TOTAL OIL MARINE LTD
FRIGG FIELD PROJECT

DESIGN MANUAL
VOLUME 1

SUMMARY

DESIGN MANUAL

FRIGG FIELD PROJECT

SUMMARY - VOLUME 1

for

TOTAL OIL MARINE LTD.

PARIS, FRANCE

1976 - 1977

Prepared by

TOTAL EXPLORATION PRODUCTION

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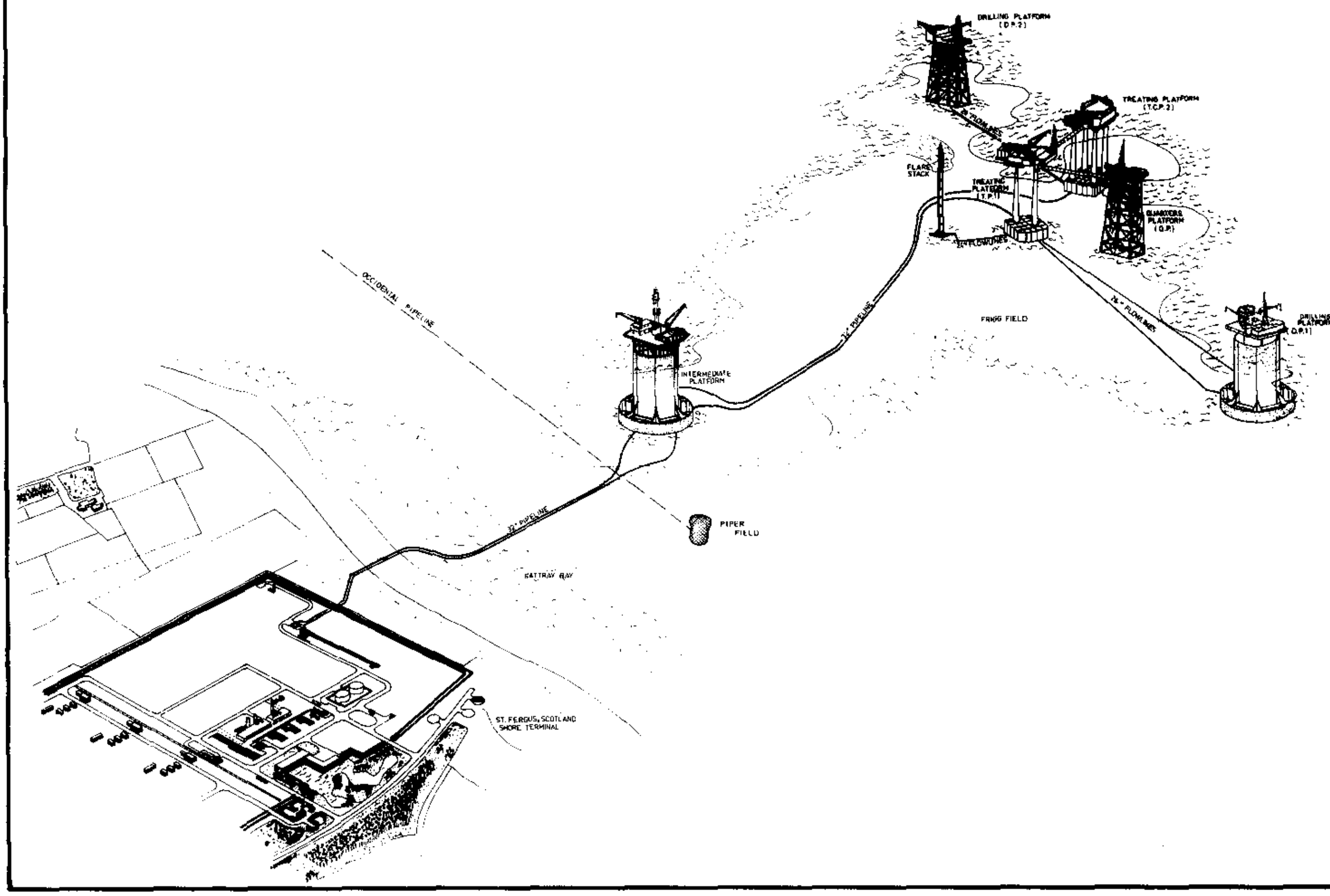

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SUMMARY

INTRODUCTION

SUMMARY

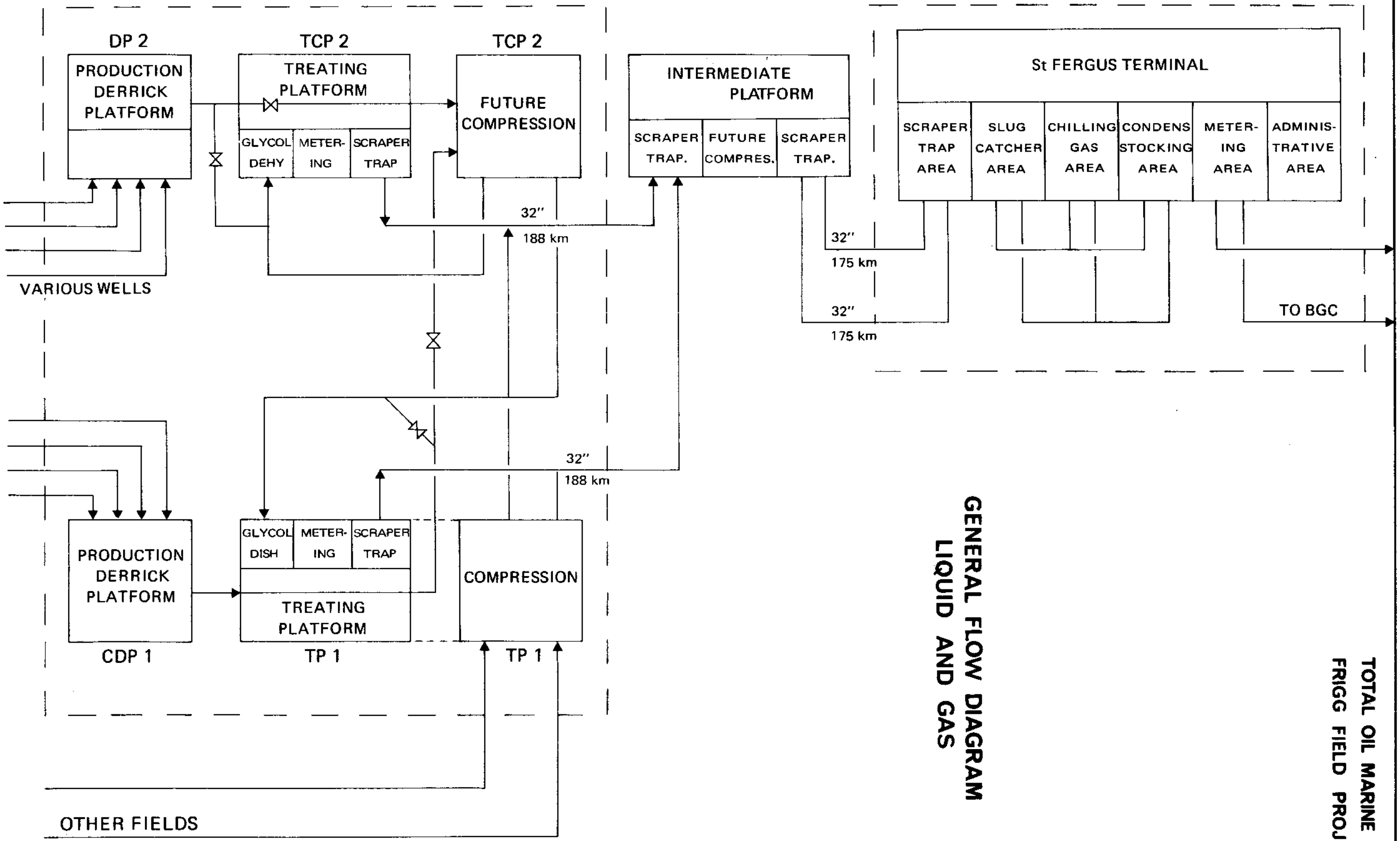
1.0 INTRODUCTION

In June 1971 Petronord discovered the Frigg Gas Field, one of the largest gas fields in the world, which is located on both sides of the United Kingdom-Norwegian boundary in the North Sea. Facilities required to produce gas from the field and deliver it to the British Gas Corporation at St. Fergus, Scotland have been designed and constructed as the Frigg Field Project. The design work was started early in 1973.

1.1 Description of Project

The project consists of the design and construction of the facilities required to house field personnel on a quarters platform, to produce gas in the field from two drilling platforms, initial field treatment of the gas on two treatment platforms, underwater flow lines between field platforms, separate flare stack, two underwater 32 inch pipelines for transportation of gas to Scotland, an intermediate platform with piping manifolds for future compression, a shore approach section of the two pipelines, and a shore terminal where the gas is given final treatment and delivered to the British Gas Corporation through gas custody transfer equipment. These facilities are shown graphically in the frontispiece of this volume and in Figure 1.1.1.

A portion of these facilities is not included in this design manual and is the responsibility of others. The starting point for the facilities covered herein is at a transition piece at the bottom of the riser piping at the treating platforms. Thus the items not included consist of the complete quarters platform, the two producing platforms, the flow lines between platforms, the complete flare stack and the two treating platforms up to the point listed above.



GENERAL FLOW DIAGRAM
LIQUID AND GAS

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The design manual for these facilities is made up of the following volumes with volumes broken down into separate books when required :

Vol. 1	Summary
Vol. 2	Pipeline
Vol. 3	Intermediate Platform
Vol. 4	Shore Terminal
Vol. 5	Communications, Supervisory and Telemetry Systems.

1.2 Frigg Field Description

The Frigg gas field is described as a retrograde condensate gas field, discovered by Petronord in June 1971. The Frigg field, named after the wife of the Norse god Odin, straddles the U.K./Norwegian boundary in the North Sea. It is just south of the 60th parallel approximately 180 kilometers south east of the Shetland Islands and 364 kilometers north east of St. Fergus, Scotland.

The Frigg field has a surface area of approximately 150 square kilometers and is covered by the North Sea, with an average water depth between 100 and 150 meters. The reservoir contains approximately 230 x 10^9 Sm^3 of recoverable gas, and is produced from the Eocene Sands at a depth of approximately 1,800/2,000 meters. The reserves contained in the reservoir are to be eventually distributed between the U.K. and Norwegian areas.

The annual deliveries of each of the two pipelines have been determined from the recoverable reserves of the field on the basis of an average daily flow equal to 1/5000 of these reserves. The maximum daily flow which will be delivered by each pipeline and its related facilities is to be 1.3 times the average daily requirements of the British Gas Corporation.

The Frigg gas contains approximately 6 grams per meter cube of recoverable hydro carbon condensate. The processed hydrocarbons contain approximately 95 mol. % methane, 0.6 mol. % nitrogen, 0.3 mol. % CO_2 and 4.1 mol. % C_3+. Its specific gravity is approximately 0.578.

A most important factor is that Frigg gas contains no hydrogen sulphide or other constituents which would require special processing prior to usage.

1.3 System Capacity

Each pipeline can initially flow at a rate of 30.5×10^6 Sm^3/day and the addition of compression would increase the flow to 41.5×10^6 Sm^3/day.

1.4 Time Frame

This design manual was prepared in late 1976 and early 1977. Portions of the work were not complete at the time of writing and some variations could occur as a result.

1.5 Composition of Volume 1

Volume 1 is divided into eight major sections :

Introduction
Project Characteristics
Route Selection and Marine Survey
Pipeline Design
Pipeline Construction
Intermediate and Treating Platforms
Shore Terminal
Communications, Supervisory and Telemetry Systems.

A certain amount of repetition exists in the various sections in order to minimize referring from one section to another. Drawings, however, are not repeated and are placed on the next page after first being referred to.

2.0 DEVELOPMENT PROGRAM

The development of the U.K. side is being accomplished by the British Joint Venture which includes Total Oil Marine G.B., ELF Oil U.K., and Aquitaine U.K., while the Norwegian zone is being developed by the Norwegian Joint Venture including Total Oil Marine Norsk, ELF Norge A.S., Norsk Hydro and Statoil. The Joint Ventures agreed to share the responsibility for the development and operation of the Frigg Field and for the transportation system required. ELF has been given the responsibility for the development and production of the gas from the Frigg Field. T.O.M. has been given the responsibility for the construction of the pipeline to the British coast, and related facilities.

The Frigg Field location is surrounded by several other minor gas fields which are under development. These are East Frigg, West Frigg, West/East Frigg, Odin, Heimdal and parts of Block 25/1. Should these fields be developed, they will probably be tied into the pipe line system and the gas conveyed to the mainland.

The development of the Frigg Field, to include production and pipeline facilities, was originally to be completed in three phases as outlined below.

2.1 Phase I - Construction to be completed by 1976

Phase I is the development of the Frigg Field production facilities and the pipeline facilities for the exploitation of the U.K. zone. This phase includes up to 24 gas wells and dehydration treatment facilities located at the Frigg Field site, one 32 inch outside diameter pipe line approximately 364 kilometers in length, one intermediate platform and one shore terminal processing and gas metering facilities. It will maintain both hydrocarbon and water dew point control and flow of 30.5×10^6 Sm^3/day with an annual delivery of 8.5×10^9 Sm^3.

2.2 Phase II - Construction to be completed by 1978

Basically, the Norwegian zone adds approximately twenty four (24) gas wells, related platform production equipment and additional processing facilities within the shore terminal complex to the system. The second 32 inch pipe line parallels the first line and utilises the previously completed intermediate platform for pig receiving, launching and future compression. It is designed for maximum daily flow of 30.5×10^6 Sm^3/day with an expected average daily flow of 23.5×10^6 Sm^3/day, or an annual delivery of approximately 8.5×10^9 Sm^3.

2.3 Phase III - Construction to be completed after 1978

Frigg Field gas pressure will start declining about this time. To maintain pipeline inlet pressure, it will then be necessary to install a compressor station at the treatment platform. To increase pipeline throughput, a compressor station will have to be installed on the intermediate platform. The system will have a maximum daily flow of 83×10^6 Sm^3/day with an expected average flow of 61×10^6 Sm^3/day or an annual system delivery of approximately 23×10^9 Sm^3.

2.4 Program Changes

Due to a large number of factors, the above program was not met as of the time of this writing i.e. late 1976 - early 1977. Also for various reasons, the second pipeline was started in construction during the 1975 construction season.

It now appears that construction will be such that both 32 inch pipelines, the shore terminal and other required facilities will be completed allowing gas deliveries to commence mid or late 1977. A determining factor in the gas deliverability of the project is expected to be the number of wells completed and available.

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SUMMARY

PROJECT CHARACTERISTICS

3.0 FIELD FACILITIES

The facilities provided at the Frigg Field were designed by others and in summary consist of :

3.1 Drilling Production Platforms, CDP 1 and DP 2

CDP 1 is constructed of concrete with a perforated caisson known as the Jarlan wall. It was installed in the U.K. zone the 1st September 1975 and was built by Howard Doris in Norway. A major design feature is the central shaft which permits dry access to the riser pipes for maintenance during the productive life of the field.

Platform DP 2 is a steel fabricated platform and was installed the 11th May 1976 in the Norwegian zone to allow the development of gas wells for its zone. The two platforms are installed about 1.4 kilometers apart. It is intended that as many as 24 wells will be drilled and controlled from each platform. The wells are completed with production tubing of 7 5/8 inch diameter with a maximum deviation angle of 35°.

3.2 Treatment Platforms TP 1 and TCP 2

Treatment and future compression of the collected gas will be done on these two platforms before the gas is introduced into the conveying pipelines. TP 1 is a concrete structure with two columns and was built by Sea Tank Company. At the base of the platform is a concrete caisson about 230 feet on each side and 128 feet high. Two columns rise 272 feet above the base and support a steel deck and gas treatment - compression platform which also incorporates a helicopter deck. The platform was installed the 5th of June 1976, after a 900 mile tow, in the British zone. Gas to and from the platform is Phase I gas i.e. gas from the United Kingdom zone which is transported ashore by the first 32 inch pipeline.

TCP 2 is also a concrete structure but consists of four columns, to be installed in the Norwegian zone for gas from that zone and to provide gas to the second 32 inch pipeline.

3.3 Flow Lines

Each drilling production platform is connected to its treatment platform by two 26 inch flow lines. In addition there are various 4, 6, 8 inch lines for gas condensate, water etc. between the platforms.

TP 1 treatment platform has a 24 inch flow line to the flare stack for flowing of gas when required by abnormal conditions.

3.4 Flare Stack

The flare stack is a steel fabricated structure which was installed the 12th of October 1975. It is located 500 meters from TP 1 and will burn gas and condensate in the event abnormal operations make this necessary. The stack is connected by one 24 inch flow line to the treatment platform TP 1.

3.5 Quarters Platform

A single quarters platform is provided to serve the entire field. It is a steel fabricated platform designed with facilities for 120 people. The facilities consist of living quarters, offices, laboratories, workshops, radio control rooms and one helideck for helicopters. The platform was installed the 15th of July 1975. A steel causeway about 100 meters long connects the quarters platform to TP 1 and TP 1 is connected to TCP 2 by a similar 100 meter long causeway. Figure 3.2.1 shows these facilities and their interrelationships.

I

FRIGG FIELD FACILITIES UNDER CONSTRUCTION

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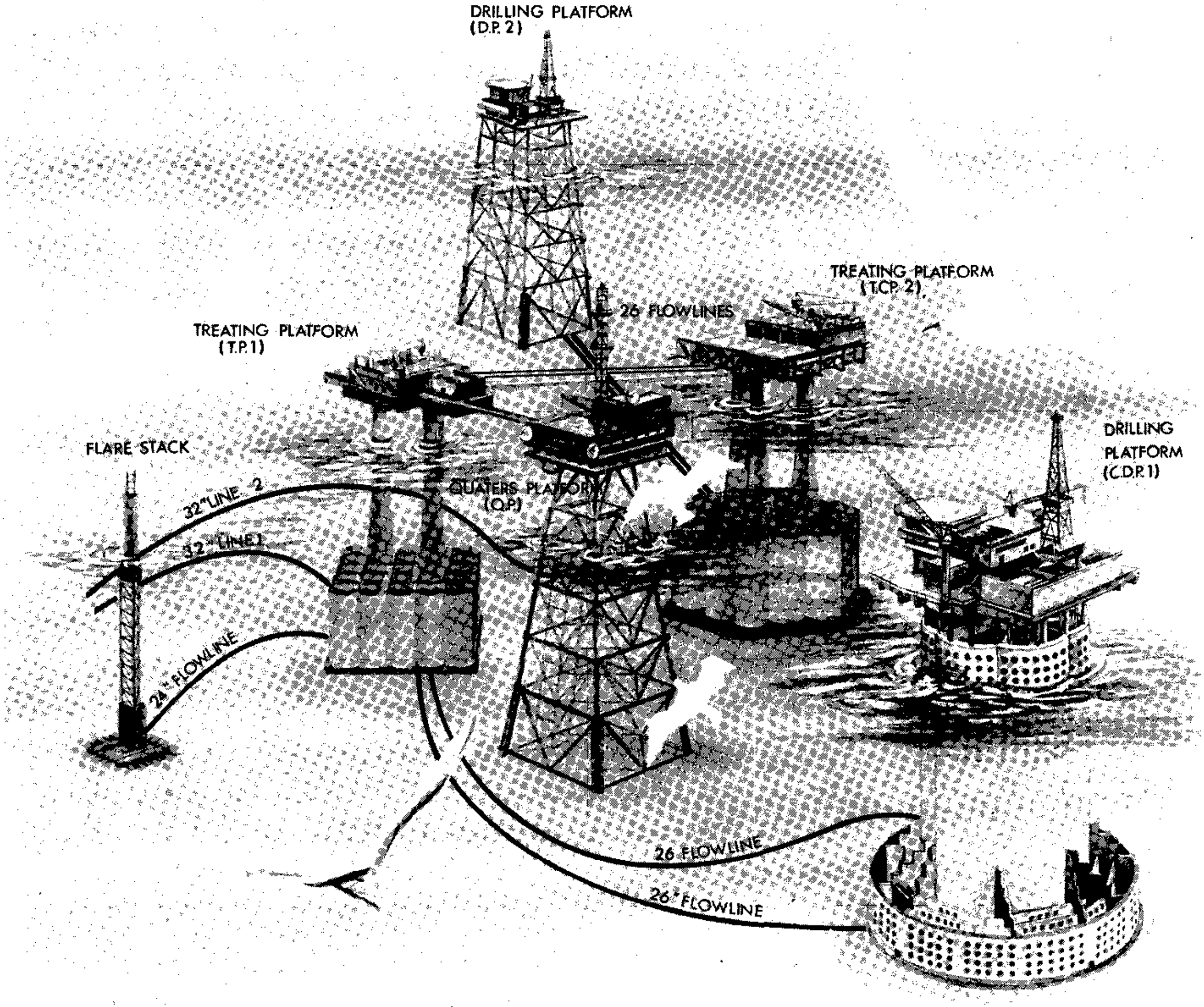

LAYBARGE BAR 324 WITH PIPE SUPPLY BOAT ALONGSIDE

4.0 PIPELINE - FRIGG FIELD TO ST. FERGUS, SCOTLAND

4.1 Pipeline Description

Frigg Field production, consisting of natural gas and a small amount of condensate, will be transported to shore by means of two pipe lines each of 32 inch outside diameter. The two pipelines follow parallel routes, approximately 70 meters apart, between Frigg Field and St. Fergus on the North East Scottish coast. Water depths exceed 100 meters along more than 80 % of the route and in some places reach 150 meters. The length of the first pipeline (Phase 1) amounts to 361 kilometers (228 miles) while the second pipeline is 363 kilometers (229 miles). The pipelines are nominally referred to as 364 kilometers (230 miles) in length and are shown in Figure 4.1.1.

As a result of the long distance, an intermediate platform is located approximately half-way between Frigg Field and St. Fergus, thus permitting the installations of pig receivers, liquid/gas separators and subsequent compression facilities. The regular cleaning of the lines, when needed to maintain pipeline efficiency, will require the launching of cleaning pigs which cannot travel the full distance without the risk of excessive wear.

The maximum continuous operating pressure for the pipeline and the intermediate platform is 2160 psig (147.9 bars absolute).

However, the shore terminal has a maximum continuous operating pressure of 800 psig and is protected by pressure control and safety valves at the entrance to the terminal.

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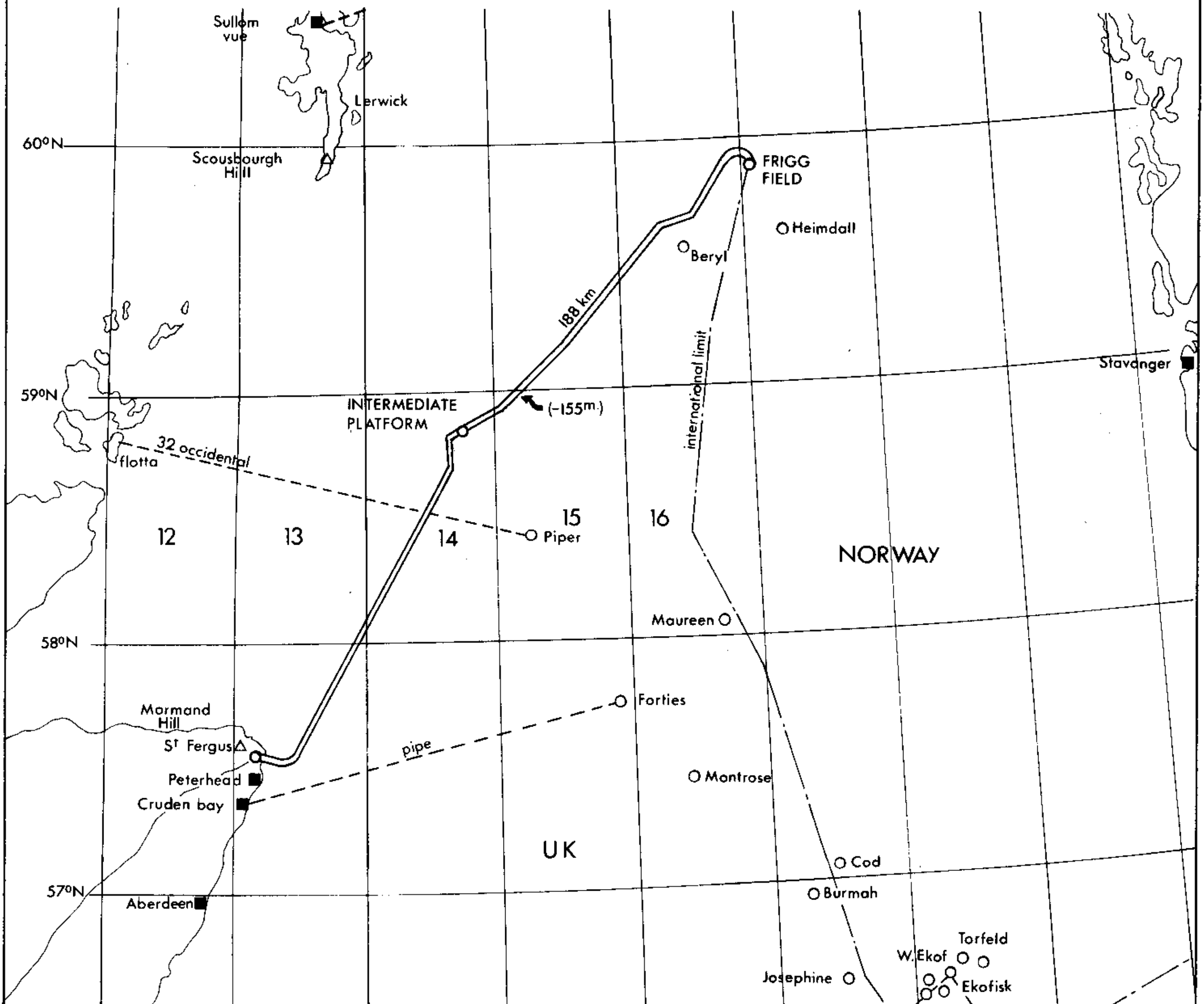

FRIGG FIELD TO SCOTLAND PIPELINE

When operating at the maximum pressure of 2160 psig, the maximum daily flow is 30.5 x 10^6 Sm^3/day for each pipeline, representing a total production of 61 x 10^6 Sm^3/day without compression.

When a 144,000 horsepower compressor station is installed on the intermediate platform (Phase III), flow increases to 41.5 x 10^6 Sm^3/day per line, a total of 83 x 10^6 Sm^3/day. Compression would also be required at Frigg to maintain pipeline inlet pressure due to gas reservoir pressure decline.

At the St. Fergus terminal, facilities are provided to separate liquid condensate from the gas, treat the gas for hydrocarbon dew point control, stabilize the condensate after separation, and custody transfer metering. Administrative and technical facilities are also included.

4.2 Materials

4.2.1 Pipe

The pipe selected for the submarine pipeline has been manufactured in accordance with specification API 5LX 65. The high yield strength of 65,000 psi is needed to withstand the high stresses resulting from construction procedures in moving pipe over the lay barge stinger and to the sea bottom. The steel is a low carbon equivalent resulting in weldability without pre-heating and without inter-pass heating.

4.2.2 Concrete Coating

The concrete weight coating applied to the pipe is in various thicknesses to provide pipeline stability. Variation in thickness is due to variation in sea bottom soil composition and sea bottom current. Pipe for installation from the coast to approximately 12 kilometers offshore requires 4 5/8 inches (11.75 centimeters) thick concrete coating for stability due to the high current velocity along the coast.

As the pipeline is laid seaward, the required concrete coating thickness for stability decreases since sea current velocities are less farther from the shore. The minimum concrete thickness is 1 7/8 inches (48 millimeters). Figure 4.2.1 illustrates concrete coating settling with current.

To make certain that the concrete does not separate from the pipe during the laying operation and to also make certain that the concrete coating can withstand blows from trawler fishing boards, the concrete coating is reinforced with steel bars. Where the thickness of the concrete coating is above 1 7/8 inches (48 millimeters), saw cuts are made every 3 feet (90 centimeters) to improve flexibility of the coated pipe during the laying operation.

The concrete alone has a nominal density of 190 pounds per cubic foot. The density of the coated pipeline varies depending on the thickness of the applied concrete and by specific gravity varies from 1.16 min. to 1.60 max.

4.2.3 Corrosion Protection

Corrosion protection is provided by the application of a 3/16 inch thickness of bitumen and fibre glass coating to the outside of the pipe. This coating electrically insulates the pipe while the attachment of sacrificial zinc anodes gives the pipe a negative polarity. The anodes are 610 kilogram bracelets attached to the pipeline every fourteenth joint (170 meters) and are designed to protect the pipeline for twenty years. Figure 4.2.3 illustrates the zinc anodes.

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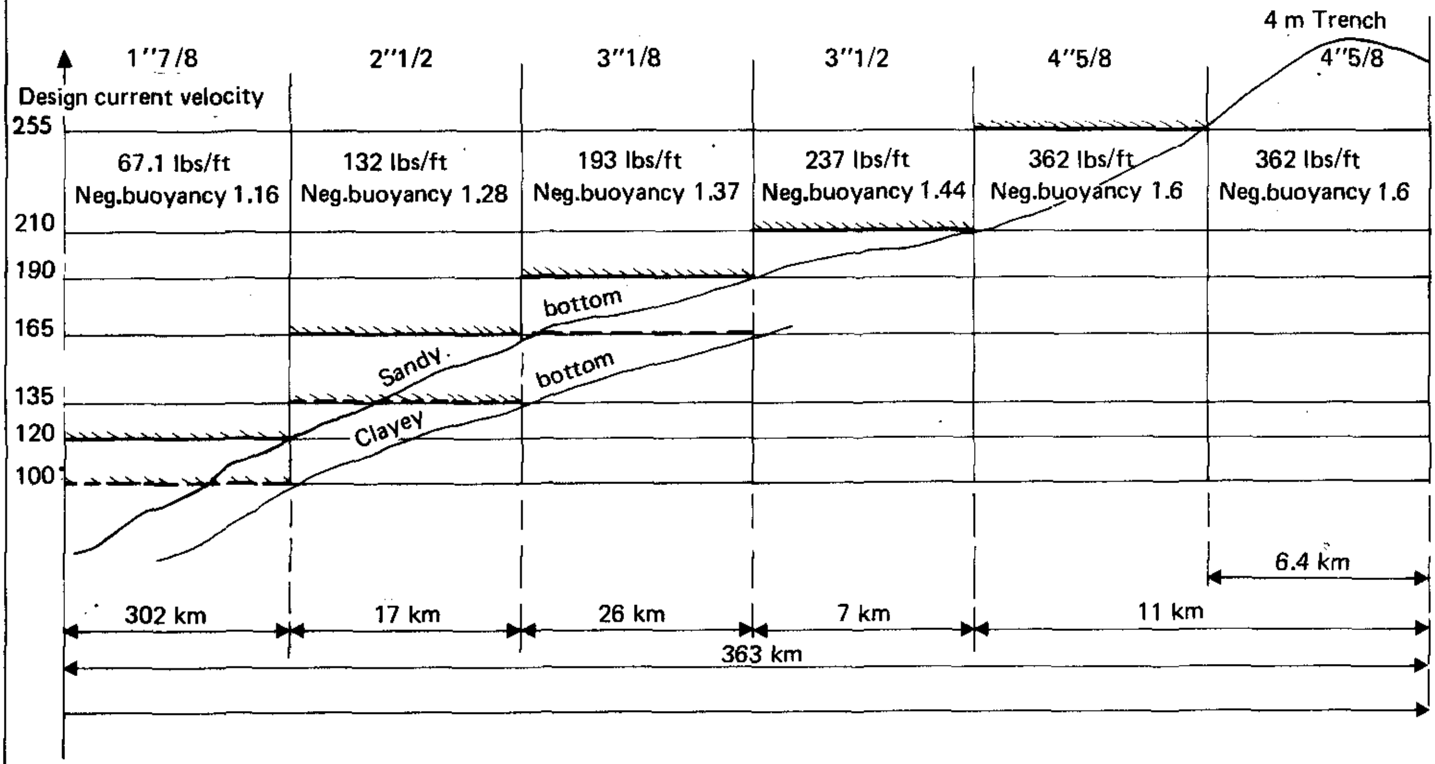

LENGTH AND CONCRETE COATING THICKNESS
SETTLING ACCORDING TO SUBMARINE CURRENTS

4.2.4 Buckle Arrestors

Buckle arrestors are 36 inch outside diameter steel sleeves 1.83 meters long, which are positioned on every fourteenth pipe joint when the laying depth is greater than 107 meters. Seven joints separate each anode and buckle arrestor. The purpose of these buckle arrestors is to reduce the length of damaged pipe by limiting the propagation of a buckle resulting from excessive stresses applied to the pipe during the laying operations. Figures 4.2.2 and 4.2.3 illustrate buckles and arrestors.

4.3 Pipeline Construction Method and Equipment

4.3.1 Laying Method

Approximately 80 % of the two lines is laid in water depths between 100 and 150 meters. This requires the use of the "S" Bend Pipe Laying Technique as shown in Figure 4.3.1.

Laying a 32 inch outside diameter pipeline in these depths is difficult, due to the long section of unsupported pipe between the end of the barge stinger and the sea bottom. This unsupported section of pipe can be as long as 250 meters when laying in water depths of 150 meters and imparts a high tension in the pipe and stinger. Barge movements due to wave action increase the stresses and ultimately will buckle the pipe and stinger. Figure 4.3.1 also shows the variation in bending moments along the S bend.

Safely laying pipe in this depth of water necesssitates sea conditions with wave and swell heights of less than 2 1/2 to 3 meters. When these conditions are exceeded, pipe laying must stop and the line must be laid on the bottom until sea conditions improve.

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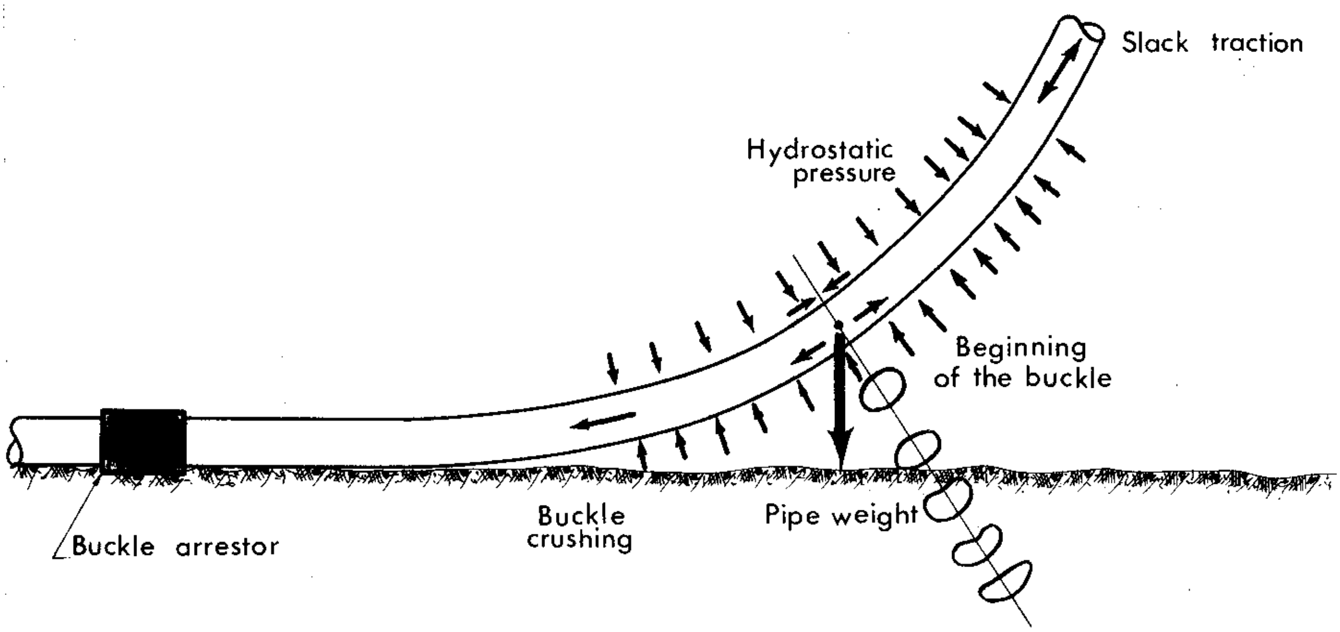

BEGINNING OF BUCKLE AND BUCKLE ARRESTOR EFFECT

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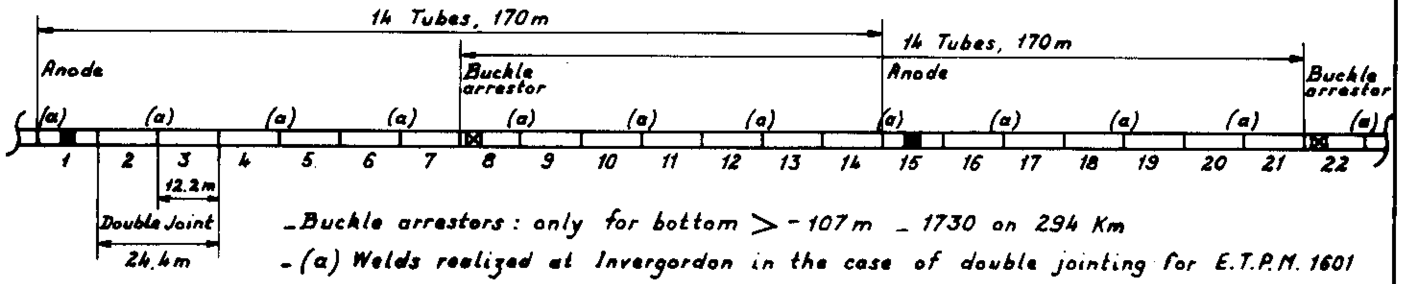
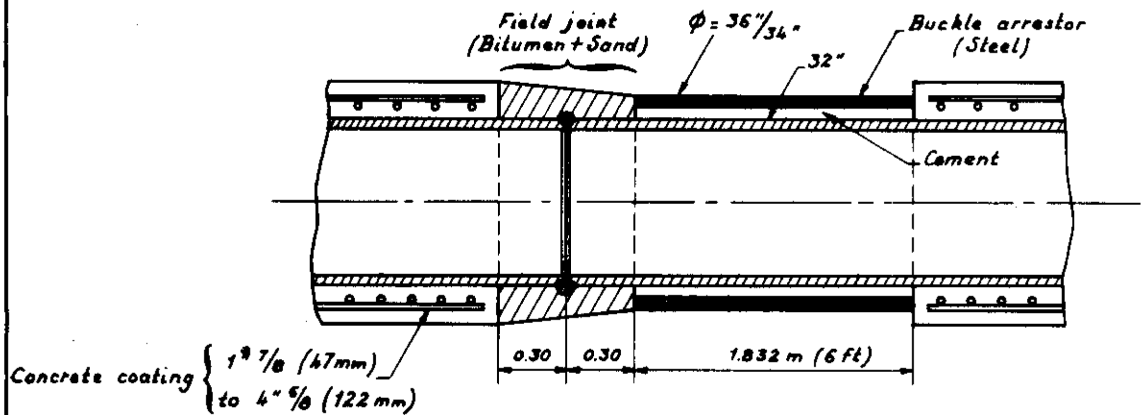
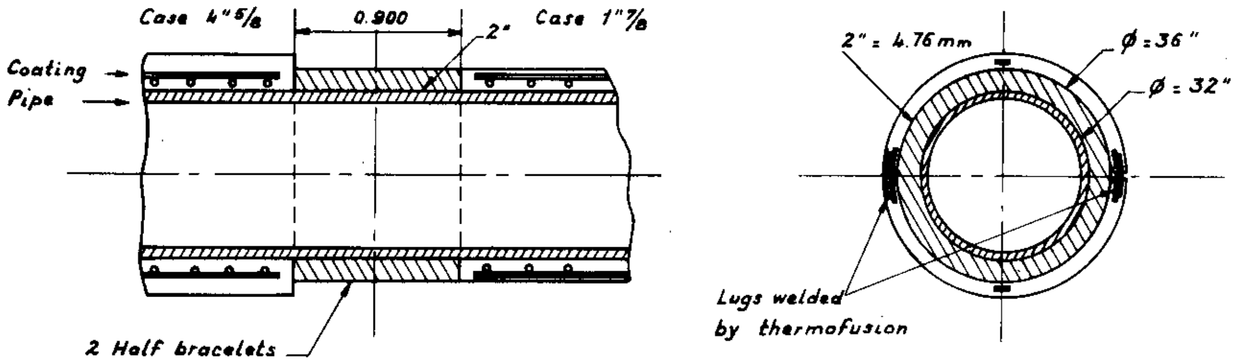


LINE SKETCH WITH PIPES, ANODES AND BUCKLE ARRESTORS



BUCKLE ARRESTOR ASSEMBLY



SACRIFICIAL ZINC ANODE

BUCKLE ARRESTORS & ZINC ANODES

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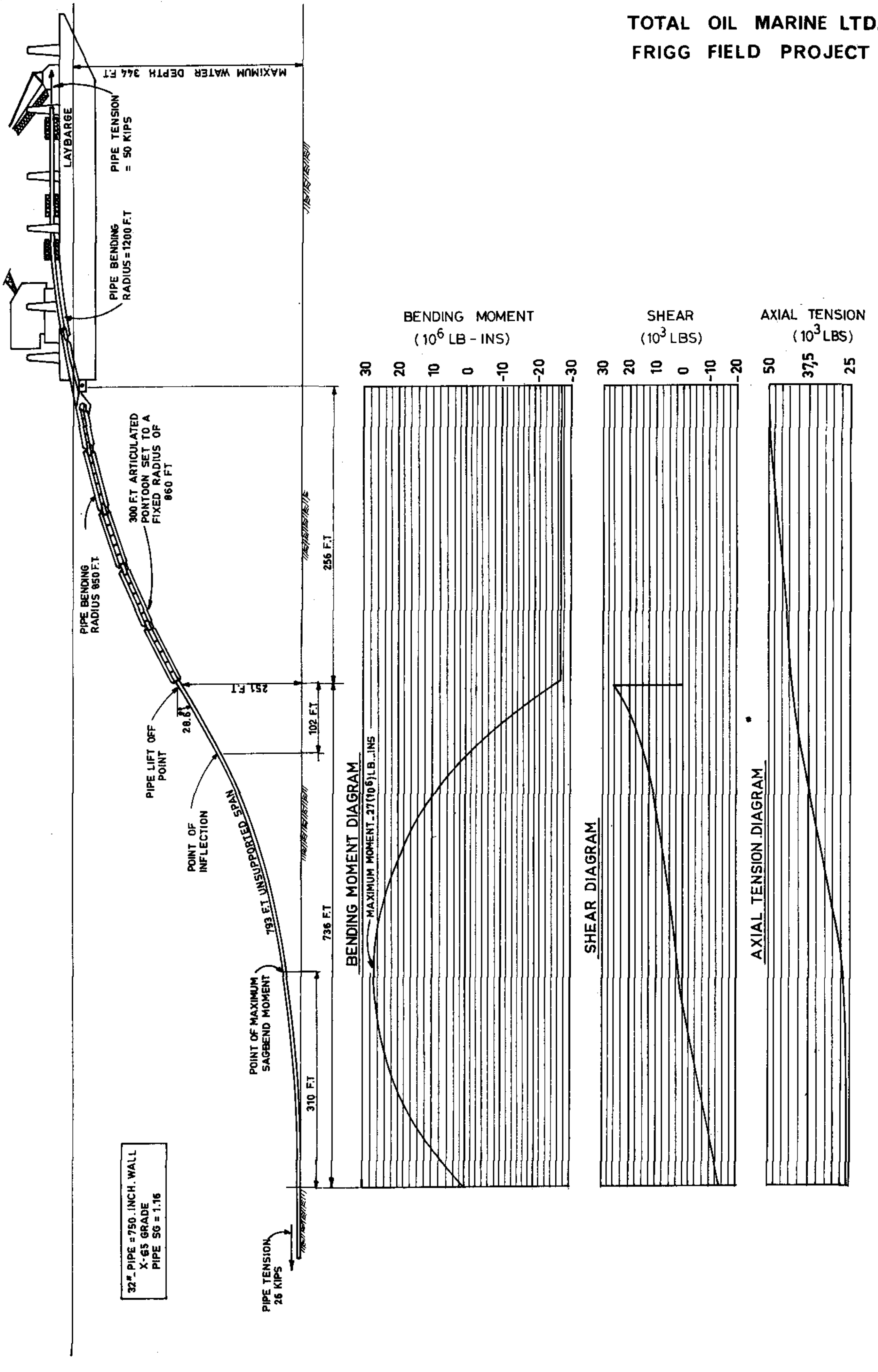

The area in the North Sea in which the Frigg Field to Scotland pipeline is being laid has extreme hostile weather conditions and allows pipe to be laid only between May and October. Even then, about 50 % non-lay time due to excessive weather conditions and barge repair are experienced.

As a result of the foregoing, pipelaying has been scheduled over a three year period, April to November each year.

4.3.2 Laybarges

Each laybarge operates continuously around the clock, 24 hours per day, and is attended by a fleet of ten ancillary vessels for towing operations, handling of anchors, barge positioning, pipe supply, fuel oil, water supply and personnel movement. Over 200 persons are required on each barge for operations.

The laybarges used were :

Brown & Root BAR 324

This laybarge is a conventional type laybarge, 400 feet long, 100 feet wide, 30 feet deep, equipped with a 250 ton crane, a semi-articulated stinger and 10 anchors. It has a side production line with automatic welding equipment and is shown in Figure 4.3.2.

Barge LB 27 from Oceanic Constructors

Oceanic's parent company is McDermott Co. The barge is of similar design to BAR 324 : 420 feet long, 128 feet wide, 28 feet deep, equipped with a 65 ton crane, a semi-articulated stinger and 12 anchors. It has a centre production line with automatic welding equipment and is shown in Figure 4.3.3.

E.T.P.M. 1601

This is a self propelled lay ship of an entirely new design. She is at present one of the largest vessels designed for off-shore pipelaying. The hull measures 607 feet long, 115 feet wide and 50 feet deep. She is equipped with a 1600 ton crane and 10 anchors. Her maindeck area is 70,000 square feet which is sufficient to enable her to store and handle 24 meter long double jointed pipe thus doubling the laying rate. In 1975 a rigid stinger and automatic welding equipment were installed. She has a centre-slot production line as shown in Figure 4.3.4.

Stingers

A pipeline support or stinger, with controlled buoyancy, which is fixed at the stern end of the barge and designed to support the section of pipe spanning between the barge and the sea floor. The "S" bend helps to minimise the construction stresses and keep them within the maximum allowable construction stress of 80 % of the yield strength.

Stingers are a fabricated steel tube structure as long as 110 meters. A rigid stinger is one continuous section while an articulated stinger is composed of several sections hinged together to allow movement. The stingers are the weakest part of the laying equipment and are easily damaged making it necessary to always have a spare stinger as back-up.

Tensioners

A tensioning system of 2 or 3 tensioners grip the pipe during the laying and withstand tensions in the pipe up to 80/90 tons as the pipe passes over the stinger. This tension is due to the weight of the pipe extending from the barge to the sea floor, the length of which can amount to 250 meters.

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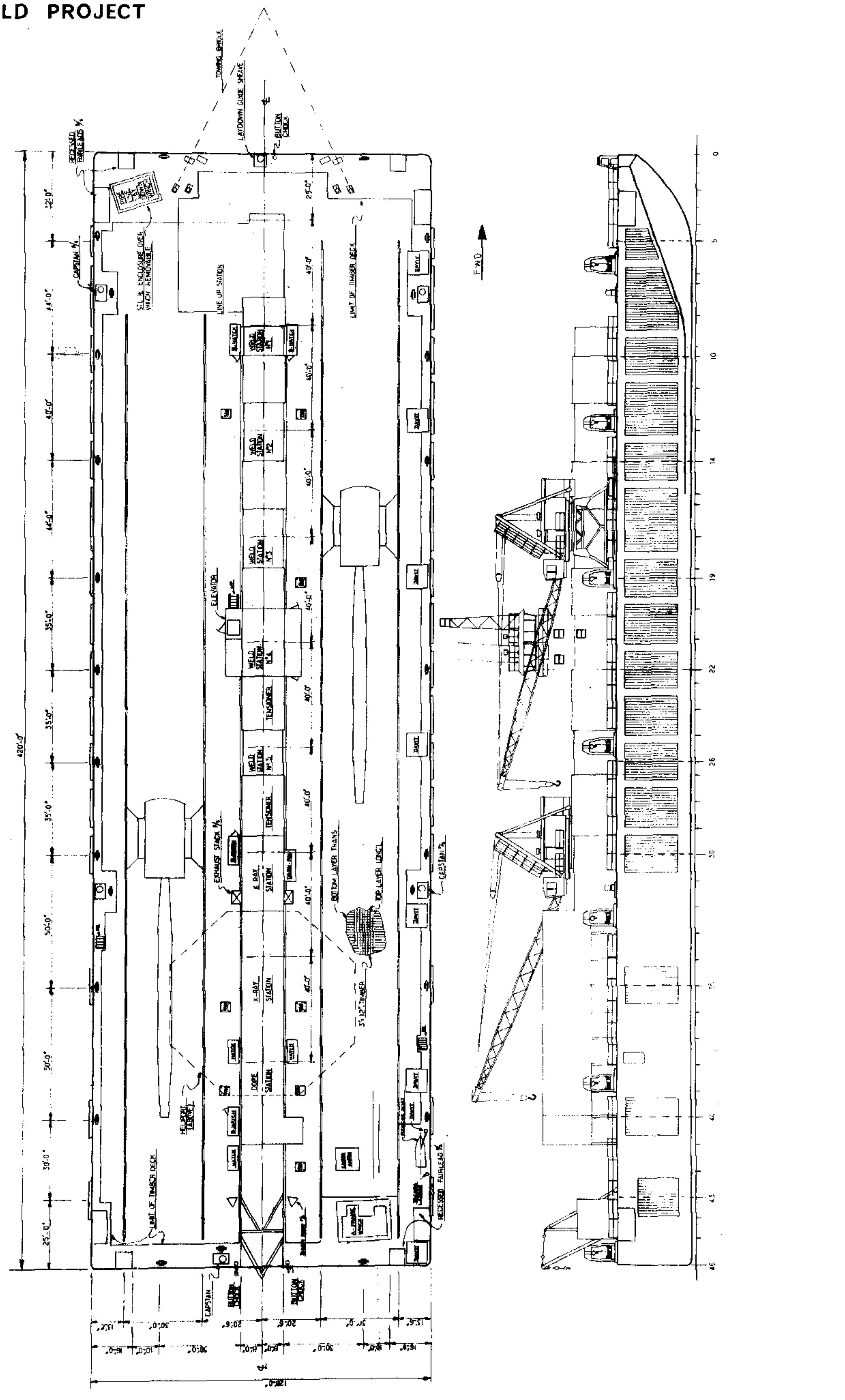

DESIGN MANUAL – VOL.1 – Fig. 4. 3. 3.

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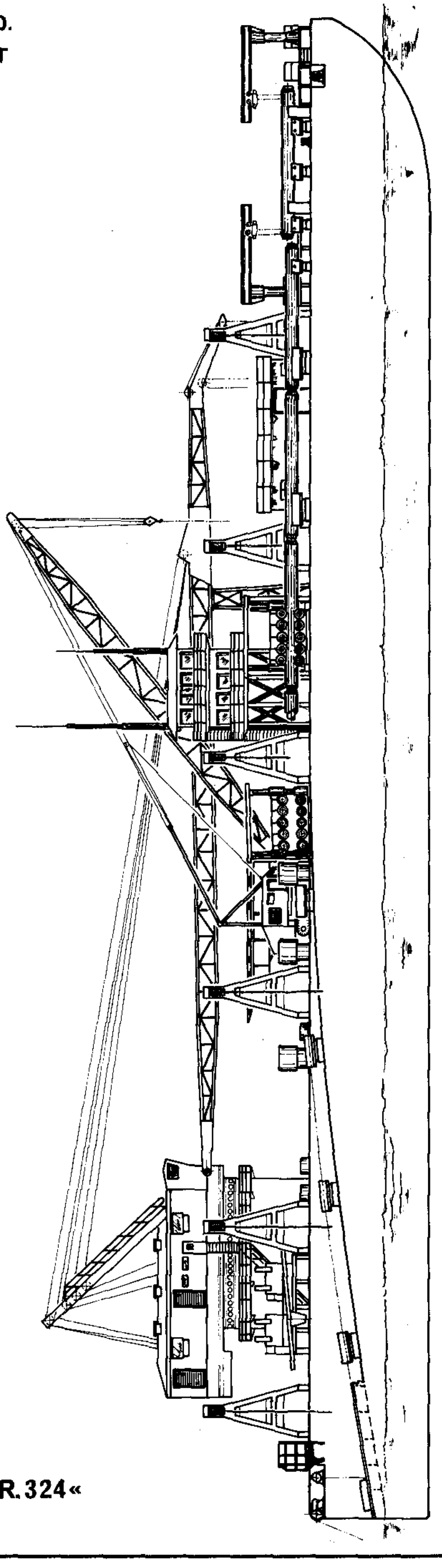
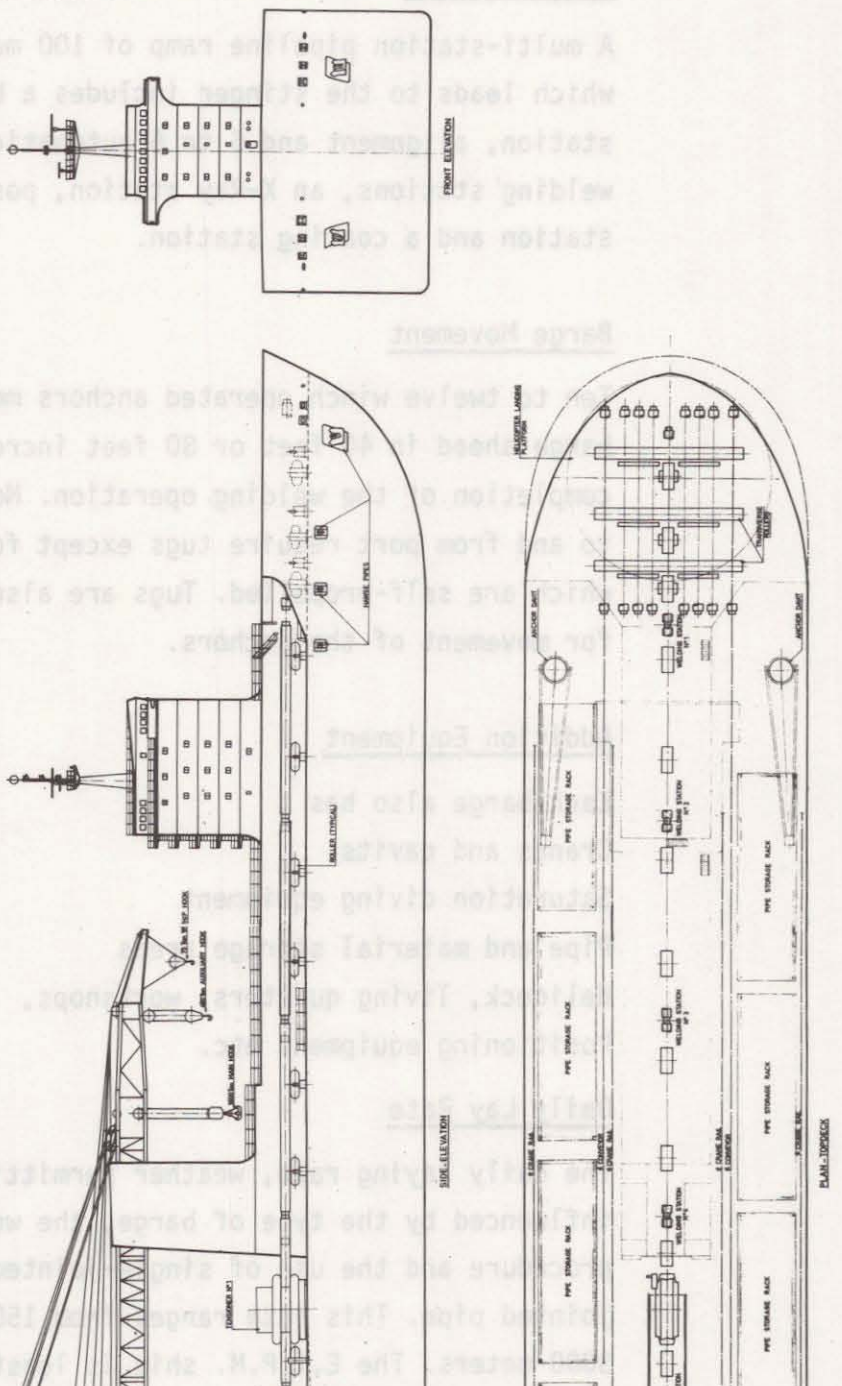


LAY BARGE »BAR.324«

LAYBARGE LB 27

V LAYBARGE ETPM 1601 WITH STINGER ALONGSIDE



LAY BARGE »E.T.P.M. 1601«

Pipeline Ramp

A multi-station pipeline ramp of 100 meters length which leads to the stinger includes a bevelling station, alignment and 5 to 6 automatic or manual welding stations, an X-Ray station, post heat station and a coating station.

Barge Movement

Ten to twelve winch operated anchors move the barge ahead in 40 feet or 80 feet increments upon completion of the welding operation. Movements to and from port require tugs except for ETPM ships which are self-propelled. Tugs are also required for movement of the anchors.

Addition Equipment

Each barge also has :
Cranes and davits
Saturation diving equipment
Pipe and material storage areas
Helideck, living quarters, workshops,
Positioning equipment etc.

Daily Lay Rate

The daily laying rate, weather permitting, is influenced by the type of barge, the welding procedure and the use of single-jointed or double-jointed pipe. This rate ranges from 1500 to 3000 meters. The E.T.P.M. ship is least affected by wave action, the Brown & Root barge is most affected and the Oceanic barge is between the two. This variation is due to displacement and to location of pipeline ramp (side or center).

During the laying seasons of the past two years, 1975 and 1976, weather standby amounted to 37 % of the time. Downtime for repairs was just over 5 % while for other operations it amounted to almost 18 %. The remaining 40 % was spent in laying. These figures are for the BAR 324 and the LB 27 only.

LAYBARGE BAR 323 WITH SPAR AND WELDING HABITAT

4.4 Pipeline Construction Procedure

4.4.1 Normal Laying

When a welding sequence is completed :

a) the barge is moved forward the length of a pipe section by taking up tension on the bow anchor winches with simultaneous control of the tensioners in order to hold the pipe with sufficient tension. The pipe section (single or double length) is brought into position at each of the pipe stations.

b) A new length of pipe enters the sequence and is initially bevelled for welding.

c) The new pipe is lined-up and clamped to the last pipe in the sequence and then is ready for welding.

d) Welding is simultanecusly conducted by the five stations on five joints :

Station 1 : Internal Root Pass & External Hot Pass
Station 2 : First Filler Pass
Station 3 : Second Filler Pass
Station 4 : Third Filler Pass
Station 5 : Cap Pass

e) X-Ray examination is conducted at station 6

f) Post-heating and priming of the welded joint is performed at station 7.

g) Mastic is poured into an aluminium form at station 8 to cover the welded joint to the same thickness as the concrete coating. The aluminium form is not removed.

The total cycle varies from 6 to 12 minutes.

4.4.2 Weather Limitations

The unsupported section of pipe coming off the stinger and the stinger are subjected to various stresses which are acceptable only when the sea conditions of amplitude and frequency of waves and swell do not reach the limiting conditions.

When amplitude exceeds 2 1/2 to 3 meters, the laying operations must be shut down. The end of the pipe section is then covered with a welded cap equipped with a lifting eye and a cable and the pipe is laid on the sea bottom until sea conditions improve.

The operations can be resumed but recovery of the abandoned pipe requires much better sea conditions than those acceptable for the regular laying operations and swell amplitude should not exceed 2 meters.

The E.T.P.M. lay ship can work in somewhat rougher weather than the lay barges.

4.4.3 Automatic Welding

The automatic welding allows 30 % greater welding rates than manual welding, thus increasing the laying rate by the same proportion. C.R.C. automatic welding procedure is used on all 3 barges.

4.4.4 Double Jointing

The pipes are double jointed in Invergordon. Barge E.T.P.M. 1601's handling and storage capacities are sufficient to handle double jointing. The daily cost of the E.T.P.M. lay ship is higher than the conventional barges but she maintains better production rates since she can lay double joints in somewhat rougher weather.

4.4.5 Shore Approach

The laying technique near the shore differs from the one used on the high seas. Shallow depths and high velocity coastal currents make necessary the use of heavy coated pipe with a higher negative buoyancy and also prevent lay barge operation near the shore. Jetting must be made to a higher cover in order to avoid future scouring or undermining effects which could result in stresses in the line. The first 2000 meters of line, of which 1500 meters are immersed, were laid by pulling from the shore as the pipeline was welded on board the E.T.P.M. 1601 lay ship. Three coupled winches induced a maximum tension of 700 tons on the pipeline which was floated by buoys fixed at regular intervals. Figure 4.4.1 shows the winch arrangement.

Jetting the line was done using winches on shore and on Land & Marine Barge LM Balder to move the jet equipment over the pipe. Several passes were required.

4.4.6 Jetting

The pipeline is normally buried with one meter of cover in order to avoid being struck by trawls anchors and to prevent damage to both trawlers and pipe coating. In selected locations three meters of cover was required.

For the first 1500 meters of immersed line starting at the shore, the pipeline is buried to a higher cover in order to avoid scouring or undermining effects which could result in excessive stress on the line due to high velocity coastal currents.

Jetting is accomplished by special barges equipped with powerful pumps and air compressors which feed

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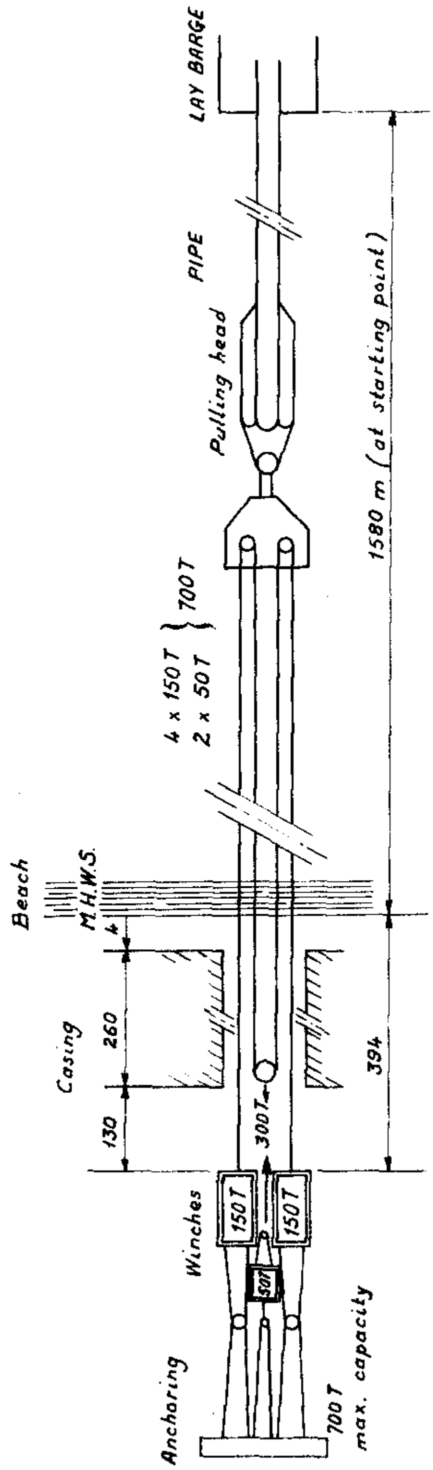


PIPE LAYING BY PULLING FROM THE SHORE

VI

BURYBARGE JB4 UNDER TOW

through hoses into the jet sled towed on the pipe. The water jets excavate the ditch while the air jets lift the excavated soil. The pipeline then sags in the jetted ditch and submarine currents complete the backfilling. Figure 4.4.2 illustrates pipe bury equipment.

4.4.7 Underwater Tie-In

The sections of pipeline laid on the sea floor by the barges are connected together by means of underwater tie-ins. About 11 to 12 subsea connections are expected for the 2 lines.

For safety reasons and due to the great depths and the nature of the product conveyed, couplings were not used to connect the various sections of pipeline. Instead it was decided to use saturation diving and underwater habitats for welding the sections together. Taylor Diving and Comex worked on perfecting this technique which is called hyperbaric welding.

The procedure consists of using an underwater habitat, accessible to the divers who work under helium-oxygen atmosphere at hydrostatic pressure. Work done in the habitat consists of and includes the equipment for the following operations :

a) cutting of pipes, pipe coating and end preparation for welding

b) alignment of cuts

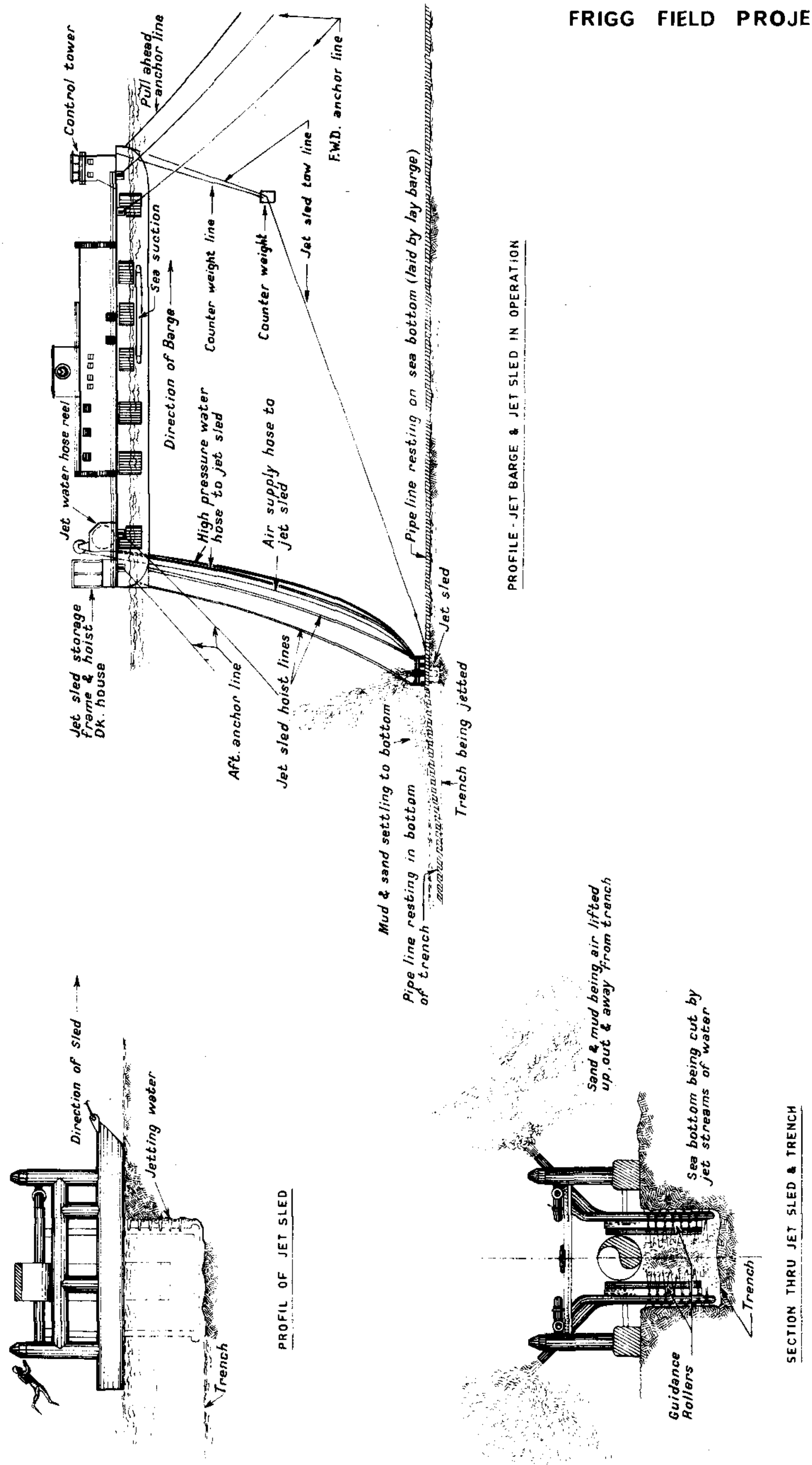
c) manual welding

d) gammagraphic inspection of welds

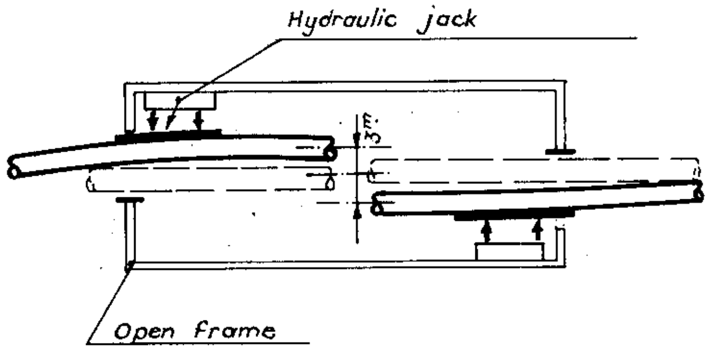
e) joint coating.

Divers are transported to the habitat in diving bells and a saturation system is necessary. Operations are conducted from especially equipped derrick barges such as Hugh Gordon, E.T.P.M. 701 or BAR 323. Figure 4.4.3 illustrates hyperbaric welding.

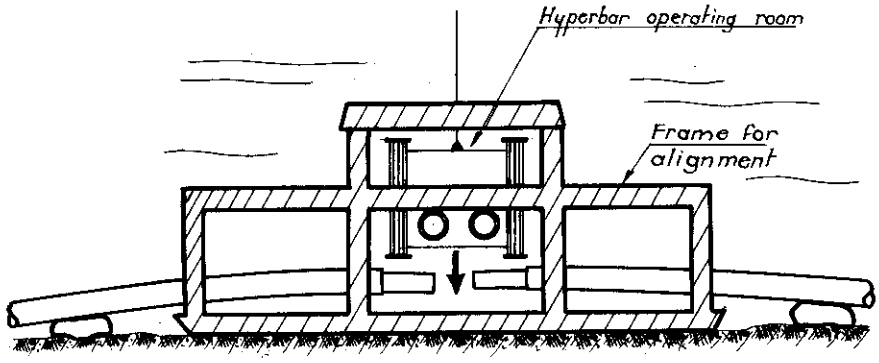
TOTAL OIL MARINE LTD
FRIGG FIELD PROJECT



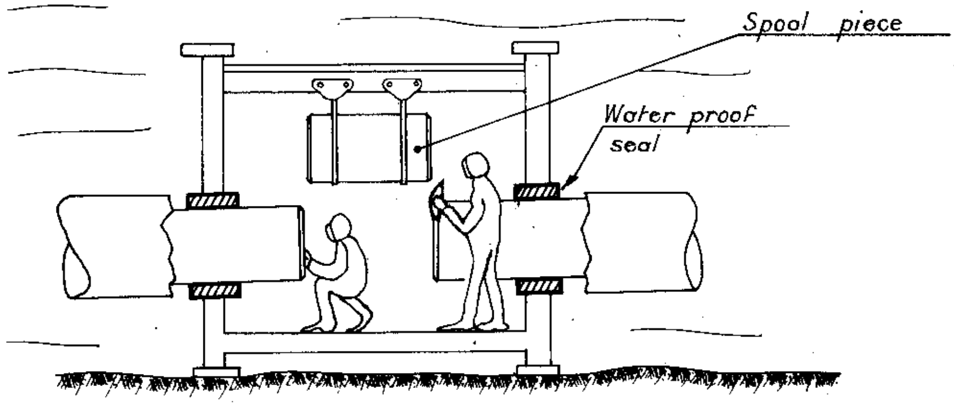
PIPE BURYING ILLUSTRATION



ALIGNMENT PRINCIPLE



INSERTION OF THE HYPERBARIC ROOM ON THE LINE FOR WELDING AND TIE IN



HYPERBARIC ROOM FOR WELDING

4.4.8 Hydrostatic Test

Each pipeline is hydrostatically tested to verify that there are no leaks; the test pressure being 2750 psig measured at L.A.T. (Lowest Astronomical Tide).

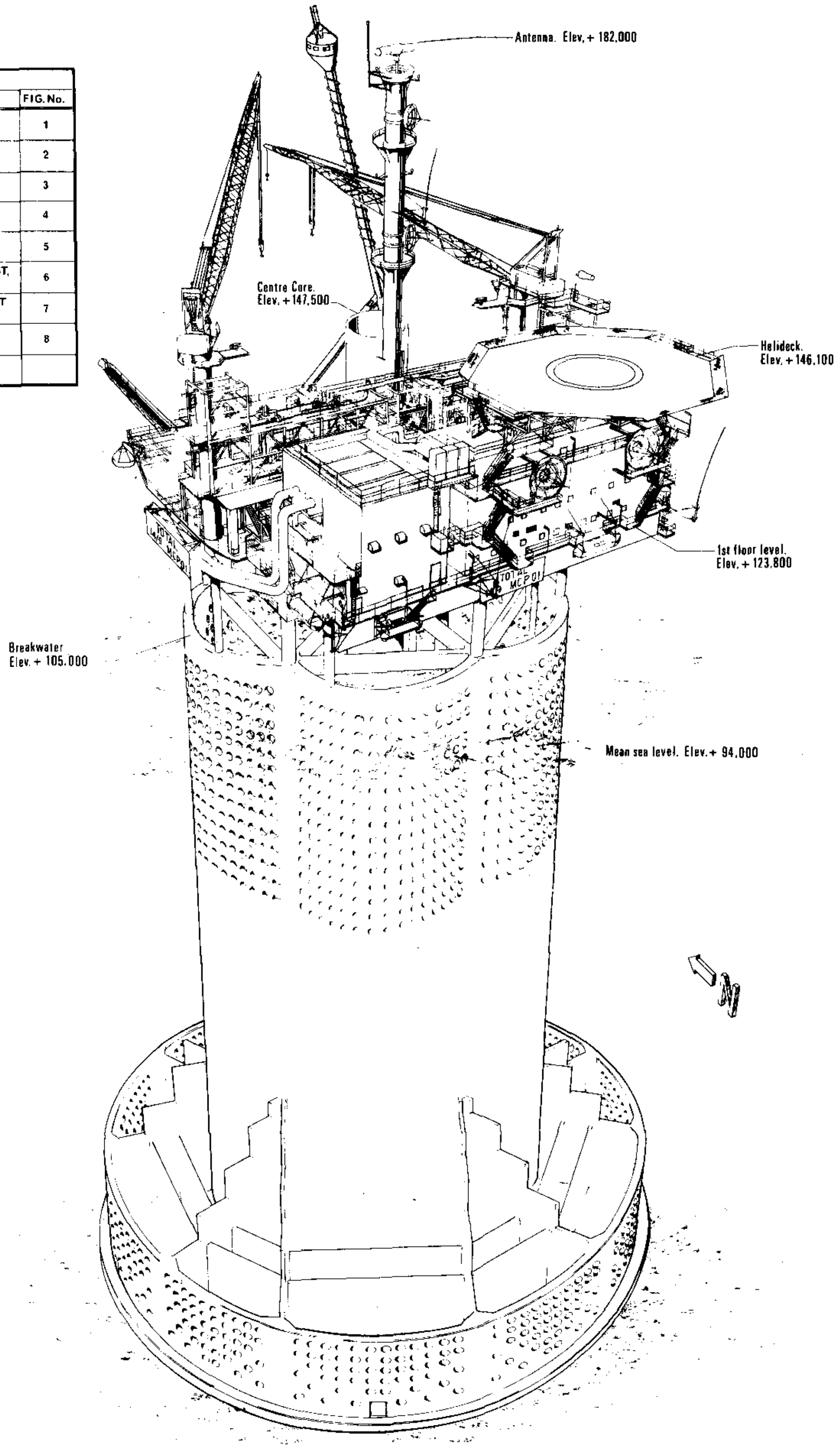
Testing is performed in sections from the intermediate platform to the shore terminal and from the intermediate platform to the production platforms. Pumps and other required items are located on the intermediate platform.

After filling each section with inhibited sea water the pressure is slowly raised to the test pressure, allowed to stabilize, repressured if necessary, and then held for 24 hours.

If testing is done before complete burying the pipelines, the Norwegian regulations require that the line be retested to 2376 psig (maximum operating pressure plus 10 %) for an 8 hour period. Regulations of the United Kingdom do not require similar action.

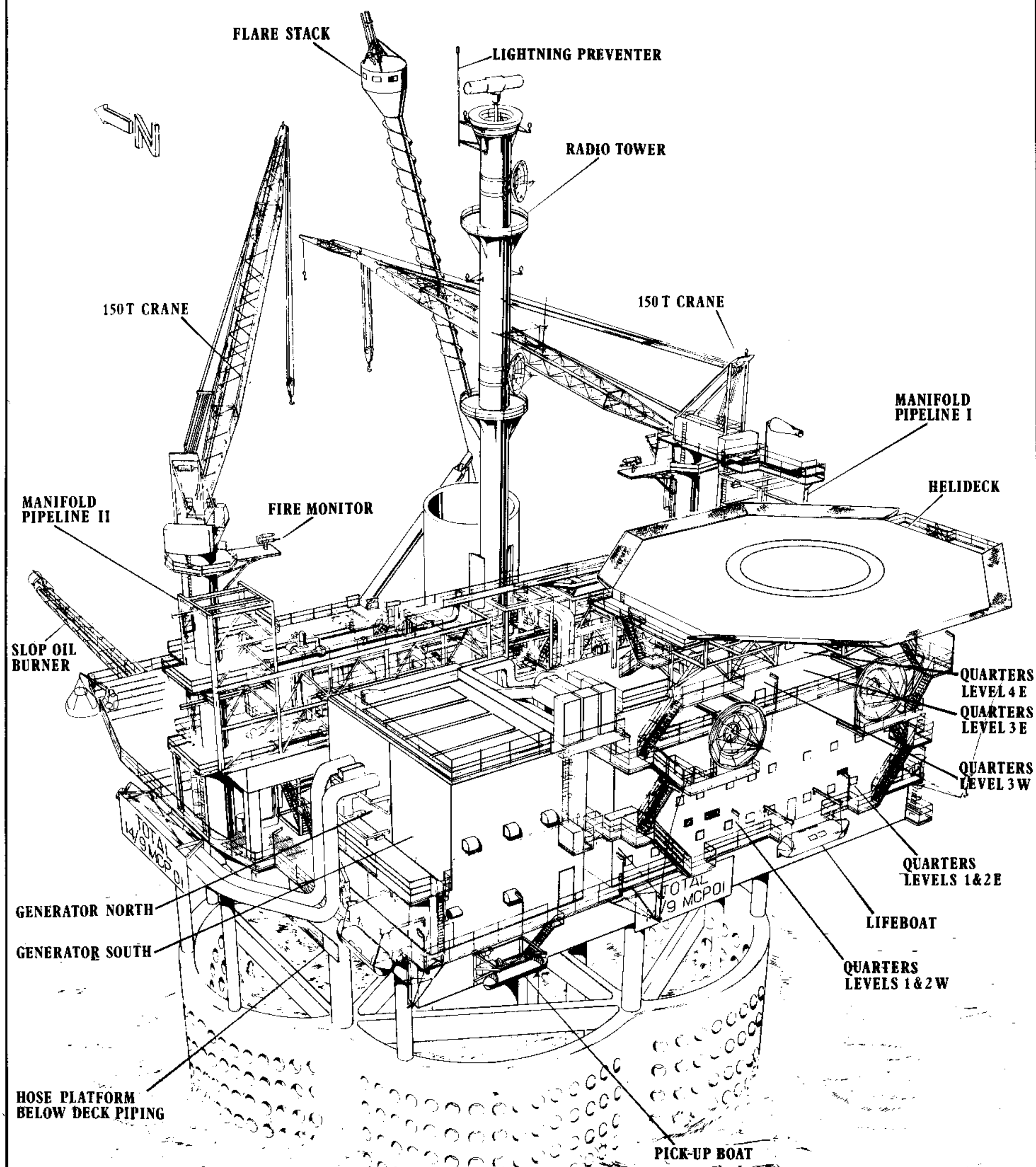
TOTAL OIL MARINE LTD.
FRIGG FIELD PROJECT

LEGEND	
PACKAGE	FIG. No.
GENERAL ARRANGEMENT	1
GENERAL ARRANGEMENT - DECKS	2
TANKS & PIPING BELOW DECKS	3
MANIFOLD PHASE 1& 2 CRANES & RADIO TOWER	4
UTILITIES, PKG. 1&2	5
QUARTERS EAST AND WEST, LEVELS 1& 2	6
QUARTERS EAST AND WEST LEVELS 3& 4	7
HELIDECK AND GENERATOR PKG. 1&2	8



MANIFOLD PLATFORM MCP-01
GENERAL ARRANGEMENT

TOTAL OIL MARINE LTD.
FRIGG FIELD PROJECT



MANIFOLD PLATFORM MCP-01
GENERAL ARRANGEMENT-DECKS

e) Water ballasting for grounding at minus 94 meters.

f) Sand ballasting to ensure final stability on sea floor.

g) Pull-in of the pipelines.

h) Completion of deck equipment installation by the derrick crane and dismounting of same.

The temporary utilisation of a derrick crane avoids the use of a derrick barge for the installation of deck equipment. The derrick crane is also used for the construction of the deck proper.

These steps are illustrated in Figure 5.2.1.

5.2.2 Pull-In's

During the construction and towing operations, tunnels and centre shaft were kept dry by water-tight hatches.

Once the platform was immersed and ballasted, tunnels and shaft were flooded and the lines pulled into the tunnels up to the set position. Sealing joints were then inflated and the tunnels and centre shaft were dewatered by pumps. Water tightness was ensured by Polyurethane injection with the pipe ends being anchored and then welded to the risers. The caisson and waterproof seal is shown in Figure 5.2.2.

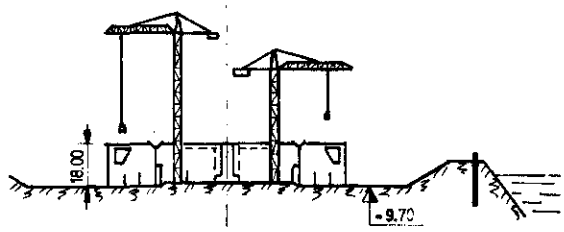
The pull-in of line one, south of the platform was accomplished with a winch on the deck of the platform. As pipe was welded together on a lay barge, the deck mounted winch pulled it into the platform tunnel.

The other three lines were welded together on board a lay barge and lowered to the sea bottom in lengths of about 700 meters, one for each line. Each length was connected by line to a towing vessel which pulled the section to the mouth of a tunnel. Here the tow line was disconnected and the pulling head attached to the winch line from the winch on the platform deck.

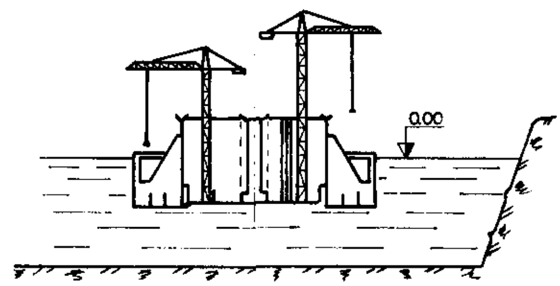
When the pipelines were pulled into the tunnels, to previously arranged set stops, and being observed by TV cameras, the seal was closed, water pumped out of the tunnel and a spool piece welded which connected the riser to the just pulled in pipeline.

Figure 5.2.3 shows the route of the lines immediately around the platform. This configuration made placement of laybarge anchors critical and was a major reason in deciding upon the construction method for the three lines installed by towing.

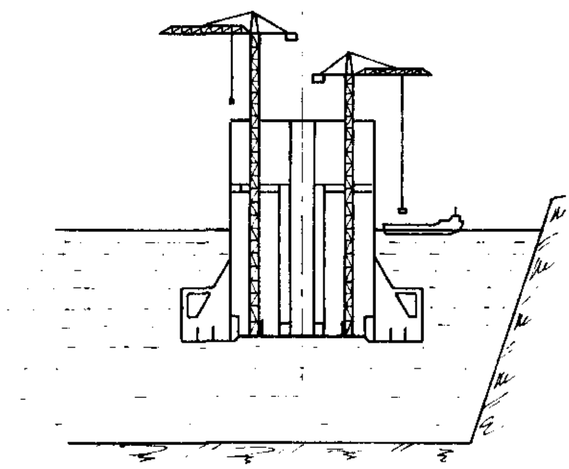
TOTAL OIL MARINE LTD
FRIGG FIELD PROJECT



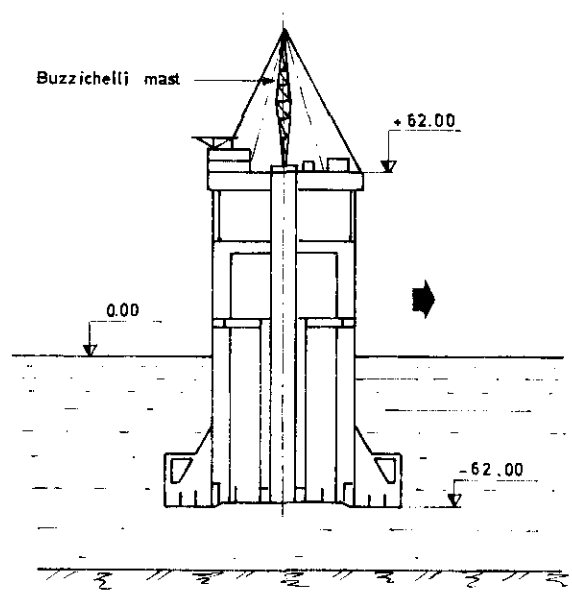
BASE PLANT IN DRY DOCK



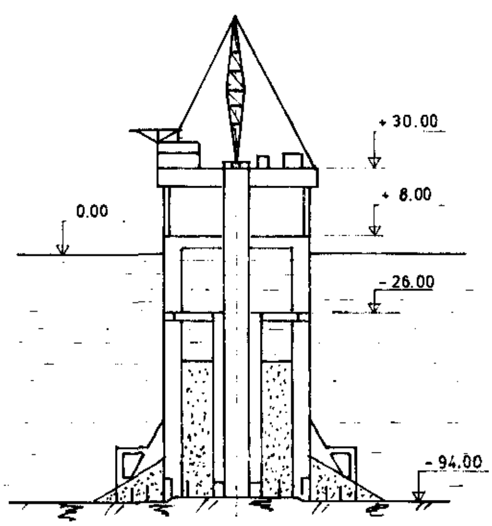
BUILDING CONTINUATION WITH SLIDING CASE AFTER LAUNCHING



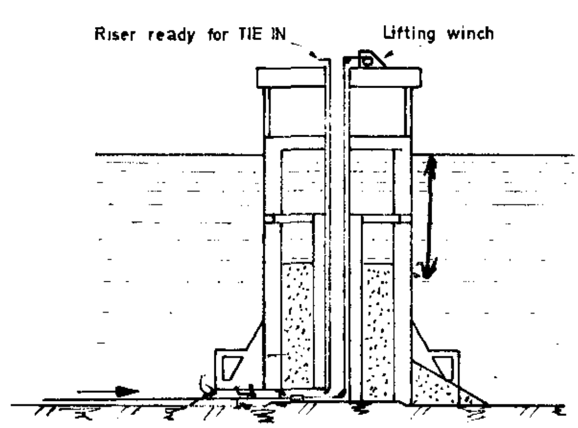
BUILDING CONTINUATION



TOWING

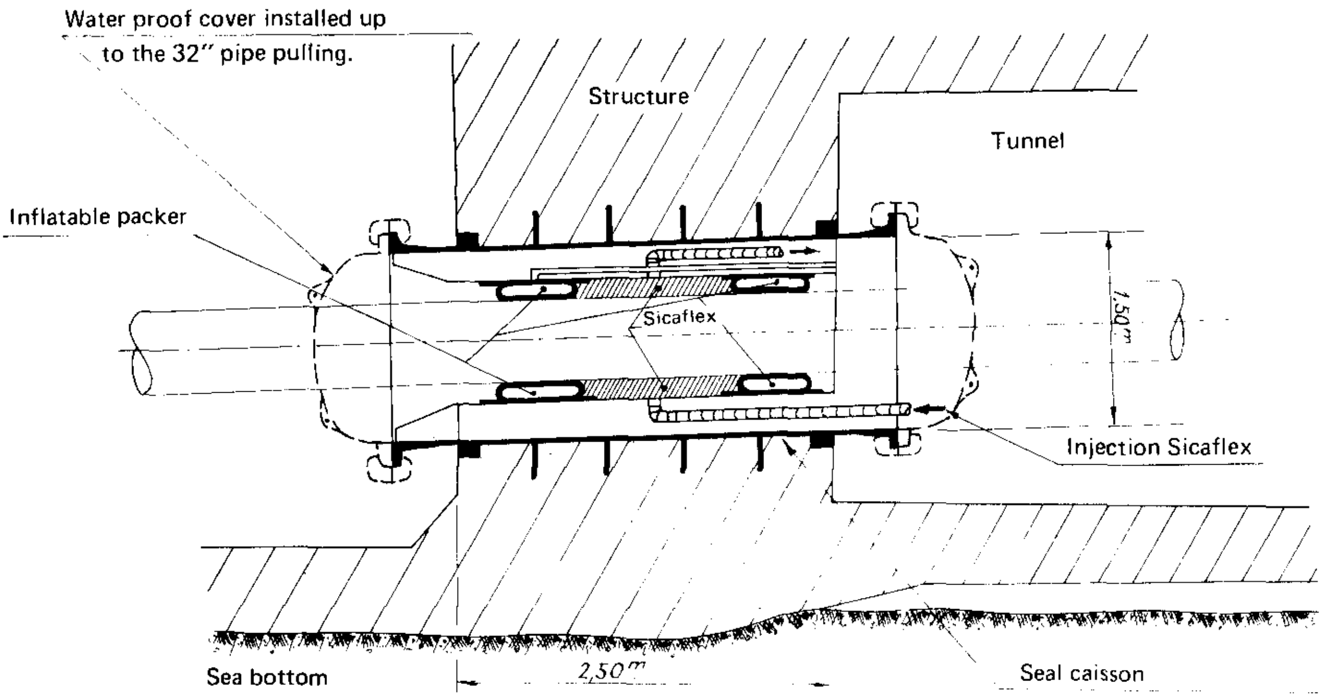


IMMERSION AND BALASTING



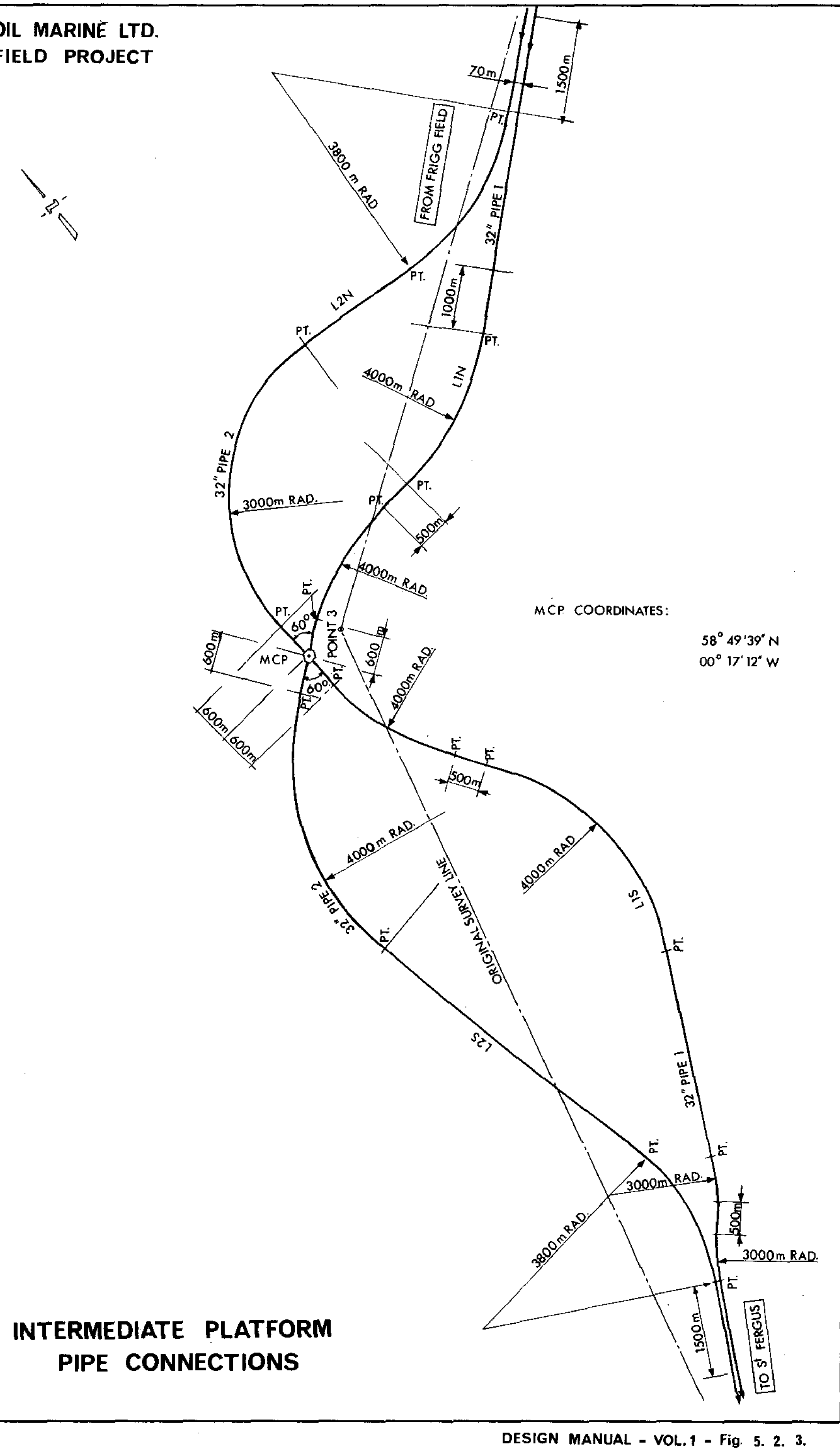
TIE IN

INTERMEDIATE PLATFORM



CAISSON AND WATER PROOF SEAL

TOTAL OIL MARINE LTD.
FRIGG FIELD PROJECT



INTERMEDIATE PLATFORM PIPE CONNECTIONS

6.0 SHORE TERMINAL

The Frigg field gas pipelines will terminate at St. Fergus, 40 miles north of Aberdeen, Scotland.

British Gas Corporation has constructed a compressor station along side the terminal. Here gas will be received, compressed and injected into two 36 inch pipelines for delivery to the south of Scotland.

The main purpose of the terminal is to process the gas so that no liquid hydrocarbons nor liquid water will form in the British Gas Corporation's two 36 inch pipelines. It will also serve other purposes and includes the following facilities :

6.1 Sphere Receivers

A sphere receiver is provided for each pipeline to receive and remove spheres.

6.2 Condensate Separation

The flowing temperature of the pipeline gas will be 5° C, which facilitates the formation of liquid condensate and since Frigg gas contains an average of 6 grams of condensate per cubic meter of gas, some liquid will collect in the low spots along the pipeline. The remainder will exist in the gas phase. The regular passage of spheres will result in liquid slugs which will be removed by the slug catchers.

Slug catchers are made of 32 inch pipe of the same quality as the pipeline. They will mechanically remove up to 3500 barrels of condensate per line at a service pressure of 68 to 148 bars absolute.

6.3 Treating Plant

A gas treatment plant serving two purposes :

To lower the amount of heavy hydrocarbons in the gas in order to ensure a dew point of minus 18° C (between 0 and 60 bars) in conformity with B.G.C.'s requirement.

To stabilize the condensates in order to transport them from the terminal.

6.4 Custody Transfer (Metering)

Stations for measuring and recording the flow of treated gas and for measuring and recording the calorific value of the gas. At this point gas is officially transferred from the custody of Total Oil Marine Ltd. to the custody of the British Gas Corporation. Measurements performed here are the basis for payment for gas.

6.5 Buildings

The following buildings are located at the terminal :

Terminal control building
Maintenance building
Substation switch room and generator house
Fire water pumps house, gate house
Utilities building and compressor house
Metering and calorimetry building
Pipeline control centre including control rooms,
Telesupervision and telecommunication rooms, offices.

6.6 Capacity

The treatment plant contains multi-process trains (units) for gas treatment. Each train has a capacity of 15×10^6 Sm^3/day. Five trains are installed resulting in a total capacity of 75×10^6 Sm^3/day. Each pipeline can initially flow 30.5×10^6 Sm^3/day or a total for the two

5.0 MANIFOLD PLATFORM MCP 01

The 364 kilometer length of the pipelines is too long for transmission of pigging equipment without undue risk and an intermediate platform is required where pigs would be withdrawn and new pigs reinserted. In addition the throughput capability of the pipeline can be increased substantially by the installation of compression facilities at an intermediate platform.

The manifold platform MCP 01, which is also referred to as intermediate platform, is located at the half-way point along the pipeline and is in 94 meters depth of water.

5.1 Description

The platform will accommodate facilities required for up to 3 large capacity lines. These facilities consist of the following installations :

Scraper traps and slug catchers for receiving scrapers (pigs) and liquid condensate (Phase I and II).

Compression facilities (Phase III and following) which will permit the increase of the flowrate capacity of both the 32 inch lines by 30 % (41.5 x 10^6 Sm^3/day instead of 30.5 x 10^6 Sm^3/day). 144,000 horsepower in turbine compressors are scheduled, but up to 180,000 horsepower can be installed. 6 to 8 turbo-compressor units of 20,000 to 32,000 horsepower, gas cooling, combustion air exhaust and silencing systems and fuel gas facilities are expected to be installed in the future.

The platform selected is 62 meters in diameter and 105 meters high. It is a barrel concrete structure designed by C.G. Doris and includes a Jarlan breakwater wall in the wave zone area.

Its circular base is 102 meters in diameter and is also equipped with a Jarlan wall of 15 meters high in order to avoid water undermining. It is installed with 6 radial tunnels terminating at a centre shaft of 9 meters internal diameter where risers and various piping will be placed.

The platform work required more than 150,000 tons of concrete and steel reinforcing with 53,000 tons of sand ballasting.

The rectangular maindeck has an area of 3600 square meters. The south part is assigned to the quarters and scraper traps piping. Two 100 ton pillar cranes and a radio mast are provided.

The north part will be assigned to the compressor facilities with an upper deck of 1800 square meters installed for the compressor trains that will be located above the gas cooling facilities. The intermediate platform is shown in Figures 5.1.1 and 5.1.2.

5.2 Construction

5.2.1 Construction Sequence

The sequence or progress of construction were as follows :

a) Construction of the platform base up to + 18 meters in a 10 meters deep dry dock at Kalvic, Sweden.

b) Launching of the platform base and towing to deep water in the fjord.

c) Construction of the platform by means of a slipforming technique, mounting of a derrick crane and of risers. Progressive ballasting in order to maintain a maximum 68 meters draft. Loading of 2000 tons of equipment modules, cranes, pumps etc.

d) Towing of the structure from Kalvic to its final location by a 45,000 horsepower fleet of tug boats.

SHORE TERMINAL

lines of 61.0 x 10^6 Sm^3/day. The addition of compression on the pipelines would increase the flow to 41.5 x 10^6 Sm^3/day or 82.0 x 10^6 Sm^3/day. Thus an additional train would be required when compression is added (Phase III).

7.0 TELECOMMUNICATIONS

Since off-shore facilities are a considerable distance from shore and operating conditions and production rates vary according to demand, it is necessary to have a permanent and reliable telecommunication system between the operating field, the intermediate facilities and the gas treatment and delivery terminal.

Due to the great distance and to the capacity and reliability required, a system of trans horizon hertzian signals in tropospheric scattering was selected since it met all requirements.

Each platform to be served will be equipped with 2 parabolic antennae 7 meters in diameter (quadruple diversity) at a 2.6 GHz frequency with a reliability around 99.9 %.

In order to ensure complete reliability of the connections and reduce downtime due to equipment failure, the British Post Office (B.P.O.) inter-connected the Frigg and intermediate platform links with the VHF microwave links serving the platforms of the Occidental and Mobil companies. The general network is indicated on the schematic Figure 7.0.1.

MCP-01 platform will be equipped with :

VHF radio links for boats
HF back-up radio link
VHF radio links for helicopters
A supervision radar
Local connections by walkie-talkie.

DESIGN MANUAL - VOLUME 1

SUMMARY

ROUTE SELECTION AND MARINE SURVEY

8.0 ROUTE DESCRIPTION

The pipelines begin at treatment platforms TP 1 and TCP 2 whose coordinates are approximately : 59° 52' 48" N latitude, 02° 04' 01" E longitude. The lines proceed southwest to the manifold platform : 58° 49' 39" N latitude, 00° 17' 12" W longitude, and then southwest to an offshore point at 57° 34' 44" N latitude, 01° 49' 32" W longitude. There the shore approach piping connects it to the shore terminal piping.

9.0 MARINE SURVEY

9.1 Description of Survey Equipment

Surveying was conducted almost continuously depending on weather and other factors. The following were typical of the equipment and were used in 1975-1976.

Survey Vessel

The vessel employed for the pipeline route survey was the M/V "Sperus", built in 1939 as a twin-screwed lighthouse tender. In size she is 210 feet long, 36 feet beam, 13 feet draught with a gross tonnage of 922 and a net tonnage of 299. She was equipped with gyrocompass and automatic pilot, with a Decca 350 TS trackplotter and has two Decca Main Chain receivers.

Positioning

"Sperus" was equipped with Decca Hi-Fix receivers set on north Scottish Cromarty chain. This chain gives a repeatable accuracy of $\pm$ 45 m near Frigg area increasing to $\pm$ 10 m near the coast and heavily decreasing when very close to shore (within a few miles) due to landpath interference (where Decca range-range trisponder system was adopted). "Hi-Fix" is affected by sky-waves and is generally not operational at night.

Echo Sounder

The echo sounder employed was an Atlas straight line recording echo sounder type DESO 10. The echo sounder measures the depth of the sea-floor directly beneath the vessel. This echo sounder can operate on two frequencies simultaneously (30 kHz and 210 kHz). It has 4 ranges, each of 18 scales, zero to 1,400 meters.

Its accuracy is $\pm$ 5 centimeters at 600 soundings per minute to $\pm$ 20 centimeters at 150 soundings per minute. All soundings were reduced to Lowest Astronomical Tide according to Admiralty tide tables.

Side Scan Sonar

The side scan sonar employed was an E.G. & G. dual channel MK 1B along with an E.G. & G 259 Recorder. The side scan sonar instrument called a "fish" is towed astern the vessel, near the bottom and yields a sonar picture of the sea-floor for 500 feet on either side of the ship's route. This is useful for distinguishing cables, exposed wrecks or pipelines, sandwaves and other features and gives information about the nature of the sea floor. This equipment can achieve a resolution in distance of as little as 30 centimeters.

Stratigraphic Recorder

The stratigraphic recorder employed was an E.G. & G 254 recorder with E.G. & G 232 "boomer" and 267 "sparker" trigger bank. The stratographic recorder consists of a towed sled carrying the transducer which emits signals that are reflected by the sea-floor and sub sea-floor strata. These are received by a towed hydrophone which passes the signals to a recorder which prints out a picture of the sea-floor and substrata on a moving roll of paper. The "boomer" trigger bank has a penetration of about 75 meters and an approximate resolution of about 0.4 meters. The "sparker" trigger bank has a penetration of about 150 meters and a resolution of 6-9 meters. The limiting water depth for the "boomer" is about 200 meters. The choice of "boomer" or "sparker" is a function of the water depth in which the work is performed, the sea state, the nature of the substrata, and the penetration and resolution required.

Magnetometer

The magnetometer employed was a Geometrics type G-801 Marine Proton Magnetometer. The magnetometer is towed behind the ship and records anomalies in the earth's magnetic field caused by submarine metallic objects. It is useful for : locating pipelines, cables, wrecks, etc. and giving an estimate of the mass of such metal objects.

Corers

Gravity and percussion corers were used to determine the nature of the upper layers. The results of a "Geoceanic" campaign on line 1 (with Kullenberg and Rotary corers) were also helpful.

9.2 Geology and Bathymetry

The pipeline route survey was undertaken by "Decca Survey" from PK 8 to Frigg Field and Geoceanic from shore to PK 8 (PK is the abreviation for point kilometrique and starts with PK 0 at the shore terminal with PK 364 at the field).

The seabed relief along the pipeline route is in general slight. The average depth variations are between 100 to 130 meters with slope gradients rarely exceeding 2 - 4 %. The maximum depth attained is 149.7 meters at PK 248.6 (A.S. 230) with 17 % gradient.
Other low points are : 147 meters at PK 232 and 145 meters at PK 185. Figure 9.3.1 shows the profile.

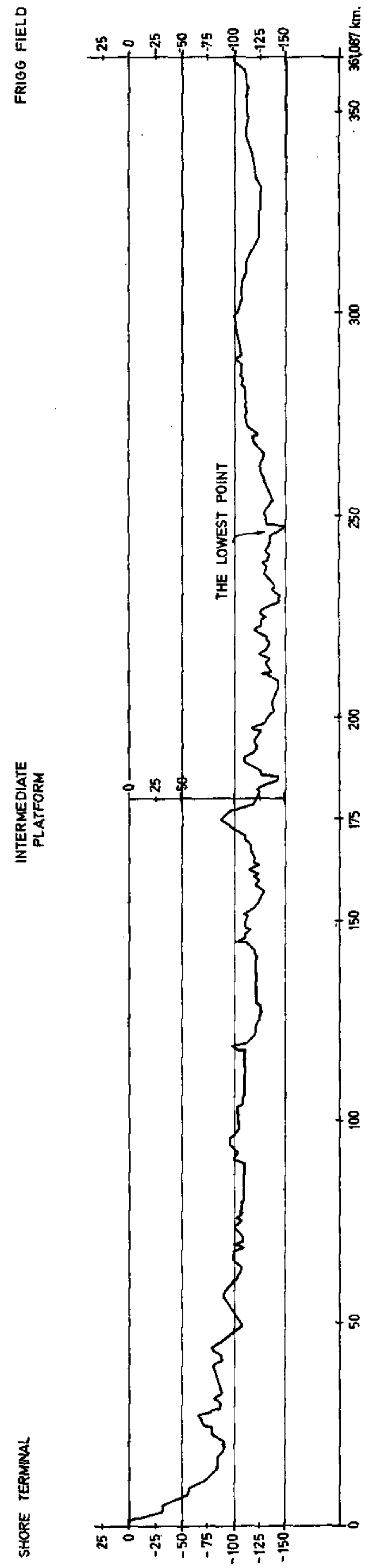
There are three distinct geological categories encountered :

a) Post-glacial sediments, which include the sandy seabed, recent marine sands and silts and the recent marine silts and clays.

b) Periglacial and glacial sediments, which include the morainic deposits and the fluvioglacial and glacio-marine sequences.

c) Palaeozoic basement between PK 7 and 17.2

TOTAL OIL MARINE LTD.
FRIGG FIELD PROJECT



PIPELINE PROFILE

9.3 Tidal and Ocean Currents

A survey of tide stream measurements was made for the major portion of the pipeline route by River and Harbour laboratory, Technical University of Norway (a Sintef Associated Laboratory), Trondheim, Norway. The report prepared for this work included study of the effects of maximum tide range, barometric pressure, storm tide, density and wind drift, currents etc. so that total quasi-steady current could be determined and "extreme predicted current" evaluated. More recently, Compagnie Générale Géophysique measured tidal currents in Rattray Bay. Due to the proximity of Pipeline N° 1 to Pipeline N° 2, separate surveys of tide streams were not necessary.

9.4 Meteorological-Oceanographic Data

Meteorologist-oceanographer A.H. Glenn and Associates prepared a report of wind and sea conditions forecasts for normal and storm conditions. This included prediction of maximum wave and tide current bottom velocities. Mr. Glenn has 30 years experience forecasting for offshore oil industry operations throughout the world, including the North Sea.

Reports of other environmental investigations have been studied to evaluate their significance to Frigg Pipeline design and construction. These reports included :

a) "Environmental Conditions of the Shetlands - February 1973 to February 1974", prepared by Marine Explorations Ltd. (MAREX) Isle of Wight, U.K.

b) "Environmental Data Analysis - Winds and Waves in the Northern North Sea, Summer 1972" (as recorded by marine drilling rig "STAFLO") prepared by Shell U.K. Exploration and Production Ltd., London.

c) "Climatology North Sea - Winds and Waves Observed from Offshore Installations" by Dr. D.M. Burridge Meteorological Office, London Weather Centre, London (U.K. September 1973).

9.5 Alignment Sheets

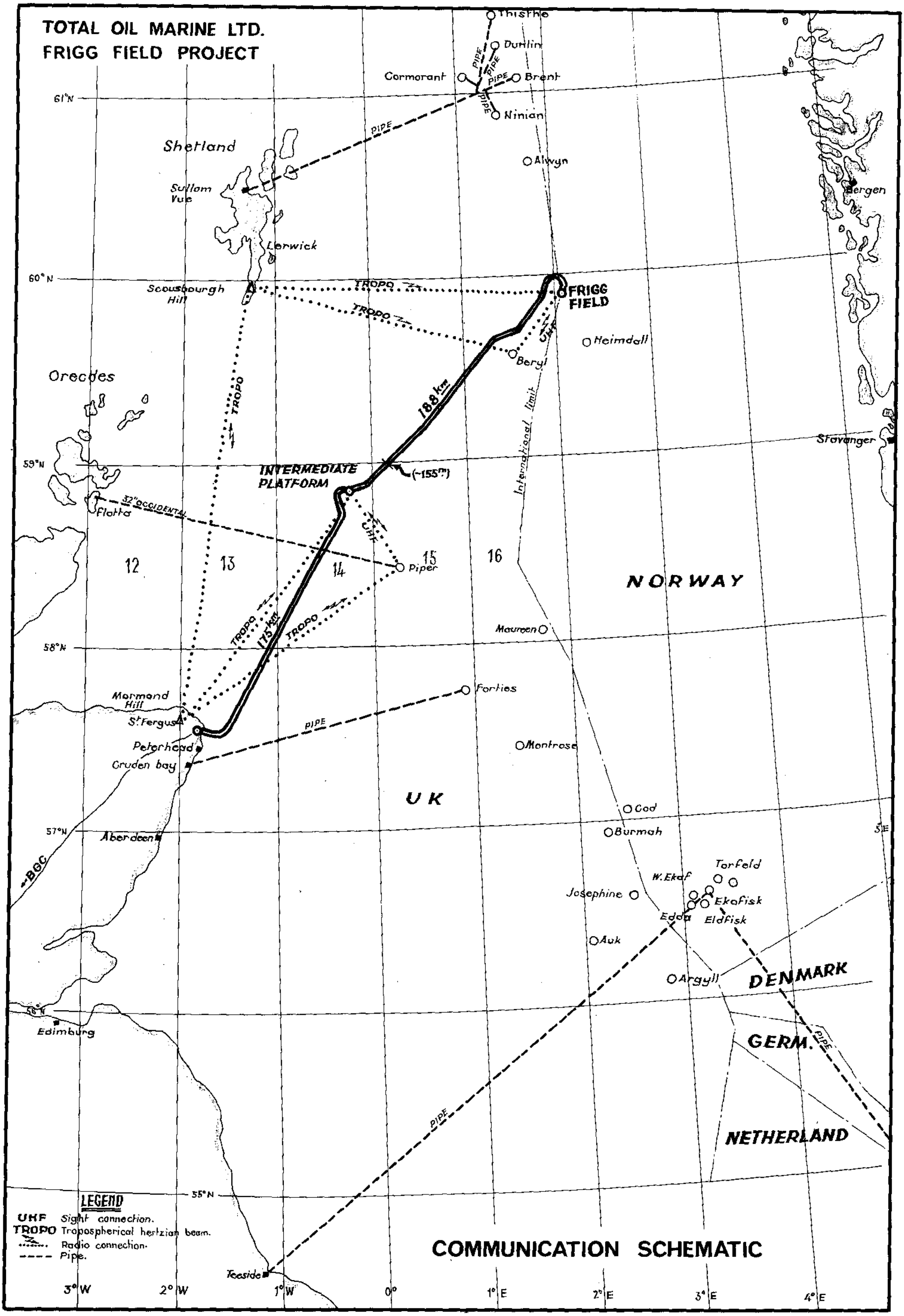
All necessary marine information for the construction of pipelines has been compiled in a set of alignment sheets numbered 101 to 141 and 201 to 244 including :

- a plan view showing the pipeline route versus Decca Hi-fix and main chain, UTM and geographical grids
- a bathymetric plan
- a profile view with geological data.

An alignment sheet layout is shown in Figures 9.5.1 and 9.5.2.

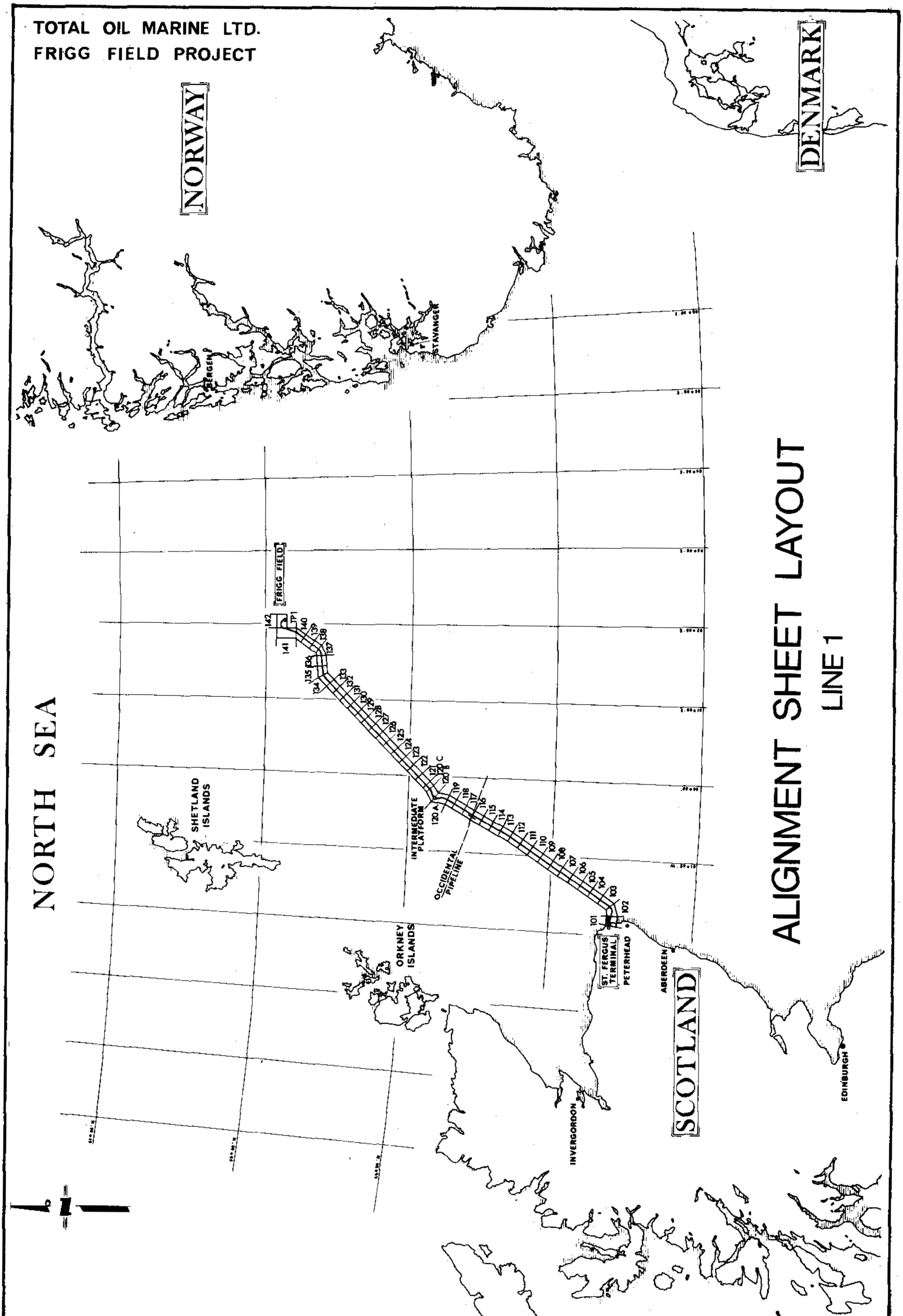
9.6 Pipeline Route Topography

The topography along the second pipeline route is summarized on the following page.

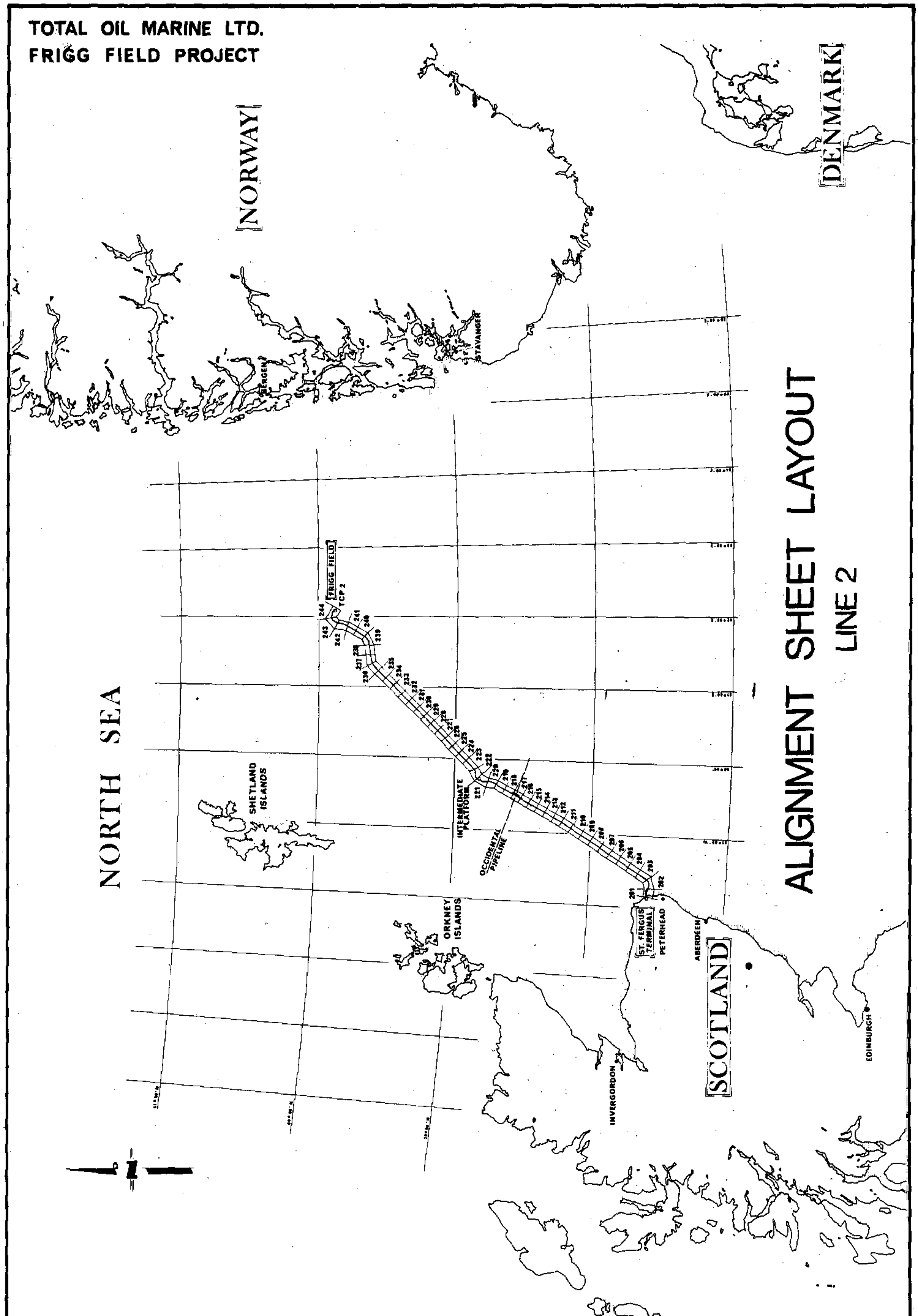


DESIGN MANUAL - VOL.1 - Fig. 7. 0. 1.

TOTAL OIL MARINE LTD.
FRIGG FIELD PROJECT



TOTAL OIL MARINE LTD.
FRIGG FIELD PROJECT



ALIGNMENT SHEET LAYOUT
LINE 2

PIPELINE ROUTE TOPOGRAPHY

ZONE N°	ALIGNMENT SHEET N° PK	SEAFLOOR SOILS	MIN./MAX. WATER DEPTHS (METERS)
1 Rattray Bay Shore Approach	AS : 201 PK : 0 - 8	Sand, clay boulders and boulder clay	0 - 57
2 Intermediate	AS : 202 - 206 PK : 8 - 45.5	Sand waves, bedrock outcrops near the route layered sands and clays	57 - 110
3 Southern Plain	AS : 206 - 218 PK : 45.5 - 153	Fine sand veneer, occasional patches of clay and isolated pebbles large outcrop of clay PK 152 - 153	80 - 135
4 Southern Plain Boundary Valley	AS : 219 - 221 PK : 153 - 173	Sandy veneer with some patches of clay - pockmark PK 155, small boulders PK 157	115 - 136
5 Intermediate Rise	AS : 221 - 222 PK : 173 - 178	Sand covering broken by large areas of exposed clay patches of shell and coarse gravel (morainic)	93
6 Ridge and Valley	AS : 222 - 234 PK : 178 - 287	Fine sand or consolidated clay fill channels and cut valleys outcrops of pebbles PK 238 - 239	104 - 150
7 Frigg Field West Plain	AS : 235 - 244 PK : 287 - 363	Patches of shell and gravel with predominant fine sand	97 - 125

10.0 OBSTRUCTIONS AND OTHER PIPELINES

10.1 Other Pipelines

The first pipeline route is approximately 70 meters south east of the second pipeline.

The 30" Occidental pipeline crosses the second pipeline at PK 141.53 (A.S. 217)

The Brent to St. Fergus pipeline runs 120 meters N.W. of the second pipeline at the shore approach.

10.2 Wrecks

Two wrecks have been detected near the route :

The first wreck is at PK 65.36, 375 meters north west of the route and is 60 meters long and 8 meters high.

The second wreck is at PK 278, 280 meters south west of the route.

10.3 Cables

Four possible cables were detected by side scan sonar at PK 298.5, 313.7, 314.4 and 314.8 which were not confirmed with the magnetometer. Inquiries were unsuccessful but nevertheless much care was taken during construction.

DESIGN MANUAL - VOLUME 1

SUMMARY

PIPELINE DESIGN

11.0 SUMMARY OF THE PIPELINE DESIGN

Frigg Project's pipelines 1 and 2 will provide underwater transportation facilities for gas products from the treating platforms of Frigg Field, located in the English and Norwegian sectors of the North Sea. The Northern section of the lines connect the Frigg treating facilities to the sphere receiving and launching equipment at the Intermediate Platform, a point approximately 185 kilometers southwest of Frigg Field. The lines continue in a south-westerly direction for approximately another 179 kilometers (364 kilometers total) to the shore terminal facilities on Scotland's coast at St. Fergus.

Pipe diameter is 32 inches with 1 7/8 inch to 4 5/8 inch outer concrete coating. The 1 7/8 inch coating is used in the deeper water where the tidal currents are less, while coating thicknesses up to 4 5/8 inches are used closer to shore where the tidal currents become much more severe. The concrete coating helps to maintain an overall negative buoyancy that prevents the pipe from moving along the sea bed furnishing the required pipeline stability.

The pipe consists of welded joints approximately 40 feet in length. Buckle arrestors and anodes are attached to every 14th joint of pipe with 7 joints separating each buckle arrestor and anode. The anodes are installed along the entire length of the pipeline while the buckle arrestors are only used in water depths greater than 107 meters. The buckle arrestors prevent the propagation of pipe buckles, should they occur, whereas the anodes furnish the cathodic protection that is required for pipeline longevity once the gas transportation system goes into service.

The pipeline portion of the Frigg Project begins at the sphere launching facilities at the treating platforms from each sector and ends at the shore terminal inlet control valve. Maximum operating line pressure is 2160 psig (150 bars absolute) at Frigg with a minimum shore terminal inlet control valve pressure of 49 bars absolute.

12.0 SYSTEM CAPABILITIES AND LIMITATIONS

12.1 System Limitations

Unlike reserves on shore, the North Sea, with its adverse weather conditions and deep water areas, requires a transportation system design to be based solely on present day materials and construction installation capabilities and not on a flow volume basis which is standard for a shore system.

Feasibility studies have determined that 32 inch was the optimum size line based on construction installation capabilities.

The pipeline upper operating pressure limit is 147.9 bars absolute occurring at Frigg Field's platforms TP 1 and TCP 2 and at the intermediate platform once compression is installed and in use. The lower pressure limit acceptable at the shore terminal facilities inlet valve is 49 bars absolute.

12.2 System Capabilities

Each of the 32 inch pipeline systems is capable of delivering flow rates as small as 5×10^6 Sm^3/ day and up to the maximum level provided by one intermediate compressor station. The maximum inlet operating pressure at Frigg Field's treating platforms TP 1 and TCP 2 is 147.9 bars absolute guaranteeing the shore terminal facilities a minimum pressure of 49 bars absolute. Although each pipeline is capable of a flowrate of 41.5×10^6 Sm^3/day, flow rates above 30.5×10^6 Sm^3/day can only be achieved by the installation and use of compression on the intermediate platform. The above pressures and flow rates are based on pipeline inlet gas temperatures of 35° C both at Frigg Field and the intermediate platform. Any increase in gas inlet temperature at either platform would have the effect of increasing horsepower requirements and fuel consumption while decreasing flow throughput. A change in gas inlet pressure at Frigg Field would have a corresponding effect at the shore terminal inlet. The maximum flow rate of 41.5 x 10^6 Sm^3/day would require 72,000 horsepower to most effectively operate the system within the design pressure limits.

13.0 PIPE SELECTION

The required wall thickness of the pipe was calculated from ANSI B 31.8, entitled "Gas Transmission and Distribution Piping System" Department of Transportation, 1968 edition, paragraph 841.1 page 31, using a Type "A" construction factor of 0.72. The thickness was calculated as 0.7385 inches but for pipe service, a 0.750 inch wall thickness with a 0.000 inch under tolerance was selected. The design pressure is 2160 psig with a maximum calculated allowable pressure of 2194 psig. However valves and flanges in the system are series 900 which limit the system to 2160 psig.

Pipe material is API-5LX-65 and 32 inch outside pipe diameter. The 32 inch diameter pipe was considered to be the largest size pipe that laybarges were capable of laying in the water depths that are encountered along the route.

14.0 GAS ANALYSIS

The following information pertaining to the East Frigg Field gas composition was furnished by ELF and is the basis for all engineering calculations throughout this manual. The program or method of calculation using the composition must calculate the dew point under pool conditions as well as compositions and quantity under separator conditions based on equilibrium constants developed by the NGPSA (1972 edition).

East-Frigg Gas Pool Conditions	TEP/DP/LAB Composition Table 12-Report DV/cm/72		ADJUSTED COMPOSITION	
Element	% Weight	% Mol	% Weight	% Mol
CO_2	0,833	0,320	0,832	0,320
N_2	1,012	0,612	1,011	0,612
C_1	89,816	94,813+	89,724	94,812 (M
C_2	7,200	4,055	7,193	4,055
C_3	0,219	0,084	0,219	0,084
iC_4	0,036	0,010	0,036	0,010
nC_4	0,011	0,003	0,011	0,003
iC_5	0,015	0,004	0,015	0,004
nC_5	0,006	0,001	0,006	0,001
iC_6	0,027	0,005	0,027	0,005
nC_6	0,000	0,000	0,000	0,000
iC_7	0,017	0,003	0,017	0,003
nC_7	0,001	0,000	0,001	0,000
iC_8	0,075	0,011	0,075	0,011
nC_8	0,007	0,001	0,007	0,001
iC_9	0,025	0,003	0,025	0,003
nC_9	0,009	0,001	0,009	0,001
iC_{10}	0,056	0,007	0,056	0,007
nC_{10}	0,020	0,002	0,020	0,002
C_{11+}	0,615	0,063	0,716	0,066 (M)
TOTAL	100	99.998	100	100
MC_{11+}		165		
	+ in fact the calculation gives : CO_2 = 0,32053 and C_1 94,8137		(M) These values have been adjusted to obtain through calculation (SHG method) the working data.	

15.0 HYDRAULICS, FLOW EQUATIONS AND FLOW DIAGRAMS

15.1 Flow Equations

The hydraulic calculations are based on the two phase flow of a wet gas in one 32 inch pipeline. The A.G.A. method for "Steady State Flow Computations for Natural Gas Transmission Lines" has been used. This is a calculation method for a dry gas. To allow for the liquid hydrocarbon movement with the gas, which reduces the amount of gas flowing between any two pressures, all volumes stated are calculated using a 12 % greater volume. This method yields a greater pressure drop for a given flow rate and is expected to be averaging in determining pressure at intermediate points.

15.2 Daily Throughput

The daily flow rates for each 32 inch pipeline at the maximum operating pressure of 147.9 bars absolute is 30.5 x 10^6 Sm^3/day. The minimum pressure at the shore terminal inlet value is 49 bars absolute. Figure 15.2.1 indicates the pressure at any point along the pipeline for three different discharge pressures at Frigg. Figure 15.2.2 was developed to illustrate the pressures at the three main points of concern on the Frigg Pipeline System. This figure was prepared for any flow rate, varying discharge pressures from 110 bars absolute to 147.9 bars absolute at the Frigg platform, and inlet pressures of 49, 60, 70 and 80 bars absolute at St. Fergus. From this figure, the flow rate at which the gas in the pipeline will free-flow may be read. Note on Figure 15.2.2 at 147.9 bars from Frigg and 49 bars inlet at St. Fergus, the platform inlet and outlet pressures (110 bars) coincide at 30.5 x 10^6 Sm^3/day. Both figures are for a Frigg gas discharge temperature of 35° C and a sea temperature of 7° C. Shore terminal inlet temperature is approximately 5° C. Figure 15.2.3 shows the temperature variation along the pipeline for different inlet gas temperatures.

Average daily throughput of gas per pipeline delivered to St. Fergus is 1/1.3 of maximum daily throughput : 23.5 million standard cubic meters per day.

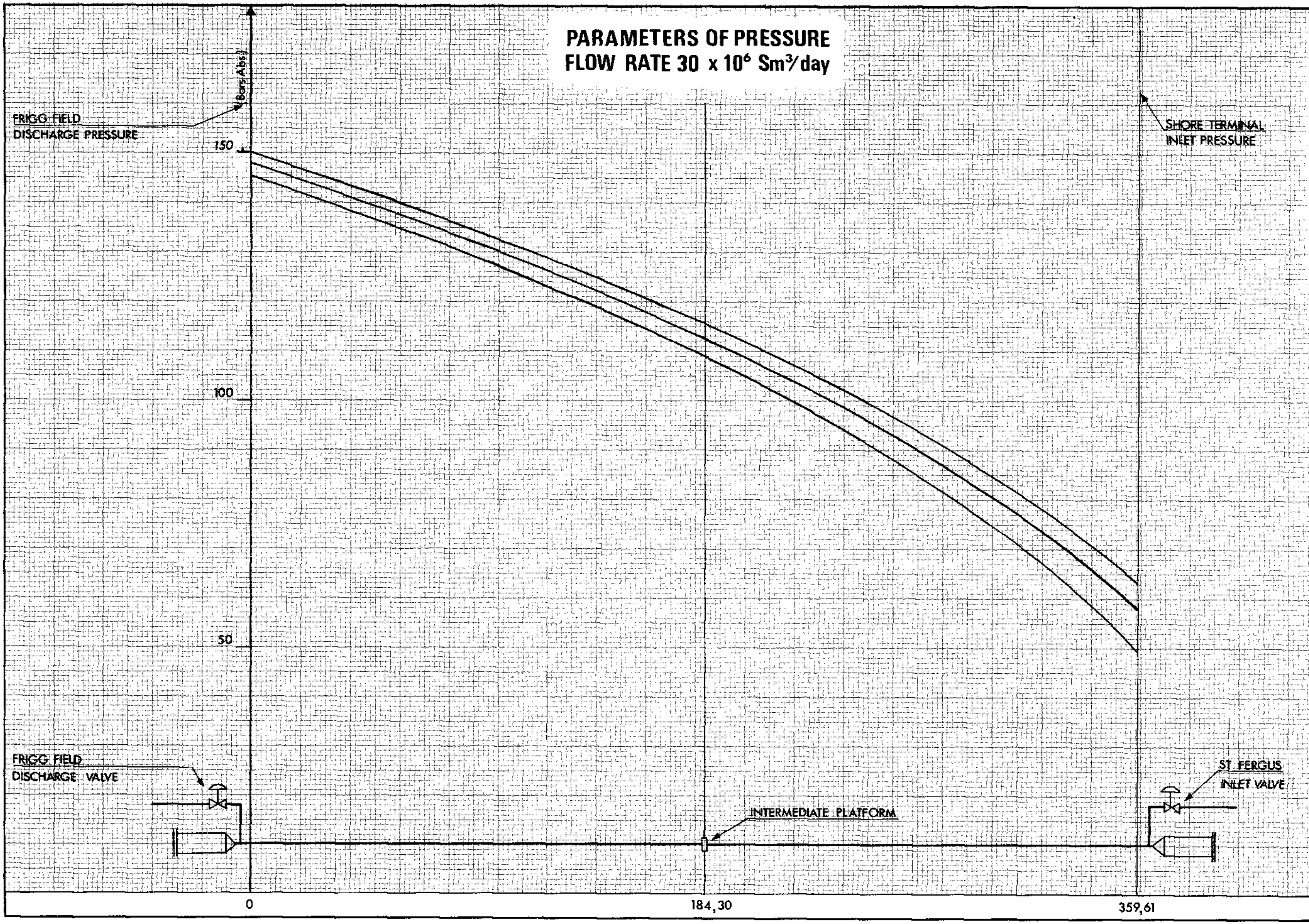
15.3 Flow Diagrams

Flow diagrams are included for the following rates per pipeline :

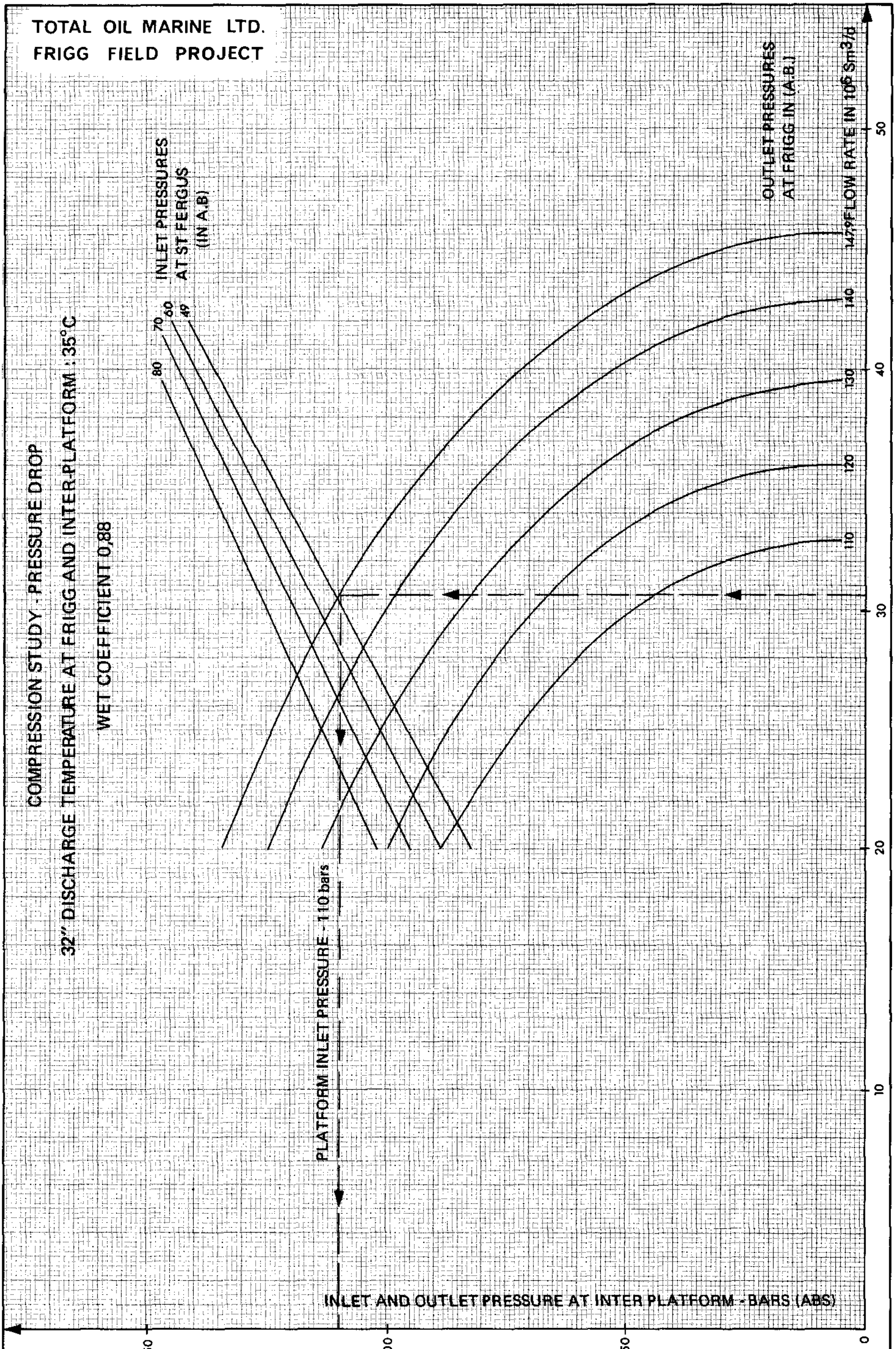
a) Flowrate 30 million standard cubic meters per day of gas (Figure 15.2.1)

b) Flowrate 20 million standard cubic meters per day of gas (Figure 15.2.4)

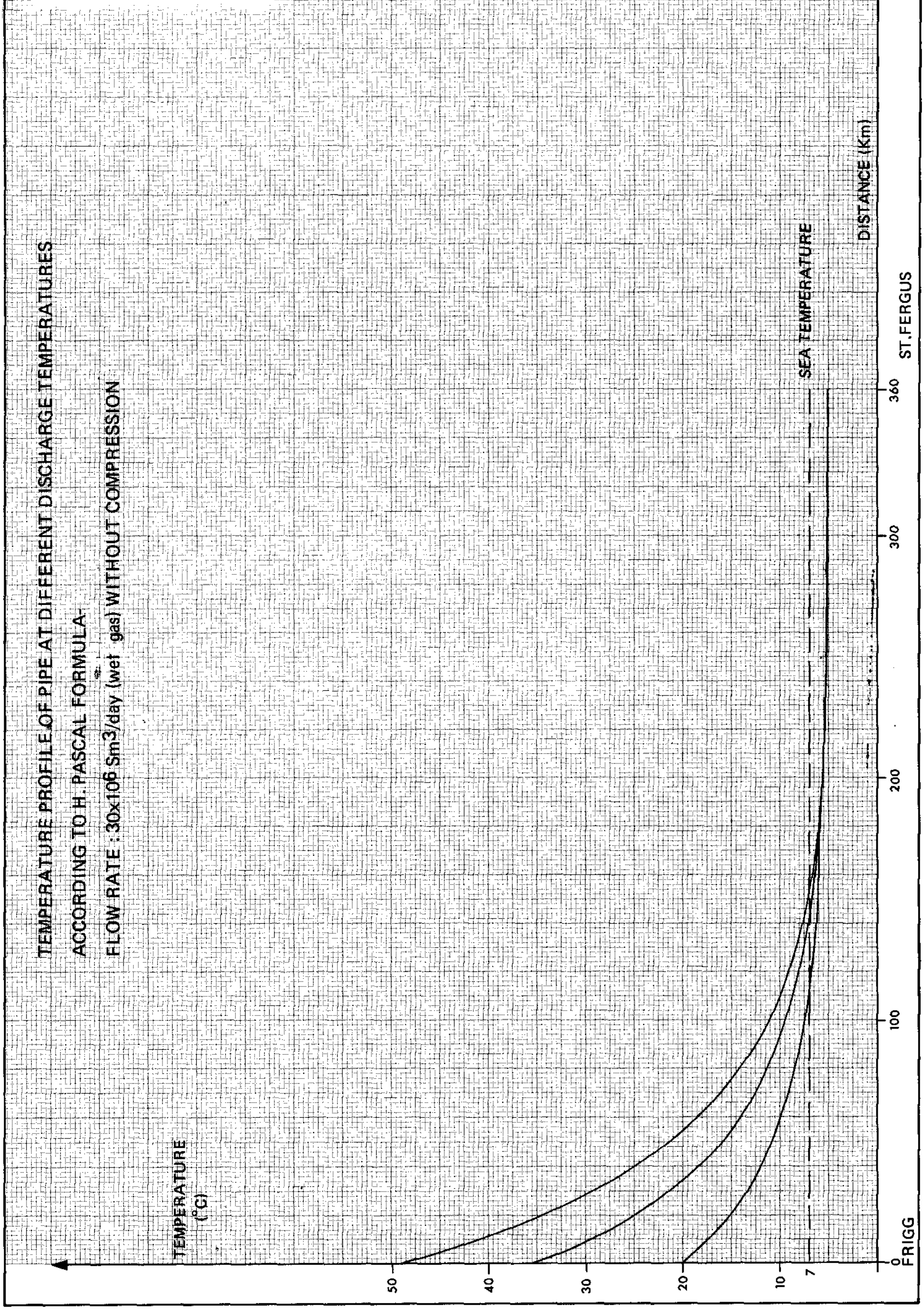
c) Flowrate 10 million standard cubic meters per day of gas (Figure 15.2.5)


PARAMETERS OF PRESSURE
FLOW RATE 30 x 10^6 Sm^3/day
(Bars Abs)
FRIGG FIELD
DISCHARGE PRESSURE
SHORE TERMINAL
INLET PRESSURE
150
100
50
FRIGG FIELD
DISCHARGE VALVE
INTERMEDIATE PLATFORM
ST FERGUS
INLET VALVE
0
184,30
359,61

TOTAL OIL MARINE LTD.
FRIGG FIELD PROJECT

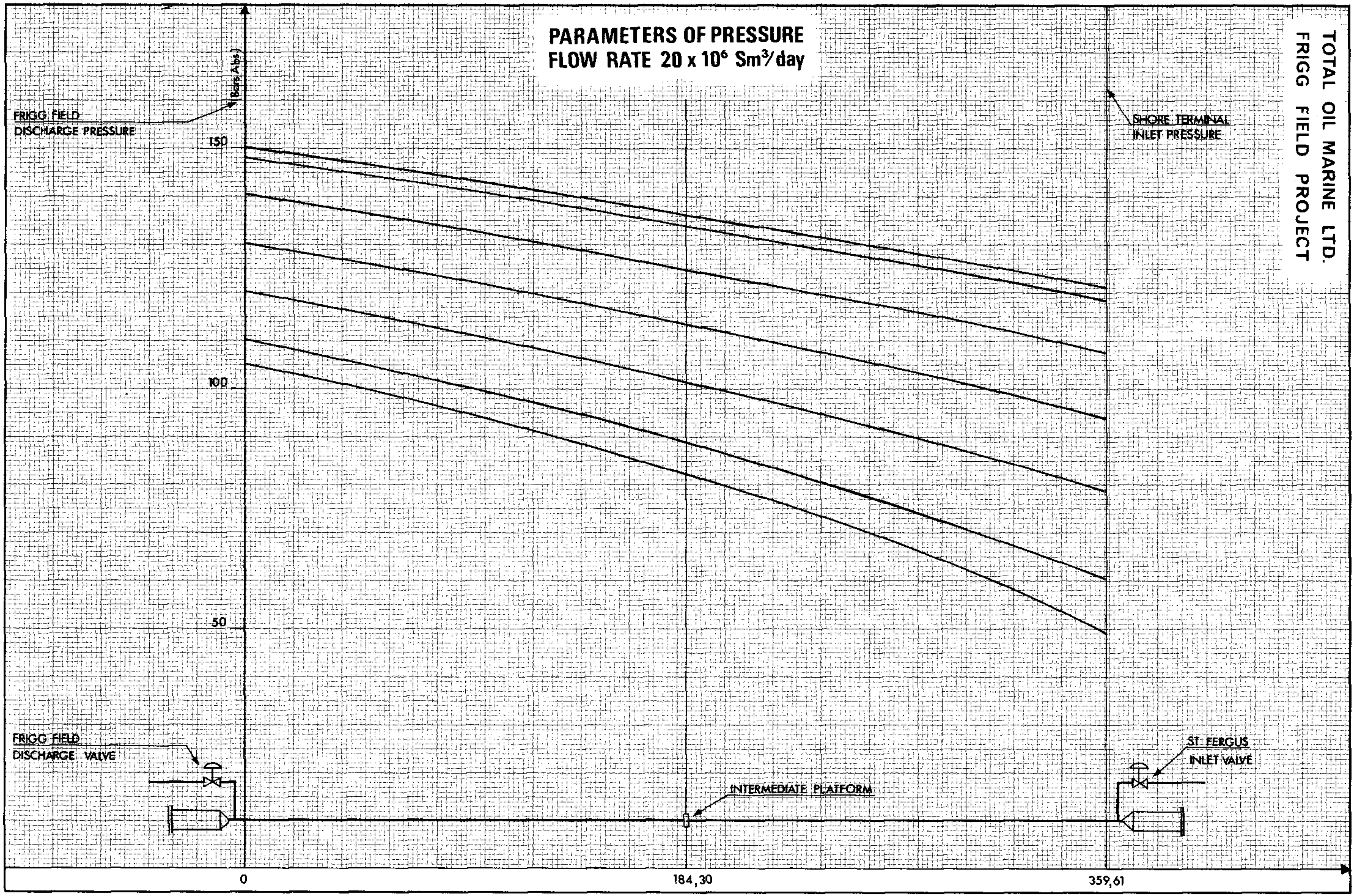


TOTAL OIL MARINE LTD.
FRIGG FIELD PROJECT



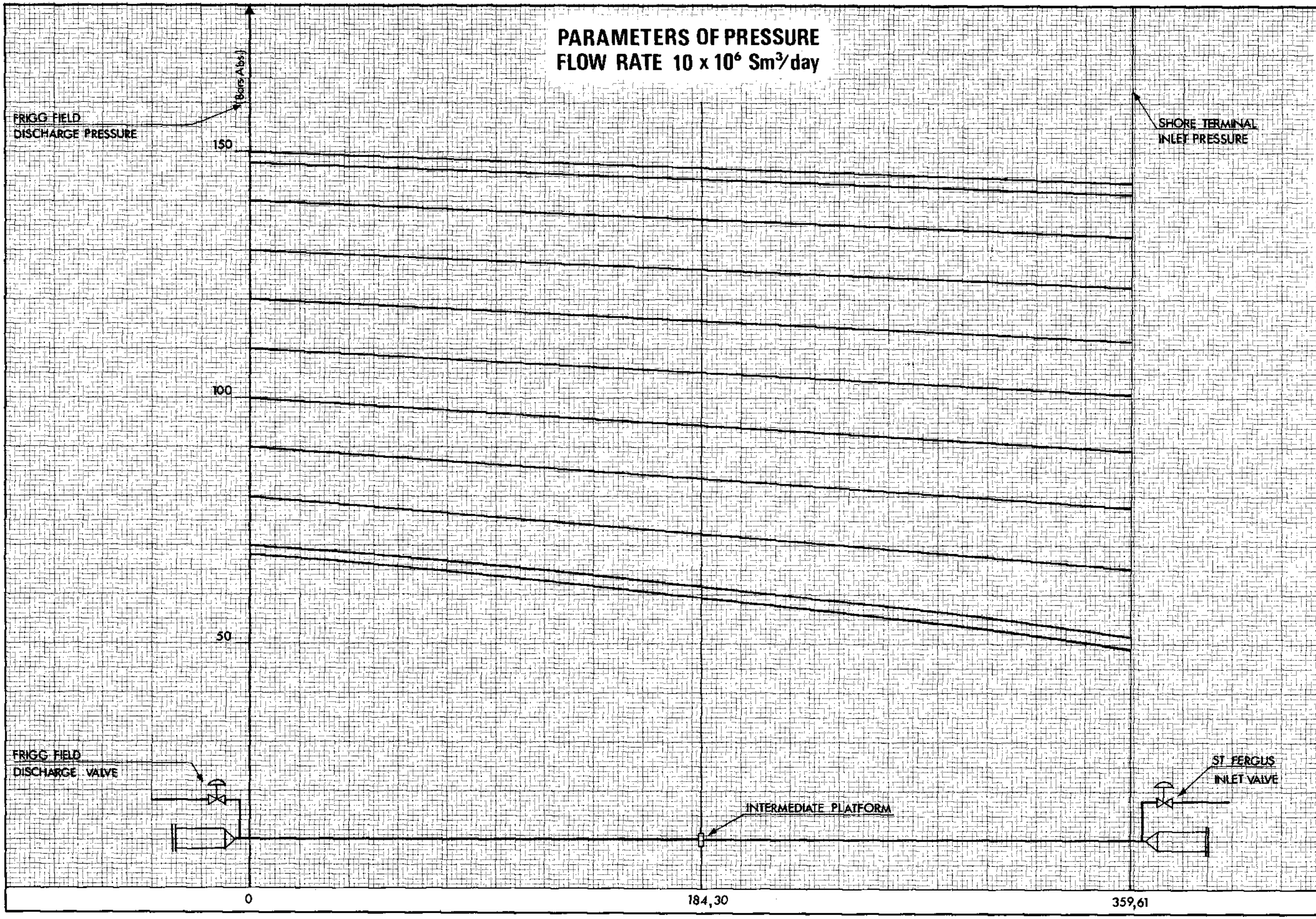
DESIGN MANUAL - VOL.1 - Fig. 15. 2. 3.

DESIGN MANUAL - VOL. 1 - Fig. 15. 2.4.



TOTAL OIL MARINE LTD.
FRIGG FIELD PROJECT

TOTAL OIL MARINE LTD.
FRIGG FIELD PROJECT



16.0 PIPELINE STABILITY AND WEIGHT COATING

In making the investigation of pipeline stability in the seafloor environment, all environmental information available to establish design criteria was reviewed. The principle results are presented in tables 16.1, 16.2, 16.3 and 16.4.

The greatest potential hazards to pipeline stability that might be confronted would be the existence of rock or zones of seafloor scour that would create unsupported free spans of pipeline. In the high energy surf and breaking wave zone, the pipeline would be subject to vortex shedding vibration which if allowed to occur, could lead to severe damage, perhaps pipeline failure.

In deep water, i.e. depths greater than 50 meters, current velocities diminish and the potential for scour is reduced. The vortex shedding frequency becomes less, narrowing the range of the frequencies. Also, the energy available is lessened and vibration amplitude is reduced even if vibrations could be induced.

To ensure pipeline stability on both Frigg field to Scotland pipelines, the 4 5/8 inch concrete coated pipe is used in the near shore areas where the tidal currents are greater. The pipelines will also be trenched so that the top of the pipe will be four meters below seafloor in the shore approach zone where water depth is less than 15 meters. Thus the pipeline will be below seabed through the foreshore, surf and breaking wave zones where the highest water velocities would be experienced. Seaward of 15 meter water depths, the natural sag or bend of the pipeline would conform to seafloor contours and the lower velocities would less likely cause scour to occur.

Proper trenching of the pipeline takes care of the situations where vortex shedding vibration might possibly exist. The various thicknesses of concrete coating used along the route are designed to keep the pipe in the bottom of the sea floor trench and keep the pipe from moving in a lateral direction.

TABLE 16.1

PIPELINE ROUTE TOPOGRAPHY

Zone N°	Zone	Align. Sheets	Seafloor Soils	Min/Max Water Depth Meters
1	Rattray Bay Shore Approach	101-102	Sand, clay boulders and boulder clay	0 - 90
2	Intermediate	103-105	Mostly glacial some sand and clay	68 - 93
3	Glacial Plain	106-107	Sand or glacial	79 - 108
4	Plateau	108-113	Sand or glacial some clay	100 - 115
5	Domes	114-118	Sand or glacial	105 - 135
6	Valleys	119-129	Sand or glacial	93 - 158
7	Frigg Plain West	136-139	Sand or glacial	100 - 120

TABLE 16.2

PIPE-TO-SOIL FRICTION FACTORS

Sands	:	0.54
Sand and gravel	:	0.61
Sand, gravel and pebbles	:	0.80
Soft clay	:	0.35
Medium glacial clay	:	0.77

TABLE 16.3

MAXIMUM SPAN LENGTH COMBINED LOADING+

Nom. Conc. Thick.	Pipe S.G. Sea Water	Negative Buoyancy lb/ft		Maximum Span Length-Metres			
				Hinged		Fixed Ends	
		Empty Pipe	Seawater Filled	Empty Pipe	Water Filled	Empty Pipe	Water Filled
4 5/8"	1.60	362	689	31.6	22.9	38.7	28.1
3 1/2"	1.44	237	564	39.1	25.3	47.9	31.0
3"	1.37	193	520	43.3	26.4	53.0	32.3
2 1/2"	1.28	132	459	52.4	28.1	64.1	34.4
1 7/8"	1.16	67.1	394	73.5	30.3	90.0	37.1

+Computed in accordance with ANSI - B31.8 gas pipeline under combined loading.

TABLE 16-4

HYDRODYNAMIC STABILITY AND WEIGHT COATING DESIGN
FRIGG FIELD TO SCOTLAND SUBMARINE PIPELINE

Based upon marine surveys and seabed profile of T.L.M. - C.G.G. - BEICIP 1974 Tech. Univ. Norway current measurement 1972; A.H.Glenn meteorology-oceanography 1972 and Pipe-to-oil friction factors by Techniques Louis Menard experiments 1973.

(32" x 0,750" w.t. API 5L-X65 Pipe)

Zone	A.S. No.	Seafloor Soil*	T.L.M. Friction Factor for Soil f	Water Depth Range Métres	Design Velocity Range cm/S	Stability Velocity cm/S	Nominal Concrete Thickness ins.	Specific Gravity Seawater	Negative Buoyancy lb/ft	Remarks
Rattray Bay Shore Approach	101*	Sand, clay, boulders and boulder clay	0,54	0-56	364-234	252	4 5/8	1.60	362.0	Pipeline not stable in water depths less than 50m Trench to 3m.
"	102*	Sand or glacial	0,54	56-77	234-179	252	"	"	"	
"	102	Glacial	0,54	76-90	180-146	193	3	1,37	193.0	
Intermediate	103	Glacial	0,54	73-94	188-136	193	"	"	"	Install to 73m. depth
"	103	Glacial	0,54	69-73	199-188	210	3 1/2	1,44	237.0	
"	104	Glacial	0,54	68-78	201-176	210	"	"	"	Install to 78m. depth
"	104	Glacial	0,54	78-93	176-138	193	3	1.3	193.0	
"	104	Soft clay	0,35	87-93	154-138	161	"	"	"	
"	105	Glacial or sand	0,54	79-91	172-144	193	"	"	"	
Glacial Plain	106	Sand	0,54	79-85	172-160	193	"	"	"	Install to 85m. depth
"	106	Sand	0,54	85-108	160-90	160	2 1/2	1.28	132.0	Install to 106m. depth
"	106	Sand	0,54	105-106	102-98	120	1 7/8	1.16	67.1	
"	107	Glacial or sand	0,54	95-107	132-96	120	"	"	"	Trench to 3m.depth < 100m.
Plateau	108 - 113	Glacial or sand	0,54	100-115	76-120	120	"	"	"	
"	" 114	Soft clay	0,35	100-115	76-120	100	"	"	"	
Doines	- 118 119	Sand or glacial	0,54	105-135	54-100	120	"	"	"	
Valleys	-* 129	Sand or glacial*	0,54	93-158	38-138	120	"	"	"	Trench to 3m. depths < 100m.
—	130 - 135 136	Re-routing P/1 avoid Beryl Field development - Surveys in progress								
Frigg Plain West	- 139	Sand or glacial	0,54	100-120	68-120	120	1 7/8	1.16	67.1	Trench to 3m. depths < 100m.

* Some outcrop or occurrence of boulder clay

17.0 BUCKLE ARRESTORS

When laying pipeline in hostile sea elements such as the North Sea, care must be taken to prevent collapse buckling and buckle propagation. This buckle propagation may occur when external pressure from water depths becomes too great, when pulling stresses from the barges while pipe laying become excessive, or when lengthy unsupported spans occur due to seabed anomalies or current scouring. The purpose of buckle arrestors on deepwater submarine pipelines is two fold :

a) A properly designed arrestor will terminate the buckle propagation once it begins and

b) Knowing the arrestor location will provide information on the amount of pipe damaged and the point on the seafloor where only the undamaged pipe exists.

Buckle arrestors are pressure grouted to the seaward, or barge stern end of every fourteenth joint of pipe that is laid in water depths greater than 107 meters. The sleeve arrestor material is of ASTM A-285 Grade C or ASTM A-36, API 5L Grade B, and is 72 inches long, 36 inches in diameter and 1 inch thick. A safety factor of 1.25 is used resulting in a design depth of 189 meters (620 feet).

Figures 4.2.2 in section 4.2 shows the buckle arrestor effect and Figure 4.2.3 shows details of the buckle arrestor and their locations.

18.0 CATHODIC PROTECTION

The cathodic protection for the 20 year design life of the 32 inch Frigg to Scotland submarine pipelines is furnished by very low iron content zinc anode bracelets. The analysis is based upon the U.S. Military Specification 18.001 - H. Zinc has proven to be a more suitable sacrificial anode system in sea water than either aluminium or magnesium. For most materials in sea water applications when buried in sand or mud, the cathodic protection is reduced by 30 to 50 % when calco-magnesium or other mineral or sea vegetation deposits build up over a period of years. These deposits have a negligible effect on the cathodic protection furnished by the zinc bracelets and protection is furnished throughout the life of the bracelet.

Approximately 2000 zinc anode bracelets each weighing 610 kilograms are used. An anode is placed on every fourteenth joint of pipe. In water depths greater than 107 meters, seven joints separate each buckle arrestor and sacrificial anode.

The anode potential is -1.05 volts/immunity potential -0.8 volts. The efficiency is 95 % Ag/Ag Cl ref. with a capacity of 355 Amp/hour/pound.

Figure 4.2.3 in section 4.2 shows an anode and the anode locations on the pipe.

19.0 COMPUTER PROGRAMS

19.1 Offshore Pipelaying Simulation/-OPLS

OPLS 2D and OPLS 3D are computer programs for the static two and three dimensional analysis of offshore pipe laying problems. They utilise a non-linear finite element method solution procedure, developed especially for program OPLS, to calculate the pipe coordinates, forces and stresses. The entire pipe length, from the tensioning device on the laybarge to the bottom, is modelled by one continuous finite element model. The interaction between the pipe and stinger can be simulated by the simultaneous use of a finite element model of the stinger. The pipe support rollers on the laybarge and stinger and the soil on the bottom are simulated by special finite elements.

In analysing the pipe laying problem OPLS considers the pipe tension and position of the pipe supports on the laybarge, the structural characteristics, buoyancy and position of the pipe supports of the stinger; the pipe weight and structural properties, concentrated loadings such as buoys or anchor weights, and the support stiffness and orientation of the bottom. In addition and in three dimensions, OPLS considers the effects of current induced lift and drag forces on the pipe and stinger, the frictional properties of the soil and the special three dimensional characteristics of certain kinds of pipe support rollers.

19.2 Dry Gas Pipeline Hydraulics

This program solves the AGA equation for dry gas line flow for either flow rate, input pressure, output pressure, or line length, based on values supplied for the remaining three quantities. The method used is as described in Institute of Gas Technology Technical Report N° 10 : "Steady Flow in Gas Pipeline".

19.3 Compressibility Factor

This program calculates the compressibility factor. The method used to determine this value is the "AGA Manual for the Determination of Super Compressibility Factors for Natural Gas". PAR RESEARCH PROJECT NX 19, December 1962. This method is applied for gas without H_2S.

19.4 Natural Gas Properties

This program calculates nine properties of a natural gas containing a maximum of eighteen components. All units of the components are in mol fractions, with the physical constants introduced into the program being drawn from the NGPSA editions 1957 and 1972.

19.5 Gas Temperature Throughout the Pipeline

This program calculates the temperature along the line according to the initial pipe inlet temperature and the sea water temperature. These temperatures are calculated every twenty kilometers. It calculates also the isothermal point where the gas temperature is equal to the sea water temperature. Knowing where the isothermal point is located, makes it possible to calculate the mean temperature of this length.

19.6 Velocity Along a Gas Pipeline

This program must be used with the program which calculates the temperature. Some hypotheses are similar such as : inside diameter of pipe and length of the sections along the line which are equal to 20 kilometers. The first program also gives the value of J (° C/m) which is introduced into the program of velocity.

19.7 Time Necessary for Steady State Flow Changes

This program determines the time necessary to change from an established flow to a new steady flow rate within pressure limits.

19.8 Pipeline Temperature Profile

This calculation method determines the temperature profile for steady state conditions alongside the gas pipeline. The conditions with compression and without compression at the intermediate platform for several discharge temperatures were considered. Once the pressure profile is known the temperature is calculated by the Pascal formula based on thermal balance including Joule-Thomson effect. Iterations are necessary.