IKM Ocean Design AS

PETROLEUMSTILSYNET

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NCS Trawl Development Study

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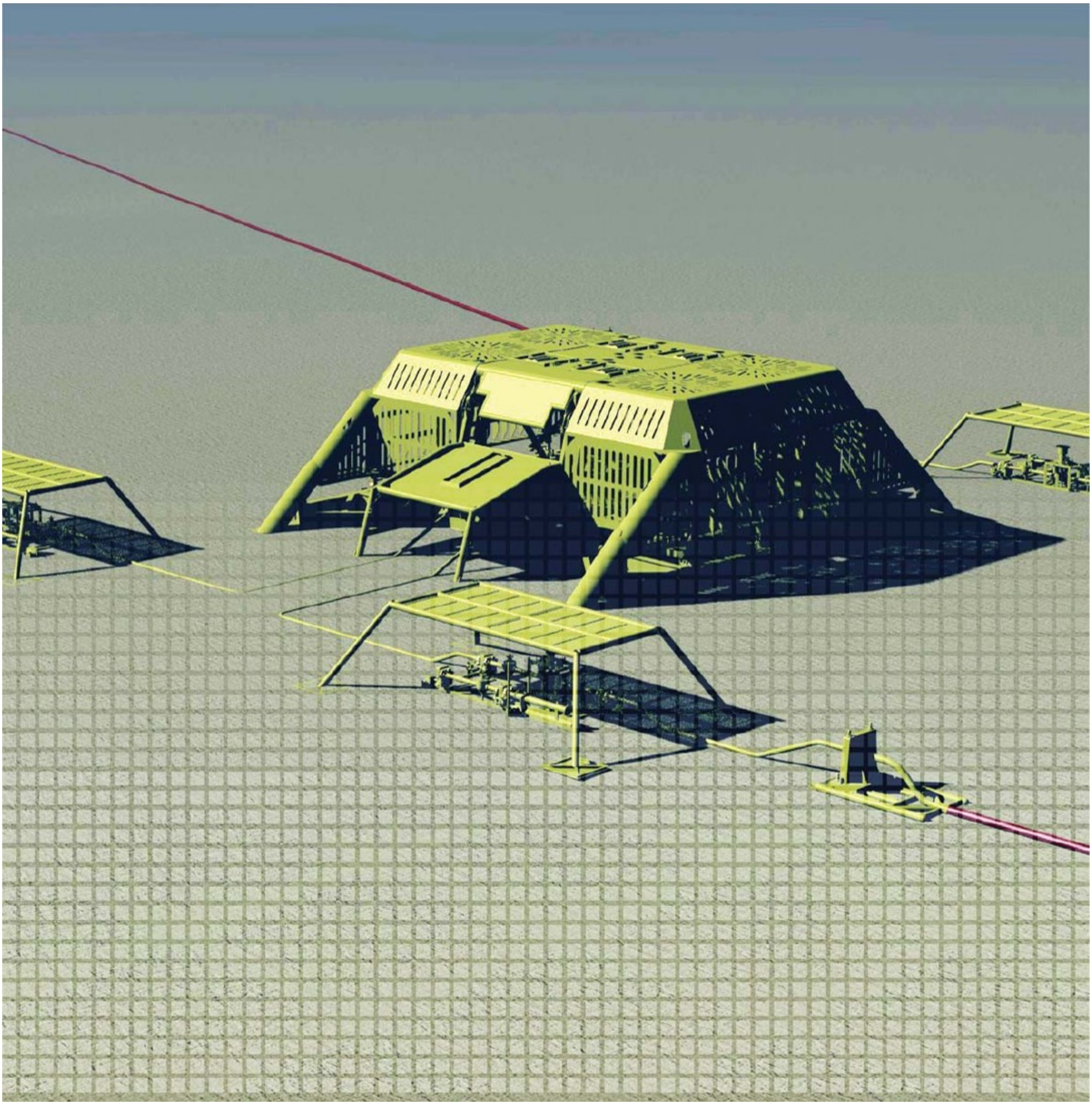

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Table of Contents

1 Introduction

1.1 Background and Study Scope

Petroleumstilsynet (Ptil) has commissioned IKM Ocean Design (IKM) to perform a study to evaluate the development trends in the trawling industry, particularly with regards to the trend that indicate an increase in trawl gear size and mass.

Based on this, the scope is to evaluate effects of increasing trawl gear, evaluate how these trends are captured in the relevant subsea design standards and guidelines and evaluate where the damage potential is largest wrt subsea installations.

Finally, some trawl analyses examples for relevant scenarios will be performed.

1.2 Abbreviations

The following abbreviations are used throughout the report:

Abbreviation	Description
AIS	Automatic Identification System
ALARP	As Low As Reasonably Possible
ALS	Accidental Limit State
AUV	Autonomous Underwater Vehicle
BHP	Break Horse Power
DNV-GL	Det Norske Veritas - Germanischer Lloyd
DO	Dropped Object
DS	Demersal Seines
DWP	(Norwegian) Deep Water Pipeline Committee
FAO	Food and Agricultural Organisation of the United Nations
FPSO	Floating Production, Storage and Offloading
GI/GL	Gas Injection - Gas Lift
GRP	Glass-fibre Reinforced Plastic
Hazid	Hazard Identification
HP	Horse power
HSE	Health, Safety and Environment
ICES	International Council for the Exploration of the Seas
ID	Internal Diameter or Identity/Identification
ILS	Inline Structure
ILT	Inline Tee
ILW	Inline Wye
IMO	International Maritime Organization (IMO no. - vessel identification number)
NCS	Norwegian Continental Shelf
NPD	Norwegian Petroleum Directorate
NPF	Norwegian Petroleum Society
OD	Outer Diameter
OS	Offshore Standard
OT	Otter Trawl

PLEM	Pipeline End Manifold
PLS	Progressive Limit State
PRM	Permanent Reservoir Monitoring
PRS	Pipeline Repair System
PSA	Petroleum Safety Authority Norway (Petroleumstilsynet)
Ptil	Petroleumstilsynet (Petroleum Safety Authority Norway)
ROV	Remote Operated Vehicle
RP	Recommended Practice
SOW	Scope of Work
SPS	Subsea Production System
SRA	Structural Reliability Analysis
SRI	Subsea Rock Installation
TN	Technical Note
TOP	Top of Product (or Top of Pipe)
ULS	Ultimate Limit State
UN	United Nations
UTA	Umbilical Termination Assembly
VIV	Vortex Induced Vibrations
VMS	Vessel Monitoring System
WI	Water Injection
XT	Xmas tree

1.3 Hold Items

Section	Hold Item

1.4 Document Revision Sheet

Revision	Date	Notes
01	02.12.2019	Issued for Discipline Internal Check
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2 Summary and Conclusions

Bottom Trawl Gear Development Trends

Over the last 40 - 50 years, the Norwegian fishing industry as well as other international fishing industries have undergone large structural changes where number of fishing vessels has declined while size has increased. Increased vessel size has allowed larger equipment, more storage capacity, longer trips, increased quotas and more industrialised fisheries.

This trend in increasing vessel size appears to have continued up until today. Not just in physical dimensions, but also in available engine power, enabling the use of larger trawl gear and the ability to carry a range of different type of gear.

IKM Ocean Design has over the last 5-6 years collected data for Norwegian and international trawl vessels, in order to gradually build a complete database for trawlers that may operate on NCS from time to time, but also for international waters. The database, which has been gradually populated also with new builds and planned builds, are based on news articles from trawl ship designers, trawl equipments manufacturers, the trawl companies themselves as well as telephone conversations with people in the fishing industry including research personnel etc. The total list of vessels in the database currently consist of more than 950 trawl vessel, where approximately 200-250 of these frequently operates in Norwegian waters. The main population of vessels are registered and operating out of Norway, Russia, Iceland, Faroe Islands, Denmark, Greenland, UK, Baltic countries etc.

Some example relationships and trends are shown below based on trawl vessels that typically operate on NCS.

Fig. 2.1 Vessel Engine BHP vs Build Year

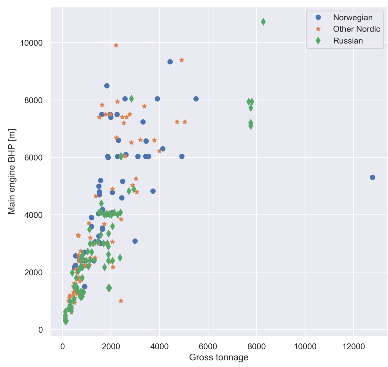

Fig. 2.2 Vessel Engine BHP vs Vessel Gross Tonnage

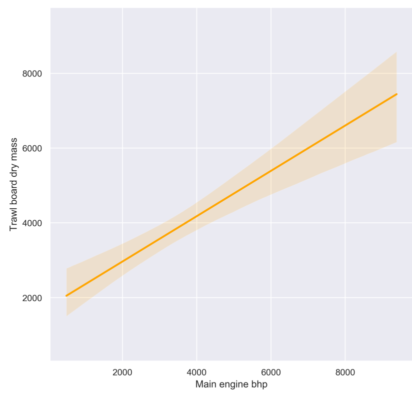

Fig. 2.3 Trawl Board Weight vs Engine BHP

The different type of trawl boards evaluated in the work varies in design, size and weight and are found to be typically provided in standard sizes up to 6500 - 7500 kg. These trawl board weights seems to correspond well with the design boards given in the latest DNVGL-RP-F111 guideline.

The clump weight used for twin rig trawling is seen to develop in size, and currently all the main clump weight manufacturers are delivering roller clump weights up to 10 tons. Examples are:

- Thyborøn Trawl in Denmark are marketing roller clumps up to 10 tons as part of their standard design.
- Rock had a news bulletin on 24th November 2019 where they announced that a roller clump weight of 9.8 tons were delivered to the trawl vessel Svend C.

Even though not all of these large roller clump weights may be applicable for fishing in Norwegian waters, they indicate the industry trend of increasing trawl gear sizes. The maximum catalogued Thyborøn roller clump weight has increased for instance increased from 8 to 10 tons over the last period of 3-4 years.

For clump weights, the DNVGL-RP-F111 reduced its maximum design weight from 9000 kg to 8000 kg, however advices each project to evaluate the maximum gear used within the project region and surrounding fishing areas. It seems, however, that it should be evaluated to increase the maximum clump weight mass to 10000 - 11000 kg in order to allow for some custom designed clumps and to account for some future development. *It should be mentioned that IKM, during the finalisation of this study, checked its online map wrt the trawl vessels with the largest clump weights. A few of the trawlers having clumps of 9000 kg were seen to be currently operating on NCS.*

Pipeline route sections away from platform safety zones and of some length, is seen to attract fish and consequently fishing activity during life of field due to the pipeline having a reef effect and potentially being heated etc. Such effects should be considered during design phase as well as continually monitored during its operational life.

Bottom Trawling and Water Depth Limits
Based on available publications from the fishing industry and marine research institutions, it seems to be regular trawling along the slopes on NCS down to 700 - 800 m depth. Below these depths, the feedback is that trawling for the time being is less commercially viable. As a common understanding in the subsea oil and gas industry appears to be that trawling on NCS is more or less absent below water depths of 400-450 m, it should be considered to include trawl frequency evaluations for deeper waters as well.

Penetration Depth of Bottom Trawl Gear
The potential depth of a trawl board or clump weight is of interest with regards to protection requirements for subsea umbilical, cables and small diameter flowlines. Eigaard et al. (2016) and other sources has investigated the penetration of different trawl gear in different soil conditions and found trawl boards to be governing. In mud (very soft clay), trawl board penetrations can reach 15-35 cm while clump weights is expected to penetrate less in the same soil conditions (10-15 cm). In sand, the estimated maximum penetrations are 10 and 15 cm for trawl board and clumps respectively. Based on the work by Buhl-Mortensen (2018) and Eigaard et al. (2016), it is seen advisable to apply a maximum potential penetration of trawl boards of 50 cm when evaluating protection requirements for flexible products such as flexible lines, umbilicals and cables.

It seems like the general rule of thumb to trench and backfill cables and umbilicals to minimum 50 cm TOP is adequate, however project specific assessment is recommended in order to ensure a robust design.

Trawl Velocity
The publications evaluated, support the general assumption that bottom trawling is mainly performed at vessel velocities ranging from 2 to 5 knots. However, the data also indicate that some of the trawling actually take places at both lower and higher velocity.

Another consideration wrt trawl velocity is the velocity at the trawl boards themselves. For instance, when the vessel is moving through curves, the outer trawl board will traverse longer length than the vessel itself, and hence the trawl board velocity may be significantly larger than the vessel speed, particularly when the vessel makes sharp turns. Opposite effects may be for the inner board in the curve. This effect may be further enhanced for double and triple trawl configurations since the trawl doors will have a larger offset to centrelines in curves.

Reporting frequency of trawl vessel GPS position is also identified to be a source for under-reporting of trawling vessel velocity, and frequent position reports

With reference to the sensitivity analyses performed in Section 6 Trawl Gear Analysis Examples with regards to the effect of trawl velocity on pipeline response, it is found that low trawl velocity in some cases is more onerous than high velocity. Since it is quite common in subsea pipeline and structures design to assume that the highest trawl velocity gives the worst load condition, it is recommended to further evaluate this finding and which parameters that influence this behaviour.

Catch Data Published by Norwegian Directorate of Fisheries (www.fiskeridir.no)
The detailed historical catch data made available through the w*ww.fiskeridir.no* web-site provides catch statistics categorized into many of the different type of trawl types employed on NCS. The data site includes both catch from Norwegian and International vessels operating on NCS.

Twin and triple rig trawling is seen to represent a very small percentage of the total trawl catch from Norwegian trawlers in the 19 year period evaluated: less than 1% on average while bottom single trawl is seen to represent on average approximately 40%. Over the last 5 years, there is no registered catch from double trawling in the statistics. If these statistics are correct however, it may appear that the usage and concern of clump weight as a load is currently overestimated by the oil and gas industry

Further evaluations is recommended in order to validate the indicative low use of double and triple rig nets in bottom trawling since this directly affects the clump weight frequency, loads and protection requirements for subsea installations. One such factor that may be further assessed, is if the classification types "Bunntrål", "Udefinert trål" and "Reketrål" receive catch data that should have been reported towards the "Dobbeltrål" or "Trippeltrål" categories? Another question is how much of the international "Bunntrål" catch tonnage which derives from using more than one trawl net during bottom trawling.

Trawl Design Loads for Subsea Structures
An update of the NORSOK U-001 (Subsea Production Systems) standard was introduced in 2015.

For trawl board overpull, the design load increased from 300 kN (2002) to 450 kN (2015), while for closed/smooth protection covers such as GRP, the 300 kN load continued to apply. For horizontal impact, the load increased from 13 kJ to 30 kJ and an object geometry was defined (diameter 500 mm). Another change introduced in the new standard, is that the minimum trawl speed has been reduced from 3.0 m/s to 2.8 m/s.

Except for these two load adjustments and reduction in minimum trawl velocity in 2015, it seems like the trawl design loads for subsea structures have only marginally been adjusted since 1998 (NORSOK U-002 Rev. 02).

During the same period, DNV Guideline 13 gave a maximum trawl board weight of 3500 kg in 1997, DNV RP-F111 in 2006 gave an increased maximum trawl board weight to 5000 kg but also introduced the clump weight load of maximum 9000 kg, and in 2014 these loads were adjusted to 7400 kg and 8000 kg respectively.

Some comments and questions:

- This review leaves a question if the trawl design loads in the NORSOK U-001 standard has been able to capture the development of bottom trawl gear over the last period. Further assessment of these requirements should be considered.
- NORSOK U-001 has few references and it is challenging to track the sources for the information and requirements provided in the standard. It should be considered to make the standard more traceable with clear references to tests, research, publications etc.
- The recommendations in Section 5.3.4.3 related to Model Tests requirements. It seems like these requirements have not been changed since 2002. Due to the introduction of new type bottom trawl gear and larger masses, a revisit of the test requirements and detailing should be considered.
- Some NORSOK standards are said to be discontinued and responsibility transferred to ISO. Since ISO 13628 is of more general nature than e.g. the NORSOK U-001 requirements, it leaves a question to how the Norwegian specific requirement to subsea structure design will be continued and ensured in the future.

The Potential for Bottom Trawl Gear within Platform Safety Zones
An example analysis for a single trawl spread of 200 m width circling a platform safety zone in 150 m water depth is included in Section 6 Trawl Gear Analysis Examples.

The following is observed from the analysis that is based on the methodology outlined in DNVGL-RP-F111:

- If the vessel is following the platform safety zone for 360 degrees, the minimum physical distance between the inner trawl board and the platform will be approximately 200 m, i.e. 250 m within the platform safety zone. A more realistic scenario is that the trawler touches the safety zone, follows it say 45 degrees before departing out. Even in this case, the inner trawl board will come 150 m within the safety zone.
- In an extreme case with larger water depth, a double trawl with a width between trawl boards of 300-350 m, the inner trawl board may touch the foot of the platform legs.

Since there have been examples of trawl gear interference with subsea installations within platform safety zones, it seems like these type of sensitivity assessments should be further utilised during design phase in order to evaluate risk and if mitigations should be taken.

Alternative Methods in DNVGL-RP-F111
The DNV GL RP-F111 from 2014 (Sect. 4.8) introduced the methodology and procedure for an alternative to the standard deterministic approach, by performing project specific structural reliability analysis (SRA) in order to demonstrate that the safety level/target failure probability defined by DNV GL ST-F101 is maintained. This alternative has been used on several recent pipeline projects for fields with little or no trawling (low frequency trawling).

It is considered that by utilising such an alternative method for optimisation processes of e.g. seabed rock volumes (free span mitigation for trawl loads in uneven seabed such as the Haltenbanken and Barents Sea areas), it allows the engineers and decision makers to better evaluate risk and consequences for the product being considered.

Considerations for Further Testing
Testing of interference between clump weight and pipeline has not been performed since 2003/2004 (for the Kristin and Snøhvit projects) and a lot of learning has been gained by the industry since then. 3D numerical simulations such as those being available in SIMLA are able to reproduce the Kristin/Snøhvit clump weight test results as well as the general behaviour of trawl boards, hence allowing "numerical tests" of trawl gear interaction with subsea pipelines and structures.

Despite the great advances of the simulation tools, it is generally recommended for the industry to carry out additional testing for a wider range of parameters and to incorporate the findings and development from the last 15 years. Very few signs of lateral pull-out has been identified during as-built inspections of existing pipelines even though design analyses suggest that significant lateral displacements will take place when a trawl passes. The existing trawl tests performed, both on trawl board and clump weight, are for small to medium size gears, while large gears are dominant in design. Further testing will increase knowledge, will allow for further optimisation and will improve design robustness.

Little test data is publically available for trawl gear crossing at an angle with the pipeline and it is uncertain if such trawl tests have been performed for clump weight gear. Further testing should be considered, particularly for skew angle trawl crossings and clump weight gear. In addition, making previous trawl test data publically available is considered important in order to generally improve different stake holders knowledge and awareness about the topic.

Based on results in Section 6 Trawl Gear Analysis Examples and other similar numerical studies, the following is observed:

- For pipelines and products with diameter less than approximately 350 - 400 mm, the governing interaction is seen to be limited to the roll-over effect, i.e.:
  - smaller products will have less risk for high pullover loads for on-bottom conditions
  - small diameter products may still be able to sustain clump weight masses >7T for the roller type for on-bottom case

    - larger diameter products may be more exposed to increases in clump weight gear for the on-bottom case.
- It also seems like the DNVGL-RP-F111 clump weight load formulation for on-bottom and low span cases (span height < 0.5 m) should be further evaluated wrt level of conservatism. Additional model testing or numerical studies should be considered in order to achieve a more unified safety level from on-bottom to high free span pipeline conditions.

Reduced seabed intervention works (trenching, rock dumping etc) is also environmentally friendly, in that less marine sediments are disturbed, less fuel and vessel time is used and little permanent change to the seabed environment will be present after the field is decommissioned.

Two Industries, Side by Side
Due to a good cooperation and mutual understanding between the "long term" fishing industry and the "short term" offshore oil and gas industry, both has been able to develop and grow alongside each other with minimal conflicts. Key factors for this good cooperation are considered to be:

- Very stringent requirements and proactive attitude wrt health, safety and environment
- Early dialogue in the field development process with the fishing organisations and similar stake holders
- The principles given by the Petroleum Safety Authority in their PSA Framework HSE regulations wrt regulation for Development Concepts including requirements such that, "*Subsea facilities and pipeline systems shall also be designed and installed such that <u>the facilities can withstand mechanical damage caused by other activity, and such that they do not damage fishing gear or obstruct fishery activity to an unreasonable extent</u>*", [1].
- Performing full scale trawl pullover tests relevant for new field developments and interaction with fisheries in order to document that pipelines of varying sizes and conditions are overtrawlable without negligible hindrance for the bottom fishing activity.

Continuing the above policy and principles is considered important also for the future success of offshore petroleum field developments. In addition, the same principles are considered important for new type "short term" industries that may also interfere with traditional fisheries on NCS, e.g. offshore wind farms.

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4 General on Trawling, Types and Trends

4.1 Trawling on NCS

4.1.1 Introduction and history

This section takes a brief look at the history of trawling, and how it has developed towards modern times.

The principle of trawling, i.e. dragging fishing gear along the sea bottom, has existed for centuries. The earliest description of a trawl in England dates as far back as to 1376. The description of this trawl gear is similar to what we know as beam trawl today, where a beam (made from wood or steel), keeps the net open. A beam trawl is shown in Fig. 4.1.

Great Britain was the centre of trawl fishing development in the 19th century. Key to this was that the development of the trawl fishing was tightly connected to the development of the rail road. Great Britain had a relatively well developed rail road network in the 1880's, and became the leading country in supplying fresh fish to the population. Thereby, it also became the leading country in trawl fishing.

Up until 1893, trawling were only performed with beam trawls. This year, in Granton Scotland, a new kind of trawl gear was introduced to the fishing industry, namely the otter trawl.

The otter trawl has two trawl doors that keeps the trawl net open, as shown in Fig. 4.2, Ref. [76].

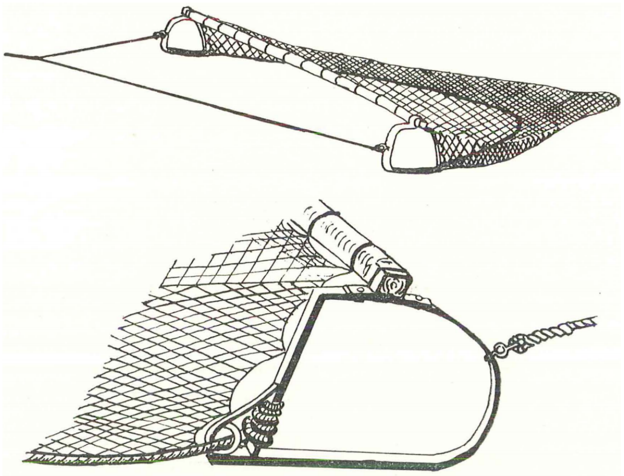


Fig. 4.1 Beam trawl

Fig. 4.2 Otter trawl

The otter trawl, together with steam driven fishing vessels, revolutionised the fishing. The otter trawl was easier to handle than the beam trawl, and allowed for increased dimensions on the gear. Further, the increased (and also even) pulling force and range of the steamships made it possible to fish deeper, and farther away from home. Fishing activities down to 100 fathoms, or about 182 m, was now common. It was the British North Sea fleet who saw this development first, and the switch from beam trawls to otter trawls took place over a time of about two years. Trawling was not yet common in Norway in the 19th century.

Entering the 20th century, steam trawlers represented the greatest proportion of the trawlers in Great Britain. The number of sailing trawlers started to decline, and engine driven trawlers also entered the market. Prior to 1930, the fleet of the larger seagoing trawlers in Norway was minimal. In 1935, Norway had 8 seagoing steam trawlers. 4 were located in Kristiansund, while Bergen, Bodø, Harstad and Tromsø had one each. Great Britain were by far still the largest trawl nation, representing half the total fleet. France and Germany had the second largest fleets. France had one of the largest and most modern vessels; a diesel powered factory trawler with a gross tonnage of 1200. In comparison, the largest Norwegian trawler was "Nordhav 1", with a gross tonnage of 644.

Over the last 40 - 50 years, the Norwegian fishing industry as well as other international fishing industries have undergone large structural changes where number of fishing vessels has declined. Instead, fishing vessels has increased in size, with more personnel, larger equipment, more storage capacity and more industrialised. As can be seen in Fig. 4.3, the total number of Norwegian fishing vessels has declined from approximately 26,000 in 1980 to approximately 6000 vessels today (Fiskeridirektoratet 2019). Of these 6,000, approximately 5,000 vessels are active, Ref. [80].

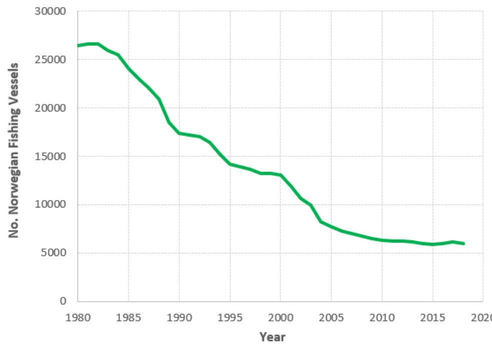


Fig. 4.3 Decline in Norwegian fishing vessels since 1980

This trend in increasing vessel size appears to have continued up until today. Not just in physical dimensions, but also in available engine power, enabling the use of larger trawl gear and in some cases carrying different type of gear. The below figures shows examples of the recent Norwegian trawler Granit, which is a factory trawler operated by Halstensen Granit AS in Bekkjarvik, Ref. [87]. Granit is 81.2 m long, has a gross tonnage of 4427 and is a very modern vessel built for operating in all locations and conditions all year round. Also shown below, is the planned Russian supertrawler RK Lenina company and is understood to be operating in the Russian Far East once built, Ref. [86]. The new trawler will have a unique combination of capabilities for both bringing its own nets of fish onto the deck and pumping catches aboard, as well as operating as a mother ship by taking catches from other vessels for processing. It is said to be the largest fishing vessel built over the last 30 years in Russia.

Fig. 4.5 Planned Russian "Supertrawler" (www. fiskerforum.com)

Fig. 4.4 The Norwegian trawler Granit (Maritimt Magasin 10/2017)

This structural change in the fishing industry has happened in parallel with the gradual development of offshore oil and gas developments on NCS. Due to a good cooperation and understanding between the two industries, both has been able to develop and grow alongside each other with minimal conflicts. Key factors for this good cooperation are considered to be elements such as:

- Very stringent requirements (and record) wrt health, safety and environment
- Early information and feedback from fishing organisations during a field development
- The principles given by Ptil in their PSA Framework HSE regulations wrt regulation for Development Concepts including requirements such that, "*Subsea facilities and pipeline systems shall also be designed and installed such that the facilities can withstand mechanical damage caused by other activity, and such that they do not damage fishing gear or obstruct fishery activity to an unreasonable extent*", see <broken cross-reference> for further details [1].

- Performing full scale trawl pullover tests relevant for new field developments and interaction with fisheries in order to document that pipelines of varying sizes and conditions are overtrawlable without negligible hindrance for the bottom fishing activity.

The following subsections will take a look at this development, based on data available in various ship registers.

4.1.2 Bottom Trawls (Demersal trawling) vs Pelagic Trawling

Bottom Trawling

Bottom trawls are essentially conical nets that are dragged along the sea floor, see Fig. 4.6 [76]. The trawl net is held open using trawl floats, ground gear and trawl doors/boards. The trawl doors used by the biggest vessels weighs up to 5-6 tonnes and even heavier in recent designs.

The trawl gear is dragged along the bottom at speed of typically two knots (shrimp trawling) to four - five knots (fish trawling) and fishing can take place at depths down to 2500 m (Valdemarsen *et al*. 2007, [62]).

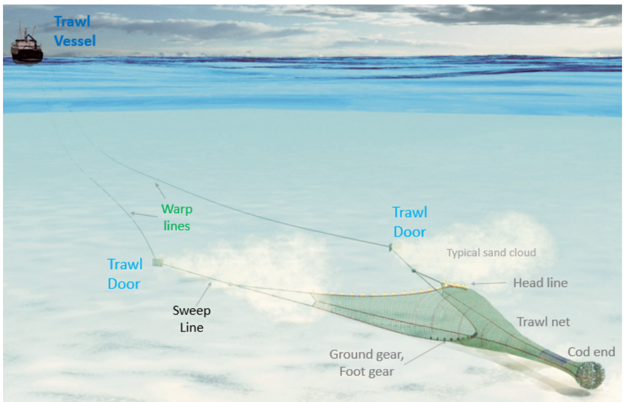


Fig. 4.6 Single net bottom trawl

The trawl doors are connected to the vessel by warp lines and to the trawl net by sweep lines, typically made of steel wire or nylon rope with a steel wire core.

Fig. 4.7 Typical Trawl Door for bottom use

The sweep length varies significantly depending on vessel and target species (Eigaard *et al*. 2011, [64]) and vary typically between 30 to 150 m. Under the trawl net there is the ground gear, which is designed to protect the net against wear and tear, and to help the net across rough terrain and obstacles.

There are various designs of ground gears, as shown in Fig. 4.8, Ref. [63]. In traditional bottom trawling, the trawl doors, sweeps and ground gear all come into contact with the ground during trawling. Depending on the length of the sweeps, the width of seabed affected by a single bottom trawl can vary substantially, typically in the range between 25 - 250 m.

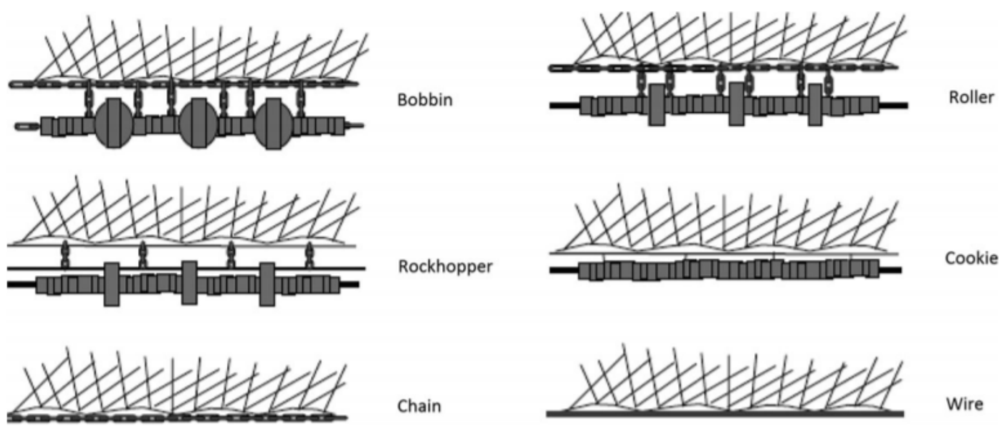


Fig. 4.8 Typical Ground Gear (He and Winger 2010)

Assuming a speed of four knots, and a width of 200 m at the trawl doors, this equates to 1,500,000 m2 of affected seabed for each hour of trawling.

In modern bottom trawling, multi-rig trawling is also used, which involves two or three trawl nets being tied together so that they can be dragged side by side, see Fig. 4.9 and Fig. 4.10 . Twin rig trawling involves the use of two trawl doors, two trawls and a clump weight located between the middle warp (towing cable) and the sweeps going to each of the trawls. The clump weight is typically 20 - 40 per cent heavier than each of the trawl doors.

Twin rigs are frequently used for shrimp trawling, and to some extent for cod trawling and other types. Triple rigs, which consist of three trawl nets, two trawl doors and two weights, are also used for shrimp trawling. A third type of bottom trawling is pair trawling, where two vessels drag a single trawl. In that case there are no trawl doors, but there may be weights at the transition between the warps and sweeps.

As mentioned above, the trawl speed is influenced by what is to be fished. The speed and its size are adjusted according to type of catch. Big saithe can speed up, and the trawl speed is adjusted if necessary to catch the amount of fish they need. Shrimps are less sensitive and does not accelerate and hence low tow speeds (1.2 - 2.5 knots) can be held. The tow speed is also economically driven (fuel consumption), and the trawl speed is kept at the speed required to maintain the catch rate.

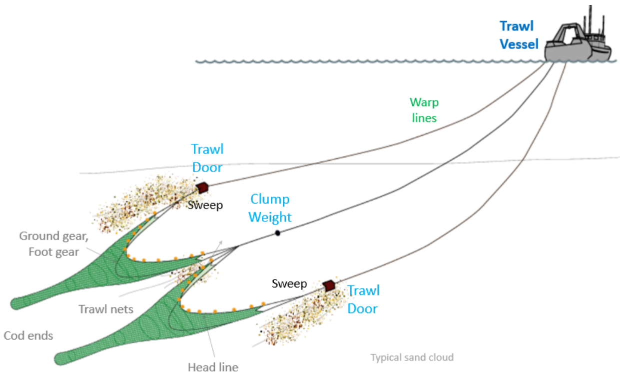


Fig. 4.9 Double Net Bottom Trawl

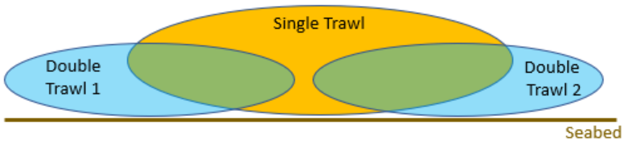


Fig. 4.10 Singe vs Double Net Mouth Opening

Beam Trawling

Beam trawling as discussed in Section 4.1.1 Introduction and history, is not so common on NCS and is mainly used in the shallow water southern parts of the North Sea.

Pelagic Trawling

This fishing gear is mainly used when targeting pelagic species (e.g herring, mackerel, capelin, blue whiting). The trawl is towed through the pelagic zone, and does not come into contact with the seabed. Under current regulations, pelagic (midwater) trawling is defined as trawling where no parts of the fishing gear contact the seabed. However, pelagic trawling is also increasingly being used to catch cod fishes during the periods when they swim up from the sea floor. Pelagic trawling has been particularly successful in the saithe fishery, where it is often used in such a way that parts of the trawl come into contact with the seabed.

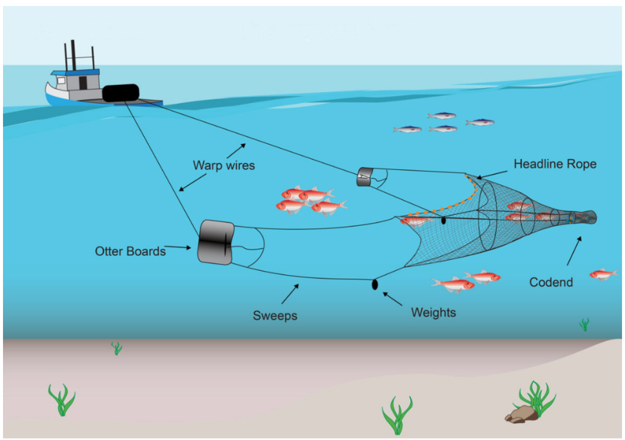


Fig. 4.11 Pelagic/Midwater Trawling

Semi-pelagic Trawling

There has also been research and testing towards semi-pelagic trawling, i.e. with trawl doors flying 2-7 m above the sea floor (or with less ground pressure) in order to reduce impact on seabed as well as optimise fuel consumption.

The semi-pelagic approach is to some extent used in shrimp trawls, especially around Greenland (Fjeldsbø 2019, [75]).

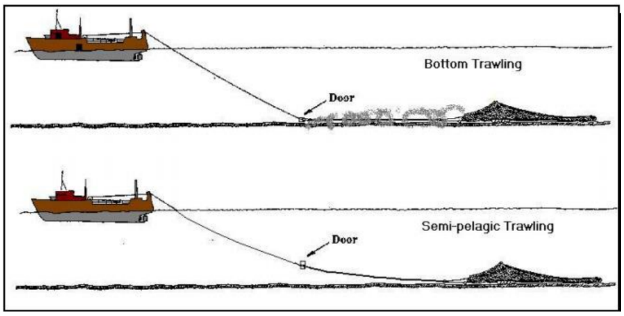


Fig. 4.12 Semi-Pelagic vs Bottom Trawling

For catching cod, the semi-pelagic method is considered to reduce catch rate and hence it is assumed that more testing and development is required before being implemented on a wider scale. Again, the catch rate and economy controls the development and use. From an environmental point of view it would obviously be advantageous since less disturbance on megabenthos and bottom sediments will take place.

For double net trawling, there will still be the need for a clump weight in the middle in order to keep the trawl spread on the ground.

Use of sensors

There has been an increasing use of sensors, cameras, echo sounder etc on the trawl gear allowing the vessel to monitor the continuous behaviour , symmetry and effectivity of the gear tuning. It is assumed that the implementation of semi-pelagic trawl boards will depend heavily on such sensor systems in order to allow fine-tuning to optimal gear performance.

One supplier of trawl gear sensors is the company Scanmar (www.Scanmar.no, [88]). The following information is taken from their sensor installation on the Norwegian stern trawler Vesttind, built in 2000 and owned by Havfisk AS. Vesttind has a length overall of 60 m, a gross tonnage of 2243 tons and an engine of 7500 hp.

The vessel is rigged for twin trawling with Injector doors, Thyborøn 6000 kg clump, Alfredo 5 trawls, pelagic trawl and a complete Scanmar Catch System. The trawl doors are equipped with multifunctional SS4 Door sensors with double Distance, Angle, Depth and Temperature function. And on the clump; a SS4 Clump sensor with extended Distance, Depth, and Angle function. There is a TrawlEye and a TrawlSpeed sensor mounted on the headline of each trawl, while the cod end is equipped with several multifunctional SS4 Catch sensors.

Fig. 4.13 Clump weight sensor

Towing without sensors is like fishing blindly, says skipper Helge Larsen. The Scanmar system is one of the most important decision making tools on board. First mate Ronny Brynjulfsen comments that the total image of information we get from the Scanmar system, combined with our experience, makes it possible to make the right decisions. With Scanmar's ScanScreen system on the bridge, the crew on Vesttind has a good overview of all the data they wish to monitor at any time.

Quality of the Product

Over the last 20-30 years, there has been an increasing focus towards the quality of the catch. The fishing and fishing methods affect the raw materials to a greater or lesser extent. The fish can die before it comes out of the sea, and in this way it will not be bloated, soaked and gutted as it should. Traps, snares and line trapping keep the fish alive long after caught in the gear, thus providing a good chance of bringing the catch live out of the sea. The catch (fish, shrimps and nephrops etc) may be exposed to impact damage, transport damage, other mechanical stresses and processing defects that will affect both texture and durability. The longer the catch stays in the gear, and the more it is dragged and compressed, the greater the risk for reduced quality becomes.

This means that also the quality focus and the affected price per kilo catch, is a factor in the fishing industry. Less damaged catch makes the initial selection process onboard easier, less spillage is achieved and finally, better cost effectiveness is the result.

Similarly, efforts are being made to improve fishing gear so that bi-catch escape the gear and survive, while the regulations lay the basis for the bi-catch that end up in the gear are being used and not discarded.

4.1.3 Trawl Activity

Trawling activity can be monitored and assessed through processing of AIS data (VMS). AIS and VMS stands for Automatic Identification System and Vessel Monitoring System respectively, and was introduced by the UN's maritime organisation IMO in 2000. The system is used to transmit information about each vessel, such as identity, type, position, current speed, course and other safety-related information. These transmittals are then captured by other vessels, as well as AIS satellites and land based stations.

In Norway, VMS was introduced on all Norwegian fishing vessels of length >24 m in July 2000. Since then, the Norwegian Directorate of Fisheries has received information about time (minute resolution), vessel position, permit number, heading, and speed approximately every 60 min.

The AIS system is mandatory for passenger ships, tankers and ships of 300 gross tonnage and upwards. In addition to AIS, Norwegian authorities require vessels involved in fishing operations (and length above 15 m) to comply with another position reporting system, VMS. The fishing vessel monitoring system is also mandatory for foreign vessels of 24 meters or more (15 meters or more in the case of EU vessels) when operating in Norwegian waters outside Skagerrak. As of October 1st, 2019, the Norwegian Directorate of Fisheries opens up for access to vessel position data and electronic fishing records, Ref. [80]. This is done as a part of increasing transparency policy, and will allow for an even greater insight into fishing patterns relevant to subsea installations.

Historical data from AIS or VMS can then be used to identify trawling activity relevant for any area of interest, e.g. trawl frequency within an area, governing crossing angles across pipelines, trawl velocity distribution etc.

Unique trawl vessels can be identified, and linked to a database with vessel specific equipment information. This could be information such as:

- Manufacturer and type of trawl boards (i.e pelagic trawl boards, multifunction or bottom trawl gear)
- Size and mass of trawl boards
- Manufacturer and type of clump weight
- Size and mass of clump weight

Fig. 4.14 shows the bottom trawl intensity for Northern Europe in the period between 2010 to 2012 (Eigaard 2017, [66]). Plot (b) show that beam trawling is mainly taking place in the southern parts of the North Sea, English Channel etc. Beam trawling in the Norwegian economic zone only occurs in the North Sea, south of 58°North, and not by Norwegian vessels.

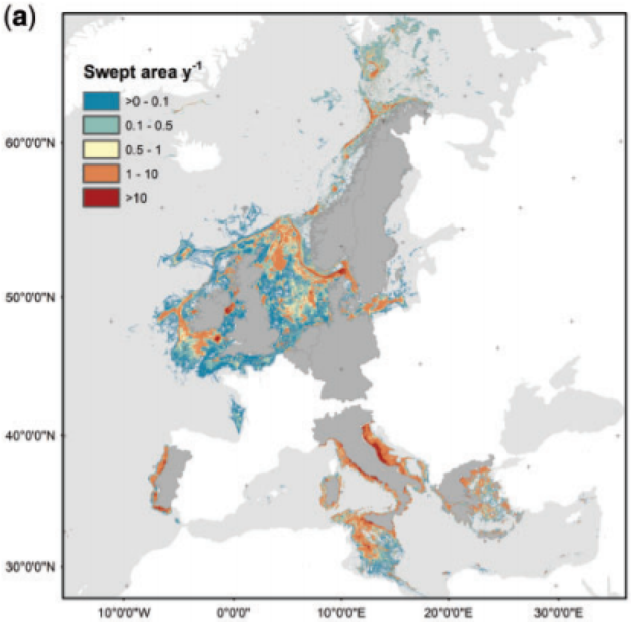


Fig. 4.14 Otter and beam trawl intensity 2010-2012 (Eigaard 2017)

Fig. 4.15 and Fig. 4.16 shows an example of processing of AIS/VMS data performed by IKM along a typical pipeline in the North Sea. Processing of vessel data is made towards velocity, movement pattern and vessel ID in order to identify fishing vessels performing bottom trawling. In this work we adopted a speed rule of 2 –5 knots based on results from Skaar et al. (2011, [67]) in order to identify actual trawling activity. Based on this various classification of parameters can be made in order to define trawl frequency along the pipeline route, variations in trawl gear size, governing trawl direction vs pipeline route heading, cross checking these trawl activities vs free spanning sections & lateral buckles etc.

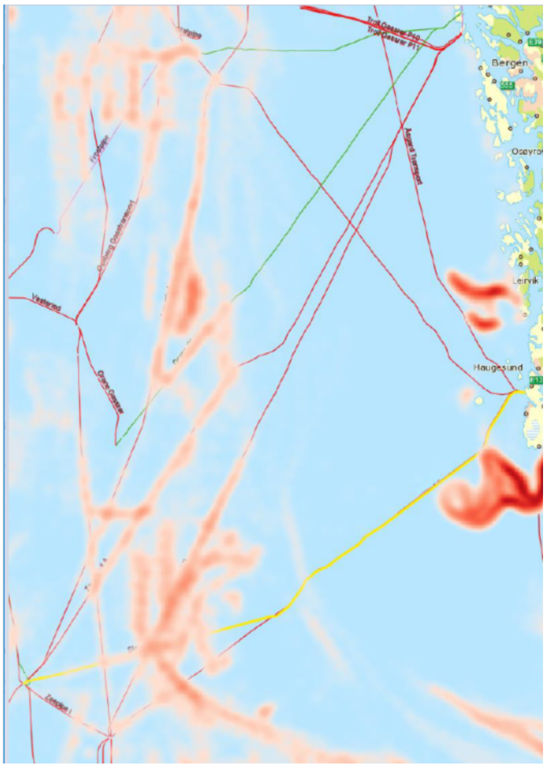


Fig. 4.15 IKM Trawl Intensity Charts for Small Vessels (2015)

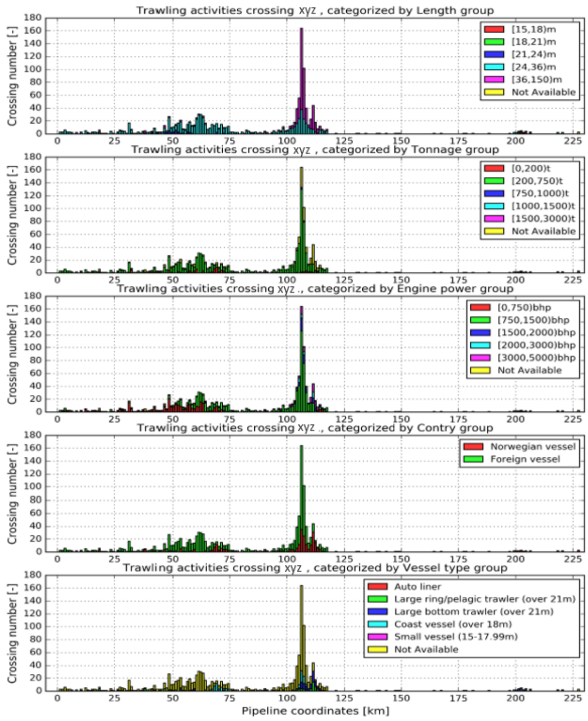


Fig. 4.16 IKM Trawl Activity Classification along Typical Pipeline (2015)

By doing such detailed screening of trawl activity, the pipeline route can be split into different trawl frequency classes and hence optimisation can be achieved. The example in Fig. 4.16 shows for instance that a higher trawl frequency may be adopted for KP 100-125 as compared to KP 150-175.

In Fig. 4.15, it can be clearly seen that trawl activity typically follows major pipeline routes, particularly on the Western Slope and on the Plateau. Hence, an increase in trawl activity may be expected along long pipeline sections compared with the pre-installation phase, since pipelines form a "reef" effect on the seabed.

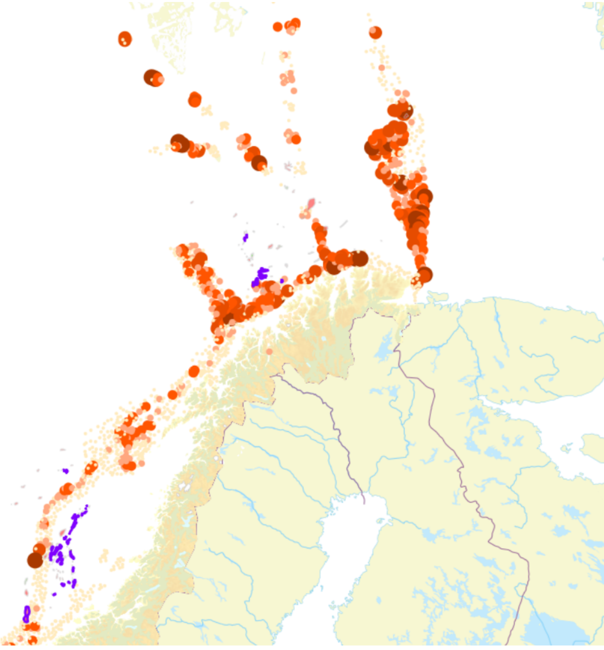


Fig. 4.17 Registered Trawl Marks (Barents Watch)

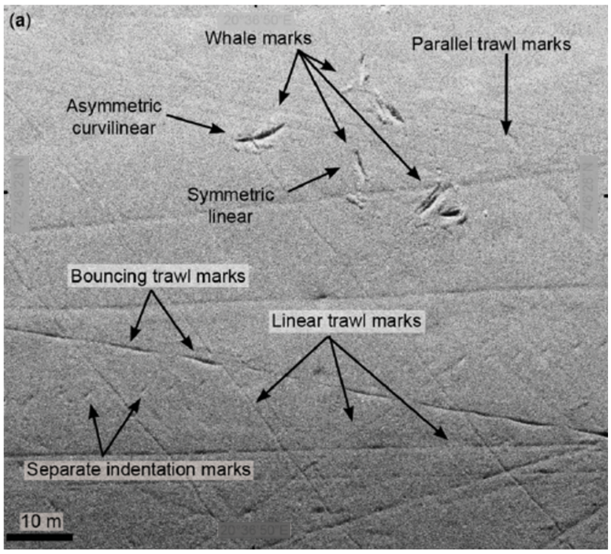


Fig. 4.18 Example area with trawl marks (Thorsnes 2016)

Fig. 4.17 shows registered trawl marks from seabed and marine surveys as presented by Barents Watch, Ref. [89] (based work performed by Havforskningsinstituttet). It also shows oil and gas developments in purple. An example of such trawl marks based on high resolution multibeam echosounder bathymetric data are shown in Fig. 4.18, Ref. [72]. Also indicated on the plot are potential whale-feeding penetration marks.

Fig. 4.19 overleaf, shows a trawl intensity map for the entire Norwegian Continental Shelf for year 2011, Ref. [69]. While it can be seen that the North Sea region sees quite a lot of trawling on the Plateau, the Western slopes of the Norwegian Trench and along major pipelines, the Haltenbanken area sees more scattered trawl activity. The same is seen for the Barents Sea where a lot of trawling occurs along the Finnmark coast, around Bjørnøya and at Svalbard. Many of the oil and gas fields on Haltenbanken and Barents Sea are located at some distance from main fishing fields, and hence only have low potential to experience trawling.

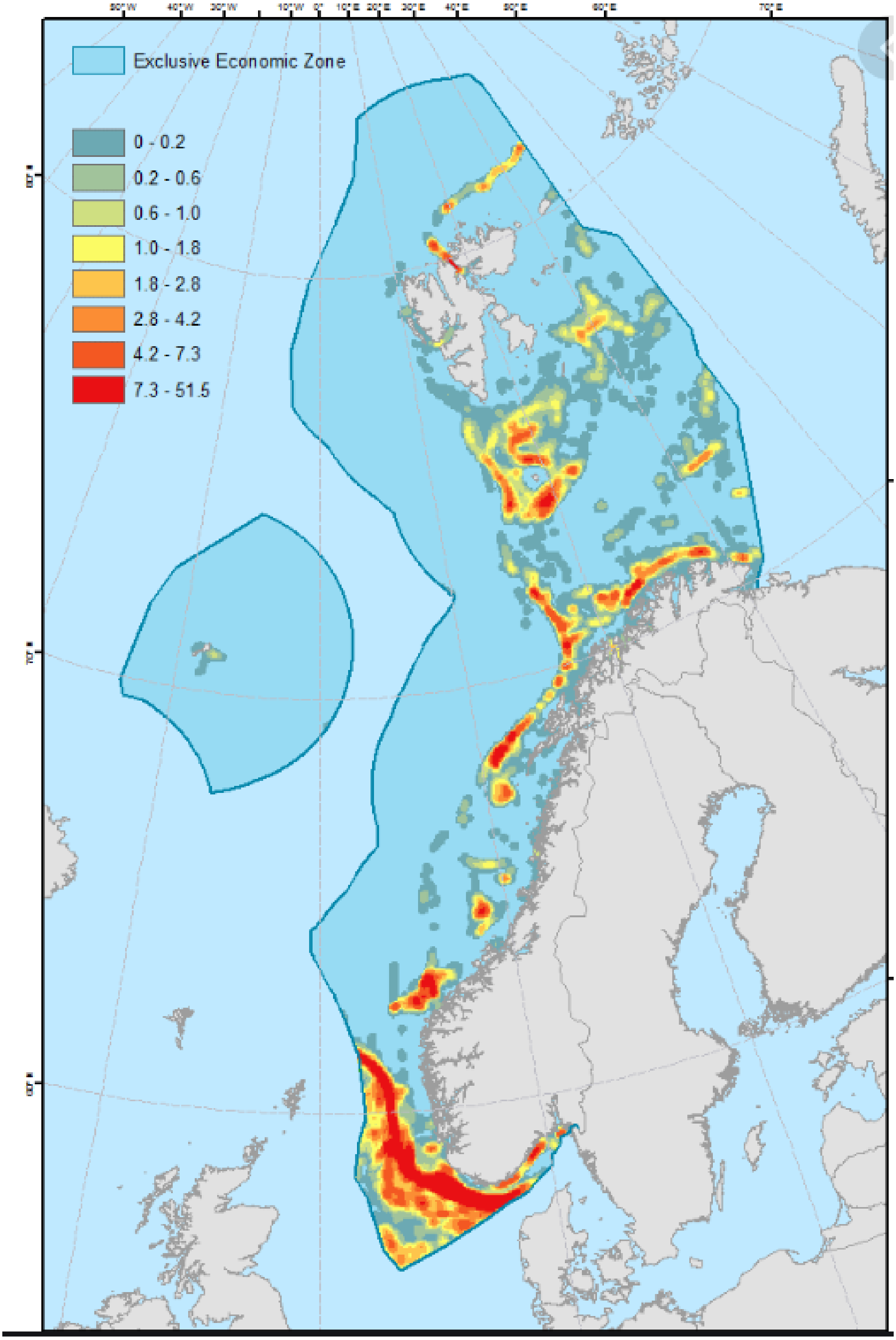


Fig. 4.19 Trawl Intensity Map (Buhl-Mortensen et al 2013)

Havforskningsinstituttet (Buhl-Mortensen 2018) has based on a large bathymetric survey database also investigated to which depth trawling takes place to within the Norwegian Economical, i.e. to which depth trawl marks have been identified on seabed surveys.

In Fig. 4.20, the bathymetric distribution of VMS records and observed trawl marks on NCS are plotted as a function of water depth (Buhl-Mortensen 2018, [71]). The highest density of recorded trawl activity is between 200 and 400 m depth, however, there was also a less pronounced peak at depths between 600 and 700 m. These two peaks correspond to the relatively shallow fisheries for white fish on the continental shelf and close to the shelf break, and the deeper fisheries for Greenland halibut on the continental slope (Buhl-Mortensen et al. 2013, [69]). This survey also indicates some low frequency trawl activity/trawl marks as deep as 1200-1450 m.

It is believed though based on this survey as well as the general feed-back from the fishing industry, that trawling below 800 - 900 m depth currently has little commercial interest.

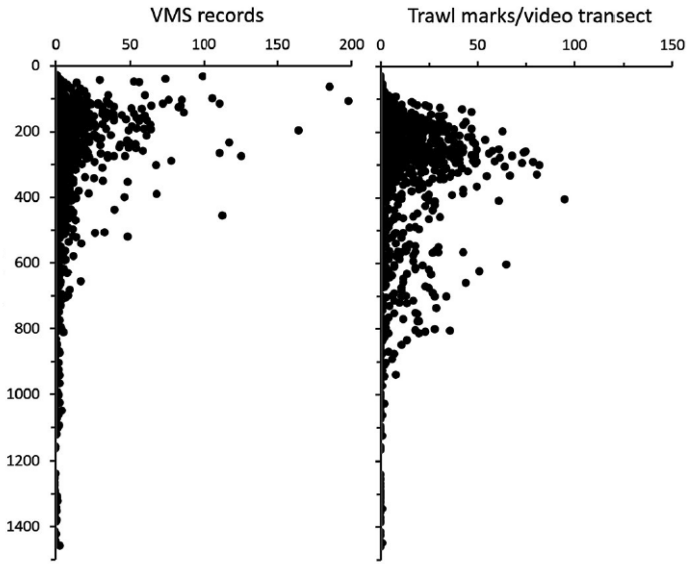


Fig. 4.20 VMS records and Observed Trawl Marks vs Depth

The potential depth of a trawl board or clump weight is of interest with regards to protection requirements for subsea umbilical, cables and small diameter flowlines. Since trawl marks appear as trenches or furrows on the seabed, they are identifiable on high resolution surveys. Their shape reflects the part of the trawl gear that has made the impact. The conclusion from the work by Buhl-Mortensen (2018) is that trawl doors leave marks that are up to ca 50 cm deep and wide v-shaped trenches up to 3-4 m. Eigaard et al. (2016, [65]) summarised the experience from various studies into the penetration values given in . In mud (very soft clay), trawl board penetrations can reach 15-35 cm while clump weights is expected to penetrate less in the same soil conditions, i.e. 10-15 cm. In sand, the estimated maximum penetrations are 10 and 15 cm for trawl board and clumps respectively. Based on the these studies by Buhl-Mortensen and Eigaard, it is seen advisable to apply a maximum potential penetration of trawl boards of 50 cm when evaluating protection requirements and minimum trench depth (TOP) and backfill height for small diameter flowlines, flexible products, umbilicals and cables.

Table 4.1 Penetration depths (cm) of main gear components as estimated from literature review for different sediments types (Eigaard et al. 2016)

Gear types	Gear components	Coarse sediment	Sand	Mud	Mixed sediments	Indexed component impacts (maximum depth in brackets in cm)
OT	Sweeps and bridles		0–2	0		Surface (<2)
	Sweep chains		0–2	2–5		Subsurface (≤5)
	Tickler chains	2–5	2–5		2–5	Subsurface (≤5)
	Trawl doors	5–10	0–10	≤15–35	10	Subsurface (≤35)
	Multi-rig clump		3–15	10–15		Subsurface (≤15)
	Groundgear		0–2	0–10	1–8	[a]
DS	Seine ropes[b]					Surface (<2)
	Groundgear[b]					[a]
Beam trawl	Shoes	≤5–10	≤5–10	≤5–10	≤5–10	Subsurface (≤10)
	Tickler chains	≤3–10	≤3–10	≤10	≤3	Subsurface (≤10)
	Groundgear		1–8		0	[a]
Dredge	Groundgear		1–15	6		[a]

With regards to trawl velocity distribution, Salthaug 2006 [68], analysed the VMS data for two trawler over a three year periode from 2002 to 2005. The tracking of the two vessels over the period is shown by blue crosses in Fig. 4.21. The velocity distribution for the two trawl vessels are shown in Fig. 4.22.

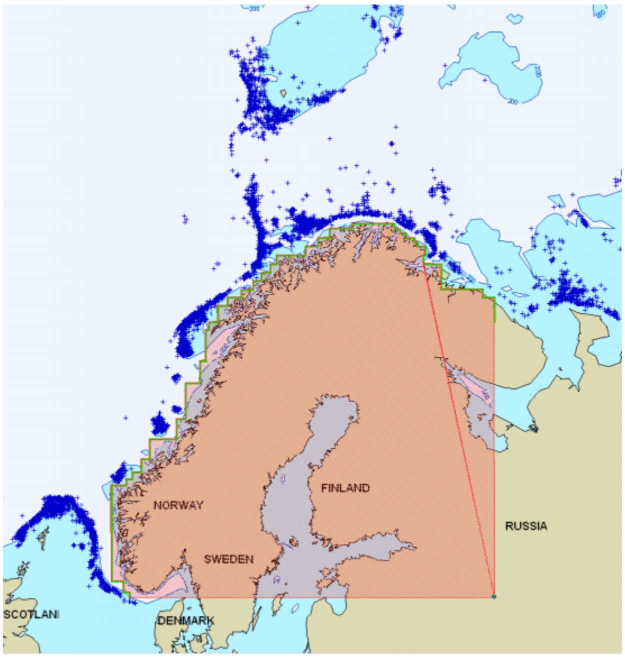


Fig. 4.21 Recorded trawl positions from the two trawlers' logbooks in 2002-2005 (Salthaug 2006)

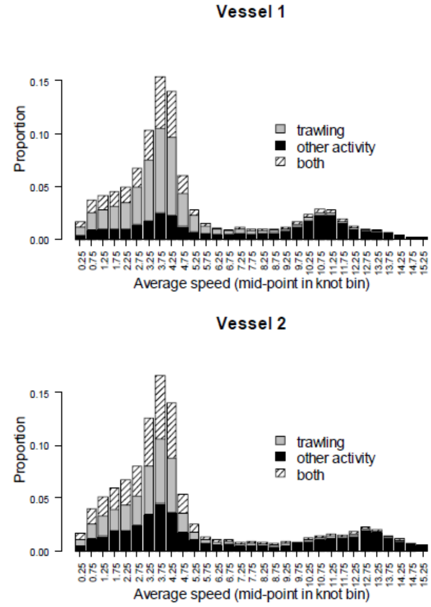


Figure 3. Relative distribution of speed between consecutive VMS observations (0.5-knot bins) and assigned activity: *trawling* corresponds to Interval 2 in Fig. 1 and *both* correspond to Interval 1 and 3.

Fig. 4.22 Relative distribution of speed between consecutive VMS observations

The data presented by Salthaug supports the general assumption that trawling is performed at velocities ranging from 2 to 5 knots. However, the data also indicate that there some of the trawling actually takes places at both lower and higher velocity. Skaar et al. (2011, [67]) studied the accuracy of VMS data from Norwegian demersal stern trawlers operating in the Barents Sea. The analysis showed that a speed rule classifying vessels as actively fishing when the VMS-estimated speed was 2–5 knots correctly identified 80% of fishing activity. Skaar also discussed that vessels often change direction during trawling and have sinuosity-shaped track lines. This is significantly less than the 99% success rate reported by Mills et al. (2007, [61]) for beam trawlers in the North Sea, whose fishing speeds were considered to be in the range 2 – 8 knots.

Another consideration wrt trawl velocity is the velocity at the trawl board itself. For instance, when the vessel is moving through curves, the outer trawl board will traverse longer length than the vessel itself, and hence the trawl board velocity may be significantly larger than the vessel speed, particularly when the vessel makes sharp turns. This effect is further enhanced for double and triple trawl configurations since the outer trawl door will have a longer offset to centrelines in curves.

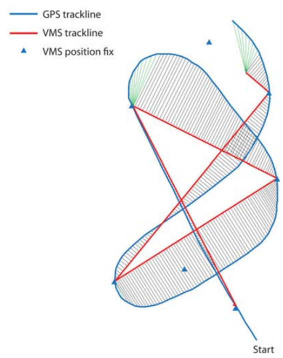


Fig. 4.23 Typical Trawl Trajectory & Comparison between Actual GPS positions and VMS trackline (Skaar et al. 2011)

The difference between the two studies is probably a result of different fishing patterns between the two fleets. In the Barents Sea, stern trawlers often take large catches that require long processing times, and the trawl cannot be launched again before a good part of the previous catch has been processed. In such circumstances, vessels often sail to the next fishing position, or conduct searches for good fish registrations, at low speed similar to that used during trawling. Frequent GPS position recording is considered important for an accurate velocity and tracking analysis, since the trawl trajectories in many cases does not follow straight routes, see example in Fig. 4.23.

Warp line length versus water depth (angle) is another parameter that influence the trawl gear force equilibrium and consequently overtrawling loads on subsea installations. The International Council for the Exploration of the Sea (ICES) evaluated such factors for bottom trawler operating in the North Sea region (Danish, Swedish, Norwegian, UK, German, Dutch vessels etc), Ref. [73]. Fig. 4.24 shows the warp line length versus water depth for Norwegian trawl hauls. This indicates a warp line factor of approximately 2.5 throughout the water depth range of 100 - 200m, and a small tendency for reduced factor with increasing water depth.

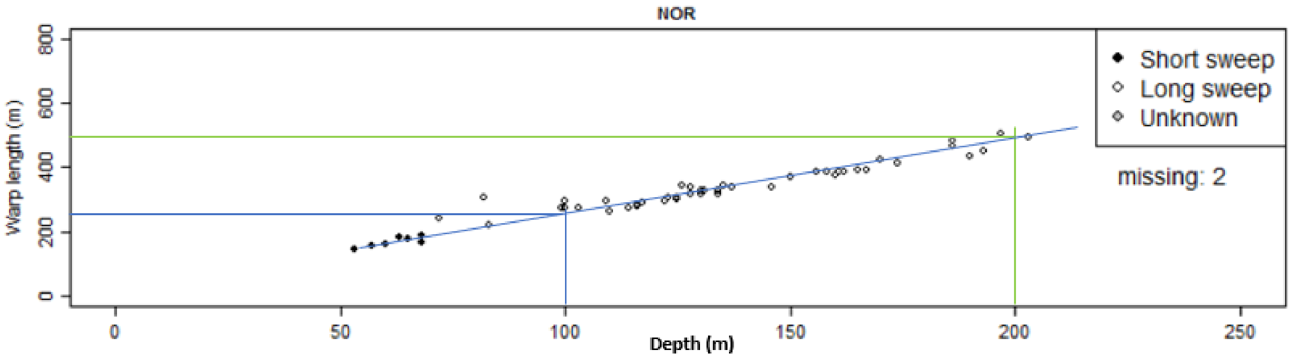


Fig. 4.24 Warp line length for typical Norwegian vessels in North Sea (ICES 2018)

4.1.4 Type and Size of Trawl Gear

Trawl Boards
Pictures of typical trawl doors available on the market from various trawl gear manufacturers are shown in the below figures (typical). Current focus among trawl gear manufacturers and users is hydrodynamic efficiency vs fuel economy, ease of use, reduced wear etc. For semi-pelagic boards also the lift factor and vertical stability is important. The different type of trawl boards varies in design, size and weight and are typically provided in standard sizes up to 6500 - 7500 kg. Semi-pelagic and pelagic boards are seen to have a height/width larger than the bottom trawl boards.

Fig. 4.25 Rock Super Shark

Fig. 4.26 Rock Sea Lion

Fig. 4.27 Rock Sea Hunter

Fig. 4.28 Rock Sea Bat

Fig. 4.29 Thyborøn Type 11

Fig. 4.30 Thyborøn Type 12

Fig. 4.31 Thyborøn Type 14

Fig. 4.32 Thyborøn Type 16

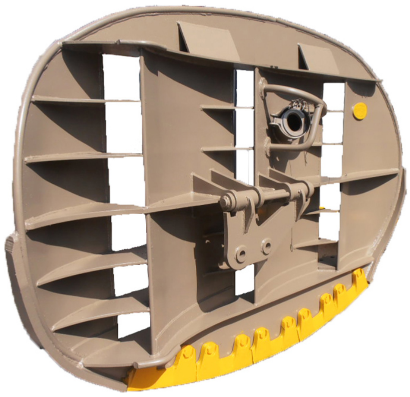


Fig. 4.33 Morgere Ovalfoil

Clump Weights

As discussed in 4.1.2 Bottom Trawls (Demersal trawling) vs Pelagic Trawling, clump weights are used when two or more trawl nets are pulled by one trawler. This trawl method that use two trawl nets with a clump weight in between, picked up popularity by UK fishermen during the 1980ies.

Currently all the main clump weight manufacturers are delivering roller clump weights up to 10 tons. Examples are:

- Thyborøn Trawl in Denmark are marketing roller clumps up to 10 tons as part of their standard design (http://thyboron-trawldoor.dk/products/clumps/, [83])
- Rock had a news bulletin on 24th November 2019 where they announced that a roller clump weight of 9.8 tons were delivered to the Trawl vessel Svend C (https://www.rock.fo/blank-zqdf5, [82])

Even though these large roller clump weights may not be applicable for fishing in Norwegian waters, they indicate the industry trend of increasing trawl gear sizes. The maximum catalogued roller clump weight has increased for instance increased from 8 to 10 tons over a period of 3-4 years.

The bobbin roller clump type, e.g. by Morgere [85], is currently available in standard sizes up to typically 5000 kg.

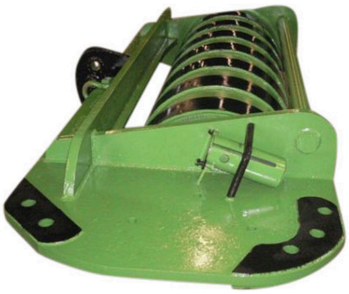


Fig. 4.34 Rock roller clump

Fig. 4.35 Injector roller clump

Fig. 4.36 Thyborøn roller clump

Fig. 4.37 Morgere roller clump

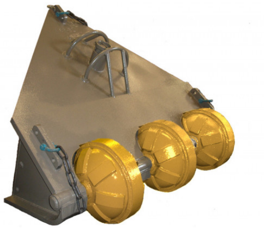


Fig. 4.38 Morgere bobbin clump

Fig. 4.39 Clump of chains

Fig. 4.40 Simple roller clump

4.1.5 Trends and Statistics in Trawling

In parallel with the general digitalization of public data records and the opening up for access to position data and electronic fishing records, access to vessel information through ships registers such as DNV GL and Lloyd's can be made via online portals. National databases also provide good overviews of fishing vessels and their home ports.

As part of this opening up, IKM Ocean Design has over the last 5-6 years collected data about trawl vessels in order to gradually build a database for trawlers that operate in the Norwegian Economic regions, but also for international waters. The database has been gradually populated also with new builds and planned builds based on news articles from trawl ship designers, trawl equipments manufacturers, the trawl companies themselves as well as telephone conversations with people in the fishing industry including research personnel etc.

The total list of vessels in the database consist of more than 960 trawl vessel, where approximately 200-250 of these frequently operate in Norwegian waters. The main population of vessels are registered and operating out of Norway, Russia, Iceland, Faroe Islands, Denmark, Greenland, UK etc.

An example from the trawl database is presented below, where trawl vessels fishing/in-transit/in-port in Northern Norway and Russia is shown for early February 2019.

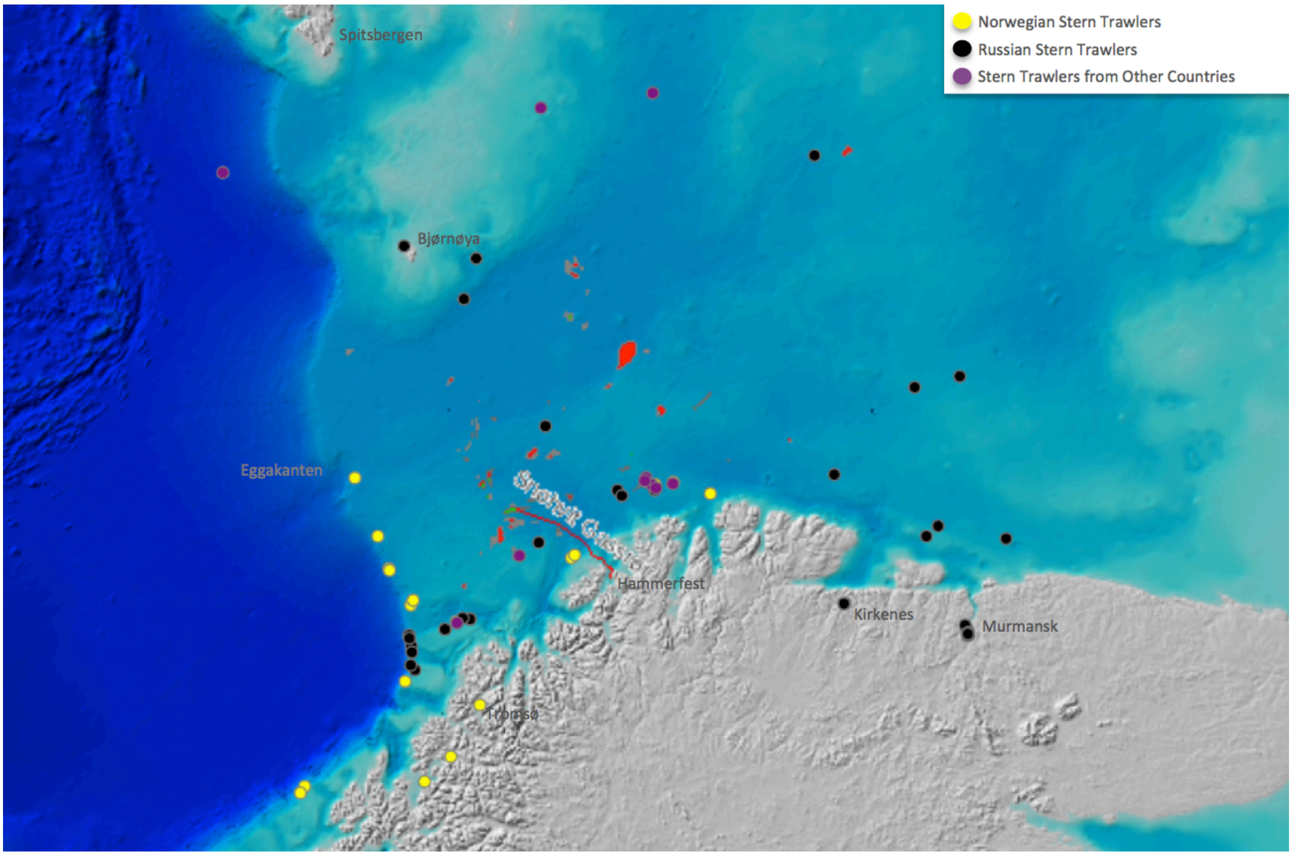


Fig. 4.41 Trawlers in North of Norway & Russia on 1st Feb. 2019

The overview above clearly shows the heavy trawling activity along Eggakanten, i.e. along the slope between Tromsøflaket continental shelf and the deep water to the West. Other fishing banks with several active trawler were 'Hjelmsøybanken' North of Hammerfest, 'Nordvestbanken' North of Tromsø as well as a lot of scattered trawl activity across the region. In addition, a number of trawl vessels are in ports across the region from Murmansk, Kirkenes and different ports in Troms county.

A large no. Russian trawlers have home base in the Russian Far East with ice challenges and great sailing distances to NCS. Hence, the focus in this study has been towards the Russian trawling fleet operating from North-Westerly ports like Murmansk, Arkhangelsk and White Sea etc.

The below plots shows main ship data of some of the registered trawl vessels versus build year split between Norwegian, representative Russian vessels and Nordic vessels (Danish, Faroe, Greenland, Island etc).

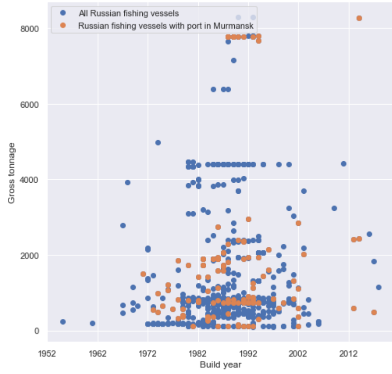


Fig. 4.42 Gross Tonnage Development for Russian Trawlers vs Build Year

Fig. 4.43 Vessel Overall Length vs Build Year

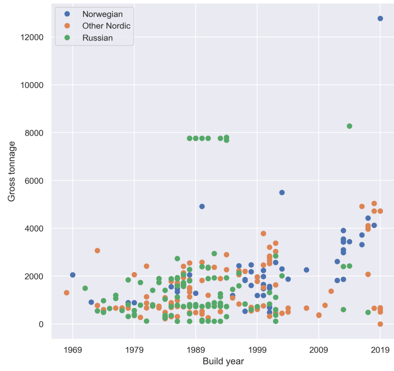


Fig. 4.44 Vessel Gross Tonnage vs Build Year

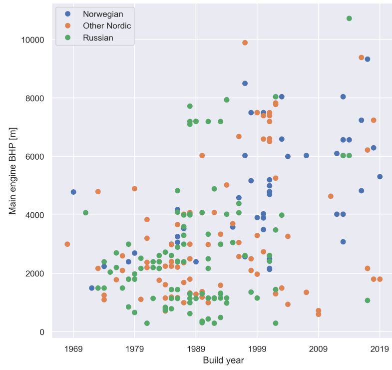


Fig. 4.45 Vessel Engine BHP vs Build Year

The general data plotted with Vessel Gross Tonnage, Vessel Lengths and Vessel Engine BHP as function of build year reveal that all these three vessel parameters have an increasing trend over the 50 year period evaluated. Particularly for the Norwegian and Nordic trawl vessels (green and orange markers), there is a clear trend in the vessel gross tonnage with time.

The data may also support the re-structuring in the fishing industry from smaller vessels into more economies of scale through larger but fewer quotas and vessels. Many factors comes into play with regards to choice of ship size, equipment, engine horse power. Such factors are mainly economically (profit) driven. For instance, for engines less than 750 kW (approx. 1000 BHP), there is no requirement for a engine chief engineer onboard (salary saving) and may hence be a factor for smaller trawl vessels.

Vessels with BHP exceeding 3000-5000, are mainly ships with overall length typically greater than 45 m. For such larger vessels with larger engines, larger equipment can be used, more fish can be caught per haul and more processing and storage is available.

An important factor for measuring the efficiency, is cost of operation per kg fish caught.

The relationship and trends of trawl vessel development become even clearer when plotting Vessel Length and Vessel Gross Tonnage versus Vessel Engine BHP as seen in Fig. 4.46 and Fig. 4.47.

These two figures therefore supports the general ship design considerations that increased tonnage/length requires additional

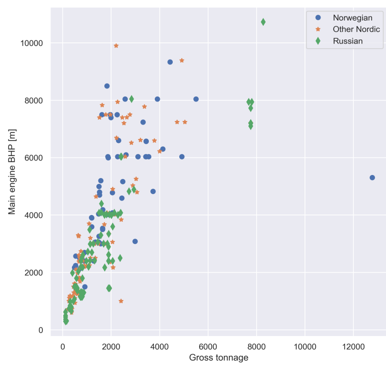


Fig. 4.46 Engine BHP vs Vessel Tonnage

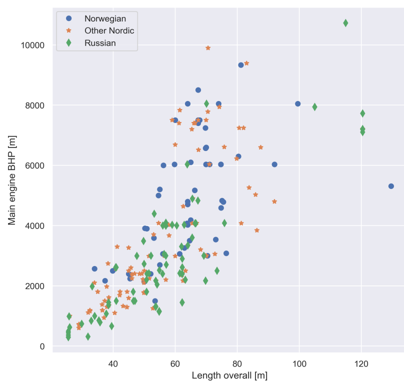


Fig. 4.47 Vessel Length vs Engine BHP

power for maintaining traditional characteristics both during fishing operation including towing of gear as well as transit speed.

Based on the industry trend of larger and fewer fishing vessels, the increasing size and demand for efficiency in the trawling fleet also enables them to increase the size of the bottom gear. On the counter side of the increase trend, is fuel consumption and overall operational costs per kg fish.

Based on surveys, screening of databases, interviews, checking through news publishments, the IKM trawl database has also been supplemented with size of trawl gear for the numerous trawl vessels operating in Norwegian waters. This database population has been partly through internal development work and by supervising the MSc-project performed by A. Fjeldsbø (UiS 2019, [75]).

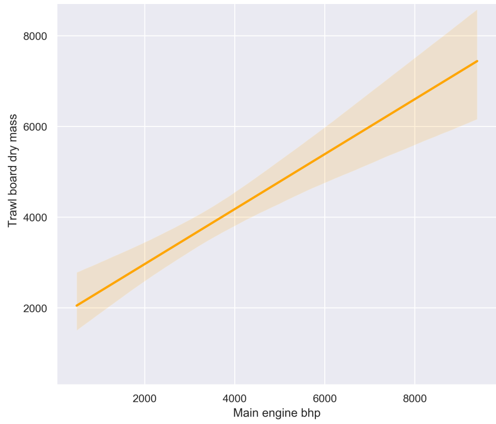


Fig. 4.48 Trawl Board Weight vs Engine BHP

By combining these two trawl gear survey projects, the development trend in trawl board and clump weight weight have been established:

- Fig. 4.48 shows the trend of Trawl board dry mass versus Vessel Engine BHP
- Fig. 4.49 shows the trend band of Clump Weight dry mass versus Vessel Engine BHP. Also indicated are the 95% prediction bands of which only 5% of the data falls outside.

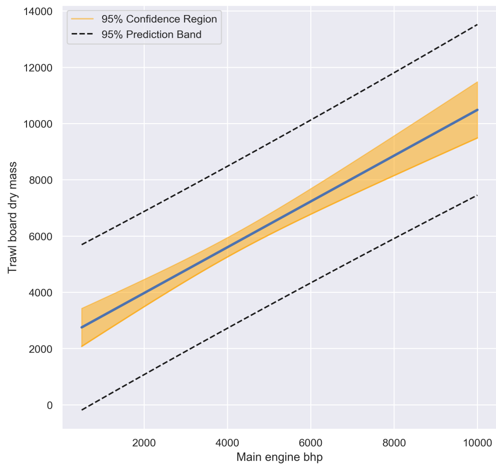


Fig. 4.49 Clump Weight mass vs Engine BHP

The maximum weights found in the curves corresponds well with the maximum clump weight and trawl board sizes delivered by the main equipment manufacturers, i.e. 10 tons and 7.5 - 8 tons respectively.

Since the maximum loads mentioned in DNV GL RP-F111 Trawling Guideline [12] is 8-9 tons for clump weights, it is recommended to revisit the maximum loads for both clump weight and trawl board based on the latest industry use.

Distribution Between Single- and Multi-Rig Trawling
When it comes to the distribution between single rig trawling and multi-rig trawling in the Norwegian waters, the website for the Norwegian Directorate for Fisheries (Fiskeridirektoratet, [80]) provides extensive and useful statistics and data. Table 4.2 and Table 4.3 (as well as Fig. 4.50 and Fig. 4.51) summarises the annual catch made by Norwegian and International trawl vessels including the split between different trawl classification types:

- "**Udefinert trål**" - Undefined trawl activity. Description: In accordance to Fiskeridirektoratet, the main part of the undefined catch derives from krill fisheries in the Souther Ocean near Antarctica.
- "**Trippel trål**" - Triple rig trawl activity. Description: *Triple rig trawl, 3 trawl nets being pulled by one vessel*. Note: triple trawl activity is only provided in the database for Norwegian trawlers.
- "**Reketrål (herunder sputnik trål)**" - Shrimp trawl (including sputnik trawls): Description: *Trawl gear designed for shrimp fishing*.
- "**Krepsetrål**" - Trawl for catching nephrops (seawater crayfish).
- "**Flytetrål par**" - Midwater (pelagic) trawl pulled by two vessels.
- "**Flytetrål**" - Midwater (pelagic) trawl. Description: *Trawl gear where no part of the gear comes in*

contact with the bottom. Same as pelagic trawl.

- "**Dobbeltrål**" - Twin rig trawl activity. Description: Double *rig trawl, 2 trawl nets being pulled by one vessel*. Note: triple trawl activity is only provided in the database for Norwegian trawlers.
- "**Bunntrål par**" - Bottom trawl net pulled by two vessels.
- "**Bunntrål**" - Bottom trawl. Description: *Trawl gear pulled along bottom*.
- "**Bomtrål**" - Beam trawl. Trawl gear where trawl doors and bullet lines are replaced with fixed metal construction/beam.

The trawl catch statistics provided by the Norwegian Directorate of Fisheries shows that the main catch tonnage for both Norwegian and international vessels are obtained by pelagic and bottom trawling. Twin and triple rig trawling is seen to represent a very small percentage of the total trawl catch from Norwegian trawlers in the 19 year period evaluated (<1%) with a maximum of 2.3% in 2005, see Fig. 4.52. It should be further noted that over the last 5 year period, no catch is registered for double or triple trawl.

Table 4.2 Catch statistics for different Norwegian trawl types from 2000-2018 (Norwegian Directorate of Fisheries)

Fangstår	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Udefinert trål	103	764	1440	1281	1285	886	1148	54908	69351	49723	103868	80755	85170	124100	167899	177485	187189	202217	206098
Trippeltrål	0	0	0	0	0	5788	3792	2908	0	0	0	0	0	0	0	0	0	0	0
Reketrål (herunder sputniktrål)	67079	66772	70315	54010	53621	21695	26176	30304	32439	28541	23150	25321	19753	14681	17131	24019	20234	14675	29039
Krepsetrål	425	389	365	428	594	625	407	324	305	216	193	242	150	83	82	65	60	44	41
Flytetrål par	12953	15155	16167	10929	12835	18184	17652	21566	15039	5048	3098	2814	744	1494	940	260	269	222	1046
Flytetrål	557778	582215	550339	765883	879829	699950	726690	635116	501833	391752	368720	196203	205173	282820	459838	573484	390275	488728	557090
Dobbeltrål	975	0	0	13735	6728	26699	12315	6419	884	1266	1099	1352	1086	471	0	0	0	74	208
Bunntrål par	65	207	417	473	76	172	85	231	3268	1088	1568	146	0	0	1263	4769	4412	2617	1226
Bunntrål	451938	497165	523599	417531	436910	381200	276475	296324	343761	332453	412409	385314	323335	358188	388479	394386	388930	477260	408866
Bomtrål	1129	2255	1943	2109	1622	2395	902	749	0	101	0	0	0	0	113	33	0	0	0
Totalfangst for trål (tonn)	1092446	1164921	1164587	1266379	1393500	1157594	1065643	1048849	966880	810187	914104	692148	635409	781837	1035745	1174502	991368	1185837	1203615
Trippeltrål, % av Totalfangst trål	0,0	0,0	0,0	0,0	0,0	0,5	0,4	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Dobbeltrål, % av Totalfangst trål	0,1	0,0	0,0	1,1	0,5	2,3	1,2	0,6	0,1	0,2	0,1	0,2	0,2	0,1	0,0	0,0	0,0	0,0	0,0
Bunntrål, % av Totalfangst trål	41,4	42,7	45,0	33,0	31,4	32,9	25,9	28,3	35,6	41,0	45,1	55,7	50,9	45,8	37,5	33,6	39,2	40,2	34,0

Table 4.3 Distribution of International Trawl Catch Types registered in Norwegian waters from 2000 - 2018 (Norwegian Directorate of Fisheries)

Fangstår	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Udefinert trål	0	8	6	0	0	1	8	0	685	0	0	0	0	0	1043	995	319	0	0
Reketrål (herunder sputniktrål)	25015	9707	8850	3808	5484	4851	2112	3777	5503	3867	3808	5296	4946	3679	7834	13205	12881	9882	13875
Krepsetrål	3	14	13	40	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Flytetrål par	1018	1617	6131	14297	836	1854	581	11832	6685	2602	3510	2730	2468	568	0	786	156	1362	0
Flytetrål	167011	173105	156138	171343	128813	48742	64653	115010	96552	135328	117529	118424	135835	126574	192447	174623	171437	147638	160057
Bunntrål par	127	0	0	590	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0
Bunntrål	154607	176882	175427	104391	94456	89928	113348	114778	116780	126268	141944	132946	130263	119064	150276	150567	173774	157784	145645
Bomtrål	704	3203	0	35	0	6	0	0	248	0	0	0	0	0	0	0	13	0	0
Totalfangst for trål (tonn)	348485	364537	346566	294504	229599	145383	180713	245397	226453	268066	266791	259396	273512	249886	351601	340176	358579	316666	319577
Bunntrål Utenlandske fartøy Som % av Totalfangst trål	44,4	48,5	50,6	35,4	41,1	61,9	62,7	46,8	51,6	47,1	53,2	51,3	47,6	47,6	42,7	44,3	48,5	49,8	45,6

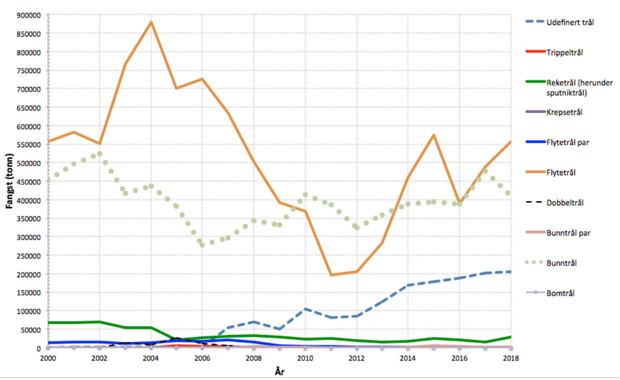


Fig. 4.50 Distribution in Norwegian waters for Norwegian trawler classifications, year 2000-2018 (Norwegian Directorate of Fisheries)

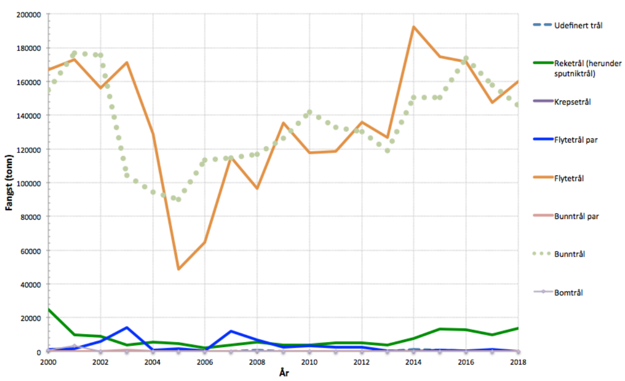


Fig. 4.51 Distribution in Norwegian waters for International trawler classifications, year 2000-2018 (Norwegian Directorate of Fisheries)

Further data collection and evaluations are required in order to validate the indicative low use of double and triple rig nets in bottom trawling since this directly affect the clump weight frequency, its associated loads and required protection requirements for subsea installations.

One such factor that should be further assessed, is the potential level mis-reporting by the trawling fleet, e.g. does classification types "Bunntrål", "Udefinert trål" and "Reketrål" receive catch data that should have been reported towards the "Dobbeltrål" or "Trippeltrål" categories?

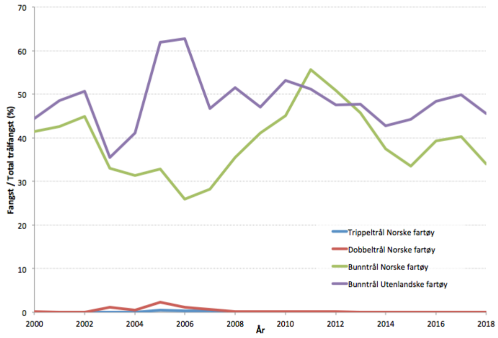


Fig. 4.52 Percentage catch from single and multi rig trawl, year 2000 - 2018 (Norwegian Directorate of Fisheries)

A second question may be how much of the international "Bunntrål" catch tonnage derives from using more than one trawl net during bottom trawling?

Some Notes on Future Trends

As fishing vessels and fishing gear becomes more industrialised and advanced, focus is being put into optimising the gear towards optimal economical results and minimum environmental impact, i.e. optimising fuel efficiency while reducing by-catch and physical ecological impact. It appears that future modern trawl vessels and equipment will not only have the potential of becoming larger, but may also seek reduced contact with the bottom when possible. The combination of innovation and optimization of trawl gear and utilizing sensors for monitoring and tuning to optimimal performance are factors considered to be competitive in the future. Fishing authorities may also follow up with requirements towards such optimised trawl gear.

The trawling industry is also seeing a trend that low-aspect trawl doors are beginning to be replaced with high-aspect doors, many of which can be used as semi-pelagic doors, if the target species does not require as much herding. Modern trawl boards models have hydrodynamic foils in order to produce additional lift, enabling smaller trawl boards to do the same job as large older boards.

Some of the most modern type boards allows the trawl vessel to go down two sizes achieving the same net dynamics and catch. One issue with increased trawl gear efficiency may be that instead of utilising this optimization gain, it may typically lead to increased trawl gear (board, clump and net) for the same fuel consumption, or as long as net profits increase.

5 A Review of how Trawl Loads has been Treated in Standards used for NCS

5.1 Subsea Pipeline Systems

5.1.1 General NCS Oil & Gas History related to Subsea Pipelines/Structures and Development of Requirements for Trawl Loads

General NCS Oil and Gas History related to Subsea Pipelines
The Norwegian petroleum history marks its 50th anniversary at the time of issuing this study report, i.e. the 50 years since Phillips Petroleum informed the Norwegian authorities of the discovery of Ekofisk just before Christmas in 1969. Production from Ekofisk started in June 1971, followed by a series of major discoveries in the following years. In 1972, birth was given to two Norwegian oil companies, the privately owned Saga Petroleum and the fully state owned Statoil, while the Norwegian Petroleum Directorate (NPD) was established in 1973.

Even before discovering Ekofisk, the Norwegian Parliament had established as a main rule that all petroleum found on the Norwegian shelf should be landed and processed in Norway. Studies performed in 1971/1972 for a pipeline from the Ekofisk field to a location on the Norwegian coast would have to cross the Norwegian trench. The study concluded that such a pipeline would be beyond the technology at the time and that such a pipeline could not be laid without significant uncertainties, Ref. [27].

The Norwegian Parliament, therefore, had to accept landing of the Ekofisk oil and gas, respectively, to Teeside in UK and to Emden in Germany (via a 34" oil pipeline and a 36" gas pipeline). In order to pursue its goal for bringing petroleum back to Norway, the government decided in 1972 to establish a committee to secure development of technology to enable landing future oil and gas to Norway. This committee was named the Deep Water Pipeline Project Committee (DWP).

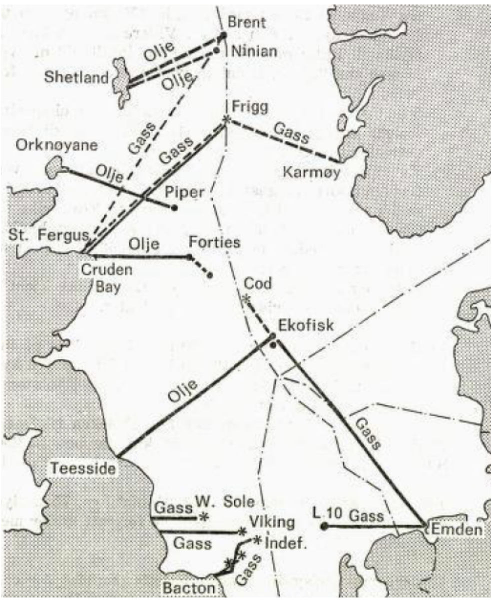


Fig. 5.1 North Sea Pipelines Map, Ref. NOU/DWP 1974

The "barrier" represented by a water depth of 300-350 m in the Norwegian trench was identified as one of the the critical issues to be solved for pipelines to Norway. The depth in combination with large diameter was a step-out or two in technology compared with the depth record in 1972 held by two 4 km, 8 " pipelines across the Puget Sound near Seattle at about 200 m depth. The North Sea installation experience until 1972 was limited to 50 m depth and diameters up to 30".

The resulting report from the Norwegian Deepwater Pipeline Committee in 1974, provided the foundation for the modern subsea pipeline technology development in Norway considering deep water, large diameter, requirements to next generation lay vessels, deep water repair technology, deepwater diving technology, diverless technology, new trenching equipment etc, Ref. [26]. For Statoil, after its establishment and the Norwegian oil and gas industry in general, the continuation of the above development work became essential after the discovery of the Statfjord field in 1974.

Main Timeline wrt Trawl Interference with Subsea Pipelines and Structures on NCS

One of the first industry mentions of trawl related interference subsea pipelines were made by R.J Brown in his 1972 paper at OTC named "*Pipelines can be designed to resist impact from Dragging Anchors and Fishing Boards*", Ref. [28]. Even though the main focus was towards dragged anchor hazards and protection, the work also discussed the loads from trawl boards up to 5000 lbs (~2300 kg), armoured concrete coating etc.

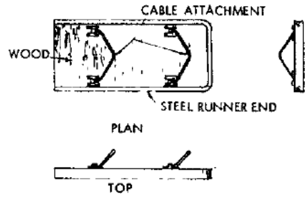


Fig. 5.2 Typical Trawl Board illustrated by Ref. R.J. Brown in 1972

Another important aspect identified by the Norwegian Deepwater Pipeline Committee wrt laying a deepwater pipeline back to the Norwegian coast, was the potential conflicts between pipelines and the important fisheries along pipeline routes. In the 1974 NOU report from the Deepwater Pipeline Committee, [26], various types of trawl boards were evaluated including:

- Oval shaped iron boards (3.2 x 1.6 m with mass from 700-1200 kg) used by large trawlers for cod and blue whiting.
- Rectangular wooden boards with iron shoes (3 x 1.4 m with mass from 700-800 kg) used by large trawlers for cod and blue whiting.
- For shrimps, V-shaped iron boards (2.6 x 1.6 m with mass 400-500 kg) and rectangular wooden boards with iron shoes (1 x 1.5 m with typical mass 200 kg).
- Overall, maximum trawl board masses up to 2000 kg were identified.

The following main load cases wrt interference between trawl boards and pipelines were discussed:

- Impact
- Hooking of trawl gear under the pipeline
- Sawing effect with trawl wires being pulled across the pipeline
- Local hooking with protruding parts, e.g. anodes.

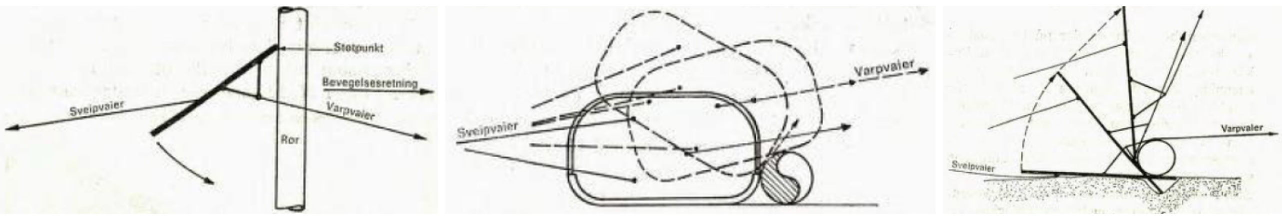


Fig. 5.3 Typical Trawl-Pipeline Interaction Figures from NOU/DWP 1974

Some of the work initiated by DWP to further address the interaction between heavy fishing activity on the Norwegian continental shelf and pipelines included both theoretical studies as well as model- and full scale experiments. The field tests were performed on a 300 m long 16" pipeline with concrete coating in 20 m water depth and a 150 GRT trawler. The test studied effects such as trawl velocity, angle between trawl and pipeline, trawl board mass etc. The findings from this work was presented by Gjørsvik, Kjeldsen and Lund at OTC in 1975, Ref. [29].

T. Carstens, also from the River and Harbour Laboratory in Trondheim, presented work related to laboratory field tests with otter doors up to 1800 kg and a beam trawl of 1720 kg pulled across a 40 cm diameter pipeline, Ref. [30].

The above work were followed up new studies and tests and examples of such development were presented for instance presented by Moshagen and Kjeldsen at OTC in 1980, Ref. [31]. This work investigated both 16" and 36" diameter pipelines, looked at different type of trawl boards, but also included beam trawls to the study. Both impact, pullover and hooking were considered in the work.

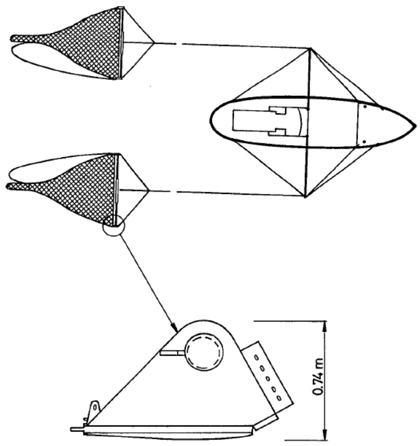


Fig. 5.4 Beam Trawl Shoe Tests (Moshagen 1980)

During this period, the first design code for subsea pipelines were issued, the *DNV 1976* - Rules for the Design, Construction and Inspection of Submarine Pipelines and Pipeline Risers, Ref. [4]. DNV'76 included requirements for considering trawl loads when designing submarine pipelines in areas where bottom fishing activity was taking place, see further details below in 5.1.2 DNV 1976 - Rules for the Design, Construction and Inspection of Submarine Pipelines and Pipeline Risers.

In 1981, DNV issued the *DNV 1981* - Rules for Submarine Pipelines [5], which became the main design code for subsea pipeline engineers for the next 15 years or so. The same requirements towards trawl loads were included as for DNV'76.

During this period, the Statfjord Transportation System Project in 1978 concluded that installing and operating a large diameter pipeline across the Norwegian trench was technically feasible. In 1983 and 1984, the 30" rich gas pipeline and 28" dry gas pipeline were installed across the Norwegian trench in water depths down to 300 m.

Throughout the next decade and a half, there was several new development projects that focussed on trawl-pipeline interference. Such work included:

- Worked performed by Bergan and Mollestad in 1981, Ref. [32], presented more details wrt analysing the dynamic behaviour of pipelines subjected to impact loads.
- de Groot and van der Hak performed full scale tests on the interaction between bottom fishing gear and an 18" gas pipeline in the North Sea where it was confirmed that pipelines with the latest coating could endure the impact loads from beam trawl (trawl shoes), Ref. [33].
- Work by Guijt and Horenberg, Shell proposing more realistic and less conservative test set-ups, presented at OTC in 1987, [34].

- One of the early discussions of trawl protection of subsea structures was made by Towers-Perkins from Kongsberg Subsea in 1987, [35]. Here, different type of protection structures were discussed:
  - *snagging structures*, are usually deployed where either the area has been declared a fishing exclusion zone or there has traditionally been very httle fishing.
  - *deflection structures*, are used in areas of high fishing activity, see example from Frigg in Fig. 5.5. It was mentioned that, "In order to deflect trawl gear, a great deal of attention must be paid to details such as pad-eyes, brackets and hinges. The upper bumper frame must be continuous, and if openings in it are required for lay-away of flowlines and umbilicals, provision must be made to close the gap during template operation". Further, "Model testing is usually required to confirm the overtrawlability. of the structure."

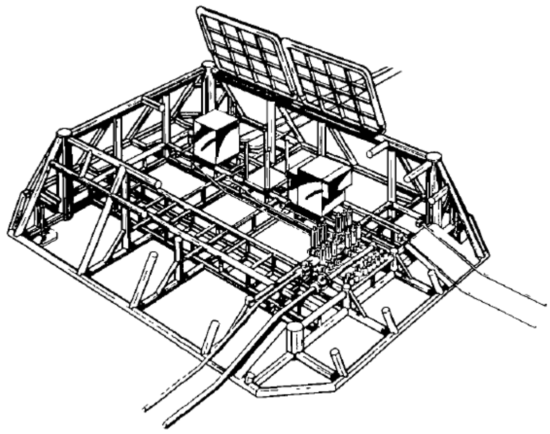


Fig. 5.5 Frigg Additional Subsea template structure, Towers-Perkins 1987

- As part of the planning of the Zeepipe II 40" gas pipeline between Kollsnes and Sleipner, Statoil and Havforskningsinstituttet carried out full scale trawl tests on the existing 40" Zeepipe pipeline between Sleipner and Zeebrügge using the research vessel Michael Sars. The test results were presented by Valdemarsen in 1993 [38] for a total of 111 pullover cases using industrial, shrimp and nephrops trawls, where 13 pullover tests were rigged as double trawl. The findings from these trawl tests was similar to the conclusions presented by Valdemarsen in 1989 for earlier tests on 28" - 30" pipelines, [37].
- Work presented by Verley et al. in 1992 and 1994 ([39] and [36]), that introduced the effects due to free span height and length into the design assessment for interference between trawl gear and pipelines. Polyvalent (rectangular) trawl boards of up to 2600 kg weight were considered for the work. The background for this development was the discovery of hydrocarbons off mid-Norway, at Haltenbanken, and that such development presented new challenges in terms of free-spanning pipelines. The water depths of typically 250-350 m and with uneven seabed having numerous iceberg scour marks of 10 m depth and 100 m width meant new challenges for the upcoming pipeline designs for this region. The studies by Verley et al. also formed an important basis for the upcoming DNV design guidelines for trawl pipeline interaction, Ref. [12] and [10].

As a result of the various studies performed by Statoil, DNV and others during the 1990's, the new DNV - Rules for Submarine Pipeline Systems was issued in 1996 [6] and accompanied by its supporting Guideline 13 for Interference between Trawl Gear and Pipeline in 1997 [10]. A new revision of the Rules for Submarine Pipeline Systems was issued in year 2000 as DNV-OS-F101 [7].

During planning for the Snøhvit and Kristin developments in the Barent Sea and Haltenbanken areas respectively, surveys of the latest trawl gear used identified that use of double net trawl spreads were in use and that trawl doors and the so-called mid-weight (clump weight) had increased in size since the mid 1990's. The clump weight load was presented by Fyrileiv ans Spiten in 2006 [53] and was also implemented into the DNV-RP-F111 which replaced Guideline 13.

In parallel, on the Ormen Lange deepwater development, MARINTEK (now SINTEF Ocean) and Prof. Svein Sævik developed the SIMLA 3D pipeline simulation tool [24]. Through numerous MSc- and PhD projects, it was demonstrated that SIMLA was also capable of simulating the main types of trawl gear (trawl board and clump weight) very accurately, and could be used to perform "numerical model tests". Examples of such SIMLA related trawl projects include:

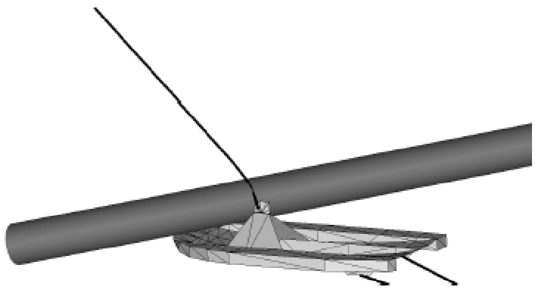
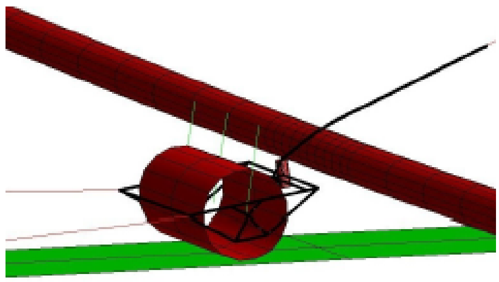


Fig. 5.6 Trawl Board - Pipeline Interaction in SIMLA, Longva 2015

- Longva, Sævik et al. presented several studies (MSc and PhD) related fully integrated modelling of trawl board pullover on pipelines and new type of contact elements, [43] and [42] etc.
- Maalø presented work related to fully integrated roller clump weight modelling comparing well with the Snøhvit and Kristin trawl model tests, [57] and [44].
- Berg continued on the work performed by Maalø on roller clump weight into new type of challenges [58].
- Lyngsaunet carried out his MSc-thesis developing a fully integrated model for bobbin type clump weight [49].
- Wu as part of his PhD, continued modelling work of trawl



(b) Warp line interaction, t = 0.3s

Fig. 5.7 Roller clump weight-pipeline interaction, Maalø 2011

board pullover across pipeline related to hooking, free spans and skew angle approach of the board [48].
- And several others

Also similar fully integrated trawl simulation work was performed using other finite element tools, e.g. in ANSYS and Abaqus ref. Igland [56]. However, due to SIMLA's numerical efficiency, its tailor making for 3D pipelines and contact problems and the fact that it has been thoroughly validated against trawl model tests, makes it the state-of-the-art pipeline and trawl pullover simulation tool for years to come.

Oosterkamp et al. (2017) described the methodology and refined finite element models for highly detailed 3D finite element simulations of trawl gear impact on pipeline, using the multi-physics simulation software LS-DYNA.

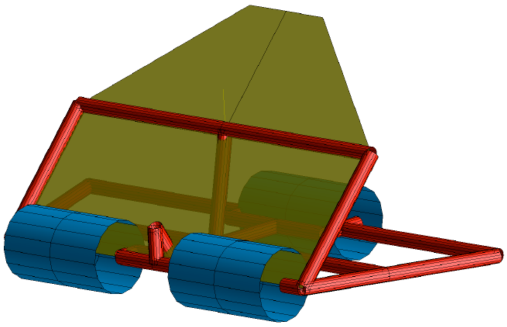


Fig. 5.8 The bobbin clump weight model, Lyngsaunet et al. 2015

The DNV GL RP-F111 [12] also includes a methodology for performing project specific structural reliability analysis (SRA) in order to document that the safety level/target failure probability defined by DNV GL ST-F101 [8] is maintained. An example use of such approach was presented by Amdal et al. in 2011 [59] and project implementations were presented by Norland et al. in 2018 for the Maria project [74] and Lyngsaunet et al. in 2019 for the Johan Castberg project [50].

Experience from the Fishing Industry wrt Trawling on Pipelines
In 2006, Arnesen [54] presented a list of registered incidents and snagging of fishing equipment on NCS:

- *Elsy* (2000): a trawl board was snagged into bottom sediments at Europipe 2.
- *Bentin* (2000): a trawl board was snagged into bottom sediments at Statpipe S31.
- *Eigenes* (2001): report snagged gear at/on Europipe 2, the vessel managed to release the gear itself.
- *Andenesfisk* II (2001): snagged and damaged a flange inside the 500 m safety zone at GFC. This resulted in an expensive repair.
- *Lilletut* (DK) - (2001): reported snagged at Zeepipe 2B, however the vessel managed to free the gear itself.
- *Galeota* (DK) - (2001): a trawl board was snagged in a free span on Zeepipe 2B. The trawl board including Scanmar sensors was recovered by ROV and returned to the owner.
- *Andrea Klitbo* (DK) - (2002); a trawl board was snagged under Zeepipe 2B. Was released with assistance from an ROV.
- *Pia Daniel* (DK) - (2003): reported snagging into Zeepipe 2A, however was able to free itself without assistance.
- Unknown trawler (UK?) - (2004): snagged into a flange on an 8" gass line. The incident resulted in a costly repair as well as loss of production.
- *Luna* (DK) - (2005): a trawl board got snagged into a free span on Zeepipe 2B and was assisted by ROV to free the gear.
- *Sjøvik* (2006): a trawl board got stuck in a free span along Zeepipe 2B and managed to free itself without assistance.
- *Annalisa* (DK) - (2006): a trawl got snagged into an 8" gas pipeline within the 500 m safety zone at Snorre A.

Arnesen also listed the snagging of trawl gear that had resulted in vessel capsizing and fatalities (any reason):

- UK waters:
  - *Antares (1990)*: was assumed pulled down while pelagic trawling by the submarine *Trenchant*, all 4

on board died, ref. [90].

  - *Westhaven* (1997): Snagged its trawl gear into the 30" Piper Bravo - Flotta oil pipeline and capsized when attempting to free its gear [40]. All four of her crew lost their lives.
  - *Harvest Hope* (1997): Snagged its trawl gear in the vicinity of seabed pipelines. The vessel capsized however the crew managed to deploy one of its life-rafts and all members were picked up by a nearby fishing vessel. An subsequent ROV inspection of the wreck and area showed that the trawl gear had snagged into large mounds of boulder clay, probably
    created when a plough had either stalled or jumped during the trenching back-fill process to cover a pipeline [55].
- Norwegian waters: No pipeline related incidents appear to have caused capsizing of fishing vessels, however Arnesen report three incidents (*Njord*, *Børge Alexander* and *Stokkøy*) that capsized due to other reasons.

Arnesen's recommendations for improved coexistence between the fishing and offshore petroleum industry were:

1. Collaboration arena between the two industries.
2. Release of updated digital charts.
3. Improved emergency response when a trawler snags into a subsea pipeline/subsea structure.
4. Verify that new pipelines are not an unreasonable obstacle by performing trawl tests.
5. Changed practice when hiring in guard vessels - requirements for fishing competence.
6. Resume wreckage and debris cleaning program

Rouse et al. [77] investigated the losses in fisheries arising from interactions with offshore pipelines and other oil and gas infrastructure. The annual number of UK incidents showed a general decrease from the 1980s to 2018, see Fig. 5.9. In 2015, the number of incidents was 20 times lower than it was in 1990. The majority of incidents occurred in the northern North Sea and 60% of all claims occurred on muddy substrate. The work also presented further processing of the trawl board analysis work performed for different interference angles by Wu et al. [47] in 2015. Fig. 5.10, shows crossing angle risk weightings as calculated by Rouse et al. based on the analyses work performed Wu et al. As the results from Wu et al. [47] indicates, the highest risk for snagging is at low crossing angles with a maximum at around 10°. The lowest risk of snagging is found at 90° crossing angle.

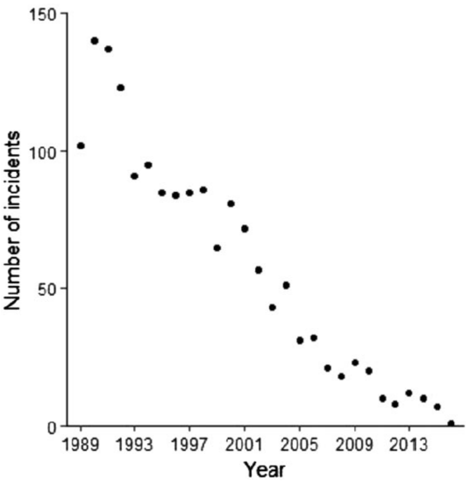


Fig. 5.9 Annual incidents between UK oil & gas infrastructure and fishing vessels, Rouse et al. 2018

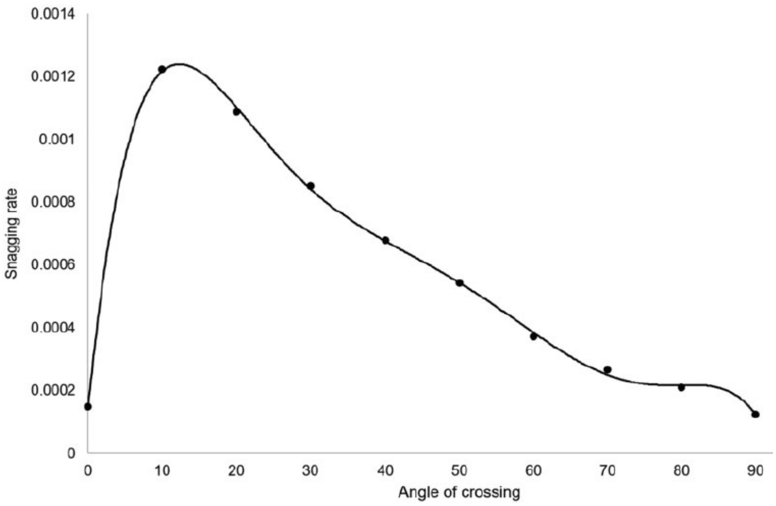


Fig. 5.10 Snagging Rates vs Crossing Angle, Wu et al. 2015 and Rouse et al. 2018

Little test data is publically available for trawl gear crossing at an angle with the pipeline and it is uncertain if such trawl tests have been performed for clump weight gear. Further testing should be considered, particularly for skew angle trawl crossings and clump weight gear. In addition, making previous trawl test data publically available is considered important in order to generally improve different stake holders knowledge and awareness about the topic.

5.1.2 DNV 1976 - Rules for the Design, Construction and Inspection of Submarine Pipelines and Pipeline Risers

In Section 2.3.9 Interference of DNV 1976 [4], it stated:

- 2.3.9.1 *If the pipeline during installation or operation may be exposed to or interfere with human activities, the effects of these activities on the pipeline is to be investigated. Particular attention is to be paid to bottom trawling and anchorage.*
- 2.3.9.2 *When the installation or operation of the pipeline may cause interference with private or public interests, and this may impair safety of the line, reference is made to national regulations.*

In Section 3.3.7 Accidental Loads, it stated:

- 3.3.7.1 *Accidental loads are to be taken into consideration for those parts of the system where such loads are likely to occur. An example of accidental loads is impact from trawl boards.*

5.1.3 DNV 1981 - Rules for Submarine Pipeline Systems

In Section 3.3.8 Accidental Loads of DNV 1981 [5], it stated:

- 3.3.8.1 *Accidental loads are to be classified as environmental loads, and they are to be taken into consideration for those parts of the system where such loads are likely to occur. Examples of accidental loads are impact from vessels, trawl boards and dropped object as well as fire.*
- *3.3.8.2 The pipeline and its accessories are to be protected against loads which are likely to occur. Such loads are:*
  - *impacts from vessels*
  - *impacts from trawl boards*
  - *impacts from dropped objects*

5.1.4 DNV 1996 and DNV Guideline 13 - Interference between Trawl Gear and Pipelines (1997)

DNV 1996 - *Rules for Submarine Pipeline Systems, [6]*
In 1996, DNV issued its *Rules for Submarine Pipeline Systems (denoted DNV'96)*, which marked the start of a new era for design of subsea pipelines.

The new rules constituted a complete revision of the DNV'81 rules that included the following main changes:

- introduction of Limit State based design format with reliability based partial safety factors
- new materials
- new design scenarios
- new installation methods
- implementation of results from major R&D projects (such as the SUPERB project)
- provide a recipe for reliability based design methods
- give credit for improved materials and quality
- requirements to condition assessment and re-qualification

The DNV'96 rules were accompanied by two relevant guidelines for the ongoing projects taking place in parallel with the issuing of the new rules, e.g. Åsgard field development, Åsgard Transport pipeline including Norne-Heidrun pipelines, Europipe II etc. These two guidelines were:

- DNV Guideline 13, "Interference between Trawling Gear and Pipelines" in 1997, Ref. [10].
- DNV Guideline 14, "Design Guideline for Free Spanning Pipelines Subjected to Vortex Induced Vibrations" in 1998, Ref. [11].

DNV Guideline 13 - Interference between Trawling Gear and Pipelines, [10]

The new and specific guideline focusing on interference between trawl gear and subsea pipelines looked more systematically into various aspects of fishing gear used for bottom contact including updated trawl gear types, sizes and introduced frequency classes, trawl-pipeline interaction phases and proposed design trawl loads to be used in design and analyses.

	Consumption		*Industrial*	*Beam*
	Polyvalent	*V-board*	*V-board*	
Mass [kg]	3500	2300	1525	5500
Dimension [m]	4,8 x 2,8	3,8 x 2,25	3,7 x 2,4	17,0
Trawl velocity [m/s]	2,8	2,8	1,8	3,4

Fig. 5.11 Table 2-1 from Guideline 13, Data for the largest trawl gears in use in the North Sea in 1996

The three trawl-pipeline interaction phases were described in Sect. 1.4 and design methodology included:

- *Impact*, i.e. the initial impact phase when a trawl board or beam hits a pipeline. This phase typically lasts some hundredths of a second. It is mainly the local resistance of the pipe shell, including any protective coating, that is mobilised to resist the impact force.
- *Pull-over*, i.e. the second phase where the trawl board or beam is pulled over the pipeline. This phase can last from about 1 second to some 10 seconds, dependent on the water depth, span height, and other factors. This will usually give a more global response of the pipeline.
- *Hooking*, i.e. a situation whereby the trawl board or beam is "stuck" under the pipeline. This is a seldom occurring accidental situation where forces as large as the breaking strength of the warp line may in extreme cases be applied to the pipeline.

As seen in Fig. 5.11, the maximum trawl board size considered was a polyvalent trawl board of 3500 kg and trawl velocity of 2.8 m/s.

5.1.5 DNV OS-F101 / ST-F101

The first revision of DNV OS-F101 issued January 2000, Ref. [7], mentions trawling or fishing activity in several places:

- In Section 3 - C100 Location: The pipeline route shall be selected with due regard to safety of the public and personnel, protection of the environment, and the probability of damage to the pipe or other facilities.
- In Section 4 - F. Other Loads F100 Trawling Loads, it stated:
  - 101 For calculation of characteristic trawling loads, reference is made to the principles given in Guideline 13 - Interference between Trawl Gear and Pipelines.
  - 102 The requirement for designing pipelines for trawling loads shall be determined based upon trawling frequency studies and assessment of the potential damage due to trawling, in orer to ensure that the integrity of the pipeline is not compromised.
  - 103 Trawling loads may be imposed by either trawl boards or trawl beams depending on what is the preferred fishing tool in the area.
  - 104 Fishing gear and hence trawl loads may vay significantly, not only between pipeline systems, but also along a pipeline system..............
  - 105 The following trawling data shall be determined:
    - the maximum trawling equipment size normally used in the area;

        - future trends (new types, (gear) mass, trawling velocity, shape); and
        - the frequency of the trawling activity in the area.
    - 106 The trawling load effects can be divided in accordance with the three crossing phases:
        - a) Trawl impact, i.e. the initial impact from the trawl board or beam which may cause local dents on the pipe or damage to the coating. This should be classified as an environmental load.
        - b) Over-trawling, often referred to as pull-over, i.e. the second phase caused by the wire and trawl board or beam sliding over the pipe. This will usually give a more global response of the pipeline. This should be classified as an environmental load.
        - c) Hooking, i.e. the trawl board is stuck under the pipe and in extreme cases, forces as large as the breaking strength of the trawl wire are applied to the pipeline. This should be classified as an accidental load.
    - 107 The impact energy shall be determined considering, as a minimum:
        - the trawl board or trawl beam mass and velocity, and
        - the effective added mass and velocity.
- In Section 5 D600 Global Buckling, it stated:
    - 604 The following global buckling initiators shall be considered:
        - trawl board impact, pullover and hooking.
    - In Section 5 E500 Trawling Interference, it stated:
        - 501 The pipeline systen shall be checked for all three loading phases due to trawl gear interaction, as outlined in Section 4F. For more detailed description, reference is made to the Guideline 13.....
        - 502 The acceptance criteria are dependent on the trawling frequency (impact) and the safety classification (pull-over and hooking).....
        - 505 Pullover loads shall be checked in combination with other relevant load effects.

The OS-F101 has since then been revised several times and is now named DNVGL ST-F101, Ref. [8].

5.1.6 DNVGL-RP-F111 Interference Between Trawl Gear and Pipelines

Introducing the Clump Weight and Maximum Size Development
DNV-RP-F111, Ref. [12], was introduced in 2006 as an update to DNV Guidelines No. 13 "Interference between trawl gear and pipelines" and thus replaced the DNV Guideline No. 13 which was withdrawn.

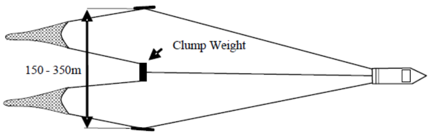


Fig. 5.12 The twin-rig trawl spread as depicted in Fig. 1-3 in DNV RP-F111 (2006)

The main new changes included:

- Considering the development in trawl equipment which had taken place since 1997, where for instance the "new" clump weight were included for cases were twin or multi-rig trawling are performed.
- As part of the qualification of new pipelines in the Norwegian Sea (Kristin, Snøhvit and Ormen Lange), several studies and model tests of clump weight interference with pipelines were conducted. The results from these studies were also implemented into the new RP.
- In addition, harmonisation of the design format and acceptance criteria with other DNV Offshore Codes were implemented.

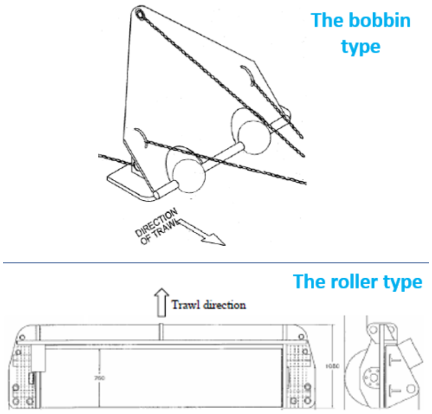


Fig. 5.13 Clump weight types introduced by RP-F111 (2006)

Due to the introduction of the clump weight load into the DNV RP-F111, Ref. [12] and [53], simplified and detailed modelling recommendations were provided. In addition, a trawl pull-over factor f_T, was included to allow for reduced loads where trawling frequency trawling areas.

Since its introduction in 2006, RP-F111 has been revised a few times and changed name in 2014 to DNV GL RP-F111 and the latest amendments were included in September 2019.

The below four tables gives the development of trawl board and clump weight sizes from 2006 until today.

Table 5.1 Maximum Trawl Gear identified used on NCS (DNV RP-F111, 2006)

	Consump-tion	*Industrial*	*Beam*	*Clump weight*
Mass [kg]	4 500	5 000	5 500	9 000
Dimension Lxh [m]	4.5 × 3.5	4.9 × 3.8	17.0²⁾	1)
Trawl velocity [m/s]	2.8	1.8	3.4	2.8

1) Typical dimension of the largest clump weights of 9 tonnes are L = 4 m wide (i.e. length of roller) by 0.76 meter diameter cross section. For smaller size roller type clump weights (i.e. 3 500 to 6 000 kg), the width L is typically 3.2 m, whereas the roller diameter is unchanged.
2) Beam trawl length (i.e. distance between outside of each shoe)

Table 5.2 Maximum Trawl Gear identified used on NCS (DNV RP-F111, 2010)

	Consump-tion	*Industrial*	*Beam*	*Clump weight*
Mass [kg]	4 500	5 000	5 500	9 000
Dimension Lxh [m]	4.5 × 3.5	4.9 × 3.8	17.0 2)	1)
Trawl velocity [m/s]	2.8	1.8	3.4	2.8

1) Typical dimension of the largest clump weights of 9 tonnes are L = 4 m wide (i.e. length of roller) by 0.76 meter diameter cross section. For smaller size roller type clump weights (i.e. 3 500 to 6 000 kg), the width L is typically 3.2 m, whereas the roller diameter is unchanged.
2) Beam trawl length (i.e. distance between outside of each shoe)

Table 5.3 Maximum Trawl Gear identified for NCS (DNV RP-F111, 2014)

Table 2-2 Data for largest trawl gears in use in the North Sea and the Norwegian Sea in 2014

	Trawl boards			*Clump weights*		*Beam*
	Consumption		*Industrial*	*Consumption*		
	Prawn	*Fish*		*Prawn*	*Fish*	
Mass [kg]	6500	5000	7300	8000	6500	5000
Dimension Lxh [m]	4.6 × 4.0	4.0 × 3.5	5.2 × 4.4	1)	1)	12.0 2)
Trawl velocity [m/s]	1.7	2.6	2.0	1.7	2.6	3.6

1) Typical dimension of the clump weights of 8 tonnes are L = 3.0 m wide (i.e. length of roller) by 0.8 meter diameter cross section. For smaller size roller type clump weights (i.e. 6 500 kg), the width L is shorter, whereas the roller diameter is unchanged. Typically length of the roller is between 2.0 to 3.0 m.
2) Beam trawl length (i.e. distance between outside of each shoe)

Table 5.4 Maximum Trawl Gear identified used on NCS (DNV GL RP-F111, 2019)

	Trawl boards			*Clump weights*		
	Consumption		*Industrial*	*Consumption*		*Beam*
	Prawn	*Fish*		*Prawn*	*Fish*	
Mass [kg]	6500	5000	7300	8000	6500	5000
Dimension Lxh [m]	4.6 × 4.0	4.0 × 3.5	5.2 × 4.4	1)	1)	12.0 2)
	Trawl boards			*Clump weights*		
	Consumption		*Industrial*	*Consumption*		*Beam*
	Prawn	*Fish*		*Prawn*	*Fish*	
Trawl velocity [m/s]	1.7	2.6	2.0	1.7	2.6	3.6

1) Typical dimension of the clump weights of 8 tonnes are L = 3.0 m wide (i.e. length of roller) by 0.8 meter diameter cross section. For smaller size roller type clump weights (i.e. 6 500 kg), the width L is shorter, whereas the roller diameter is unchanged. Typically length of the roller is between 2.0 to 3.0 m.
2) Beam trawl length (i.e. distance between outside of each shoe)

From these four tables it can be seen that:

- Maximum trawl board sizes have been increased from 4500/5000 kg in 2006 to 6500/7300 kg in 2014 and 2019 for consumption and industrial purposes respectively.
- Maximum clump weight size started at 9000 kg in 2006 but was reduced to maximum 8000 kg for prawn trawling in 2014 and 2019 (and 6500 kg for fish trawling). The text in RP-F111 for 2014 and 2019 also mentions that clump weights up to 9000 kg are currently being used by prawn trawlers in the Barents Sea and that area specific trawl data needs to be investigated for each project.

It seems like that the latest review and update of the maximum trawl data was done in 2014. Based on the equipment survey performed as part of this study, it seems like the largest off-the-shelf-standard-design clump weights have increased by 1000-2000 kg over the last 3-4 years, and this development may be relevant for the design loads recommended by the RP.

The Potential for Bottom Trawl Gear within Platform Safety Zones
DNV RP-F111 in 2006 also introduced another important aspect with regards to trawling, which was the potential for bottom trawl gear inside a platform safety zone, see Fig. 5.14. Trawling occurs often along curves and the trajectory of the trawl boards may be quite different from the vessel route. Water depth, warp and sweep line lengths, size of gear, single rig or twin rig, amount of catch, lateral currents, vessel speed and route etc all influence how the bottom trawl gear moves in relation to the vessel itself, Ref. [52].

Several incidents with trawl gear snagging close to subsea structures within platform safety zones indicate that this may be an issue that is not sufficiently addressed during design and operation.

An example analysis for such potential are included in Section 6 Trawl Gear Analysis Examples.

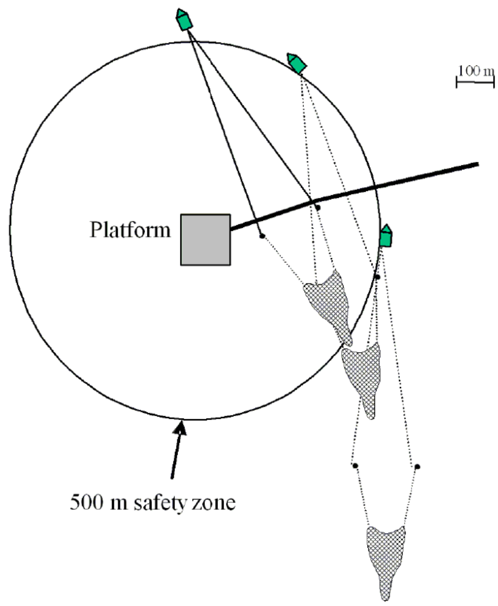


Fig. 5.14 The Potential for Bottom Trawl Gear within Safety Zones (DNV RP-F111, 2006 and 2019)

Alternative Methods and Procedures
The DNV GL RP-F111 in 2014 (Sect. 4.8) also introduced a methodology and procedure for an alternative to the standard deterministic approach, by performing project specific structural reliability analysis (SRA) in order to demonstrate that the safety level/target failure probability defined by DNV GL ST-F101 is maintained. This alternative has been used on several recent pipeline projects for fields with little or no trawling (very low frequency):

- **Maria flowlines, Wintershall/Subsea 7/DNVGL, Ref. [74]:** *Trawling protection of subsea pipelines is traditionally achieved with either trenching or by the installation of rock cover over the pipeline. For the Maria project, Wintershall had identified structural reliability analysis (SRA) as a potential opportunity. Norland et al. [74] presented an optimised trawl pullover and free span design solution based on structural reliability analysis for the Maria flowlines allowing. The optimised design allowed the flowlines to be free spanning without span infill rock installation (or trenching of shoulders), and hence reduced the rock volume requirement by 300,00 Te.*
- **Johan Castberg flowlines, Equinor/IKM Ocean Design, Ref. [50]**: *For the low probability trawling Johan Castberg field, a detailed SRA methodology was developed to enable an improved and optimised assessment of the trawl interaction for the 12" GI/GL flowlines. The methodology accounts for the protection effect gained by close laying two pipelines (12" gas and 12"/16" PIP), distributions of the variables applicable for input to calculation of trawl loads, pipeline response and pipeline capacity. This SRA methodology and acceptance criteria are in compliance with the governing design code requirements of DNVGL-ST-F101 and DNVGL-RP-F111 for trawl interference loads, ref.*

Lyngsaunet et al., "Optimising the Johan Castberg Trawl Interference Design Using Close Lay of Rigid Flowlines and Structural Reliability Analysis", presented at the ISOPE conference 2019.

The following requirements are outlined by RP-F111 (Sect. 4.8) for such alternative approaches.

DNVGL-ST-F101 Sec.1 states that in case alternative methods and procedures are used, it shall be demonstrated that the obtained safety level is equivalent to the requirements in DNVGL-ST-F101, i.e. that the nominal failure probability is equal or less than the target values (see DNVGL-ST-F101 Sec.2). For a direct estimation of the inherent failure probability for pull-over loads, the following approach may be used:

- Estimate the pipeline response for trawl pullover loads.
- Perform structural reliability analysis of the response in order to estimate the inherent failure probability. Relevant failure modes and loads needs to be considered, see below.
- Evaluate the estimated failure probability vs. the acceptable failure probability. If the estimated failure probability is unacceptable, mitigations to reduce the potential trawl pull over load is required (e.g. trenching or rock dumping).

The following needs to be included in the structural reliability assessment as a minimum:

- Trawling activity in the area or representative nearby areas.
- Distributions/overview of relevant trawl gear sizes, types and trawling velocities at the relevant location.
- Estimation of trawl pullover loads for various trawl equipment.
- Uncertainties in trawl pullover loads for given trawl equipment.
- Estimation of pipeline response for given trawl pullover load. Sensitivity analyses for axial and lateral friction including intermittent rock berms and sensitivity analyses with variation in the material properties. Different locations along the pipeline need to be considered.

The following failure modes need to be considered as a minimum:

- Local buckling. Point loads on the pipeline will reduce the local buckling resistance, and this needs to be
- reflected in the assessment.
- Fracture including hydrogen induced stress cracking.

It is considered that by utilising this alternative method for optimisation processes of e.g. seabed rock volumes (free span mitigation for trawl loads in very uneven seabed such as the Haltenbanken and Barents Sea areas), it allows the engineers and decision makers to better evaluate risk and consequences for the product being considered.

5.1.7 DNVGL-RP-F107 Risk Assessment of Pipeline Protection

The DNV GL RP-F107 *Risk assessment of pipeline protection, Ref. [9]*, gives some guidance wrt trawls loads (Section 5.6):

Trawling activity is usually concentrated in certain areas. If pipelines and umbilicals are routed in such areas the annual frequency of a trawl board hit will normally be very high, e.g. from 10-2 to 100 per km per year. The failure frequency of the same order as the hit frequency unless the pipelines and umbilicals are protected
against trawling.
If a pipeline is designed to withstand trawling, then the failure frequency is negligible (i.e. only minor damage to the protection). If not already designed, larger diameter pipelines (i.e. larger than 12”-14”) may be protected by coating to reduce the failure frequency. Smaller diameter pipelines, flexibles and umbilicals should be trenched, gravel dumped, etc.

Reference is made to DNVGL-RP-F111 for pipeline design against trawl interaction.

5.1.8 Summary of Increased Trawl Gear Size for Pipelines

General
The general effect of increasing trawl vessel size, increased engine power, increased trawl gear etc is that the trawl load potential increases, i.e. pullover load, impact energy, hooking, snag loads, friction loads, abrasion etc.

Large Diameter Pipelines

As seen in Section 6 Trawl Gear Analysis Examples, large diameter pipelines (OD > ca 400 mm) may be more exposed to increases in clump weight size than small diameter products, for the on-bottom case. For large diameter free span sections, an increase in clump weight size leads to a general increase in trawl loads.

Increases in trawl board size leads to a general increase in trawl loads (both on-bottom and free spans).

Small Diameter Pipelines - Flowlines

<u>Short Distance flowlines exposed (0 - 10 km, within eye sight from platform)</u>

As seen in Section 6 Trawl Gear Analysis Examples, pipelines and products with diameter less than approximately 350 - 400 mm, the governing interaction is seen to be limited to the roll-over effect for a roller type clump weight (even for increasing clumps). For free spanning sections, an increase in clump weight and trawl board size gives an increase in trawl loads.

<u>Long Distance flowlines (10 km and above)</u>

Flowlines over longer lengths such as long tie-backs may have route sections exposed to trawl gear that is outside of sight from the platform. Such long distance tie-backs may be considered to have a slightly higher risk for trawl crossings than short distance flowlines that are within the eye sight of the platform.

Pipeline route sections away from platform safety zones and of some length, may attract fishing activity during life of field due to the flowline having a reef effect and potentially being heated etc. Such effects should be considered during design phase as well as continually monitored during its operational life.

5.2 Subsea Structures and Manifolds

5.2.1 NORSOK U-001 and U-002

NORSOK U-002 Subsea Structures and Piping System
The NORSOK U-002 standard, started as NORSOK standard U-CR-001 in its Rev. 01 in 1995, Ref. [15] and was renamed to U-002 in its Rev.02 in 1998, [14].

NORSOK U-002 defines the minimum requirements for subsea structures and piping systems (template and satellite structures, manifold and riser base structures, protection structures, piping modules).

In Rev.02, NORSOK U-002 gave the following recommendations wrt design for overtrawlability (Sect. 4.2.5):

Overtrawlability design will have to be done with due consideration to access requirements. For overtrawlable structures the following requirements shall apply:

1. The protective structure shall deflect all fishing equipment.
2. The structure shall include corners, with the maximum true angle of 58° from the horizontal optimised

to assist trawl and trawl wire deflection.

3. Corners, ramps and equivalent structures shall penetrate the seabed to avoid snagging from trawl warp lines and ground rope. Effects from installation tolerances and expected scouring shall be accommodated.
4. The overall geometry of the structure and the size of openings, shall be such that trawl doors are prevented from entering into the structure.
5. If vertical side bracings are included, these shall be spaced to prevent intrusion and rotation of trawl equipment, without restricting subsea structure access for the intervention systems.

Notice should be taken to the following comments:

- All protuberances shall be minimised to prevent snagging of nets.
- The lower the structure the less effect the trawl gear will have in friction, pullover and snagging.
- All external edges/members shall have a minimum radius of 250 mm.

In section 4.2.6 Loads from fishing gear it stated:

Loads from fishing gear In areas where it is required to design the subsea system for fishing gear loads the following apply: As a general rule, snagging shall be considered as an abnormal operation (PLS), while impact and frictional loads caused by passing fishing gear shall be regarded as normal operation (ULS) unless frequency of trawling allows it to be considered as a PLS condition. In Annex A data sheet UDSA07 characteristical loads for a typical North Sea location are given. Model tests may be used to document smaller loads (See Note below). Loads from beam trawls shall, in addition, be considered for areas where such equipment are being used. When an overtrawlable/snag free concept can be documented through model test or a geometric evaluation combined with data from relevant model tests, the following design loads can be disregarded : Trawl-board snag, Trawl Ground rope snag, Trawl-board snag on sealine.

SUBSEA DATA SHEET	**UDS-A07**	U-002 Rev. 2	
Page 1 of 1			
TITLE: Loads from fishing gear on subsea structures			
Field:		Design life:	
Location(Block/UTM):		Water depth:	

Design Load Type	Design Load Figure		
Trawlnet friction	2x200 kN	0-20 deg. vertical	ULS
Trawlboard overpull	300	0-20 deg. vertical	ULS
Trawlboard impact	13 kJ		ULS
Trawlboard snag	600 kN	0-20 deg. vertical	PLS (If not overtrawlable/snagfree)
Trawl ground rope snag	1000 kN	0-20 deg. vertical	PLS (If not overtrawlable/snagfree)
Trawlboard snag on sealine	600 kN		PLS (If not overtrawlable/snagfree)
BASIS IS LOADS FROM OTHER TRAWL FISHING GEAR			

Fig. 5.15 Subsea Datasheet UDS-A07 - Loads from fishing gear on subsea structures

Note: *A trawl model test shall investigate the overtrawlability of the structure and quantify the trawl loads to which it may be subjected. The model test shall as a minimum simulate the following: Trawl gear type (otter/cotesi, beam etc.), trawl speed, water depth, friction on seabed and structure, length, stiffness and angle of warp lines, minimum breaking strength in warp lines, bobbins and ground rope. Test procedure and set-up should be verified by the local fishing authorities and/or a fishing/trawling expert with experience from that particular area. Test set-up may vary to suit local test facilities.*

NORSOK U-001 Subsea Production Systems, Rev. 03 (2002), [13]
The NORSOK U-001 standard, had a major revision update in 2002 when it was re-issued as Rev.03. In addition to replacing the Rev. 02 of the U-001 standard, it also incorporated:

1. The above NORSOK U-002 Subsea Structures and Piping System, Rev. 2 [14]
2. NORSOK U-006, Subsea Production Control Umbilicals, Rev. 2
3. NORSOK U-007, Subsea Intervention, Rev. 2.

The new revision of the NORSOK U-001 standard is further based on ISO 13628 [18], Petroleum and natural gas industries – Design and operation of subsea production systems series of standards, and includes specific national requirements and recommendations that are not covered by ISO 13628. This NORSOK standard shall therefore be read in conjunction with all parts of ISO 13628.

The U-001 2002 update included the following general design requirements wrt overtrawlability and loads (Sect. 5.3.1-5.3.4):

Snagging shall be considered as an abnormal operation (PLS), while impact and frictional loads caused by passing fishing gear shall be regarded as normal operation (ULS). This applies unless the frequency of trawling allows it to be considered as a PLS condition. Specific loads for a typical North Sea location are given in 5.1 (see Fig. 5.16).

Design load type	Design load figure		
Trawlnet friction	2x200 kN	0° to 20° horizontal	ULS
Trawlboard overpull	300 kN	0° to 20° horizontal	ULS
Trawlboard impact	13 kJ		ULS
Trawlboard snag	600 kN	0° to 20° horizontal	PLS (If not overtrawlable/snagfree)
Trawl ground rope snag	1000 kN	0° to 20° horizontal	PLS (If not overtrawlable/snagfree)
Trawlboard snag on sealine	600 kN		PLS (If not overtrawlable/snagfree)

Fig. 5.16 Fishing Gear Design Loads (NORSOK U-001, 2002)

Model tests may be used to document smaller loads. Loads from beam trawls shall, in addition, be considered for areas where such equipment is used.
When an overtrawlable/snag free concept can be documented through model test or a geometric evaluation combined with data from relevant model tests, the following design loads can be disregarded:

- trawl board snag;
- trawl ground rope snag;
- trawl board snag on sealine.

A model test shall investigate the overtrawlability of the structure and quantify the trawl loads to which it may be subjected. The model test shall as a minimum simulate the following:

- trawl gear type (otter/cotesi, beam etc.);
- trawl speed;
- water depth;
- friction on seabed and structure;
- length;
- stiffness and angle of warp lines;
- minimum breaking strength of warp lines;
- bobbins and ground ropes.

The test procedure and set-up should be verified by the local fishing authorities and/or a fishing/trawling expert with experience from that particular area. The test set-up may vary to suit local test facilities.

For overtrawlable structures the following design requirements shall apply:

a) the protective structure shall deflect all fishing equipment;
b) structural corners shall have maximum true angle of 58° from the horizontal to assist trawl and trawl wire deflection;
c) corners, ramps and equivalent structures shall penetrate the seabed to avoid snagging from trawl warp lines and ground rope. Effects from installation tolerances and expected scouring shall be accommodated;
d) the overall geometry of the structure and the size of openings, shall be such that trawl doors are prevented from entering into the structure;
e) if vertical side bracings are included, these shall be spaced to prevent intrusion and rotation of trawl equipment, without restricting subsea structure access for the intervention systems;
f) all protuberances shall be designed to prevent snagging of nets;
g) all external edges/members which are not part of a closed protection structure shall have a minimum radius of 250 mm;
h) minimum trawl speed shall be 3,0 m/s.

NORSOK U-001 Subsea Production Systems, Rev. 04 (2015)

An update of the NORSOK U-001 standard was introduced in 2015, [13]. Table 5.5, shows the updated trawl design loads proposed in the new standard.

Table 5.5 Trawl Design Loads (NORSOK U-001, 2015)

Design load type	Design load figure		
Ground rope friction load	2x200 kN	0° to 20° Relative to the horizontal plane	ULS
Trawlboard overpull	450 kN*	0° to 20° Relative to the horizontal plane	ALS
Horizontal impact load	30 kJ	Object diameter 500mm	ALS
Trawlboard snag	600 kN	0° to 20° Relative to the horizontal plane	ALS (If not overtrawlable/snagfree)
Trawl ground rope snag	1000 kN	0° to 20° Relative to the horizontal plane	ALS (If not overtrawlable/snagfree)
Trawlboard snag on sealine	600 kN		ALS (If not overtrawlable/snagfree)

**For closed, smooth protection structures; such as GRP covers, 300 kN shall apply.*

For trawl board overpull, the design load increased from 300 kN (2002) to 450 kN (2015), however for closed/smooth protection covers such as GRP, the 300 kN load continues to apply. In addition, the horizontal impact load increased from 13 kJ to 30 kJ and an object geometry was defined (diameter 500 mm). Another change in the new standard, is that the minimum trawl speed has been reduced from 3.0 m/s to 2.8 m/s. The new revision also includes requirements for a truncated pyramid and trapezoid shaped structures to assist trawl and trawl wire deflection.

Except for these two load adjustments and reduction in minimum trawl velocity in 2015, it seems like the trawl design loads for subsea structures have only marginally been adjusted since 1998 (NORSOK U-002 Rev. 02).

During the same period, DNV Guideline 13 gave a maximum trawl board weight of 3500 kg in 1997, DNV RP-F111 in 2006 gave an increased maximum trawl board weight to 5000 kg but also introduced the clump weight load of maximum 9000 kg, and in 2014 these loads were adjusted to 7400 kg and 8000/9000 kg respectively. For the trawl load, this constitutes an increase of more than 110% and in addition the clump weight has been introduced as a new type of load.

Some comments to the above discussion:

- This review leaves a small question if the trawl design loads in NORSOK U-001 has kept track with the significant development within the fishing industry over the last 25 years related to vessel size and engine power, type and size of gear etc. Since this development is still continuing, further work may be considered to assess how aligned the standard is wrt the trends in the trawling industry.
- NORSOK U-001 has very few references and it is hence very challenging to track sources for information and design requirements. It should considered to make the standard more traceable with references to tests, research, publications etc.
- The recommendations in Section 5.3.4.3 related to Model Tests requirements. It appears like these requirements have not been changed since 2002. Due to the introduction of new type bottom trawl gear and larger masses, it may be considered to revisit the test requirements and detailing.

5.2.2 Summary of Increased Trawl Gear for Subsea Structures and Manifolds

An increase in the trawl size will generally increase the trawl load potential and hence also the damage potential for subsea structures and manifolds. A subsea well does however always have two barriers towards the reservoir and the probability of damaging both the primary barrier (Downhole safety valve, DHSV) and the secondary barrier i.e. the well x-mas tree is considered to be low even with an increase in the trawl equipment. There may be a possibility that the subsea protection structure and the xmas tree may be damaged. This will lead to a situation that well integrity is depending on the primary barrier i.e. the DHSV but a loss of integrity of the secondary barrier will be noticed by the operator who will take action to restore the secondary barrier. Depending on the spare philosophy for the operator this situation may be repaired after a relatively short period of time with no emissions to the seas. The probability of damaging the second barrier at the same time as the primary barrier is not functioning is also considered to be low as it is expected that all operators on the NCS will maintain two barriers intact throughout the field life and test these barriers regularly.

As discussed above, it should be considered if the NORSOK U-001 trawl load requirements are up to date wrt the latest developments in the size and type of trawl gear. The origin and background for the trawl loads defined by the standard is not clear and as such an update of the loads should be considered in order to establish a base case related to trawl load sizes. Furthermore, any testing of the overtrawlability should be done to a sufficient level of detail to cover all possible trawl angles and assure that the protection structure are overtrawlable for all type of gear being used in the area. Trawl gear size trends should be considered during design phase as well as monitored throughout the design life.

Within platform safety zones there have been recorded several incidents of trawl gear snagging in subsea structures and equipment. The potential reach of bottom trawl gear within the safety zone should be considered during design phase.

Minor damage to SPS protection structures may not be discovered until the operators next regular inspection. Depending of the frequency of inspection this could possibly increase the risk for the wellhead christmas tree to be damaged by the next trawl.

If the protection structures around the SPS is protected by rock installation, repeated trawling may remove parts of the rock and thus gradually increasing the probability of the trawl hitting the protection structure in an unfavourable way.

Even though an increase in trawl gear size gives generally larger loads and risk, todays modern fishing vessels have very good tracking of their bottom gear with sensors/cameras, GPS-positioning etc as well as detailed positions of subsea structures and other seabed obstructions. Hence, the potential for interaction between trawl gear and subsea structures is generally reduced.

6 Trawl Gear Analysis Examples

The effect of an increase in trawl gear interference loads are evaluated through some example cases.

Case 1 - 12" rigid flowline - Using Screening Analysis based on Trawl Loads from DNVGL-RP-F111
A typical 12" rigid pipeline is analysed using the general 3D pipeline simulation software SIMLA (by SINTEF Ocean), and a relationship between pull-over force and bending moment response is established. The results are shown in Fig. 6.1. Also shown in this figure is the allowable bending moment, calculated in accordance with capacity for combined loading for a load controlled condition in DNVGL-ST-F101.

This relationship allows the identification of an allowable pull-over force. Such analysis would typically have to be done for multiple locations along a pipeline route focusing on parameters such as flat seabed versus free spanning sections, span height/ length, effective force, 3D effects such as route curves, lateral buckles etc.

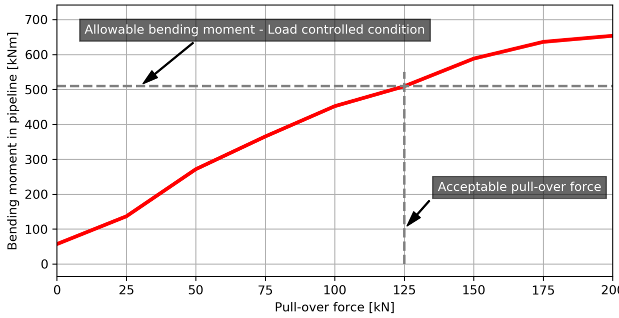


Fig. 6.1 Pull-over Force versus Bending Moment in Example 12in Pipeline

This example is hence just one of many potential combinations, and is included here for illustration. Based on the calculated capacity, an acceptable horizontal pull-over force of about 125 kN is defined.

Based on the above results, the next step will be to investigate what maximum trawl board and clump weight mass that gives 125 kN horizontal pull-over force.

In Fig. 6.2, a 3D surface plot is shown of calculated pull-over forces, based on varying the trawl board mass between 500 kg up to 7000 kg and varying the span height between flat seabed up to a span height of 5 m. The maximum acceptable pullover load of 125 kN is represented by the plane/surface in green.

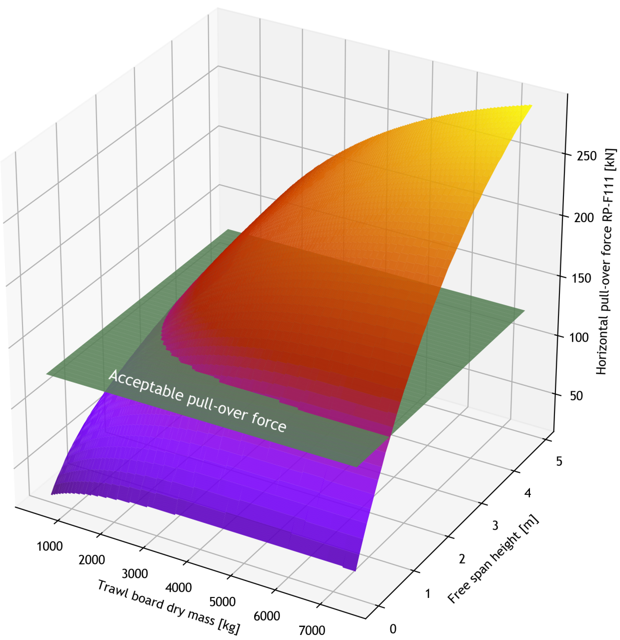


Fig. 6.2 Pull-over Force versus Free Span Height - Trawl Board

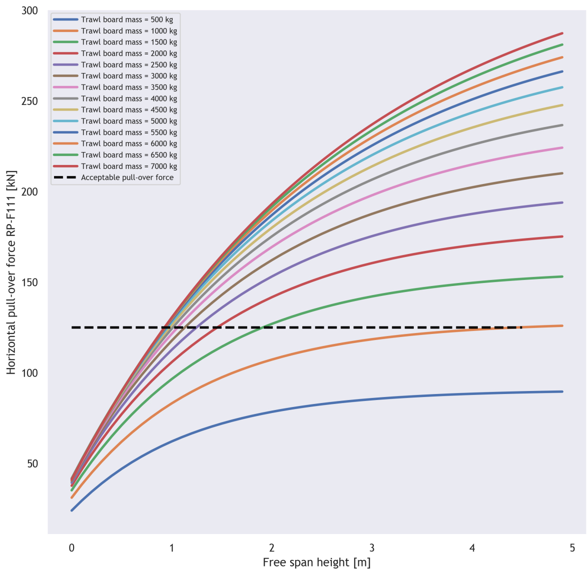


Fig. 6.3 Pull-over Force versus Free Span Height - Trawl Board - 2D view

Based on this, the cut line between the response surface and the 125 kN plane indicates all the trawl board mass vs span height combinations that equates to the maximum trawl board pullover load.

In Fig. 6.3, the results from are presented in Fig. 6.2 2D by plotting span height versus horizontal pullforce. The dashed black-line represents the defined maximum pullover force. This shows that for a 2 m span height, the maximum acceptable trawl board mass would be approximately 1500 kg, while for a 1 m span height the maximum allowable trawl board mass would be approximately 4000-4500 kg.

The same exercise is then performed for clump weight trawl loads, and adopting the same maximum allowable horizontal load of 125 kN as discussed above.

Again, pull-over forces are calculated by varying clump weight mass between 1000 kg up to 10000 kg in combination with flat seabed up to 5 m span height, in order to develop the 3D surface presented in Fig. 6.4. The maximum acceptable pullover load of 125 kN is represented by the plane/surface in green and the resulting cut-line between response surface and 125 kN plane provides acceptable clump weight vs span height combinations.

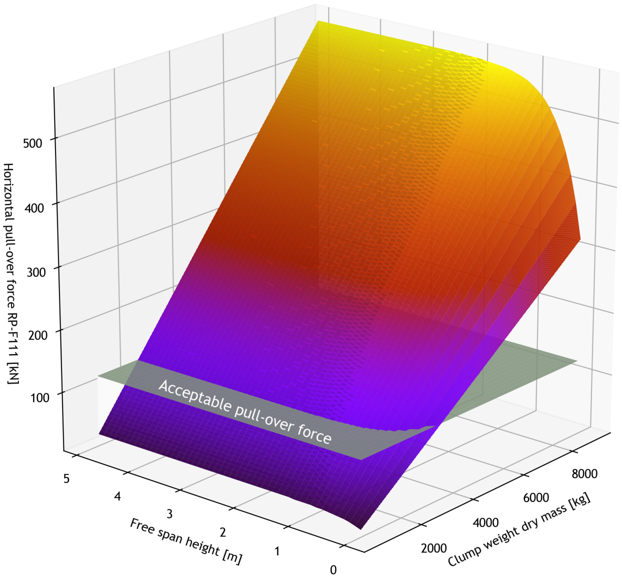


Fig. 6.4 Pull-over Force versus Free Span Height - Clump Weight

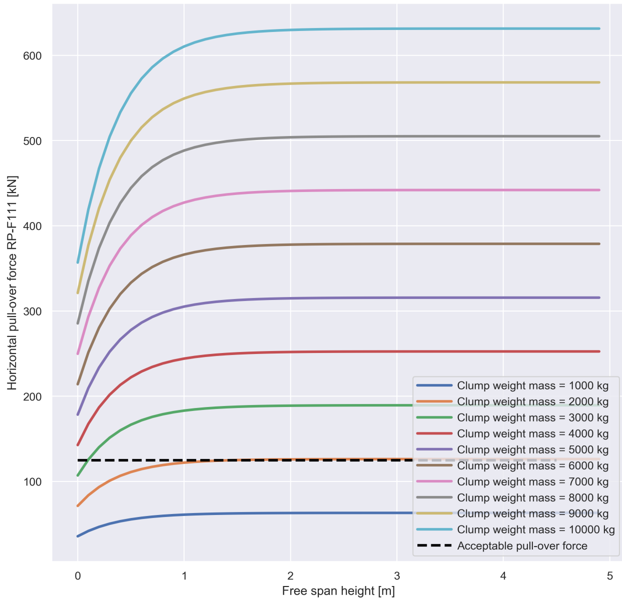


Fig. 6.5 Pull-over Force versus Free Span Height - Clump Weight - 2D view

In Fig. 6.5, the results from Fig. 6.6 are presented in 2D by plotting span height versus horizontal pullover force. The dashed black-line represents the defined maximum pullover force of 125 kN. The results indicates that the clump weight load is more severe than the trawl board and it shows that for a 1 m span height, the maximum allowable clump weight is approximately 2000 kg. For the flat seabed case (span height of 0 m), the allowable clump weight is approximately 3500 kg.

The results above shows that an increase in trawl gear size/weight influences the pipeline pullover response significantly, particularly for clump weights.

The above approach illustrates the relationship between allowable pull-over force, trawl board/clump weight sizes and free span heights and hence enables quickly screening pipeline routes vs critical parameters in order to define if further detailing is required.

Case 2 - 16" rigid flowline - Detailed Integrated Modelling in SIMLA - Sensitivity of Trawl Velocity

Trawl pullover sensitivity analyses have been performed for a 16" rigid flowline for two clump weight masses (5T and 7T) and two velocities (1.95 m/s and 2.6 m/s) for a span height of 1.5 m, see SIMLA model detail in Fig. 6.6. The actual geometry, COG and warp/sweep line connection points of the roller clump weight, trawl net drag, sweep lines and warp line stiffness towards the vessel etc is modelled. Contact is simulated between clump weight and seabed, clump weight and pipeline as well as warp line against pipeline. An important step in the process with fully integrated trawl models, is calibration of the model versus existing trawl model tests. This calibration process however, has not been included in this work.

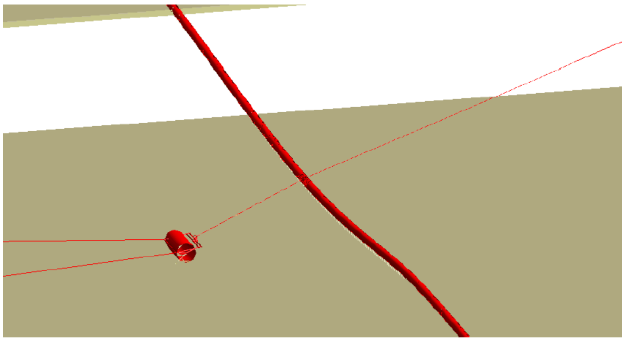


Fig. 6.6 SIMLA Integrated Clump Weight Trawl Model

Fig. 6.7, shows the results from the four integrated trawl analyses performed.

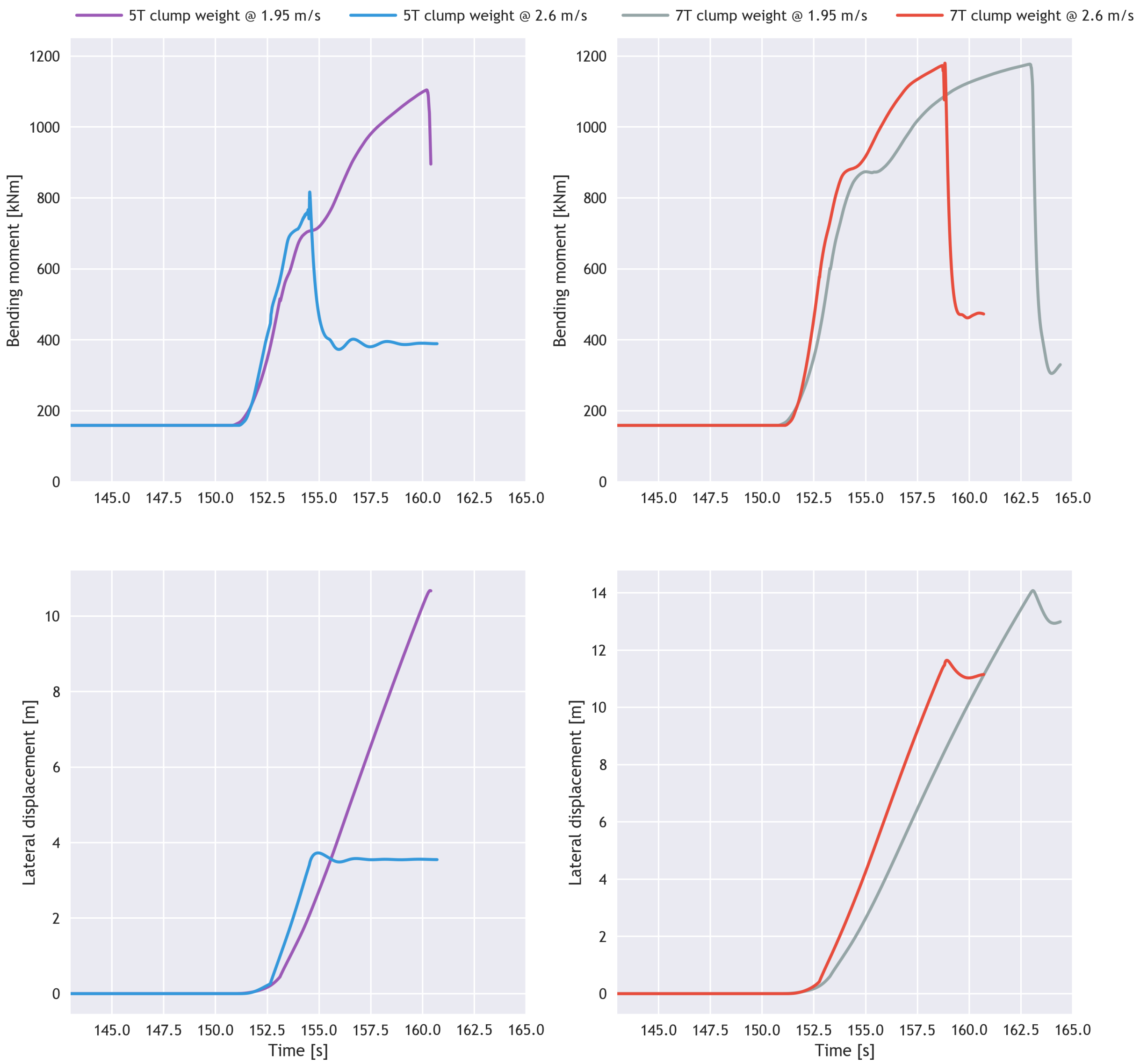


Fig. 6.7 Example analysis with integrated FE model - velocity dependency

- 5T case: For the 5T case, the bottom left plot shows lateral displacements for the two velocity cases and the upper left shows the results bending moment results for the cases. The lateral displacement results show that the clump weight for the low velocity case tend to hang on the pipeline longer than for the high velocity case. It seems like it requires additional time before it gains sufficient momentum to flip/roll over the 16" pipeline. The increased lateral pull-out also shows a significant increase in bending moment.
- 7T case: For the 7T case, a similar tendency for the clump weight to interact longer with the pipeline for the low velocity case, even though the difference is smaller for this weight. The difference in duration is also seen in the bending moment plot, however the difference in bending moment is relatively small.
- Combined: The general increase in lateral displacement and bending moment when comparing results for the 5T and 7T clump weight cases for the same velocity.
  - v=1.95 m/s: Bending moment increases by approximately 7% from 5T to 7T.
  - v=2.6 m/s: Bending moment increases by more than 40% from 5T to 7T.

Fig. 6.8 shows a storyboard of the above analysis at four different time steps, 1) the clump weight approaching the 12" pipeline and the warp line pushes the pipeline down, 2) the clump weight bracket hits the pipeline contact/friction starts the pull-out, 3) the clump has pulled the pipeline laterally resulting in an increase in the warp line force and 4) the clump leaves the pipeline.

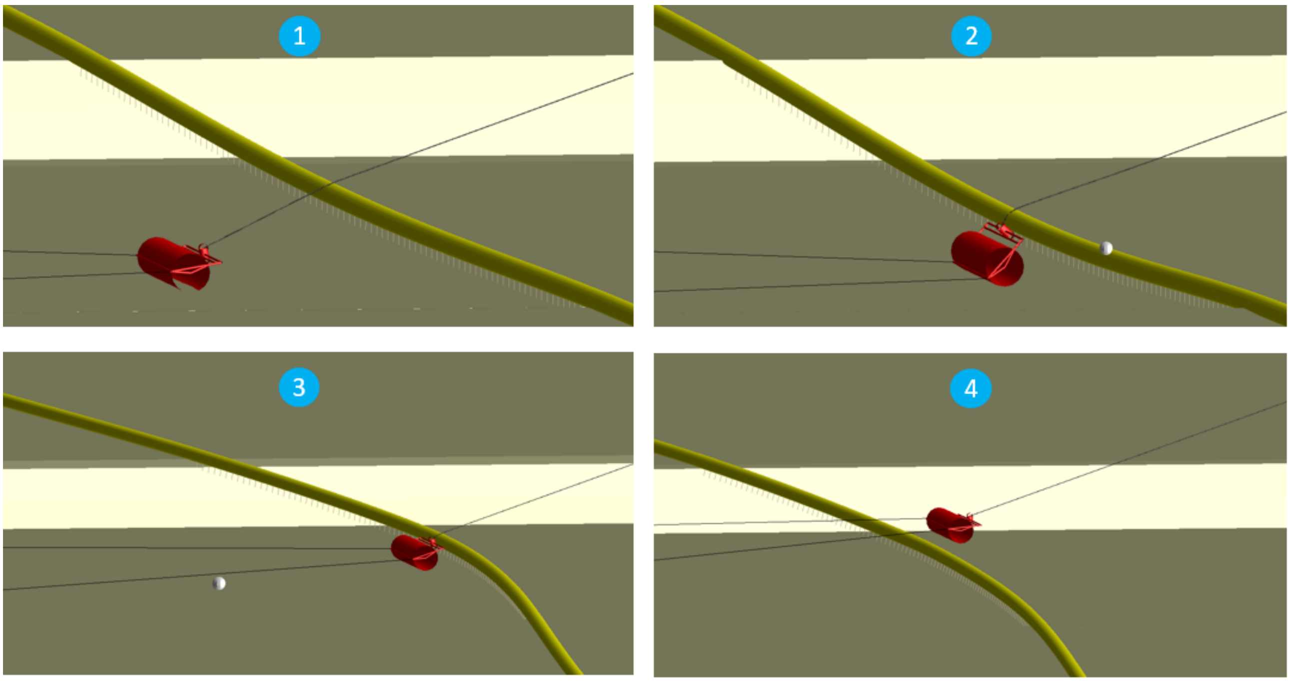


Fig. 6.8 Storyboard for clump weight overtrawling of 16" in the 45 m long & 1.5 m high span

While it is quite common in subsea pipeline and structures design to assume that the highest velocity gives the most onerous load condition, the above results suggest that the low velocity case may in some cases be governing. It is recommended to further evaluate this finding and further evaluate which parameters that influence this behaviour.

Testing of clump weight to pipeline interaction has not been performed since 2003/2004 (for Kristin and Snøhvit) and a lot of learning has been gained by the industry since then. 3D numerical simulations such as those being available in SIMLA are able to reproduce the Kristin/Snøhvit test results as well as the general behaviour of trawl boards. Despite the great advances of the simulation tools, it is generally recommended for the industry to carry out additional testing for a wider range parameters and to incorporate the findings from the last 15 years. Very few (or no) signs of lateral pull-out has been identified during as-built inspections of existing pipelines even though design analyses suggest that significant lateral displacements will take place when a trawl passes. Further testing will increase knowledge, will allow both optimisation and improve design robustness.

Case 3 - 12" rigid flowline - Fully Integrated Trawl Modelling in SIMLA - Flat Seabed and low spans
In order to assess the considered conservatism in the trawl load formulations given in DNVGL-RP-F111, some sensitivity analyses were performed using the SIMLA integrated clump weight trawl model, see above in Fig. 6.9. The following cases were considered:

- Pipeline OD: 12"
- Span heights: 0.0, 0.1, 0.2, 0.25, 0.3, 0.4, 0.5 and 0.75 m (approximate 45 m span length where applicable)
- Clump weight mass: 7000 kg (roller clump type)

Fig. 6.9 shows the results from these eight span cases (0 - 0.75m height) showing the resulting horizontal pullover force. Also shown are the corresponding force distributions as defined by DNVGL-RP-F111, for Load Factor 1.0 and 0.8. As the results suggest, the detailed analysis results are signficantly lower than the loads defined by DNVGL-RP-F111, particularly for on-bottom and low span height cases.

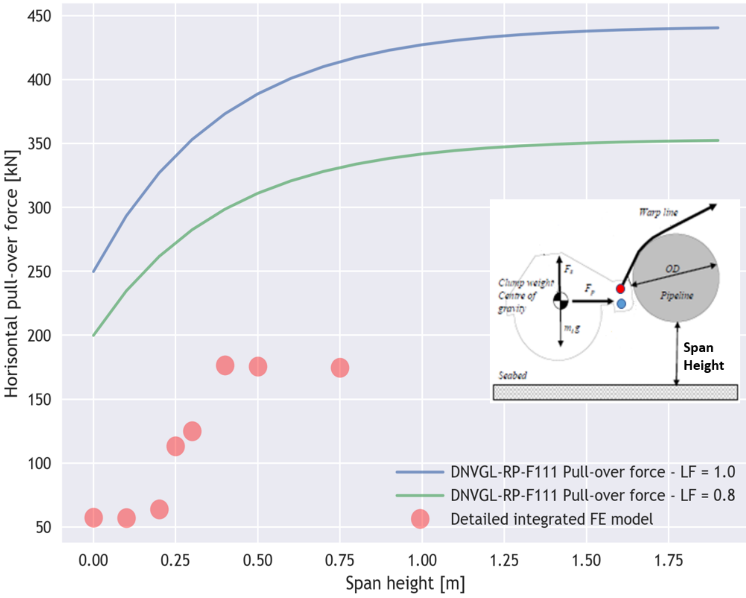


Fig. 6.9 Integrated Clump Weight Analysis in SIMLA for 12 " Pipeline & Low Span Heights, CW 7T

For on-bottom case until a span height of 0.2 m, the position/height of the warp line connection plate is located too high to interact with the 12" flowline, and hence a "roll-over" behaviour for the on-bottom dominates. Between span gaps of 0.25 - 0.4 m the warp line connection plate starts to interact and full interaction is reached for gaps >0.4 m. These results indicate that the DNVGL-RP-F111 load curves for on-bottom condition corresponds to a span height of approximately 0.5 m using detailed integrated FE simulations.

The storyboard of plots from the on-bottom case below illustrates the roll-over effect for the evaluated 12 " flowline and that the warp line connection bracket is positioned too high for interaction with the pipe.

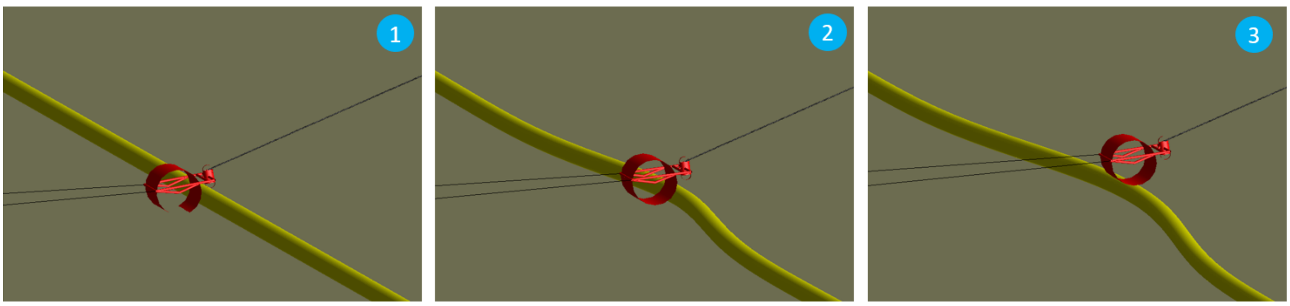


Fig. 6.10 Storyboard for 7T CW Pullover for on-bottom 12" pipe

Fig. 6.11 below shows the resulting lateral displacement and bending moment for the 12" on-bottom case. A maximum displacement of 1 m and max. bending moment of approximately 210 kNm is seen at the pull-over location. For the same scenario using RP-F111 loads (Case 1 above), the 7T clump weight for on-bottom condition gave a bending moment >650 kNm, i.e. three times the BM seen when using the fully integrated clump weight model.

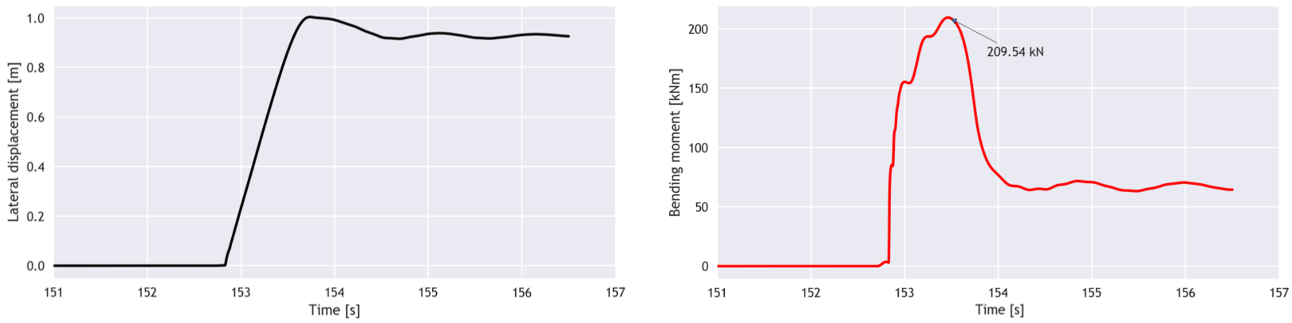


Fig. 6.11 Lat. Displacement & BM for 12" on-bottom Case, 7T CW

For pipelines and products with diameter less than approximately 350 - 400 mm, the governing interaction is seen to be limited to the roll-over effect. Based on this it can be concluded that, 1) smaller products will have less risk for high pullover loads for on-bottom conditions, 2) small diameter products may still be able to sustain clump weight masses >7T for the roller type for on-bottom case and 3) larger diameter products may be more exposed to increases in clump weight gear for the on-bottom case.

The COG for the clump weight may vary and influence the gap height at which full interaction with the warp line connection bracket takes place. Sensitivity analyses should be performed for the most common parameters that governs the pipeline response due to clump weight pullover, e.g.:

Clump Weight Parameters:

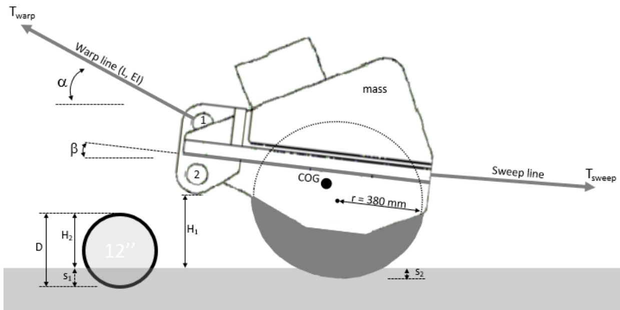


Fig. 6.12 Typical Roller Clump Cross-section vs 12" pipe

- Clump weight geometry
- Clump weight mass
- Warp line connection bracket geometry (is considered very important for level of interference with pipelines)
- Warp line connection point, see red and blue connection points in Fig. 6.9 for a Thyborøn type design. Other designs such as Rock has both 2 and 3 alternative connection points while Injector appears to have 2. The warp line connection point is considered very important for level of interference with pipelines.
- Trawl velocity
- COG variation
- Clump weight seabed penetration
- Warp line length/inclination angle, i.e. warp line length vs water depth
- Drag from the trawl net
- Contact friction between clump and pipe
- Warp line and sweep line stiffness (not expected to influence the response significantly)

Pipeline and Route Parameters:

- Pipeline parameters such as OD, WT, YS variations
- Pipeline configuration (on-bottom, free span, thermal buckles etc)
- Axial flexibility, i.e. interaction with neighbouring pipeline sections
- Effective axial force
- Pipe-soil interaction resistance
- Pipeline seabed penetration
- Straight vs curved route sections

Based on this work and other similar numerical studies, it seems like the DNVGL-RP-F111 load formulation for on-bottom and low span cases should be further addressed wrt level of conservatism.

Case 4 - Potential for Bottom Trawl Gear within Platform Safety Zone

A typical platform in 150 m water depth with its 500 m safety zone is analysed wrt the potential for how far within the platform safety zone a typical bottom trawl spread can reach. The following assumptions are made:

- Water depth = 150 m
- Single net trawl spread
- Warp line length = 400 m
- Safety zone radius = 500 m
- Trawl vessel trajectory is 550 m from the platform, i.e. 50 m outside the platform safety zone
- Methodology: Based on DVNGL-RP-F111

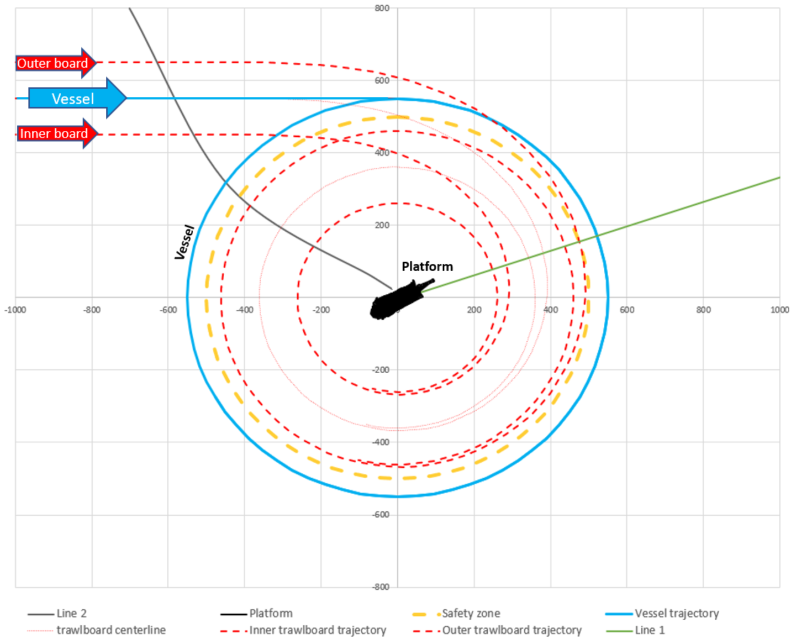


Fig. 6.13 Potential Trawl spread trajectory near platform safety zone

The following is observed from the results in Fig. 6.13:

- If the vessel is following the platform safety zone for 360 degrees, the minimum physical distance between the inner trawl board and the platform will be approximately 200 m, i.e. 250 m within the platform safety zone. A more realistic scenario is maybe that the trawler touches the safety zone, follows it 45 degrees before departing out. Even in this case, the inner trawl board will come 150 m within the safety zone.
- If a maximum case with larger water depth, a double trawl with a width between trawl boards of 300-350 m, the inner trawl board may touch the foot of the platform legs.

Since there have been examples of trawl gear interference with subsea installations within platform safety zones, it seems like these type of sensitivity assessments is useful in order to evaluate risk and if mitigations should be taken.