INTERACTION BETWEEN THE FISHING INDUSTRY
AND THE
OFFSHORE GAS/OIL INDUSTRIES
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INTRODUCTION

At the 65th Statutory Meeting of ICES in September 1977 a special joint session of the Gear and Behaviour Committee with the Fisheries Improvement Committee was held on the interaction between the fishing industry and the offshore gas/oil industries.

Information was requested on national regulations and procedures relating to the coexistence of fisheries and gas/oil operations as well as contributions on the potential hazard to each industry from the operation of the other. In the single (half-day) session available it was clearly not possible to deal comprehensively or in depth with the subject and since most of the papers came from fishery scientists it was inevitable that the emphasis should be on effects on fish stocks and gear, but the question of damage to underwater pipe-lines was also considered. A total of 17 papers were presented and discussed (see Appendix). Subsequently it was proposed that we should edit the material for publication as a Cooperative Research Report.

In assessing the contributions, we considered that authors should be given an opportunity to update their presentations and that any additional relevant material from the 1978 Statutory Meeting should be considered. This allowed us to include a paper from USA. After further consultations with the authors we have reproduced some papers more or less as originally presented, while others have been abstracted or summarised.

It must be emphasised that offshore oil activities are continuously developing, and that fishing patterns are changing, so both industries are in a highly dynamic state. The picture presented by these papers must thus be regarded as a limited snapshot of things in the period 1977/78.

A D McIntyre
S J de Groot

NATIONAL REGULATIONS

Papers from six countries (Belgium, Canada, Federal Republic of Germany, Netherlands, Norway, and United Kingdom) provide information on national regulations and procedures relevant to the co-existence of gas/oil operations and fisheries. Appropriate extracts from these papers are given in this section of the report. Each extract is headed by the name of the country and the code number of the original paper, of which full details of title and authorship are provided in the Appendix.

Belgium (C.M.1977/B:27)

In accordance with the Convention on the Continental Shelf (United Nations Conference on the Law of the Sea, Geneva 1958), the Law on the Continental Shelf of Belgium came into force in 1969. This law embodies the conditions
for the exploration and exploitation of the natural resources on the continental shelf, i.e. mineral and other non-living resources, as well as sedentary living organisms.

In 1974, a Royal Decree was published concerning the granting of concessions for the exploration and exploitation of the mineral and other non-living resources on the continental shelf.

The measures on the protection of navigation, the sea fishery, the environment and other essential interests came into force in 1977. The law first requires a concession for the exploitation of mineral and other non-living resources of the sea floor and the subsoil. Concessions are granted only in specified areas, and so far only two areas have been specified (Figure 1). The conditions relating to a concession are stipulated by Royal Decree. Concessions are granted for a fixed period, with a maximum of 30 years, the depth and the areas for exploration and exploitation having been exactly defined. The decree stipulates the circumstances in which a concession can be withdrawn.

Secondly, the offshore installations and other equipment necessary for exploration and exploitation, as well as the eventual security areas, may not unreasonably hinder navigation, fishing activities or the maintenance of the living resources of the sea. Regulations can be imposed with regard to warning systems and to the prevention of pollution of the sea water and damage to submarine cables and pipe-lines.

A security area is also imposed for any installation or device on the continental shelf. This area extends to a distance of 500 metres, measured from each point on the outer boundaries of the installation or device.

Up till now no concessions have been granted for the exploitation of gas/oil or for the carrying out of test drillings on the Belgian continental shelf, so there is as yet no practical application of the law.

---

Figure 1

Areas retained for exploitation
In recent times it has become increasingly evident that the world's reserves of hydrocarbons are finite and that few new sources of gas and oil remain to be discovered and developed. In Canada, the Mackenzie Delta/Beaufort Sea area, the islands and inter-island waters of the Arctic Archipelago and Baffin Bay/Davis Strait/Labrador Sea appear to be the most promising area for the discovery of new reserves. To date some 16 trillion cubic feet (tcf) of natural gas have been discovered in the Arctic islands and 6.7 tcf in the Mackenzie Delta. Although exploration has just begun, geologists speculate that the majority of the area's potential lies offshore.

This paper describes the present regulatory mechanisms used by environmental agencies in marine exploration in Canada, some of the problems of working within the present system and changes that are proposed to improve the system.

In contrast to many parts of the world where exploration leases must be acquired by direct purchase, Canada opted for a system to induce the oil industry to explore Canada's northern frontier regions by which an operator was required to spend $2.65 per acre over 12 years either in direct exploration costs or, since the interest in environmental impact assessment, by undertaking environmental studies. The basic problem with this system is that when it was implemented in the mid-1950s, the social, economic and environmental consequences of exploration of these areas were not considered by Government prior to permits being issued.

In response to an increasing awareness of the environmental impacts resulting from exploration, the Government, in 1972, established a two-staged process:

1. an Approval-in-Principle process for proposed offshore drilling operations where new technology or procedures are involved, and
2. a site-specific Drilling Authority issued for each well to be drilled on the advice of an Arctic Waters Advisory Committee.

The intent of the Approval-in-Principle process is to provide a mechanism through which a company can be given assurance that untried new technology or new applications of existing technology can be used for drilling before any irrevocable commitments such as construction of drilling vessels are made. The information required for approval-in-principle covers all facets of the drilling system and supporting services. The environmental feasibility of the system is considered by an environmental Review Committee (ERC) consisting primarily of representatives from the Department of Indian and Northern Affairs (DINA) and the Department of Fisheries and the Environment (DFE). In most cases, the applications are deficient in terms of environmental impact assessment and an approval-in-principle is granted conditional to fulfillment of terms and conditions specified by the ERC. The proponent must satisfy all of these conditions prior to proceeding to the next phase of the permitting procedure, an application for a Drilling Authority.

A Drilling Authority is issued under the purveyance of DINA and applications are reviewed by the Arctic Waters Advisory Committee. The committee, consisting of DINA and DFE members, determines the adequacy of waste management plans, oil spill contingency plans and site-specific environmental information, and advises the Oil and Minerals Branch of
DINA in regard to further environmental information that may be required of an applicant and also on operating conditions necessary to protect the environment. These additional stipulations are incorporated into the Drilling Authority. Having satisfied all of these requirements, the proponent can then drill the well.

An Approval-in-Principle was necessary for the first well drilled from a reinforced ice island (i.e. new concept) and for drillships in the Beaufort Sea (i.e. a new area in which environmental conditions are particularly harsh) whereas individual drilling authorities must be obtained for each well drilled.

From the above brief description of the system, DFE has an opportunity to express its concerns with respect to environmental matters and to recommend suitable terms and conditions for inclusion in Approvals-in-Principle or in Drilling Authorities to mitigate potential impacts.

Perhaps the greatest obstacle facing environmental agencies is the fact that by early 1972, almost the entire Arctic area both onshore and offshore was under exploration permit and that operators were committed to expending monies on active exploration in order to retain their permits. Once a permit is let, and preliminary geological, geophysical and seismic work done, the government to all intents and purposes is committed to allow a proponent to drill a well. If on review of an Approval-in-Principle or Drilling Authority application, the environmental agencies decide that an area is too sensitive to permit drilling, is the Government in a position to refuse approval without first reimbursing the proponent for exploration costs already incurred in meeting the work requirements? This question does not appear to have been addressed, but Canada may be faced with this decision in the future.

Examples of some of the problems of working within the confines of this system from an environmentalist's point of view are given below.

Exploration permits have been granted for the Beaufort Sea since 1961 and under the terms of some, operators were required to have met their obligations by 1974 or 1975 despite the fact that no extensive environmental work had been done in the area. Several companies were granted Approval-in-Principle in 1973 to commence exploration of the Beaufort Sea. In consideration of the need for environmental research, prior to drilling, it was stipulated that the Government would undertake a crash program of environmental research that was to be funded in part by the petroleum industry. Under the terms of the Beaufort Sea Study Project, the industry agreed to support 21 of the 29 studies to the sum of $4.1 million while $1.2 million for the other 8 studies would come from within Government.

As the Beaufort Sea Study Project progressed, a proponent company acting under the terms of their Approval-in-Principle proceeded with the construction of a fleet of offshore drilling and supply vessels. The decision facing the Government on completion of the study was whether or not to authorise drilling to proceed despite the fact that should an oil blow-out occur, effective countermeasure technology had not been developed or to deny the company permission to proceed despite an investment of approximately $150 million. After due consideration of the environmental issues, drilling authorities for three wells were issued and drilling commenced in August 1976. Of these first three wells, one experienced a blow-out of freshwater from outside of the well casing and had to be abandoned, the second experienced a flow of gas and water between subsurface geological horizons and the third proceeded without incident. Had these two mishaps involved oil instead of gas and water, there could well have been an environmental disaster. Despite these experiences, the risks were considered to be acceptable and approval was given to continue the program.
In July 1973, a company having 45% government equity applied for Approval-in-Principle to drill an experimental well to delineate the seaward extension of a gas field from a strengthened ice pad approximately 130 m in diameter and 5.2 m thick at the centre situated atop sea ice some 2.3 m thick in a location 13 km from the Sabine Peninsula, Melville Island in Hecla and Griper Bay. Following a meeting with Government on August 28, 1973 the company was requested to prepare an oil spill contingency plan and to undertake an environmental impact assessment of the proposal. Despite concerns from DFE, an Approval-in-Principle and subsequently, a Drilling Authority were granted. The well was drilled without incident in late winter 1974.

Even though this was a delineation well, the concept should have been subjected to a very careful evaluation. The technology had never been tried before anywhere in the world and by permitting the operation, a precedent was set. Since then, seven more wells have been successfully drilled from ice islands. Six of these have been delineation wells, but one, at Jackson Bay, off Ellef Ringnes Island, was a wildcat with no idea of what would be encountered. The well did experience problems when unexpected ice movement caused the drill pipe to rub on the riser pipe, resulting in riser failure. Technology has now been advanced such that moderate ice movements can be tolerated without having to move the drilling rig.

In all of these operations, DFE has insisted that a second ice pad be built in the event that drilling of a relief well is required. DFE also stipulated that the operators have the ability to complete a relief well within the same season as the original well is drilled. This stipulation forced the proponent to abandon a plan to drill a 3 200 m well at Roche Point, Melville Island last year.

The petroleum industry has informed Government that there are at least 73 prospective structures in the offshore areas of the Arctic islands to be drilled. Of these, only a few can be drilled from ice islands while the remainder will probably be tested from an as yet to be approved air cushion drilling rig.

The Government is attempting to undertake an environmental assessment of the potential effects of drilling in the Baffin Bay/Davis Strait area on a regional basis. This is a new concept for Canada. In late 1973 the Government of Canada directed DFE to establish the Environmental Assessment and Review Process (EARP) to consider the environmental implications of any actions or projects involving lands and waters under Federal jurisdiction or supported by Federal funds. Procedures have been developed and will be used to assess the environmental implications of drilling in this area. Although the area has been under exploration permit for many years and a major oil company has expressed a desire to drill a well, the Government has imposed a moratorium on drilling until the environmental impact assessment has been completed. We hope that the decision to allow drilling in this area will be contingent on the outcome of this project. However, the urgency for Canada to delineate its hydrocarbon reserves may again force the Government to take risks. Negotiations are currently under way to induce industry to fund the Eastern Arctic Marine Environmental Study (EAMES) much as was done for the Beaufort Sea Study Project. But while the Government delays, the oil industry is preparing to drill as soon as the moratorium is lifted.

At present, the pressures for development of frontier hydrocarbon reserves are very intensive within the Federal Government and strong determination is required from environmental agencies to effect a reasonable balance between environmental protection and resource exploitation. Because of the
present system under which the Government is more or less committed to allow exploratory drilling once a permit has been granted, we (DFE) have a set of rules under which we must work. The major piece of legislation under which we work is the Fisheries Act. We realise that if exploration must occur, there are ways to mitigate its impacts. Seismic exploration of leases must occur before there is any drilling and we have developed guidelines for industry to lessen the impacts. In most areas only non-explosive energy sources such as air-guns are permitted. Explosives are permitted in some instances providing there are no major fish populations in the area. We realise that marine disposal of drilling fluids is a common world-wide practice. Guidelines have been developed with the cooperation of industry to eliminate some of the more toxic components in these fluids and to reduce the volumes used. The Fisheries Act is also one of the tools under which appropriate terms and conditions for inclusion in Approval-in-Principle and Drilling Authorities are developed.

New legislation has been proposed through a new Petroleum and Natural Gas Act, to be put before Parliament soon, to consider the environmental social and economic costs of exploration and development as well as all of the technical details. Prior to exploration permits being issued a full assessment will be undertaken and areas either wholly or partly excluded from exploration should environmental or social factors demand it. It has also been agreed by proponents of this new legislation that renewals of existing permits and leases should also come under this same review process. It is anticipated that the Environmental Assessment and Review Process will be used as the mechanism for the environmental part of the selection process.

In addition, Canada's extended jurisdiction for management of fisheries resources and amendments to the Fisheries Act such as expanded definitions of fish and fish habitat will give my Department broader powers to ensure that the marine environment is given due consideration while at the same time permitting orderly development of hydrocarbon resources.

In summary, it can be said that a system is evolving from no consideration of impacts prior to drilling, to some concern and consideration through the present Approval-in-Principle and Drilling Authority Process, to a system in which legislation guarantees due consideration for potential environmental impacts prior to drilling.

Federal Republic of Germany (C.M.1977/E:7)

Relevant activities on the German continental shelf are shown in Figure 2 and the position of wells in Table 1.

All applicants requesting permission to undertake bottom investigations aiming at the exploration and production of minerals (gas, oil) on the German continental shelf outside the 3-mile zone are required to contact the German Hydrographic Institute and the Oberbergamt in Clausthal-Zellerfeld. Several institutions such as the Air Force, Navy, the Directorate of Post and Navigation, and the Federal Research Centre of Fisheries, which are directly concerned with the applicant's performance, receive detailed information on position, time duration and the type of activity on the German continental shelf. If there is no objection from any of these institutions, permission is granted to perform the exploration under certain conditions. If there is any objection, the final decision is made by the Ministry of Traffic and Transport weighing the economical or essential importance of the applicant's project against the interest of fisheries. A list of obligations for companies undertaking any activities on and in the sea bed of the German continental
shelf has been worked out containing several paragraphs dealing with:
1. Cleanliness of the sea and the sea bottom;
2. Safety measures on board the operating platforms;
3. Preventing of damage to cables, buoys, vessels, etc.;
4. Fisheries;
5. Reserved areas for Air Force and Navy.

Obligations concerning pollution of the sea and cleanliness of the sea bed which have direct consequences on the activities of the fisheries are as follows.

The applicants have to take care:
1. that no oil or other toxic contaminant which has any influence on the biology or chemistry of the sea water is spilled into the sea. This refers particularly to bilge and engine oil, waste, waste water and all kinds of packing material;
2. that in case of oil spills, sufficient quantities of non-toxic chemicals and a spraying device must be available;
3. that no equipment, cables, wire, etc. are disposed of overboard, or left at the bottom of the sea when no longer required;
4. that official reports are made on drifting anchor buoys or sunken buoys, machinery and other components. Measures to find lost equipment and salvage material have to be taken immediately at the applicant's expense;
5. that the sea bed is not being altered to someone's disadvantage. In case of a water depth reduction of more than 1 m, the applicant has to restore the sea bed to the former condition. After the drilling rig has left the location the applicant has to certify the cleanliness of the sea bed at his own expense;
6. that well heads are marked by buoys;
7. that the safety zone for a drilling rig does not exceed a diameter of 500 m;
8. that fisheries are not hampered unduly nor hampered unnecessarily.

On the fishery side, vessels must keep outside the 500 m safety zone round drilling rigs, but there is as yet no law on the German continental shelf which prohibits fishing near a pipe-line. For safety reasons, however, notice is always given to fishing vessels and merchant ships to avoid pipe lines when trawling or anchoring.
Table 1. Position and number of wells drilled on the German continental shelf.

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Figure 2. German continental shelf.
- drilling locations
/ Ekofisk gas pipe-line
■ platform of gas pipe-line
○ research platform
The Netherlands (C.M.1977/B:15)

Upon completion of the Geneva Convention on the Continental Shelf (1958), the Netherlands Government put into effect a law dealing with the exploration for and exploitation of minerals (Mining Law Continental Shelf).

It should be noted that sand, gravel and clay are not regarded as minerals within the context of this law; the rules for the exploration and exploitation of these minerals have been laid down in a separate law, which has, however, not yet been put into force.

The Mining Law Continental Shelf should be seen as a framework law, i.e., it contains a number of main rules, which are to be worked out in more detail through further regulations. As far as this law deals with the protection of other interests of users of the (North) Sea, the following definitions are of importance for fisheries.

1. It can be ruled by General Order – a Royal Decree – that certain parts of the Continental shelf are not to be covered by a mining licence. This article has so far only been applied to exclude mining activities in the interest of shipping (e.g. approaches to harbours) and defence (exercise areas).

   It has not proved necessary to apply similar arrangements with regard to fisheries.

2. Also by Royal Decree regulations can be put into force with respect to:
   a. protection of the natural resources of the sea;
   b. preventing pollution of the sea;
   c. other interests acknowledged by international law.

The regulations under 2. above contain a large number which are of importance to fisheries. They cover the following subjects:

A. Seismic Activities

Vessels engaged in this type of survey have to be equipped with communication gear which will enable them to contact fishing vessels through the established fishery wave-length, and also with suitable equipment to trace fish shoals.

Sufficient expert personnel should be on board to operate the aforementioned equipment.

The ship's crew should be able to recognise vessels actually fishing, fixed fishing equipment, dragnets and floating nets.

No activities are allowed within a given distance from vessels actually fishing or fixed fishing gear. No explosives may be detonated close to fish shoals.

A fishery expert can be appointed to accompany the survey upon request of the Minister of Agriculture and Fisheries.

All indications related to the impact of detonated explosives on the living resources of the sea, as observed at the sea surface, have to be entered into a ledger; this ledger is available to the proper authority if so requested.
B. Pollution of the Sea

It is forbidden to discharge oil or oily substances. Proper arrangements must be made to prevent these pollutants entering the sea even inadvertently.

Pipe-lines should be strongly constructed; adequate corrosion prevention techniques should be applied and a regular check on leakage and general condition should be carried out.

Leaking sections have to be put out of operation immediately and repair work has to start as soon as possible thereafter.

C. Shipping (including Fisheries)

All mining installations have to be adequately lighted, carry radar-reflectors and emit sound-warnings during poor visibility.

When no longer in use, installations and pipe-lines have to be removed. Abandoned holes have to be completed at such a depth below the sea floor, that no obstruction to shipping remains.

Pipe-lines have to be buried according to specifications if they would otherwise endanger shipping or fishing activities.

The track of pipe-line can be laid down by central government, taking into account a variety of spheres of interest.

All known obstacles should be published in the "Notice to Mariners" and also be plotted on relevant charts.

Finally, it should be noted that the Mining Law Continental Shelf provides for a safety zone around mining installations. In practice the safety zones, with a radius of 500 m, are only established around permanent installations. Unauthorised entry of such a safety zone is regarded as punishable offence.

Norway (C.M.1977/E:59)

The oil activity on the Norwegian continental shelf is regulated by special legislation. The basic rules for protection of the fisheries are laid down in the Royal Decree of 1975 relating to safe practice in exploration for submarine petroleum resources, and the Royal Decree of 1972 relating to the exploration and exploitation for petroleum of the Norwegian shelf. According to these regulations the interested oil companies must apply for a concession to carry out seismic work on the continental shelf, and a production licence for exploiting oil. The licence documents contain rules and conditions regulating the activity.

In the rules relating to safe practice in exploration work it is required that the seismic vessels should be acquainted with international and Norwegian regulations concerning navigation. The vessels shall furthermore be acquainted with the Norwegian rules for marking of floating and stationary fishing gear and be acquainted with the light signals carried out by trawlers and other fishing vessels. The seismic vessels must keep a safe distance from those engaged in fishing and from floating stationary fishing gear. Seismic work must not be carried out near vessels engaged in fishing or if shoals of fish are detected under or in the vicinity of the seismic vessels. A public inspector may at any time go on board the seismic vessel to check that the work is carried out in accordance with the rules and regulations. The Directorate of Fisheries is kept informed about planned seismic work by
the oil companies. A representative from the Directorate then inspects the vessel when it calls at a Norwegian port. If considered necessary, the inspector also stays on board during the work at sea. The Director of Fisheries informs the local fishery inspectors beforehand about the plans for seismic work, the dates and area concerned and the name of the vessel. This information is forwarded to the local fishermen's unions and to the local press. Before starting the seismic work, the officer in charge of the vessel must contact the local fishery inspector to be informed about the fishing activity in the area. The Norwegian continental shelf north of the 62nd parallel is not open to general seismic work, which is carried out by leased vessels in charge of the Norwegian Oil Directorate.

The exploration for, and exploitation of, petroleum must be carried out in a safe manner and in accordance with the regulations in force at all times. The oil industry must not, for instance, interfere with fishing to an unreasonable degree. Before provisional or permanent installations are placed on the sea bed, the oil company must have written consent from the Oil Directorate. The Oil Directorate shall also be notified of removal of such installations and towing of platforms to new locations. A notice concerning an approved location for an oil platform is inserted by the licensee in the "Norwegian Notices to Mariners" and likewise announced on the Norwegian broadcasting fisheries service.

The Department of Industry shall through the Oil Directorate be informed in good time about the plans for any exploitation. Drilling cannot start before the licensee has obtained written consent from the authorities. When an application for drilling has been received, the Oil Directorate asks the Directorate of Fisheries for information concerning the types of fisheries carried out in the area, which nations are fishing there, and what special precautions should be carried out. Any special requirements will then be stated in the consent.

The space occupied by a platform including the safety zone of 500 metres is a circular area with a radius of about 600 metres. According to the Norwegian safety regulations, a drilling platform should have at least four buoys placed around it at a distance of 500 metres. These buoys should be supplied with lights, sound signals and radar reflectors. However, some drilling platforms are now operating in deeper and deeper waters, and these require anchor chains going far outside the safety zone with the anchors placed up to 1000 metres out from the platform. This means an additional danger area for the fishermen and their gear.

When a well is abandoned, casing strings and other installations protruding from the sea bed must be removed to such a depth that no obstruction remains which may cause danger or impediment to fishing or shipping. Before final abandonment of the well, the licensee must make sure that no such constructions remain on the sea bed. If a well is abandoned temporarily due to bad weather or other reasons, the drilling bore should be plugged in a safe manner and a buoy laid out to mark the wellhead. Temporary abandonment is generally limited to 6 months.

The licensees are further instructed not to throw overboard from the platform or from the supply vessels any debris of iron, empty barrels or other obstacles that interfere with fishing operations. The licensee must carry out an inspection of the sea bed by divers or by other means and certify that such an inspection has been undertaken.

The safety zone of 500 metres, which according to the Geneva Convention applies to platforms and other installations on the sea bottom, does not apply to pipe-lines. They come within the same scope as telegraph and
telephone cables on the sea bottom. To reduce the problem of interference with fisheries, the Norwegian authorities require that oil and gas pipe-lines on the Norwegian continental shelf or having their starting point there, shall be buried as far as their points of destination. This has been done with the oil pipe-line laid from the Ekofisk field to Teesside in England, and likewise with the gas pipe-line from Ekofisk to Emden in the Federal Republic of Germany. These pipe-lines are buried between 1 and 3 metres under the sea bottom, except for a few stretches of the Emden pipe where sandbags are used for cover.

A temporary compensation fund was established in June 1976 to cover damages incurred by Norwegian fishermen due to the activities of the oil industry. An advisory committee has, since September 1976, thoroughly examined reported damages and claims, and recommended compensation in cases which in all probability or certainty were caused by littering of the sea floor by the oil industry. The final decision as to whether or not compensation is warranted is made by the Director of Fisheries. Compensation is applicable to Norwegian fishermen irrespective of the sector in which the damage occurred. Up to 18 August 1977 about 1 700 claims for damages to fishing gear and catch losses have been registered with the Directorate of Fisheries, and 1 379 have so far been handled. Compensation has so far been paid to 1 050 of these claims, about one-half each from the British and Norwegian sectors, and less than one per cent from the Danish (Figure 3).

**Figure 3.** Incidences of damage to Norwegian fishing gear resulting from sea floor obstructions. Of the 1 050 claims granted compensation, 784 are plotted on the ICES ocean grid system.
One approach to this topic is to list the various operations and to consider the appropriate regulations and procedures under each head. The order of listing adopted below is related to the order in which exploration and exploitation would usually proceed. A list of relevant legislation is given in Appendix 1 (p. 19).

Seismic surveys

There are no statutory clearances required for seismic surveys but under Continental Shelf Operations Notices numbers 10 to 33, operators are requested to provide advance warning of forthcoming seismic survey activities.

Drilling rigs

Before drilling can commence operators are normally required as a condition of their petroleum production and exploration licences to obtain consent from the Secretary of State for Energy /Petroleum Production Regulations 1976 - clause 7 in Sch 7. Consent from the Trade Minister may also be required under Section 34 of the Coast Protection Act 1949 as extended by Section 4 of the Continental Shelf Act 1964 since the placing of a drilling structure/vessel presents a potential obstacle or danger to navigation. The Trade consents require that the Hydrographer be given at least 48 hours advance warning of rig movements. Continental Shelf Operations Notice number 16 (revised) requests operators to inform the coastguard of the final location of all mobile drilling rigs in United Kingdom waters.

Platforms

Under Section 34 of the Coast Protection Act 1949 as extended by Section 4 of the Continental Shelf Act 1964 consent for the establishment of "permanent" installations is required from the Department of Trade. Such consents require notification to the Hydrographer and also contain buoys and marking requirements.

Permanent installations are protected by safety zones of 500 metres established by orders made under Sections 2(1) of the Continental Shelf Act 1964. Ships of all nationalities are prohibited to go within the 500 metre safety zone but special exception is made for vessels having legitimate business with the installation and for any ship that is dealing with an emergency or is itself in difficulties or distress. Such safety zones had been established round 68 installations by May 1978.

Pipe-lines

Consent for the laying of submarine pipe-lines must be obtained from the Secretary of State for Trade under Section 34 of the Coast Protection Act 1949 and from the Energy Minister under Section 20 of the Petroleum and Submarine Pipe-lines Act 1975. Anyone wishing to construct a sub-sea pipe-line is required to obtain a works authorisation.

Section 21(3) of the Petroleum and Submarine Pipe-lines Act 1975 enables the Secretary of State for Energy to include in the authorisation under Section 20 terms as to "the steps to be taken by the person authorised to avoid or reduce interference by the pipe-line with fishing". In addition, under the terms of schedule 4 part 1, 2b, if the Secretary
of State on receipt of an application for works authorisation decides that the application should be considered further he may give "the applicant such directions with respect to the application as the Secretary of State considers appropriate". These directions may include a requirement "to serve a copy of the notice on such persons as the Secretary of State directs" (schedule 4 part 1, 3c). Who is consulted is a matter for the Secretary of State to decide, but in the cases considered so far the main United Kingdom fishermen's federations have been included in the list of persons to whom the notice has been served. The Secretary of State may also require the route of a submarine pipe-line to be altered in the light of representations made to him (Schedule 4, part 1, 4). Any authorisations issued under both the Coast Protection Act 1949 and the Petroleum and Submarine Pipe-lines Act 1975 would require that the pipe-line should be trenched to allow burial by natural backfill. The normal requirement would be for the pipe-line to be covered to a depth of 1 metre. The authorisation issued by the Department of Energy would also include provisions forbidding the dumping of waste material and the Department of Trade consents cover the conditions relating to buoys and during pipe-line operations.

In addition to the consents and authorisations required from Trade and Energy Ministers the construction of a submarine pipe-line may also require to be licensed by the Shetland Islands District Council and the Orkney Islands District Council within tidal waters if it is likely to interfere with public rights of navigation or other public rights under Section 11(l) of the Zetland County Council Act 1974 and Section 11(l) of the Orkney County Council Act 1974. (The Orkney Act only applies to certain harbour areas.) The licence issued to Shell in January 1975 for their pipe-line into Sullom Voe requires among other things that suitable arrangements must be made with the Shetland Fishermen's Association for compensating fishermen for loss of fishing and also for a suitable system for dealing with claims for loss of gear to be set up. Article VII of the Convention scheduled to the Submarine Telegraph Act 1885 as applied by Section 8 of the Continental Shelf Act 1964 provides that owners of ships or vessels who can prove that they have sacrificed an anchor, net or other fishing gear in order to avoid injuring a submarine pipe-line shall receive compensation from the owner of the pipe-line. The same legislation makes it an offence to unlawfully and wilfully or by culpable negligence, break or damage a submarine pipe-line.

The Submarine Pipe-lines (Inspectors) regulations 1977 set out the powers and duties of inspectors concerned with pipe-line operations. Under the regulations inspectors are empowered to require a submarine pipe-line to be shut down to avoid the risk of accident or pollution.

Abandoned/suspended well heads

It is a normal condition of Exploration and Production licences that a consent is required for the abandonment or suspension of drilling or production activities on any well. Petroleum (Production) Regulations 1976 - clause 7 in Sch. 7. Continental Shelf Notice number 11 specifies that it is a requirement on the abandonment of a well head that a certificate is submitted to the effect that the sea bed is free of all obstructions.

The consents issued by Trade for a drilling structure/vessel also specifies that where the water depth is 45 metres or less the height of the projection above the sea bed should be not more than 2 metres and also requires suspended well heads to be marked as required by the Secretary of State for Trade if at any time he considers this necessary.
for the purpose of preventing obstruction or damage to navigation. The consent also requires details of all buoys marking well heads to be notified to the Hydrographer. Regular updated lists of the positions of well heads and other fixtures are issued for the information of mariners by DAFS/UKOOA.

Buoy and marking of offshore installations

Requirements relating to buoys and the marking of offshore installations are covered by the Department of Trade consents issued for pipe-lines, permanent installations and drilling structures/vessels as indicated in several of the above paragraphs. The Department of Trade consents also require buoys to carry identification markings indicating the buoy's position or its ownership.

Platform fabrication

The Offshore Petroleum Development (Scotland) Act 1975 enables the Secretary of State for Scotland to make Orders specifying certain parts of the sea as designated areas, and to regulate operations, restrict or prohibit entry into such designated areas, prevent pollution and nuisance and protect fishing within them. Operations within these designated areas require to be licensed by the Scottish Office.

Debris

The Dumping at Sea Act 1974 makes it an offence for substances or articles to be dumped in United Kingdom territorial waters or outside these waters if dumped from a British ship or marine structure, without a licence from the appropriate fisheries department. The provisions of the Dumping at Sea Act were subsumed under Section 45 of the Petroleum and Submarine Pipeline Act 1975 for the laying of submarine pipe-lines. However conditions in the authorisations issued under the Petroleum and Submarine Pipe-lines Act 1975 for pipe-lines, consents under the Coast Protection Act 1949 for drilling structures/vessels and the licences issued under the Offshore Petroleum Development (Scotland) Act 1975, all contain some reference to control or elimination of debris.

Continental Shelf Operation Notice number 8 draws attention to some of the problems created by debris and recommends that all waste materials are disposed of ashore.

General licence conditions

Exploration and production licences are issued to operators by the Department of Energy under the Petroleum (Production) Act 1934 and the Continental Shelf Act 1964. It is a term of such licences that the licensee shall not carry out any operations in such a manner as to interfere unjustifiably with navigation or fishing or with the conservation of living resources of the sea.

Compensation arrangements for damage to fishing gear by oil-related debris

The operating company responsible for such debris is considered to be liable for damage. The skipper of a fishing vessel whose gear has been damaged by what he considers to be oil-related debris should record the incident in his log book noting the time and location and report the incident to the local fishery officer immediately on his return to port. The fishery officer will provide a claim form and will help as necessary with its completion. The fishery officer will also inspect the damage to gear, and the debris which whenever possible should have been brought ashore and any other factual evidence to support the claim. If the debris
is too awkward to haul on board detailed description should be noted. Descriptions should be vouched for by any member of the crew and a photograph would be regarded as helpful. If the incident is witnessed by another vessel a separate statement signed by the skipper or a crew member of that vessel should accompany that claim.

The skipper should then forward a copy of the claim to his owner or agent and the fishery officer will ascertain from records available which oil company was operating in the area of the incident and will inform the owner or agent of the fishing vessel so that the latter may forward a claim to that company.

If the fishery officer is not able to attribute the oil-related debris to the operation of a particular company or if a claim referred to an oil company is rejected on the grounds that the debris was not considered to be associated with this operation, a claim may be considered under a compensation scheme for unattributable debris funded by the United Kingdom Offshore Operators' Association (UKOOA). The fishing industry, as represented by the Scottish Fishermen's Federation and British Fishing Federation is responsible for the operation of the scheme and to this end has arranged the appointment of a Management Committee with representatives from the two Federations. The Committee meets at suitable intervals to consider claims, and settlement is at the discretion of the Committee depending on the merits of each individual case. The Committee's decision on each claim is final and binding. In funding this scheme, the UKOOA have imposed a condition that any settlement will not imply a legal responsibility on the part of the oil industry and will be on the understanding that the claimant waives all right to claim against a member company of the UKOOA.

Pollution

Most of the above items related directly to interference with fishing, but the impact of oil itself is also relevant, in terms of fouling of nets and fish, and of toxic effects in the environment.

The best approaches to this problem are clearly prevention of spillage and the establishment of highly responsible management. It is required that offshore installations are designed and built to a high standard and are operated with care and attention. In United Kingdom, regulations in the Offshore Installations (Construction and Survey) Regulations 1974 were introduced to this end, and the Petroleum and Submarine Pipe-lines Act 1975 enables the Secretary of State for Energy to control all aspects of the construction and operation of submarine pipe-lines and empowers him to make regulations providing for the safe operation of pipe-lines. Operators are also required under the terms of production licences to follow good oil field practice and prevent the escape of petroleum.

The discharge of suitably treated oily water is however necessary for the operation of most oil offshore installations, particularly at the end of an oil field's life when large volumes of water are produced along with the oil. These are controlled by Section 23 of the Prevention of Oil Pollution Act 1971 as amended by Section 45 (2) of the Petroleum and Submarine Pipe-lines Act 1975. This requires oil operators to obtain permission (or more strictly an exemption from the provision of the 1971 Act) for the discharge of oily water. This permission is given only with stringent conditions, taking into account the amount of oil in the final effluent, the capabilities of the treatment plant, the total volume of the discharge anticipated, and the dispersing capability of the environment. Six exemptions have already been issued for offshore installations. The total quantity of oil releases so far in such controlled discharges on the United Kingdom continental shelf has been less than
200 tonnes. This can be compared with discharges in excess of 1,000 tonnes per year from certain refineries and accident spills of more than 200,000 tonnes in the recent 'Amoco Cadiz' incident.

Consultation

The United Kingdom has found that consultation is the key to ensuring minimum interference with the fishing industry from offshore oil and gas operations and it is for this reason that a Fisheries and Offshore Oil Consultative Group was set up by the Government in July 1974. The Group includes representatives of the offshore oil and fishing industries and is designed to exchange information on matters of general interest, to discuss broad principles and to keep under review developments in connection with the exploitation of offshore oil and gas resources with the object of fostering close relations between the two industries, so that each may carry out its operations with minimum of interference to the other. Matters discussed have included arrangements for consultations, notification procedures, buoys and associated matters, navigational problems, oil-related debris in the North Sea, drilling muds, pipe-lines, underwater installations, and the effects of offshore installations on access to fishing grounds.

Education is also important and in this connection government departments have prepared two booklets. One is for the fishing industry and explains the nature of oil operations, the second is designed for the oil industry and sets out details of fishermen's problems and how fishing operations are carried out.

Contingency planning

Each offshore operator is responsible for cleaning up any oil spills that result from his activities. He is required to have a contingency plan, covering the action he would take and the resources he would deploy in such a situation. In practice the operators have limited clean-up resources at the platforms, but primarily rely on pooled resources held at some 4 centres round the United Kingdom coasts. In a given incident he would be required to report a spill to the Department of Energy and the coastguards and deal with the pollution in accordance with his plan and the guidelines laid down by Government. The Government would monitor the operators' activities offering advice and assistance and intervening where necessary. There would be full consultation with fisheries departments and other environmental interests on the appropriate treatment strategy following any major incident.

The Department of Trade has been given responsibility for dealing with oil spills at sea which threaten to cause major pollution of the coast or to harm important concentrations of sea birds. In no way does it see this role as derogating from the primary responsibility of offshore operators to deal with spills from their own installations. The Department has a Principal Officer in each of the nine Districts who would be the Government contact following an incident, and would implement the plans for his district as appropriate.

Should an oil slick threaten the coastline, action would be taken by the local authority, assisted where necessary by resources from central government. As early as 1968 the local authorities have had schemes for dealing with any oil spills which might threaten the coastline. Certain of the local authorities were invited to review these schemes and update them in the light of the increased activities near their shores. Periodic exercises are held to ensure that men, materials and communications systems are in a constant state of preparedness. Training of staff is arranged both locally and nationally. The cost of clearing spills where the source of the spillage cannot be traced falls to the authority.
APPENDIX 1

RELEVANT UNITED KINGDOM LEGISLATION

Acts
Submarine Telegraph Act 1885 (S3 Sch Art IV and VII) [48 and 49 Victoria Chapter 42]
Petroleum (Production) Act 1934 [24 and 25 Geo.5 Chapter 36]
Coast Protection Act 1949 (S34), [12 and 13 Geo.6 Chapter 74]
Pipe-lines Act 1962
Continental Shelf Act 1964 (S 1(i), 2, 8), [Chapter 29]
Prevention of Oil Pollution Act 1971 [Chapter 60]
Dumping at Sea Act 1974 [Chapter 20]
Orkney County Council Act 1974 (S 11)
Zetland County Council Act 1974 (S 11)
Offshore Petroleum Development (Scotland) Act 1975 (S 3-6 Sch 3)[Chapter 8]
Petroleum and Submarine Pipe-lines Act 1975 (S 20, 22 and Sch 4)[Chapter 74]
Prevention of Oil Pollution Act 1971 [Chapter 60]

Orders
The Petroleum (Production) Regulations 1976 [S.I.1976 No.1122]
Sea Designation (Inner Sound of Raasay)(Scotland) Order 1975
Sea Designation (Loch Fyne) (Scotland) Order 1975
Sea Designation (Inner Sound of Raasay)(Scotland) Regulations 1976
Continental Shelf (Protection of Installations) Order 1976
Continental Shelf (Protection of Installations) Orders 1976, Nos. 2, 3 and 4
Submarine Pipe-line (Inspectors, etc.) Regulations 1977 [S.I.1977 No.835]

Other References
Continental Shelf Operations Notices (Department of Energy, Petroleum Engineering Division, Room 1019, Thames House South, Westminster, London SW1).

No.8 Loss or Dumping of Synthetic Materials or other Refuse at Sea
No.10 Liaison with Other Bodies - Notification to Chief Constables of Location of Installations - Liaison with Fishing Interests - Seismic Activities
No.11 Consents to the Drilling and Abandonment of Wells
No.16 Notification of the Movement of Mobile Drilling Installations to HM Coastguard
No.33 Geophysical Surveys

Oil Installations in the North Sea; issued by the Department of Agriculture and Fisheries for Scotland on behalf of the United Kingdom Offshore Operators' Association
Two papers were presented which gave the results of experiments on the physical impact of fishing gear on pipe-lines. Each paper has been updated by its authors since the meeting, and each is reproduced here in full.

The first, by Carstens (C.M.1977/B:5) describes a series of international collaborative experiments on the effects of bottom trawling across pipe-lines on the sea bed, in which both field and model tests were used. Three field cruises employed three different vessels of 145, 697 and 1123 GRT. The gear included trawl doors up to 1800 kg and a beam trawl weighing 1720 kg, all pulled across a 300 m length of 40 cm pipe-line. The results of the field tests agreed well enough with the model tests to permit firm conclusions on the behaviour of otter trawl doors passing pipe-lines. Perhaps the most important result is that the crucial event, hooking of the pipe-line, was never observed with otter doors, but burial of a door in the bottom after release from a hold-up is possible, leading to the snapping of the warp. Impact damage to pipe-lines by trawl doors was insignificant, but beam trawls damaged the pipe-line coating.

The second paper, by de Groot (C.M.1977/B:8) concentrates on beam trawl experiments, and summarises their history and course. In particular, he details the improvements which can be made to beam trawl design to reduce their impact on pipe-lines, and describes how the work was extended to include submarine cables.

Bottom Trawling across Sea Pipe-Lines

(L T Carstens, C.M.1977/B:5)

Laying of Pipe-Lines

In order to appreciate the additional problems arising from trawling across pipe-lines, it is useful to have an understanding of the normal problems associated with the laying of submarine pipe-lines. The final stages in the construction of a pipe-line are therefore discussed first in general terms, omitting the technology of actually producing pipe sections.

Normal Procedure

The pipe is almost invariably made of steel and arrives on the site in 12 m long sections. The lay barge therefore acts as a pipe-line factory where the pipe sections are welded together (Figure 4).
The second step is to lower the finished pipeline from the deck to the sea bottom. This operation represents for most of the pipe-line the critical phase. The pipe-line is bent twice, first through the upper "over"-bend when leaving the barge, and then through the lower "sag"-bend near the bed.

For each pipe there is a maximum curvature that cannot be exceeded without damaging the pipe. The curvature of the sag-bend is controlled by pulling the pipe with a horizontal force, which is applied through a special tensioner on the lay barge. The over-bend also requires support by a so-called stinger, a ramp extending out from the barge (Figure 5).

![Figure 5](image)

If the pipe is properly laid, it will rest on a flat bottom without residual curvature due to yielding.

The third step is to lower the pipe into the sea bottom. For this purpose one utilises a trencher with either a rotating cutter head (Figure 6) or jetting nozzles, depending on the soil (Figure 7). The spoils are sucked into a pipe, discharged and carried away by any prevailing currents.

![Figure 6](image)
The resulting trench will vary in depth and width according to the strength properties of the soil. Clay supports vertical walls, and consequently a trench through clay is narrow. Sand on the other hand, has an angle of repos of perhaps 30°, and therefore a trench through sand becomes wider. In some muds the width of the trench gets very wide, while in other muds the pipe sinks in under its own weight.

The fourth and final process is the backfill, the burial of the pipe-line. This is normally left for Nature to accomplish, and natural backfilling by prevailing current and wave action has indeed proved to be satisfactory for thousands of kilometres of trenched pipe-lines.

Complications
Although the procedure described above has been successfully used under many different conditions, it may fail on a number of points.

Before the pipe-line is safely buried below the mudline, a trench has to be opened, the pipe-line must sink in, and the trench must be backfilled. Moreover, the pipe must remain in the buried position. On all these points failures have occurred in the past, resulting in an exposed pipe-line and sometimes in leaks.

A common occurrence is that the trench caves in before the pipe, which is fairly stiff, sinks in. As a result the pipe-line is lowered only a fraction of its diameter into the bottom for each pass of the trencher. Thus many expensive passes are required for the pipe to be completely buried.

When the trench sediments contain boulders that are too large for the trenchers to remove, the pipe may get hung up. To protect unsupported spans it is frequently necessary to resort to an expensive piling up by divers of sand bags all around the spanning pipe. Occasional rock outcrops are negotiated by the same method, while more massive rocks are blasted.
Pressure and shear force fluctuations from wave action propagate into a porous sea bed, and in certain muds pore pressures are built up. As a result contact forces between soil grains are reduced, sometimes to the extent that the soil structure collapses. The bed is then converted into a heavy liquid, i.e. a suspension of bed particles. If this happens in a backfilled trench and the density of the backfill suspension exceeds that of the pipe, some of the pipe will rise out of the trench.

There are on record cases where the sand drift is so negligible that natural deposition does not occur. In fact, the reverse process is also observed, where the trench is widened by scour.

PLANNED AND UNPLANNED EXPOSURE

Since a conflict between pipe-lines and fishing gear is unlikely for buried pipe-lines, the question of their exposure is a crucial one. Whether the exposed pipe rests on the undisturbed sea bed or in an open trench is less important as the open trench offers little or no protection.

A successful pipe-laying operation includes two periods of planned exposure, one on the undisturbed sea bottom and one in the trench.

With the present technology — and no change is expected in the near future — laying and trenching are two separate operations requiring highly specialised ships and gear. The interval between laying and trenching varies from a few months to a full year depending on the weather. In the North Sea the pipe-lines are likely to remain untrenched the first winter after laying.

Exposure in a trench during the backfilling period varies widely from a few hours to infinitely long. Normally the pipe-line is buried after a few weeks or months, but in any case the backfilling is considered successful if it is completed within one year.

Unplanned exposure is the result of any of the calamities described above and as such cannot be predicted except statistically. Such statistics are hard to come by, however, perhaps because pipe-line companies worry about adverse public reaction. Enough is known, however, to state that just about every pipe-line has one or more stretches where it is unintendedly exposed.

The Depth Problem

The present pipe-laying technology, in particular the trenching operation, is not designed for deep water. Today it is probably unrealistic to hope for a successful trenching when the depth exceeds, say, 200 m. This depth limitation is temporary, however, and the pipeline industry can be expected to come up with the innovations required to extend the depth range if a sufficiently strong demand for trenching of deep water pipe-lines is heard. As in many offshore operations, the cost of burying may turn out to be a rapidly increasing function of water depth.

Untrenched Pipe-lines

The difficulties encountered in the burying process have nourished doubts about the soundness of the entire effort. When planned exposure is part of the scheme and unplanned exposure is almost certain, why not design the pipeline so that burial is unnecessary?
The alternative approach is to let the pipe rest untrenched on the sea floor and protect it with a sufficiently strong coating or cover to withstand the anticipated forces.

A STUDY OF THE TRAWL PROBLEM

Background

The possibility of leaving the pipe-line untrenched triggered a study in Norway of the interaction between pipe-lines and bottom trawls, of which very little was known in 1973 when the project was initiated. The study still goes on, sponsored by an international group of interested parties including or having included British, Dutch and Norwegian government agencies and oil companies from these countries as well as from France, Italy and the United States.

The research is carried out by The River and Harbour Laboratory at the Norwegian Institute of Technology, Trondheim (VHL). It is a comprehensive study including theoretical work with mathematical models, small-scale laboratory tests and field tests with actual trawls in the Trondheimsfjord.

The steering committee has included representatives from the Norwegian Fishermen's Association, the Norwegian Fisheries Directorate and the Norwegian Research Institute for Fisheries and Technology.

There is a one-year freeze of the results after they have been reported to the sponsors. Until now two papers have been released (Gjørsvik et al., 1975; Carstens et al., 1976). This paper summarises the two previous papers and also includes some results that have not been published before, from field tests carried out in 1975.

Gear

The study has dealt in a rather general way with the encounter between bottom trawls and exposed pipe-lines. To date the most common trawl, the otter trawl, has been thoroughly investigated. Figure 8 shows the situation when one of these trawls is about to cross a pipe-line. Although in special circumstances the trawl net and its accessories may hook on to a pipe-line the major hazard, both to the gear and the pipe-line, is the passing of the trawl doors. For this reason only trawl doors were included in the test programme.

![Figure 8](image-url)

**Figure 8**

**THE OTTER TRAWL**
In 1975 when the investigation of otter trawls was nearing its completion, Dutch authorities convinced a smaller group of sponsors that the heavier beam trawl (Figure 9) should be tested as well.

The map in Figure 10 gives the distribution of the number of fishing hours with beam trawl by Dutch vessels in 1975. This relatively new gear is at present spreading rather rapidly. However, being specialized for flatfish, the beam trawl is not expected to be taken into extensive use in the deeper water of the northern North Sea.
The philosophy has been to let the laboratory results suggest and the field results confirm. Sometimes it works the other way round, however, and so for maximum progress alternating between laboratory and field is likely to be the best strategy.
In this study a rather comprehensive laboratory investigation was made of the otter doors prior to the field cruises. On the other hand, the beam trawl was first tested in the field in 1975 while the corresponding laboratory tests were carried out in 1976. A new set of field tests with the beam trawl, duplicating the most recent model tests, is planned with the 'Tridens' in August 1977.

The introductory paper study by Gjørvik and Kjeldsen (1974) identified a set of the more important variables described in Table 2 below. These were all tested within the practical limits of the laboratory and field experiments.

<table>
<thead>
<tr>
<th>FACTORS VARIED DURING THE PERFORMANCE OF THE MODEL TEST</th>
<th>ILLUSTRATION OF THE SITUATION (Not in scale)</th>
</tr>
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<tbody>
<tr>
<td>DESIGN AND SIZE OF TRAWL DOOR</td>
<td><img src="image" alt="Illustration of trawl door designs" /></td>
</tr>
<tr>
<td>RELATION PIPELINE DIAMETER (D) TRAWLDOOR HEIGHT (H)</td>
<td><img src="image" alt="Illustration of pipeline diameter relation" /></td>
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<tr>
<td>ANGLE OF INCIDENCE (≤) (ANGLE BETWEEN THE LONGITUDINAL AXIS OF TRAWLDOOR AND PIPELINE)</td>
<td><img src="image" alt="Illustration of angle of incidence" /></td>
</tr>
<tr>
<td>PIPELINE POSITION ON BOTTOM</td>
<td><img src="image" alt="Illustration of pipeline position" /></td>
</tr>
<tr>
<td>RIGIDITY OF PIPELINE SYSTEM</td>
<td><img src="image" alt="Illustration of pipeline rigidity" /></td>
</tr>
<tr>
<td>LENGTH OF TOWING WARP</td>
<td><img src="image" alt="Illustration of towing warp" /></td>
</tr>
<tr>
<td>TOWING SPEED</td>
<td><img src="image" alt="Illustration of towing speed" /></td>
</tr>
</tbody>
</table>

**Table 2**

**THE LABORATORY INVESTIGATION**

Test set-up

The testing facilities are described by Gjørvik et al. 1975. For convenience the main data are repeated below:

The model tests were performed in a wave basin at VHL. The basin is 54 m long, 5 m wide and 1.45 m deep (Figure 11). A 20 cm thick layer of sand with d50 = 0.25 mm covered the floor.
Admittedly, only a rather imperfect modelling was feasible in the laboratory. We chose to sacrifice half of the trawl to gain on model scale. Accordingly, we operated one tow line only, employing several tricks to make up for the missing parts of the actual system. The limited width of the flume also called for devices to reduce the stiffness of the pipe to allow reasonable deflections under the applied warp force. The following major adaptions were made: a) The drag of the trawl was simulated by towing either a parachute with primarily hydrodynamic drag or a weight with primarily bottom friction. b) The warp characteristics were changed by inserting springs in the tow line. c) The pipe-line section was made flexible by attaching the ends to an elastic frame.

Model scale and model law
A length scale of $L_r = 1:4$ was decided upon, and since gravitational forces were important, Froude's model law was the natural choice for the experiments. According to Froude's law the following main conversion factors apply:
velocity \( L_v^{3/4} = 1:2 \)  
acceleration \( L_a^0 = 1:1 \)  
time \( L_t^{3/4} = 1:2 \)  
force \( L_f^3 = 1:64 \)

The pipe diameters to be simulated were \( D = 0.4 \) and \( 0.9 \) m, i.e. model diameters \( D_m = 0.1 \) and \( 0.225 \) m, respectively.

Test programme

A listing of the test parameters is presented below. All dimensions have been converted to full scale by applying Froude’s model law.

Otter doors (Fig. 12 above) Table 3

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Weight</th>
<th>Height H</th>
<th>2 D/H</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>rectangular</td>
<td>1100</td>
<td>1.52</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.18</td>
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<td>2</td>
<td>V-shaped</td>
<td>1550</td>
<td>1.84</td>
<td>0.43</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0.97</td>
</tr>
<tr>
<td>3</td>
<td>V-shaped</td>
<td>500</td>
<td>1.24</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.45</td>
</tr>
<tr>
<td>4</td>
<td>oval</td>
<td>1200</td>
<td>1.84</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.97</td>
</tr>
</tbody>
</table>

Figure 12
Angle of incidence  The majority of the tests was performed with the tow line perpendicular to the pipe-line. As the angle of attack was approximately 25°, the angle of incidence became 65°. The pipe-line was then rotated to allow the angle of incidence to become 90° and 25°, respectively.

Pipe-line/sea bed configuration  The simulation included pipe-lines in an open trench as well as freely suspended above the bed, in addition to the central case with the pipe just touching the bed. The side slopes of the trench were kept constant at 1:4 while two trench depths of 1D and 2D were tried out. The clearances for the spanning pipe were also 1D and 2D, respectively.

Deflection of pipe-line  Horizontal displacement of the pipe-line was estimated using a simple theory which neglected axial forces and assumed static reaction forces from the ground with a coefficient of friction \( \mu = 1 \).

Length of towing warp  Elastic springs were used to simulate various warp lengths for a wire with known stress-strain curve. Warp lengths of 50, 100 and 200 m were used.

Towing speed  Two towing speeds were tested, corresponding to 3.5 and 5 knots.

Hooking  This important case was given special attention, and a set of hooking tests was made with the trawl doors laying flat when pulled towards the pipe.

Laboratory results

Hooking  Probably the most important observation was that hooking of the pipe-line never occurred when the attitude of the trawl board was normal, that is, the board was upright and not flat on its outer side.

Upon impacting the upright boards in one way or another passed the pipe-line and quickly resumed normal attitude. This behaviour was surprisingly similar whether the pipe-line was resting on the bottom, suspended above it or placed in a trench.

However, for small angles of incidence another kind of hooking took place, caused by the hold-up of the trawl board at the pipe for a few seconds. During this delay in passing, the warp was stretched elastically. When the board suddenly released itself, the rubber string action of the warp almost instantly accelerated the board to a very high velocity.

The V-shaped board actually took off for a flight of a few metres and, when landing, dug itself firmly into the bottom.

While this hooking of the bottom did not harm the pipe-line in any way, it represents a hazard to the trawler. The warp might snap not during, but after the crossing of the pipe-line.

The tests with provoked hooking of a fallen board demonstrated a lever action that can raise the force on the pipe-line to several times the warp force (Figure 13). The actual release force in the warp depends on the strength of the soil and on the stiffness of the pipe in addition to the geometrical configuration. Unless a large trawl board is wedged in below a small pipe, the pipe-line will deflect or the soil will fail so that the board is released before dangerous strain develops in the pipe-line. If a hooked pipe-line for some reason is prevented from deflecting, however, it may fail.
Towing forces A typical force record is shown in Figure 14 below. The first peak in the towing force is the actual impact, which has a typical duration of 0.01 second. The second peak is the force required for the trawl board to be pulled across the pipe-line, with a duration of order 1 s.

Several of the test parameters had a significant influence on the warp force. For instance, this force increased with decreasing ratio D/H and decreased with increased warp length. But as long as the warp force does not approach the elastic limit, no harm is done, and therefore these results are of secondary practical importance. They are useful, however, for estimating scale effects in the tests.

Impact forces The impact force depends on the elastic properties of the colliding bodies, which are hard to model correctly. It was not the purpose of these laboratory tests to investigate impact, so the recorded impulse has not been used for prediction. Nevertheless, the sequence of events, later to be seen in the field, was well displayed in the force records of the laboratory experiments.

FIELD INVESTIGATION

As little or no experience existed with scaling of laboratory results of the kind described above, field tests were considered essential.

Site A site was chosen in Bjugnfjorden, located 100 km northwest of Trondheim. This site met our requirements to convenient diving depth (20 m), bottom sediments (sand, gravel), proximity to shipyard for welding of the pipe-line, and to Trondheim.

Pipe 300 m of 40 cm (16") diameter pipe (steel API-X60) were purchased, with an external anti-corrosion coating of 3 mm polyethylene. Half of the length had a 40-50 mm thick weight coating of concrete (BREDERO PRICE B.V.'s "Hevicote").
Figure 1.2

INSTRUMENT BOAT

ENVIRONMENTAL DATA:

- INSTRUMENT BUOY

- DIVER BOAT
- TV-BOAT

- PIPELINE
- TOWING WARP

Figure 15
Anchoring  The pipe ends were fastened to the sea bed in order to keep the pipe from rolling and to absorb axial loads more or less as a continuous pipe-line would. A 3 m long triangular steel frame was welded to each end. Through 24 guides on the frame, 1 m long 50 mm steel pipes were driven into the ground with a pneumatic hammer. The holding capacity was estimated to be about $10^5$N horizontal force.

This anchoring system was considered adequate for the first field cruise with light gear, and indeed turned out to be so. Before the second field cruise, with heavier gear, the anchoring was strengthened with two 50 m anchor chains that were nailed to the bottom in the same way as the frame. The chains were placed perpendicular to the pipe on the side from which the trawler came. However, it turned out that this anchoring was insufficient. In retrospect this experimental flaw turned out to be serious, as it blurred the evidence of the only test that damaged the pipe.

Vessels  For the first cruise an all-round fishing vessel of 145 GRT "Nyvarden", was chartered between seasons. Two smaller boats were also needed, one for the divers and one for the recording instruments. Figure 15 (p.33) shows the general layout of the test site and how instruments and cameras were deployed.

The second cruise employed the Dutch research vessel "Tridens" of 1 123 GRT. The ship is built as a stern trawler and has a bow thruster, which was a great advantage during manoeuvres in the rather narrow fjord.

The purpose of the "Tridens" cruise was to test the beam trawl and to extend the range of otter doors to the largest sizes encountered in the North Sea.

The third cruise was made with the Norwegian research vessel "Johan Hjort" of 697 GRT. For this test series the pipe-line had been elevated and rested on special bents as shown in Figure 16 below.

![ELEVATED PIPE-LINE](image)

In this way a spanning pipe was simulated, a suspect case associated with an added risk of hooking, which was not confirmed in the tests.

The vessels used in the field tests are seen in Figures 17-19.
TRAWL TEST P-34. (Time history)

Figure 20

1. START OF IMPACT
2. POSSIBLE TUMBLING OF DOOR
3. DOOR SLIDING ALONG PIPELINE
4. PULL OVER PIPELINE
5. FLYING OVER BOTTOM
6. DIGGING IN BOTTOM
7. STABILIZING TO NORMAL TOWING
A total of trawl passes were made across the pipe-line, distributed as follows: "Nyvarden" 50, "Tridens" 41 and "Johan Hjort" 16.

"Tridens" was better equipped than the other vessels. For instance, all signals could be transmitted from the gear via a net sonde cable to the bridge, while the other vessels required an auxiliary "electronics" boat.

Measurements and Observations

With a reasonable effort it proved feasible to obtain recordings of the towing force and the accelerations of the trawl during impact with and passing of the pipe (Figure 20, p.36). Divers identified hit marks and described the damage inflicted on the pipe. Trawl tracks on the bottom were obtained partly from diver photos and TV films and partly from sidescan sonar records (Figure 21 below). Hit points were determined with an acoustic system consisting of a pinger on the trawl and a hydrophone at either end of the pipe.

In the last two cruises ship tracks were obtained with high precision using ARTEMIS and MOTOROLA navigation systems, respectively.
Laboratory vs Field Tests

The field tests confirmed our qualitative laboratory findings with otter doors very well. The force records, of which Figure 20 is an example, reveal the same sequence of events as in the laboratory study (Figure 14, p.32).

In Table 4 are listed those field tests that were nearly duplications of laboratory tests. When one considers the crude reduced scale model, the quantitative agreement is rather surprising.

<p>| Table 4 |
|------------------|------------------|------------------|
| <strong>Upscaled laboratory test</strong> | <strong>Field test</strong> |
| <strong>Test</strong> | <strong>Angle of incidence</strong> | <strong>Velocity</strong> | <strong>Towing force steady max.</strong> | <strong>Test</strong> | <strong>Angle of incidence</strong> | <strong>Velocity</strong> | <strong>Towing force steady max.</strong> |</p>
<table>
<thead>
<tr>
<th>No.</th>
<th>ε</th>
<th>V</th>
<th>FT</th>
<th>FT²</th>
<th>No.</th>
<th>ε</th>
<th>V</th>
<th>FT</th>
<th>FT²</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>65</td>
<td>2.57</td>
<td>15100</td>
<td>33600</td>
<td>P-34</td>
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<td>15450</td>
<td>44000</td>
</tr>
<tr>
<td>32</td>
<td>65</td>
<td>2.57</td>
<td>15600</td>
<td>36200</td>
<td>P-36</td>
<td>59</td>
<td>≈ 2.6</td>
<td>15600</td>
<td>Hooking</td>
</tr>
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<td>44900</td>
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<td>14600</td>
<td>66600</td>
</tr>
<tr>
<td>47</td>
<td>90</td>
<td>1.80</td>
<td>11600</td>
<td>20400</td>
<td>P-28</td>
<td>87</td>
<td>≈ 2.6</td>
<td>16400</td>
<td>58200</td>
</tr>
<tr>
<td>48</td>
<td>90</td>
<td>1.80</td>
<td>10000</td>
<td>19700</td>
<td>P-31</td>
<td>91</td>
<td>≈ 1.5</td>
<td>16510</td>
<td>26100</td>
</tr>
<tr>
<td>49</td>
<td>90</td>
<td>1.80</td>
<td>11400</td>
<td>21400</td>
<td>P-32</td>
<td>94</td>
<td>≈ 2.1</td>
<td>15250</td>
<td>54800</td>
</tr>
<tr>
<td>50</td>
<td>90</td>
<td>1.80</td>
<td>10600</td>
<td>20800</td>
<td>P-33</td>
<td>94</td>
<td>≈ 2.1</td>
<td>15770</td>
<td>26700</td>
</tr>
</tbody>
</table>

Hooking

Otter doors  The laboratory results with hooking of otter doors were well confirmed. In no case did hooking of the pipe without subsequent unhooking take place, and in no case did the warp force exceed the yield strength of the warp.

However, for angles of incidence less than 45° there was a sufficient hold-up of the trawl-door to shoot it deeply into the sea bed upon release.

These cases of hooking the bottom were dangerous for the crew, as the warp snapped twice.

In another case the ship was stopped completely without breaking the warp, because its velocity was low enough.

When crossing a pipe-line at a small angle, the prudent trawler should slow down to the minimum speed required to keep the otter doors from falling.
Beam trawl After 15 undramatic passes with the beam trawl, the pipe was hooked in the 16th run and bent as seen in Figures 22 below and 23 (p.40).

Figure 22

Figure 24 (p.41) gives the warp force history during this event.
Although hooking did occur, there are doubts about how well the circumstances of that test simulated a real pipe-line. The trawl hit closer to the end of the pipe than in previous passes. The anchoring failed, but the manner in which it failed is not known. At any rate the time history of the warp force in Figure 24 suggests that the force required to fail the pipe is about \(8 \times 10^4\)N, which is only a fraction of the breaking strength of an ordinary warp line.

![Diagram](image_url)

The fear that a spanning pipe is very prone to hooking was not substantiated for otter doors. It never happened with the door in normal upright position. Hooking of a fallen door did happen once at low towing speed, 1.2 - 1.5 knots. The trawler was brought to a full stop against the thrust of the propellers, but neither the warp nor the pipe failed. The recorded warp force was \(4.9 \times 10^4\)N, which is less than the yield force of the pipe. Again the hooking occurred close to a discontinuity in the pipe-line, this time near the bend. Perhaps the bend prevented the pipe from deflecting, and so the trawl did not unhook.
Hooking of the Bottom

For angles of incidence less than 45° hooking of the bottom happened three times with otter doors. Figure 25 shows one of these situations as sketched by the divers. The vessel was stopped and held by the warp one time when the speed was low, while the warp snapped twice.

The hold-up of the otter door at the pipe resulting in stretching of the warp, the subsequent release, flying and landing of the door, thus may create a dangerous situation for the crew. The beam trawl never caught the bottom, probably because it does not fly well.

Impact

Impact forces were derived from observed accelerations of the trawl door and the beam, respectively. Figure 26 (p.43) shows the acceleration record of the test that yielded the highest value, $a_x = -322 \text{ ms}^{-2}$. Decelerations around $30 \text{ g}$ were not uncommon for the lighter doors, producing forces of $15 \cdot 10^4 \text{N}$ and $30 \cdot 10^4 \text{N}$ for the doors weighing 500 kg and 1000 kg, respectively (Force = acceleration times mass).

The accelerations decreased somewhat for the heavier doors, but not enough to prevent the impact force from increasing with increasing trawl weight (Figure 27, p.44).
STARBOARD DOOR
(Pressure side)

\[
\Delta t \int_0^t \dot{x} \, dt = 2.104 \text{m/sec.}
\]
\[(dt = 0.1875 \cdot 10^{-3} \text{sec.})\]

TRAWL TEST P - 28

Data from navigation routine: \(V^* = 2.11 \text{m/sec.}\)
Angle of incidence for trawl door: \(\epsilon = 91^\circ\).

\(\dot{x} = 322 \text{m/sec.}^2\)

IMPACT TIME
\(\Delta t = 1.01 \cdot 10^{-2} \text{ sec}\)
\(= 1/1000 \text{ sec}\)

PERPENDICULAR IMPACT

\(0 - \text{LEVEL}\)

Figure 26
Damage Impact is a symmetric event in the sense that equal forces are felt by both colliding bodies. Mutual damage is conceivable, but damage due to impact was almost exclusively on the pipe-line. In all of the more than 100 collisions the trawl gear was damaged once, while the pipe-line suffered badly.

In spite of the large impact forces \((0.3 - 0.4 \text{ MN})\) generated by the otter doors, the damage to the pipe was rather insignificant. There was some flaking of the concrete coating down to the reinforcement netting, with the largest piece falling off \(30 \times 30\) cm.

It was only after the beam trawl was introduced that severe damage appeared. Practically every pass left holes in the concrete coating. Figures 28 and 29 (p.45) give an impression of what the pipe-line looked like after it was recovered.

The result is interesting because the observed accelerations were not much higher for the beam trawl than for the otter doors. The inference is that geometrical details are important, and if so, the chances of improving the design of the beam trawl are good indeed.
Conclusions

The investigation at VHL has to a large extent clarified the behaviour of bottom trawls encountering exposed pipe-lines. In particular, we feel that the crucial event, hooking, has been rather thoroughly studied and is now well understood. At this stage the following conclusions can be drawn from the continuing study:

Hooking without unhooking is a dangerous, but remote event. It requires a) an improperly operated otter door lying flat when hitting the pipe-line, b) a spanning pipe-line with a small bottom clearance, c) restraints that prevent horizontal deflection and d) a stiff bottom material. Conditions a) and b) are prerequisites for engaging the trawl, while c) and d) are necessary to prevent unhooking.

The consequences are likely to be disastrous for the pipe-line when the trawl warp has enough strength to bend or buckle the pipe as was the case with the 16" test pipe-line.

Hooking with unhooking, or hold-up of the trawl by a pipe-line, is a fairly common occurrence for crossings at angles smaller than 45°, when the trawl tends to slide along the pipe-line several seconds before passing. This mode of passing does not harm the pipe-line, but is a hazard to the crew of the trawler. Upon release, otter doors may catch the bottom so firmly that the warp snaps.

Impact was observed in field tests with a 40 cm pipe-line to have a typical duration of 0.01 second. Maximum force for trawl doors or beam trawl less than 1 800 kg was 0.4 - 0.5 MN.

Impact damage to the trawls was insignificant.

Impact damage to the pipe coating was insignificant for all tested otter doors. The tested 1 720 kg beam trawl caused severe damage for almost every impact.

From the point of view of impact damage, the beam trawl seems to have a poor shape. On the other hand, the possibility of improving the trawl is correspondingly good.

Acknowledgements

Invaluable input to the study reported here came from both of the two offshore adversaries, the oil industry and the fishing industry. The VHL staff as well as the hired hands worked diligently on this unusual and sometimes rather tough assignment.

The greatest individual effort was made by the late Ola Gjørsvik.
Summary of Subsequent Work 1976-77

The investigation of trawl/pipeline interaction continued in 1976-77 with a laboratory study of beam trawls (Extension II) followed by a second field test in August 1977 (Extension III). The sponsors of Extension II were: Bredero Price B.V.; Department of Energy, United Kingdom; Esso Exploration and Production, Norway Inc.; NORPIPE A.S.; Rijkswaterstaat; Shell International Petroleum Co.

Extension III was sponsored by the same group plus STATOIL.

On request I have added this summary of the two extensions of the trawl programme at VHL.

Laboratory tests

The laboratory study of the beam trawl was similar to the previous otter trawl study in that it covered much the same ground. The test parameters were towing speed, angle of incidence, pipe diameter, pipeline/sea bed configuration and pipeline deflection. The length scale 1:4 allowed the entire beam trawl to be reproduced.

The broad similarity observed previously between model and prototype behaviour encouraged attempts at quantitative prediction, and theoretical models were proposed for both towing force and impact force.

The main purpose of the laboratory tests was to identify worst cases. For the towing force this proved, not unexpectedly, to be an angular crossing with the pipeline resting on the sea bed. Another high-force case was a normal crossing of 0.4 m pipeline with a bottom clearance of one diameter.

Hooking was never observed, and seems as unlikely to happen with the beam trawl as with the otter trawl. Hooking of the bottom after hold-up at the pipeline, an event that did happen with the otter doors, never occurred with the beam trawl.

Impact was observed by means of an accelerometer that recorded central impact only. The geometrical factors preventing central impacts were mapped.

A special concern was the possibility of reducing forces by modifying the design of the beam shoe. Simple changes proved very efficient, as for instance the addition of extra bridles and deflecting hoops. Reductions of the towing force by 50% were obtained.

Field tests

The purpose of the field tests was to obtain information on a variety of trawls passing a big pipeline. The field campaign, employing again R/S "Tridens", resulted in the following 38 successful tests:

<table>
<thead>
<tr>
<th>Type of gear</th>
<th>Dry weight kg</th>
<th>No of tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular doors</td>
<td>1472</td>
<td>1</td>
</tr>
<tr>
<td>Rectangular doors</td>
<td>860</td>
<td>4</td>
</tr>
<tr>
<td>V-door</td>
<td>1490</td>
<td>8</td>
</tr>
<tr>
<td>Oval door</td>
<td>2320</td>
<td>10</td>
</tr>
<tr>
<td>Conventional beam</td>
<td>1840</td>
<td>8</td>
</tr>
<tr>
<td>Modified beam</td>
<td>2010</td>
<td>7</td>
</tr>
</tbody>
</table>
The test pipe data are given in Table 5. The test site was in Stjørdalsfjorden not far from the Trondheim airport. The water depth was 17 m, except for a 25 m wide pit where the bottom was excavated from 1 to 4 m. Across this pit the pipe was spanning.

The anchoring of the pipe, which caused problems in the previous field tests, was adequately solved in a very simple manner. The outer 75 m was filled with water.

Table 5

<table>
<thead>
<tr>
<th>Test pipe data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Outer steel diameter</td>
</tr>
<tr>
<td>Wall thickness</td>
</tr>
<tr>
<td>Steel quality</td>
</tr>
<tr>
<td>Corrosion coating</td>
</tr>
<tr>
<td>Concrete coating</td>
</tr>
<tr>
<td>Total outer diameter</td>
</tr>
</tbody>
</table>

Reinforcing of concrete coating:
- 8 mm steel bar spirally wound around pipe at centre of concrete layer.
- 12.5 mm steel bars along pipe, spot-welded to spiral.

Results

The most important observation was that the big pipe-line survived the ordeals of the tests virtually unharmed. The pipe-line was subjected to the heaviest gear, and the recordings show very high impact forces. Yet the pipe coating suffered no serious damage, in contrast to the previously tested pipe-line.

Impact The recorded accelerations are shown in Figure 30 (p.49). The peak values are about 2.5 times those of the 1975 tests given in Figure 27. The large spread is more than a simple theory of central elastic impact can account for, the ratio of calculated to observed force varying by an order of magnitude between 0.96 and 11.6. Again the small rectangular door gave the highest force 0.75 MN. The beam trawl produced rather high impact, which was not substantially reduced by the modifications tested.

Towing force The maximum towing force was typically about 0.1 MN for the trawl doors, and about twice that for the beam trawls. The reduction in pull force for the modified beam was some 20%.

A special feature of the force records for the beam trawl was superimposed spikes of very short duration, 0.01 - 0.005 s. These random tension events just about doubled the instantaneous towing force. Their origin is believed to be local hold-up of the bridles in the roughness elements of the concrete.
Hooking The nearest case of hooking was a hold-up of a rectangular door for 4.4 seconds at the pipe, raising the towing force to 0.16 MN. Perhaps the door dipped into the sea bed, which then failed locally under the lever action of the door. In no case was hooking of the beam trawl observed.

Conclusions
Extensions II and III of the trawl programme have left two main impressions:

1. The beam trawl seems as capable of passing a large diameter pipe-line without hooking as are otter trawls.

2. The concrete coating of the 36" pipe-line delivered by Shell/Esso seems adequate for the loadings caused by trawl gear.
The Relation between Beam Trawling and Submarine Pipe-Lines and Possible Adaptations of the Fishing Gear to Reduce the Impact Forces

(S J de Groot, C.M.1977/B:8)

Introduction

The oil/gas industries were the first to recognise the problems which might arise when pipe-lines which it had not been possible to protect by burial were hit by fishing gear and dragging anchors (Brown, 1971, 1972; Ellis, 1975). The general attitude was that a state-of-the-art had been developed that would permit the engineer to design an adequate pipe protection system. Also that the risk level from damage by fishing gear and anchors for non-buried pipe-lines could be improved.

In the beginning of the 1970s a Committee was appointed by the Norwegian Royal Ministry of Industry, the Deep Water Pipe-line Project Committee (DWPPC). This Committee studies the problems likely to be met, when in the North Sea and in its adjacent water, owing to either adverse marine environmental or to soil conditions, pipe-lines could only be partly trenched or not trenched at all. A non-buried pipe-line is exposed to trawl gear and dragging anchors and could be hit and possibly damaged (de Groot, 1975).

The North Sea Directorate of the Netherlands Ministry of Public Works and Transport carried out an extensive literature survey on anchor penetration into the North Sea bottom (Koster, 1973, 1975). The main conclusion in relation to the safety of pipe-lines was that for the largest of some of the most usual types of anchors used, digging into a sandy bottom may be estimated at 2.0 to 2.5 m.

Research in relation to fishing gear and pipe-lines

The DWPPC Committee - via the River and Harbour Laboratory (VHL), Trondheim, Norway - carried out a literature study (Gjørsvik and Kjeldsen, 1974), and a model study to clarify the factors which influence the behaviour of trawl doors, including the forces which act when the gear passes the pipe-lines (Gjørsvik and Kjeldsen, 1975a). They also carried out field tests to study the behaviour and impact of the fishing gear upon a 16 inch pipe-line with a length of 300 m. The fishing vessel and gear used in the experiments were of medium size, a 145 ton trawler (length 31 m, 450 HP) towed otter trawls with V-doors (500, 975 kg) over the test pipe. For a full description see Gjørsvik, Kjeldsen and Lunch, 1975; Gjørsvik, Kjeldsen and Tekle, 1975.

The tests were carried out by the VHL, Trondheim, while the steering and funds came from a team of 15 sponsors. The main report was given limited circulation and was published one year later (Gjørsvik and Kjeldsen, 1975b). The paper by Carstens, Kjeldsen and Gjørsvik, 1976, is also relevant.

The problems which might result from the interaction of beam trawls and pipe-lines, and other submarine installations of the offshore industry, were not generally recognised at that time.

This was appreciated, however, by a small team of research workers within the North Sea Directorate RWS-Rijswijk and the Netherlands Institute for Fishery Investigations, who independently of the Norwegian experiments, of which they were totally unaware, tried to start a field test to study
the beam trawl/pipe-line relationship. As the pipe-line coating industry, at that time, performed only impact tests to simulate the contact between trawl doors and pipe-lines with relatively low impact forces, this team was not convinced by the known facts that pipe-lines could not be damaged by fishing gear and anchors. The coating industry performed their tests on a section of pipe, in air, which was struck at half height horizontally 40 times, by a 1 000 kg weight at a speed of approximately 2 m/sec (4 knots). The average weight of the rigid part of a beam trawl could, however, be estimated, at that time, to be approximately 4 000 kg and the average fishing speed 3 m/sec (6 knots).

It is also possible that beam trawls could become entangled under a free spanning section of a pipe-line. The breaking strain of the towing warp varies between 30-40 tonnes, and a 36-inch pipe under water only has a weight of approximately 225 kg/m (γ - 1.25). There is a likelihood that a confrontation between an entangled beam trawl on a pipe-line might lead to a dangerous situation.

As the costs of performing this type of field test are very high, and we became aware of the work performed in Norway, it was thought to be better to join forces with the VHL Laboratory, Trondheim.

A proposal was made and accepted by a team of 6 sponsors to revive the just terminated investigations, in which the Netherlands took a greater share of the costs as the beam trawl is a typical Dutch fishing gear, hardly in use, with a small exception for Belgium and the Federal Republic of Germany, in other countries (de Groot, see this report).

The field tests were carried out on the same 16-inch pipe-line as mentioned above in the summer of 1975.

The new field tests with trawl gear were carried out in collaboration with the VHL in the Bjugnfjorden near Trondheim, for the greater part with the Netherlands R/V "Tridens" of the Ministry of Agriculture and Fisheries.

It was shown that a beam trawl could destroy the concrete coating and corrosion protection down to the steel. The concrete weight coating was removed each time the beam trawl hit the pipe-line, sometimes over the whole pipe diameter. A special polyethylene coating, sold as trawling gear resistant, was cut through over a length of 20 metres or more, and big flakes of this type of coating were removed.

In the discussions of the team of sponsors after these field tests, it was put forward that it was perhaps possible to adapt the beam trawl (Figure 31 (p.52) - original model) a little to make it slide more easily over pipe-lines. The suggested changes were:

- a hoop in front or a new type of rounded shoe (Figures 32 and 33, p.52)
- a double bridle in front of the trawl (Figure 33).

In May 1976 a new team of six sponsors agreed to ask the River and Harbour Laboratory (VHL), Trondheim, to perform a model study on the behaviour of a beam trawl passing a pipe-line. The results of this study were published in a report in the middle of 1977 by Kjeldsen, Langen and Moshagen, 1977. The study consisted of a simple mechanical analysis of the beam trawl; how a model (physical) 1:4 of the beam trawl in a test basin passed over pipe-lines of various diameters (16, 36-inch) and under various circumstances, e.g. free spanning, partly buried, open trench.
Figure 31. Sideview of a beam trawl shoe as used in Norwegian experiments. Also a cross-section of a 16 inch pipeline is shown.

Figure 32. Sideview of an adapted beam trawl shoe, a hoop is welded in front.

Figure 33. Sideview of a proposed type of beam trawl shoe and the double bridles.
The adapted version of the beam trawl was also studied in comparison with the old version in relation to the previously mentioned factors. A mathematical impact model was also studied and the results compared with the physical model. The field data gathered in the earlier experiments were evaluated in this new study. The experiments were successful and elucidated several earlier experiments. The best design reduced the pull-force to about 30% of the value found without the modifications.

The results of the model test - Extension II programme - gave impetus for a new series of experiments and field tests (Extension III programme) with various bottom trawling gear, e.g. the beam trawl with and without the adaptations, on a 36 inch pipe-line. The 36 inch pipe-line test section was composed of spare joints from the Brent line and Emden-Ekofisk line.

An entirely new heavily armoured coating was used to cover these sections. The Netherlands Fishery Research vessel R/V "Tridens" took part in the 1977 field tests in the Trondheimfjord, Norway, carried out again with the VHL Laboratory (Kjeldsen and Holthe, 1977a,b; Kjeldsen, 1978).

In this report Carstens describes the investigations in more detail. It was found that an adapted beam trawl slides more easily over the pipe-line on the bottom. A reduction of the towing force of about 50% was observed and this was in accordance with the model tests.

A very important conclusion was that the now applied concrete coating could fully resist the attack of various trawl gears. The scratches on the coating were negligible.

As mentioned above, the adaptations of the beam trawl were discussed at the VHL, just after the first field tests with the beam trawl on a 16 inch pipe-line in the Bjugnfjorden in the late summer of 1975.

In discussions with Ir. F Lous of the North Sea Directorate, the idea emerged that these adaptations could be also beneficial to counter part of the cable faults of submarine telephone cables in the southern North Sea, as an adapted beam trawl would slide far more easily off the cable. The model tests carried out at the VHL in 1976 with the adapted beam trawl, just a hoop in front, gave further impetus to these thoughts. Contact was made with the Dutch Post Office also in 1976 and the adaptations suggested to the Nautical Department.

Here we were informed of the existence of the International Cable Protection Committee (ICPC) and their fruitless efforts to solve the adverse effects of fishing on submarine telephone cables. This led to direct contact with Captain R S Aitken of the Post Office Telecommunications, Marine Division, Southampton, who acted also on behalf of the ICPC.

When the proposal was made for Extension III of the field tests with 36 inch pipe-line, telephone cables were also incorporated in the programme, and discussed at the VHL-Trondheim on the 14 April 1977. Representatives of the ICPC and the Asea cableworks, Stockholm, attended the meeting. Problems around the split of the costs between the offshore oil and gas industry and telephone cable people were solved; however, the ICPC was just not able to provide the estimated costs of Dfl. 120,000,-. Therefore it was decided to continue only the pipe-line fishing gear aspect of the programme.

Again, an attempt was made to start field tests on telephone cables at the end of 1977 on bilateral basis between the United Kingdom and the Netherlands. In the meantime the ICES Statutory Meeting in 1977 took place with the Special Meeting on the Interactions between Fishery and Offshore Oil and Gas Activities. R S Aitken contributed (see his report), outlining history of the work carried out on this problem by the G.P.O. and also pointing out that the area in which about 30% of the cable
faults occur corresponds with the location of maximum beam trawling by Dutch and Belgian vessels. Discussions at the meeting led to the Council Resolution 1977/4:2 that "member countries should be urged to give favourable consideration to cooperating with the 'International Cable Protection Committee' on problems arising from conflicts between fishing operations and submarine cables".

At a meeting held in The Hague in November 1977, mentioned above, field tests were planned again. However, this time the costs were estimated at Dfl. 280,000.-.

In the meantime at the Post Office Research Centre, Martlesham Heath, Ipswich, an attempt was made to simulate on land the effect of a beam trawl on a 1.47 inch armoured cable. The results were very promising, it being shown that the same type of damages occurred as found at sea, causing difficulties in the location of shunt faults.

It was estimated that to equip the Dutch beam trawl fleet with adapted beam trawl shoes (1977 prices), assuming 6 trawl shoes per vessel and 400 beam trawlers in total, would cost about Dfl. 4 million. These adapted shoes would lessen the impact on pipe-lines and would be less dangerous to submarine telephone cables.

Trawl shoes adapted only to lessen the risks to telephone cables are of course less expensive. In this field a step forward was made by the Dutch Post Office, in 1978, by equipping on an experimental scale a few beam trawlers with adapted shoes to counteract cable damages (de Bruin, 1978). They clearly showed that the way to solve this problem, as discussed at the various meetings during the years, is simple. An academic approach is not needed, merely a simple adaptation of the gear, performed by the fisherman and the supplier of his trawl gear, based on instructions by the authorities.

Funds to cover the expenses are, of course, needed.

Figure 34. Beam trawl shoe adapted to trawl over telephone cables, hoops are welded in front (after de Bruin, 1978).
FISHING ACTIVITIES AND PIPE-LINES

Four papers were presented relevant to this topic, and three of them are reproduced here in full.

Lous (C.M.1977/B:13) points out that a careful evaluation is needed of all users of the sea and the sea bed before a pipe-line route is established and that the pipe-line as well as the users must be protected. He gives data on the depth of penetration of anchors into the sea bed, and proposes 2 m as the required depth of burial for pipe-lines.

De Groot (C.M.1977/B:9) gives data on the location and type of the main Dutch fishing activities as a background against which to consider possible interactions with pipe-lines, and the paper by MacLennan and Strange (C.M.1977/B:33) deals in the same way with fishing activities in the northern North Sea. The gears most commonly used in this area are the smaller otter trawls and the seine net, but the low momentum of these light gears implies that their influence in contact with exposed submarine installations should be limited to abrasive effects. The most important gear to be considered as regards shock and point loading effects on pipe-lines is undoubtedly the heavy otter trawl used by vessels larger than 800 HP. The momentum of a heavy beam trawl is also substantial, but this is seldom used in the northern North Sea. Paper C.M.1977/B:33 is not reproduced in this report as it is available as Working Paper N. 77/10 from the Marine Laboratory, Aberdeen.

The fourth paper (C.M.1977/B:32, by Aitken) deals with faults in underwater cables in the southern North Sea. The author notes that sea bed formation is likely to be a factor relevant to fault rates, but he also indicates a positive correlation between high fault rate and beam trawling intensity. The experiments described in the previous section of this report are obviously relevant.

Burial Depth Requirements and Experience with Pipe-Line Burial on the Dutch Continental Shelf

(F Lous, C.M.1977/B:13)

Introduction

Due to the spectacular technical developments of the last century the sea and the sea bottom are now accessible to mankind for various activities such as: shipping, fishing, communication cables, defensive activities, offshore mining, land reclamation, dumping of waste materials and construction work for shipping or offshore mining. Offshore pipe-lines can influence or limit some of these activities, or even be in direct conflict. Careful route selection is necessary in order to limit - as far as possible or acceptable - interference of the pipe-line with other users of the sea bottom. Pipe-line routes in the southern part of the North Sea cannot steer clear of all these users, and will encounter most of them. Therefore, protection of the other users as well as the pipe-line is necessary.

Protection of the pipe-line

During its expected lifetime (20 to 30 years) a pipe-line has to be protected very carefully. Maintenance and repair work is expensive and sometimes impossible. Therefore, the protective measures are also designed
for a lifetime of 20 to 30 years. An offshore pipe-line is normally protected by a corrosion coating, a cathodic protection, a concrete coating, and finally by burial.

With the corrosion coatings of today, when fully intact, an offshore pipe-line is sufficiently protected against corrosion during its lifetime. However, damage during construction and during the lifetime of the pipe-line is possible, and this is why a cathodic protection is also provided.

For negative buoyancy and stability under wave influence the large diameter pipe-lines also need a weight coating, usually made of concrete, which also affords some protection for the corrosion coating. Concrete coating, especially the older types, can hardly withstand mechanical impact forces, and although modern types are stronger, some additional protection is required, especially from ships' anchors or heavy fishing gear which can buckle or even totally destroy a pipe-line. In such a situation it is clear that the ship and her crew are exposed to real risk.

These risks, in combination with the possibility of sea pollution in the event of leakage, call for measures by which the pipe-line is placed out of reach of fishing gear and ships' anchors. It is beyond dispute that in the southern part of the North Sea, with its heavy shipping and fishing, burial of the pipe-lines is essential.

Burial depth requirements

General Determination of the burial depth should be based on a wide range of considerations, including the following: the stability of the sea bottom; penetration depth of fishing gear; penetration depth of ships' anchors; probability and depth of soil liquefaction under storm conditions; other dangers to the pipe in specific areas, such as those used for naval gunnery practice; the possible environmental consequences in the case of a pipe-line leak or break; the possible economic loss to the pipe-line owner in the case of damage, and the possible cost of repair.

In principle, an increase in the burial depth will decrease the risk of damage, and in theory it must be possible to determine the optimum burial depth by reference to a risk analysis and a cost-benefit analysis. In his paper "How to protect offshore pipe-lines", Brown (1975) mentions a method for such an analysis. In practice, however, it is difficult, if not impossible, to obtain all the necessary input data.

Based on the available data, the Dutch Government has specified a cover of 2 m for the two pipe-lines to its coast, and some important factors in this choice are discussed below.

Stability of the sea bottom A vital factor in deciding burial depth is the stability of the sea bottom, since erosion of the sea bed directly affects the burial depth. However, on the high seas the data on sea bottom stability are very inaccurate and differences of 0.50 to 1 m are still possible at present. The inaccuracy of soundings is mainly due to the absence of a fixed datum and because of this inaccuracy, any trend in the changes of the sea bed level is very difficult to show. From the available data on the Dutch shelf, however, it may be concluded that changes in the bottom level outside surf zones are of minor importance.

Another problem of the Dutch coast is the large sand-wave area (see paper C.M.1977/B:52). The height of the sand waves sometimes exceeds
10 m, and the data on the movement of these waves are also very poor. The problem is compounded by the inaccuracy of the depth soundings and of the horizontal positioning system. Some authors suggest that there is a slow movement in a northeasterly direction (Houbolt, 1968; McCave, 1971).

Extensive surveys by the Dutch Public Works Department show that, on an annual basis, where there is movement, it is within the accuracy of the positioning systems. Via long-term investigations, better data will become available within some years.

Due to the height of the sand waves, their movement must be treated as a very important factor in determining the route and the burial depth of a pipe-line. The problems can be overcome by choosing a burial depth below the lowest points in the valleys, but this leads to an unrealistic burial depth below the top of the sand waves, and such a proposal seems unreasonable on the basis of incomplete data. For these reasons possible changes in the sea bottom level of the Dutch shelf are disregarded in the determination of the burial depth, and because of the unreliability of the data, maintenance of the prescribed burial depth is stipulated in the licence.

Effects of fishing gear on pipe-lines De Groot (1975) describes the situation in the Dutch sector of the continental shelf in detail, indicating that the following sea bed fishing gear are used: beam trawls (total weight 4 000 kg - 8 000 kg) and otter trawls (weight of a board approximately 1 200 kg), with the beam trawl the most common sea bed gear of the Dutch fisheries.

From the results of field tests in Trondheim (see paper C.M.1977/B:5) it may be concluded that concrete coatings with chicken-wire reinforcement cannot withstand the impact forces of a Dutch beam trawl. In certain areas these impacts can be very frequent. From knowledge of the number of fishing hours with beam trawls of the Dutch fleet (see paper C.M.1977/B:9) and given an average beam length of 10 m and a normal fishing velocity of 4 to 5 knots, a simple calculation shows that every point in some of the rectangles is fished 3 to 4 times each year.

Another interesting comparison is the strength of the fishing warps and the negative buoyancy of the pipe-line. For example, fishing warps with a tensile strength of 40 000 kg or more are not unusual and the negative buoyancy of a 36" pipe-line (specific gravity 1.25) is only 225 kg per metre. In theory, a fishing vessel with these fishing warps can lift a length of more than 150 m. In areas where such fishing gear are used burial of pipe-lines is clearly necessary.

The necessary burial depth to protect a pipe-line against the effects of fishing gear is limited. Normally penetration is less than 0.10 to 0.30 m. In exceptional cases, like hooking, the penetration depth can be much more.

Anchor penetration To determine the risk to pipe-lines from ships' anchors we have to answer the following questions: (a) What is the penetration depth of a certain anchor? (b) What is the risk that such an anchor will hit the pipe-line?

The answer to the first question is provided by the data available in the literature (Anon., 1941; Koster, 1975; Krämer, 1975). It appears that an anchor dropped on a sandy sea bed is first dragged over the sea bed and then penetrates until the required holding strength is reached. If equilibrium is not reached, the dragging goes on. Due to unequal
loading of the flukes (the soil is never homogeneous) the anchor will
twist out of the bottom. Then penetration starts again. This penetration
behaviour is illustrated in Figure 35 (p.59). On the basis of this
behaviour a relation can be derived between ship dimensions, anchor
dimensions and penetration depth (see Figures 36 and 37, pp. 60 and 61).
The second question is more difficult to answer. Lloyds' Register of
Shipping publishes all the shipping casualties and their positions. But
nobody knows the relation between these casualties in a certain area and
the number of dragging anchors.

Another problem is the effect of the pipe-line on the behaviour of the
seaman. The pipe-lines are charted. It is reasonable to suppose that
a pipe-line route will be more or less respected by anchoring vessels. On
the other hand, such a positive reaction is doubtful in emergencies.
The probability of a dragging anchor crossing a pipe-line route is still
unknown.

From Figures 36 and 37 it appears that in a sandy bottom a cover of 2 m
gives a pipe-line reasonable protection against dragging anchors of ships
above 50 000 dead weight tonnes (d.w.t.); a cover of 1.50 gives
reasonable protection against anchors of ships over 10 000 d.w.t., while
with a cover of 1 m the pipe-line remains within reach of the anchors of
even small ships.

From the total world fleet 98% of the ships are smaller than 50 000 d.w.t.,
80% are smaller than 10 000 d.w.t., and Lloyds' figures show that small
ships are more susceptible to accidents than the large ones.

Experiences on the Dutch shelf

At present there are two gas pipe-lines to the Dutch coast, a 36" pipe-
line 178 km long was laid in 1974 from the Placid fields in block L 10,
50 km northwest of Texel, to Uithuizermedum. Also a 36" pipe-line 120 km
long was laid in 1975 from the Pennzoil gasfields in block K 13 west of
Texel to Callantsoog south of Den Helder.

Because of the dense shipping and fishing in these areas, the Dutch
government stipulated a cover of 2 m, but in spite of great efforts, the
companies were not able to meet this requirement. The only available
burying method using jetting equipment, was found to be very inefficient
in the fine, loosely packed sandy bottom of the Dutch shelf. Immediately
after the jetting equipment had passed, the trench was filled up again
by distortion of the slopes.

Consequently, the pipe-line reached the bottom of a shallow trench with
gentle slopes. Only in a few specific areas could the pipe-line be
lowered to a level where the top of the pipe-line was 2 m below the level
of the sea bottom. With this burial method the cover on the pipe-line is
dependent on natural backfill, and the rate of this backfill supports the
opinion mentioned above that changes in the level of the sea bottom are
very slow processes.

Berry (1968) reports that in 1967, during the burial of the Shell Esso pipe-
line from Leman Bank to the English coast near Bacton, the jetting equipment
met the same trouble. It is disappointing to find that today, 10 years
after this experience, the offshore industry is still using the same
techniques with the same disappointing results in a loose sandy bottom.
Methods based on the fluidisation principle are known, by which a pipe-line
can be buried and covered in a loose sandy bottom, and field tests have
shown that the principle of the Fluidisation method produces good results,
although due to some unfortunate experiences, the offshore industry is
reluctant to develop this method further (see paper C.M.1977/B:5 for fuller
discussion).
Figure 35
Figure 36. Relation between ship tonnage and penetration depth of anchors in a sandy bottom.
Figure 37. Relation between ship tonnage and penetration depth of anchors in a sandy bottom.

Anchor types
- Stokes
- Hall's
- Union
- Byers
- Baldt
- Poolanker
Conclusions

1. For protection of offshore pipe-lines and their environment, burying of the pipe-lines in the southern North Sea is necessary.

2. Due to the lack of essential input data, optimisation of the burial depth is impossible.

3. Data on the changes in the level of the sea bottom are limited. However, they indicate that outside the surf zone the changes develop slowly and are of minor importance in the choice of burial depth.

4. Instances of a pipe-line route in the southern part of the North Sea being crossed by heavy bottom-fishing gear can be very frequent. The penetration depth of fishing gear is limited and therefore not important in the choice of burial depth.

5. The available data on anchor penetration show that in a sandy bottom a cover of 1 m above a pipe-line hardly gives protection. A cover a 2 m places the pipe outside the reach of nearly all the penetrating anchors.

6. On the basis of the above-mentioned data, a cover of 2 m has been stipulated for the pipe-lines to the Dutch coast. The jetting method has proved unsuitable for burying these pipe-lines to the required depth.

7. One may expect that burying equipment based on the fluidisation principle will give better results in comparable situations. However, the development of such equipment has been delayed by some unfortunate experiences.

Dutch Fishing Activities in the North Sea and Adjacent Waters relevant to the Safety of Underwater Pipe-Lines

(S J de Groot, C.M.1977/B.9)

Introduction

This paper provides facts on Dutch fisheries in the North Sea and adjacent waters which are relevant to the relation between the fisheries and the offshore activities of the gas and oil industries.

For a short general introduction of the subject, see e.g. Bennett, 1974; Gjørvik et al., 1975; de Groot, 1975; Allen et al., 1976; Carstens et al., 1976; MacLennan and Strange, 1977.

The type of fishing gear and the number of fishing hours with that gear will determine the risk of damage to offshore installations such as platforms, suspended wellheads and submarine pipe-lines.

Although pipe-lines should be completely buried, it is a fact that, especially in the northern North Sea, rocks or certain soil types (boulder clay) can prevent complete burial.
The difficulties encountered in the northern North Sea seem now to lead to an acceptance in some countries that they cannot be buried, which is still against the regulations and consequently in these areas pipe-lines may be hit by fishing gear.

The data given in this paper are thought to be relevant in the evaluation of the risk of the confrontation of two North Sea users.

**Landings and proceeds**

In 1975 the Dutch seagoing fishing fleet landed a total of $185 \times 10^6$ kg of fish with a value of Dfl. $374 \times 10^6$. The most important species were: herring, mackerel, cod, whiting, haddock, plaice, dab, sole, turbot and shrimps. Some details are given below.

<table>
<thead>
<tr>
<th>Weight (kg)</th>
<th>Value (Dfl.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common sole</td>
<td>$14 \times 10^6$</td>
</tr>
<tr>
<td>Plaice</td>
<td>$44 \times 10^6$</td>
</tr>
<tr>
<td>Cod</td>
<td>$18 \times 10^6$</td>
</tr>
<tr>
<td>Herring</td>
<td>$59 \times 10^6$</td>
</tr>
</tbody>
</table>

**Inventory of fishing vessels (1975)**

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
<th>BRT</th>
<th>Horse-Power</th>
<th>Crew</th>
</tr>
</thead>
<tbody>
<tr>
<td>I - Trawlers</td>
<td>-</td>
<td>268</td>
<td>59.758</td>
<td>309.328</td>
</tr>
<tr>
<td>(inclusive cutters with a length of more than 27 m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II - Cutters</td>
<td>-</td>
<td>450</td>
<td>25.730</td>
<td>139.143</td>
</tr>
<tr>
<td>III - Small inshore vessels</td>
<td>-</td>
<td>286</td>
<td>10.633</td>
<td>35.823</td>
</tr>
<tr>
<td>IV - Very small vessels</td>
<td>-</td>
<td>69</td>
<td>191</td>
<td>-</td>
</tr>
</tbody>
</table>

Of category I, 177 vessels have a HP of more than 1 000 HP, and of category II, 94 vessels between 500-799 HP and 11 vessels between 800-999 HP.

There was a decrease in the number of vessels and crew from 1971 to 1975, respectively from 1 156 to 1 073 vessels (-8%) and from 5 063 to 4 619 fishermen (-444 or about 9%).

**Gear**

The trawlers are equipped with bottom trawls (herring trawl and high opening bottom trawl) and pelagic trawls. It is, however, possible to fish close to the bottom with pelagic trawls.

The cutters mainly fish with beam trawls. However, the same vessels also pair trawl for roundfish or herring. Roughly estimated, 80% of the gear in use are beam trawls. The average total weight of a fully rigged beam trawl is about 4-5 tonnes; however, the maximum weight can be 6 tonnes. The average beam trawler at the moment has a horsepower between 800-1 400. Each vessel fishes with two beam trawls. To recover lost gear, old anchors or dredges are used. The ship whose gear is lost circles around with the pointed dredge in the area to recover it. The average weight of the dredge is about 500 kg.
For a detailed description of the beam trawl, see de Boer (no date) and for a description of the development of the beam trawlers to a multi-purpose vessel, de Boer, 1975.

For the weight of the trawl doors used in the otter trawl fishery there is a rule of thumb that the weight of the door is 1 kg for each HP of the vessel.

The average breaking strength of the warps varies between 30-40 tonnes.

For a short description of the gear mentioned above, see MacLennan and Strange, 1977.

The relation between beam trawling and submarine pipe-lines and possible adaptations of the gear to reduce the impact forces are discussed in de Groot, 1977. The literature in relation to the interaction between fishing gear and pipe-line is also referred to in this paper.

Fishery damage attributed to offshore activities

Notwithstanding the fact that fishermen claim regularly that they lose or damage their gear on submarine offshore installations, e.g. pipe-lines, it is difficult to prove that this was the true origin of their damage as they more often encounter shipwrecks, heavy stones etc. causing the same sort of effects. During the last two years (1975, 1976) a careful selection was made, based on information supplied by reliable persons.

Based on their information two attempts were made to trace the lost gear; however, bad weather or offshore activities in the area prevented success. The search was carried out by the Ministry of Transport and Public Works - North Sea Directorate, with their research vessel "Volans".

Most of the damage reports came from areas where pipe-laying was taking place or had just been completed. Therefore it is possible that either the bottom around the trench was still unstable, or the pipe-line only partly buried at that time. As no information reached us in the first half of this year it seems that the situation improved.

Some fishermen told us that they haul their gear when they are in the vicinity of the pipe-lines and shoot again after passing the pipe; others state that they fish parallel to the pipe to catch the fish gathered near the pipe-line or structure. They could all feel a partly buried pipe-line when they crossed it with their gear. From my own experience this can be confirmed. The following data from over the whole southern North Sea, not the Dutch shelf only, were collected from beam trawler skippers.

### Reported data on the damage to beam trawl in three-monthly periods for 1975-76

<table>
<thead>
<tr>
<th></th>
<th>1975</th>
<th></th>
<th></th>
<th></th>
<th>1976</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tot.</td>
<td>I</td>
<td>II</td>
<td>III</td>
<td>IV</td>
<td>Tot.</td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>Gear entangled on pipe-line</td>
<td>5</td>
<td>-2</td>
<td>3</td>
<td>-5</td>
<td>-1</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Gear lost on pipe-line</td>
<td>2</td>
<td>-1</td>
<td>1</td>
<td>-4</td>
<td>-1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Gear recovered</td>
<td>2</td>
<td>-1</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Use of dredge, anchor</td>
<td>2</td>
<td>-1</td>
<td>1</td>
<td>-2</td>
<td>-1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net damage only</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chunks of pipe-line coating</td>
<td>2</td>
<td>-1</td>
<td>1</td>
<td>-</td>
<td>-1</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Offshore debris, e.g. anchors</td>
<td>1</td>
<td>-</td>
<td>-1</td>
<td>-1</td>
<td>-</td>
<td>-1</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
Fishing effort in the ICES statistical rectangles (Figures 38-41, pp. 66-69)

The beam trawl is the most prominent Dutch fishing gear used in the North Sea as can be seen on the charts showing the fishing hours for the year 1975 in the ICES statistical rectangles. Comparison of the four charts (beam trawl, pair trawl, herring trawl, trawl) reveals a distinct pattern.

To demonstrate the activity of the beam trawl, consider an average of about 50,000 fishing hours/year in a certain rectangle say with a surface area of 2,500 km², and assume a fishing speed of 7 knots/hr. Then the fished area, when two 10 m beam trawls are used, will be $50,000 \times 7 \times 2 \times 10 \times 10^{-3} = 7,000$ km²/year. Such an area will be entirely swept 2-3 times a year.

To indicate the areas where a possible confrontation between the fishing industry and the gas/oil offshore industry may take place the main pipe-line routes are also drawn on the maps.
Figure 38

Beamtrawl
Total Fishing Hours 1975
Figure 39

PIPELINE (OIL)
PIPELINE (GAS)
PIPELINE (PROPOSED)

PAIR TRAWLING
TOTAL FISHING HOURS 1975
TOTAL FISHING HOURS 1975

Figure 40
Figure 41
Introduction

Since the first submarine cable was laid between England and France in 1850 interference has been caused to cables by fishermen. Despite the introduction of legislation making it an offence to "break or injure a submarine cable wilfully or by culpable negligence in such a manner as might interrupt or obstruct telegraphic communication" there has been no reduction in the number of cable faults so caused.

Before about 1960, the expectations with submarine cables were that they would be free of faults for the first few years and then show a fault rate of about one fault every two years. However, this low rate was not experienced with two cables laid from Covehithe, in Norfolk, England, to Katwijk in Holland during the mid-1960s. These cables exhibited a very high fault incidence in their early life and this fault rate steadily increased to the mid-1970s. The situation is made more peculiar when compared with two cables from Lowestoft in Suffolk to Scheveningen in Holland which lie close to the Covehithe to Katwijk cables, but have fairly normal fault records (Figure 42, p.71). It should be noted that the Lowestoft cables were laid 10 years earlier than those from Covehithe.

Areas of risk

The North Sea can be broken into four areas of risk due to damage by trawlers:

i) That area approximately north of 55°N where cables can be said to be fairly free of fault hazard except for random cases which can probably never be avoided.

ii) That area approximately between 52°30'N and 55°N where a fault hazard of about one per cable per year is experienced.

iii) That area south of 52°30'N to a point south of the Hinder Banks or more accurately 51°20'N. This area has recently experienced a degree of flatfish trawling unprecedented in the North Sea using beam trawlers much larger than hitherto. Since 1974 the fault rate in this area has increased drastically and it can be reasonably stated that No.1 cable running between Covehithe and Katwijk was rarely in service between 1974 and 1976.

iv) That area between the Straits of Dover and the southern end of the Hinder Banks. This area contains all the UK to Belgium cables which, since 1960, have enjoyed a low fault rate commensurate with the cables in the northern North Sea.

The vast majority of faults in area (iii) lie between latitudes 52°15'N and 52°20'N and longitudes 3°00 and 3°30'E. This location corresponds with an area of high sand waves (McCave, 1971) and these have recently been well charted. Superimposing a cable chart of fault incidence on a contour map of sand wave heights convincingly demonstrates an apparent correlation between sand wave height and fault rate.
Figure 42. Fault rates on selected North Sea cables.
It is significant that this area also corresponds with the location of maximum beam trawling by Dutch and Belgian vessels for the year 1975 (see paper C.M.1977/B:9 by de Groot in this report). This fact, together with the area of sand waves known to exist in this part of the North Sea combine to provide a set of conditions in which the probability of cable survival is very low.

**Cause of faults**

The question to be answered is - are cable faults due to the formation of the sea bed, or to the increase in the use of the beam trawl? It is believed that the new generation of beam trawlers, much larger and more powerful, which has been increasingly brought into service since 1970 has been the deciding factor in the increased fault rate, but the sea bed conditions must be contributory to this rate or the correlation between sand wave height and cable faults could not be demonstrable. It had been thought that sand wave movement would have set up cable suspensions between sand peaks which could easily be fouled by trawls. However, recent surveys carried out with a submersible have shown that this is not the case. These surveys carried out over the two Covehithe-Katwijk cables that had suffered so badly in 1975 also disproved the belief that the cables were being fouled by trawlers because of the bights of slack cable that result from a cable repair. During the surveys, both cables were observed to be lying half buried in the sea bed in a very proper manner.

It is now believed that the existence of sand waves together with the method of operation of the large beam trawlers combine to hazard submarine cables. Beam trawling for flatfish is not new, nor is the demand for such fish in the European market. Cable owners had too easily attributed part of the blame for the increased fishing activities to the subsidy offered to trawlermen in 1973-74 by the Netherlands Government. It is now appreciated that this is not the case as the subsidy has been withdrawn and quotas placed on the tonnage of fish landed; yet the fault rate persists.

Investigation into beam trawling carried out by the MAFF Fisheries Laboratory at Lowestoft indicated that beam trawls barely penetrate the sea bed. One hypothesis put forward by the cable industry is that a powerful beam trawler of greater than 1 200 HP, fishing with two 10 metre beams at speeds of up to 7 knots could chop the crest off the top of a sand wave peak and barely notice it. Should a cable be in the way it would be fouled but not necessarily broken. There is evidence that trawlers lift their gear with a fouled cable and cut the cable with an axe or even a gas burner.

**Protecting cables**

What can the owner do to protect his cables? There are four possible approaches to the problem:

1) Select cable routes where fishing is at a minimum

When new cable routes are planned, areas of fishing activity are carefully studied, but these areas, with some exceptions, are constantly changing. Studies of existing cable routes have failed to produce a reliable forecast of active areas, e.g. Lowestoft-Scheveningen route. There is a definite connection between fishing activity, high sand waves and fault incidence. It is therefore prudent to avoid this combination. However, large route deviations to avoid constantly changing fishing areas are neither economical nor viable.
ii) Make it more difficult for fishermen to break cables

It has been suggested that large objects of considerable mass be deliberately deposited on the sea bed at calculated intervals along cable routes to impede trawls and cause fishermen to give greater regard to cables, but cable owners would never resort to such an anti-social act and in any case, the laws concerning dumping at sea would prohibit such action.

There is, however, a strong case to look at the armouring on present day cables. Double armour has successfully been used in areas where cables lie on rocky sea beds. The answer to the problem may be to use double or even triple armour in sand-wave areas. The disadvantage of this is the very large increase in costs and the problems likely to arise on small cable ships when repairing the more heavily armoured cable.

iii) Bury the cable beneath the sea bed

There is evidence that cables that have been buried or trenchsed into the sea bed have a greater immunity to trawler damage than those that lie on the sea bed. Such action has been taken on the continental shelves of North America and Europe with a fair amount of success, but burial or trenching in the North Sea is a different proposition.

Oil companies who have spent large sums of money on pipe-line burial are now finding that in certain areas the pipe-line is no longer buried due to the scouring effect of tide or possibly the migration of sand.

The high tidal flow together with poor underwater visibility has to date ruled out the use of manned submersibles for cable trenching in the southern North Sea. The sea plough that has been used successfully in European and American waters is not really suited to the shallow areas of the North Sea. However, developments in burial and trenching methods are being closely followed by Cable Administrations and the solution may well lie in this field.

iv) Investigate the possibility of designing fishing gear that will not foul cables

In the mid-1960s a research programme was undertaken by the British Post Office, with support from the Marine Laboratory, Aberdeen, into the possibility of designing fishing gear which would minimise the likelihood of otterboards fouling cables. Unfortunately no actual hardware resulted from this programme due to lack of funds.

Recently, a series of tests into the effect of bottom fishing gear on submarine pipe-lines has been conducted by VHL in Trondheim, Norway. This presented an ideal opportunity for cable owners to further research into the conflict between otterboards and beam trawls on the one hand and submarine cables on the other. Regrettably, mainly because of lack of time, the cable owners were unable to take advantage of this opportunity. However, it is hoped that in the near future work on this subject will resume. But it must be recognised that once a safe otterboard or modified beam trawl has been designed, the cable owners will then have to convince the fishermen that they should use the new gear! (See papers C.M.1977/B:5 and C.M.1977/B:8 in this report.)
The International Cable Protection Committee was formed a number of years ago with a prime objective of reducing the number of cable faults by advising fishermen of the location of cables. The individual fishing vessel skipper is answerable only to himself.

International laws and conventions are forgotten when the fisherman is "on fish". Publicity put out on cable protection is not heeded if the result of it is going to be no catch.

In July 1974 a United Kingdom Fisheries and Offshore Oil Consultative Group was formed to exchange information on general matters concerning the fishing and oil industries. It may be that such a group comprised of the telecommunication and fishing industries could do much to reduce the ever-increasing fault rate now being experienced by submarine cables.

OTHER TOPICS

Four further papers were presented at the 1977 meeting which did not fall easily into the categories so far considered.

The first (which is not reproduced in this report) by McDiarmid (C.M.1977/B:31) of the United Kingdom White Fish Authority, deals with an important aspect of the fisherman's problem of avoiding sea bed obstructions. He points out that thanks to the United Kingdom Fisheries and Offshore Operators' Consultative Group there is a good flow of immediate information on subtidal obstructions from the oil industry to the fisherman's representatives. However, this information is usually in the form of latitudes and longitudes, while in fact what is needed is frequently updated lists of DECCA coordinates, since fishermen in the North Sea normally use DECCA for position reference. The author describes the results of the Kingfisher Automatic Cartography System (KACS) which can rapidly produce printed lists of coordinates of the positions of underwater obstructions for circulation. This computerised cartography facility can also be used to provide displays of accumulated information on trawling tracks and obstructions in a given area on track plotter paper which is immediately available for use on fishing vessels.

The second paper (C.M.1977/B:11) by VanderWal describes the procedures used for surveying gas pipe-lines on the Dutch continental shelf, and can usefully be read in conjunction with C.M.1977/B:13 in the previous section, which discusses burial requirements for pipe-lines.

A third paper (not reproduced here, C.M.1977/B:12) by Brouwer, describes the use of offshore platforms for a range of activities other than the production of gas or oil. These include collecting hydrographic and meteorological data; establishing transmarine beamed telephone links; use as a navigation aid and for research and development of measuring sensors and techniques.

Paper C.M.1977/B:41 by Olsen and Valdemarsen provides information on some preliminary studies of fish round offshore installations, and suggests confirmation of the observation that cod aggregate in considerable numbers round rigs.
Finally, although in 1977 a contribution was not made by USA, an opportunity was taken to do this in 1978 when these problems were further discussed at the Statutory Meeting. Reid and Steimle presented a general paper (C.M.1978/E:46) summarizing the interactions between offshore oil production and fisheries in USA, and that paper is reproduced here in its entirety.

Pipe-Line Surveying on the Dutch Shelf
(H R vanderWal, C.M.1977/B:11)

Introduction
In the Dutch sector of the continental shelf there are at present two marine gas pipe-lines. They are the pipe-line from block L-10 to Uithuizermedum (about 165 km long and 36" in diameter) and the pipe-line running from block K-13 to Callantsoog (some 120 km long and 36" in diameter). Since the Netherlands Government has stipulated special requirements relating, among other things, to burial depth and infill, the locations of the two pipe-lines must be checked at regular intervals.

The burial depth requirements are necessary because the pipe-lines:
- cross major shipping lanes (penetration depth of ships' anchors is relevant)
- lie in intensively fished areas (penetration depth of sea bed fishing gear is relevant)
- lie in areas where the location of the sea bed is subject to fairly marked change (mega ripples could alter burial).

Damage to pipe-line, possibly followed by fracture, caused by anchors or fishing gear, may present serious hazards to the environment, to navigation and to fisheries.

To ascertain whether the burying requirement of the pipe-lines is being satisfied, and to enable any dangerous situations to be detected at an early stage, random testing is essential.

The methods and equipment used in performing such tests have undergone considerable changes of late. One of the reasons for these changes is the development in electronics which has been greatly accelerated by the rapid increase in the costs of offshore operations.

The following paragraphs deal more fully with the equipment and methods used by the Public Works Department's North Sea Directorate in checking the location of the pipe-lines on the Dutch sector of the continental shelf.

Equipment
The equipment may conveniently be divided into basic equipment consisting of a subbottom profiling system, and additional equipment consisting of (a) locating system, (b) echo sounder, (c) side scan sonar, (d) magnetometer, (e) underwater television.

In addition to the above equipment, the vessels carry apparatus with which the collected data can be automatically recorded (e.g. mini computers, analoge/digital converters, magnetic tape recorders, etc.).

Basic equipment: the subbottom profiling system
Subbottom profiling systems, otherwise known as penetrating echo sounders, are systems for determining up to certain depths, the various structures
below the surface of the sea bed. Closely resembling in action the echo sounder on the one hand and seismic systems on the other, these systems have now been modified by various manufacturers to such an extent that they are also suitable for determining the location of wholly or partly buried wrecks, telephone cables, pipe-lines, etc.

A subbottom profiling system (Figure 43, p.77) consists of three elementary parts.

- the source of sound: This may be built-in to a vessel or on a stable, fish-like body, which is towed behind the vessel, on or below the surface of the sea. It transmits acoustical signals to the sea bed.

- the receiver: which receives the signals reflected via reflecting layers/objects in the sea bed and converts these into electrical signals.

- a recorder: in which the electrical signals are processed and of which a graphic display is then presented in the form of markings.

In this manner a continuous reflection profile of the subbottom of the sea bed is registered.

The sources of sound are electro-acoustical transducers (electrical energy being converted into acoustical energy), and are distinguishable by the way in which the necessary acoustical energy is generated (Figure 44, p.78). This is possible by using piezo-electrical transducers, in which high alternating current generates the acoustical energy by oscillating quartz crystals. The systems that operate on this principle are known as pingers. The acoustical energy can also be obtained from electrical energy stored in a large number of condensers. The boomer (in which the discharge of a coil causes an aluminium plate to be vigorously repelled by it), and the sparker (in which the energy is discharged through a pair of electrodes suspended in the sea) both operate on this principle.

Since the electro-acoustical effect in piezo-electrical transducers is reversible (which means that these transducers can re-convert acoustical energy into electrical energy; the acoustical-electro effect), these transducers can also function as receivers. By contrast, the sparker and the boomer need to use a separate receiver (hydrophone) or several of them positioned in line (streamer).

Because of the relatively low frequencies and relatively high power with which the acoustical energy is transmitted, the sparkers, boomers and pingers are capable of detecting stratifications and objects in the sea bed. Not all sound waves reflected from the sea bed and the sea bed strata are received direct by transducer (hydrophone); a large number of them pass the receiver, rebound against the surface of the sea and are then reflected for the second time by the sea bed or the subbottom.

This process may repeat itself several times, until the energy of the sound waves is exhausted by reflection losses, absorption, etc. Each time the sound waves pass the receiver, they are registered by the recorder (multiple reflection), which is a very disturbing effect and whereby the maximum sea bed penetration is determined.

Additional equipment

An adequate locating system and echo-sounding equipment must obviously be available for each survey. Details of the principle of these systems are not discussed here.
Schematic overview subbottom profiling system

Figure 43
Classification systems.

- **Electro-acoustic transducers**
  - **Pingers:** penetration depth 20-50 m; frequency band 1 KHz - 12 KHz; power 0.1 - 1 joule.
  - **Sparkers:** penetration depth 50-500 m; frequency band 500 Hz - 12 KHz; power 200 - 8000 joule.
  - **Boomers:** penetration depth 50 - 100 m; frequency band 500 Hz - 10 KHz; power 100 - 1000 joule.

*Figure 44*
For the operations described here frequent use is made nowadays of side scan sonar equipment, magnetometers and, occasionally, underwater television. With a side scan sonar it is possible to inspect a relatively large area of the sea bed surface. The recordings obtained with this system may supply information on the possible presence of a trench and whether or not the pipe-line is buried. The side scan sonar transmits acoustical signals with a frequency of about 100 KHZ and shaped like a fan. The reflected signals are converted in the recorder into markings on the recording paper, after these signals have been amplified by a time-base amplification factor. In this way an acoustical reflection image is produced of the sea bed and the objects upon it (e.g., wrecks, pipe-lines, mega ripples, etc.).

With a magnetometer the presence of a pipe-line/telephone cable can be detected. This system, which can only be used in combination with other equipment, registers changes in the strength of the earth's magnetic field. Such changes may indicate the presence of cables, pipe-lines, etc.

For obtaining precise information about the extent to which pipe-lines are exposed or damage has occurred, the use of underwater television is indispensable. In principle there are three ways of using underwater television, viz.:

- with the aid of divers. The drawback here is that the system can only be used for a few hours a day.
- built-in, in a remote controlled vehicle. This method also has its drawbacks, being difficult to use continuously in areas with strong tidal currents.
- built-in, in a submersible. This is the most efficient, but also the costliest method of inspecting the sea bed.

The Directorate occasionally employs divers during pipe-line surveys. It is being investigated whether one of the other two systems could also be used for other kinds of work (Figure 45 gives a diagrammatic survey of the equipment used for inspecting pipe-lines).
Method of scanning

In practice, the usual procedure for determining the horizontal and vertical position of a pipe-line is to start with a side scan sonar view, especially if it is known that the pipe-line is without ground covering in places. For this scanning, which is done in the longitudinal direction of the pipe-line, one needs to have the use of a locating system with a high degree of reproducibility (reproducibility in this context means the accuracy of the locating system with which one can return to points previously determined with it).

The survey can start with a rough magnetometer or subbottom profiling test. The recordings obtained should indicate the location of the pipe-line. After a side scan sonar shot it will be necessary to sail a zig-zag course over the pipe-line, using a subbottom profiling system.

The distance between the different crossings of the pipe-line depends on a number of factors, such as:

- purpose of the survey. It may be a routine survey, a spot check.
- the results of the scan sonar survey. If areas are detected where the pipe-line has no ground covering, or there are doubts about the ground covering owing to the presence of a trench, the turn distance has to be shorter.
- composition and topography of the sea bed. In a mega ripple area the distance between turns will be shorter than in an area where few changes, if any, occur in the sea bed.

In practice, the Directorate use a turn distance of 250 metres, while in areas where the pipe-line has no ground covering and/or the sea bed undergoes marked changes the turn distance is reduced to 50 or 25 metres.

The transducer of the subbottom profiling system will have to have a relatively large aperture angle to enable the pipe-line to be detected at an early stage, and relatively small penetration depth so as to prevent the echoes from the pipe-line from being combined with bottom strata echoes, which would make interpretation of the recorder difficult. The larger the aperture angle of the transducer or, in other words, the larger the "irradiated" area of the sea bed, the greater the chance of detection, so that the reflection of the pipe-line will increasingly manifest itself as a hyperbola (Figure 46, p.81).

The difference in vertical distance between the first (sea bed) reflection and the apex of the recorded hyperbola determines the ground covering of the pipe-line at the time.

During scanning of the pipe-line the motion of the waves may considerably influence the possibility of interpreting and subsequently presenting the results of the shots (Figures 47 and 48, pp. 82 and 83).

So long as there are no means of reducing or compensating for the effect of the waves on the subbottom profiling registration of pipe-lines, limits will have to be set to the height of the waves at which measuring is still possible.

To enable the results of different observations to be compared, the pipe-line must always be crossed at the same place. To ensure that this is done, the vessel is sailed along predetermined whole and/or half lanes of the locating system used.

As pointed out previously, this scanning method exacts a high standard of reproducibility of the locating system. If the sea bed location is likely to undergo changes, additional data regarding the location of the sea bed will have to be obtained, if only to enable the various observations to be compared in absolute terms. This necessitates not only location and depth data, but also measurement of the water level (with the aid of, say, a monitored tide gauge), so as to enable the depth measurements to be reduced to a reproducible reference level.
MODEL

direction of sailing

Water surface

\( v_1 \)

Sea bottom. \( v_2 \)

\( v = \text{Sound velocity} \)

Suppose: \( v_1 = v_2 = v \)

Traveltime:

\[
t^2 = 4 \frac{x^2}{v^2} + 4 \frac{(d_1 + d_2)^2}{v^2}
\]

(SCHEMATIC SEISMOGRAM)

( Hyperbola )

Seabottom reflection

\( t = \frac{2d_1}{v} \)

\( t = \frac{2(d_1 + d_2)}{v} \)

Pipeline registration

\[
t = \sqrt{\frac{x^2}{v^2} + 4 \frac{(d_1 + d_2)}{v^2}}
\]

Figure 46
Figure 47
"Subbottom-profiling" registration of a pipeline (corrected for wave-movement: wave-compensation)
Figure 48
"Subbottom-profiling" registration of a pipeline (not corrected for wave-movement)
Conclusion

This paper outlines the way in which the Public Works Department's North Sea Directorate monitors the gas pipe-lines in the Dutch sector of the continental shelf.

Clearly, the method of scanning and the equipment used leave room for improvement.

The ultimate result of these improvements will have to be that the location of pipe-lines, both in the horizontal and the vertical plane, can be determined with extreme accuracy and a high degree of reproducibility.

In this context mention should be made of the cooperation between the North Sea Board and the Exploration and Production Laboratory of Royal Dutch Shell, in the course of which considerable attention has been paid to encouraging manufacturers to develop systems which will make it possible to follow the pipe-lines in longitudinal direction and to make direct compensation in the registrations for the movement of the waves.

Fish Distribution Studies around Offshore Installations
(S Olsen and J W Valdemarsen, C.M.1977/B:41)

It is well known that many species of fish are attracted to structures situated on or above the sea bed. In the North Sea this is particularly apparent in locations of sunken ships, and a commercial "wreck fishery" has been developed. The numerous reports by people engaged in the North Sea oil exploration of large concentrations of fish around the offshore installations therefore come as no surprise.

Reliable quantitative data on the extent of fish attraction by these offshore structures, however, are not available and practically nothing is known about diurnal and seasonal variations, differences in attraction with regard to species etc. Such information is vital for the assessment of any negative as well as positive effects that the oil activity might have on the North Sea fisheries, and a programme for a detailed study of these matters has therefore been initiated in Norway.

With assistance from Phillips Petroleum Company, Norway, the Institute of Fishery Technology Research during one week in May 1977 made observations and conducted fishing experiments within the 500 m security zone around the Ekofisk installations in the North Sea.

Fishing was done with traps, jiggers and vertical baited lines at different distances and directions from the installations of the Ekofisk complex.

The trap experiments were restricted to an area between 100 m and 1 000 m S-SW from the "Alfa" structure, a production rig situated about one nautical mile south of the Ekofisk complex. A few ling (Molva molva L.) were caught in traps, but no significant difference in catches was observed at different distances from the rig.

The experimental jiggling trials, except for one at the "Alfa" rig, were carried out around the Ekofisk complex, which is composed of 12 installations on the bottom in a restricted area. The trials gave some useful information
on the distribution of cod (*Gadus morhua* L.) (Table 6).

Table 6. Catch data of cod from jigging trials at various distances from the Ekofisk complex.

<table>
<thead>
<tr>
<th>Distance in metres</th>
<th>0-50</th>
<th>50-100</th>
<th>100-200</th>
<th>200-500</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total fishing time (in hours and minutes)</td>
<td>5:45</td>
<td>1:00</td>
<td>0:45</td>
<td>0:30</td>
<td>0:30</td>
</tr>
<tr>
<td>Average no. of fish per 15 minutes</td>
<td>3.3</td>
<td>1.7</td>
<td>0.6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Minimum &quot; &quot; &quot;</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Maximum &quot; &quot; &quot;</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Cod between 35 and 65 cm was the only species of fish caught during the jigging experiments. This, however, was not surprising as the kind of jig used is known to be very selective for cod and the availability of other species in the area is, therefore, still unknown.

Although the jigging method does not give a quantitative assessment, it seemed that cod was aggregated in substantial numbers in the proximity of the installations, whereas only scattered concentrations were present in the surrounding areas. This situation is of course only valid for the period of these investigations. In other seasons the situation might be different. These first results are, however, consistent with reports from supply and stand-by vessels operating in the area throughout the year. They always have high catch rates of cod close to the platforms and small catches of cod further away than 500 metres from any installation.

An interesting observation from these experiments was that krill (*Meganyctiphanes norvegicus*) dominated the stomach contents of the cod. This might be related to the high level of artificial lights at Ekofisk, but eddies in the currents on the leeward side of the installations might also concentrate planktonic food organisms.

The experience from these preliminary investigations have demonstrated that the following points are particularly important and will be studied in detail during our further experiments:

1. Reliable methods are to be developed for estimating gradients in fish density at any distance from the installations within approximately 5 000 m, as well as for determining density differences of fish.
2. Annual variations in the distribution of fish are to be investigated by systematic sampling during a period of at least one year.
3. Estimates are to be made of the total amount of different species of fish unavailable for fishing inside the safety boundaries around oil installations.
4. The amount of food organisms near the installations needs to be compared with that in the surrounding areas.
5. Studies are to be made of whether fish in the proximity of the installations are stationary for long periods. This can probably best be done by tagging.
Offshore Oil Production and United States Fisheries
(R N Reid and F W Steimle, C.M.1978/E:46)

Introduction
Oil has been produced from U.S. offshore wells for over 50 years. Offshore production is presently centered in the Gulf of Mexico, and also occurs off California and at Cook Inlet, Alaska. Within the last decade a number of additional areas have been proposed for oil development. On the middle Atlantic continental shelf, exploratory drilling began in spring 1978. Oil exploration on Georges Bank, a very important fishing ground off New England, has been delayed by litigation. Other oil leases are also being considered in the southern Atlantic (Kumpf, 1977) and off Alaska (Bourne, 1976). A summary of oil-producing and potentially productive areas is shown in Figure 49 (p.87).

Effects of oil drilling and production platforms on fishing have been controversial. Both beneficial and adverse effects are possible. The major positive impact would be the enhancement of fishing around platforms due to an "artificial reef" effect. Negative impacts could include: gear damage and loss of fishing area around platforms, rigs and pipe-lines; effects of pipe-line placements (via jetting), drilling muds and cuttings; impacts of oil, other contaminants, and brines (formation waters). We will discuss each of these effects in turn.

Offshore oil production may ultimately have inshore effects, related to increased refinery activity and tanker traffic, pipe-lines coming ashore, etc. These are beyond the scope of this paper, as are discussions of tanker spills and other inputs of oil which are not directly related to production.

Offshore platforms as artificial reefs
The most important benefit of platforms to fisheries thus far is their function as artificial reefs. The submerged support members, legs and cross braces of an oil drilling or production platform have been found to provide habitat and shelter for fish and other marine organisms. Recent studies of platforms off California and in the Gulf of Mexico (Carlisle et al., 1964; Mearns and Moore, 1976; Hastings et al., 1976; Sonnier et al., 1976) have shown that a wide variety of fish is attracted to them. Most studies indicate that some of the fish attracted to the platforms become residents; these are usually species with strong associations to nearby kelp beds or natural reefs. Other species are seasonal or occasional visitors. The numbers of fish around the platforms often surpass, by 20 to 50 times, numbers found on surrounding flat, muddy or sandy bottoms (Simpson, 1977).

Benefits of the fish-attracting feature of platforms have, for the most part, occurred to the recreational fishery (Hardesty, 1964; Shinn, 1974b). Because the platforms are excellent navigational aids, often visible from the shore, and support abundant fish populations, recreational fishermen have quickly popularised the platforms as fishing spots. Benefits to commercial fishing have been small, mostly to the hand-line fishery for red snappers, Lutjanus campechanus, in the Gulf of Mexico. Harvesting the large numbers of small pelagic schooling species which seasonally frequent the platforms has been proposed (Treybig, 1971); this would involve herding the fish, by the use of lights and electrical stimulation, to a central area where they would be pumped aboard waiting barges (Klima, 1970). Use of platforms for mariculture of molluscs (Ogle et al., 1977) is now being studied.
Figure 49. Distribution of current offshore oil production and drilling platforms in U.S. waters, and areas which are considered to have production potential. Symbols have no relationship to relative concentration of platforms, only relative locations and distributions. (From: Dept. of the Interior, 1974).
The question of whether the platforms, and artificial reefs in general, are increasing the production of fishery resources or just concentrating them has not been adequately answered. For example, some demersal species attracted to platforms have territorial habits, e.g. groupers (Epinephelus and Mycteroperca). The additional acceptable habitat created by the platforms also increases the number of available territories, thus increasing the population. For other species, the proliferation of encrusting fauna and algae on the platform provides protection for juveniles. Many other species attracted to the platforms, however, are present because of other behavioural responses, e.g. thigmoe- or skototaxis (shelter or cover association) or perhaps attraction to a novelty object; these species are usually those which form schools or shoals. Larger predators, including many "sport" fish, are attracted by the presence of the smaller species that they can prey upon. Finucane and Collins (1977) report that some species of fish may use oil platform areas for spawning in the Gulf of Mexico.

The reef effect is expected to be less important in Alaskan and in Atlantic production areas, which would be ~50 km from shore. In these waters sport fishing effort is dominated by small boats making day trips. Despite the facts that Shinn (1974a) reported hundred of small boats at platforms 48 km from land in the Gulf of Mexico, and that some charter and private boats make trips as long as 62 km to fish the Hudson and Baltimore Canyons off New Jersey, costs, distances and unpredicted weather and sea conditions involved in reaching the platforms will probably preclude any significant increase in sport fishing (Kumpf, 1977). Kumpf felt that quantification of impact of offshore platforms as artificial reefs was not practical.

Gear damage and loss of fishing area

Evidence to date indicates that these negative impacts of physical structures related to oil production are relatively minor. Each of the 7,575 offshore wells in the Gulf of Mexico in 1972 occupied an average 0.5 ha and was surrounded by a 1.5 ha safety zone. Total area closed to trawling (15 150 ha) was only 0.002% of the "trawlable substrate" (taken as all bottom area out to the 1,900 m depth contour) in the Gulf (Pequegnat, 1974). Pequegnat considered this lost space less of a problem than gear damage due to protruding well remains and litter. Regulations now require removal of underwater obstructions, but litter and rubble disposal need greater attention (Pequegnat, 1974; Allen et al., 1976).

In other areas, estimates of impacts of physical structures are still conjectural. Allen et al. (1976) state that catches on Georges Bank could be reduced 0.06% due to presence of platforms, or 0.2% if trawling were also prohibited between platforms due to presence of gathering pipe-lines. Most of the Georges Bank lease areas do not coincide with the historically most productive fishing areas (Allen et al., 1976). In the Middle Atlantic, the maximum area which would be closed at any time would be 1,311 ha; this would occur while semi-submersible drilling rigs were in place. Maximum space lost due to presence of platforms is estimated at 101 ha.

If a 500 m radius around pipe-lines is also closed, a possibility discussed by Rauuck (1977) for the Ekofisk pipe-lines, we calculate that another 91 427 ha (914 km²) would be lost. This represents 70 x the area lost under the platforms alone. The present intention, however, is to bury these pipe-lines, and closing areas around them has not been considered (Department of the Interior, 1976). In the South Atlantic region it is estimated that a maximum of only 104 ha around platforms would be unavailable for trawling (Kumpf, 1977).
Closure of areas around platforms, and the regulations concerning removal of structures after production ceases, should minimise damage to trawling gear. Burial of pipe-lines will also help in this regard, though it is uncertain that they will remain buried in some dynamic shelf sediments. Connor and Howarth (1976) felt the strong bottom currents on Georges Bank might expose buried pipe-lines. This would increase the potential for both fishing gear damage and pipe-line rupture. Kumpf (1977) reported that dragging anchors over pipe-lines was the largest source of oil introduction into the world's oceans. Fouling of trawling gear by spilled oil is another form of damage, which has apparently not been a major problem in U.S. waters.

Finally, oil platforms can cause damage to fishing vessels themselves. In the Gulf of Mexico, 10 collisions between fishing vessels and platforms were reported between 1962 and 1973, causing damages of $151,000 to vessels and $24,000 to platforms (Department of Interior, 1976). This damage must be weighed against the use of platforms as a navigation aid and as a safety factor for disabled vessels and medical emergencies far at sea.

Effects of pipe-line jetting, drilling mud and cutting disposal, and contaminants

These types of impacts are less easily quantified. Pipe-line jetting, mud and cutting disposal occur only during exploration and early production phases, while oil spills and introduction of contaminants (for instance those associated with production brines) may take place throughout the life of a well.

Pipe-line jetting

There is a paucity of studies dealing with impacts of jetting sediments during pipe-line burial. However, it can be assumed that where the sediments involved are predominantly sands, effects should be localised around the pipes and should be temporarily small, since the sands will be redeposited rapidly. Impacts are probably comparable to those of several passes of a hydraulic clam dredge. Total areas affected would thus be small relative to the area perturbed, say, by hydraulic clam dredging on the Middle Atlantic shelf. Worst case effects of jetting will involve introduction or disturbance of finer sediments in deep outer shelf waters. Here suspended materials may persist longer in an area, due to the less dynamic current regimes, and the fauna may be less adapted to shifting or suspended sediments. Laying pipe-lines through dump sites, which could remobilise significant quantities of contaminants, will usually be avoided (Department of Interior, 1976).

Drilling muds and cuttings

More information is available on effects of mud and cutting discharges. A cuttings pile under platform Hazel, 3.2 km off the California coast, has been the subject of several studies since the platform's installation in 1958. After three years of cutting disposal, a conical pile of predominantly fine silt, 37 m in diameter and 6-8 m high, was present under the platform. The pile surface was smooth and did not attract fish or sessile epifauna. At that time it was stated that the pile neither added to nor detracted from the environment (Carlisle et al., 1964), although the area covered by the pile was rendered temporarily unproductive. The authors observed that such piles could serve as fishing reefs if they were discharged several hundred feet from platforms and capped with rubble.
Seventeen years after initial cutting disposal, the pile was reported to be the same height but 76 m in diameter, and supported a flourishing fauna (Mearns and Moore, 1976). A bottom area of 1 396 - 2 792 m$^2$ around Hazel appeared to have increased productivity, due to input of material such as feces and eggs from platform fauna or to altered current patterns with resultant changes in sedimentation or resuspension. The pile was augmented by clumps of mussels falling from the platform.

In another drilling impacts study, conducted 161 km off California, in situ observations uncovered no build-up of cuttings or muds (Ray et al., 1978). This was attributed to the currents and surge present. The discharges created a turbidity plume typically extending to perhaps 350 m downstream of the platform.

A summary of studies in the Gulf of Mexico (Monaghan, 1975) also indicated that plumes from mud dumping were quickly dissipated (within 183 m). No adverse effects of the discharges on fish or other organisms were observed. Fish did not avoid plumes, and browsed in cutting piles. "Normal" benthic communities were re-established on a cuttings pile within 8 $\frac{1}{2}$ months of drilling, and were still present at former drilling sites 10+ years later (Monaghan, 1975). Cuttings piles in the Gulf were typically 1 m high and 0.2 ha in area, and their substrate supported greater numbers and diversity of fauna than did the surrounding sea floor (Shinn, 1974a). By 10-15 years after drilling, cuttings piles have been dispersed by storms and mixed with surrounding sediments to the extent that the piles can no longer be distinguished (Shinn, 1974a; Monaghan, 1975).

Pequegnat (1974) disagreed with Monaghan in suggesting that the majority of benthic fishes avoided drilling sites in the Gulf of Mexico. Pequegnat felt that the bottom compactness, litter and shell hash under rigs and platforms reduced stocks of infauna on which some benthic fishes fed; toxicity of drilling mud components was suggested as another possible contributing factor.

Oil leaks and spills

Of the chemical contaminants introduced with offshore oil development, the oil itself poses by far the greatest threat to fish, shellfish and their habitats. Even for oil, there is little evidence of damage to resource species. The National Academy of Sciences (1975) considered tainting of oysters to be the principal negative effect of more than 40 years of intensive oil production in the Gulf of Mexico off Louisiana; commercial catches have remained high despite the input of an estimated 1.1 million barrels of oil. The character of the catch has changed somewhat (for instance, from dominance of shrimp landings by Penaeus setiferus to roughly equal proportions of P. setiferus and P. aztecus), but this is more likely due to inshore physical impacts.

Pequegnat (1974) considered chronic introduction of oil (and also drilling fluids) to be more of an environmental problem than major oil spills in the Gulf of Mexico. He felt that chronic impacts could not yet be assessed in the Gulf. The National Academy of Sciences (1975) also held that there was not sufficient evidence available to demonstrate that there have been no chronic effects of oil. Any chronic oil inputs have usually not resulted in detectable hydrocarbon increases around platforms; we uncovered only one reported instance of elevated hydrocarbons in the Gulf (5.3 ppb in water near a platform, vs 1.2 ppb control; there was no increase in sediments (Kumpf, 1977)). Probably twice as much oil is introduced in Louisiana coastal waters through released formation water as through accidental spills (National Academy of Sciences, 1975).
In assessing effects of chronic oil pollution, it is often stated that natural seepage of oil has little or no environmental impact. Shinn (1974a) noted that seepage of up to 100 barrels/day off Santa Barbara, California had not resulted in toxic levels of dissolved hydrocarbons (≤ 200 ppb were measured in the seepage area) and had apparently not altered the local fauna. Straughan (1976) reported that no faunal malformations, changes in abundance or biomass were seen in the same seepage area. Food species such as abalone and spiny lobster did not have elevated muscle hydrocarbon concentrations, although mussels and urchins had elevated levels in all tissues. No adverse sublethal effects on the abalone, mussels, urchins or barnacles were found. We know of no reports of clear impacts of production-related oil in California waters. A blow-out in the Santa Barbara Channel was followed by decreased biomass of several species, but this could also have been due to other perturbations such as increased sewage pollution, drilling, or change in sediments (Department of Interior, 1976).

Again, impacts of oil from production on the east coast can only be speculated on at this time. Connor and Howarth (1976) felt that much of any oil spilled on Georges Bank would accumulate in sediments and could (through food web transfers) affect populations of commercial finfish species, most of which are bottom feeders in the Georges Bank area. Eggs and larvae of these species are often neustonic and patchily distributed, so that under certain conditions an oil spill could doom an entire year class (Connor and Howarth, 1976). Connor and Howarth were thus unconvinced that oil can be produced on Georges Bank without serious risk to fisheries. The hardest evidence to date, however, is that the "continuous" oil spills off the east coast during World War II apparently resulted in no irreversible damage to biota (Department of Interior, 1976).

Georges Bank production would probably involve tankers, whereas in the Middle Atlantic there may be sufficient oil to warrant laying pipelines. If this production reduced the volume of tanker traffic, it might result in no change or even a net decrease in oil input to the marine environment (Allen et al., 1976).

Heavy metals

Evidence is scarcer still that other oil-related contaminants, such as heavy metals and brines, have caused environmental damage. Heavy metals of special concern are chromium and barium (constituents of drilling muds) and nickel and vanadium (found in the oils themselves). Formation waters are another source of metals. In a study (mentioned above) of well-drilling impacts, Ray et al. (1975) reported elevated concentrations of barium, chromium and lead in the drilling mud plume. Values usually returned to background within 200 m of drilling; at maximum mud discharge rates (750 barrels/hour), however, elevated concentrations extended at least 755 m from the rig. At another California platform, Mearns and Moore (1976) measured a suite of metals in many platform species and found only vanadium in rockfish to have increased significantly over control values.

Brines

Besides containing oils and heavy metals, formation waters (brines) can have harmfully high salinity and low dissolved oxygen. A review by Mackin (1973) indicated that brines released from deep-water platforms
are quickly dispersed and have no impacts. In shallow areas local destruction of benthic fauna has been observed, probably due to oil associated with the brines (Mackin, 1973). Anoxic brines could conceivably add to environmental stresses in areas (such as the New York Bight) where low dissolved oxygen is a chronic problem.

Conclusions

Although oil has been produced from offshore facilities for over 50 years in United States waters, the net impact to offshore fisheries appears to be minor. There is evidence that in the Gulf of Mexico and off California the recreational fishery may benefit from presence of drilling or production platforms. The habitat and shelter created by the structures can attract fish and possibly increase productivity and survival. The loss of traditional fishing grounds and fishing gear appears to be negligible. Limited information on the effects on fishery resources of pipe-line jetting, drilling muds and cuttings, oil leakage, brines and heavy metal contamination, also indicates apparently minor impacts. The overall impression that effects of offshore production are small relative to other perturbations agrees with Johnston's (1977) assessment for the North Sea.

As noted above, however, there is still some doubt over whether chronic, long-term and synergistic effects have been accurately measured to date. The National Marine Fisheries Service is currently conducting a thorough environmental analysis of the Buccaneer oil field off Texas, which may help resolve these questions. The Ocean Pulse program of NMFS is also designed to monitor long-term impacts to fisheries of offshore production, as well as other environmental perturbations, in the Middle Atlantic and Georges Bank areas.
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This list includes papers referred to in this issue and is, in addition, an updated version of the references given in C.M.1977/B:10. See also Appendix, p. 101.


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APPENDIX: LIST OF PAPERS PRESENTED AT THE ICES SPECIAL SESSION

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