EARTHQUAKE ENGINEERING AND STRUCTURAL DYNAMICS, VOL. 13, 421–424 (1985)

SHORT COMMUNICATION

A DAMAGING SEAQUAKE

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The term seaquake is used to mean shaking caused exclusively by an earthquake but felt on board a vessel at sea, excluding effects from tsunamis. Thousands of such occurrences are known which are occasionally listed in the casualty reports of Lloyd's List and in other sources, causing considerable concern to mariners but rarely serious structural damage to seaworthy vessels. Seaquakes, because the sensation they often create is one of the ship running aground, have been responsible for some of the fictitious reefs and shoals shown in early navigation charts. This research note brings to attention a little known case of a damaging seaquake which is of interest for the study of the vulnerability of offshore engineering structures and marine vessels, particularly submarines, as well as containers for the disposal of nuclear waste, and also provides information on the earthquake source responsible for the seaquake, that with the data available cannot be obtained by normal seismological methods.

On the 28th February 1969 the motor tanker 'Ida Knudsen', a 32,000-tonne vessel built in 1958, was sailing in ballast from Lisbon to the Persian Gulf when it experienced a 'violent vertical shock'. This happened at about 02 h 45 min (GMT) when the ship was at a position 36·12°N–10·70°W in 2,700 fathoms of water. At the time the general state of the sea in this part of the Atlantic was 3 to 4 with moderate swell, and the windforce was 4 to 5.

From the available log-extracts, maritime declaration and other survey documents it appears that as a result of the shock the vessel sustained very serious structural damage. In the wheelhouse, chartroom and radio station binnacles, compasses and permanent instruments were torn loose and collapsed. Doors and fixtures in the superstructure were torn loose and thrown about. The signal mast with the radarscanner was distorted and all its cross-bars were broken. Damage in the superstructure was more serious at midship than at the aft peak. From eyewitness accounts it appears that the vessel was lifted up bodily, the bow moving up faster than the bridge, and then the whole ship slammed back with violent vibrations, the whole event lasting about ten seconds. Serious damage was also caused both to the machinery and hull where piping was broken and leakage developed between tanks. After hours of drifting and with a misaligned propeller shaft the ship returned to Lisbon where it was drydocked and surveyed.[1]

The surveys proved that the hull, machinery and other equipment had sustained great damage and, on account of the permanent deformation and breaks, the ship had lost a substantial part of her longitudinal strength. The complete surface of the vessel's skin from cofferdam to cofferdam buckled, in places with permanent sets of 4 cm and the hull was twisted to port by 18 cm. Bulkheads, hull frames and girders were buckled or torn apart and all the wing tanks leaked. Moreover, the bottom parts of the side platings were torn away from the girders, in places by as much as 5 cm, effects resembling those from an underwater mine explosion. The ship was condemned as a total loss. Later, she was rebuilt as 'Petros Hajikyriakos' (see Lloyd's Register of Ships).

All this was apparently the result of an earthquake at 02 h 40 mm 33 s (GMT) with an epicentre offshore of Gibraltar at 35·97°N–10·59°W (ISC normal depth determination), i.e. 20 km from where the ship was damaged. No other ships are known to have been in the near-field of this major earthquake ($M_s = 7{\cdot}8$, $M_0 = 6{\cdot}0 \times 10^{27}$ dyn-cm).[2] A number of vessels further away, Figure 1, particularly those sailing along the

0098–8847/85/030421–04$01.00

Received 17 October 1984

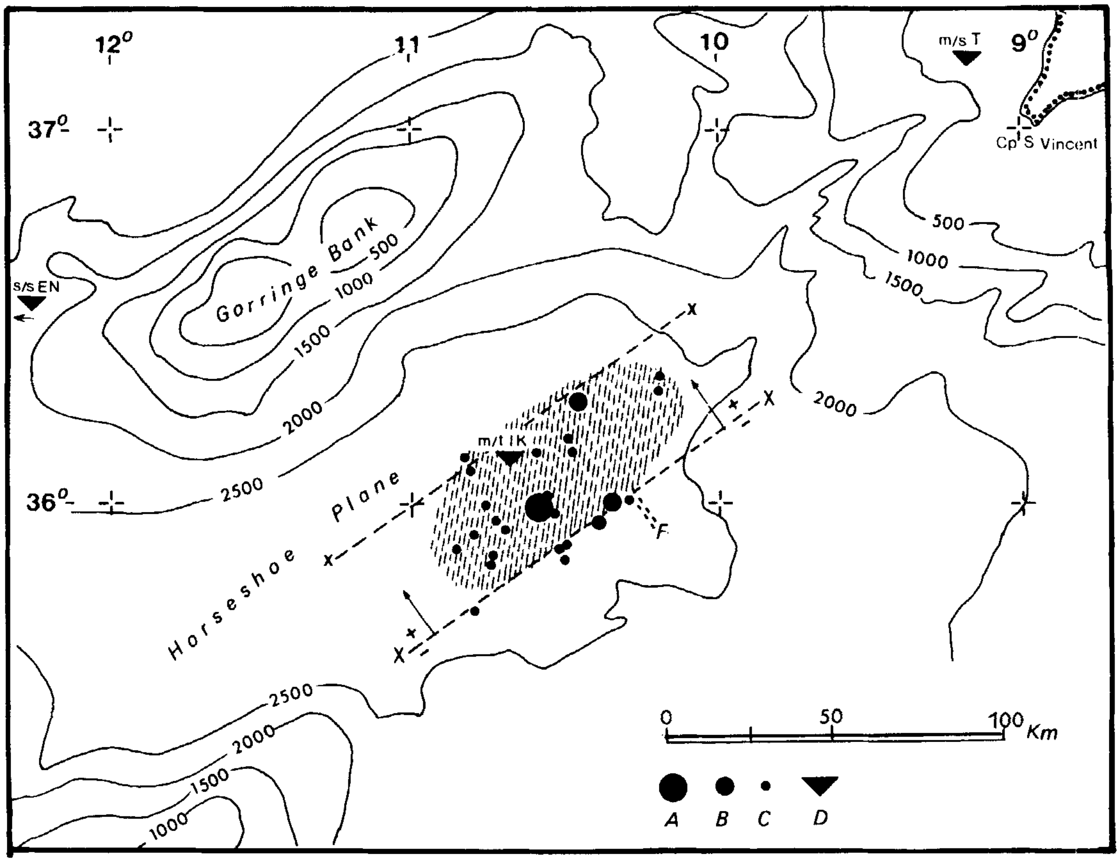

Figure 1. Map of epicentral region of the earthquake of 28 February 1969 (based on Fukao[2]), showing bathymetry (in fathoms). A: main shock, and the distribution of the aftershocks, B: 5·0 ⩽ m and C: m ⩽ 4·0 (ISC determinations); X–X indicates the surface strike direction and upthrusted (+) block; hatchings show projection of assumed fault plane. D: position of ships that reported the main shock (four more vessels north of m/s 'T', not shown). F: approximate location and trend of secondary escarpment[5]

coast of Portugal and Spain, felt the shock with different degrees of intensity but with no damage. For instance, m/s 'Toubkal' at 37·18°N–9·20°W, 180 km away in 250 fathoms of water was set into violent vibrations for about one minute. Further out in the Atlantic, 190 km from the epicentre, s/s 'Esso Newcastle', at 36·52°N–12·55°W in 2,000 fathoms of water experienced a severe vertical shock as if the vessel were lifting out of the water. There is no evidence of large quantities of dead fish near the coast that could indicate large overpressures there. The earthquake triggered a seismic sea-wave which was reported from the Gulf of Cadiz, from Casablanca and from Santa Cruz de Tenerife where it had an amplitude of 0·2, 1·2 and 0·2 m respectively.

For this earthquake McKenzie's fault-plane solution[3] shows pure thrust while that of Udias[4] has a considerable strike-slip component. The latter agrees with the solution obtained by Fukao[2] from surface-waves, but Udias considers the southwards dipping plane to be the fault plane. However, this is unlikely to be the case as the aftershocks lie in a NE–SW direction, parallel to a nodal plane that dips northwest, Figures 1 and 2. Also the damage sustained by 'Ida Knudsen' can best be explained by a predominantly vertical motion of the ocean bottom under the vessel associated with thrust rather than strike-slip for which the vertical motion should have been very much smaller. These arguments resolve the ambiguity between fault and auxiliary planes and show that the earthquake had a thrust mechanism and, using Fukao's estimate of moment ($6{\cdot}0 \times 10^{27}$ dyn-cm), a slip of about 2·5 m on a plane 80 × 50 km dipping at 52° in a direction of 16°W of N.[2] This places 'Ida Knudsen' above the immediate vicinity of the central part of the uplifted block, Figures 1 and 2. Deep-sea photographs taken near the location of the epicentre show what appears to be a recent example of normal faulting, probably associated with this and earlier earthquakes in the region.[5] However, such features

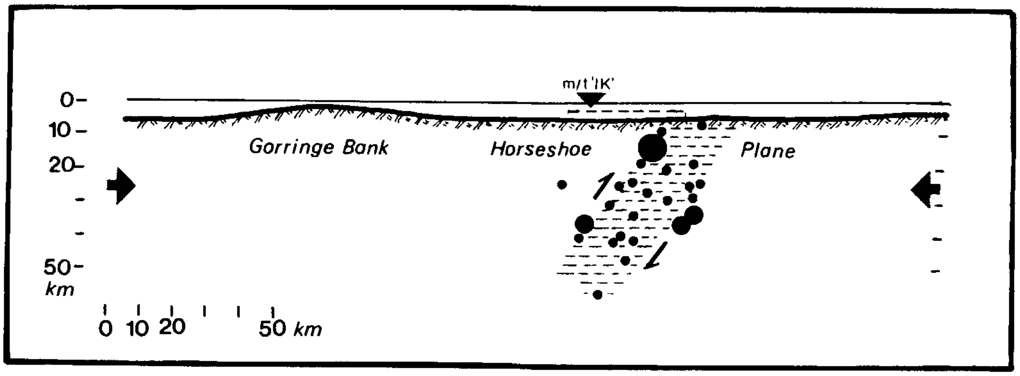

Figure 2. Cross-section of aftershock distribution and bathymetry along a profile at right angles to X–X in Figure 1. Dashed line under m/t 'IK' shows diagramatically assumed motion of sea bottom (X–X to x–x) during the event. Convention of symbols as for Figure 1. Focal depths of the aftershocks used in this projection are from the International Seismological Centre (ISC). The main reason for preferring the northwest dipping plane of Fukao's solution[2] is that it can lead to the formation of the Gorringe Bank[7]

are common in the hanging wall block of thrust faults, which often collapse by normal faulting. The superficial nature of these normal faults is revealed by their fault planes, which do not contain the seismically determined slip vector.[6] These normal features could also be the result of slumping following the earthquake. However, the observed seamounts in this area[7] clearly reflect crustal shortening and suggest a violent upward motion of the ocean bottom being responsible for the large overpressures experienced by the vessel.

It appears, therefore, that at the time of the earthquake 'Ida Knudsen' was in 5 km of water immediately above the central part of the 80 km long portion of the ocean bottom which was uplifted vertically by 2·0 m. Although there are not enough data to calculate the response of the ship and there is a good deal of uncertainty about the actual duration of the event, as a first approximation we may assess the overpressure generated in the near-field by assuming at $t = 0$ an infinite line of ocean bottom, coinciding with the fault-trace X–X (Figure 1), and moving up with a velocity (Z/Dt) for Dt seconds, and then stopping. Also by assuming at the same time that this line X–X moves away from the trace in the direction of the dip with a velocity c ($c > a$ = speed of sound in water), acting as a trigger for the vertical motion (Z), and stopping at x–x, Figure 1. For this earthquake the rise time has been estimated at 6·2 s[8] for a 2·0 m vertical displacement of the upthrusted block so that we may take $Z/Dt = 33$ cm/s. Concentrating on near-field transient effects, i.e. disregarding the decay of the pressure pulse due to waterflow to restore hydrostatic equilibrium and the reverberation of the water layer, by assuming $c = 3{\cdot}0$ km/s, it can be shown[9] that the overpressure in the near-field should be about 6·0 atm. If we take $Z/Dt = 100$ cm/s which accounts for stopping phases for a rise time of 2 s, the overpressure should be 17 atm. This transient overpressure, which is well over design limits for vessels such as 'Ida Knudsen', should have been produced over a large region of the ocean, comparable to the linear dimensions of the dislocated crust of about 50 km, and it was probably responsible for the observed buckling and instability of structural members of the vessel. On the whole, in spite of the great variability of the quantities that enter into the calculations, the results from this particular case, for which we considered only one type of motion as a contribution to the acoustic wave in the water with no quantification of the response of the ship, are of interest because they illustrate some of the factors to be considered in the relatively rare event of hydrodynamic loading of ships and of offshore structures due to the sudden deformation of the sea bottom associated with large earthquakes. For a pressure–time variation of a 10-atm pulse of 0·5 s duration, it can be shown[10] that a 25 mm thick steel plate of the bottom shell of the vessel will be shifted inwards by about 50 cm. The damage that will result from such a pulse will be due to the presence of stiff bracings. In the present case the vessel appears to have behaved in an asymmetric way, in a situation where one would expect the applied overpressure to be uniform within the dimensions of the ship. The bow is reported as rising more than the stern. Is it possible that the earthquake overpressures detonated a large quantity of dumped explosives to give results rather like the impact of a large explosion? There are places, like the Hurd Deep, for example, where enormous quantities of explosive have been dumped at one time or another.[11]

There are quite a few more additional cases of damaging seaquakes but the available information is too incomplete to be of any use. The earthquake of the 23rd July 1894 in the Lofoten Islands of $M_s \approx 6{\cdot}0$ was felt by a number of vessels in the region. One of them, north of Napströmmen, near 68·50°N–13·00°E and in calm weather, experienced such an intense shock that it sprang a leak, sinking 14 h later.[12] Also cases of serious structural damage to vessels during some of the large Japanese earthquakes of this century are known, but details are lacking.

The absence of well-documented cases of damage to ships does not mean that such incidents are extremely rare. Access to ships' logs, which are the sources for such information, is extremely difficult particularly when the inquiry concerns damage details. Moreover, such logs are never kept by ship owners for more than 6 to 9 years, after which they are invariably destroyed. Also Lloyd's casualty record does not include a list of vessels reportedly damaged by earthquake activity and their records show no evidence of damage caused to 'Ida Knudsen' by earthquake shock or other phenomenon of this nature, the loss of which was settled on a compromise basis. Not all marine policies would include the peril of 'earthquake' and it could well be that policy wordings have kept earthquake damage to vessels out of the casualty list under this heading.

ACKNOWLEDGEMENTS

I would like to thank N. Kallonas of N. J. Goulandris Ltd. and Mr. K. Hove of Det Norske Veritas for initial information that lead to the study of this event. This work was supported by the SRC London Centre for Marine Technology in connection with the Seismicity Studies of the British Isles and the North Sea.

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