2 Overview of Selected Problems in Offshore Technology

Extraction of undersea natural resources, particularly oil and gas, has expedited the progress in offshore technology for a few decades, including the construction of platforms as well as the development of new extraction techniques and methods of laying underwater pipelines. Various types of cranes are an important aid in the construction of extraction infrastructure as well as its operation and servicing. The current chapter describes some most important elements of the infrastructure necessary for extracting oil and gas and methods of installation of offshore pipelines. Specific conditions pertaining to offshore cranes' operation and their basic typology are presented.

2.1 Platforms as One of the Main Features of Offshore Infrastructure

The idea of extracting oil and gas from sea beds occurred over 100 years ago. The first wooden drilling platform was applieded at the end of 19^{th} century off the coast of California. In 1911, the first installation to extract oil was engaged. It was located on the Caddo lake (on the border between the states of Louisiana and Texas) and yielded daily about 450 barrels [Wilson J. F., 2003]. The period following the World War II was marked by unceasing growth in number of offshore installations and as a consequence also in the amount of oil and gas being extracted. At that time, the areas where deposits were exploited and sought widened considerably. Presently, in many areas traditionally valued for such opportunities the deposits are running out or even already have. This applies particularly to the North Sea and the Norwegian Sea, where the existing deposits consist mainly of natural gas [Dokka A., Midttun O., 2006]. This situation forces companies to reach for resources located in less accessible areas featuring harder weather or greater depths. In Europe, the Barents Sea and other polar seas offer sample natural resources still remaining to be exploited. This opportunity doesn't come without difficulties though, namely: depth, heavy weather conditions and low temperatures. There has recently been a notable increase in amounts of resources yielded from waters surrounding South America (especially Brazil), West Africa, India, Australia and Oceania. Most of these endeavours are fairly new, thus

E. Wittbrodt et al.: Rigid Finite Element Method, OEO 1, pp. 5–25.
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employing post-2000 technology enabling extraction of oil and gas from large depths. Brazil in particular has shown considerable development of technology related to extracting resources from 2000 m and deeper, due primarily to their oil and gas search and extraction tycoon Petrobras. It is however worthy of notice that the rate of discovering new deposits is dropping, whereas just the opposite is the case with the demand for sources of energy and the pace at which known resources are exploited. Some forecasts thus state that between 2010 and 2015 we are at the peak amount of oil extracted from sea and ocean beds. Despite this, modern technologies created for the extraction of hard to reach resources and experience acquired may underlie new projects, including ones related to the production of energy. It is in seas and oceans where vast supplies of energy are to be found (waves, sea currents). Works aimed at exploiting them are gaining momentum.

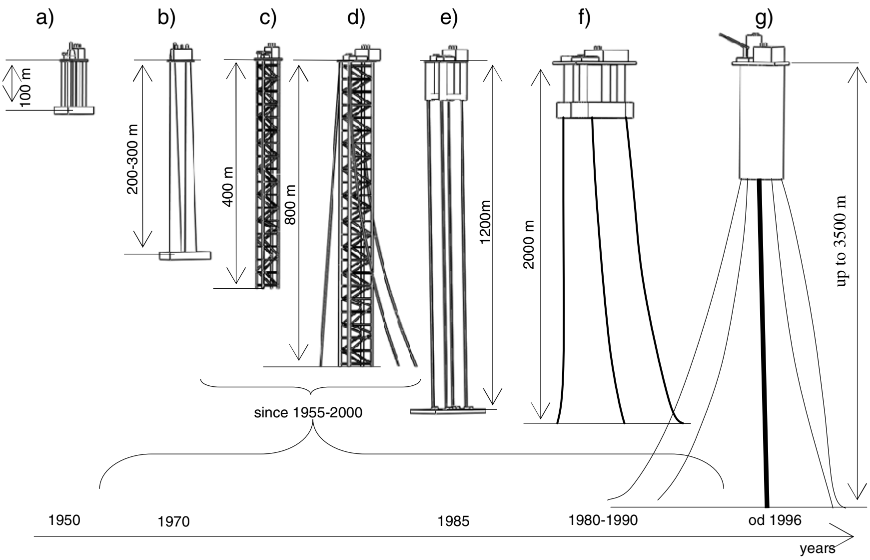

Fig. 2.1. Basic types of platforms

Drilling and extraction platforms are the most characteristic offshore structures related to the extraction of oil and gas (Fig. 2.1). A drilling platform is a floating structure equipped with a drilling rig, suited for making wells in the bottom of a sea. Platforms of this type are sporadically used simultaneously to exploit the deposits. An extraction (production) platform is suited for extraction of gas and oil and their preliminary purification. From there the stock is loaded onto tankers or transferred further by an underwater pipeline. These are usually structures supported off the bottom, although recently they have more and more often been constructed as floating or semi-floating.

Platforms were initially built on shallow seas, up to about 100 m in depth (Fig. 2.1a). They had a steel foundation lying on the bottom to which legs (three to six) were attached. Gravity platforms (Fig. 2.1b) started to be used shortly afterwards. Their foundations as well as legs were made of concrete. They enabled reaching depths of 200 m to 300 m. The type of structure based on a truss is most common nowadays (Fig. 2.1c). Of these the first to appear was a 30 m tall one in 1955. Their contemporary capability of operation in terms of depth reaches 400 m. A variation thereof are truss platforms equipped with additional mooring lines (Fig. 2.1d). In extraction industry they have been in use since the beginning of 1980s [Chakrabarti S. K., 2005]. They allow for extraction of deposits on seas with depths up to about 800 m, simultaneously admitting significant movement of the platform due to waves. Since the second half of 1980s, platforms lacking fixed connection with the bottom and instead kept afloat by buoyancy forces have started to be widely introduced. Their positioning with respect to the sea bottom requires additional elements to be installed in the bottom (Fig. 2.1e). Platforms of this type, called Tension Leg Platform (TLP), are installed mainly in areas 800 m to 1200 m deep. As their advantages count stability and immunity to vertical and rotary movements. Fig. 2.1f shows a scheme of a multihull semi-submersible platform used with depths in the range of 2000 m (in extreme cases even up to 3000 m). Such platforms are usually equipped with own propulsion assuring continual operation and stability even under intense waves and avoidance of personnel evacuation. Similarly constructed SPAR type platforms are shaped as vertical cylinders (Fig. 2.1g) with profile diameters up to 30 m or 40 m and heights of hundreds of meters.

In many cases when depth exceeds 1000 m, an additional infrastructure aiding the extraction of resources from a seabed is placed on the bottom which takes over some of the platform's tasks. The necessity to built an expensive production platform is thus avoided. Its role is fulfilled by specialized ships moored above the extraction field, or the stock is transferred by pipelines to land stations or nearby platforms.

2.2 Offshore Pipelines: Applications and Sample Installations

For over 100 years, transport of oil, gas, derivative compounds and water has been performed by means of pipelines. They are the most efficient way to transfer continuous medium to large distances. Their role has greatly increased with the development of extraction of resources from undersea deposits. Underwater pipelines presently constitute a considerable part of the entire infrastructure existing for oil and gas transportation. Because of the working environment, their structure, installation and extraction are much different to the case of overland and underground ones.

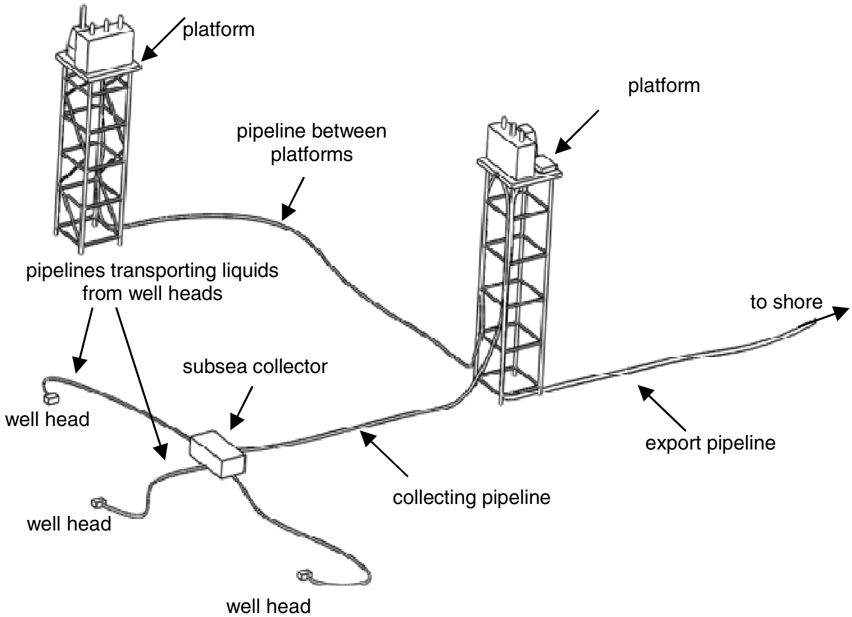

Fig. 2.2. Sample offshore infrastructure with miscellaneous pipelines

A sample gas field is shown in Fig. 2.2. The role of the production unit is fulfilled by an extraction platform. On the platform the stock is processed into the ready product, which is subsequently transferred by exporting pipelines to a receiving station.

Offshore pipelines may be basically divided as follows (Fig. 2.2):

- connecting heads of wells with collectors,
- collective – transferring resources from collectors to production platforms,
- transfer – connecting production platforms within a single oil or gas field or neighbouring ones,
- export – transporting products from production units to receiving stations (land bases, customer's receptive infrastructure),
- serving to transport water or other chemical compounds from production units (platforms or land facilities) to drilling heads,
- otherwise construed, often in the form of bundles of pipes or cables.

Large oil fields often have many platforms providing for different needs: accommodation, production, storage. The Ekofisk field in the North Sea built in 1970s may serve as an example.

Extraction and processing of oil and gas has lately more and more often been supported by Floating Production Storage & Offloading (FPSO) vessels (Fig. 2.3). Due to large dimensions (typically 300m to 500m in length), ships of this kind are very stable. An FSPO vessel is held in the desired position by means of mooring lines. It departs for a safe seclusion only under extreme storms. The extraction technique employing FSPO vessels is a fairly new development. Its main application is on smaller gas fields where periodic relocation of a vessel is desirable. Usually individual wells are connected by special pipelines to risers, which are vertical segments of pipes connecting collectors with a turret placed in the hull of an FSPO ship. Risers are highly flexible and feature special loops to compensate for FSPO movements due to waves and wind. In case of an FSPO vessel's emergency departure from a field the turret with risers and mooring lines is lowered to the bottom. Its reinstallation requires using a specialized winch with high capacity (800 T to 1000 T).

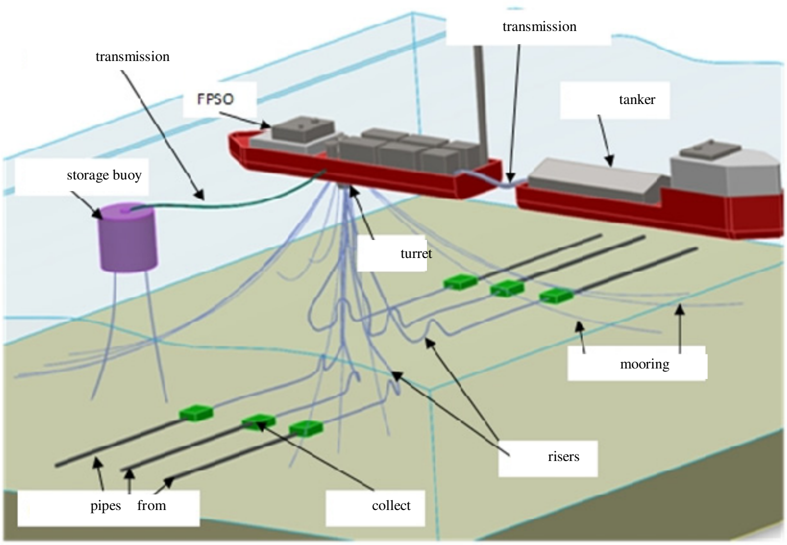

Fig. 2.3. Extraction and processing of oil or gas using an FPSO ship

In some cases only a processing station located on shore is used in the extraction of a deposit. The stock is then transferred by pipelines directly from the well to the land. The Ormen Lange gas field situated on the west coast of Norway (Fig. 2.4) is one such example.

As already mentioned, risers (Fig. 2.3) are used to transport oil or gas, as well as water and other substances, between the seabed and a drilling or production unit on the surface of the sea (platform, ship, FSPO). Risers may be drilling risers used for transport of fluids utilized in the process of making wells, or production risers which transport the stock from wells to vessels or platforms. It ought to be mentioned that the cost of risers may be comparable to that of a ship or a platform

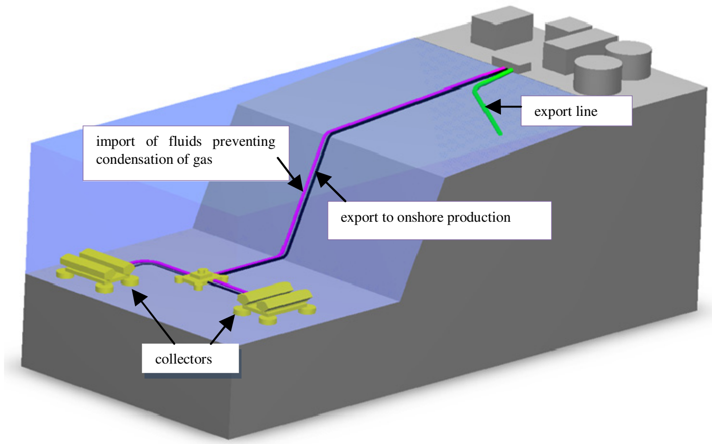

Fig. 2.4. Ormen Lange gas field

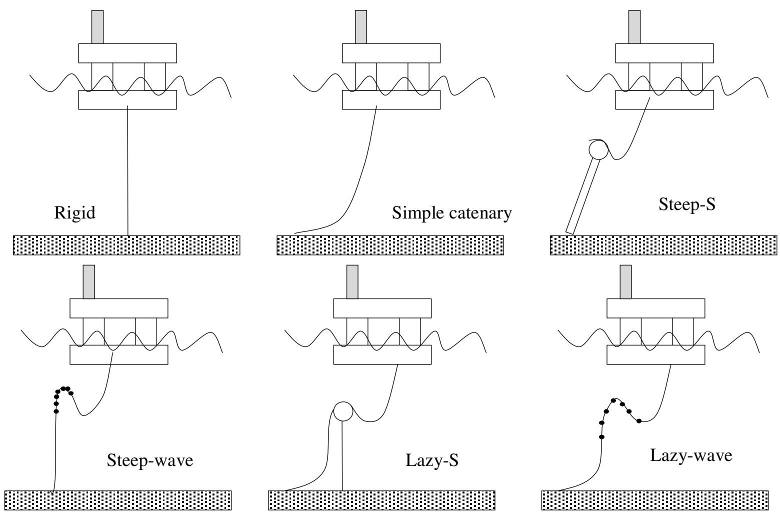

Fig. 2.5. Systems of risers used in oil and gas extraction

in case of deep sea extraction [Bai Y., Bai Q., 2005], [Chakrabarti S. K., 2005]. Basic configurations of risers are schematically depicted in Fig. 2.5. The choice of a given system depends on multiple factors: depth of the sea, structure and functionality of the vessel (particularly its manoeuvrability under wave action), number and setup of mooring lines, conditions present in the extraction area, including the intensity of sea currents.

A wide overview of the technology and elements of the infrastructure used in offshore industry can be found among others in [Gerwick B. D., 2000], [Bai Y., Bai Q., 2005] and [Chakrabarti S. K., 2005].

2.3 Offshore Pipelines Installation Techniques

Installation of underwater pipelines is a technically difficult operation, which differs substantially from the case of land ones. It requires using a separate set of often innovative methods. Currently the following basic methods of laying offshore pipelines may be distinguished:

- S-lay,
- J-lay,
- reel method,
- tow method.

Each of them has both advantages and disadvantages and limitations. The criteria for choosing the method for a particular case are following:

- sea depth,
- length of the segment to install,
- diameter of the pipeline,
- time allowed for the installation,
- total budget of the operation.

2.3.1 The S-Lay Method

The S-lay method is one of the oldest methods of laying underwater pipelines. It was used mainly for installations in shallow seas. It can be performed from either a specially equipped vessel or a platform. Low amplitudes of motion of multihull semi-submersible platforms have made them an often preferred utility for laying pipelines with the S-lay method. Such a solution is especially popular on seas with intense waves for the most part of the year (e.g. the North Sea and the Norwegian Sea). The schematic concept of the S-lay method is shown in Fig. 2.6. It is named after the shape taken by the pipeline being laid on the segment between the unit and the bottom. It resembles the letter *S*. A special structure called a stringer is used to support the pipeline suspended from the deck.

For installing long and high capacity pipelines in seas up to 600 m deep the S-lay method is most popular. It is applicable to pipelines of greatest diameters, even exceeding 1m.

The length and geometry of the ramp guiding the pipe depend primarily on the depth of the sea and the diameter of the pipeline. Control of the inclination angle of the ramp, thus also the shape of the pipeline being laid, is provided by two means:

- built-in buoyant elements whose filling appropriately with water makes it possible to regulate the immersion of individual segments of the ramp – such are the multi-modular buoyancy ramps,
- leveraging systems of ropes and a winch or other mechanisms controlling the inclination angle of the ramp.

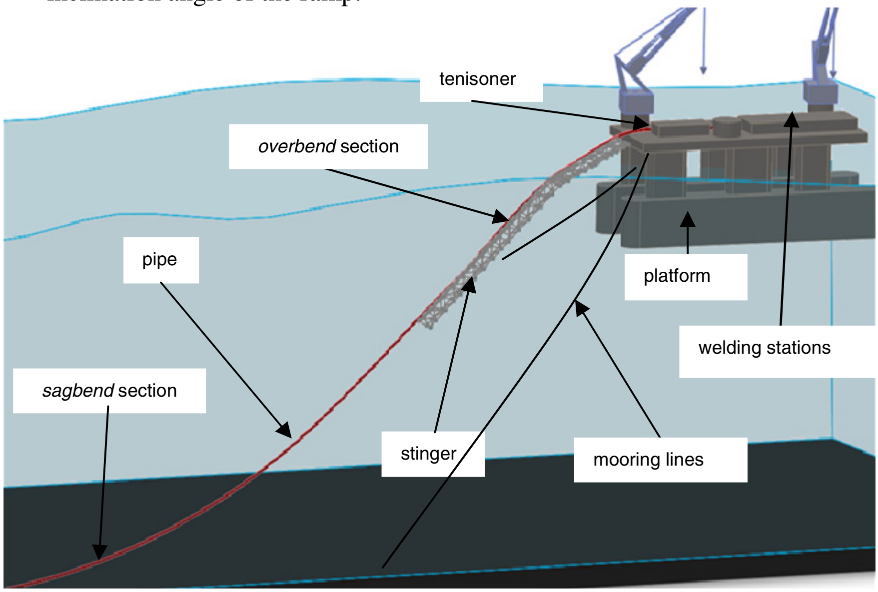

Fig. 2.6. Application of a semi-submersible platform to install o pipeline with the S-lay method

Tension systems are used to prevent buckling of the pipe being laid in the lower deflection and to keep the deformation of the material within the desired limits. These are specialized mechanisms placed in front of the entry point of the pipe onto the ramp guiding the pipeline and a set of anchor winches. Additional vessels control the anchors. Appropriate tension may also be created with thrusters along with sufficiently powerful engines. The necessity of creating an axial force in the pipeline being installed is a rather significant disadvantage of the method discussed. Its impact is more evident with greater depths, therefore the S-lay method is limited to shallower seas. Laying pipelines with the S-lay method may also be performed from ships or barges.

2.3.2 The J-Lay Method

Usage limitations of the S-lay method and simultaneously growing demand to lay pipelines at greater depths motivated the development of the J-lay method. Its name also reflects the shape of the pipe being laid. When suspended between the unit and the bottom, it resembles the letter *J*.

Similarly to the previous method, laying pipes with the J-lay method can be performed from decks of multihull semi-submersible platforms as well as monohull barges and ships. Its characteristic feature is a vertical guiding ramp. Setting the ramp in an almost vertical position eliminates the problems with exceeding admissible tensions in the material of the pipe in the area of the upper deflection. Additionally the J-lay method allows for considerable reduction of necessary forces to be exerted by tensioners and the unit itself. A disadvantage of the J-lay method is the ability to use a single welding station only, thus limiting the efficiency of laying pipelines. It typically reaches 1.5 km to 2 km per day, whereas with the S-lay method 5 km to 6 km per day are usual values.

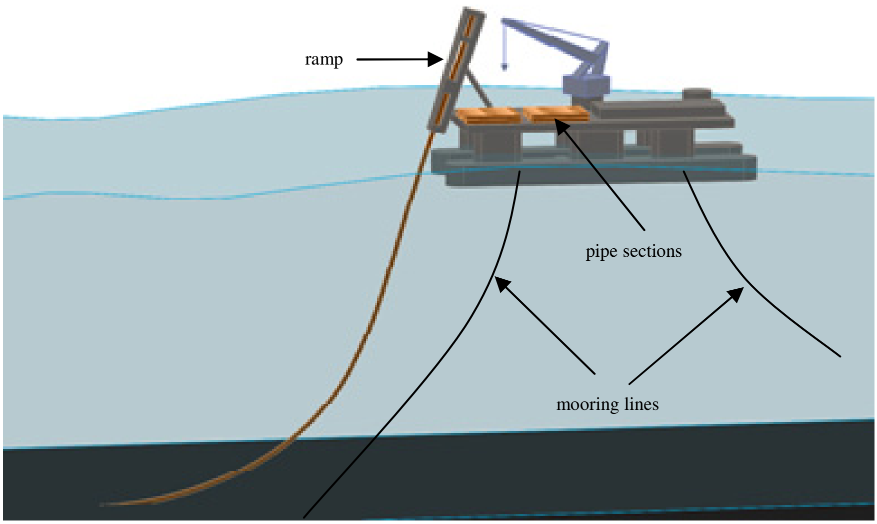

Fig. 2.7. Scheme of laying a pipeline with the J-lay method

In Fig. 2.7, a scheme of a platform installing a pipeline with the J-lay method is shown. The platform Saipem 7000 is one of the largest such units in the world. It was used, among other things, to install a high capacity pipeline running across the Black Sea with depths reaching 2200 m.

Whenever the inclination angle of the ramp can be controlled, the J-lay method may also be used in shallower seas. Usually, the angle can be set between about 65° and 90°, however in some ramps it can even be 30°.

2.3.3 The Reel Method

Among the major drawbacks of the S-lay and J-lay methods is the necessity to connect pipes on the platform or the vessel prior to laying them. Hence they require using transport ships supplying segments of pipes from the land, usually of lengths between 12 m and 50 m. Those must be subsequently reloaded with an offshore crane to the main unit. Therefore, in the case of pipelines with lower diameters, the reel method is popularly chosen. A vessel used in this method features a specialized reel. The pipe is wound onto the reel on the land, including connecting its segments by welding. Next, the vessel transports the entire pipe to its destination where it is installed. The reel method is used mainly on the North Sea. Its primary usage domain is laying relatively short segments of pipelines, e.g. those constituting elements of oil and gas fields infrastructure (Fig. 2.2). One of the foremost advantages of the method is its high efficiency reaching 2 km per hour.

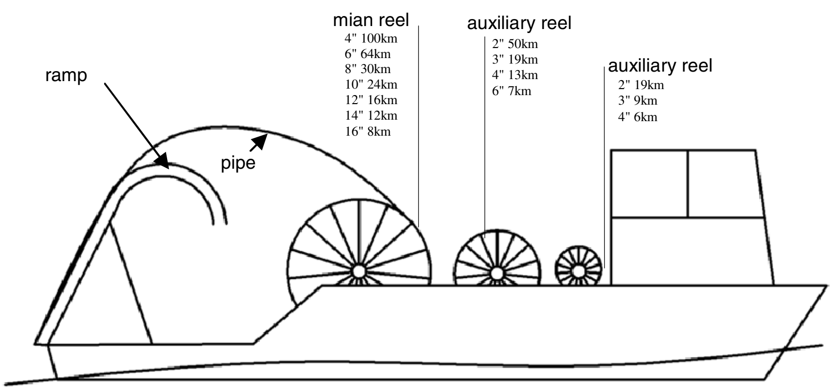

Fig. 2.8. A ship with a reel to wind pipelines

First installations made with floating reels were performed already in 1994 by the Allies during their invasion of France. In Fig. 2.8, a contemporary ship Apache[1] is shown, whose purpose is to work with the reel method. It features a main reel onto which 8 km to 100 km of pipes (depending on the diameter) can be wound and two smaller ones for short fragments of pipes and risers.

Winding of pipes onto the reel may cause permanent plastic deformations. It is the case with pipes with large outer diameters and small winding diameters of reels. This may substantially and adversely influence the properties of the installed pipeline. Therefore, only slight permanent plastic deformation of pipes being laid is admissible. The magnitudes of these deformations depend on: dimensions of the reel, outer and inner diameter of the pipes, tension during the winding.

At present, large reels are used, which can accommodate between 2000 T and 3500 T of a pipeline. Diameters of such reels exceed 30 m and the forces generated by their drives surpass 200 T. Smaller reels may form sets (of two or three pieces) which are supplied by transport vessels. An integral part of a ship suitable for laying

[1] The informations were taken from the operator's web page, the Technim company.

pipelines with the reel method is a guiding ramp, usually installed on the stern. Its purpose is to give shape to the pipe leaving the ship, whereby typically the reel method is combined with the J-lay method (Fig. 2.9). The ramp simultaneously serves as the supporting structure for elements guiding and straightening the pipe. In its upper part there is an aligner wheel, and following it a device straightening the pipe, eliminating its permanent deformations caused during winding. Additionally on the ramp, a set of devices is installed which control the speed at which the pipe slides from the ramp and hold the weight of the pipeline suspended in the water.

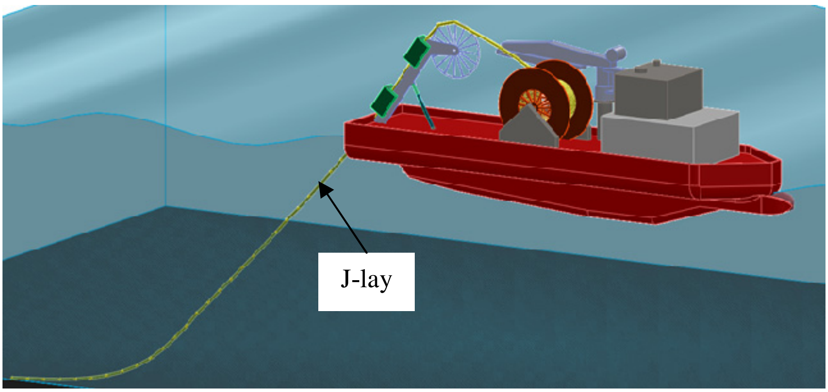

Fig. 2.9. A ship unwinding a pipe from a reel and laying it with the J-lay method

A similar solution is a structure with a reel whose rotation axis is vertical. Systems of this type are mainly used for installing bundles and cables. They are unwound from the reel (called a carousel) and passing through a system of tensioners are laid on the bottom. Another system in existence is one with the reel's axis parallel to the ship's longitudinal axis, in which case the laying is carried out from the vessel's side.

Limitation of the maximal outer diameter of the pipeline to be laid is the primary disadvantage of the reel method related to plastic deformations. Pipes installed using this technique have diameters up to 28 in. The reel method, moreover, introduces relatively large deformations in the material of the pipe (up to 5%) which may weaken the welds and deteriorate the pipeline's stability, including the occurrence of a spiral line. Furthermore, there exists a risk of ovalization of the pipeline's section leading to local instability. It may also occur that a pipeline needs to contain segments with different diameters or other components (e.g. valves, splitters and so on). These add to the difficulty of the method discussed. When the base in which the winding of pipes onto the reel takes place is distant from the destination, considerable growth of cost and time of the operation is to be expected. Additionally, huge mass of the reel and pipes or cables wound onto it exacerbates the dynamic forces caused by waves. Stability of the device and the whole ship is thus worsened. Despite all of these, the reel method is, as mentioned, eagerly used.

2.3.4 Methods of Towing Pipelines

In cases of short segments of pipelines, a few kilometres in length, it is possible to assemble them on the land and next to tow them wholly to the location where they are installed. The longest segment to have been installed in this way had 7km [Bai Y., Bai Q., 2005]. Towing is usually performed by two vessels, one towing the beginning and the other the end of the pipeline (Fig. 2.10). Buoyant elements placed along the pipeline are used to prevent damage. They are selected so that the pipeline stays at a certain controlled depth beneath the water surface. The influence of hydrodynamic forces due to waves is thus reduced. On arrival at the destination, the buoyant modules are removed and the pipeline is lowered to the bottom. Sometimes other towing techniques are used in which the pipeline floats on the surface, or is dragged on the bottom [Chakrabarti S. K., 2005].

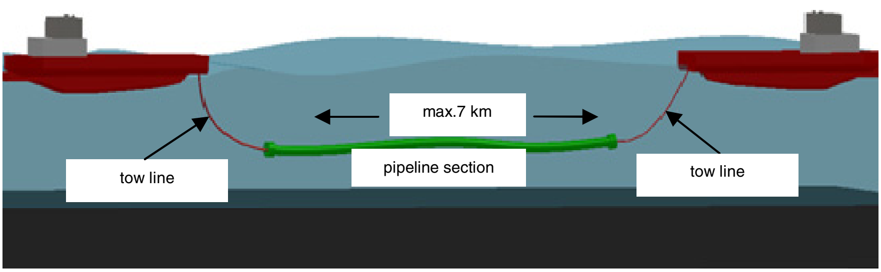

Fig. 2.10. Installing a pipeline using the towing method

Ease of preparation on the ground of the elements to be laid (which may be complex bundles of various cables and pipes installed together) is definitely an advantage here. The problems and costs related to the production of a pipeline or bundle in offshore conditions are avoided. An undeniable disadvantage is the difficulty of constructing longer pipelines with this method (control of forces and displacements during towing is a problem) and great amount of work and costs in cases of laying curved segments. For these reasons, the total number of kilometres of pipelines laid with the towing method is modest.

2.3.5 Other Operations in Service of Pipeline

Other than the very process of laying a pipeline, there exists a multitude of important operations forming comprehensive construction and extraction of exploration infrastructure. Among them are the following:

- securing a pipeline on the bottom,
- winding of pipes onto reels in specialized bases,
- operations of lifting a pipeline from the bottom, repairing, de-installing etc.

Securing pipelines is done with specialized ploughs. After the pipe has been laid on the bottom, the plough is lowered from the vessel and then towed by it. The plough forms a ditch in the seabed and simultaneously inserts the pipe into it. Another plough is used to bury the pipeline. When the diameter of the pipeline is small, devices cutting the ditch in the seabed may be used directly before laying it. The same devices usually install the pipe itself, provided that it is elastic enough. Yet another solution is to use specialized machines powered with high pressure. In some cases, the pipelines installed are buried with a layer of material supplied by ships (pebbles, gravel).

An example spool base in which offshore pipelines are produced is Orkanger base, Norway. Such bases must have the ability to store ready fragments of pipes of length up to a few kilometres. They are located in areas of intense extraction, where further works are planned for several years. Their advantages are low production costs and immunity to weather conditions.

Repairs and servicing of underwater pipelines is performed using specialized vessels capable of lifting pipes from the bottom. They are equipped with multiple reels onto which pipes or cables can be wound when they are damaged or being removed.

2.4 Reloading and Assembly Works Using Cranes: Tasks, Environmental Conditions, Types

Reloading and assembly works realised using various types of cranes are among widely performed and highly important operations in offshore engineering. One of the main features distinguishing offshore cranes from land ones are significant movements of the base caused by sea waves. In the case whereby a load is lifted from a supply ship also the load is in such motion. As a result, offshore cranes are far more exposed to dynamic overloads than their land counterparts. Those overloads have significant influence on the permissible operating range of the device. Constructors aim at designing a device in such a way that it can operate under wave action as intense as possible. Offshore cranes are therefore equipped with specialized anti-overload systems which minimize load oscillations and increase safety. It is also worth noting that weights of loads carried by offshore cranes often reach hundreds of tonnes. Winds, which are common in maritime areas, as well as extreme temperatures add further difficulty to their operation.

Taking the criterion of construction into account, the following types of offshore cranes may be distinguished:

- gantries,
- A-frames,
- boom cranes.

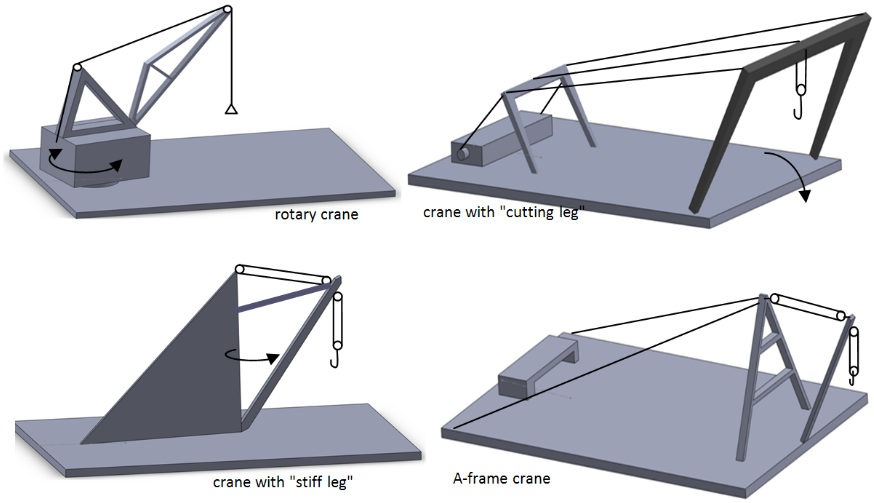

Fig. 2.11. Examples of cranes installed on vessels

Offshore cranes are installed both on platforms and sea vessels (ships, specialized barges). If they are equipped with a boom, it may be fixed or telescopic.

A common solution is to install offshore cranes on a special column. Depending on the criterion, column cranes may be classified as featuring:

- rope overhang control system
- hydraulic overhang control system
- truss boom
- box boom
- telescopic boom
- knuckle boom

Sample structures of offshore column cranes are depicted in Fig. 2.12.

Similarly to land technology, gantries are a popular choice. They often appear on large container ships. They are also installed on other sea vessels and platforms where they are used for assembly and service works. A gantry installed on platforms and used to relocate and lower the valves of a BlowOut Preventor (BOP) may serve as an example. Schemes of different installation possibilities of offshore gantries are in Fig. 2.13.

The multitude of construction solutions of offshore cranes is a result of the variety of their applications. Those range from reloading goods transported overseas, constructing and operating offshore infrastructure, to scientific research etc. In many cases such devices are constructed one-off for a particular order.

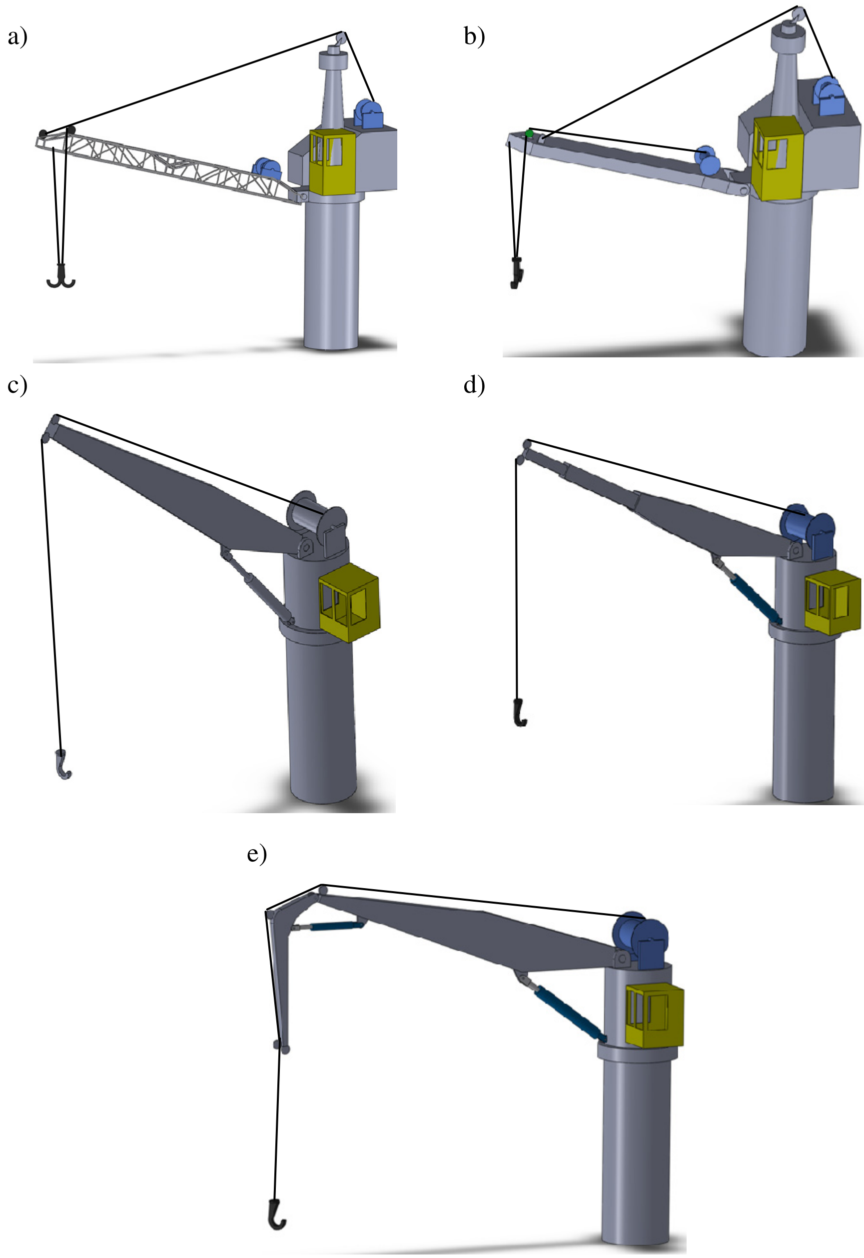

Fig. 2.12. Column cranes: a) with a rope overhang control system and a truss boom, b) with a rope overhang control system and a box boom, c) with a hydraulic overhang control system and a box boom, d) with a telescopic boom, e) with a knuckle boom

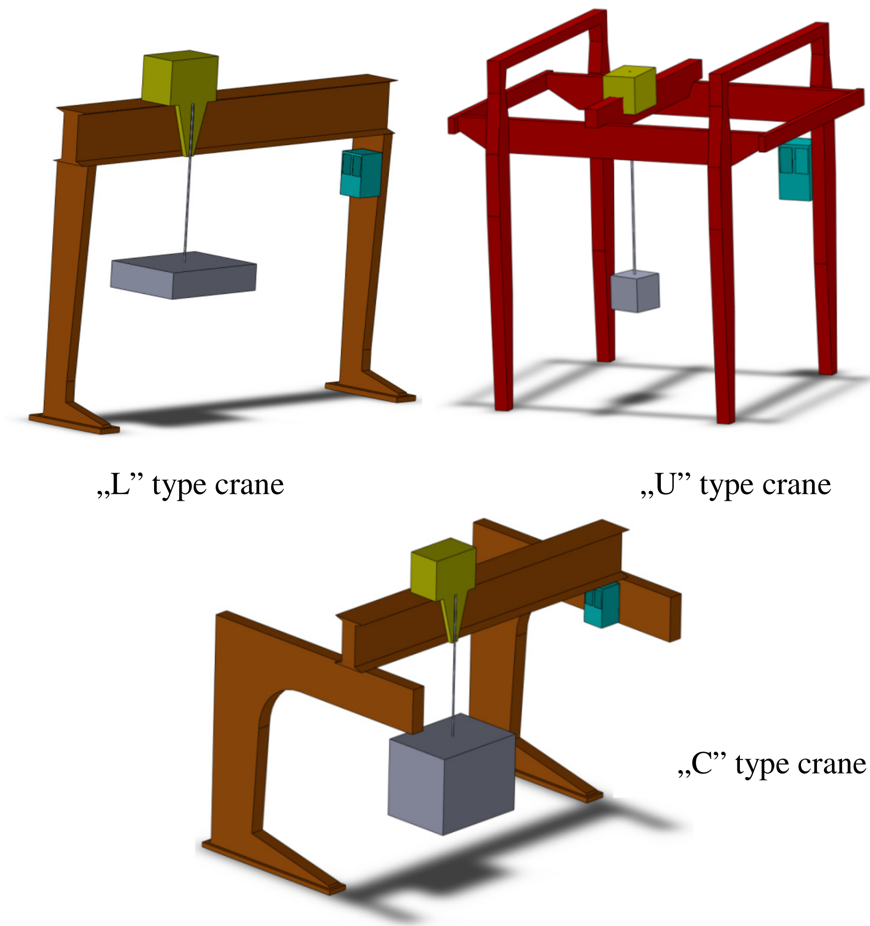

Fig. 2.13. Structures of different types of offshore gantries

2.4.1 Stabilization of Load Position and Minimization of Its Oscillations

When operating an offshore crane, the problem of load oscillations is of special importance. Those oscillations, caused mainly by sea waves, not only make reloading and assembly works more difficult, but also create an immediate danger for the personnel. In extreme cases, the load may hit a side of the sea vessel carrying the load or the supply vessel. Thus, market leaders endeavour to equip their products with specialized anti-oscillation systems. A system of this type, the SmartCrane™ Anti-Sway Crane Control for Rotating Boom Cranes, is offered by SmartCrane. Its working principle is to move the suspension point of the rope at the end of the boom. Li Y. and Balachandrana B. of the University of Maryland presented it at the symposiums MURI on Nonlinear Active Control of Dynamical Systems (Virginia Polytechnic Institute and State University, 1998-2001) as well as in their papers [Balachandran B., et al., 1999], [Li Y. Y., Balachandran B., 2001]. This solution may be enhanced by a closed-loop control system. In the mentioned papers, the mathematical models applied omitted the flexibility of the supporting structure of the crane. At the MURI symposiums it was also proposed that there exists another possibility of solving the problem of load oscillations. It consists in adequately controlling (also by means of a closed-loop system) the rotary motion and raising of the boom. The method was verified numerically and experimentally on a test stand. [Masoud Z. N., 2000], [Nayfeh A., Masoud Z., 2001], [Masoud Z., et al., 2004], [Nayfeh A., et al., 2005a]. The analyzed problem required a spatial model of the crane. However, the created model ignored the flexibility of the system. A feature worth mentioning is an additional provision for minimizing the motions of both the supplying and the receiving vessel by means of a stabilizing system. It consists in tying them together with ropes once positioned appropriately against the waves and moving at a specified speed. The concept is discussed in detail in [Nayfeh A. H., et al., 2005b]. Another method of stabilizing the load position in an offshore crane was the topic of the following works, among others: [Maczyński A., 2005], [Maczyński A., 2006], [Maczyński A., Wojciech S., 2007]. It will be presented with details in chapter 10. It assumes the use of an additional unit suspended at the end of the boom, guiding the tow rope at a certain segment. Changing its deviation from the vertical is a way to influence the load's tangential and radial oscillations. This solution provides for a great deal of influence on the motion of the load, and in combination with the winch it enables stabilization of the load in three directions. In [Maczyński A., Wojciech S., 2009] it was shown that stabilization of the load also minimizes the undesirable effect whereby the tow rope is stressed and eased. The analyses presented in the above mentioned papers were carried out for an offshore crane with a hydraulic overhang control system and a telescopic boom. In [Spathopoulos M. P., Fragopoulos D., 2004] a similar solution was considered in the planar case based on a simplified model of a crane ignoring the flexibility of the system. Control methods for both linear and nonlinear objects were used. Two different control algorithms minimizing load oscillations were also discussed in [Schaub H., 2008]. One algorithm was based on current measurements only, whereas the other additionally performed computations on a model of the system. Due to the necessity of real-time operation, the model of a crane should in this case be very simplified. The boom was thus modelled as a rigid link, the load as a material point and the distance between the end of the boom and the load was constant.

In industry practice, also other systems have been in use for years, e.g. PDC 200 scanning the profile of the load with a laser and subsequently compensating for the oscillations electronically. They are produced by the company Cegelec-AEG. Yet other solutions are ABB's System CPC and Caillard's ESCAD [Cosstick H., 1996].

2.4.2 Safety Systems: Systems Limiting Dynamic Overloads in Offshore Cranes

As can be seen from the previously presented reasoning, offshore cranes are heavily exploited devices often exposed to extreme conditions. Their malfunction during operation may cause significant material losses and even pose threats to human health and life. According to the EN13852-1 norm, each offshore crane must feature the following safety systems:

- emergency operation – in case of power failure, means shall be provided for a controlled slew, luff down and load lowering operations, to land the load and boom safely,
- emergency stop – the emergency stop shall retain its function regardless of any malfunction of the programmable control system, if installed,
- lateral boom protection system – an automatic protection system shall be provided to prevent lateral overload of the boom or overload on the slew mechanism if sidelead loads occur outside the design limits,
- manual overload protection system (MOPS) – system, activated by the crane operator, that protects the crane against possible overload by reducing the load carrying capacity and allowing the hook to be pulled away from the crane in any direction,
- automatic overload protection system (AOPS) – system that automatically safeguards and protects the crane against the effects of a gross overload during operations by allowing the hook to be pulled away from the crane in downwards direction within specified offlead and sidelead angles, without causing significant damage to the crane.

Appendix J to the norm EN13852-1 establishes a hierarchy of importance of these systems and signalling components. It is summarized in tables 2.1 and 2.2.

Table 2.1. Normal ranking of safety measures

Order of precedence	Safety measure	Safety measure
1^{st} priority	Emergency stop	Manual overload protection system (MOPS)
2^{nd} priority	Automatic overload protection system (AOPS)	
3^{rd} priority	Other limiters	
4^{th} priority	Indicators	

Table 2.2. Ranking of safety measures when mode for personnel lifting is selected

Order of precedence	Safety measure
1^{st} priority	Emergency stop
2^{nd} priority	Mode section switch and other limiters
3^{rd} priority	Indicators

The so-called shock absorbers are another type of systems limiting dynamic overloads used in offshore cranes. One is installed on the boom (Fig. 2.14), the other at the manifold (Fig. 2.16). The task of a shock absorber is to consume the energy of a momentary overload. In the case of the first solution, the dynamic overloads are minimized by passing the rope through an additional movable sheave connected to a hydraulic system. The concept of its operation is explained with a scheme (Fig. 2.15). It is a system consisting of an accumulator filled with gas and a hydraulic actuator. When the force *S* applied to the piston rod increases to the cutoff level (static load summed with flow resistance in the actuator is usually assumed), it starts moving and the oil starts flowing from the cylinder to the accumulator. The working stroke Δ_2 of the piston is reached for the maximal value of the dynamic force. That stroke is lower than the maximal stroke Δ_{max}, as for safety reasons the stroke Δ_{safe} should be maintained. The force *S* is balanced by

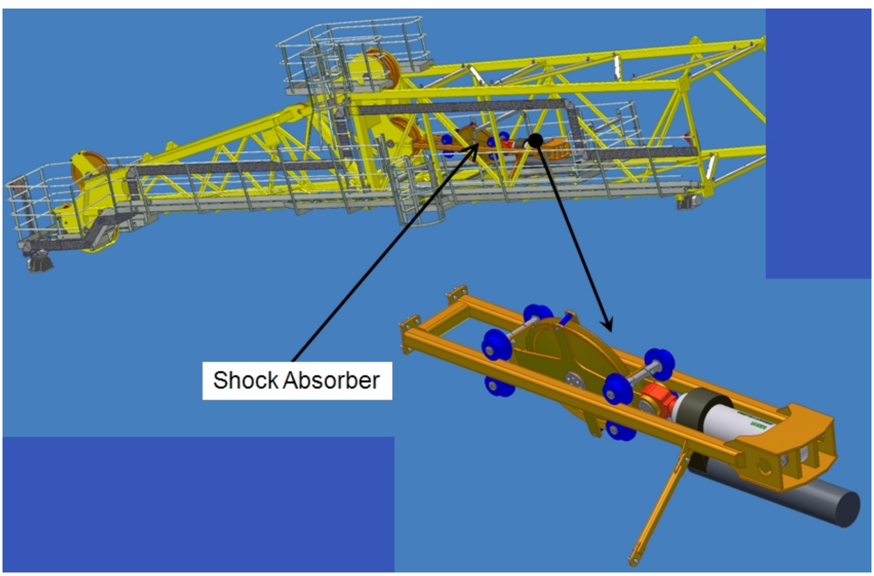

Fig. 2.14. Shock absorber installed on a boom[2]

[2] Picture published with the permission of National Oilwell Varco.

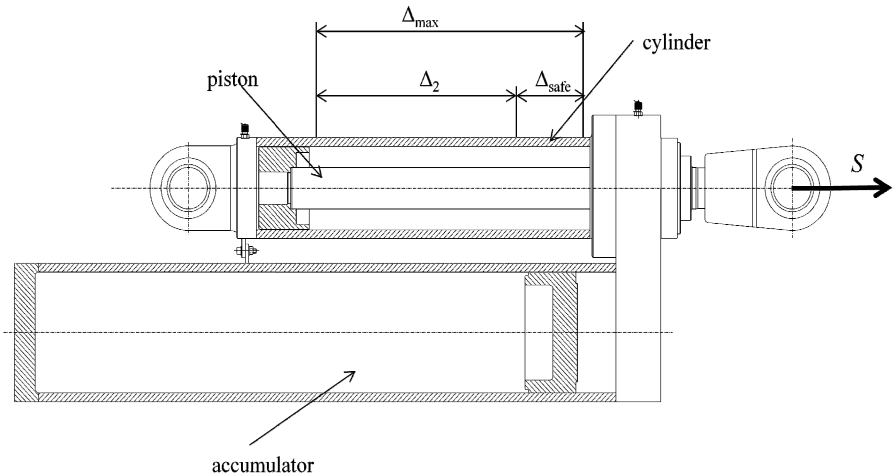

Fig. 2.15. Scheme of the system of a hydraulic shock absorber

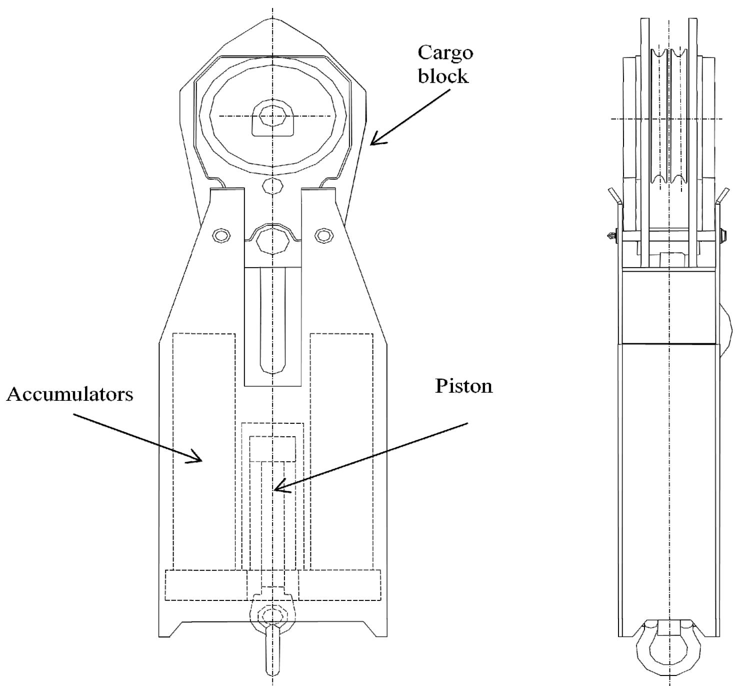

Fig. 2.16. Scheme of a shock absorber integrated with the manifold

the gas pressure in the accumulator. This type of shock absorber is especially recommended with single ratio in the lifting system because of the efficiency (the piston rod moves by the shortest distance).

The working principle of the second type of shock absorbers (Fig. 2.16) is analogous to the design described above, the difference being the placement of hydraulic accumulators consuming the energy in the manifold. This type of shock absorbers is particularly efficient with a multiple tackle in the lifting system of cranes. Its main disadvantage is the difficulty of supplying hydraulic installation to the manifold.