Marine operations and marine analyses

MEK4450

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1 Introduction

This document summarizes the theory and exercises in the "Marine Operations module" in the course MEK 4450 at the University of Oslo. Typical marine operations that are covered ranges from laying of electric cables and smaller units to tow- out and installation of enormous oil platforms. This module covers several aspects of the marine operations: organization of the projects, planning of the operations, typical technical challenges, how analysis may help us out and finally the content of the actual operation.

The document does not give a complete description of any aspect or part of the marine operations. People with another background and experience will probably say that the document contains big holes and shortcomings. Never the less, it is the authors hope and intention that the document will serve as a gateway into the challenging and exciting world of marine operations.

2 Marine operations

Marine operations have been conducted through the whole history of man. Fishing expeditions, as well as hunting of whales and other sea mammals, are early examples of challenging operations,- often in hostile environments. Transportation of different cargo's along the seaways has also been conducted with great skills and under demanding conditions. Other examples include naval warfare, pirate activities and other destructive actions.

Both vessel designs, marine equipment and human skills have improved substantially over the years. This has been achieved without much knowledge of mathematics and dynamic systems. Instead, improvements have been made by the "trial and error"- method. The price has been high,- the ocean is no doubt the greatest churchyard on this planet. Today mathematical analysis and other systematic planning of the marine operations have reduced the price substantially,- regardless if you count the price in human lives or in dollars. The purpose of this document is to give the reader an idea of how this is possible. The focus is on operations related to oilfield developments. Never the less, the knowledge will be relevant to other types of existing and future marine operations.

2.1 The players in an offshore field development

The activities and organizations involved in an offshore field development may be divided in three levels, illustrated in Figure 1. The fundamental level consists of the oil and the oil company. The company's ultimate goal is to bring the oil to shore and to sell it. To achieve this they need a number of platforms, subsea modules, oil pipes and other items installed offshore. The next level is the contractors providing these items. Typical scope of work is the engineering (E), procurement (P), construction (C) and installation (I). Some oil companies prefer to place a single contract covering the whole scope,- this is denoted a "EPCI contract". Normally different parts of this scope are then subcontracted. An successful oilfield installation is crucial for the oil companies overall economy. Substantial budget overruns occurs easily and frequently. A delay of, say, a year, may cost much more and be far more critical. Due to this the oil companies normally involve themselves heavily into contractors work during all phases of the project. This is why they often prefer to split the main EPCI contract. In Figure 1 the two main contracts are indicated, covering the production of a certain oilfield component (EPC) and the tow-out and installation (T&I).

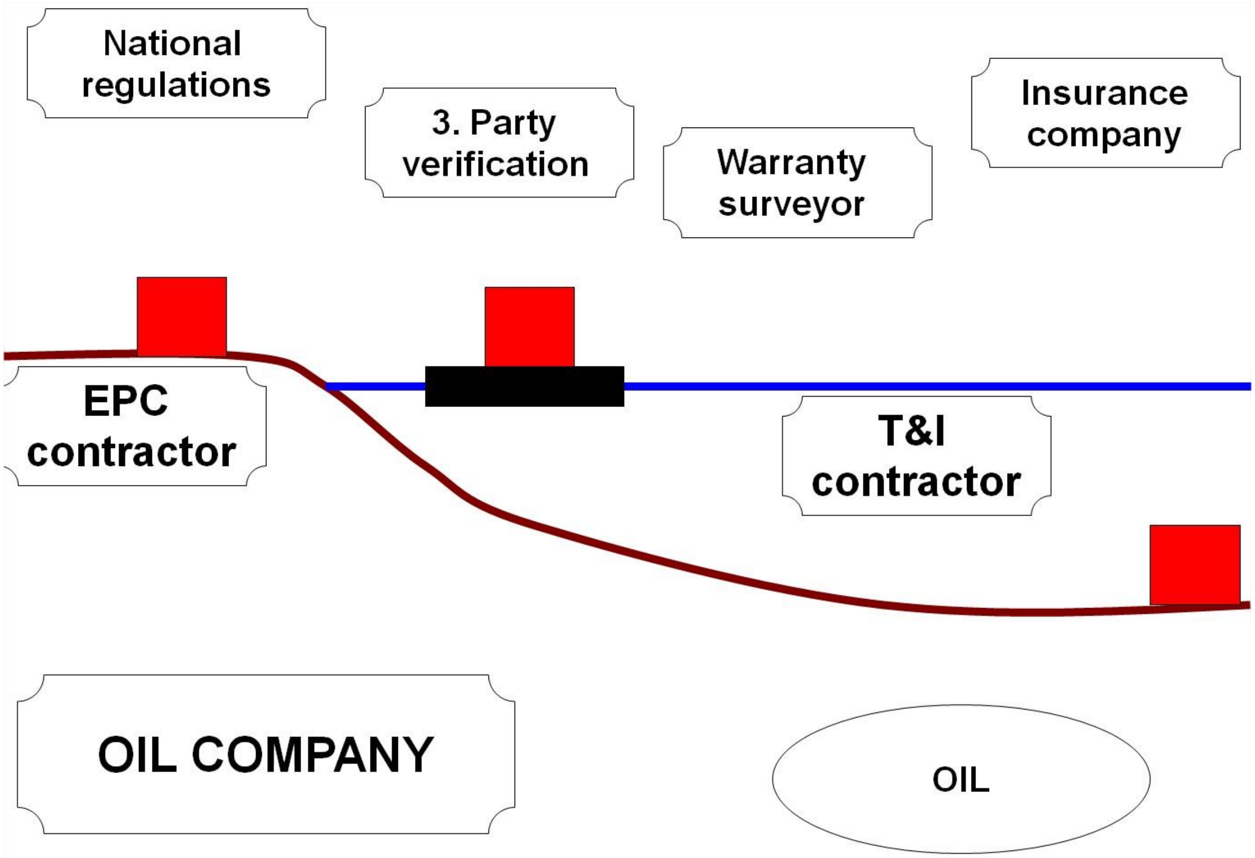

Figure 1: The players in an oil field development project

The oil company now has to take the responsibility for the interface between the contractors. This is a lot of work, and requires highly skilled personnel, but it certainly adds to the degree of control the oil company seeks.

The upper level of the figure represents different requirements that all parties have to obey, and the organizations behind them. Typically there are some requirements origination from the authorities, and some rules requested by insurance companies. In addition, there are some fundamental laws of nature and economics that need to be considered.

The national requirements to the offshore industry vary a lot from country to country. In some parts of the world the requirements are weak, and the oil companies have their own internal "rules" that are more demanding, and more in line with, say, Norwegian rules. For activities in Norwegian waters the NORSOK requirements gives a good summary. NORSOK is written for engineers, and in our eyes it contains "what matters".

It should be noted that the installation part is covered with less firm requirements in the NORSOK rules. For the installation the rules from warranty surveyor and the oil companies themselves are normally more demanding. The oil companies use warranty surveyors to convince the insurance companies that the planned marine operations are safe and well prepared.

Companies acting as warranty surveyors (WS) should be as independent as possible. Ideally, they should be some kind of foundation. Larger WS have comprehensive sets of rules and regulations, smaller ones will normally follow the rules from one of the larger ones. In addition to convincing the insurance company, the WS will assist the companies when the quality of contractors work is examined. The role as WS includes extensive quality check of reports and drawings, and various types of formal and informal meetings / discussions with contractor. Normally, alternative, parallel analysis and engineering work is not performed by the WS. If this is required it will be performed by an engineering consultancy company. This role is denoted 3. party verification. It is important that there is no commercial link or competition between the 3. party and the contractor.

2.2 Project phases during installation

A typical offshore project runs through distinct phases, with milestone deliveries at each step. It is crucially important that all project participants deliver in time, since time is short and people in other disciplines are waiting for your result. To be a good project participant you need to:

- Strive to understand the information you receive from other disciplines
- Minimize your work scope to a necessary minimum
- Perform your work effectively and accurately
- Strive to ensure that your results are fully understood by those who need them

The phases of a typical installation project are described in the subsections below.

2.2.1 Start-up phase

The first thing to do when a contract is landed is to set up an organization with qualified key personnel. The first thing these people need to do is to fully understand the job and to make an overall plan. Important constraints are given in the contractors offer to the client and in the contract. Hence, cooperation with the tendering personnel is useful.

It is important to determine all required deliverables, regarding drawings, analyses, installation manuals, technical requisitions for purchasing equipment’s etc. Further, it is important to establish which activities that need input from each other.

The lines of activities that are most time consuming need to be given special attention, these are denoted "critical line". Typically, some marine equipment’s may have extremely long delivery time, hence analysis leading to a specification of such equipment need to be finalized very early.

Typical output from this first phase is a "master document and drawing register", "MDDR", defining milestone deliverables for different phases of the project. Further, the total manning of the project is established and a proper familiarization is conducted.

2.2.2 Engineering execution phase

This phase is normally the longest part of the project. In this phase it is important that all project members stick to the plan, and deliver on time. Normally, adjustment to the planned installation method should be avoided if possible: a "smart" improvement may easily have unforeseen consequences for other aspects of the operations. Pioneering within method development should be made in studies, not during final design.

If some activities need to be postponed due to delayed input it may be a very good idea to finalize other parts of the project scope before schedule

2.2.3 Mobilization

At a certain date close to the marine operation the project takes the economical responsibility for the day-hire of the offshore vessel. The project will then ensure that the offshore crew, marine equipment and tools are on board.

Familiarization of all personnel is important: everyone should have an idea of what will happen, and it must be ensured that everyone understands their own tasks properly. The use of simple sketches and 3-D animation is recommended.

Finally, the object to be installed must be transferred to a "transportation mode". This may for instance introduce crane lifting operation or sea fastening attachment on transportation vessel / barges.

2.2.4 Marine operations

The marine operation consists of transportation and installation of the object. Detailed step-by-step procedures are needed. Ad hoc adjustments to the plans should be avoided, since unforeseen consequences may easily occur. Late changes in the method will never be covered by engineering to the same extent as the original method.

2.2.5 De-mobilization

After installation the vessel goes to shore, and all marine equipment that are not permanent need to be taken off the boat. The offshore crew are then demobilized.

Normally the demobilization contains few technical challenges. Everyone has the feeling that "the job is done", and they want to go home. This may lead to sloppiness, and there are unnecessarily many dangerous episodes in this phase.

2.2.6 Clean- up

In order to continuously improve, the marine contractor need to learn from every projects. This means that this last phase in many ways is the most important one. Experience of all kinds need to be properly documented, "as installed" documentation needs to be produced, analysis models need to be stored in in a logical manner etc.

It may be difficult to find motivated personnel for all this tidy work, especially when new exciting projects are waiting. But make no mistakes: experiences that are not documented in a systematic manner are of no value. Wait six months, and people will disagree upon what they learned. The worst ink is better than the best memory.

2.3 Why analysis and engineering

As an applied mathematician your typical challenges in a project will be to perform analyses and other engineering to ensure safe and efficient operations. There may be a general attitude among some project participants that the analyses and engineering are a waste of time. Their argument may be we have done this before. This is normally not a valid point- most operations contain new elements. It will be your job to ensure that proper analyses are performed. Some important tasks are discussed in the following.

Figure 2. Why do we need marine engineering?

2.3.1 Sufficient clearance and accessibility

Surprisingly often marine operations are delayed or come into other types of trouble due to "geometrical mismatch". Examples are shackles that should fit into chain links, sufficient deck space to store modules that will be transported, sufficient space to remove sea fastening and lift the object out, clearance when vessels enter in between two platforms etc. The clearances should allow for motions induced by waves and other environmental forces, operational induced motions, production tolerances etc. In many cases some kind of guiding need to be designed, so that if the installed object is inserted inside the guide openings and forced to intrude further, it is guided into correct position. Typically, the guide is wide at the opening and become more and narrower. An example is illustrated in Figure 3.

Notice that the access and clearance for safe and efficient manual work need to be considered. This includes access for various tools and machines that are to be used. The safety and health of the deck crew should also be considered. Sufficient barriers versus wire ruptures, avoid working under hanging load and avoid working for hours with curved back, are some examples.

Figure 3. Conical guiding to ensure correct end final position

2.3.2 Sufficient structural capacity

When objects are installed, it will be forces in lifting wires, guides, toward ship deck, internally in installed object etc. These forces are induced by static weight and buoyancy, environment and operational actions. One of the main purposes with marine analyses is to establish these loads and verify sufficient structural capacity.

2.3.3 Sufficient stability and capacity

Most marine installation are spectacular operations including a certain amount of novelty. This means that unexpected instability mechanisms may occur. Even when the equipment's are of the right type, the maximum capacity may be too low: total bollard pull from the towing vessels are too small compared to the wind, total buoyancy from the barge too small compared to the cargo etc. All this need to be verified with analyses

2.3.4 Determine maximum environmental conditions for the operations

The most common task for an analysis engineer is to quantify the effect of waves and other environmental impacts on the marine operation. This is used to establish the environmental criteria for operation start- up. If you perform wrong calculations, and establish too low design waves, there will be huge extra costs due to waiting on weather. If your design waves are too high it may cost lives.

The elements of the marine operation (vessels, cranes, wires, fenders etc) are defined. Key parameters are established. These key parameters will define things like

- Structural capacity of an object
- Forces being transferred to the object at a given wind speed
- Buoyancy of an object for a given submergence
- Roll angles for a vessel for a given incident wave system

All this elements are put together in a mathematical model, either based on hand calculations or (more normal) a numerical model. The model is exposed for a user defined environmental condition. Typically, the user will try to increase wave heights etc until critical responses from the model occurs. This will define the design environmental condition.

Alternatively, the iteration will consist of modifying the system (i.e. increasing wire diameters, selecting larger vessels etc) until the marine operation is able to withstand the desired design environmental condition.

According to requirements from various regulatory bodies the actual marine operation shall not be performed if the forecasted weather is higher than a certain operational environmental condition. The operational conditions typically equals the design condition times a certain reduction factor, denoted "alpha". The alpha- factor compensate for uncertainties in the weather forecast, i.e. the weather is coming up faster during the marine operation than expected. It will also cover up for uncertainties in defining the actual environmental condition. Typically: how large are the waves we are seeing out of the window? Due to this the alpha-factor depends of the duration of the marine operation and the equipments and means available for accurate determination of weather and weather forecast. The alpha- factor is not intended to cover up for any other uncertainties, and does not replace any other safety factors. Some people claims this, but they are wrong.

Figure 4. Waiting on weather

2.3.5 The walk- through

There are another positive effect of analyses in an offshore project that should not be underestimated: analysis models have a clear tendency to reveal problems that anyone can see in retrospect. After all the analyses may provide a mental walk- through of the whole method. Hence, even "overly accurate" models may add an extra layer of safety to the operations.

2.4 Ethical squeeze

An offshore project will normally contain a series of ethical challenges. Some examples are listed below

- You discover an error in your calculations. It is probably not important, but you are not sure. Rerunning your analyses to find out will take a lot of time. The offshore mobilization starts tomorrow, hence any delay will have a substantial cost impact.
- It's your first day in the project. Your engineering manager tells you which part of the marine operations that needs to be verified by analyses, and the available man hours for this job. In your opinion more analyses need to be performed. Further, the number of man hours is not sufficient to ensure quality even for the limited scope. A possible solution is to use more resources (people / money).
- An offshore vessel is in a transit to an oil field. The weather forecast tells that the job can not start in a while. The captain wants to slow down the speed to save fuel and for human comfort for his land crab passengers. Client will pay full day rates, but only upon arrival at field.
- The contractor have won a job because they can promise the oil company that they will use a certain vessel "A" which is very well suited for the job. In the early project phase the contractor finds out that vessel “A” will not be available, and need to be replaced with a simpler vessel, "B". If the client finds out, the contract may be cancelled. If this matter comes up immediately before the marine operations the company will accept vessel B. The contractor is convinced vessel B is good enough. Should they inform the client immediately?
- During an offshore campaign there is a breakdown in the main crane. The alternative is to utilize the smaller stern crane or to go to shore for repair. The cost of the last alternative is tremendous,- your company is in financial trouble, this may the last nail in the coffin. The experienced sailors says that the smaller crane will do the job. As engineering support onboard you are told to perform lift analyses to verify the operations. The client representative says that your results will be crucial for his decision,- and hence for the whole operations. In your opinion the time is way to short for a proper lifting analysis. Some simple calculations looks promising. You would never have accepted this as a proper lift analysis if you had more time.

All examples are real cases

Figure 5. Ethical squeeze. Who are you.

2.5 Exercises

Exercise 2.1:

For a marine installation, quality may be defined as delivery on time, at agreed price, and with a risk level as low as possible. Risk will typically cover both personnel safety, damaging environmental impacts and risks for not adequate installations or damages to the unit.
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List a few situations that may occur during a marine operation related to lack of quality. For each example, discuss causes, how it could have been avoided and how to handle the situation after it has occurred. Example: towline rupture during towing of an offshore platform. Discuss how an oil company can ensure that their marine contractor is delivering sufficient quality.

An insurance company is asked to provide an insurance policy for a certain marine installation. How will they normally ensure themselves that this is a smart thing to do?

Exercise 2.2:

An ethical squeeze occurs when you have to choose between two options: accept a high risk in order to provide a good business opportunity to yourself or your company, or reject and jeopardize the opportunity. For each of the examples below, indicate who has an ethical squeeze, why, and recommend how to solve it.

- During the tendering phase of a project you have calculated that the required tug vessel is a certain small vessel. During the detailed engineering you discover an error, and you establish a much more costly vessel as required. Your leader asks you to keep silent about this.
- Your client tells you how satisfied they are with your selected subcontractor: a ship yard with excellent safety statistics. You have personally visited the yard, and observed that the workers are not wearing hard hats, and some of them are bare footed.
- Your company has won a contract and are going to install a certain offshore module. This is a fast track project, and the time available for detailed engineering is one month. In your opinion the installation analysis would require at least three months, including a proper quality check. You know a faster way to do it, but do not thrust the accuracy of this procedure 100%. Your leader tells you that if you refuse to do it he will ask a colleague,- a person you do not trust for this type of work at all.
- An offshore project has been successfully conducted, and all units properly installed. During the preparation of “as built documentation” you discover a serious error in your own calculation. As a matter of fact, if the wave height during installation had reached the design limits you have established you feel certain things would have gone very wrong. What do you do?

<u>Exercise 2.3:</u>

A client asks a marine contractor to place a set of heavy objects on the deck of a flat top barge and tow this barge across the North Sea. List and briefly discuss issues that the engineers should be focusing on during planning of the tow.

3 Hand calculation models

Hand calculations are used frequently in marine industry. The purpose may be to establish final design values or perform final verifications. More frequently, the purpose is:

- To provide input to more complex numerical analyses.
- To provide quick estimates in an early project phase.
- To clarify if a complex numerical models gives reasonable results
- To gain increased physical insight in the involved phenomena

Hand calculations are often performed for local structural analyses, even in final design. Standard text book and recommendations from regulatory bodies contain procedures for checking structural capacity of beams, wire slings, bolts and nuts, welding etc. For more complex structures a numerical method called the finite element method (FEM) is used.

Although structural analysis is a vital part of the engineering we will not go deeper into these methods. Instead, we will focus on some other examples:

- Formulas used for establishing the shape of free hanging chain
- simple calculation of viscous towing force at constant speed
- Simple calculation of hydrodynamic forces for cases including acceleration

In several exercises given at the end of this document we are combining the calculated hydrodynamic force with point mass dynamics to achieve simple mathematical models of marine operations.

3.1 Catenary

The catenary is the curve that an idealized hanging chain or cable assumes when supported at its ends and acted on only by its own weight. The curve is the graph of the hyperbolic cosine function, and has a U-like shape, superficially similar in appearance to a parabola (though mathematically quite different).

The word catenary is derived from the Latin word catena, which means "chain". Investigation of the catenary and determination of the shape of this curve is among the classic problems in mathematics.

Catenary curves occur frequently within the offshore industry. Typically, this phenomenon occurs when flexible elements are supported at a floater and are hanging in a half U- shape to a touch-down point at the sea floor. This configuration is illustrated in Figure 6. The key parameters are defined properly in section 7. Here some useful catenary formulas are provided.

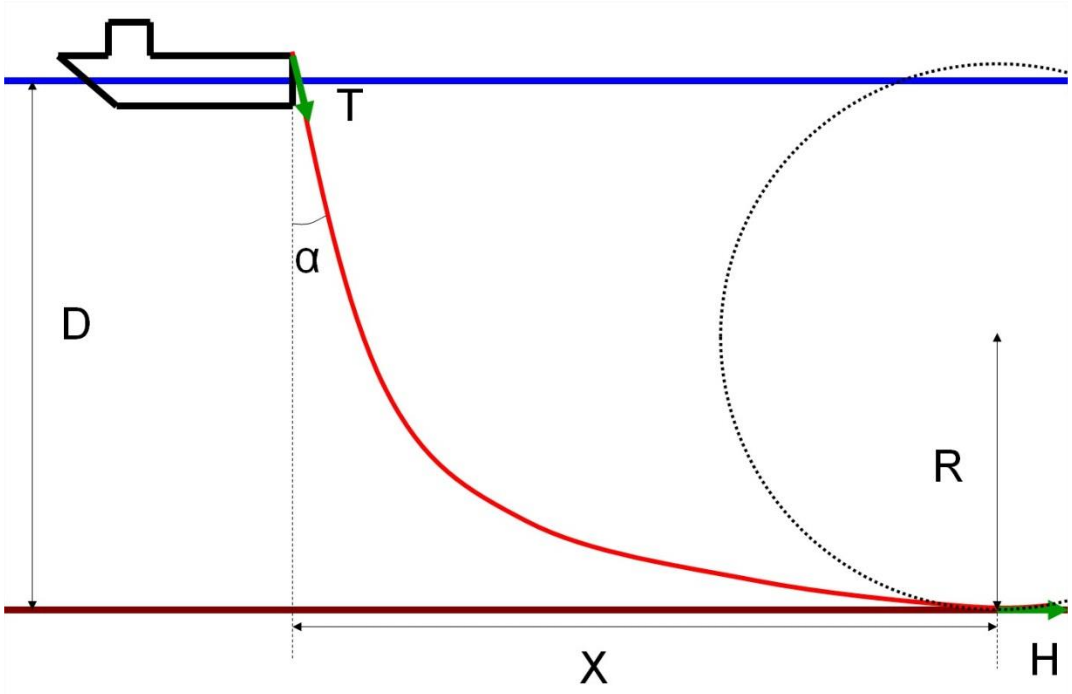


Figure 6. Catenary configuration of cables during laying of flexible elements

Mooring lines for offshore vessels are often forming catenary shapes,- so called catenary mooring. This type of mooring will lead to a soft positioning system keeping the vessel in position, but still not arresting the wave induced motions of the vessel. To achieve this a relatively heavy mooring line is needed. Huge chains are often used.

Another typical offshore application is the shape of electric cables and similar objects being laid down and installed along a route on the sea floor.

3.2 Viscous drag

We now turn our attention to one of the classic problems in fluid mechanics: a body with arbitrary shape is towed with constant speed V through the water: which force is required. It is evident that for a given body and a given fluid type, the force will be a unique function of the towing speed.

There are two mechanisms that may generate a towing resistance: the pressure drop between the windward and the lee side, and the shear tensions (skin friction) along planes nearly parallel to the towing direction. The first type will occur at moderate and high speed, since an unorganized flow pattern with reduced pressure is generated in the wake. For a surface piercing body the generation of waves will contribute to the total pressure drop. The relationship between the towing force and the velocity is normally written as

$$F = \frac{1}{2}\rho S C_D V^2$$

where ρ is the sea water density, S is a reference area and C_D is a dimensionless drag coefficient. Normally, S is selected as the frontal area of the object, then C_D will be of order 1. C_D is normally a function of flow properties, typically the Reynolds number $R_e = \frac{VL}{\upsilon}$where L is a length scale of the object and υ is the kinematic viscosity coefficient.

In many cases a constant value for C_D may be appropriate. The actual value may be found in tables provided in standard textbooks, by the DNV etc. Alternatively, C_D may be calculated using numerical method. Many pitfalls are present for the last strategy. Grid refinement tests and parameter sensitivity tests are vital.

For complex geometries consisting of several shapes with known coefficient a block building strategy with simple summation is tempting. Notice, however, that interaction effect like shielding may need to be considered. Semi- empirical formulas for shielding may be found in the literature, covering at least some types of interaction.

At some current speeds a phenomenon called vortex shedding may occur in the wake. This gives rise to a transversal load that oscillates between positive and negative values at a certain vortex shedding frequency. This may introduce so called vortex induced vibrations (VIV), which may be an issue, especially if the shedding frequency is close to the natural period of the systems.

Unsymmetrical bodies may also introduce steady current forces not parallel with the current. This is observed for instance for the wings of an airplane.

2.3 Added mass

We will now considered the towed object for a body starting from rest, with acceleration a. In the first stages of the process the velocity is small, and the viscous effects may be neglected.

Obviously, one contribution to the force needed to make this acceleration happens is the inertia force Ma, where M is the mass of the object. This is not a part of the hydrodynamic force, and will not be discussed further below. If the object contains pockets with trapped water, like buckets and pipes will do, there will be a distinct volume of fluid having the same acceleration a. The forces needed to accelerate this water is then $M_b a$, where M_b is the mass of the trapped water. This force has occurred as a contact force between the object and the trapped fluid. According to the third law of Newton, we then conclude that the contribution to the required applied force is $M_b a$

In addition to this trapped water there will be accelerated volumes of water surrounding the object. Different small portions of fluid will have their individual acceleration, forming an acceleration field as the body accelerates. The forces applied to the body to achieve the accelerations also need to compensate for this fluid particle accelerations. It may be shown that this contribution may be written $M_a a$, where M_a is a unik function of the body shape an orientation. M_a has the unit mass, and is denoted added mass.

We conclude that for vanishing velocities the forces needed to accelerate the body is

$F = (M_b + M_a)a.$

The value for Ma are tabulated in textbooks and publications from DNV etc. Alternatively, the value may be determined using numerical methods. Although this need to be done with care, it is a simpler procedure than determining viscous drag coefficients.

Shielding effects etc are equally important when using the block- building strategy as for viscous effects, see discussion in previous section.

It should be noted that the following formula is valid for cases where the object is accelerating, while the fluid is at rest. Alternative formulations valid for accelerated fluids exist. Details are not provided here, but it is not correct to simply replace a with fluid acceleration!

3.3 Morisson equation

In many cases both acceleration and velocity is important, and both theories discussed so far will fail. It is much more difficult to investigate the intermediate stage accurately, since no simple model of the wake exist. Typically, for the case with constant velocity and zero acceleration a fully developed wake will occur, and for the opposite case there will be no wake at all. In the intermediate case the object is moving in and out of its own not fully developed wake, leading to more unpredictable dynamics.

Never the less a very simple approach exists, named after the man who first developed the theory: Morissons law. This law simply states that the actual hydrodynamic force is a sum of the viscous force and the inertia force as developed above

$$F = (M_b + M_a)a + \frac{1}{2}\rho S C_D V^2$$

More accurate methods and laboratory tests has shown that this formula is a usable simplification for many typical offshore applications. Never the less it needs to be stressed that no formal justification of the formula exists for the summation. Morissons law is not a law of nature.

Due to a desperate need for design values,- and a quick determination of them,- the offshore industry are using Morissons law extensively. The order of magnitude provided by the formula combined with several safety factors are normally leading to acceptable designs.

3.4 Exercises

Exercise 3.1

A sphere with radius r and mass m is located in an unbounded fluid with density ρ. Initial velocity is zero. A vertical gravity is assumed, and $g = 9.81\, {}^{m}/_{sec^2}$
Non dimensional drag and added mass coefficients can be set to 0.5. (Both)

a) What is the initial acceleration?

b) What is the constant velocity after a sufficiently long time?

c) Will the sphere move upwards or downwards? Establish the criteria for downward motion.

d) Establish an equation valid for the sphere motions for all times. Demonstrate how the solutions in a) and b) may be found by neglecting appropriate terms in this equation.

e) Find the vertical coordinate of the sphere as a function of time, valid for all times. (This require solving a differential equation)

Exercise 3.2

A simplified calculation of the vertical wave induced motion of a floating, vertical pile is to be performed. Assume a wave elevation surrounding the pile given by

$$\eta = \mathrm{A}\sin(\varpi \mathrm{t}) = \mathrm{A}\sin(\frac{2\pi \mathrm{t}}{\mathrm{T}})$$

Where A is wave amplitude and T is the wave period. Further, assume that the pile performs vertical motions only, and that the only forces acting are the weight and the buoyancy

$$\mathrm{B} = \mathrm{B}_0 + \eta\rho\mathrm{g}\mathrm{A}$$

Where B_0 is the static buoyancy, ρ is the sea water density and A is the cross sectional area at waterline. Assume no drag, damping or added mass in vertical direction.

Show that the motions are governed by the following equation

$$\mathrm{C}_1 \frac{\mathrm{d}^2\mathrm{Z_a}}{\mathrm{dt}^2} + \mathrm{C}_2\mathrm{Z_a} = \mathrm{C}_3\eta$$

Where Za is the vertical wave induced motion. Determine the constants C1, C2 and C3. Find Za.

Make a sketch showing the amplitude of the response relative to A as a function of A. Briefly discuss the behaviour at low and high T values.

4 Commercially available calculation tools

4.1 Hydrostatic stability analyses

Stability analyses of floating objects are the oldest and most important analysis type within marine industry. Complex and highly relevant analyses were performed long before computers become available. This included both analytical calculations and numerical simulations by hand.

Today, commercial hydrostatic analysis programs are available and frequently used. Typically, such programs are purpose-made for free floating, ship shaped floaters. Both input and output are streamlined toward traditional vessel operations. The basic input to a hydrostatic analysis program is the total mass and centre of gravity, and the shape of the wet part of the hull. The distribution of masses, i.e. radius of gyration etc, is not relevant for this type of analyses. Notice that the parts of the hull which may become wet during tilting for need to be defined. Further, hull openings that lead to water ingress into the hull need to be defined.

The vessel geometry is defined through line spans, the same formats that are used by the ship yards to define and document their construction process. The masses are defined through various point masses representing steel weights, cargo etc. Swift methods for defining tanks and filling them to a certain level with various constant are available.

The output of the program is also Tailor made for ship designers and operators, where complex rules for stability checks given by DNV etc are implemented and tested automatically.

A more general formulation allowing for non-standard destabilizing phenomena, is normally not possible. Some examples that may be difficult to model are listed below:

- Forces and force-elongation characteristics introduced from contact with winch or crane wires, fenders, sea floor etc.
- Interaction between two floating objects, i.e. a vessel lifting a floating object out of the water
- Air filled compartment communicating with the open sea. Changing hydrostatic pressure at sea water opening compress / expand the air inside and leads to changes in buoyancy.

Figure 7. A vessel with poor stability

4.2 Frequency domain analyses

One of most fundamental hydrodynamic problem you may deal with is the interaction between a floating object and an incident wave. The simplest approach to this problem is to study a singel harmonic (sinusoidal) wave component and assume low amplitude wave and responses. This lead to linear equations and to harmonic responses.

Analysis programs based on this approach require the geometry of the wet part of the hull and the mass distribution. The mass may be defined by the user through a list of individual point masses with positions, or through integrated properties like radius of gyrations etc. Notice that each point mass should represent relatively confined parts of the structure.

Although viscous damping is not a part of the basic formulation of this type of programs, such effect may be "`taken in the back door"'. This may be necessary if incident waves close to the resonance period are studied. For a vessel like geometries the most relevant example is side sea with period near the eigenperiod in roll motion. The input to the program consists of directions and wave periods required for the analyses. Since the analysis consists of stepping through and solving the problem for a set of different frequencies, the method is denoted frequency domain The fundamental output of this type of programs are the amplitude and phase delay of various responses. Typically, the results are displayed as a function of incident wave periods, and denoted transfer functions or response amplitude operators (RAO). In addition, hydrodynamic vessel characteristics needed for more sophisticated calculations with other types of programs are provided.

The most well-known RAO- curves are those showing the vessel motion response for all six degrees of freedom. RAO- curves may also display responses like total wave forces, pressures at certain locations etc. The RAO curves are often post processed to give new responses not directly outputted by the program: the bending moment in a midship section, the vertical acceleration in the crane tip etc.

Actual seastates consists of a huge set of harmonic waves with different periods and directions. Statistical post processing methods have been developed where RAO's and the wave spectrum is combined to give most likely maximum for the response. There are two main motives for running frequency domain analyses:

a) the free floating responses discussed above may be useful by them self, and
b) the program produces coefficients needed for more sophisticated analyses.

4.3 Time domain analysis

Although the basic hydrodynamic analyses as described in the previous section may provide useful results in many situation, the limitations are striking:

- Nonlinear hydrodynamic features in the wave description and in the floater response analyses, cannot be included. This is less critical for marine operations than for a survival analyses: a marine operation is not performed during a storm, where nonlinear effects are more dominating.
- Nonlinear contact characteristics between different objects can not be included. Such contacts may represent fenders, lifting wires, sea bed contact etc.
- Although viscous damping can be included, the description of these effects are poorly represented.
- The traditional way to deal with the phenomena above is to perform computer simulations with time stepping. Here, the solution on current and previous time steps are used to establish solutions on next time step. Repeating this operations leads to a so called time domain simulation.

Time domain analyses may be performed in many ways, and for many reasons. We will focus on a certain class suited for simulation of marine operations. Within this class of methods the following elements exists:

- Environment: Incident sea state parameters, wind speed etc, user defined.coeffisients: Simple rules transferring environmental actions into force, e.g. wind speed into wind force.
- Links: fenders, wires, sea floor etc, connecting different rigid bodies. Each link may have an arbitrary user defined force- elongation characteristics.
- Rigid bodies. Standard dynamic equations are solved for these bodies. The bodies receive forces from link elements attached to them, and from environmental forces through the coefficients. A vessel requires coefficients calculated by a frequency domain program, while a small buoy requires a much simpler representation.

The inclusion of flexible element like a long steel pipe or an electric cable requires an finite element formulation linked to the body properties. The mass need to be distributed along the element, and the axial and bending stiffness need to be defined. Normally, a fully nonlinear beam theory is required, while the hydrodynamic loads are performed according to Morisson equation. The basic output from time domain simulations are time series for various types of responses. These series need to be post processed to achieve design values.

4.4 CFD

The time domain analyses described in the previous theory section provides a quick and efficient way of simulating marine operations. The critical factor is the use of coefficients: predefined numbers telling how large motions or forces that will occur for a given wave height, wind speed or similar. The accuracy of the method depends crucially on the accuracy and relevancy of these coefficients.

In order to study this further we need an analysis model where the actual velocity fields are simulated. This is done in the CFD method, where the celebrated Navier Stokes equations are solved. CFD programs may include important features like turbulence, a free surface and simple bodies performing prescribed motion. A full simulation of a marine operation, including interaction with freely moving bodies with complex shapes, are very time consuming and not always feasible. This means that, for marine operations, the main use of CFD will be to investigate and quantify hydrodynamic and aerodynamic coefficients.

Typical input to a CFD program is the geometry occupied by the fluid, and fluid properties like viscosity and density. Turbulence occurs for many practical applications, then parameters used to select turbulence modelling need to be defined. Further, the condition along the boundary needs to be given.

The basic output from such programs are time series for local values of velocity, pressure and other stress components. Integrated quantities giving the total force on a certain object, the total mass flux through certain boundary etc may easily be obtained.

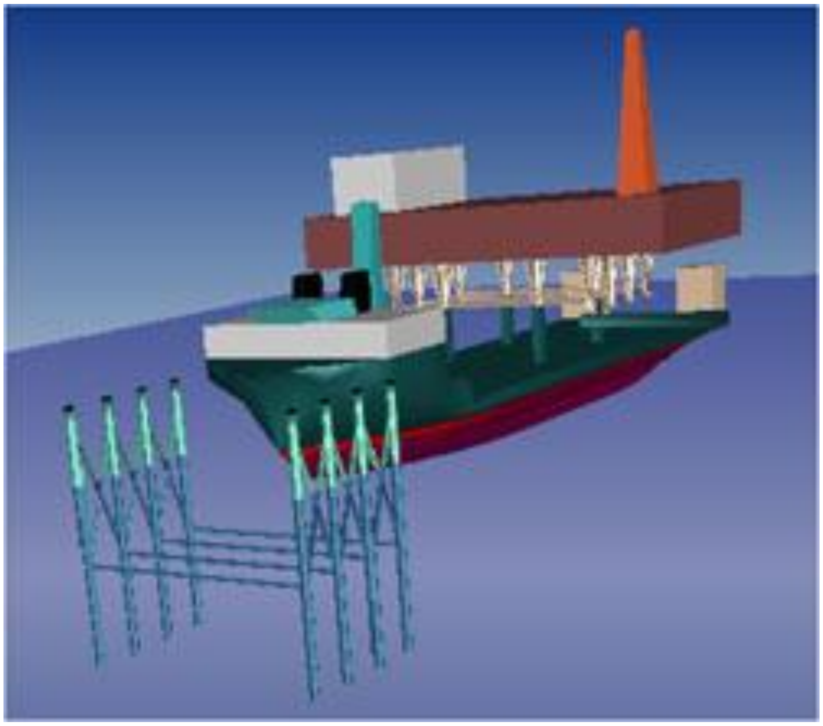


Figure 8. Snapshot from animation of a time domain simulation

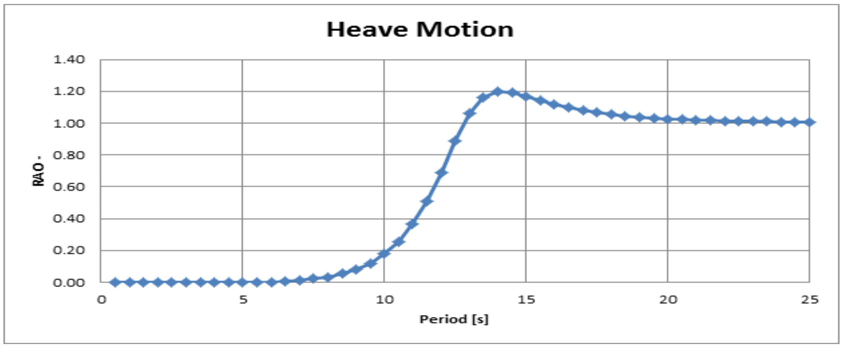
4.5 Exercises

Exercise 4.1

In a certain marine operation an offshore module is lifted from the deck of a crane vessel, over boarded, lowered down and put on the sea bed.

Which commercial software may be relevant for this job, and why?

Exercise 4.2

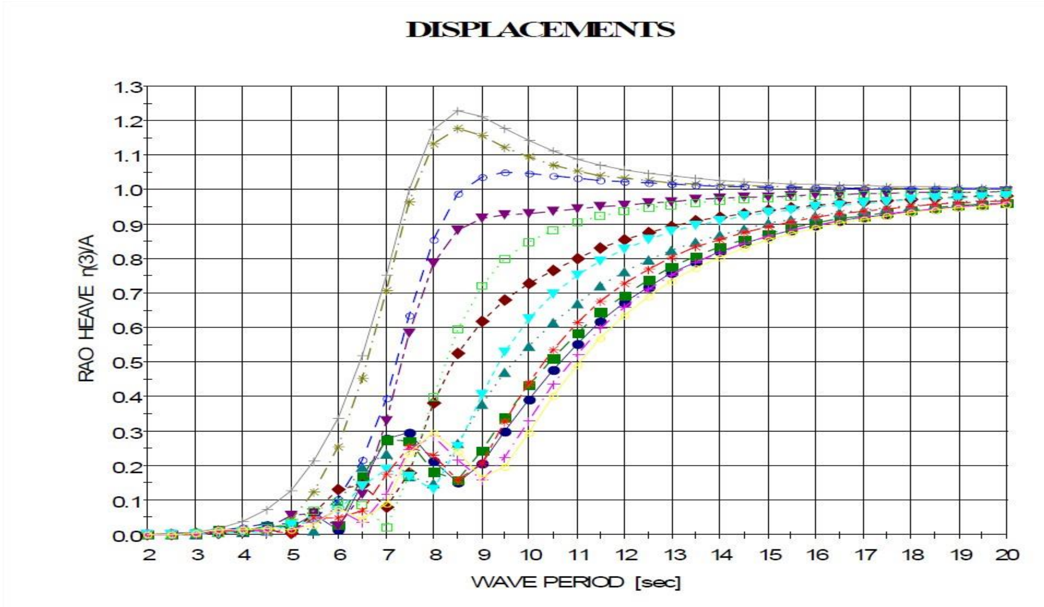


The curve above displays the amplitude of the vertical motion of a floater as a function of incident wave periods. The values are calculated for unit amplitude of the incident wave, i.e. this is a transfer function.

Discuss the response level at small and large wave periods. Is this what we should expect?

Exercise 4.3

Given the below heave RAO, what is the vessel´s resonance period in heave? What is the amplitude of the vessel´s vertical motion in terms of wave height?


DISPLACEMENTS
RAO HEAVE η(3)/A
WAVE PERIOD [sec]
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2
3
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5 Extreme value statistics

The most important tool for investigating marine operations by theoretical means is the time domain simulations. The basic output from these analyses are time series for vessel positions, line loads etc. Similar time series are basic output from model tests and full scale tests as well. The typical application of these series is to link design values for marine equipments to the design sea states for the marine operations: If a certain offshore lift is to be conducted in, say maximum 2 m wave height, the lifting wire needs to be strong enough to withstand the corresponding dynamic line loads. If a barge towing is to be conducted at, say, maximum 5 m wave height and 25 m/s wind the objects placed on the deck of the barge need to be sea fastened to withstand the corresponding dynamic roll motion and wind heel.

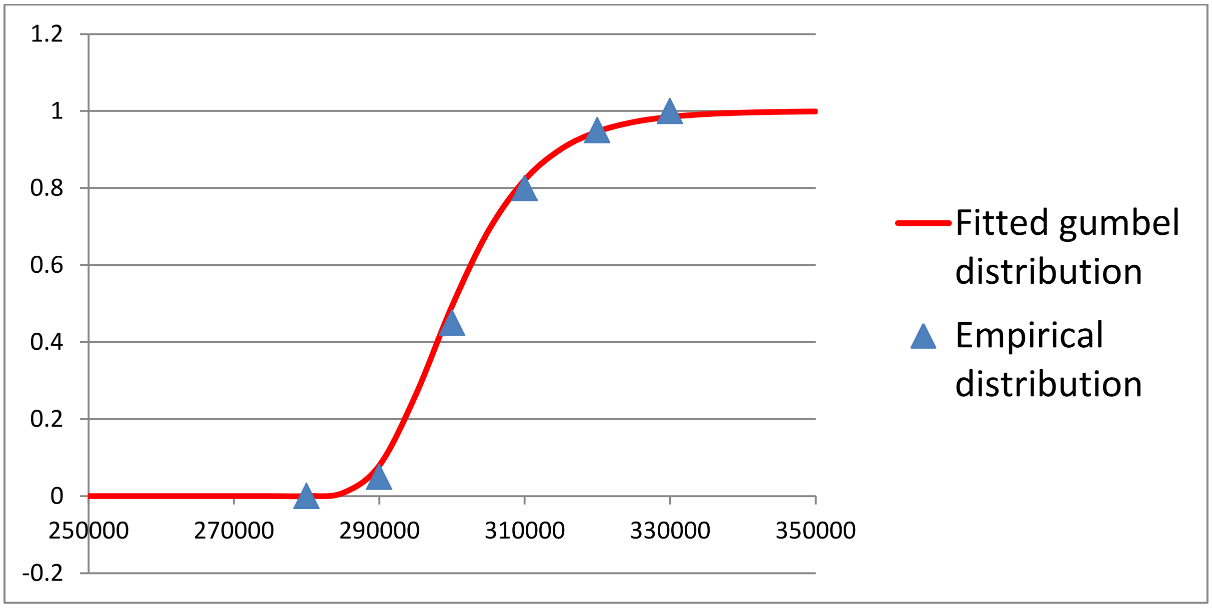
The simplest approach would be to pick out the highest value in the time series and use as design value. This approach has serious shortcomings. First, the sea state variation is a stochastic process, so the highest waves and the highest response value will vary for different realizations. Second, the expected maximum response is higher for a longer time series; hence the numerical simulation time and the planned operational time need to be similar. Third, this design value will, at it's best, capture the expected maximum response. No additional safety due to variations between different time series realizations is provided.

The next step would be to repeat the model test or numerical simulation. Even though average wave heights, wind speeds etc are kept constant the actual time series for the response will not be identical; neither will the observed highest response. If we keep repeating this we end up with a series of observed maxima from individual time series.

An appropriate requirement to the design value is to perform some kind of statistical postprocessing so that the design value is independent of the fluctuation between the time series. Some simple options are listed below:

- Pick the average of the observed maxima
- Pick the median value of the observed maxima, i.e. 50% of the observed maxima is larger than our selected value, and 50% is smaller.
- Pick a value so that a given percent, say p%, of the observed maxima is smaller, the rest larger.

The parameter p defined above is denoted percentile. p is normally selected in the range 50% to 90%. A higher value is a conservative approach, leading to more costly and robust designs that less likely will be overloaded during the marine operations.
An empirical distribution may be established given a list of observed maxima from individual sea states. This is illustrated in the figure below, blue markers. Typically, if the y value for a marker is, say, 0.8 this means that 80% of the observed maxima are less than or equal to the x coordinate value.



An accurate determination of the design value, at a given percentile, and based on the empirical distribution only, is not possible. More precise values may be calculated if a theoretical distribution is fitted to the empirical.

Advanced statistical theory shows that a certain theoretical distribution, the Gumbel distribution, fits well to this type of empirical distributions. The Gumbel distribution is given by $F(x) = \exp(-\exp(-\alpha(x-u)))$

F is the probability that the observed maximum from an arbitrary series is less than x. The free parameters α and u need to be adjusted to fit the actual empirical distribution. Fortunately, these parameters can be linked directly to the average μ and standard deviation σ of the series of observed maxima:

$$\alpha = \mu - \frac{\Upsilon}{\sigma}$$

$$u = \sqrt{\frac{\pi^2}{6\sigma}}$$

Where ϒ is the Euler-Mascheroni constant ≈0.577. The accuracy of this procedure increases as the number of time series realizations and corresponding observed maxima increases. A typical Gumbel fit is shown in the figure above.
When the Gumbel parameters are established the design value, at a given percentile p, follows directly.

$$X_{design} = u - \frac{\ln(-\ln(p))}{\alpha}$$

It should be noted that the procedure described above require many realizations of the time series. This implies that this procedure is a robust, but relatively costly way to establish statistical extremes. In some cases the cost and schedule impact may be higher than what can be accommodated.

5.1 Alternative approach

The Gumbel- based approach as described above is a simple and robust approach that hardly ever fails if a sufficient number of time series repetitions are considered. Notice, however, that performing a large set of repetitions of the numerical simulation or model test may require a lot of time, and the cost and schedule impact for a project may be severe.

This section presents an alternative approach, where one repetition is required only. In short, we find the extreme value by extrapolation from the individual maxima in a certain time series, instead of interpolation between observed extreme values from a huge set of time series. Even though this approach is used extensively, it has it’s short comings and pitfalls, and the relevancy of the method is being discussed.

In any case, this alternative approach will only work for stationary processes. A stationary process implies that the distribution of individual maxima within the time series looks almost the same for any long subset of the series. Stationary responses will often result when marine systems are exposed to ocean environments with constant average wave heights/ wind speeds.

Changes in the average properties of the sea state during the marine operations will lead to non- stationary responses. Non- stationary responses may also result due to marine operational decisions. If a module is lifted out of the water, the wave induced wire loads will certainly not behave stationary.

The fundamental idea in this alternative approach is to establish a distribution of individual extremes within the time series, and fit an appropriate theoretical distribution. Several theoretical distributions may be considered. The most commonly used ones are the Weibull distribution and the Generalized Pareto distribution.

Predicted extreme values based on this distribution will normally be a stable value: if the numerical or physical experiment is repeated and a similar time series is reproduced, the statistically predicted extreme value shows much less variations than the observed maximum. As such this approach provides a more reliable design value than simply picking the extreme value.

Long time series are required to achieve the statistically stable results described above. The actual required length is hard to quantify, since it depends on the type of process going on, but normally the number of individual maxima need to be somewhere between 100 tops and 1000 tops.

Serious objections have been made to this approach. After all, we are relying entirely on which type of theoretical distribution we are selecting for the statistical fitting. If the actual individual extremes are not distributed according to the assumed theory, the extrapolated extreme value may be completely wrong. This is particularly a problem when the duration of the time series is smaller than the duration of the planned marine operations, since the statistical process then is more of an extrapolation than a curve fitting.

5.2 Exercises

Exercise 5.1

Which of the processes below can be considered to be stationary?

a) The wire load in a crane wire is recorded during the stages when an offshore module is lifted off the deck of a vessel and submerged into a wavy ocean.

b) The free surface elevation is recorded during a few hours. Average wave height is constant in this period.

c) The roll angle of a vessel is measured over a few hours. The average wave height is constant. The vessel changes it’s heading.

Exercise 5.2

We consider a marine operation were an electrical cable is paid out from the stern of an installation vessel and laid down on the sea floor, while the vessel moves slowly forward. A catenary shape will result for the cable. Dynamic variations to the static cable load are introduced through wave induced motion of the vessel.

The design installation analyses produces time series for the cable load for the design sea state

.

a) Assume one time series are available only. Explain why the maximum observed value in this time series is a pure design value for checking cable strength.

b) Assume you have access to a large set of time series, i.e. you may repeat your numerical simulation. Explain how you may use this to improve the estimate for the design value for cable load.

c) Assume 20 time repetitions have been made, and that the individual maxima are listed below:

316,000	309,000	312,000	281,000	299,000	299,000
307,000	291,000	302,000	291,000	305,000	291,000
325,000	302,000	303,000	300,000	315,000	295,000
295,000	298,000				

Calculate a design value for the maximum value based on the Gumbel approach and an 80% percentile.

Hint: the calculation procedure is well suited for implementation in an XL sheet or similar.

d) Explain how one time series only in principle could have been used to calculate the design value. Briefly discuss the drawbacks with this approach.

6 Installation of subsea modules.

In a typical offshore lifting operation a heavy subsea unit is lifted from deck of the crane vessel and lowered to the sea floor. Alternatively, the operation involves two vessels, a transportation barge / vessel and a crane vessel. Operations where subsea modules are lifted from sea floor to deck for removal / repair, or moved from one location to another, is also denoted lifting. The different phases of an offshore lifting operation are discussed in the subsections below.

6.1 Load-out

The module is lifted or skidded from a production / storage site and onto the crane vessel deck. Since a full utilization of the expensive crane vessels are desired, the deck tends to be crowded. This need to be planned carefully, to ensure simple and safe lifting routes in air at the offshore installation site.

6.2 Transportation

A proper sea fastening of all modules on deck is required. Further, the deck strength needs to be checked, both local damages and a complete collapse of the hull may need to be considered. Finally, for tall and heavy units, the stability of the vessel may be an issue. The most dominant loads for the sea fastening and deck strength are module self weight and wave induced accelerations and deck tilts. This means that a hydrodynamic analysis may be relevant. A proper planning of the sea fastening, ensuring easy, swift and cost efficient installation and removal, should be focused on.

6.3 Lifting from deck of vessel

Upon arrival the sea fastening need to be removed and the module is lifted along a route to a location ready for lowering. The involved crane operations should be as simple as possible. Test-lifting inshore is highly recommended, these costs may be a very good investment. Pendulum oscillation of the object easily occurs, both due to wave induced motions and due to quick shift of horizontal centre of gravity during crane operation. Although this is a substantial problem in reality, analysis models will often predict even worse results. This is typical for resonant dynamic systems, where the small amount of damping that actually exists is hard to quantify.

Analysis of lift in air is an area which probably will be given much attention in the years to come. A challenge, besides the damping issue, is that this is manually controlled operations,- it is not possible to calculate how clever a crane driver is going to be.

The stability of the vessel is reduced when the heavy load is lifted from deck, stability-wise it correspond to place the module weight in the crane hook. The accidental case occurring if the load is suddenly dropped also needs to be addressed.

Figure 9; Lifting a suction anchor from the deck of a transportation barge

6.4 Splash-zone

Any pendulum motion of the lifted object will be dramatically reduced when the object is lowered and penetrates the free surface. Seen from a crane drivers point of view this will be a point of the operation where he can relax.

Never the less, the splash zone is where the most violent dynamics occur, and normally where the crane wire loads will reach their maximum. Different types of relative motions between the object and the water will contribute:

- Particle velocity and acceleration due to wave motion
- Slamming toward at members of the object
- Object motions due to crane tip motions.

The wave induced vessel motions will normally represent a higher contribution than the operationally defined lowering speed of the object.

The purpose of the analyses for this stage is to establish design dynamic loads. This is normally done using a time domain analyses. The hydrodynamic coefficients that are input to this program, quantify the hydrodynamic forces. These coefficients may be hard to quantify, especially the slamming coefficient.

The stability of the object may also be a point of interest. Although the crane load itself normally acts at a high level and stabilize the lift, destabilizing effects may become critical. Typical destabilizing effects are buoyancy forces acting below centre of gravity, partly water filled compartment, air filled compartment communicating with the open sea etc. Further, the effect of the crane load cannot be fully understood without including some kind of interaction with the lifting vessel. Traditional stability programs are not able to handle this, hence a hand calculation or a time domain simulation may need to be performed.

Figure 10. Lifting through the splash zone. Air evacuation.

6.5 Further lowering.

When the object is lowered further the direct impact from the waves will vanish, and the dynamics are governed by the wave induced crane tip motion only. This means that the splash zone normally is governing for the dimensioning forces. One important exception occurs at ultra-deep sites, where the long lifting wire represent a softer system, leading to large eigenperiods. If the eigenperiods becomes similar to the period of the surface wave and crane tip motion resonance may occur. This is discussed further in an exercise. Another thing that need to be considered during further lowering is the wire weight, which may introduce high wire loads in the upper end. Wire wear may also be an issue.

Figure 11. Landing on sea floor. Do you see the guiding?

6.6 Landing.

A soft landing of the object is important, partly to protect the lifted object, and partly to avoid damages to the soil supporting the object after installation. Further, an accurate positioning of the object are required.

Time domain simulations may become relevant even for this phase. During the actual operations some kind of load or motion compensator are frequently used for this phase. The force characteristics of such devices are very complex, and the crane manufactures tends to keep the algorithm as an secrete. This makes it difficult to quantify their effect for a marine contractor.

6.7 Recovery.

Removal of old subsea modules for demolition or repair is an increasing market for installation contractors. Further, a recovery of the module may be a contingency case required by the client for a typical installation case. The engineering concerns for the recovery are similar to installation. Two additional challenges are the suction forces from the soil, that suddenly yields, and the weight of trapped water when lifted in air.

6.8 Exercises

Exercise 6.1

A torpedo- shaped anchor is to be dropped from a certain height above the sea floor. The purpose is to penetrate the sea floor to a certain depth and provide a safe anchoring point. According to the geotechnical report a collision speed of 100m/s is appropriate for a correct seabed penetration.

The key parameters are

- Weight 50tons
- Buoyancy 5tons
- Added mas 5tons
- Dimensionless drag coefficient Cd = 0:2. Corresponding frontal area. S = 1:5m2.

At what height should you drop the anchor? You may assume that wires and chains attached to the anchor have no impact in the anchor motion after being dropped.

Exercise 6.2

An offshore module is suspended from a crane. The crane tip motion is given by

$$C(t) = A\cos\omega t$$

Where A=1m is the amplitude and $T = \frac{2\pi}{\omega} = 6\ sec$ is the period of the crane tip oscillation. The following parameters are governing:

- M=100 tonne: module mass
- Ma=400 tonne: module added mass
- B=50 tonne: module buoyancy

The viscous drag can be neglected

The wire load acting on the module (positive means upwards) is given by

$$F = \frac{EA}{L}(C - z) + P$$

Where z is the vertical motion of the module and P is the tension in the wire at equilibrium. P will equal the mass and buoyancy of the module, while C and z measures the deviations from a static position. We assume EA=200 000 kN.

a) Establish the dynamic equation for the motion and establish z(t). Give the answer without specifying the numeric value of the parameter above.
b) Discuss the solutions for three ranges of the period T: small T, a value for T where the curve for z peaks and large T.
c) Insert the numeric values. For which value of L will resonance occur.

7 Platform installation

Even though completely submerged solutions for offshore oil productions are feasible and have been made, the vast majority of the oilfields contains surface piercing platforms. Some of the most typical oil platforms and their installation is discussed in the following.

Typically, the platform consists of a fixed or floating fundation, and an upper unit with living quarters, production facilities and units for separation of oils and gas and various other processes. In cases where the upper unit is clearly separated from the rest it is denoted topside.

The transportation to field consists of towing or, if relevant, using the platforms own propulsion. Two types of towing are used: wet tow, where the platform is floating, and dry tow, where the platform is located on deck of a transportation barge. In both cases the towing fleet is a main cost driver, hence calculating the required towing resistance is one of the main tasks for the engineer.

7.1 Jacket

The steel jacket type platform on a pile foundation is by far the most common kind of offshore structure and they exist worldwide. The "substructure" or "jacket" is fabricated from steel welded pipes and is pinned to the sea floor with steel piles, which are driven through piles guides on the outer members of the jacket.

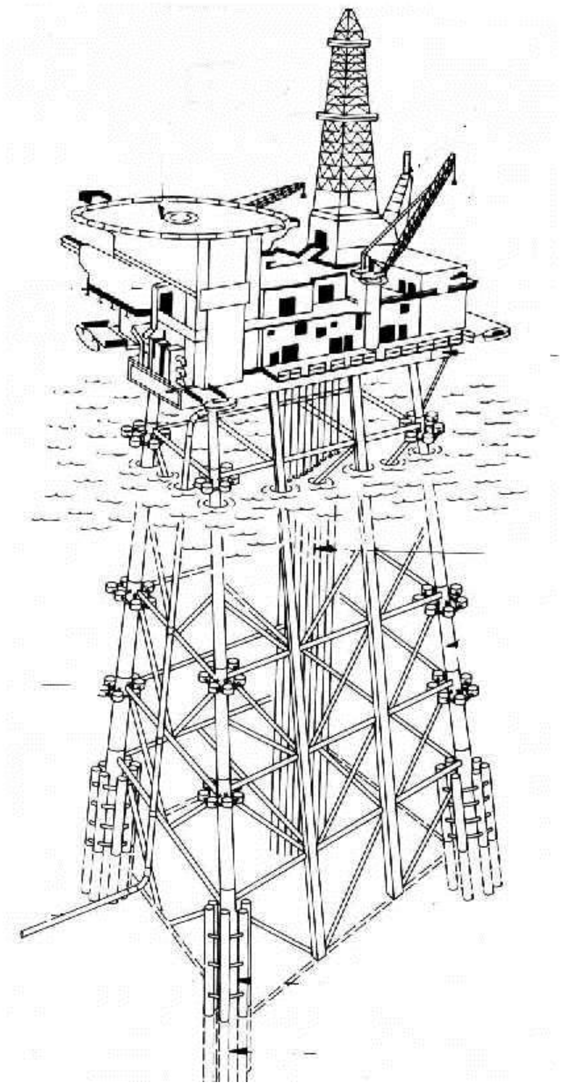


Figure 12. A jacket with a topside

The phases of a jacket installation are

- The production site is normally at a yard with a huge keyside. Preparation of different jacket parts in production halls, assemble at key side. Production logistic to ensure effective use of material and man hour is a main cost- driver.
- The jacket is transferred to a transportation barge with skidding or trailers
  - Skidding: Low friction shoes underneath the jacket, use of winching or jacks.
  - Trailers: Wheels mounted underneath the jacket to provide vanishing friction.
- Transportation to field,- dry towing
- Small jacket: lifted off barge deck and upended with crane vessel
- Larger jackets are launched: barge is ballasted to a certain trim angle, jacket slides into the water. Then upending with a crane vessel

- Crane assisted positioning and set-down on sea floor.
- Piling

The installation analysis determines loads that need to be included both for the jacket design and for the design of temporary buoyancy tanks. Some challenges during jacket launch and upending is listed below

- Position and size of temporary buoyancy tanks
- Maximum conatct force between jacket and barge.
- Maximum depth during launch
- Structural loads due to hydrostatic pressure
- Bottom clearance
- Floating condition after launch. Ensure access to lifting arrangement
- Upending. Check of structural loads crane load and bottom clearances.
- Proper upright position. Ballasting of side legs

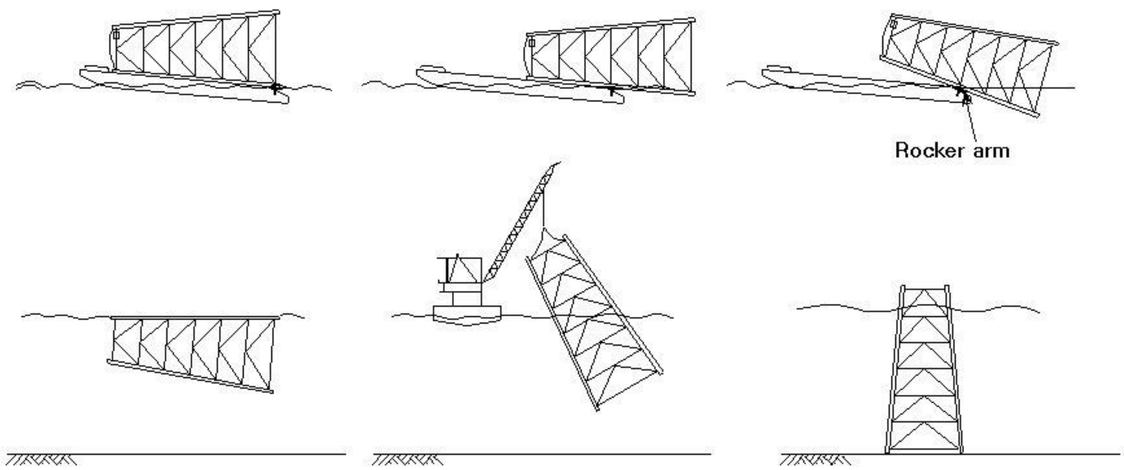


Figure 13. Jacket installation by launching

7.2 Topside

After securing the jacket with piles the topside installation follows. A light topside is normally installed in a single lift operation with an offshore crane. For heavier topsides, crane vessels may be unavailable or too expensive. The traditional alternative is an installation piece by piece. Another option is the floatover method: an opening in the top of the jacket is designed where the transportation barge may enter. After entry, the barge is ballasted, and conical units underneath the topside enter into receptors in top of the jacket corner legs. Some kind of rubber or shock- absorbing material may be needed. The barge is ballasted to a proper air gap to the transported topside and pulled out.

After installation of the topside the electric cables, risers etc are pulled in, all equipment's and facilities are commissioned and the production may start. The oil wells are normally predrilled to ensure a quick start-up of the production. When the floatover method is used for a floating platform the operation is normally denoted mating

7.3 Gravity based structures

A gravity-based structure (GBS) is a support structure held in place by gravity. These structures are often constructed in fjords, especially for units with extremely deep drafts. Fjords gives sufficient depths and are sheltered from extreme waves. The fjord sill will normally be dimensioning for the maximum draft that can be made.

The extremely tall GBS concept used in the North Sea, denoted Condeep platforms, were made this way. This type of platforms lost their popularity in Norwegian sector after the sinkage of the first Heidrun platform. Today there is an increasing interest for GBS- platforms all over the world, both Condeep- type and solutions suited for more shallow water.

A GBS is normally constructed of steel reinforced concrete, often with tanks or cells which can be used to control the buoyancy of the finished GBS. The topside may be mated or otherwise installed before or after tow-out.

Mating before transportation was normally done for the Condeep platform in Norwegian sector. These platforms are the largest man made structures ever been transported. Due to the extreme weights the only option is to wet tow the platforms to site. A huge fleet of towing vessels is normally required.

This is shown on the next slide, for a Condeep platform. Upon arrival at the offshore site the platform need to be positioned and ballasted down to the sea floor. Finally, the platform is filled with grout, a sort of concrete, to ensure a stable platform even in extreme weather.

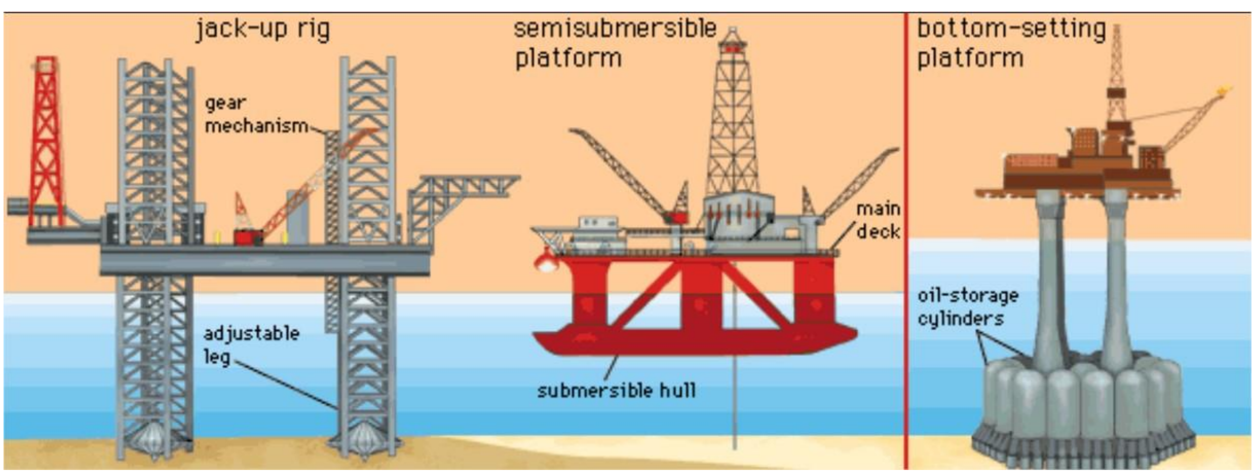


Figure 14 Jack-up, semisubmersible and GBS,

7.4 Jack-up

A jackup is a floating barge fitted with long support legs that can be raised or lowered. The jackup is maneuvered (self-propelled or by towing) into location with its legs up and the hull floating on the water. Upon arrival at the work location, the legs are jacked down onto the seafloor. Then "preloading" takes place, where the weight of the barge and additional ballast water are used to drive the legs securely into the sea bottom so they will not penetrate further while operations are carried out. After preloading, the jacking system is used to raise the entire barge above the water to a predetermined height or "air gap", so that wave, tidal and current loading acts only on the relatively slender legs and not on the barge hull.

The jackup may stay on a certain location for long time periods. Never the less, the platform type is particularly useful for short time engagements and frequent transits. The jackup will meet new soil conditions at each new location. This means that geotechnical issues and proper planning need to be constantly focused on. The most dangerous phenomenon is denoted punch through. This may occur if the soil is soft underneath a relatively firm upper layer. If the firm layer withstands the static loads and normal dynamic loads, the installation process may be believed to be successful. During a storm event the overturning forces acting on the platform may lead to a leg punch trough of the firm layer, and a sudden lack of platform support. Critical structural damages may then occur.

The normal way to prevent punch through is to apply an even higher static load during installation. This preloading may be performed by ballasting the barge when the legs have been lowered. Alternatively, for a four legged platform, two diagonal legs may be raised simultaneously. This means that a three legged platform normally needs to be equipped with larger ballast tanks. On the other hand, the fact that three vertical supports define a statically determined system proves to be a safe and robust solution to several operational and accidental scenarios.

Almost all Jack Up Units have footings. Their purpose is to increase the legs bearing area, thereby reducing the required capacity of the soil to provide a solid foundation upon which the Jack Up will stand. The weights and the operational and environmental loads to the seabed are then taken care of.

There are two main footing types: mats and spud cans. Mat footings connect all the Jack Up Units legs to one common footing. Mats provide a stable solution for extremely soft soils, but there are technical challenges at uneven seabed and when debris is present.

Spud cans are conical shaped individual footings underneath each leg. This will provide a stable fundament even in harder soil conditions.

7.5 Tension leg platforms

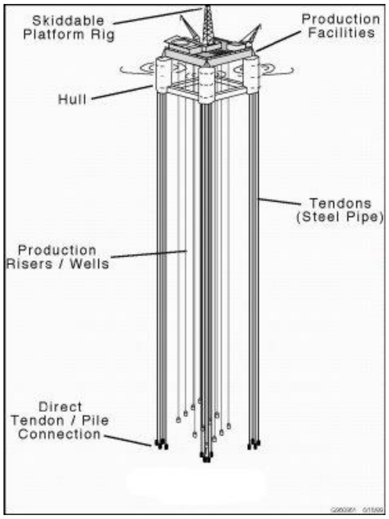


Figure 15. A tension leg platform

A tension leg platform (TLP) is a floating platform with strong vertical mooring (tendons or tension legs). After connecting the platform to the tendons a high tension is achieved through combinations of winching and deballasting. The fundamental idea is to arrest the vertical wave induced motion, while letting the horizontal motions remain. Vertical motions are the most challenging ones for risers, cables etc. Hence, the TLP may provide a more cost efficient solution than fixed platforms in deep water, without introducing the critical motions of a floater.

The installation steps may differ from platform to platform, but a typical installation may consist of the following steps:

- The fundaments for the tendons are lowered to the sea bed and secured with piles. Use of rock dumping or similar may add to the fundament stability
- A huge set of pipe sections are transported to the field. A crane vessel will upend and lower section by section. Each new section is attached to the previous section by use of some mechanism installed at the pipe section ends. When the first section reaches the sea floor it is attached to the fundament. A buoy is attached in the upper end to provide tension in the tendon, at a suitable water depth close to the surface
- Eventually all tendons are installed with buoys in the top end. Analyses need to be performed to ensure that the tendons do not tangle up for the expected worst environment that will occur in the period before the platform arrives.
- Meanwhile a floating substructure or hull is constructed and towed to field. The topside modules may be attached to the hull inshore or at site.
- The hull is then positioned above the preinstalled tendons. Winches are attached to the tendons. A high tendon pretension is then achieved by winching and ballasting. Normally the tendon elements need to be secured to the hull, and the winches released before the final stages of deballasting and pretension takes place.

7.6 Floating platforms

Floating offshore platforms may be defined as platforms with a soft positioning system, where the wave induced motions are not arrested. According to this definition the TLP is not a floater.

The purpose of the positioning system is merely to compensate for drift forces from the environment. This is normally achieved with a soft, catenary mooring. A so called DP may also be used. A DP is a computer system controlling several thrusters who continuously will change force and direction to compensate for slowly varying environmental forces. Floating platforms have several advantages, among them are

- Uncertainties related to soil conditions are reduced to a minimum. Notice, however, that anchors are required if a DP is not used.
- For deep water the price of an extreme tall structure is avoided.
- It is easy to move to other locations, take platform to land for repair etc.

The disadvantage compared to all platforms discussed earlier is the increased vertical motions. The interface with flexible products entering into the platform (cables, pipleines etc) becomes more challenging.

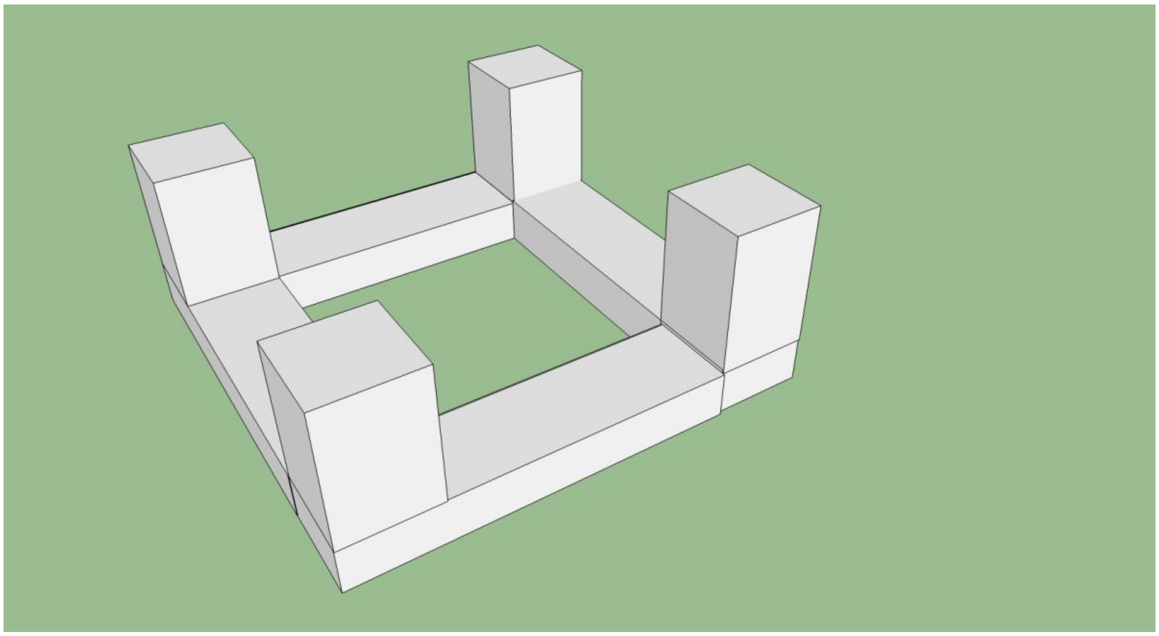
- The installation of a floater will normally go through the following steps.
- A set of anchors and mooring chain will be installed on the sea floor. The anchors will form a ring surrounding the target platform position, and the anchors will be attached to the mooring line. The chain will be laid in a U- turn toward the center, and some kind of mechanism and plans for picking it up are made.
- The floater are normally made on a ship yard, and topside modules lifted in and installed. Often the simplest work is done in low- cost areas, while the more technical challenging outfitting is done in other at more suitable locations.
- The floater is towed out and positioned between the anchors. The chains are then picked up by anchor handling vessels and handed over to the platform one by one. Each mooring line is connected to the platform winches. Finally, all lines are winched in to a proper pretension.

Hydrostatic and hydrodynamic analyses is needed for the transportation of anchors to field, for stability checks and seafastening loads. FEM analyses is needed for strength check of sea fastening.

Installation of suction anchors normally requires a typical lifting analyses. Laying of anchor chain is verified with laying analysis similar to laying of electric cables etc. Towing force need to be calculated, to select towing vessels. The strength of the tow line attachments on the floater need to be checked. The global strength of the floater itself in heavy sea is normally not checked,- the design storms used by the platform manufactures are worse than any transport condition.

7.7 Exercises

Exercise 7.1



Your company is going to conduct a wet- towing of a semi-submersible unit. A subcontracting company has been used to calculate the required towing force. Your boss does not thrust their work. He comes over to you, puts their towing analysis report on your desk and says:

"You join in in tomorrow’s meeting! And have an opinion!! Should we require an independent 3. party verification for the towing analysis? Or do we thrust them? I don't……

Look here: they claim that under zero environmental forces, they can tow the unit with 5m/s, using one towing vessel only: a tug with 40tonne pull force. This is bull sh...."

Perform some simple calculations. Can you substantiate the statements from your boss?

The platform is displayed in the figure above. The rectangular, horizontal pontoons have dimensions 20m x 10m, while the vertical corner column have dimensions 20m x 20m. The openings between the columns are 60m. The draft (distance from still water level to bottom of pontoons) is 40m.

Briefly discuss the accuracy of your analysis approach.

Exercise 7.2

A huge GBS (concrete structure) is shaped essentially as a cylinder with radius r=50m and height h=40m. The dry weight is 150 000 tonne. The GBS is constructed in a dry dock. After finalizing the construction work the dry dock will be flooded, and the platform towed to an offshore location.

Calculate the required water depth of the dock.

8 Some useful formulas

8.1 Catenary formulas

Gitt at vi ønsker å bestemme typiske parametre på en kjedelinje ut fra en ønsket radius ved touchdown, kan disse finnes som følger:

Bunnstrekk:

$$H = w \cdot R$$

Toppvinkel:

$$\alpha = \sin^{-1}\left(\frac{H}{w \cdot D + H}\right)$$

Toppstrekk:

$$T = \frac{w \cdot D}{1 - \sin(\alpha)}$$

Avstand til touchdown:

$$X = R \cdot \ln\left(\frac{1 + \cos(\alpha)}{\sin(\alpha)}\right)$$

hvor

H	=	Horisontalt strekk i produktet i touchdown [N]
w	=	Neddykket produktvekt [N/m]
R	=	Minste bøyeradius over touchdown (i "sag bend") [m]
□	=	Produktvinkel med vertikalen [radianer]
D	=	Vanndyp [m]
T	=	Produktstrekk i øverste ende [N]
X	=	Avstand mellom toppunktet og touchdown

Touchdown er definert som punktet der sjøbunnen danner en horisontal tangent med kjedelinjen

8.2 Tensioner Grip Force

Product tension is transferred to the tensioner(s) by the friction force generated between the tensioner belts and the product. The friction force is increased by increasing the tensioner grip force. However, maximum allowable grip force on the product given by the supplier must not be exceeded. Therefore, if sufficient friction force is not achieved at maximum allowable grip force, the contact length between the tensioner belts and the product must be increased. This may be achieved by installing two or more tensioners in series.

A rough estimate of required contact length between the tensioner belts and the product is given by:

$$l_{\min} = \frac{T_{\max}}{F_{allow} \cdot no \cdot \mu}$$

where

lmin = Minimum required contact length between tensioner belts and product

Tmax = Maximum installation tension

Fallow = Maximum allowable tensioner grip force

no = Number of tensioner tracks (belts)

μ = Minimum friction coefficient

In order to prevent the product internals from slipping through the outer sheath, the friction coefficient between the sheath and the underlying layer (normally armor wires) should also be considered, as it may be lower than the friction coefficient between the sheath/roving and the chute surface.

Note that a safety factor should be applied to account for inaccuracies in tensionersettings and tolerances of gauges or other equipment used to measure tensioner grip force.

8.3 Chute Contact Force

The radius of the installation chute is given by the minimum of the following:

- minimum bend radius at maximum installation tension specified by the product supplier, and
- the radius corresponding to the maximum contact force specified by the product supplier.

Minimum chute radius to comply with maximum allowable contact force may be determined as follows:

$$R_{\min} = \frac{T_{\max}}{N_{allow}}$$

where

Rmin = Minimum required chute radius

Tmax = Maximum installation tension

Nallow = Maximum allowable product contact force with chute

Required Recovery Tension over Chute

An installation operation shall in general be reversible. In order to enable recovery of a product over a tensioner, friction must be accounted for. an estimate of required recovery tension may be found as follows:

$$T_{rec} = T_{\max} \cdot e^{\mu\alpha}$$

where

Trec = Required recovery tension

Tmax = Maximum installation tension

μ = Friction coefficient between product and chute

α = Angle of sector (in radians) where the product is in contact with the chute