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Abstract

Ever since oil has been extracted on the Norwegian continental shelf, fishing activities and oil and gas retrieval has had to coexist. One of the interactions between fishers and that can be hard to avoid are the interactions between bottom trawling and subsea installations. This thesis has researched regulations relevant to the overtrawling of subsea structures and pipelines, as well as previous research relevant to these. Interviews were done with experts on trawl fishing from both the authorities and the two aforementioned industries. The answers were used as theory background help, as well as for the analysis. A data set was compiled of ships that are currently in use or were very recently in use for trawling, with a focus on bottom trawling. The collected data set was then used in a data analysis and plotting process to identify trends and developments in the fishing industry, particularly regarding the dimensions of vessels and their gear in relation to their build year. Expert opinions and data analysis partly coincide, where it was seen that developments were heading towards larger ships and larger fishing gear. Future research was recommended by the extension of the ship data set, AIS data evaluation and trawl tests on subsea structures. It was concluded that for regulations on subsea structures to be up to date and at a level of the existing regulations for subsea pipelines, modern ship and gear capabilities have to be researched and used in the development of new tests to keep up with trends in the industry.

Acknowledgements

Firstly I would like to thank my supervisors, Per Nystrøm of IKM Ocean Design and Ljiljana D. Oosterkamp of Equinor/University of Stavanger, for their guidance, help with literature and comments and helping me along all the way until the final moments of writing this thesis. The expertise and knowledge has been crucial and you have facilitated the writing of this thesis at every turn.

A very special thanks goes out to Dagfinn Lilleng, Jarle Kolle and Eivind Pettersen. Agreeing to volunteer your time to help me has really made this thesis, and without you there wouldn't be much of a thesis at all. Your expertise has been key to finish this thesis and getting the results.

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Last but not least I would like to thank my mother. If you hadn't asked me over and over how my thesis was going, or when I was coming home to visit, I don't believe for a second I could have finished it.

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Nomenclature

List of Abbreviations

ALS	Accidental Limit State
DNV-GL/DNV	Det Norske Veritas - Germanischer Lloyd
GRP	Glass Reinforced Plastic
GRT/BRT	Gross Registered Tonnage/Brutto Redistered Tonnage
IMO	International Maritime Organization
ISO	International Organization for Standardization
JIP	Joint Industry Project
NORSOK	Norsk Sokkels Konkurransefortrinn
RP	Recommended Practice
SRA	Structural Reliability Analysis
SURF	Subsea, Umbilicals, Risers and Flowlines
ULS	Ultimate Limit State

List of Symbols

C_f	A function of trawl gear type and geometrical factors in pipeline overtrawl as defined by DNV-GL
k_{wL}	Warp line stiffness in relation to pipeline overtrawl as defined by DNV-GL
m_a	Hydrodynamic added mass during pipeline overtrawl as defined by DNV-GL
m_t	The mass of a trawl door/show as defined by DNV-GL
V	Trawl velocity in a pipeline overtrawl as defined by DNV-GL

1. Introduction

1.1 Background and previous research

Fishing has for centuries been an important industry in Norway and continues to be [1]. But since the Ekofisk field was discovered in the 1960s, the oil and gas industry has emerged as a leading business and has expanded massively ever since. As the number of installations on the Norwegian Continental Shelf has expanded, interactions between fishing vessels and offshore equipment has become something of a norm. A trawl skipper was recently aquitted of having caused such an event in 2016, having originally been subject to a large fine. While trawling within the security zone of the Gullfaks C platform the vessels trawl got stuck in one of Statoil's subsea installations, and had to be removed by ROVs [2]. The two industries must work with, and around, each other to co-exist for their common benefit. One of these interactions is between trawlers and installations on the seafloor. Fishers are in many cases hindered by these and can in some cases have their gear damaged or lost. But, this goes both ways, as the large trawl boards, clump weights and the trawl bag itself could exact forces upon the pipes, templates and other equipment and damage them. In the Norwegian sector, subsea installations are required to not unreasonably or unnecessarily impede fishing activities[3]. Working perpetually with these issues and further developing new models and data is important to ensure the best possible methods to ensure efficiency in operation, reduction in maintenance cost and the costs incurred of damaging or losing equipment. Regulations must be in place and up to date to govern such installations and research into these matters. To be able to to this to a degree that suits current and future situations, it is natural that recent developments and trends in the fishing industry are taken into account.

Already there exists several Det Norske Veritas (DNV) regulations for overtrawling, particularly related to subsea pipelines, like the Recommended Practices [3, 4]. These regulate how to deal with trawling gear on pipeline installations and with counter to pipeline damage in an overtrawling situation, and have detailed outlines dealing with the actual physics of a pipeline overtrawl. These have been developed over time and with background research dating several decades back. A part of this was done by Gjørsvik et al. [5] in the 1970's. These were a series of model scale tests done of the Norwegian coast and the damage done to different kinds of pipelines, protected and non-protected, were documented by divers. This was made into the first part of a compiled paper delivered at a conference in 1980 by Moshagen and Kjeldsen [6] (the latter which was part of the model test crew), which studied the damage from fishing gear on subsea pipelines. Some of the findings were that spanning pipelines and passes at an angle were more damaging, that trenching did not necessarily help negate forces and that impact loads from fishing gear are important for pipeline design. For regulations directly related to subsea structures, in Norway there is Norsk Sokkels Konkurranseposisjon (NORSOK) with NORSOK U-001 [7]. It deals with a lot of aspects of subsea production systems, therein subsea structures. It has a section about design loads for fishing gear loads, where it leans closely on the ISO 13628 series of standards [8, 9]. There seems to be a degree uncertainty as to the origin of these design loads, however a DNV report [10] seems to relate it to trawling model tests conducted during the 1980s [11]. It also regulates how model tests should be done to adhere to it and to deviate from the given design loads in the standard, as well as containing a definition of an what properties overtrawlable structures should have.

1.2 Problem statement

After working on a pre-project for this master thesis during the fall of 2018, it came to the authors attention that there seems to be copious amounts of work done relating to the subsea pipelines and fishing gear interaction and damage. The earlier mentioned DNV documents go into great detail of these topics, and have large reference lists to back them up. While looking for the same for subsea structures, the project's supervisors presented parts of *NORSOK U-001 - Subsea production systems* as the only regulation known to him. Subsea installations are usually covered by protective structures, and they have requirements to be over-trawlable, meaning that fish gear should not be damaged and that the trawl doors should not hook onto the structure. Looking at the design loads for trawl gear interaction on subsea structures, no source or reference were given for their origin. Questions about the design loads, on which the industry currently depend, such as how recent they were and their high level of conservatism at first glance were raised. A plan was drawn for the project to look into the origin for this regulation and finding its source. Names of knowledgeable people were written down, and a list of questions drawn up. A suggestion was also made to find fishing ship data from the ship registers and press releases of trawl gear manufacturers to map a current picture of the gear and vessels in use. These could then be used for data analysis to see the developments of recent years. In what way do recent trends in vessel size and gear develop? What are the origins of fishing gear design loads in the NORSOK standard currently? How does it compare to the fishing gear design load regulations in place for subsea pipelines?

1.3 Outline

Chapter 1 Introduction and problem statement for the thesis

Chapter 2 Theoretical background and previous research relevant to the thesis

Chapter 3 Description of the thesis' methodology

Chapter 4 Results from the ship vessel data analysis and discussion

Chapter 5 Conclusions are made from the thesis work in this section

2. Theory

This chapter offers theoretic background for the thesis. It will introduce the trawling system and the different kinds of gear that is usually connected with the activity and will also explain a little bit about subsea structures, and the thesis supervisor's experience on subsea structure design. Furthermore it will highlight existing regulation on overtrawling of subsea installations and previous research done on the subject.

2.1 Typical trawling equipment

Trawling is a way of fishing where vessels pull a large fishing net, called a trawl, after it to catch fish or shellfish. A trawling system usually consists of trawl doors, the trawl itself and a vessel (called a trawler) that pulls it all. Between the doors and the trawl are sweep lines and the wires between the doors and the trawler are called warp lines. The doors are there to hold the trawl open to allow the fish to enter it and also drive them into the net. One can differentiate between midwater, or pelagic, trawling and bottom trawling by where in the sea column they occur [12, 13]. Of the types of ways of fishing, bottom trawls would be most likely to interact with subsea installations and potentially cause damage as they operate closer to the seabed. Some of the heavier trawl gear are the large clump weights in multiple trawl setups, reaching as much as 9 tonnes according to the DNV [3]. In research for this paper clump weights nearing this size has been recorded (see Appendix B).

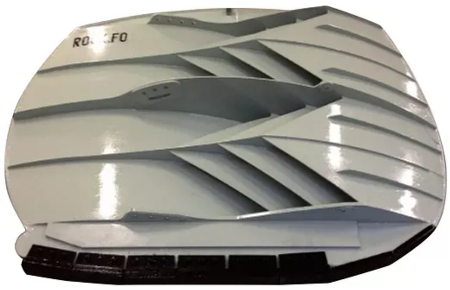
2.1.1 Trawl doors

There are several types of systems used for trawling, where two of them are most relevant to mention: the simpler beam trawl systems and otter trawl systems. The beam trawl uses flat trawl shoes that slide and scrape the seafloor and a solid iron beam connecting them to hold the trawl net open instead of wires connecting the doors, trawl and vessel (see Figure 2.1(a) [14]). The beam trawl is mostly in use for catch of prawns and flatfish on smaller vessels. Beam trawling in the Norwegian economic zone only occurs in the North Sea south of 58 °north, and not by Norwegian ships. Beam trawling usually occurs using shorter drag stretches and higher speeds than otter bottom trawling, as well as having increased maneuverability [15]. A more modern take on the beam trawl system is the wing trawl system (Figure 2.1(b) [16]). Similarly, it has a wing

(a) A beam trawl setup (Photo credit: F. Quirijns/IMARES)

(b) A wing trawl setup (Photo credit: Wing Trawling System)

(c) A semi-pelagic/combination trawl board (Photo credit: Thyborøn Trawldoors)

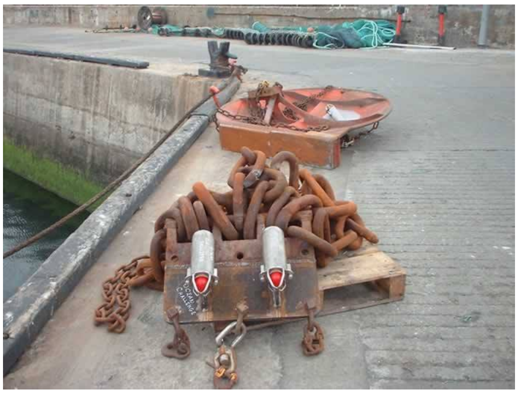


(d) A more traditional bottom trawling trawl board that has close to permanent sea bottom contact (Photo credit: Rock Trawldoors)

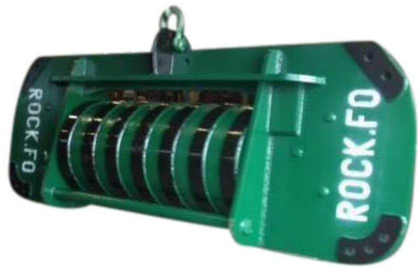
Figure 2.1: *Showing different types of trawl boards*

that spans the net to hold it open, but as such does not use any traditional type of trawl door at all. Several companies have been trying to develop this in recent years, such as HFK Engineering of the Netherlands with their ”SumWing”. They promise fuel savings, less bottom contact and higher speeds for the catch of flatfish [17]. An otter trawl uses the hydrodynamic forces acting on the trawl doors as they pass through the water to push them outwards and preventing the net from closing [18].

Otter trawl doors for bottom trawling can be divided into two types: conventional bottom trawl doors (see Figure 1(d) [19]) and semi-pelagic doors used as a ”flying door” for bottom trawling (Figure 1(c) [20]). The designs are quite distinct, and the semi-pelagic doors can be said to more closely resemble pelagic doors that are in use for fishing closer to the surface. According to experts interviewed for this report (see Appendix A) the conventional designs are still mostly in use for the purpose of bottom trawling in Norway, but the flying door designs are being tested more and



(a) An example of a primitive type of clump weight, which is just a chain link (Photo credit: Notus Electronics)



(b) A roller clump weight (Photo credit: Rock Trawldoors)

Figure 2.2: *Example of types of clump weights*

more by fishermen. Many of these hybrid style doors are being made by companies such as Rock Trawl Doors and Thyborøn Trawldoors, among others, alongside the production of conventional designs.

2.1.2 Clump weights

As for the weights in use for multiple bottom trawl setups, there has traditionally been used many different heavy objects such as chain link (see Figure 2.2(a) [21]) or large lumps of steel that could simply be added onto to add weight (see Appendix A). Along these there are purpose built weights by the same companies that produce trawl doors (see Figure 2.2(b) [22]). From the manufacturers more closely looked into on this report the roller clump design seems to be the one these manufacture and sell. The purpose of the roller clump in multiple trawl setups is to make the centre warps go down towards the seabed [23]. A roller clump seems to usually be made to specification of the buyer, and has one or more rolling wheel-type elements to help it move along the seafloor.

As mentioned previously, the clumps are used to hold the net down to the seafloor while towing multiple trawls. Twin rigging is today the most common way of trawling in the North Sea (see Appendix A). In Scottish vessels, for instance, close to all vessels built since the early 1990's were built with the intent of pulling two trawls. This transition to twin rigging has been likened in significance to the transition from sail, to steam to diesel powered vessels. Experimentation with even more trawls has been done, but has not had the same adoption rate as twin rigging did [23].

2.1.3 Sensors for use in trawling

Modern sensors can be used in the aid of trawling. Both standalone senors and more complex systems of sensors exists. Examples of the former can be seen on the product page of a manufacturer like Scanmar [24]. There are standalone sensors that provide information about for instance door spread, height in the water and their angles (pitch/roll). Other sensors are for measuring the flow through the trawl and therefore the speed, a camera (or trawl-eye) for measuring catch and trawl geometry sensors. More complex systems that monitor several of these features at once and is accompanied by computers and monitoring softwares exist, giving the skipper a complete picture of any variables in the trawl process they might need at a moments glance by the way of wireless communication to the gear. Examples of such systems are the ones supplied by Notus [25], from Canada, and the iSYM system from Scantrol [26]. The points of such sensors and sensor systems is to improve the efficiency of the trawl, minimize the miscatch of wrong species and reduce wear on trawl gear. In modern trawl fishing in Norway it has become a norm to use trawl door distance, trawl symmetry and height sensors of the trawl A.

2.2 Protective measures in use

2.2.1 Rock dumping

A traditional protection measure, particularly for pipelines, is so-called rock dumping. The pipeline on the seafloor has rocks placed on either side of it to protect from for instance anchors and overtrawling displacing the pipeline. It is normal to deploy a 1/3 slope of the rock dumping, but it has been suggested that a slope closer to 1/4 would help fishermen avoid rocks in their trawl (see Appendix A).

2.2.2 Protection of subsea structures

The main function of a protective structure is to protect the critical components such as the X-Mas Tree (XMT) with its critical valves, termination heads, piping etc. against dropped objects and fishing activity. THe design of this has to be compliant with the overtrawling demands of the NORSOK U-001 standard [7] (the list of overtrawlability demands is relayed in an upcoming section). In short it demands that the structure design should be subject to a model test or geomet-

Figure 2.3: *A typical subsea template with wellheads and the steel protective cover over it (Photo credit: FishSafe)*

Figure 2.4: *A typical subsea GRP cover (Photo credit: Stangeland Glassfiberprodukter AS)*

rical evaluation combined with model test data, as well as to fishing activity study of the area of installation.

Templates are metal structures for the support wellheads for the retrieval of hydrocarbons as well as other equipment deemed necessary for the operation, such as sensors and subsea separators. They are sized according to what needs to fit under it. Manifolds are where subsea production flowlines are gathered. It is made up of many valves and pipes and are usually mounted on a template with a protective structure over it. Coming in different shapes and sizes, they can be as large as 30 meters high. Most templates and manifolds are protected by 500 meter safety zones centered around a point, restricting other activities, including fishing, in the area. Templates and manifolds usually have a tubular steel protection cover (see Figure 2.3) above them to protect them from dropped objects and fishing gear [27]. Covers made from fiberglass, sometimes called Glass-Reinforced Plastic (GRP) covers, are used to protect a variety of subsea installations such as spools, flexible pipelines, riser bases and pipeline connections. These covers are light, corrosion resistant protective structures for use subsea. They can protect from dropped objects and fishing gear alike and a typical GRP cover can be seen in Figure 2.4 [28].

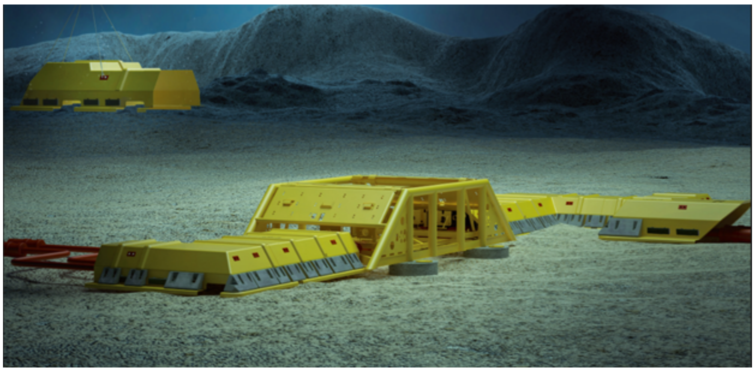


Figure 2.5: *Examples of Subsea Protection covers, GRP for spools and steel frame for templates (Picture provided by Per Nystrøm)*

2.2.3 Supervisor's experiences on overtrawling design from previous projects

One of the supervisors for this thesis is Per Nystrøm, Technical Director at IKM Ocean Design who has years of experience within subsea engineering. He has relayed some of the knowledge gained from previous projects in relation to overtrawling design of structures. Due to the sensitivity of information and respecting the confidentiality of other parties, sensitive information is omitted. The following section is therefore quoted and adapted from Nystrøm, recalling some of his experiences:

Shape and geometry is important in subsea protection structure design. The top perimeter may be open or closed based on needs, and a reason for keeping it open is to allow for vertical tie-in tools to access termination heads for umbilicals and flowlines. However if the top perimeter is kept open, both structural strength and closing of the top hatch (if present) will be challenging. If left open, the top perimeter design should be documented and tested to assure that it is snag free (like the snagging of fishing gear). A key geometrical parameter is the structure's height, as increasing it has a direct effect on the overturning moment induced by trawl doors and trawl pullover loads. The ability to resist overturning is a function of weight and size, and the hollow sections of the structure may be filled with concrete to increase weight. A larger structure foot print is favourable for stability since it increases stabilizing moments and therefore makes the structure less likely to overturn. Typical load cases for trawl loads on a protective structure is shown in Figure 2.6. With this said, the most important aspect of structure design is the foundation.

Horizontal trawl loads are transferred as friction between the mud mats and seabed. To increase horizontal load capacity, rock dumping can be done on top of the mud mats. Rock dumping is also necessary to protect from scouring (horizontal shift due to the seabed giving in). One rock dump

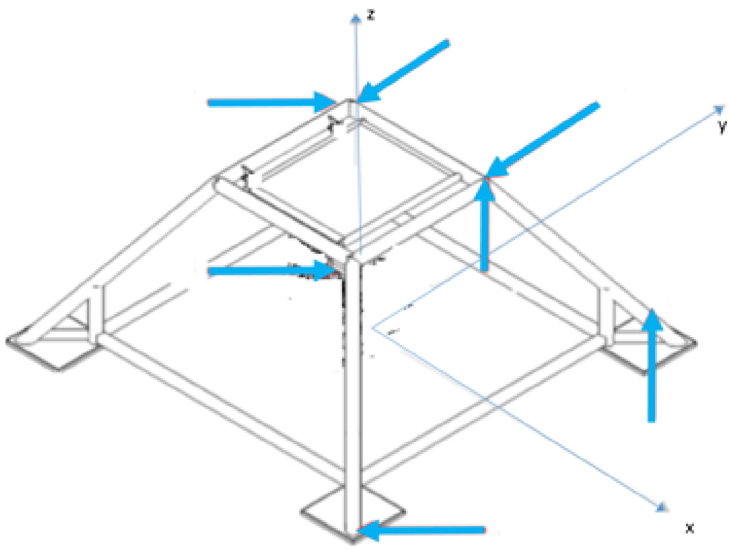


Figure 2.6: *Load cases for a subsea protection structure (Picture provided by Per Nystrøm)*

per mud mat for the structure is typical Norwegian Continental Shelf (NCS) design. The rock dumping also helps with snagging from trawl gear on the mud mats. The height of the rock dump is defined by trawl loads, counter weight requirements, potential for scouring etc. Over-dumping will in generally be advantageous, as it increases stability and scouring protection. It should be noted that vast over-dumping could be in the way of the installation of the cover for termination heads. Ensuring that a trawl door or clump weight can not get stuck between the top member and the rock dump is very important.

As mentioned above, a protective structure should be model tested with a geometrical evaluation. This lets one verify that snagging cannot occur and helps document the magnitude of trawl loads. Corners of the structure should be designed with smooth transitions in the joints to prevent snagging (see Figure 2.7). Pads for lifting and installation (and any other obtrusions) should be placed in a way so they minimize the chances of snagging. To avoid the intrusion of trawl gear into the structure's open spaces, sufficient space and clearance to the components in the structure should be assured.

Protective structures are also in place to prevent trawl doors or clump weights from swinging into the open spaces in the structure and damage the equipment inside. Based on experiences and results from trawl tests, suppliers and designers of protective structures define an exclusion area on the structure (Figure 2.8). In this area no critical or sensitive components should be placed.

In rare occasions the trawl door hangs below the top beam, such as when the trawler stops pulling. Considering a situation where the trawl door is not connected to the trawl net, it can be argued that

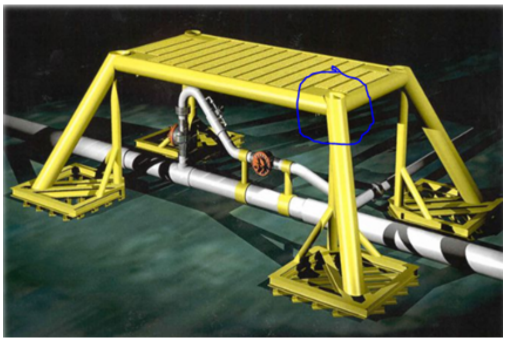


Figure 2.7: *Typical corner of a protection structure (Picture provided by Per Nystrøm)*

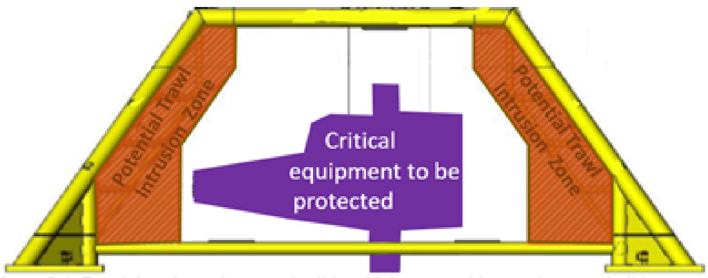


Figure 2.8: *In red: the trawl intrusion area, or security zone, where no critical equipment should be located (Picture provided by Per Nystrøm)*

the trawl door could wing an additional distance. Usually there in tension in the wire that holds the door back from swinging by dragging it back to an angled position, seen in Figure 2.9. In this unlikely event the impact load would be very low when compared to pullover forces.

The objective of trawl tests (illustrative image in Figure 2.10) is both to ensure overtrawlability of the structure, making sure that the fishing gear or structure would take damage and to determine forces during the overtrawl. Scale models are used and different overtrawling scenarios are ob-

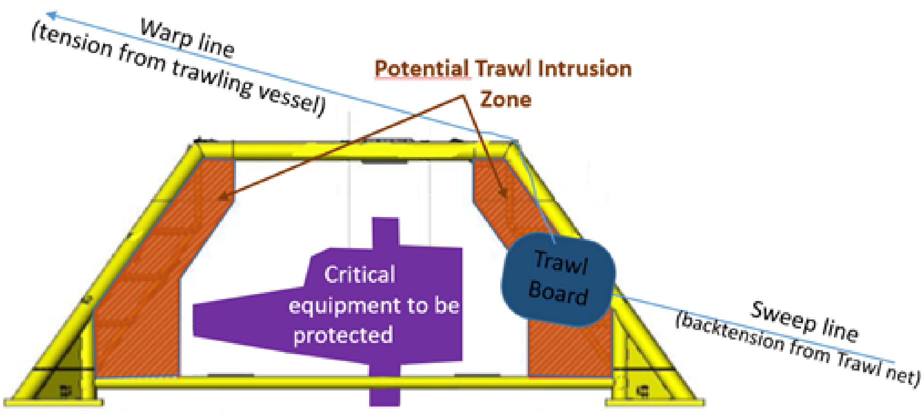


Figure 2.9: *The door hanging off the top beam, where if the trawler stopped pulling the trawl door could swing further into the structure (Picture provided by Per Nystrøm)*

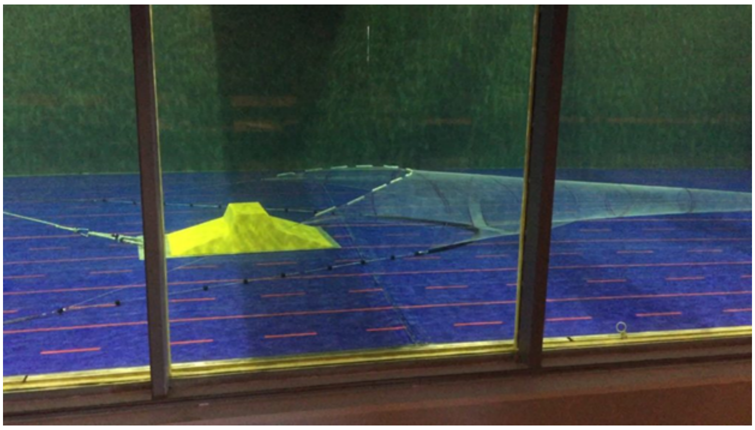


Figure 2.10: *Example of a model trawl test (Picture provided by Per Nystrøm)*

served visually to determine the structure's ability to deflect fishing gear. The direction the gear comes from, at what angles or the way the gear is tuned is changed. Other factors such as type of door or clump weight, trawl nets or warp- and sweepline parameters or the speed of the trawl are also tested. Tests are done in air to detect obvious snagging problems and then the tests are used to define the test program for tests in water. In water more detailed tests are carried out closer to how it would be on the seafloor. The tests should be thorough and recommend improvements to the structure to avoid risk of snagging or entangling, reduce loads on structure and trawl gear and reduce wear and tear.

2.3 Rules and regulations - For subsea pipelines

There are well-developed regulations in place for the handling of subsea pipeline interactions. The most relevant regulatory body for the offshore industry in Norway is the DNV-GL (Det Norske Veritas - Germanischer Lloyd). In particular two of their RP (Recommended Practice) documents are DNV-GL-RP-F111 (*Interference between trawl gear and pipelines*) [3] and DNV-GL-RP-F107 (*Risk assessment of pipeline protection*) [4].

DNV-GL-RP-F111 is concerned with matters of pipeline integrity related to overtrawling, and not the hazards encountered by fishermen. With this, it also stipulates that pipelines and other subsea installations should be routed outside fishing lanes as much as possible. The purpose of RP-F111 is to provide guidance and criteria on pipeline design methods for pipelines interacting with trawl gear. Specifically, it applies to rigid steel pipelines of $>$10" outer diameter as it is the smallest pipeline size tested in their model tests. The two most important types of interactions covered are the impact and pull over phases and their forces. Hooking of the pipeline is treated as a rare event.

The three phases are defined as such:

- Impact: the first phase where the trawl board, beam shoe or heavy clump weight hits the pipeline. It lasts a few hundredths of a second, and the resistance to impact forces comes mostly from the local pipe shell and any coating it may have.
- Pull-over: the following phase where the trawl shoe/board or the clump weight is dragged over the pipeline. It lasts from 1-10 seconds, usually and the response from the pipeline is usually more global.
- Hooking: an event considered rare, where the trawl equipment gets stuck and hitches onto the pipeline. Forces here can be as great as the breaking strength of the warp/towing line.

RP-F111 considers two types of trawling modes in particular, which are the otter trawl and the beam trawl. The most typical trawl boards associated with these are oval/polyvalent and v-boards for otter trawls and beam shoes for beam trawl.

RP-F107 is more geared towards general subsea pipeline and riser protection methods and risk assessment for a variety of operations. About trawling it does offer that pipelines in designated trawling areas could expect a 10^{-2} to 100 hit rate by trawl boards per kilometer of pipe, per year. Failure frequency is regarded to be equal to hit frequency, unless pipelines have special protection in place to protect from trawl board hits. The recommended practice for pipelines of diamater >12-14" is coating, while for smaller pipelines trenching or gravel dumping is recommended. Further pipeline design with relation to trawling refers back to RP-F111.

2.3.1 The physics behind an overtrawl

In the sections 4.3-4.6 of RP-F111, it covers the physics behind the forces and pull-over times exacted upon a pipeline as the overtrawl is taking place. It covers both trawl boards and the clump weight found in some types of twin-trawling setups.

For the total force of a overtrawling situation, one has to consider a horizontal part and a vertical part. Horizontal forces can be calculated by physical dimensions, trawl speed and an empirical coefficient. The vertical forces can then be calculated as they are a function of the horizontal force.

The RP gives the vertical force as such:

Trawl boards:

$$F_p = C_f \cdot V(m_t \cdot k_w)^{\frac{1}{2}} \tag{1}$$

Beam trawl shoe:

$$F_p = C_f \cdot V[(m_t + m_a) \cdot k_w]^{\frac{1}{2}} \tag{2}$$

And horizontal forces as such:

Polyvalent/oval and rectangular boards:

$$F_z = F_P(0.2 + 0.8 \cdot e^{-2.5 \cdot \bar{H}}) \quad (3)$$

V-doors/boards:

$$F_z = \frac{1}{2} F_p \quad (4)$$

Where C_f is a function of the type of trawl gear and geometrical factors that define the trawl-pipeline characteristics, m_t is the mass of the trawl board/shoe and m_a is hydrodynamic added mass. Furthermore, k_{wL} is warp line stiffness and V is trawl velocity. For further details refer to DNV-GL-RP-F111 sections 4.3-4.6 [3]. The background for the equations are specified as model tests done by SINTEF Marintek in the RP.

2.4 Rules and regulations - For subsea Structures

One piece of documentation being regularly updated that deals with the loads of fishing gear on subsea structures is NORSOK U-001 - *Subsea production systems* [7]. As the name suggests it covers many other aspects as well, including riser analysis and wellhead loads not considered relevant for this thesis. The relevant section is *5.3.4 Fishing gear loads* and its subsections. In this section, and indeed the entire NORSOK-standard, it's referred to the ISO 13628 series of standards to be read in conjunction with it. Some of the following things are either borrowed directly or modified slightly.

Firstly it dictates the loads for different types of loads on protection covers on the seafloor. This table can be seen in Figure 2.11. Sources for these numbers are not clearly identified in the NORSOK standard itself.

This table is very similar to the one found in ISO 13628-1, Annex F [8]. It has been modified slightly, increasing loads for certain scenarios and changing which limit state some of these loads should be considered in. The ISO standard does not define what these load numbers are based on. A DNV report from 2007 [10], a so called Joint Industry Project (JIP) was released between the newest edition of NORSOK U-001 and ISO 13628-1, in cooperation with Statoil and Norsk

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.*

Figure 2.11: *Fishing gear load limits as determined by NORSOK U-001 for a typical North Sea location*

Hydro. It declares that the NORSOK standard, at the time, got its numbers from trawl tests done in 1986-88, specifically for 100m water depth and trawl boards mass of up to 1900kg. It does state it is not known where the requirements of NORSOK come from, but suggest a study done at SINTEF Marintek released in 1988 as the source [11]. As the study is restricted, this report only reflects upon snippets such as the abstract and part of the introduction of the study. The study was done to reflect upon the increased masses of trawl gear since the original model testing was done close to 20 years prior, and it is likely that it at least in part was used to define the newer NORSOK standard with increased loads.

The standard determines that loads as a result of snags or impact are to be considered as Accidental Limit State (ALS) and that frictional loads are to be considered as Ultimate Limit State (ULS).

The document dictates how test procedures should be subject to local fishing authorities and how any model tests should be carried out to be considered sufficient for any reduction on design loads for protective structures. The tests can be physical small scale tests or simulation models, where the the simulations must be documented to represent interaction between trawl gear and subsea structure. If it can be documented as such, an overtrawlable structure can ignore snag design loads. Model tests should take into consideration trawling variables such as trawl gear type, trawl speed, water depth, friction and warp line characteristics.

NORSOK U-001 also has a definition of requirements for overtrawlable structures, which is as such:

- protective structure shall deflect all fishing gear
- corners of the structure shall have a maximum angle of 58 °from true horizontal plane to aid in gear deflection for a truncated structure (see Figure X)
- corners of the structure shall have a maximum angle of 50 °from true horizontal plane to aid in gear deflection for a trapezoidal structure (see Figure X)
- corners, ramps and other structures shall penetrate into the seabed to a certain degree as to avoid snagging from warp line and ground rope. Tolerances from installation and scouring of the seabed shall be accomodated
- the protective strucutres geometry and its openings shall be in such a way that trawl doors are prevented from entering into the structure
- if vertical side bracings are present they shall be spaced to prevent intrusion and rotation of trawl gear and at the same time not restrict access for intervention system
- all protrusions are to be designed to prevent the snagging of nets
- external edges or free standing memebers that aren't part of a closed protection structure shall have a minimum radius of 250 mm
- minimum trawl speed is to be 2,8 m/s

The way the standard is worded, along with seemingly insufficient explanations of how the load numbers came to be, it almost seems like the authors of NORSOK U-001 expected the numbers to have some degree of increased conservatism. NORSOK U-001 also suggests the reduction of these design limit criteria can be allowed with sufficient testing can be said to further suggest this.

ISO 13628:15, section 5.2.1.2 [9] sets some extra requirements for use in conjunction with the aforementioned trawl load requirements from NORSOK/ISO. It states that the following shall be established on a project basis:

- historical trawling data for the region of activity
  1. categories of type of trawling equipment
  2. frequency of trawling activity
- expectations for the future
- trawl-load parameters for the structure(s) on the field
  1. trawl net friction [kN]
  2. trawl equipment pull-over [kN]
  3. trawl equipment impact [kJ]

2.5 What the regulations do not cover

2.5.1 Heavy trawl pull-over

Even though RP111 and RP107 contain guidelines for pipeline and trawl interactions, they do not cover every single scenario. To start with, the main focus is on the most common types of trawl modes and trawl gear in Norwegian waters. It is therefore mostly applicable, but not for every situation. Furthermore, it recognizes its own shortcomings when it comes to buried pipelines, as the model tests used did not include these. It does however allow for their equations to be used in such situations, setting the pipeline span height as negative for instance. One particularly interesting thing that is missing from this, is the consideration of forces from the trawl as it is dragged over the pipeline and is full of fish. One would imagine a large trawl, such as in Figure 2.12 [29], with a large amount of fish in it could affect the pipeline in a similar manner as the pull-over of a trawl board (even if the dimensions of the forces and how they act may differ). NORSOK U-001 does have a design load limit for trawlboard overpull, but not one for the trawl itself. It does not specify if this limit state could apply to a very heavy trawl bag being dragged over the structure in question.

Figure 2.12: *A large catch from Icelandic waters, showing the dimensions of a trawl bag full of fish. (Photo credit: Birgir Runar Saemundsson)*

2.5.2 Structural Reliability Analysis in pipeline design

One aspect of subsea pipeline engineering that might see more use is the use of Structural Reliability Analysis (SRA) for a probabilistic analysis approach on trawl loads as well as dropped objects and similar events. An example of this is due to be presented at ISOPE 2019 in Hawaii in a technical paper by *Lyngsaunet et al.* [30]. It deals with subsea pipeline design optimisation within the framework of DNV-GL RP-F111 [3] and DNV-GL ST-F101 - *Submarine Pipeline Systems* [31]. The engineers from IKM Ocean Design and Equinor utilized SRA for a trawl pullover on the Johan Castberg Subsea, Umbilicals, Risers and Flowlines (SURF) project and developed a methodology for close lay of rigid pipelines. The method they developed uses the size and strength of a 12"/16" PIP production flowline to protect a smaller neighbouring 12" gas injection/gas lift from trawl interference loads. As the methodology is in compliance with the aforementioned RP-F111 and ST-F101, the acceptance criteria of the annual Probability of Failure (PoF) less than 10^4 for each separate pipeline.

2.6 Existing work and research

2.6.1 Trawl damage on subsea pipelines

An early study conducted on overtrawling of pipelines was presented in 1975 by Gjørsvik et al. [5]. It contains a literal study, model testing and field testing. It was considered that the largest contribution to forces on a pipeline in a typical trawl situation (see Figure 2.13) was the trawl doors, also known as trawl boards. The reason for this is their big mass as they are dragged over the pipelines at speeds of 3-5 knots. The researchers had identified the forces acting on a pipe in a typical overtrawling situation to be:

- Impact Forces
- Pipeline reaction forces by the trawl door being pulled over the pipe (friction and rotational forces)
- Forces on the pipeline caused by the bending of the towing warp
- Forces on the pipeline caused by hooking, which is to say the door getting hooked under the pipe and dragging it with it

It was also concluded that the impact force was dependent on the pipeline's elastic properties and the coating on the pipe, to a large degree.

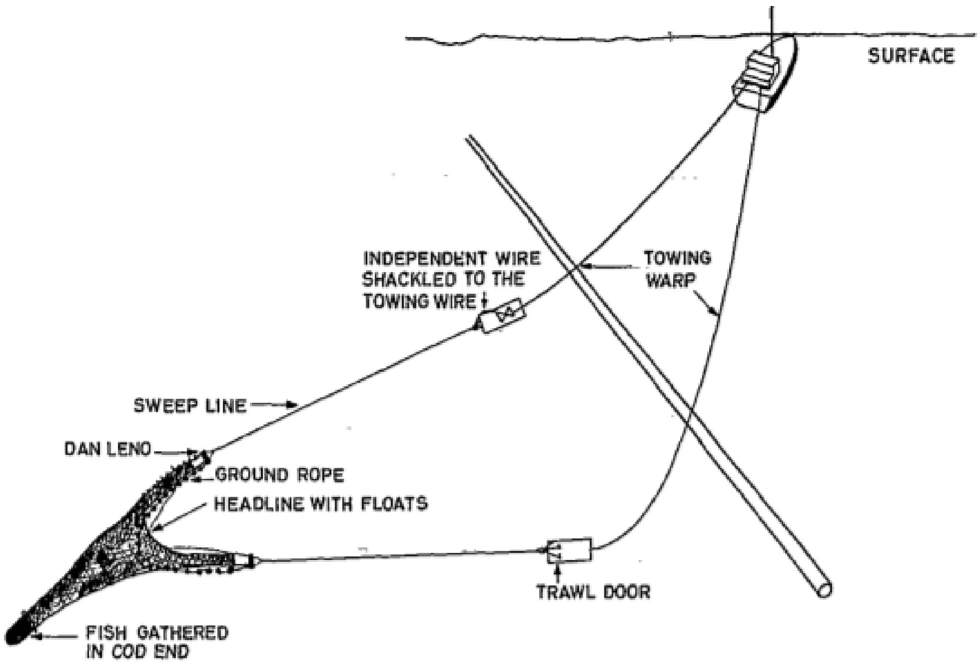


Figure 2.13: *A typical trawling scenario as described by Gjørsvik et al. (1975).*

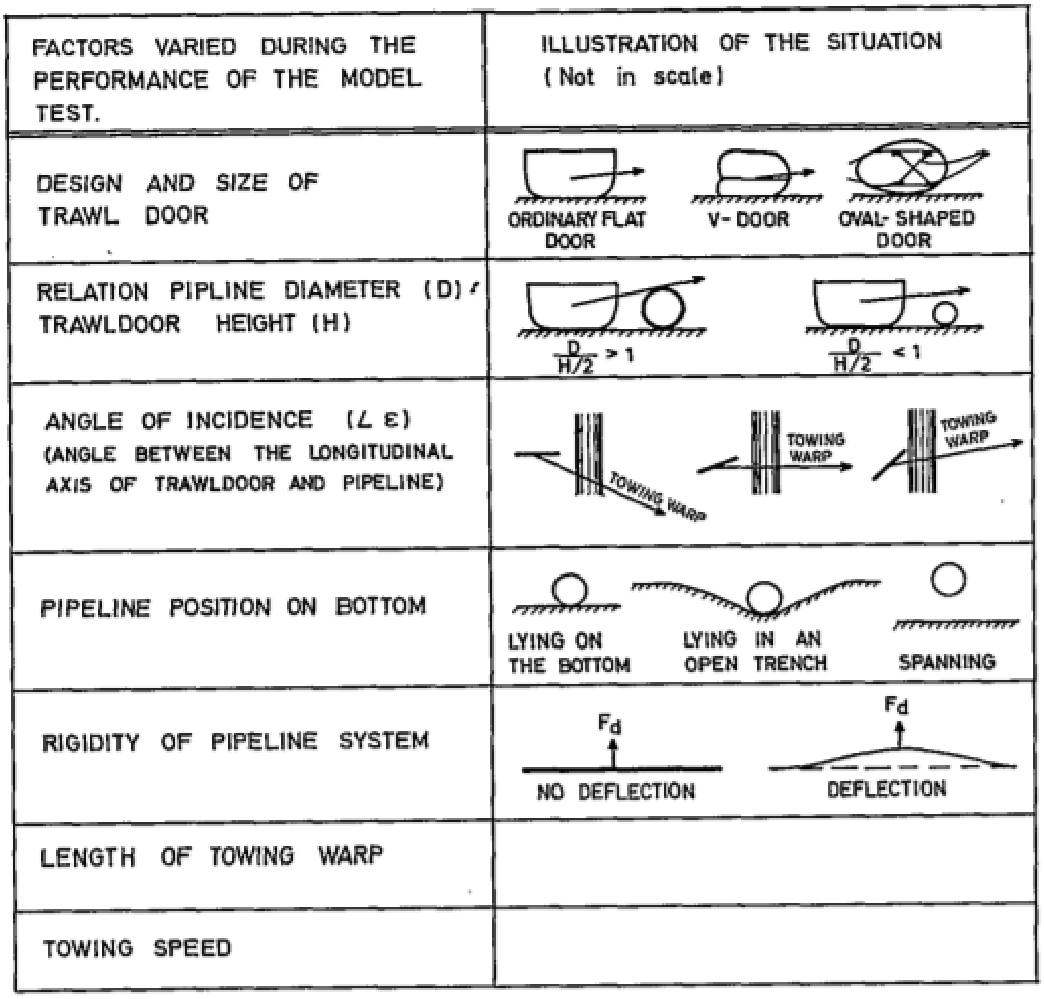
The researchers did scale model testing at the River Harbour Laboratory in Trondheim and field tests at Bjugnfjorden outside of Trondheim. The paper goes into great detail of how the tests were conducted, and the procedure is recalled here:

In the model testing, the basin was a 54 x 20 meters pool, with a varying depth. One part was 1.70 meters deep to accommodate a 20 cm sand layer for entrenching a model pipeline. There was a scale model of each type of trawl door, and the trawl net was emulated by the use of a "parachute" to cause a similar drag effect on the pipe. The force on the pipeline was scaled along with the size of this parachute. The towing wire was winched with a damping device to simulate elastic properties of an actual towing wire. The pipe model was supported by two different frame types in each end: one rigid to simulate pipeline reaction forces in horizontal and vertical direction and one to simulate elastic pipeline properties in the horizontal direction. The model scale was 1:4 and the force scale was 1:64.

For recording the towing forces, both continuous and the added force from the trawl door, a dynamometer on the towing line was used. The sweepline force of the towing warp was measured by a separate dynamometer. To measure the force as the trawl doors collided with the pipeline, three accelerometers were put in place. The pipe sections where the trawl doors would hit the internal pressure was monitored with manometers.

The model test varied different parameters as described in Figure 2.14. There were three type of typical trawl doors with the V-door having two different sizes. Two variations of pipe diameter were used: 22.5 cm corresponding to 90 cm full scale pipe and 10 cm corresponding to 40 cm full scale. The angle at which the door hit the pipe was varied as the researchers reckoned it would change the behavior of the trawl doors. Different degrees of pipeline burial, as is often the case, was included. To test for hooking the pipe was put in an elastic frame construction so the actual rigidity of the pipe could be simulated. Taking trawl warp elastic behavior into the model was done by attaching springs with differing properties into the line. Two different speeds were tested, corresponding to 3.5 knots and 5 knots full scale speeds. The parameters that were varied during their testing is presented in Figure 2.14.

During the field tests, some limitations were in place. For the researchers to be able to have divers investigate the effect of the impacts it was done at a small depth of 20 meters, which led to the use of a quite small trawler vessel of 150 BRT (Bruto Registered Tonnage). The resulting test was therefore considered to be a 1/2 scale test of what could be expected in a real world overtrawling scenario. In the field test the pipe was 300 meters with 16” diameter. The monitoring setup was quite similar to how the researchers solved the field setup: measuring trawl warp forces, trawl door forces and incline of the trawl door as it hit the pipeline. The tests were carried out with so-called V-doors, seen in Figure 2.15, with two different masses of 500 kg and 975 kg. Angle of incidence, the angle at which the trawl door hits the pipe, was varied between 30° and 90°. Towing speeds were between 3.5 and 5 knots. Frogmen were sent by researchers to inspect the impact zone and mark it with the test number.



FACTORS VARIED DURING THE PERFORMANCE OF THE MODEL TEST.	ILLUSTRATION OF THE SITUATION (Not in scale)
DESIGN AND SIZE OF TRAWL DOOR	ORDINARY FLAT DOOR; V- DOOR; OVAL- SHAPED DOOR
RELATION PIPLINE DIAMETER (D)/ TRAWLDOOR HEIGHT (H)	$\frac{D}{H/2} > 1$; $\frac{D}{H/2} < 1$
ANGLE OF INCIDENCE ($\angle$ ε) (ANGLE BETWEEN THE LONGITUDINAL AXIS OF TRAWLDOOR AND PIPELINE)	TOWING WARP; TOWING WARP; TOWING WARP
PIPELINE POSITION ON BOTTOM	LYING ON THE BOTTOM; LYING IN AN OPEN TRENCH; SPANNING
RIGIDITY OF PIPELINE SYSTEM	F_d NO DEFLECTION; F_d DEFLECTION
LENGTH OF TOWING WARP	
TOWING SPEED	

Figure 2.14: *The parameters in the model test that were changed during testing*

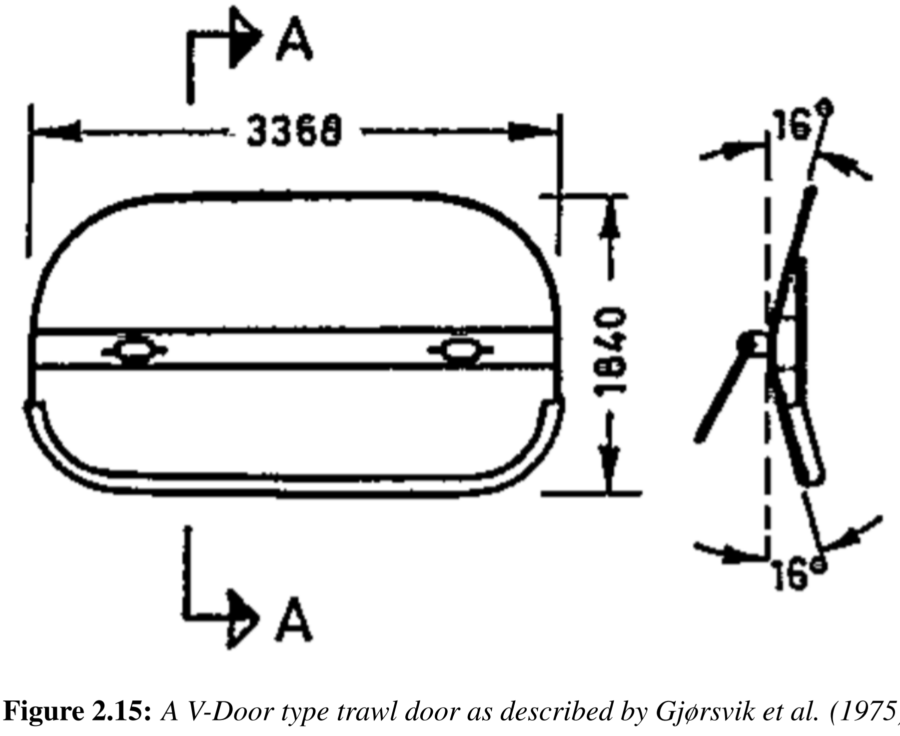


Figure 2.15: *A V-Door type trawl door as described by Gjørsvik et al. (1975)*

The results from the work of Gjørsvik et al. developed into a larger project, where their work became the first phase. The results from this research was presented by Moshagen and Kjeldsen in 1980 [6], along with the other phases of the project. These other phases also included pipelines of different diameter (36") with different types of coating and properties. Other trawl modes were also studied, as in addition to the otter trawl setup described by Gjørsvik et al. (with V-doors and oval doors) a beam trawl setup was tested with its own type of trawl board (see Figure 2.16), which is seen as a less relevant trawl technique in the Norwegian Economic Zone [15]. The other phases of the study also looked into entrenched pipelines and its effect on forces on the pipelines. Part of this research was cited in DNV-GL-RP111.

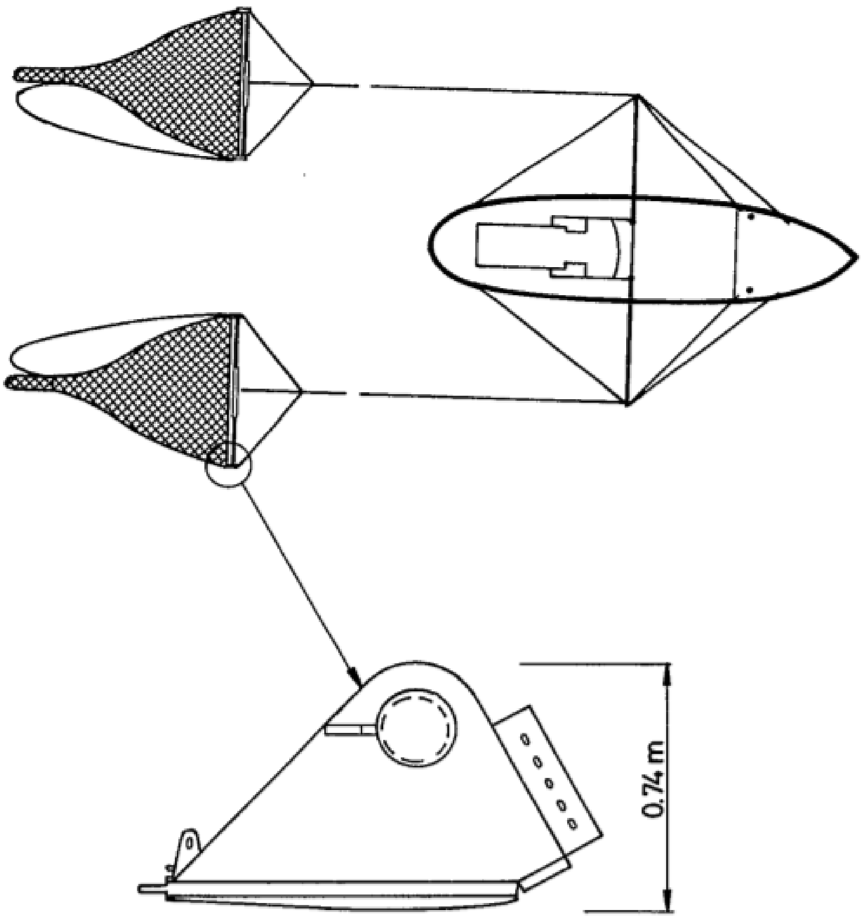


Figure 2.16: *Beam trawl setup, also showing the beam trawl shoe*

Some of the main conclusions the overall study came to were:

- The tested type of trawl doors gave little difference in their behavior when passing over the pipe and the pull over load itself.
- Pipelines on the seafloor are less subjected to loads than spanning pipelines. Furthermore, the entrenched pipelines tested did not reduce the pull over forces to any large degree and sometimes even increased it.
- Passing the pipe at an angle resulted in lower pullover force than a straight pass.
- Pull forces were higher for the smaller 16” pipe compared to the 36” pipe.
- Pull forces increase by 20% for a spanning pipeline.
- Where concrete coating was present on the smaller pipeline, it was severely damaged. The pipeline inside however was practically undamaged.

Moshagen and Kjeldsen [6] also concluded that the contact loads towing warp was of less importance than impact force or pull over force, with the latter being of utmost importance to design and classification. It was found that hooking of a pipeline was quite unlikely, where V-doors could hook after passing in soft seabed conditions. Further research on hooking by beam doors on small diameter pipes were recommended.

More recently, researchers have used more modern tools to look at other particular pipeline overtrawling scenarios. For instance in 2012 Kristoffersen et al. [32] from IKM Ocean Design modeled clump weight overtrawling of Pipe-in-Pipe designs. The researchers simulated overtrawling of PIP configurations using the Finite Element (FE) simulation program SIMLA, made by SINTEF Marintek. The model itself was a complex one, as there was a need to model the carrier pipe and the inner pipe in one stretch while conforming to the limitations of the FE-model. Their way of modelling the PIP can be seen in Figure 2.17. A PIP configuration has one pipe for fluid flow inside it, with a carrier pipe insulating it to protect from hydrate or wax formation. The inner pipe was modeled as 9” inner diameter at 300 barg of pressure and 110°C. Their outer pipe was at a 15” outer diameter, 1 barg and 10°C. The uneven seabed and rock cover environment was also included on the model.

The study modeled two clump weights of 5 tonnes and 6 tonnes respectively at a velocity of 2.8

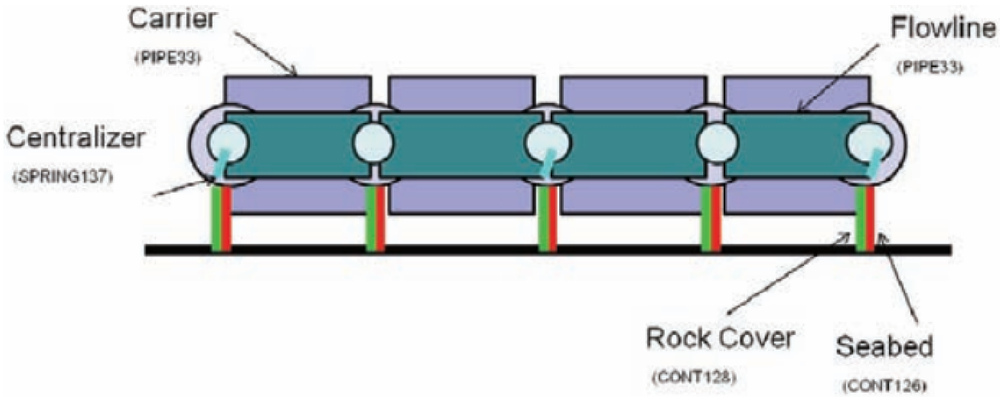


Figure 2.17: *FE-model for the PIP and rock cover/seabed conditions as it was done by Kristoffersen et al.*

m/s. These are well within the limits of the RP-111, suggesting as high as 9 ton clump weights could see use [3].

Some of the conclusions reached by the researchers were that a PIP design improved the possible design trawl loads over a single pipe, and the global buckling was restrained by the carrier pipe. Furthermore it was seen by the modelling that lowering the carrier pipe's temperature, usually considered better for utilization ratio, could stop the PIP from buckling and that the trawlover might further result in a much more severe "snap buckle"

2.6.2 Trawl damage on subsea structures

Around 15 years ago a study was conducted on the overtrawling of protection covers typically used around Haltenbanken in the Norwegian Sea [33]. This study was conducted in accordance with the previously mentioned NORSOK U-001 (as the tests were conducted previous to the newest version being released), and the results of load tests compared with these. The tests were conducted at a research facility in Norway. The tests were conducted with an overall scale of 1:10 in what constituted deep water ($>$ 300 meters water depth, the actual depth at the Haltenbanken subsea field) and 100 meters water depth. The researchers identified door types that were currently being used, had been used in the past and ones that were foreshadowed to take over regular use in the future. In testing this was reduced to one door type, the Poly-Ice Viking (a product of the Icelandic manufacturer Hampidjan), due to it giving the highest forces. The researchers also ran tests with beam trawl gear, deemed not relevant to the Norne field. Two types of protection covers were used in these tests: a small pipeline inline with closed areas with 60° inclination of the side walls over rock dumping level and with 200-300 mm radius on external curved surfaces. The other type had , 45° inclination over rock dumping level. The latter is comprised of 4 covers in a curved line, where the end covers were domed and the middle ones had vertical side walls. Production jumper covers were modeled in foam material and reinforced with fiberglass, while the Tee cover was made in thin plate steel. Covers were modeled with a rock dump with a 1/3 slope. The tests were run at 2 m/s speed with warp line elasticity at 37.9 kN/m. A higher tension elasticity of 143.5 kN/m was used to model other water depths.

From the testing of 100m and >300m equivalent test cases, and with data from earlier projects, the researchers made a evaluation of loads at 4 depths: 100m, 200m, 300m and 500m. From the test results for >300 m and with historical data, researchers assessed trawl loads for a cover similar to the small pipeline inline cover at a few meters height over rock dumping.

Water depth (m)	Tee cover		
	Net (kN)	Door (kN)	Beam trawl (kN)
100	95	95	110
200	90	90	105
300	90	90	100
500	85	80	85

Water depth (m)	Production cover		
	Net (kN)	Door (kN)	Beam trawl (kN)
100	100	95	150
200	95	90	140
300	95	90	135
500	90	85	115

Trawl gear	Tee cover 1 m height above rock dump	Tee cover 2 m height above rock dump
	Measured Force (kN)	Estimated Force (kN)
Net	87	100
Door	91	130
Beam trawl	101	145

Figure 2.18: *Loads found from the Haltenbanken model tests*

The results of this field model tests were be seen to be significantly lower than the generic requirements provided in NORSOK U-001, for both the tested covers. In this given case, design loads for such protective equipment in the North Sea can be reduced. The NORSOK standard does allow this, given that it's procedures are followed (which it has been in this case). The results of the study's tests raise questions about the accuracy and level of conservatism in the NORSOK regulation.

In 2013 a master's thesis was done by Jacob C. Emesum at the University of Stavanger [34]. It was done in cooperation with an external supervisor from Statoil (now Equinor). In this thesis the author conducted impact tests on copper pipes (length by outer diameter of 320 mm x 15 mm) by trawl gear. In these tests empty pipes, water-filled pipes in air and water-filled pipes in water. The tests did have multiple assumptions and limitations, such that they may be considered ”idealized” testing conditions. These tests showed that the water-filled pipe had greater resistance to the impact than the air-filled ones, possibly due to the pressurization of the water inside on the point of impact offering resistance to the impact energy. The medium where the pipe was contained, air or water, seemingly had less impact on these results.

The thesis brings up concerns in relation to the conservatism of standards for overtrawling in use, such as NORSOK-U001 and DNV-RP-F111. It is stated that internal documents in use at Statoil use multipliers in trawl board pull-over loads by a factor of 1.5 and trawl board impact by a factor of 2.9 compared to the levels used in NORSOK U-001/ISO 13628. The author also compares what he calls ”simplified formulas” in DNV RP-F111 to other known formulas (Ellinas and Walker's theory). The results of this comparison was that impact energy delivered to pipes using DNV's ”simplified” physics were 2.73 times larger on average. This increased conservativity on impact interactions combined with Statoil's internal practises, he argued combines to a total conservativity factor for trawl board impact of close to 8 (2.73 x 2.9). In conclusion, the report questions the great levels of conservativism in the design requirements of NORSOK U-001 and DNV-RP-F111, and whether companies such as Statoil (now Equinor) should continue to increase design loads to the degree they have been.

2.6.3 On trawl gear trends

A mapping of gear and vessel size trends akin to the ones presented in this thesis was not encountered during research. But in 2011 [35] a team of researchers researched the connections between, among other things, vessel horsepower and the circumference of the effective area being fished (called the fishing circle). The study used interviews to map gear in use in 5 European countries: Norway, Ireland, Denmark, the Faroe Islands and Italy. They also considered the type of fish being caught and what kind of rigging was used, such as multiple trawls. Researchers found that a linear relationship for the size of the fishing circle and horsepower, meaning that a more powerful vessel would sweep a larger area with its trawl and gear while fishing. One could say that an implication is that more powerful vessels fishing on the seafloor would sweep over more seabed, and have an increased chance of interfering with trawl gear.

3. Method

3.1 Literature review

A literature review was done. After recommendations from IKM, the DNV regulations that are in place were first explored to see what was already in place to deal with trawling damage on protective structures. Regulations for over trawling of subsea pipelines, such as DNV's Recommended practices, on pipelines was looked into, as they are well-developed, as well as the regulations that do exist for protective structures specifically (such as NORSOK U-001). Research related to these regulations and research work that, at least in part, touched on overtrawling damage on subsea installations.

3.2 Interviews

A number of knowledgeable people, from here on referred to as experts, were interviewed for this paper. These people's opinions and experience with the trends in the fishing and trawling business is of great value to consider the trends in sizes of fishing vessels and equipment and the technical/practical aspects of how trawling is done. As such, the insight gained from these interviews were able to be used for both theoretical background and the results of this paper. The results from these interviews can be seen in Appendix A.

Interview objects were chosen based on the supervisors recommendations. They were from the fishing industry, oil and gas industry, from regulatory bodies and from research institutions. A list of questions to be asked was compiled, and sent out in advance so that those interviewed could prepare. It was sent out to a selection of people but only a couple responded and has been included in this thesis. One interview was done in person in Bergen, while two were conducted via e-mail correspondence and over the phone. Later on in the project work, the contact information for a trawl ship captain was obtained and an interview planned. Questions for this person was adapted from the initial question list sent to the other industry experts to better cater to their experience.

3.3 Ship database and data analysis

3.3.1 Ship database spreadsheet

A database of trawling ships used in Norwegian waters and surrounding areas was made in spreadsheet from in Microsoft Excel (see Appendix B). Reason for this is it is likely that these *could* arguably interact with trawl gear on the NCS. It includes ships registered in Norway as well as Denmark, Iceland, the Faroe Islands, Greenland, Russia, and other European countries. Some ships from countries such as Canada were included, as the ships used here have some of the time previously been used in the aforementioned areas or the type of ship and equipment used is very similar. Several manufacturers were contacted, but due to a lack of responses only two manufacturers gear were considered: Rock Trawl Doors and Thybor øn Trawldoors. They had open access to which ships had purchased their gear going as far back as 2015 and ways of getting trawl gear data was also available. These ships, and their type of equipment, was mostly found on the trawl gear manufacturer's websites that have delivered to the given ship. The gear dimensions are based on the data sheets from the manufacturers or on information gained from interaction with the manufacturer. A lot of gear is made on the specification of the customer, both concerning surface area and trawl door weight. Due to this, some of the sizes used that are out of regular spec could not be included in the data set. In the case of the semi-pelagic and bottom trawl doors from Rock Trawl Doors, a "rule of thumb" table was provided by them when contacted (see recreation in Table 1). This was used to determine trawl door weight for the vessels that used them. When the door fell between the given sizes, linear interpolation was used to estimate the trawl door weight (when trawl door area was known). In the few cases when it was larger than 15m ^{2} a conservative weight of 250kg per m ^{2} was used to estimate the weight. Due to the fact that the gear is made to specification, these estimation's accuracy can not be fully known. This database was made by using the International Maritime Organization (IMO) number, and then cross checking this with databases such as DNV-GL Ship register (for DNV classed ships), Søfartsdirektoratet (for Danish ships) or online databases that track such ships and keep updated names for them, such as marinetraffic.com. By using the IMO number, it lets one know which ship it is even if it would change name or flag in the future (or has since the source of information was updated). Dimensions of the ship itself, such as length and width, engine power output and build year were all included in the database when available. The ship's owner and flag, at the time of the data being recorded, are also included. Trawl gear type, manufacturer and area of use, and their sizes and weights are included, specifically trawl boards and clump weights. All these data were acquired as far as possible, mean-

Door size	Door weight
3,5 m^2	1000 kg
5 m^2	2000 kg
8,5 m^2	3000 kg
10 m^2	3900 kg
12 m^2	5500 kg
15 m^2	7000 kg

Table 1: Rock Trawl Door ”rule of thumb” table for door size vs door weight

ing there are more data points for certain categories compared to others. Due to this, some results from the data analysis could be more indicative of actual conditions than others.

3.3.2 Ship parameter data analysis

Data analysis was done in Microsoft Excel for simplicity and convenience sake, as well as it being deemed to have the sufficient capabilitties for this study. The data was turned into graphics to be able to look at trends and developments in the equipment being used today, where there are ships having been built as far back as the 1980s. All vessels included in the data set were outfitted with their gear within the last 5 years, meaning that they all carry quite modern gear. This means that the data analysis more reflects current ships in use. The results from the data analysis was compared to the expert’s opinions gained from the conducted interviews to see in what way representatives of the industry compares to the perceived trends.

4. Results and discussion

Results from the data analysis if the data set in Appendix B are presented here, as well as the results gained from the interviewed experts. After follows a discussion of the results and potential modes of error are decalred as well as recommendations for future reaearch.

4.1 Interviews - industry expert's viewpoints

As mentioned previously, a part of the method for this thesis was a questionnaire and interview process. They were conducted with people that were identified as experts or particularly knowledgeable and/or experienced in the field of trawling. Questions asked was both to gain insight in the trawl industry and stake a course for this thesis, but also their views about the trends and developments in the trawl industry. An overview of the questions and answers is found in Appendix A.

The experts who were interviewed were mostly in agreement regarding the development occurring in ship and gear size. According to them, close to every aspect of ship dimensions have been in a period of growth for some time, with the largest increase in size being in relation to bottom trawling. This was in part accredited to structuring in the business of fishing, with fewer vessels with larger capabilities taking over for smaller but more numerous vessels. Economy and fishing efficiency has been a driver for this development. It has been a question for a number of years when this will stop, but it is also suggested that higher bunkering fees would likely have a self limiting effect and that other ways of making fishery more effective would arise. Underlined was also the fact that there was little interest in ”overdimensioning” any such factors, but they were limited in a way that the fishermen could always keep up the rate of catch that they wanted. This applied to such as weight and size of gear, trawling speeds and number of trawls used at one time. Limiting trawl speed factors would be engine output, size of gear and number of trawls. Heavier gear and larger trawl demanding more power to pull it. When asked what would affect the forces enacted by trawl gear, one of the experts answered that ship mass, engine power and gear weight were the most relevant factors.

4.2 Data analysis

A data set was made from the collection of ship data from ship tracking sites and trawl gear manufacturers. This data set can be seen in Appendix B, and includes ships as far back as 1968, and as recent as 2018. This analysis could help point towards what can be expected in the future, as it looks at trends in the industry and connections between different ship and gear dimensions.

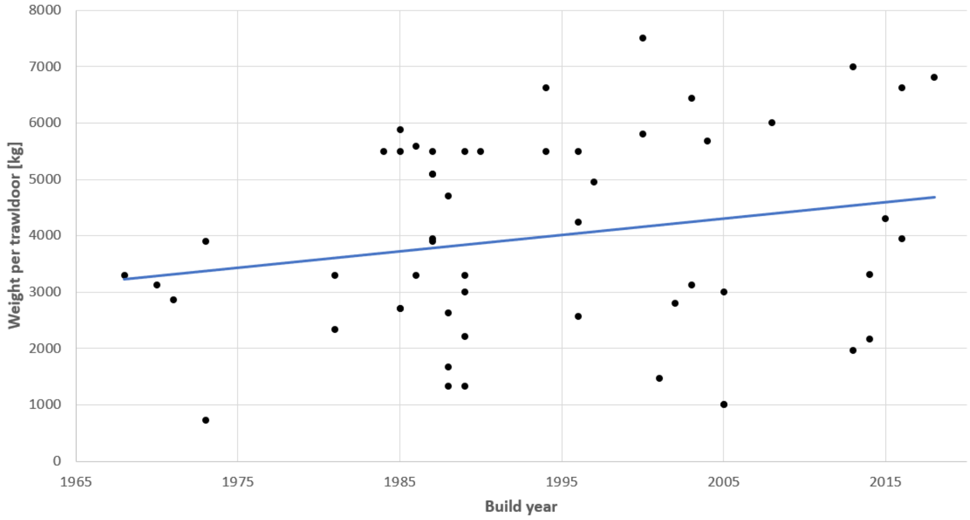


Figure 4.1: *A scatter plot showing the relationship between the build year of the ship and the weight of its individual trawl doors, with 54 data points. A trend line has been added to visualize the development more clearly (y = 29,257x - 54354).*

Figure 4.1 illustrates how the weight of trawl boards on newer ships is higher on newer ships, with the heaviest (> 6000kg) being mostly on ships from the last 20 years. This indicates a relationship where newer ships have a capability of utilizing heavier trawlboards than older ones, despite using similar, modern equipment made within the last 5 years. If such a trend were to continue, it would be reasonable to assume that the likelihood of an interaction between a ship and a subsea structure to involve such heavy trawl doors is increased. The largest at 7500 kg is above the largest considered in use for industrial trawling by the DNV-GL in the North and Norwegian Seas [3]. The number is the result of a conservative estimate, as the size exceeded the table provided by the manufacturer (Table 1). Figure 4.2 has the same data, but with color added for the 6 main countries of origin for the ships. It is hard to draw any conclusions based on this, but it aids in visualizing the representation of countries for the selection. Perhaps more interesting is Figure 4.3 illustrating the types of trawl door equipped on the ships. Semi-pelagic/pelagic/flying bottom trawling door types are represented by red dots, while traditional bottom trawl door types are left black. Of the 54 ships in the selection 24 has a multipurpose type board that could be used for bottom trawling as well

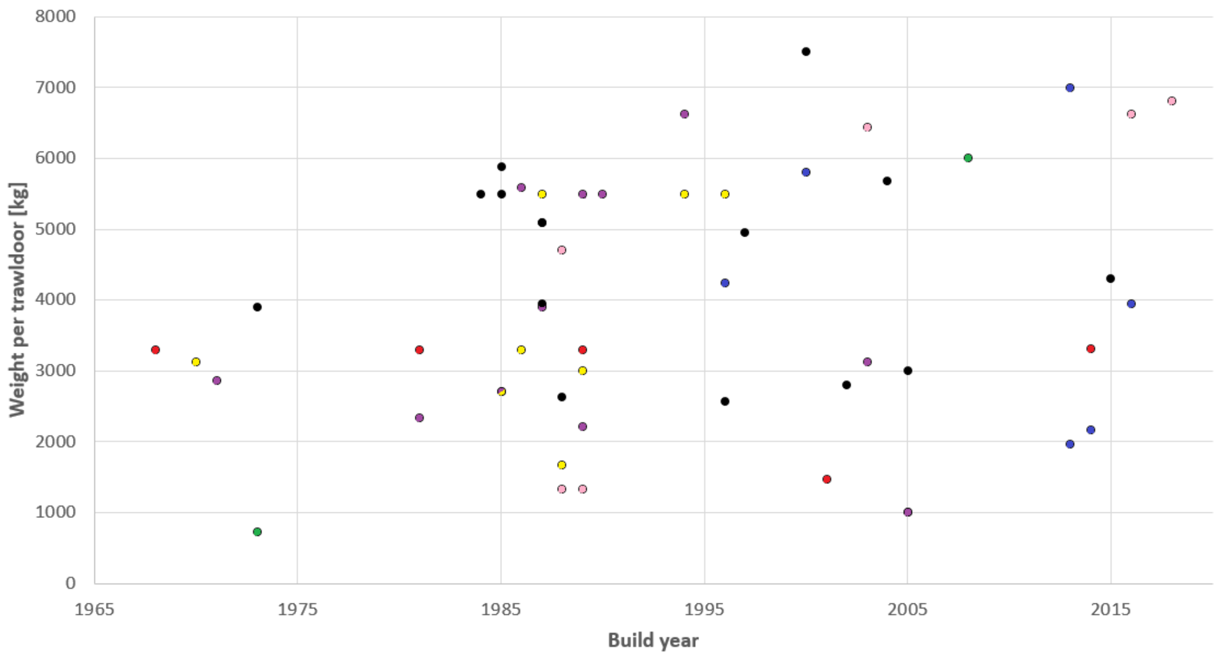


Figure 4.2: *The same scatter plot from Figure 4.1, but with the data points colored in to represent ship flag country: Red = Iceland, Yellow = Russia, Green = Denmark, Purple = Faroe Islands, Blue = Norway, Pink = Greenland. The ones left black are other countries*

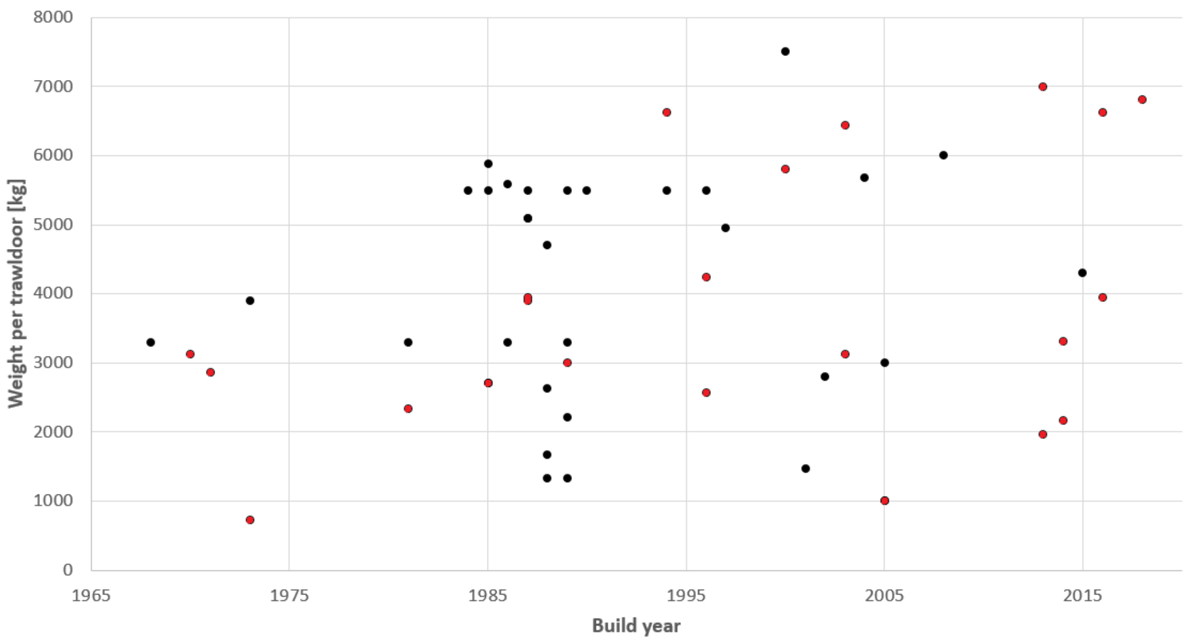


Figure 4.3: *The same scatter plot from Figure 4.1, but with the data points colored in to represent type of trawl door. The red points are trawl doors that are of a semi-pelagic/flying bottom trawl door variant, while the black points are traditional bottom trawling doors*

as pelagic/semi-pelagic trawling, which is about 44% of the total selection. Such a high number is surprising, given what the interviewed experts relayed (see Appendix A). But, it is not given that

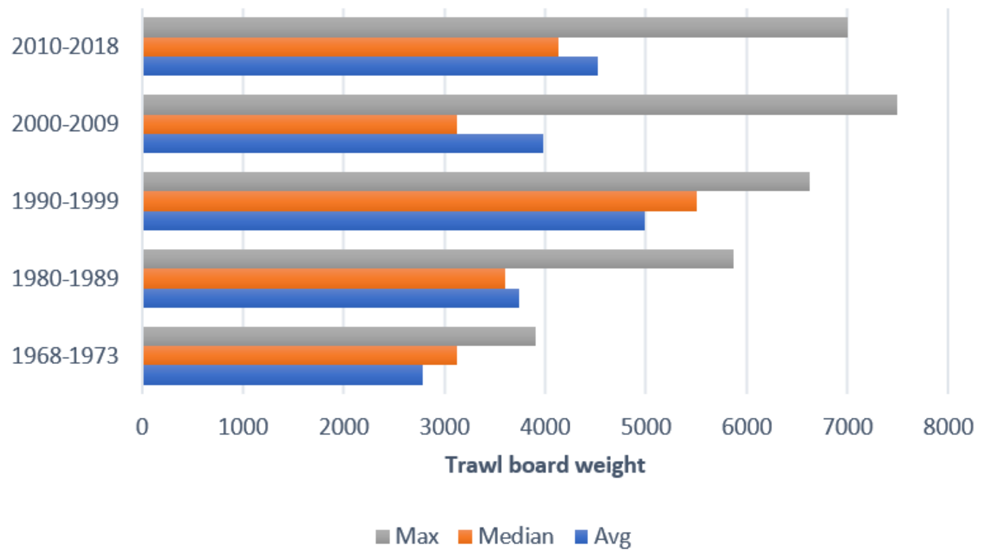


Figure 4.4: *A bar diagram depicting the average, median and maximum trawl door weight broken down by which decade the ships were produced. Data from the oldest ships, 1968-1973, were put together because of a lack of data.*

they deploy these trawl board for bottom trawling, though it is plausible that they *could* do that. Furthermore, the experts commented on Norwegian ships and this selection includes vessels from several other nations as well.

By looking at the breakdown of this same data set in Figure 4.4, it adds some further context. One can again see that the largest trawl door weight belongs to one the most recent ships, as displayed by the ”Max” value. But one can also observe that the average and median trawl board weight hasn’t had the same kind of development. On the contrary, it indicates that it has remained quite stable except for a more significant peak for both in the 1990s. So any given interaction between trawl board and subsea structure from newer ships does not necessarily involve a heavier trawl board, on average. Together with Figure 4.1, it points to a *potential* of a newer ship using a heavier trawl board design.

Larger ships would presumably enable larger gear, and also in the graph in Figure 4.5, an attempt to identify a development of the size, as Gross Registered Tonnage (GRT), of ships being built in the last decades. The trend line for the entire data set indicates that the ships getting built are generally larger than before. With this said, the very heaviest ships from the collected data set were built 25-30 years ago, which can be seen marked in yellow. To see to what degree they affected the trend, a second trend line was made with these points excluded. As can be seen, the upward trend was slightly reinforced with a steeper slope when this was the case. A separate plot for the

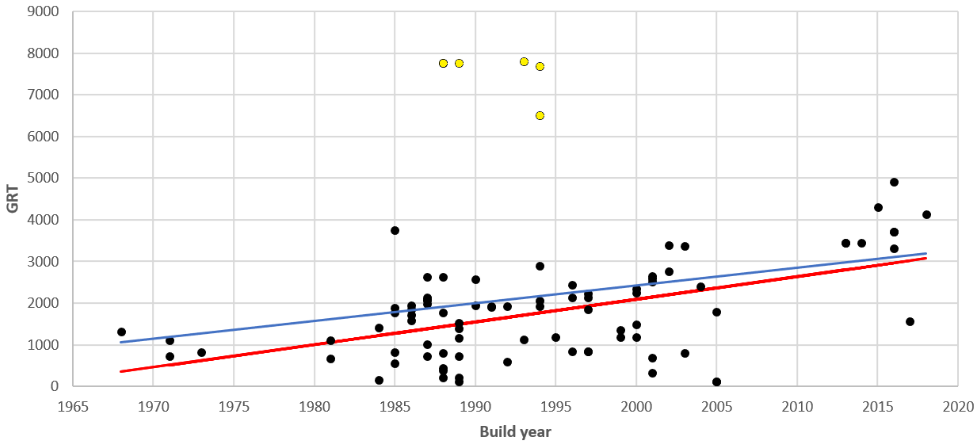


Figure 4.5: *A scatter plot showing the relationship between the build year of the ship and its GRT, with 90 data points. A trend line (y = 42.647x - 82875), blue, was added to be able to visualize the development. The second (red) line represents a trend line for the same data set with identified potential outliers (marked in yellow) left out (y = 54.431x - 106769).*

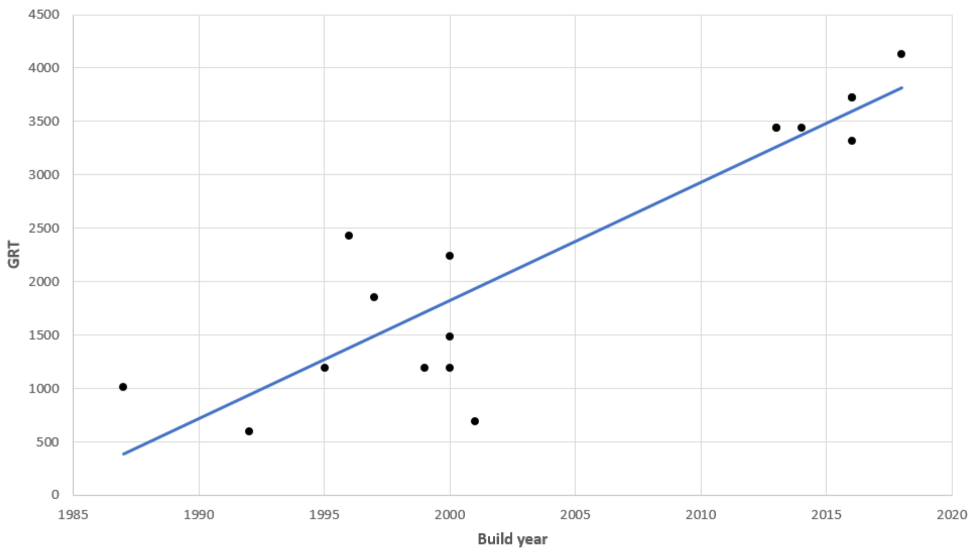


Figure 4.6: *From the same selection as Figure 4.5, but only looking at Norwegian ships, a total of 15 data points. A trend line has been added (y = 110,5x - 219167)*

development of the Norwegian ship size is also included in Figure 4.6. As can be seen, it also follows the same trend of newer ships being larger, but with a steeper slope in the trend line. This is particularly interesting, as it lines up very well with what was stated about Norwegian ships by the interviewed experts A.

To complement the scatter plot, Figure 4.7 was made from the same 90-point data set. It correctly shows that the ships with the largest GRT were produced in the 1980s and 1990s, as could be seen before. The graph also adds context to the upwards trend from earlier, by showing that the average

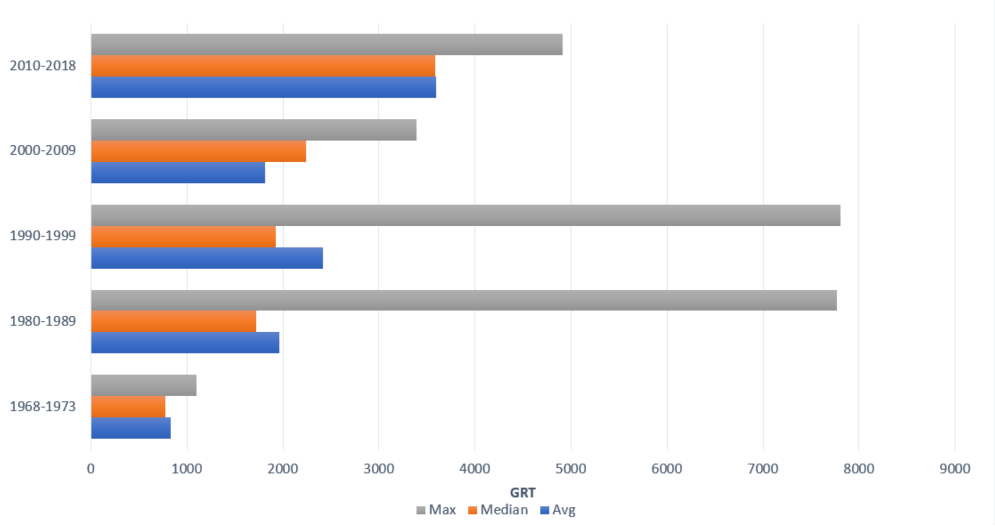


Figure 4.7: *A lying bar graph depicting average, median and maximum GRT of ships broken down by the decade of the ship's production. The oldest ships, 1968-1973, were put together due to a lack of data.*

and median GRT has for the most part increased steadily over the decades (with the average only dipping slightly from the 1990s to early 2000s). This data set thus implies that any given ship built more recently is, on average, likely to be larger than ones built a longer time ago.

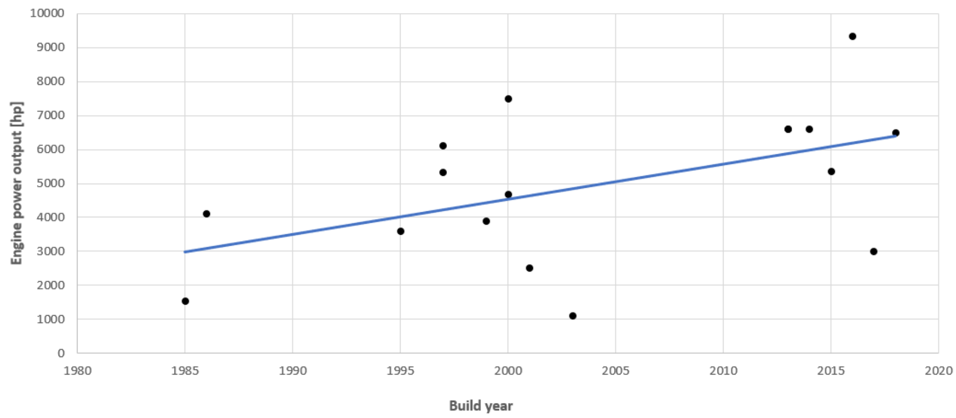


Figure 4.8: *A scatter plot showing the relationship between engine power output and build year. Trendline has been added to illustrate the development (y = 103,75x - 202972)*

Figure 4.8 shows a trend of increasing engine power output in newer ships, meaning possible increased capabilities. A larger ship with a larger engine could exact larger forces during an over-trawl if we go by what was learned from the interviews (Appendix A). Further, by simple logic, it makes sense that a larger ship would require more power to be able to complete a similar task, all else being relatively equal. In Figure 4.9 it can be seen that the engine power of a ship and its gross tonnage seems to have a quite close relationship, with them seeming to peak and fall at the same time.

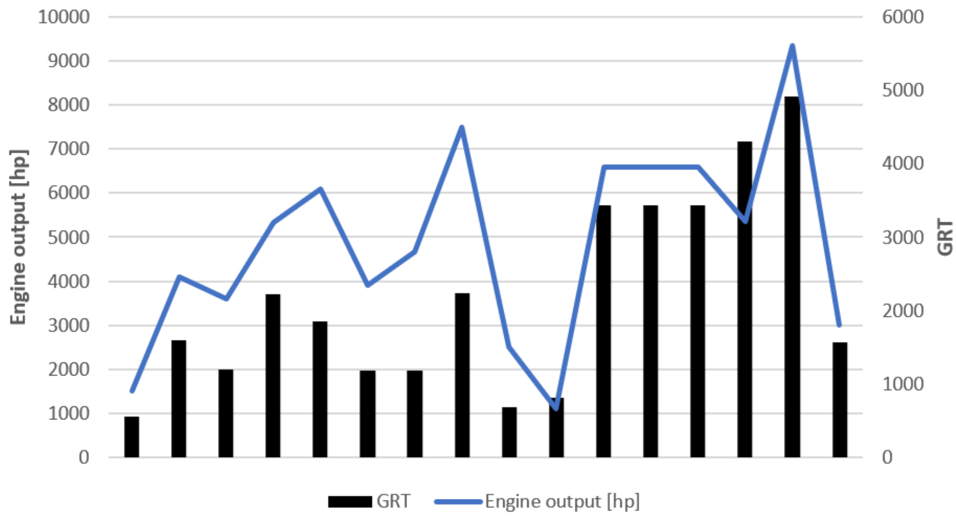


Figure 4.9: *A combined bar and line diagram displaying the relationship between the size if a ship, displayed as GRT, and its engine's power output.*

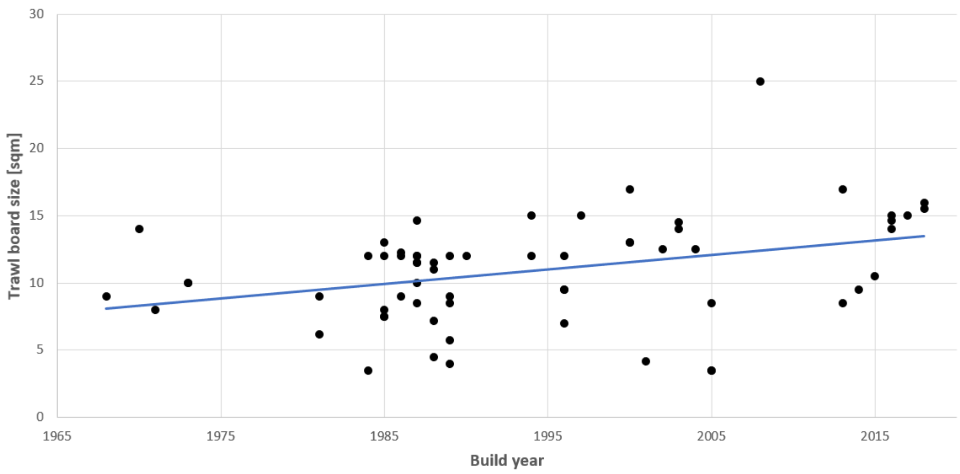


Figure 4.10: *Scatter plot of trawl board size in relation to build year of its respective ship, with 63 data points. A linear trend line has been added to more clearly illustrate the development (y = 0.1079x - 204.33)*

Figure 4.10 shows the relationship between the size of equipped trawl boards in relation to when the ship it is fitted on was built. It indicates that there is a positive trend and therefore that newer ships deploy larger area trawl boards than older ones. The trend is further broken down in Figure 4.11.

Looking at Figure 4.11, it can be seen that the average and median trawl board has a tendency to be larger on recent ships, with a slight incline for every decade (except for 1960-1980s). It can also be seen that the largest boards are on ships built within the last two decades. A larger surface area trawl board on the sea floor would likely have an increased potential of interfering with more subsea structures and gear. Were this development to continue, an increase in average trawl board

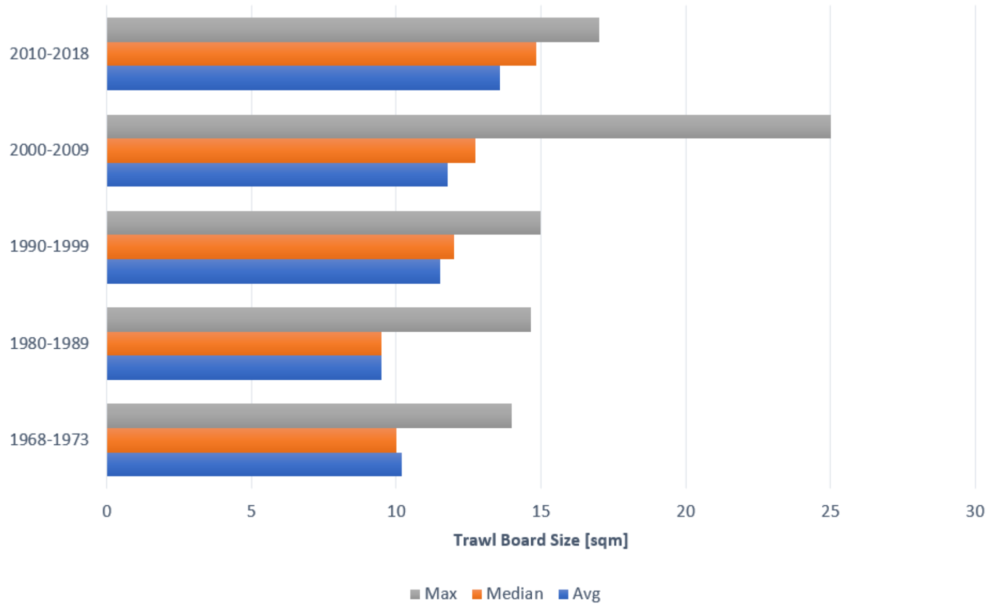


Figure 4.11: *Lying bar graph showing the average, mean and maximum trawl board sizes, by m^2, broken down by decade of the production year of the relevant ships. Due to a lack of data points the older ships, 1968-1973, are put together.*

area, one could expect larger trawl boards to interact with subsea installations more often in the future.

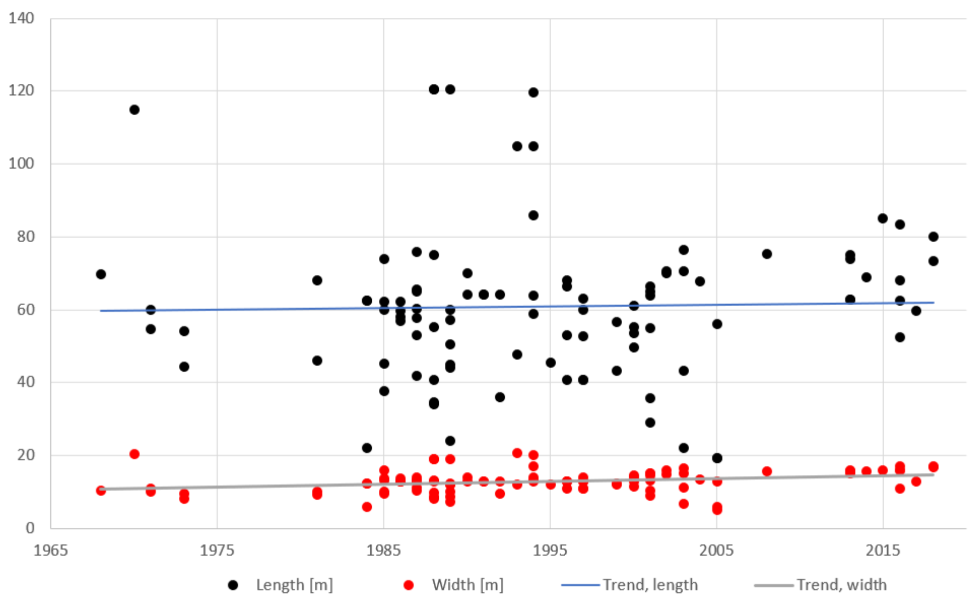


Figure 4.12: *Scatter plot of a selection of ship's length in black and the same ship's width in red, with 100 data points. Trend lines have been added to emphasize the lack of an actual trend (y =0,0403x - 19,398 and y = 0,0762x - 139,11, respectively).*

Figure 4.12 shows dimensions of the ship, in terms of width and length of the vessel. No clear trend is visible to suggest which way these dimensions are developing in general. It can be seen

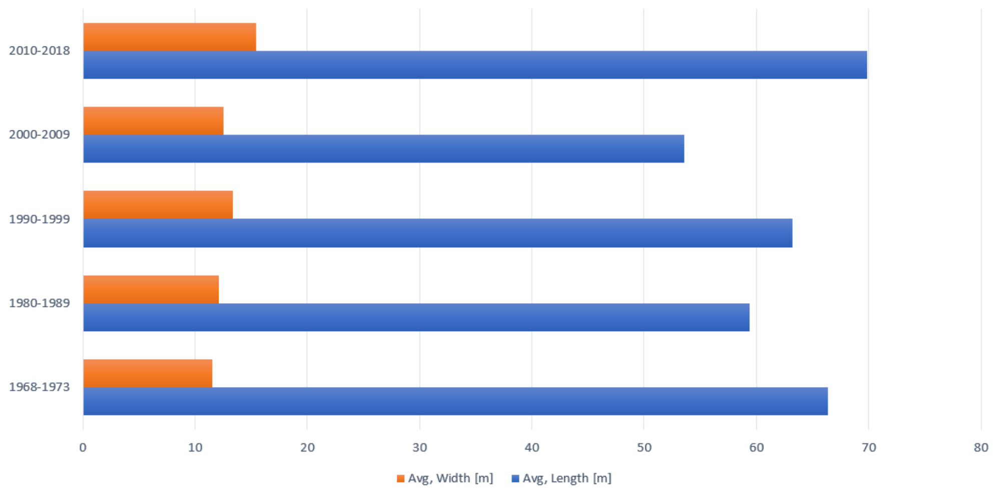


Figure 4.13: *Graph displaying the averages of both width and length of vessels, broken down by decade. The older vessels, 1968-1973 are put together due to a lack of data points.*

that the largest vessels in this data set by length (>100m) were produced more than 25 years ago. It can also be seen that a lot of smaller ships were also made in these decades. The more recent examples of ships seem to be more clustered around a more middling to large size.

When the averages of length and width are broken down in Figure 4.13, it can be seen more clearly that the average ship's length is larger in newer ships, while the average width has had at most a slight increase over time. The length difference is over 15 meters from the early 2000s, but is more akin to 3-10 meters when compared with decades further back. The data point density might play a large role here, seeing as it is much more dense it the 1980s and 1990s than previous and later decades, with about twice as many included.

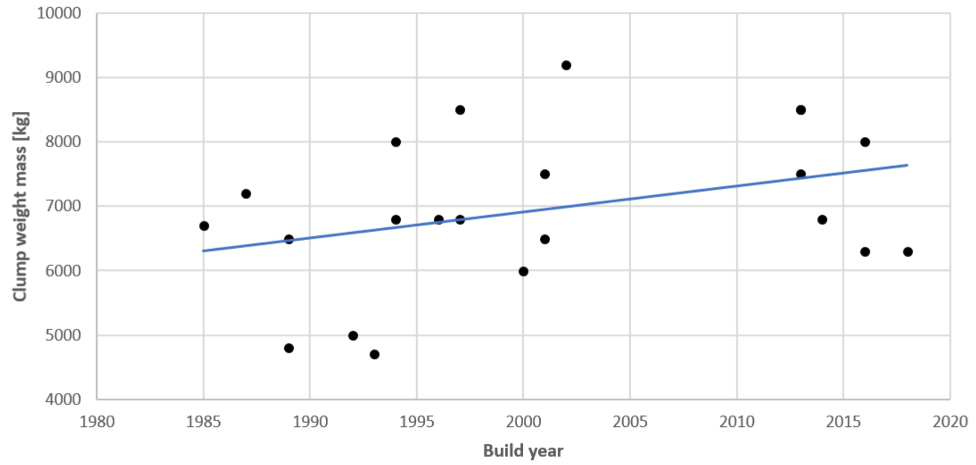


Figure 4.14: *A scatter plot of clump weight mass and build year of the ship it's installed on, with 22 data points. A trend line has been added (y = 40,347x - 73781).*

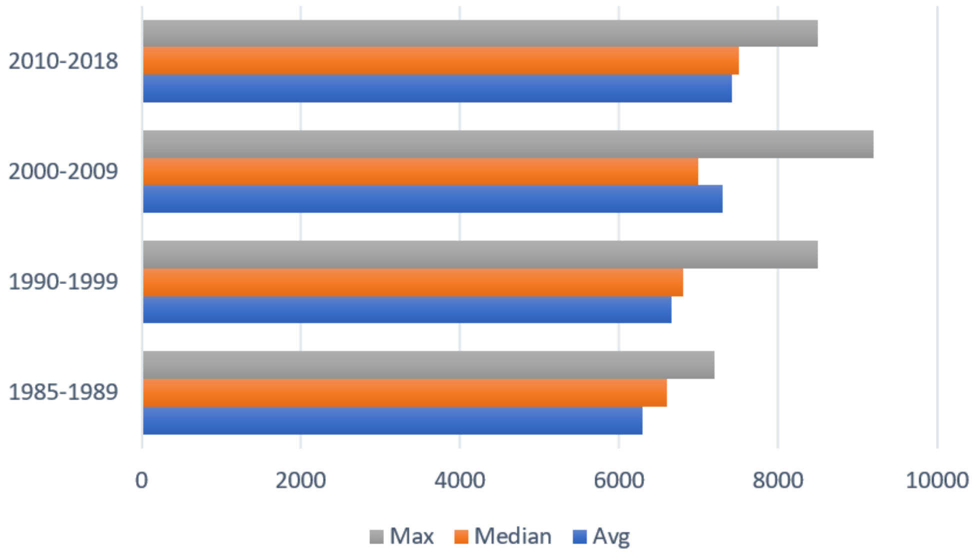


Figure 4.15: *A bar graph that breaks down clump weight mass into averages, medians and the largest and by decade.*

Figure 4.14 illustrates the relationship between the mass of a ship's clump weight and build year. It can be seen that there is a positive trend towards newer ships. The most recent ones hover around middle to large sizes with there being more variance in older ships.

Figure 4.15 helps visualizing the trends seen in the related scatter plot. The averages and medians increase slightly as ships become more recent, totalling 900 kg and 1100kg since the 1980s, respectively. As for the largest clump weights it's about 1300 kg larger in the most recent ships compared to the oldest in the selection, but have a smaller variation in the last 3 decades.

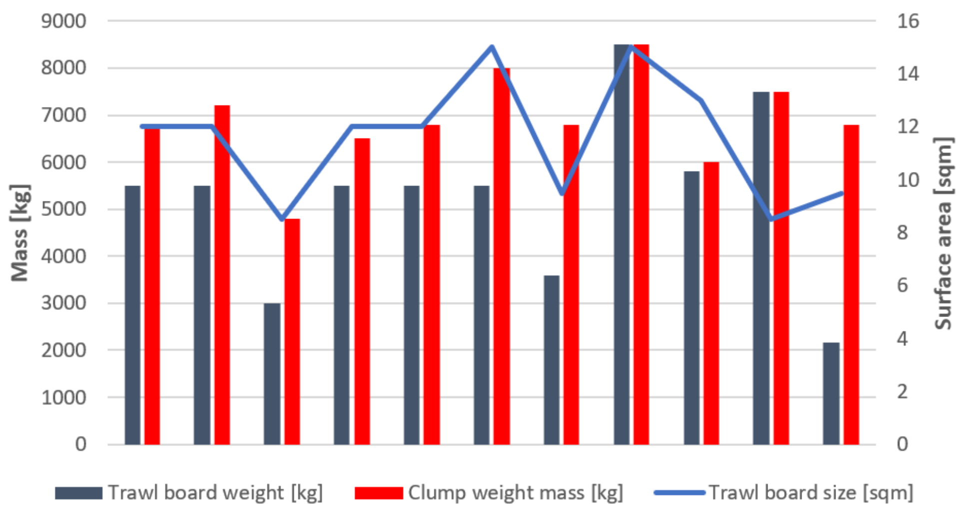


Figure 4.16: *A combined bar graph and line diagram to illustrate the relationship between clump weight mass, trawl board mass and the trawl board surface of a selection of ships, 11 data points.*

From Figure 4.16 one can discern a certain connection between trawl board mass and surface area and the mass of the clump weight in use on the vessel. As the surface area and mass of trawl boards likely are dependent on each other, this particular connection might be less interesting. Clump weight mass could be said to follow trawl board dimensions quite closely in some situations, but seeming out of proportion other times. Only a few data points were available, as there are only a few ships in the data set with all these parameters available.

4.3 Discussion

The experts opinions on industry trends trend and what was found from the data analysis seem to line up to a certain extent. The vessel gross tonnage were seen to be larger from Figures 4.5 and 4.7 displaying such a trend. But at the same time the data analysis showed that the length and width of the ships (as seen in Figures 4.12 and 4.13) did not seem to follow the same trend, with the largest ships having been built in the 1980s and 1990s. Newer ships were seen to be more clustered in the plot and thus having more even sizes as opposed to older ships with larger variance between smallest and largest. The potential of newer ships to utilize larger trawl boards were seen in Figures 4.1, 4.4, 4.10, and 4.11. The largest trawl board weights were seen on newer ships, but averages and medians were not seen to be larger in the most recent decade. Trending towards larger clump weights in newer ships were seen in Figures 4.14 and 4.15. Figure 4.8 showed that more powerful ships have been built in recent years as well. In the event of these trend continuing, project-specific trawl tests would likely be more important ensure minimal conflict between the fishing industry and oil and gas industry.

4.3.1 Potential modes of error

Quite a few of the plots did have a lack of data points, leading to the trends drawn from them to have an increased likelihood of being inaccurate. Furthermore the data set itself is gained from manual data collection and entry, leading to the possibility of human error affecting the end results. Even though the interviewed objects are seen as knowledgeable in their field, it is still their opinion that has been recorded. What was gained from this is therefore inherently subjective.

4.3.2 Suggestions for future research

- Further populating the trawl vessel database to get a better picture of developing trends in gear and ship dimensions
- Contacting different trawl skippers to get more details about the type of gear, type of fishery (pelagic, semi-pelagic or bottom trawling), type of catch and fishing areas
- Cooperation with the shipowners with larger fleets if they could be convinced this type of research is beneficial to them as well
- Combining data in conjunction with Automatic Identification System (AIS) data evaluation could paint a new picture of which trawling gear and which ships are used where and around which oil fields
- Performing numerical analysis for trawl gear interactions on subsea structures with background in collected data and with modern ship and gear sizes in mind
- Further evaluate the background NORSOK U-001 requirements for subsea structure trawl

5. Conclusion

Existing regulations for the overtrawling of subsea pipelines are based on research dating several decades back and as a result are very well-developed. Current design loads for pipelines is therefore a result of years of work. For subsea structures, however, the whole origin of these are more uncertain. Design loads defined by the current version of NORSOK U-001, which is subject to the ISO 13628 series of standards, have at best model tests from 30 years back as their origin, and with a revision that is already more than a decade old. These model tests were conducted with gear in mind that is close to 1/4 the size of the gear that can be found on modern vessels. Data analysis of vessel parameters showed that newer ships have a larger gross tonnage and deploy larger gear than older ships, and these results are supported by the view of interviewed experts. If a such a development were to continue, the standard for use in the Norwegian oil and gas industry would continue to be out of touch with current realities. Even so, recent research has concluded that the regulation's design loads might be over conservative if taken at face value. The regulation allowing the use of model tests to allow deviating design loads does make it applicable in a modern setting and project specific trawl tests could be more important with trends of larger ships and gear in the future, reducing the chance of equipment damage and conflict between fishers and the oil and gas industry. Future research in the vein of this thesis could benefit from more extensive data gathering in conjunction with AIS data evaluation and numerical model tests of overtrawling on subsea structures. This research and testing should be done with modern trawl gear and ship capability equivalents in mind. Such work could pave the way for design load regulations to continue to be relevant in the future.

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A. Interviews

Dagfinn Lilleng v/Fiskeridirektoratet (Ressursavdelingen), tidligere trålskipper.
Jarle Kolle v/Equinor, Senior Engineer i Marine Operations.
Svar adaptert fra intervju i Bergen 22.02.19 (Lilleng) og epostkorrespondanse og telefonsamtale 09.04-11.04.19 (Kolle)

Universitetet
i Stavanger

1. **Hvilke parametere anser du som viktig i en kartlegging av skip (Norske og utenlandske)? (Se liste)**
   D. Lilleng: **Ble vist liste, påpekte ikke noen andre parametere som burde tillegges**

2. **Hvilke skipsregistre er mest aktuelle for benyttes for kartlegging av skipsdata fra inn og utland?**

   D. Lilleng: For alle typer skip benytt ship-info.com (i tillegg til NIS/NOR/BYGG, DAS, DNVGL etc).

3. **Kan du indikere et typisk forhold mellom fartøystørrelse/motorkraft og størrelse på trålutstyret (trålbord og klumpvekt), og gruppere sånn omtrentlig:**
   D. Lilleng: Ingen klare trender, men mange faktorer spiller inn ved valg av størrelse på skip/utstyr/motorkraft (fangst, område) ofte økonomisk motivert. Med maskin på under 750kW (~1000hk) kreves ikke maskinist om bord og kan være en faktor for mindre aktører. For skip med motorkraft 3000-5000hk+ er skip for det meste 45m+ (*fylte ut tabell litt men ble ikke notert, etterspurt per mail, understreker at det ikke er klar trend men noen inntrykk han hadde om slike størrelsesforhold)*
   J.Kolle: Dette må du ta med redskapsprodusenter eller trålskippere

Størrelses-gruppe	Motorkraft (hk)	Tilhørende Fartøylengde min/maks (m)	Tilhørende Fartøytonnasje min/maks (tonn)	Tilhørende Normal/Maks. klumpvekt (kg)	Tilhørende Normal/Maks. Trålbord (kg)
1	0 – 750				
2	750 – 1500				
3	1500 – 2000				
4	2000 – 3000				
5	3000 - 5000				
6	>5000				

4. **Hvilke faktorer er mest med på å påvirke størrelsen på trålutsyret (trålbord og klumpvekt)?**
   D. Lilleng: Økonomisk drevet, større fartøy med større maskin kan ha større utstyr og fange mer fisk. Miljøaspektet, der det ikke trengs mer enn nødvendig kontakt med bunn eller tyngre tråldører enn nødvendig (faktorer som fører til økt drivstofforbruk).

5. **Hva er trenden/utviklingen mtp størrelse på fartøy, trålbord og klumpvekter for bunntråling, blir alt gradvis større?**
   D. Lilleng: Trender er at alt blir større pga strukturering i bransjen (færre trålere, men der fartøyene er større) og effektivisering av drift. På bunntrål har mest økning i størrelse. Trålborddesign står utvikling stille, samme typer bord har blitt brukt lenge (men størrelse øker som følge av strukturering). Har spurt seg selv i mange år «Når skal det stoppe?» (ifht størrelsesøkning). Med økt effektivitet etterspør fiskere større kvoter.
   J. Kolle: Både fartøy, motorkraft, tråldører og klumpvekt har blitt større over en periode, men det er ting som tyder på at toppen er nådd. Høye bunkerspriser gjør at dette i stor grad begrenser seg selv, og at en heller ser på andre alternativer for å ha effektiviteten.

6. **Hva er drivere for tråling/tråledesign? Vanndyp/havbunn/annet?**
   D. Lilleng: Vanndyp og havbunnstopografi ingen hindring så lenge det er profitt (skader på utstyr/tap av utstyr/ekstra vedlikeholdskost etc ikke overgår inntjeningen av fangsten i området. Torsketrål er designet for at utstyret må gå «tett på bunn». Reketrål går på mudderbunn, og har dermed fare for at trålbord skal sette seg fast/trenge ned i bunnen. Fra 800-900m havdyp er det ikke kommersiell interesse å fiske. Kvaliteten på produktet er også i større fokus enn tidligere og er en driver for trålfiske

7. **I hvor stor grad påvirker størrelsen på fartøy/utstyr kreftene som blir utøvet? Hva er trendene?**
   J. Kolle: Vekt på fartøy, motorkraft og vekt på redskapene vil alle ha innvirkning på kreftene som blir utøvet.

8. **I hvilke situasjoner benyttes dobbel eller trippeltrål? Spesielle typer fangst (reker)?**
   D. Lilleng: Antall tråler dikteres av tilgang på fangst, er det mye fisk kan man tillate seg å bruke færre trålposer. Å ha flere mindre poser er en fordel enn en stor pose, da mer enn en viss «høyde» på posen ikke nødvendigvis bidrar så mye til mer fangst (men to poser som øker bredde men beholder samme høyde er fordelaktig).
   J. Kolle: Enkeltrål benyttes først og fremst av mindre og litt eldre fartøyer som ikke har nok vinsjer, og eller maskinkraft. Dobbeltrål benyttes både til reke, sei, torsk og hyse.

9. **Basert på din erfaring, hvor stor prosentandel av all bunntråling skjer med flere trålposer i områdene (ca):**
   - **Eggakanten Mest dobbeltrål**
   - **Haltenbanken**
   - **Bjørnøya/Barentshavet**
   - **Vestskråningen av Norskerenna**
   - **Norsk side av Nordsjøen på platået på ca 100 m vanndyp *Noe pelagisk Tobisfiske, skotter som driver «rørfiske» (to skip en trål). Lite aktivitet***

   D. Lilleng: To poser (dobbeltrål) er maksimalt tillatte i Nordsjøen
   J. Kolle: Antar du mener flere tråler(dobbeltrål) og ikke flere trålposer. Noen fartøyer som fisker med en trål kan også benytte to trålposer på samme trål. Dette er veldig vanskelig å svare på og vil bare bli gjetning. Ser ikke bort fra at Fiskeridirektoratet kan gi de et svar da bruken av elektronisk fangstdagbok skal gi svar på dette.

10. **Det antas at trålhastigheten påvirkes av hva som skal fiskes. Er det andre faktorer som påvirker trålhastigheten?**

    D. Lilleng: Farten og dens størrelse tilpasses. Stor sei kan sette stor fart, og fiskerne justerer trålhastigheten om nødvendig for å fange den mengden fisk de skal ha. Reker er mindre sensitiv for dette (setter ikke fart), kan opprettholde lave hastigheter (1,2-2,5kn). Økonomisk styrt, tråles ikke over den krevde hastighet for å opprettholde fangsrate.
    J. Kolle: Både art det fiskes etter og dobbel / enkeltrål

11. **Er det en trend mot at bunntråling blir gjort med tråldører som flyr litt over havbunnen (eller med mindre marktrykk) kontra at det er kontakt med bunnen?**

    D. Lilleng: Mye brukt i reketråle (spesielt rundt Grønland), er en type semi-pelagisk trål (delvis bunnkontakt). Torsketrål så tapes fangst med denne teknikken. Det er noe som testes, men utviklingen er ikke helt kommet langt nok til implementering. Økonomien styrer utviklingen, samtidig som det ville være miljøfordelaktig å implementere (mindre påvirkning på havbunn).
    J. Kolle: Hvor vidt det er en trend vil jeg vel ikke si, men vet at det blir gjort forsøk med semipelagiske tråldører. Disse går nok også for det meste på havbunnen, men selvsagt ikke så hardt som ordinære bunntråldører. Vi har likevel klumpvekten eller midtloddet om du vil, som ruller i vei med samme vekt.

12. **Hvor vanlig er det å bruke semi-pelagiske/pelagiske tråldører til bunntråling, og er denne bruken økende? Hva er typisk avstand fra sjøbunnen når pelagiske dører blir brukt til bunntråling?**
    Se 11.
    D. Lilleng: Avstand er «et par meter over» med typisk at dørene også tar nedi havbunnen innimellom
    J. Kolle: Rederi / utstyrsprodusenter
13. **Hvordan tunes utstyret som funksjon av vanndyp, bunnforhold, fiskeart osv?**
    - Hva er typisk pitch på tråldøren? (plant med havbunnen, +5grader etc)
    - Hva er typisk lengde på sveipeliner og hva påvirker valget av sveipelinelengden (vanndyp, bunnforhold, størrelse/type trålpose el.)
    - Hva er typisk lengde på varpelina og hva påvirker valget av lengden (vanndyp, bunnforhold, størrelse/type trålpose el.)

    D. Lilleng: Tråldører er ofte tiltet innover for å unngå at trålen snur seg og bryter symmetri i trålen. Pitcher tråldøren basert på effektivitet (individuelle justeringer, ikke noen «typisk pitch»). Sveipelinelengden baseres på hvilken type fangst det fiskes etter, der for eksempel reker ikke trenger like store lengder som for hyse/torsk/sei. Ujevnheter i havbunn gjør at man ofte har kortere for å unngå at trål setter seg fast.
    Varpeline: «Tommelfingerregel» tilsier 3 ganger dybden, men på grunnere vann må man gjerne opp i lengre. Lengden justeres for å opprettholde symmetri i trål slik at trålingen blir mest effektiv.
    J. Kolle: Ja, fra produsenter

14. **Bruker de store trålfartøyene hovedsakelig tråldører og klumpvekter som er kommersielt spesialdesignet utstyr ala Thyborøn, Mørenot Injector, Rock Trawl Doors etc. eller benytter de store fartøyene også mer enkle klumpvekter som kjettingklaser, lastebilunderstell osv?**
    D. Lilleng: Kjettingklase eller enkel stålklump som kan «sveises på ekstra ved behov» er ikke uvanlig, og er også sett ved større fartøy. Inntrykk av at mye rollerclump er i bruk i bransjen.
    J. Kolle: Begge deler, men har ikke tall

15. **Vet du hva de store russiske trålerne bruker av tråldører og klumpvekter (russisk utstyr eller europeisk design)?**
    D. Lilleng: Av russiske fartøy som fisker i norske nordområder benyttes mye av det samme utstyr som på norske fartøy. De største russiske trålere kanskje ikke helt like store som de største norske.

16. **Hvilke typer trålbord og klumpvekter er de mest populære (hvorfor)?**
    D. Lilleng: Roller clump er kanskje mest vanlig, men har ulempe kontra enkle med tanke på vedlikehold og fare for å feile (sand/stein/mudder i lagre osv). Thyborøndører utbredt leverandør på mindre fartøy. «Ekte» bunntrål (der tråldører har kontakt med bunnen nærmest konstant) er mest brukt.
17. **Festepunkt for varpeline på klumpvekt påvirker hvordan klumpvekten beveger seg over hindringer som steiner, ujevnheter, rørledninger osv. (For eksempel. For Thyborøn-rullen er det et øvre og nedre festepunkt i trekkebraketten på rullen)**
    - Hvor er det mest vanlig å feste varpelinen på klumpvekten og hva påvirker dette valget?
      D. Lilleng: Festepunkt oppe og framme på brakett vanligst på roller
    - Er det mulig for deg å angi noe ca prosentvis fordeling mellom øvre og nedre festepunkt?
18. **Er det vanlig å bruke sensorer for å monitorere hvordan trålutstyret oppfører seg (avstand, vinkler, dybde, temperatur, strekk, mengde osv)?**
    D. Lilleng: Sensorer på dører og lodd som bruker relativ avstand til å monitorere trålsymmetri er vanlig. Tråløye på trålposen med ekkolodd for å se hva som går inn i trålen og med dybde/temp sensor og for å overvåke bunnkontakt i bruk. Mengdesensor på trål for å se hvor mye fangst som er tatt inn. Strekkfjær for å sjekke strekk i trål. Fiskerne setter muligens på ekstra sensorer dersom de oppfatter at noe er galt mens de tråler. Tviler ikke på at det finnes mer fancy sensorer i dag, men at alt må gå på batteri (kortere fisketid) og eventuelt økt kostnad på tap/skade på utstyr er utfordringer. «Spørre produsentene».
    J. Kolle: Ja, spesielt avstandssensorer på tråldørene og fangstsensor
19. **Hva er typisk økning/varighet i vinsjkraft de opplever på fartøyet når de passerer rørledninger? Hvordan merker de at de passerer rørledninger og ujevnheter, steiner osv og hvordan påvirker slike ting rutevalg?**
    D. Lilleng: Det merkes på strekk i trålen, der mer «rett på» treff påvirker dette mest. Teknikk er å kjøre med spiss vinkel (ikke mindre enn 45^o). Unngår å kjøre over pipelines så mye som mulig. Kan endre rute for å unngå ujevnheter med pipelines, men igjen er det økonomi som driver og dersom profitt utveier ekstra kostnad/risk. Mindre skip har større fare for å virkelig sitte fast/havarere Ofte ikke mulig å bare «skifte beite» da fisken er der den er/område er tildelt.
    J. Kolle: Har ingen oversikt, men dette er veldig forskjellig mhp fartøystørrelse, størrelse på tråldør og ikke minst rørdiameter. Mange sier at de knapt merker at de passerer.

20. **Er det vanlig å fiske der det er ujevn havbunn og hvordan påvirker dette arbeidet?**
    D. Lilleng: (Nevnt tidligere) Fisker på ujevn bunn så lenge ikke ekstra kostnad/risk utveier profitten ved å fiske der.

21. **Opplever trålfartøyene steindumping på sjøbunnen som et problem (må de fjerne mye stein fra trålposen? - Forslag til forbedring?)**
D. Lilleng: Steindumping kan gjøre at tråler med fine masker ødelegges (typisk i rekefiskesom foregår på mudderbunn der det er mindre stein), mens dersom stein er mindre enn masker på ca 130mm så er større fangst mindre utsatt (torsk/skrei etc). Har vært undersøkt mye på steindump/vært mye diskusjoner, der petroleumsbransjen nå mest bedriver en helningsgrad på 1 til 3 (lengde mot høyde) mens en slakkere helningsgrad på 1-4 ville redusere problemer med stein i trål. Jo slakkere jo bedre, men er et kostnadsspørsmål for dem som skal legge steindump (der 1-4 sees på som en gylden middelvei). Mindre stein er bedre for trålere, men må være store nok til å fungere i steindump/ha stabil steindump. Større problem er freespan i pipeline, der lavere sees på som verre (verre problem med hekting/fastsetting). Første dør som treffer kan «følge» pipeline og stoppe, så kan andre ta den igjen. Skip har ofte åpen akterende, og kan ta inn vann dersom de skulle bli sittende fast, noe som er verre for små skip med tanke på havari.
J. Kolle: Fartøy som fisker med torsketrål/fisketrål merker lite til steindumping, men fartøy som fisker med småmasket trål industri og reke har helt klart noen utfordringer i enkelte områder.

a. NORSOK U-001 har en tabell med styrkegrenser for krefter på strukturer, har du noen ideer om hva som er bakgrunnen for disse tallene (ikke videre kildet i originallitteratur)?
D. Lilleng: Ikke kjent med. Spør DNV/Marintek.
J. Kolle: Dette er det nok DNV som har utarbeidet.

Table 1 – Fishing gear loads

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.

22. **Hvordan ordlegge seg i kontakt med rederier? Love anonymitet i oppgave i en periode (2 år for eksempel), love gjennomsyn av deler der de er nevnt. Kontaktpersoner hos rederier?**

D. Lilleng: Være ærlig, si hva du holder på med (student som skriver oppgave). Ikke noen som har hemmeligheter med tanke på utstyr og slikt som vi kunne spørre om.
Ryddig å gå via deres offisielle kanaler/interesseorganisasjon: fiskebaat.no v/kontaktperson Jan Ivar Maråk (jurist).
J. Kolle: Ville prøvd forsiktig med en mail og fortalt om dine hensikter og planer. Ikke sikkert du får svar fra alle du tilskriver, men helt sikkert fra mange. Det vil være viktig å plukke ut et representativt utvalg av rederier fra de ulike gruppene, slik at du får representanter fra reke, sei, torsk, hyse, industri og stor og små fartøyer.

Intervjuspørsmål til trålkaptein på Lillevig, Eivind Pettersen med 40 års erfaring med fiske.
Svar adaptert fra telefonsamtale 10.06.19.

Universitetet i Stavanger

1. **Hvordan har du sett utviklingen i bransjen de senere år, på hvilke områder? Er det størrelse, teknologi eller annet som har endret seg?**
   - Fartøy og utstyr er blitt større og det er blitt færre fartøy, men de er generelt større. De mer effektive skipene kan benytte mindre mannskap til samme arbeid. De nye skipene er mer effektive og mindre påvirket av vær pga størrelsen. På reketråling så er fisket blitt mer kontinuerlig de siste 5-10 år, der det nå nesten alltid er noen skip ute på rekefeltene. Det er altså lite opphold i dette fisket i dag.

2. **Hva er mest med på å påvirke størrelse på trålutstyr, dører og klumpvekter?**
   - Det er i hovedsak økonomien som har drevet utviklingen, det har vært gode år og det har blitt investert i nytt og bedre utstyr.

3. **Blir fartøyene bare større i bransjen/blir det flere større fartøy og færre mindre? Ser du større skip til bunkring nå enn for 10 år siden?**
   - Se 1

4. **I hvilken grad er det samarbeid mellom dere fiskere og de som driver med oljeutvinning?**
   - Ikke relevant for felt der de bedriver fiske, da det er lite slik aktivitet. Det nærmeste er seismikkundersøkelser for å avdekke eventuelle funn. Fiskerlag har motarbeidet etablering av utvinning på Sørlandet for å verne om fiskefeltene.

5. **Hva påvirker trålhastighet, kun fangst eller er det andre faktorer?**
   - I reketråling er hastigheten påvirket av redskapets størrelse og antall tråler de benytter, der flere tråler blir mer å dra på. Hastigheten begrenses av båtens motorkraft og utstyrets størrelse, der disse må tilpasses hverandre.

6. **I hvilke situasjoner benyttes dobbel eller trippeltrål? Spesiell type fangst?**
   - Reketrål benytter nesten alltid 2 (intervjuobjektet også), der noen mindre kanskje kun benytter 1. I krepsefiske benytter de gjerne 3 tråler. Ved å dekke en større bredde kan de sikre større fangst, hvis man samtidig opprettholder en viss høyde i trålen, og få mer med på den tiden man er ute og fisker.

7. **Ser du mer bruk av kombinasjonsdører/Semi-pelagiske som kan brukes til bunntrål og lengre oppe enn før? Er det noe dere bruker?**
   - Usikker på dette, men har sett at noen har gjort forsøk med bruk av disse i en periode. Inntrykk av at de fleste har gått tilbake til tradisjonelle design som går kosntant på bunn, der inntrykket er at det er mest brukt enda i dag.

8. **Hvordan tuner man utstyret i forhold til havdyp, bunnforhold og fangst osv? Pitch på dørene, lengde på sveipeliner og varpeliner?**
   - Avstand mellom dører justeres etter informasjon fra sensor. Dette og pitch på dør er justert etter spec fra leverandør som skal gi optimale forhold. Endrer etter behov under fisket, der slitasje på dører kan gi svar på hvordan de må justere underveis. Justerer også vekt etc. etter mykere bunn, da trålen kan sette seg fast eller utstyr gå tapt i et slikt tilfelle.

9. **Brukes det hovedsakelig spesialdesignete klumpvekter eller brukes det mye kjettingklaser, stålklumper osv?**

- I hans syn og kjennskap er det klart mest brukt spesiallagde roller klumper i dag. Kan tenke seg at kjettingklaser er i bruk men da på krepsetrålere, da kanskje danske spesifikt. Ikke sett mye «hjemmelagde» type klumpvekter generelt.

10. **Er det vanlig med bruk av sensorer for å se hvordan tråldører og annet utstyr oppfører seg (avstand, vinkler, dybde, temp, strekk, mengde osv)? Er dette noe dere benytter?**
    - Vi benytter kun avstandssensor mellom dører og høydesensor, men har gått vekk fra sistnevnte pga det ikke fungerte optimalt. Noe primitivt i forhold til andre, da de fleste har avstand, symmetri og høydeseonsorer. Mengdesensor kanskje mer vanlig på fisketråling.

11. **Opplever dere steindumping som et stort problem? Kommer mye stein i trålen og ødelegger?**
    - Som tidligere nevnt er det ikke relevant for deres fiskeområder. Nærmeste problem de har kjennskap til dette er sjøkabler til kommunikasjon. Men stein kan være et problem på reketrål på grunn av fine masker i trålen.

B. Ship database

Skip	Lengde (m)	Bredde (m)	BRT	Byggår	Flagg	Fangst	Motorkraf	Trålbord, produsent	Trålbord, type	Trålbord, størrelse (m^2)	Trålbord, vekt (max)	Klumpvekt,	Klumpvekt, masse (kg)
Trawler 1	69,74	10,24	1319	1968	ISL			Super Shark 9m^2	Bunntråling	9	3300		
Trawler 2	115	20,3	7641	1970	RUS			Thyborøn Type 15VF 14m^2	Pelagisk/semipelagisk pá	14	3120		
Trawler 3	60	11	1100	1971	FÆR			Sea Hunter 8m^2 (bunn/semipelagisk hybrid)	Bunntrål/semipelagisk	8	2857,14		
Trawler 4	54,82	9,96	735	1971	RUS			Sea Bat 12m^2	Pelagisk	12			
Trawler 5	44,4	8,2		1973	DK	Rødspette		Thyborøn Typ 21VF "FLIPPER" 10m^2	Semipelagisk/bunntrål	10	734		
Trawler 6	54,02	9,66	819	1973	ISL			Super Shark 10m^2	Bunntråling	10	3900		
Trawler 7	46	9,33	671	1981	FÆR			Sea Hunter 6,2m^2	Bunntråling/multifunctior	6,2	2343		
Trawler 8	68,2	10,23	1112	1981	ISL			Super Shark 9m^2	Bunntråling	9	3300		
Trawler 9	62,55	12,3	1410	1984	LIT			Rock Sea Lion 12m^2 (bunntrål)	Bunntrål	12	5500		
Trawler 10	22	6	158	1984	FÆR			Rock Sea Hunter 3,5m^2 (bunn/semipelagisk hybrid)	Bunntrål/semipelagisk	3,5			
Trawler 11	62,55	12,3	1410	1984	EST								
Trawler 12	37,66	9,6	562	1985	DK	Tobis (Sandeel)	1520	Thyborøn Type 22 "Bluestream" 8m^2	Pelagisk/flytende bunntr.	8			
Trawler 13	60	13,03	1780	1985	EST			Super Shark 12m^2	Bunntråling	12	5500	Rock roller	6700
Trawler 14	74	16	3751	1985	CAN			Sea Lion 13m^2	Bunntråling	13	5875		
Trawler 15	45,2	10,15	828	1985	FÆR			Sea Hunter 7,5 m^2	Bunntråling/multifunctior	7,5	2714		
Trawler 16	62,25	13,82	1898	1985	RUS			Sea Lion 7,5m^2	Bunntråling	7,5	2714		
Trawler 17	59,6	13	1854	1986	ISL			Rock Super Shark (bunntrål)					
Trawler 18	57	13	1591	1986	RUS		4093	Rock Super Shark 9m^2 (bunntrål)	Bunntrål	9	3300		
Trawler 19	62,2	13,82	1937	1986	RUS			Sea Bat 12m^2	Pelagisk	12	5500		
Trawler 20	58	13	1720	1986	FÆR			Sea Lion 12,25m^2	Bunntråling	12,25	5594		
Trawler 21	53	11,23	1011	1987	Marokko			Thyborøn type 12 165"		14,66	3954		
Trawler 22	41,98	10,4	737,1	1987	ISL	Reker		Rock Super Shark 8,5m^2 (bunntrål)	Bunntrål	8,5	860		
Trawler 23	65	13	2071	1987	RUS			Rock Super Shark 12m^2 (bunntrål)	Bunntrål	12	5500	Rock Roller klı	7200
Trawler 24	65,5	13,02	2071	1987	RUS			Sea Bat 12m^2	Pelagisk	12	5500		
Trawler 25	57,9	14,03	2136	1987	FÆR			Sea Hunter 10m^2	Bunntråling/multifunctior	10	3900		
Trawler 26	60,2	13,03	1990	1987	CAN			Super Shark 11,5m^2	Bunntråling	11,5	5100		
Trawler 27	75,9	13	2634	1987	CAN			Super Shark 11,5m^2	Bunntråling	11,5	5100		
Trawler 28	120,47	19	7765	1988	RUS								
Trawler 29	120,47	19	7765	1988	RUS								
Trawler 30	34	8,75	436	1988	RUS			Rock Sea Hunter (bunn/semipelagisk hybrid)	Bunntrål/semipelagisk				
Trawler 31	40,65	9,71	810	1988	GRØ			Super Shark 7,2m^2	Bunntråling	7,2	2625,6		
Trawler 32	55,2	13,06	1772	1988	GRØ			Sea Lion 11m^2	Bunntråling	11	4700		
Trawler 33	34,6	8,16	377	1988	RUS			Super Shark 4,5m^2	Bunntråling	4,5	1667		
Trawler 34	24	8	80	1988	GRØ			Super Shark 4m^2	Bunntråling	4	1333		
Trawler 35	44	10	727	1989	FÆR			Sea Eagle 6m^2 (pelagisk)	Pelagisk	6			
Trawler 36	120,47	19	7765	1989	RUS								
Trawler 37	50,6	12	1167	1989	RUS			Rock Sea Hunter 8,5m^2 ((bunn/semipelagisk hybrid)	Bunntrål/semipelagisk	8,5	3000	Rock Roller klı	4800
Trawler 38	23,9	7,17	209	1989	GRØ			Super Shark 4 m^2	Bunntråling	4	1333,33		
Trawler 39	60,1	12,2	1530	1989	FÆR			Super Shark 12m^2	Bunntråling	12	5500	Rock Roller	6500
Trawler 40	57,35	12,1	1402	1989	ISL			Super shark 9m^2	Bunntråling	9	3300		
Trawler 41	45,01	8,62	120	1989	Fær			Super Shark 5,75m^2	Bunntråling	5,75	2214		
Trawler 42	64,05	13	1944	1990	RUS								
Trawler 43	70	14	2578	1990	FÆR			Super Shark 12m^2 + Sea Bat 14m^2	Bunntråling	12	5500		
Trawler 44	64,05	13	1927	1991	RUS								
Trawler 45	64,05	13	1899	1991	RUS								
Trawler 46	64,05	13	1928	1992	RUS								

Skip	Lengde (m)	Bredde (m)	BRT	Byggår	Flagg	Fangst	Motorkraft	Trålbord, produsent	Trålbord, type	Trålbord, størrelse (m^2)	Trålbord, vekt (max)	Klumpvekt, t	Klumpvekt, masse (kg)
Trawler 47	36	9,6	598	1992	NOR							Rock roller	5000
Trawler 48	105	20,64	7805	1993	RUS								
Trawler 49	47,6	11,92	1136	1993	RUS							Rock roller	4700
Trawler 50	119,65	17	6512	1994	NLD								
Trawler 51	105	20	7682	1994	RUS								
Trawler 52	59	13,05	1928	1994	RUS			Super Shark 12m^2	Bunntråling	12	5500	Rock Roller	6800
Trawler 53	64	13	2058	1994	RUS			Super Shark	Bunntråling				
Trawler 54	85,85	14,03	2898	1994	FÆR			Super Shark 11m^2 + Sea Hunter 15m^2	Bunntråling/multifunction	15	6625	Rock Roller klu	7000+8000
Trawler 55	45,46	12	1192	1995	NOR		3600						
Trawler 56	67,97	13	2436	1996	NOR		Forespør	Thyborøn Type 14vf 9.5m^2	Bunntrål/semipelagisk	9,5	4249		
Trawler 57	53	13	1598	1996	RUS			Super Shark 9,5m^2	Bunntråling	9,5	3600	Rock Roller klu	6800
Trawler 58	66,4	13	2134	1996	RUS			Rock Super Shark 12m^2 (bunntrål)	Bunntrål	12	5500		
Trawler 59	40,8	11	837	1996	CAN			Sea Hunter 7m^2	Bunntråling/multifunction	7,2	2571		
Trawler 60	52,8	13	1860	1997	NOR		6100					Rock roller clun	6000+6800
Trawler 61	63	13	2139	1997	EST			Rock Sea Lion 15m^2 (bunntrål)	Bunntrål	15	4948	Rock roller clun	8500 + 500 (extra)
Trawler 62	40,8	11	837	1997	RUS								
Trawler 63	40,8	11	837	1997	RUS								
Trawler 64	60	14	2223	1997	DK		5324						
Trawler 65	43,33	12,2	1190	1999	NOR		3900						
Trawler 66	56,7	12	1349	1999	GB	Sild, makrell, blåhwilling		Thyborøn Type 22 "Bluestream"	Pelagisk/flytende bunntrål				
Trawler 67	53,67	14	2243	2000	NOR		7500						
Trawler 68	49,66	12,8	1483	2000	NOR	Sei, torsk, hyse (9m^2 dør) reker (13m^2 dør)		Thyborøn Type 14VF 9m^2 (4200kg) + Type 14VF 13m^2 (5800kg)	Bunntrål/semipelagisk	13	5800	Thyborøn roller	6000
Trawler 69	55,25	11,6	1190	2000	NOR		4666	Thyborøn 20VF "Flipper" 13m^2		13			
Trawler 70	61	14,67	2350	2000	EST			Sea Lion 17m^2	Bunntråling	17	7500		
Trawler 71	35,84	10,5	691	2001	NOR		2500						
Trawler 72	55	13,22	1572	2001	NOR							Rock roller clun	6500
Trawler 73	66,4	14,63	2652	2001	GRØ			Rock Sea Eagles Pelagisk	Pelagisk				
Trawler 74	65	15	2525	2001	GRØ							Rock roller	7500
Trawler 75	64	15	2598	2001	CAN			Super shark	Bunntråling				
Trawler 76	29	9	327	2001	ISL			Super Shark 4,2m^2	Bunntråling	4,2	1467		
Trawler 77	70	14,93	2772	2002	EST			Rock Sea Lion (bunntrål)	Bunntrål			Rock roller clun	9200
Trawler 78	70.5	16	3391	2002	CA			Rock Sea Lion 12,5m^2 (pelagisk)	Bunntrål	12,5	2796		
Trawler 79	43,25	11,2	811	2003	DK	Tobis (?)	1103	Thyborøn Type 22 "Bluestream"	Pelagisk/flytende bunntrål				
Trawler 80	76,43	15		2003	FÆR			Thyborøn Type 15VF 14m^2	Pelagisk/flytende bunntrål	14	3120		
Trawler 81	21,95	6,66	113	2003	FÆR			Rock Sea Master CL/CD 3,75					
Trawler 82	70,5	16,48	3377	2003	GRØ			Rock Sea Hunter 14,5m^2 (bunn/semipelagisk hybrid)	Bunntrål/semipelagisk	14,5	6437,5		
Trawler 83			2409	2004	CA			Rock Sea Lion 12,5m^2 (bunntrål) + Super Shark 13m^2	Bunntrål	12,5	5687		
Trawler 84	19,35	5	119	2005	FÆR			Rock Sea Hunter 3,5m^2 (bunn/semipelagisk hybrid)	Bunntrål/semipelagisk	3,5	1000		
Trawler 85	19,35	6	113	2005	FÆR			Rock Sea Hunter 3,5m^3 (bunn/semipelagisk hybrid)	Bunntrål/semipelagisk	3,5	1000		
Trawler 86	56	13	1790	2005	SPA			Super Shark 8,5m^2	Bunntråling	8,5	3000		
Trawler 87	75,4	15,6		2008	DK	Tobis		Thyborøn Type 11 25m^2	Bottom trawl	25	6000		
Trawler 88	62,78	15,6	3441	2013	NOR		6600					Rock roller clun	8500
Trawler 89	62,78	15,6	3441	2013	NOR		6600					Rullevekt	8500kg x 2
Trawler 90	74	16	**3909**	2013	NOR	Sei, torsk, hyse (10m^2 dør) reker (17m^2 dør)		Thyborøn Type 14VF 10m^2 (4500kg) + Type 14VF 17m^2 (7000kg)	Bunntrål/semipelagisk	17	7000		
Trawler 91	75	15	3439	2013	NOR			Thyborøn Type 15VF "flying doors" 8,5m^2	Pelagisk/flygende bunntrå	8,5	1969	Rock roller	7500+300
Trawler 92	68,82	15,6	3441	2014	NOR		6600	Thyborøn 9.5 type 154 VFG	Pelagisk/flygende bunntrå	9,5	2165	Rock roller	6800+300
Trawler 93	80,3	17		2014	ISL			Thyborøn Type 15VF 15m^2	Bunntrål/semipelagisk	15	3313		
Trawler 94	85	16	4300	2015	TYS		5364	Sea Lion 10,5 m^2	Bunntråling	10,5	4300		
Trawler 95	62,5	16	3317	2016	NOR	Fisk(?)						Thyborøn roller	8000
Trawler 96	68,07	16	3723	2016	NOR	Reker		Thyborøn Type 14vf 14m^2	Bunntrål/semipelagisk	14		Thyborøn rollec	6300
Trawler 97	52,46	11	3723	2016	NOR			Thyborøn type 12 165"	Bunntrål/semipelagisk	14,66	3954		
Trawler 98	83,5	17	4916	2016	GRØ	Reker	9333	Rock Sea Hunter 15m^2 (bunn/semipelagisk hybrid) + Rock Sea Eagles (pelagisk)	Bunntrål/semipelagisk	15	6625		
Trawler 99	59,7	12,8	1568	2017	DK	Rødspette, torsk	2999	Thyborøn type 22 Bluestream 15m^2	Pelagisk/flytende bunntrål	15			
Trawler 100	73,26	16,7	4129	2018	NOR	Reker, hvit fisk	6500	Thyborøn type 14vf 16m^2 (shrimp) + Type 14vf 10.5m^2 (white fish) and three roller clump:	Bunntrål/semipelagisk	16	4577	Thyborøn roller	6300 x3 (?)
Trawler 101	80	17		2018	GRØ			Rock Sea Hunter 15.5m^2 (bunn/semipelagisk hybrid)	Bunntrål/semipelagisk	15,5	6812,5		