to produce. All that is required is a single unit incorporating a white, a red and a green all round light—the white light could double as a Morse light. This unit should be placed where it could best be seen, and direct light screened from the bridge. A control box should be fitted in the wheelhouse, and at any other steering positions. The only switches required on this box would be an on–off switch for each colour, and a bright–dim switch to control the intensity. An automatic off-switch to operate when opposite helm is applied would be a desirable, but not an essential, refinement; as would warning lights.

I agree with Lindsay on the usefulness of rapid flashes on a directional light as an alternative to the short and rapid blasts on the whistle authorized by Rule 28 (b), and as he states, this is being used at sea today.

Finally, on an indirectly related topic, it would be interesting to know whether, with the introduction of bridge control of main engines, ships do now slacken speed in accordance with Rule 23 as an alternative to altering course.

REFERENCES

[1] Wepster, A. (1966). Visual direction indication for ships. This *Journal*, **19**, 265.
[2] Parmiter, G. V. (1966). Visual indication of direction for ships. This *Journal*, **19**, 394.
[3] Potts, J. J. (1967). Visual direction indication for ships. This *Journal*, **20**, 105.
[4] Lindsay, D. J. (1967). Improvement of navigation lights and signals. This *Journal*, **20**, 249.

The Effect of Surveying Techniques on Underkeel Clearance

Lt-Cmdr. C. G. McQ. Weeks, R.N.(Ret.)

1. Introduction. In the paper which he read on 19 April 1967, Captain Dickson[1] described in some detail the investigations which have been carried out to determine the underkeel clearance which should be allowed in any given circumstance. These investigations have concentrated on the vertical movement of a tanker under different conditions, particularly in determining squat and the effect of wave motion. However, another factor in the underkeel clearance equation is the charted depth and this also is affected by ship movement, in this case the movement of the surveying vessel which obtained the soundings. In the following note the probable effect of this movement is discussed and suggestions made by which the effect might be reduced.

2. Sounding swell factor. Fig. 1 illustrates the kind of echo trace that might be obtained by a surveying motor boat over a perfectly flat bottom in a 2- or 3-ft. sea. The apparent variation in depth is caused partly by rolling and partly by vertical movement of the boat, but in either case the mean depth will be the true value, and this is the value normally inked in. Where a shoal is concerned, however, the risk cannot be ignored that the shallowest sounding was caused not by the sea but by the peak of the shoal, and in this case the least depth indicated is invariably selected.

In Fig. 2 is shown the trace that might be obtained over the same flat bottom when the short sea is replaced by a long swell on which the boat has risen and fallen vertically. There are two points to note here; first, that the trace is indistinguishable from that caused by a sand wave—a recognized geological phenomenon—and, second, that if a sea is superimposed on the swell, as it frequently is, it is difficult for the surveyor to appreciate that he is being so affected, nor could he do much about it if he did.

Fig. 1

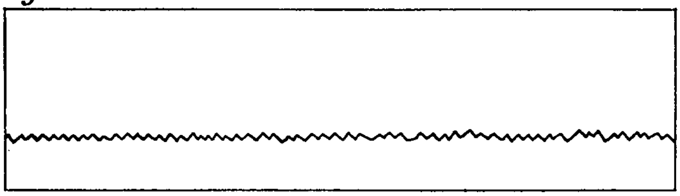


Fig. 2

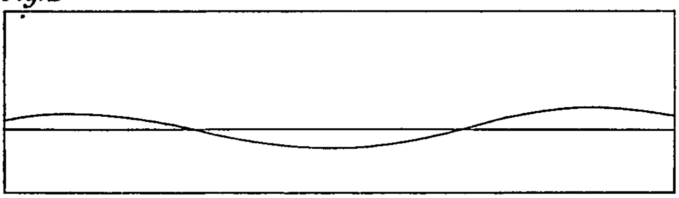
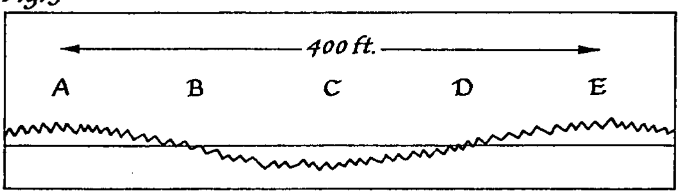


Fig. 3



	A	B	C	D	E	
i)	*27*	*30*	*32*	*30*	*27*	*Soundings selected from echo trace*
ii)	*23*	*26*	*28*	*26*	*23*	*Reduced soundings on fair chart*
iii)	*23*				*23*	*Soundings selected for published chart*

An example of both effects combined is shown in Fig. 3, with below it the soundings selected from the trace, those on the fair chart and those that would probably be selected for the published chart. In this example it is assumed that a 2-ft. sea is superimposed on a 4-ft. swell of 400-ft. wavelength, that the height of the tide is 3·5 ft., and that the sea-level is 30 ft. above the flat sea-bed. The survey is taken to be on a scale of 1/12,000 so that 1 in. on the paper represents 1000 ft. on the ground and consecutive soundings are about 100 ft. apart.

At *B* and *D* there is no effect from the swell and the mean value of the sea would be selected visually to give a depth of 30 ft., while at *C* the bottom would be apparently deeper and a mean depth of 32 ft. would be selected. At *A* and *E*, however, the least depth over the apparent shoals would be taken, thus combining the effects of sea and swell to give a depth of 27 ft. Before inking these soundings the height of tide would be subtracted. In applying tidal reductions the principle is followed that a sounding should never be increased by more than a quarter of the unit involved; so that if the tide is 3·2 ft., 3 ft. are subtracted, while if it is 3·3 ft., 4 ft are taken. In this case then, with 3·5 ft. of tide, 4 ft. are subtracted to give the reduced soundings shown in line (ii). It will be seen that the depths at *A* and *E* are each 3½ ft. less than the true depth of 26½ ft.

The published chart shows only a small proportion of the soundings on the fair sheet and selection is a skilled task. The general rule, however, is that the shoalest soundings are selected first, to which are added such other soundings as best show the general nature of the bottom. Thus in the example there is little doubt that the 23 at *A* or *E* would be selected, possibly both, but it is unlikely that space would permit the inclusion of *B*, *C* or *D*. The charted depth is thus 3½ ft. shoaler than the true depth as a result of sea conditions which are by no means extreme. This effect might be termed Sounding Swell Factor; for brevity it will be referred to in this paper, which is only concerned with soundings, as Swell Factor. It is inevitable as long as soundings are taken from vessels which rise and fall on the sea surface and it should be considered when analysing underkeel clearance. On the other hand, it would be an imprudent mariner who assumed that it was always present; it may have been a calm day when the area was sounded. In any event, the sea-bed is not the flat plane postulated hitherto, and the peak of a shoal is as likely to be under *C* as under *A* or *E*.

3. The effect of swell factor on particular areas. In his paper, Captain Dickson referred to three different types of area in which underkeel clearance is of particular interest to tanker operators; river approaches, such as the Bonny River, over which a heavy swell normally runs, dredged approaches to European ports such as London and Europoort, and the North Sea. Swell factor affects the charted depths of each of these areas but in different respects and it is best to consider them separately.

4. Areas subject to heavy swell. If the swell in an area is continual it may be presumed that a large proportion of the charted soundings will contain a swell factor of some feet, depending on the size of the swell. If it could be assumed that all soundings included this factor there would be no problem, but unfortunately this cannot safely be done. The most promising line of approach would appear to be that described by Captain Dickson in connection with the Bonny River and the approaches to Durban, in which soundings are obtained by the tankers using the port. These are affected by swell to a considerably smaller degree than conventional sounding craft and the provision of motion recorders suggests that even the residual swell effects might be removed. If each tanker on entering and leaving were to run a line of soundings it would be possible in time to compile a chart from which swell factor had been eliminated. This in turn might permit tankers to enter and leave drawing several feet more than they do at present.

5. Dredged approaches to European ports. A typical example which has already been quoted is London, where the Port Authority guarantees a depth of 48 ft. at High Water Neaps through the shifting channels of the outer Thames Estuary. There is normally sufficient sea disturbance here to affect the small craft which survey these waters and a swell factor undoubtedly exists. Its size

cannot be measured but a realistic estimate would be of the order of 2 ft. If this is the case, the channels must be dredged to 50 ft. to give a charted depth of 48 ft. (all depths in this section are below High Water Neaps). However, in the Thames Estuary swell conditions are not continuous; periods of calm do occur. If sounding is restricted to these periods and if rigorous tidal corrections are applied it is possible to carry out a precise survey of the critical areas in which the standard error is greatly reduced and the charted depth is probably less than 6 in. above the true depth. Such surveys are now being carried out.

The probable result of this increased accuracy is twofold; an immediate decrease in the dredging bill since the dredgers need only go down to 48 ft. 6 in., and, following on from this, the discovery that ships can no longer carry the draughts that they used to. It must be remembered that in the last resort the draught that can get into a port is decided by the Master and the pilot. If they find that their ship is 'smelling the bottom' in a channel where previously they had had no trouble, they will, quite rightly, insist on a lesser draught next time. Thus the effect of precision sounding might well be the opposite of what had been hoped for.

6. The North Sea. The most interesting problem is undoubtedly that presented by the third area, the North Sea. If future tankers are to be taken through at their maximum draught then their routes must be covered by precision surveys. However, in the past precision surveys have only been attempted in sheltered waters and before demanding such surveys it is worth considering whether, and under what conditions, they are obtainable.

There are three principal depth requirements for a precision survey: a correctly adjusted echo sounder designed with a discrimination of 3 in. or better, exact knowledge of tidal conditions and a flat sea surface. It is fortunate that the first of these may be disregarded since the two latter provide difficulties enough. Exact knowledge of the tides may only be obtained from readings of a tidal pole or gauge in the immediate vicinity of the area of sounding, and with present instruments the required accuracy can only be achieved if the gauge is attached to a solid structure. Until very recently this has not been possible in the North Sea and co-tidal charts have perforce been based on estimation rather than observation. However, offshore oil drilling has offered an opportunity to make good this deficiency and 30-day observations are obtained on each new rig whenever possible. Thus future co-tidal charts may be expected to be more accurate than the existing ones.

Were the rigs permanent and were they evenly distributed across the North Sea the problem might be considered to be solved, but unfortunately they are neither. The observations so far obtained have enabled tidal constants to be computed for a number of offshore positions and hence the correction of the co-tidal chart, but this alone is insufficient for precision soundings. The North Sea is vulnerable to meteorological disturbances and the actual level at any time may be 2 or more feet higher or lower than that predicted. This can only be corrected if actual tide readings in the area are available.

However, the same problem applies to those using the chart as to those making it, and if tankers are to be brought in close to the bottom it is essential that they also should be informed of actual tide conditions at the time. It would appear, therefore, that the logical solution is for the tanker operators to erect suitable structures in the vicinity of critical areas to which distant reading tide gauges could be attached. These structures could also carry navigational aids, both visual and electronic, but it is essential that they be in position before the hydrographic survey is carried out so that exact tide reductions are available to the surveyor.

The other requirement was for a flat sea surface; this is of course but rarely available and it is inevitable that a majority of charted depths will contain a swell factor, of unknown dimensions. There appears at the moment to be no modification of surveying method which would safely eliminate this factor and again it is suggested that the solution lies in the hands of the tanker operators. Once the routes have been covered by modern surveys based on accurate tidal information, the charts will show the least depths that might be expected. If then every tanker using these routes were to obtain accurate soundings corrected for both swell and tide, in time a picture would be compiled which would show what liberties might safely be taken with the charted depths.

7. Observed swell values. The results of analysis of the records of wave recorders have been published for a number of stations and it may be helpful to summarize some of the results here. During a five-month period in 1958 at Sekondi, Ghana, it was found (Draper, 1966)[2] that the significant wave height (the mean height of the highest one-third of the waves) exceeded 3 ft. for 70 per cent of the time and that the average period was about 11 sec. The relationship

$$\text{wavelength in feet} = 5{\cdot}12 \times (\text{period in seconds})^2$$

thus gives an average wavelength of 620 ft. Off Land's End a shipborne wave recorder on the Seven Stones light-vessel has shown (Draper & Fricker, 1965)[3] that the significant wave height is greater than 4 ft. for 70 per cent of the time in spring and autumn and 58 per cent of the time in summer. The average period of about 8 sec. is equivalent to a wavelength of about 330 ft. In the shallower waters of the North Sea the period is shorter. On Smiths Knoll light-vessel (Darbyshire, 1960)[4] the average period was about 5 sec., giving a wavelength of about 130 ft. The maximum wave height exceeded 3 ft. about 65 per cent of the time.

8. Summary. In the foregoing paragraphs attention has been called to a phenomenon which has been called, for want of a better name, Sounding Swell Factor. This factor is principally caused by the vertical movement of the surveying vessel and has the effect of introducing a negative systematic error to the majority of charted soundings. There is at the present time no means by which the surveyor can safely eliminate this factor and it is suggested that the tanker operators, who have most to gain from its removal, should use the relatively stable platforms provided by their vessels to compile more accurate charts of the critical areas.

Finally, a warning. The size of the swell factor will vary from chart to chart and it would therefore be unwise to assume that an allowance for underkeel clearance which had been proved safe in one situation would necessarily be safe in another.

9. Acknowledgments. The author wishes to thank his late colleagues in the Hydrographic Department and Mr. L. Draper of the National Institute of Oceanography for their advice and assistance in preparing this paper.

REFERENCES

1 Dickson, Captain A. F. (1967). Underkeel clearance, This *Journal*, **20**, 363.

[2] Draper, L. (1966). Waves at Sekondi, Ghana, *Proc. 10th Conf. Coast Eng.*

[3] Draper, L. and Fricker, H. S. (1965). Waves off Land's End. This *Journal*, **18**, 2.

[4] Darbyshire, Mollie (1960). Waves in the North Sea, *Dock & Harbour Authority*, Nov. 1960.

'Underkeel Clearance'

from J. A. Ewing

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I WOULD like to comment on the change in underkeel clearance due to the motion of a ship in a seaway (A. F. Dickson, this *Journal*, **20**, 363).

Captain Dickson, in his conclusions, states that known techniques do not allow underkeel clearance to be calculated when ship motion is present. In fact there are a number of reliable ways of calculating the motions of a ship in waves (for example References (1) and (2), which treat the case of pitch and heave) which may help in this problem. These methods usually assume the ship is in deep water and is heading directly into the waves which are further assumed to be long-crested; but I believe it may also be possible to make reliable calculations for shallow-water effects and for waves which are, in reality, short-crested.

A knowledge of the directional spectrum of sea waves is needed for precise calculations of ship motions but this is not known in many situations. Useful results can, however, be obtained when only the wave height, period and direction are known either from wave measurements or from visual observations (for example Reference (3)).

There have been attempts to correlate model results and theoretical calculations with full-scale ship measurements and References (4) and (5) show the extent to which this has been achieved. Once a theoretical calculation method has been tested against results from full-scale measurements and is considered reliable then it is very much cheaper and faster to investigate a wide range of ship forms and sea conditions than would be possible from model test work or from the statistics of full-scale measurements.

REFERENCES

[1] Korvin-Kroukovsky, B. V. and Jacobs, W. R. (1957). Pitching and heaving motions of a ship in regular waves, *Trans. SNAME.*

[2] Grim, O. (1960). A method for a more precise computation of heaving and pitching motions in smooth water and in waves, *Third Symposium on Naval Hydrodynamics.*

[3] Ewing, J. A. and Goodrich, G. J. (1967). The influence on ship motions of different wave spectra and of ship length. *Trans. RINA.*

[4] Canham, H. J. S., Cartwright, D. E., Goodrich, G. J. and Hogben, N. (1962). Seakeeping trials on O.W.S. *Weather Reporter*, *Trans. RINA.*

[5] Gerritsma, J. and Smith, W. E. (1967). Full-scale destroyer motion measurements, *Journal of Ship Research.*