determined by using the Robot Motor Recorder and computer analysis system. The central data acquisition system, particularly is very useful in recording the monitored data on a mutual time base.

Preliminary results of the analysis of long-wave data and ship motion data show that wave energy is present at periods between 50 and 150 s, while natural periods of horizontal oscillations of moored ships have been shown to be in this same range. It is expected that further correlation of environmental and ship dynamics data will permit the determination of firm relationships between cause and effect of the moored ship problems, when a sufficient number of problem cases have been monitored.

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REFERENCES

BOWERS, E C (1975). Long period oscillations of moored ships subjected to short wave seas. The Royal Institution of Naval Architects, Transactions, Paper W4.

HOLROYD, S G (1980). Coastal engineering model hall data-acquisition system. CSIR Research Report 383.

HOLROYD, S G (1982). NRIO microcomputer system. CSIR Technical Report T/SEA 8134.

KEITH, J M and MURPHY, E J (1970). Harbor study for San Nicolas Bay, Peru. Journal of the Waterways and Harbors Division, ASCE, Vol 96, No WW2.

NAGAI, S, ODA, K AND LEE, T T (1977). Impact forces, mooring forces and motions of super-tankers at offshore terminals subjected to wave actions. Proc. 24th Congress of PIANC, Leningrad.

STAMMERS, A J, BROCKBANK, R AND WENNINK, C J (1977). Investigation of vessel mooring subject to wave action. The Dock and Harbour Authority, Vol 57, No 677.

WILSON, B W (1954). The mechanism of seiches in Table Bay Harbour, Cape Town. Proc. 4th Conference on Coastal Engineering, Chicago.

WILSON, B W (1972). Sishen-Saldanha Project. Iron ore loading terminal, Saldanha Bay, oceanographic engineering evaluation. Pasadena.