3.4.1 Introduction

The techniques and equipment for drilling offshore wells (i.e. offshore drilling) are very similar to those used for onshore drilling. The main differences consist in the arrangement of the drilling rig and of the equipment, and in certain particular methods of carrying out the operations, which have to be adapted to the requirements dictated by far more difficult and often extreme environmental conditions. This obviously entails considerably higher costs, to which must also be added considerable investments to provide the facilities and plants for subsequent field development.

The earliest episodes of offshore drilling took place just after the turn of the Nineteenth century, when numerous oil fields were discovered along the coastline of southern California, and were exploited with wells drilled up to the shoreline. In the attempt to follow the fields out into the open sea, it was decided to extend operations offshore by positioning the drilling rigs on piers which stuck out for about a hundred metres into the sea. However, the big development in offshore drilling did not start until the latter half of the Twentieth century.

In Europe, the first offshore well was drilled in 1959 in an oil field off Gela, in Sicily. The development of the gas fields off the coast of Ravenna started in 1960 with the drilling of the first offshore well in Europe for the production of gas. In the early Seventies, the discovery of the large fields in the North Sea and in the Gulf of Mexico gave a final boost to the development of increasingly refined technologies for offshore hydrocarbon exploration and production.

In the last few decades, in spite of the hostile environment, the difficulty, the higher investments and the risks involved in carrying out drilling and production operations in a marine environment, exploration for hydrocarbons in the open sea has undergone unprecedented development. In fact, compared with onshore areas, by now explored almost everywhere in such detail that it is considered unlikely that any new large-scale fields can be discovered, the oceans, and above all deep-water areas (at depths of more than 1,000 m), still contain zones where little exploration has yet taken place and where the possibility of discovering large fields of hydrocarbons still seems promising. The costs entailed in offshore hydrocarbon exploration and production are increasing rapidly, due to the great depths of water concerned and the hostile nature of the environmental and meteorological conditions. For this reason, the volume of the hydrocarbon reservoirs that can be developed and which justify investments in offshore development projects is usually very large, and depends both on the investment capacities of the oil companies, and on oil prices on the international market.

An offshore drilling rig has to create the same working conditions as for onshore rigs which can move from one point to another without any difficulty. It must therefore be a mobile unit equipped to contain an autonomous drilling site, including the derrick, the technical personnel and all the service equipment. This can be done with a supporting structure (or platform) which rests on the seabed and rises above sea level, or with a floating structure, kept vertical above the well by means of anchors or with dynamic positioning systems (see below). Very often these are isolated structures which have to house not only the personnel necessary for ordinary operations, but also the equipment of the service companies (e.g. for cementing and logging) which in the case of onshore drilling, on the other hand, are transported to
the rig site and used only for the time strictly necessary. These conditions increase the complexity of the offshore supporting structures, and justify their higher daily rate, which might be up to 5-10 times greater than that for an onshore drilling rig of the same capacity.

From an operational point of view, offshore drilling may be subdivided into two main categories, depending on the water depth. Drilling with the rig standing on the seabed. The safety equipment, i.e. ordinary Blow-Out Preventers (BOPs) located permanently above sea level and accessible from the supporting structure; in this case drilling operations are practically identical to those carried out in onshore drilling. Drilling with floating rigs. The wellhead and the safety equipment (i.e. special submarine BOPs) are placed on the seabed, and are not therefore directly accessible from the supporting structure. In this case, a number of sequences of the drilling operations differ from onshore ones, as the plant is not immobile in relation to the wellhead but, because it floats, is subject to the action of the wind, currents and waves, which cause it to make small horizontal and vertical movements. Naturally, in this case, too, the drilling fluid has to rise to the floating rig, through a special pipe connecting the subsea wellhead with the rig.

The use of floating rigs is necessary for exploratory drilling in water depths of more than 100 m, while the greatest depth to which it is possible to operate under safe conditions exceeds 3,000 m. Clearly, this refers solely to exploratory drilling operations, and not to the subsequent development drilling. The technological limit for developing an offshore field and bringing it into production is a water depth of around 1,700 m. However, this limit is bound to increase within the next few years as technological innovation in this sector is extremely active: by way of example, it is recalled that in 1995 this limit was less than 1,000 m.

The main types of drilling rigs for offshore exploratory wells, with equipment designed for the sole purpose of drilling the well, are described below. If one or more exploratory wells discover a field with reserves that justify its development, it is necessary to design and prepare the permanent production structures. These also either rest on the seabed or float, and are very often able to accommodate even a rig for drilling the development wells. The permanent offshore structures for the production of hydrocarbons are hi-tech engineering and structural complexes based on architectural concepts which vary according to the water depth (see Chapter 5.2.).

3.4.2 Rigs standing on the seabed

Submersible drilling pontoons

Submersible drilling pontoons were designed in the Thirties in Louisiana, where they were used...
for drilling wells in the swampy areas of the Mississippi delta, not accessible from ordinary roads. In concept, the first pontoons consisted of an ordinary rig on a suitably adapted barge, which was transported to the site along channels dredged for the purpose. The barge was then filled with water and the pontoon came to rest on the seabed, and was held firm by means of driven piles. Today drilling pontoons consist of a shallow-draft hull (usually 2-3 m), divided into compartments which can be flooded to enable the pontoon to rest on the seabed, and emptied at the end of operations so as to refloat the pontoon and enable it to move. The hull is covered by one or two decks; in the case of two, the engine-room, the mud circulation pumps, the storage area for chemical products and the cementing unit are situated on the lower deck, while the offices, the accommodation, the deposit for tubular materials and the rig are on the upper deck, the derrick usually being located in the stern.

After drilling in swampy areas, the next step was to conquer actual delta areas, characterized by periodic variations in the sea level, which made it necessary to raise the level of the deck for the rig and the various items of equipment. To be able to operate in these conditions, a pontoon was designed with a hull that could be flooded, with the main decks raised over the hull using a series of posts. In a working position, the pontoon was transformed into a sort of pilework structure, which allowed drilling to take place in up to 8-10 m of water. The typical posts used for raising the deck gave their name to this particular type of vessel (posted barge), usable only in extremely calm waters (Fig. 1). They are still in use today, and the drilling techniques applied are identical to those of onshore wells.

Subsequently this type of rig was further modified, to be able to operate in deeper and deeper waters. The piling was transformed into a steel reticular structure, formed by big pipes welded together. The outside piles, consisting of large-diameter pipes, were enlarged to enable them to be flooded and then emptied to make the structure float, and allow it to be moved. The platform placed over the reticular structure, on which the whole of the drill rig was housed, was called a submersible bottle platform because of its design. These units, the first ones to operate in the shallow waters of the Gulf of Mexico in the 1950s and 1960s, were able to drill in depths of just a few dozen metres. The largest unit of this type, built in the early Sixties, could operate in a depth of 50 m.

**Jack-up drilling platforms**

Offshore drilling continued to be performed in deeper and deeper waters, and to do this it was necessary to use a different type of plant. To limit the high costs necessary to construct higher and higher submersible drilling pontoons, drilling platforms commonly known as jack-ups were devised (Fig. 2).

Jack-ups are triangular or rectangular floating hulls fitted with long mobile legs (usually 3 or 4) at the corners of the hull, which are able to move vertically up and down. Thanks to lifting systems using jacks, or rack-and-pinion mechanisms, it is possible to rest the feet (also known as spud cans) on the seabed and thus to lift the hull above sea level. The first jack-up was constructed in 1954, and its design made it an immediate success, thanks to its stability and
efficiency. In fact, the whole structure rests firmly on the seabed, and the big platform can house even the most complex drill rigs without difficulty. In the ensuing decades these plants were considerably improved and enlarged, this applying in particular to the size and length of the legs. The largest jack-ups can operate at considerable water depths: some of them have legs 150 m in length and are able to drill in water depths of 90-110 m, the maximum depth depending on the mechanical strength of the seabed. All modern jack-ups are also provided with a side platform for the use of helicopters.

When moving from one well to another, the legs are raised and the rig floats on the surface. Once on site, the legs are lowered until the spud cans touch the seabed. By continuing to lower the legs, the spud cans slowly penetrate the bed, compacting it so that it can bear the weight of the entire hull. When the hull has been raised about one metre above sea level, preloading takes place, using the seawater as a ballast for the hull, so as to simulate the maximum loads foreseeable in the operative phases. In this way the spud cans are further embedded, giving stability to the whole structure until drilling operations have been completed. Finally, the hull is raised some 10-15 m above sea level, according to the maximum wave height foreseen in case of storm. The height that the hull is raised has to be such that its underside cannot be reached by the crest of the waves, which could destabilize the structure. Jack-ups can have independent legs or legs that are connected together at the base by a loading plate which replaces the single spud cans (mat-supported rigs). This configuration enables the supporting area to be increased, reducing the specific weight acting on the seabed. This is necessary where the seabed has little bearing capacity.

To be moved for short distances, jack-ups are floated and towed by tugs (although some jack-ups have their own means of propulsion). For longer distances ships equipped with a submersible loading deck are used: after the jack-up has been positioned on the deck, with its legs raised, the ship proceeds normally, transporting the rig even from one continent to another in a relatively short time.

The drilling technique used on jack-ups is the same as that used onshore. Ordinary BOPs are used, located on the conductor pipe, which must be self-supporting. This is possible for depths of around 50-60 m, beyond which a fixed structure has to be installed on the seabed, to be able to withstand both the lateral stresses generated by the sea currents, and the vertical loads due to the dead weight of the conductor pipe and of the BOPs. The conductor pipe is embedded with the use of a pile driver, if the seabed is sufficiently soft. Otherwise the bedrock has to be drilled with a drill string fitted with a bit, using seawater circulation. In this case, the conductor pipe has to be completely cemented (see again Fig. 2).

Jack-ups are most frequently used to drill wells from fixed jacket-type platforms constructed specifically for the development of a field (see Chapter 5.2). After having positioned the jacket firmly on the seabed, and having prearranged the various conductor pipes of the wells, the jack-up is transported alongside the jacket for the drilling of the development wells. For this purpose, the jack-up must be of the cantilever type, with the derrick placed on a skid that slides along two axes, so that it can be positioned vertical to every single conductor pipe of each well. In these cases, the centre-to-centre spacing of the wells is usually about 2-3 m.

Lastly, it is recalled that in shallow waters drilling can be carried out with a tender rig; this system was formerly common also in the Adriatic offshore area. It is used for drilling development wells from light jackets, which are unable to house a full-scale drill rig. In this case, just the derrick is installed on the fixed platform, while all the other equipment (generators, pumps, mud tanks, materials, etc.) are housed on the tender, which is a service craft suitably equipped and moored alongside the fixed platform. The tender and the platform are connected by flexible pipes for the fluids and by cables for power supply. An inclined plane with one end on the tender and the other hinged on the drilling floor is used for the passage of the drilling crew and material. This type of rig can be used only in relatively calm waters, as the tender has to be disconnected (and drilling therefore suspended) even when the wave motion is not particularly strong.

### 3.4.3 Floating rigs

#### Types

The offshore drilling of exploratory wells is strongly conditioned by the depth of the water: beyond about 100 m, the use of rigs standing on the seabed is no longer possible, and it is therefore necessary to use floating units, i.e. buoyant structures on which a complete drill rig is installed. Such structures are designed to be kept in position as firmly as possible above the well being drilled, by means of anchoring or dynamic positioning systems. The main problem in such operations is that of obtaining a sufficiently rigid connection
between the seabed and the floating unit, enabling the drilling equipment to be lowered into the well and guaranteeing hydraulic continuity for circulation of the drilling fluid, which has to return to the rig. The connecting element between the floating unit and the wellhead (through submarine BOPs) is a special pipe called the marine riser (see below). On account of the movement of the sea, the wind and the tides, floating units, not being rigidly connected with the seabed, can move vertically and horizontally in relation to the well axis: these movements, although very modest compared with the water depth, must never exceed the limits imposed by the design conditions, compatible with the operations to be performed. As a rule, the admissible horizontal movement during drilling is about 3-5% of the water depth. During operations, the movement or displacement has to be constantly monitored so as to prevent the occurrence of excessive stresses on the structures connecting the subsea wellhead with the floating unit; if the weather and marine conditions cause the displacement to exceed the safety limits, the structures have to be disconnected.

Generally speaking, a floating craft possesses six degrees of freedom, as it is able to move and rotate along three main axes. The rotary movement around the transversal axis of the craft is called _pitching_, that around the longitudinal axis is called _rolling_, and that around the vertical axis is known as _yawing_. Motion along the transversal axis is _swaying_, that along the longitudinal axis is _surging_ and that along the vertical axis is called _heaving_. Rolling, pitching and heaving are mainly influenced by the distribution of the masses of the structure and by the load of the craft. Surging, swaying and yawing are, on the other hand, influenced by the natural oscillation period of the anchoring system.

Floating drill rigs can be divided into two main classes: semi-submersible rigs and drilling ships. In both cases they are basically vessels constructed to contain an autonomous drilling site, a platform for helicopters, quarters for all the personnel and spaces for the materials and equipment. Floating rigs are proper vessels, and therefore they have a captain and a crew of seamen. In general, drilling ships can travel at a reasonably high speed and have a considerable carrying capacity but, under equal weather and sea conditions, they are less stable than semi-submersible rigs, that are able to operate in a stable manner even in difficult environmental conditions. Both types of rig, not being firmly connected with the seabed, need to use far more complex wellheads and submarine BOPs than those used in onshore drilling operations.

**Semi-submersible rigs**

Semi-submersible drill rigs consist of a large triangular, rectangular or pentangular platform, connected with submerged hulls by means of large columns which vary in number from 3 to 8, according to the shape of the vessel (Fig. 3); they are kept vertical over the site by means of mooring or dynamic positioning systems.

The first rigs, moved by tugs, were constructed towards the end of the 1950s, and led to the development of the semi-submersible types that now exist. When being moved from one site to another, the submerged hulls are emptied and the rig becomes a floating unit, similar to an ordinary vessel. Some semi-submersible rigs have to be towed by tugs, while others have an autonomous propulsion system. In its working position, the height of the platform above sea level can be regulated by filling the hulls and the columns with seawater as ballast. By appropriately regulating the amount of ballast water, the draft of the vessel is varied, optimizing its stability during drilling operations. Moreover, when the state of the sea becomes particularly severe, the safety of the vessel can be improved by increasing the ballast, which lowers the vessel’s centre of gravity.

Semi-submersible rigs are constructed with a natural period of rolling and pitching different from the period of the waves normally encountered in the open sea, and they thus have considerable stability, which is little affected by the wave motion, and permits comfortable working conditions. In fact, as a large part of the mass of the vessel is submerged, it is hardly subject to rolling or pitching. However, it is harder to control the heave, i.e. its vertical movement. By way of example, the heave of a large semi-submersible rig, in the presence of 30-m-high waves, is about 6 m. In spite of this, semi-submersible rigs have only short WOW (Waiting On Weather) times, namely the periods when drilling has to be suspended until weather and sea conditions improve. Anchored semi-submersible rigs are used for drilling in water depths of up to about 1,000 m. At greater depths dynamic positioning systems are required.

**Drilling ships**

The first offshore well was drilled in 1947 in the Gulf of Mexico by a drilling ship, at a water depth of 6 m. The first drilling ships were usually old colliers, whalers or cruisers, with their hulls suitably adapted to make an opening, still known as the ‘moon pool’, vertically above the centre of gravity. The derrick was installed above this, together with the relevant equipment. The deck was organized to accommodate the tubular materials, while the pumps and the mud treatment plant were housed in the hold. Modern
drilling ships are designed and built specifically to act as drilling sites and they are equipped with particularly complex technological systems. Drilling ships are used for operating in deep waters, often under extreme environmental conditions, such as drilling in arctic areas. To this day it is the best means of drilling exploratory wells in remote areas, far removed from supply points, as it can carry all the material necessary for drilling even a particularly difficult well. Just as for semi-submersible rigs, drilling ships are kept in a vertical position over the well by means of mooring or dynamic positioning systems. These ships when moored can be used for drilling in depths of up to about 1,000 m, while for greater depths dynamic positioning systems must be used, and with these the ship is capable of operating in 3,000 m of water. In this case, the depth limit depends only on the weight and the mechanical strength of the connecting system with the subsea wellhead.

The mooring system

The traditional positioning system for a vessel foresees the use of mooring lines with cables or chains which run from the hull and become fixed to the seabed by anchors, arranged according to schemes depending on the geometry of the vessel and on the expected sea and weather conditions. In general, drilling ships have three or four pairs of mooring lines – at least two lines in the stern, two in the bows and one on each side – while semi-submersible rigs have at least one pair on each column at the apexes of the platform. The mooring lines are usually made of various parts, an upper part consisting of a steel cable connected to the vessel, and a lower part, consisting of a chain fastened to the anchor. Should just a single anchor not be sufficient to grip the seabed, two or more anchors in series are used, connected by another chain. The anchors are lowered vertically by a tug using a special cable. The tug tows the anchor to the anchorage, stretching the mooring line, and when the right position has been reached, it lowers the anchor to the seabed so that the flukes become embedded in the bottom. Vertically above each anchor there is a buoy marking its position and facilitating its retrieval when operations are over. In the case of very deep waters (more than 1,000 m), the traditional mooring system requires long, heavy lines, more powerful tugs and lengthy, difficult positioning and retrieval operations, which involve considerably higher costs.

The mooring of vessels is programmed according to the force exercised by the wind and the stresses induced by the sea. For example, drilling ships are normally moored with their bows towards the waves and the prevalent winds, if possible, or at least towards the strongest expected force. If the direction of the
wind and of the waves changes, the vessel’s stability can suffer, causing the rolling and the pitching to increase, as also the tension in the mooring lines and the pull on the anchors. If these movements exceed a given limit, drilling has to be suspended and it may be necessary to detach the connection with the subsea wellhead, allowing the vessel to move away safely. Regarding the wind direction, it is as well to remember that it must be possible to safely ignite the flare of the drilling rig at any moment, and that the helicopter landing pad must be accessible during the majority of weather and marine events (the helicopter has to take off into the wind, and the derrick must not hinder this operation). As mentioned, these problems are less serious in floating rigs with dynamic positioning systems, which are able to rotate more easily than anchored rigs.

The dynamic positioning system

An offshore rig can be kept in a relatively fixed position vertically above the well also by means of the dynamic positioning system. This technology is necessary when the water depth is such that it is no longer possible to use traditional mooring systems due to the weight of the mooring lines and the excessive elasticity of the system. For this purpose, the vessel must have pairs of screw propellers in the stern, in the bows and on both sides, which are always kept working (see again Fig. 4). The wellhead, which is always positioned on the seabed when drilling from floating rigs, is fitted with a device that sends an acoustic signal to the vessel, and under the keel there is a series of hydrophones which pick up the signal arriving from the seabed. This signal is then relayed to an electronic control device, which identifies in real time the position of the vessel in relation to the wellhead and, depending on its movement, it restores its vertical position by varying the speed of one or two pairs of propellers. Compared with a mooring system, dynamic positioning has the advantage of permitting a certain possibility of rotation on the part of the vessel, and therefore permits the best orientation vis-à-vis the direction of the wind, the currents and the waves. In some cases various systems of measuring the vertical position are used, as the presence of gas bubbles in the water or the interference of the sound of the screws can falsify the hydrophone recordings. It is possible, by means of special devices, to measure the angle of inclination of a cable, connected to a fixed point on the seabed and kept at a constant tension. More refined methods use modern satellite positioning systems, called GPS (Global Positioning System).

3.4.4 Drilling from floating offshore rigs

Preliminary drilling operations

The techniques for drilling offshore wells from floating rigs are basically the same as those used for onshore wells. The few differences stem from the fact that a number of additional elements are required in order to connect the wellhead safely to the rig. In general, the important factors involved in drilling wells from floating rigs are due to the following circumstance: a) the wellhead is located on the seabed; b) the submarine BOPs are located on the subsea wellhead and are controlled hydraulically or electrically from the surface; c) the BOPs are connected to the rig by means of a pipe known as the marine riser which enables the drilling fluid to circulate upwards; d) the marine riser, connected at the top of the BOP stack, has a ball joint on its base and a slip joint above sea level to offset the horizontal and vertical movements of the rig; e) the lines for preventing blowouts (kill lines for the introduction of mud, and choke lines for mud recovery purposes) run from the surface manifold on the rig to the subsea wellhead, as independent lines fixed to the outside of the marine riser.
Drilling starts after the rig has been positioned vertically over the well, by means of mooring or dynamic positioning systems. The first operation consists in placing on the seabed, by means of a pipe string, what is called the temporary guide base (Fig. 5), a strong steel framework with a central hole which has a tapered inlet at the top, provided with four guidelines and a number of steel pins that become embedded in the seabed and prevent displacement.

The pipe string is then disconnected, leaving only the temporary guide base on the seabed, with the four guidelines that connect up with the rig. Usually at the end of this operation, a television unit is sent down along a guideline, to control that the temporary support base is resting properly on the seabed. At this point the drilling phase proper can begin, so as to place the first casing, which in offshore drilling is called the foundation pile. The hole is drilled using an ordinary drill string, guided inside the hole of the temporary guide base by a frame and held in position by the four guidelines. This first drilling phase is carried out using the circulation of seawater, and the cuttings do not rise to the surface but are scattered over the seabed. The foundation pile is taken down to a depth of a few tens of metres, generally between 30 and 50, as for the conductor pipe of onshore wells. At this point the foundation pile is brought into operation, being lowered into the hole again using a light frame and the four guidelines. The light frame is made in such a way that it is severed when the foundation pile enters the hole. The foundation pile ends with a special item known as the permanent guide structure, characterized by four robust tubular columns placed at the apexes, 3-6 m long, through which run the guidelines (see again Fig. 5). The four columns serve in the subsequent phases to guide the submarine BOPs to the wellhead with precision. The permanent guide structure contains the housing for the wellhead, to which the successive casings will be anchored. This is a particular wellhead which, compared with those used on land, has a different system of flanging and anchoring the casings. The subsea wellhead is shaped in such a way as to enable the lock-up of the hydraulic connector to which the BOPs are coupled.

Next, the foundation pile is fully cemented by means of a drill string. Once the cement has set, drilling continues, boring the second section of the hole inside the foundation pile, in which the second casing is inserted (in offshore drilling this is called the conductor pipe, analogous to the surface casing in onshore wells). Once the conductor pipe has also been fully cemented, the well has a stable structure and it is possible to install the submarine BOPs. After this drilling continues with the sequence of operations typical of onshore wells.

Fig. 5. Drilling from floating vessels: A, temporary guide base; B, guide frame for the drill string; C, foundation-pile casing and permanent guide structure.
**Subsea BOPs**

In offshore drilling BOPs have the same function as those used in onshore wells, but are connected in a single complex (the BOP stack) before being mounted on the wellhead, so as to reduce assembly times at the sea bottom. They are lodged in a square-section cage structure with female columns at the apexes, into which the male tubular columns of the permanent guide structure fit (Fig. 6).

The BOP stack is lowered and fastened to the wellhead by means of a hydraulically controlled connection, ensuring hydraulic sealing. In the upper part there is the annular BOP, followed by a series of ram BOPs. In the event of temporarily abandoning the well because of adverse weather and sea conditions, it is possible to suspend the pipes on the shaped rams of the lower BOP, to unscrew the pipes and to close the well with the upper blind rams. At this point it is possible to disconnect also the marine riser and possibly to abandon the site. The marine riser can be reconnected when the sea and weather conditions improve.

The hydraulic lines controlling the various functions of the BOP stack converge in a connector block, to which is connected the bundle of flexible pipes for their control from the surface. The BOPs can be operated in a similar way to that used in onshore wells, known as the direct system. In this case, the operating system and the pressure accumulator are installed at the surface, and the controls are connected to the BOPs with flexible lines. The direct system has the advantage of being simple, cheap and easy to maintain, but it becomes impossible to use with increased water depth (beyond 100 m), due to the longer operating times. At great depths an indirect system is used, in which the operating fluid from the surface accumulators is conveyed to the seabed in a single high-pressure flexible pipe, to which the other lines for operating the distributing cock and the regulation valve are also connected.

**The marine riser for returning mud**

The marine riser, or simply the riser, connects the top part of the subsea BOP stack with the floating rig. It is a heavy-duty steel tube, very similar to casing, and its purpose is to guide the tools into the well and to bring the drilling fluid to the surface (Fig. 7). It is mounted above the BOP stack by means of a special connector fitted with a ball joint. The connections are operated hydraulically from the surface to permit rapid disconnection (in the event of bad weather and sea conditions) and easy connection of the riser. The ball joint enables the riser to displace by a few degrees to
adjust to the horizontal movements of the vessel. During drilling, to increase the speed at which the cuttings reach the surface inside the riser, mud is pumped through a special booster line into the riser above the ball joint.

The proper body of the riser starts above the ball joint. Risers are seamless pipes, usually connected by non-screwed joints. In parallel and firmly fixed by means of clamps to the body of the riser are the choke line, the kill line and the service lines (booster line, BOP controls), subdivided into sections of the same length, to make assembly easier.

The top of the riser is connected to the floating rig by means of a telescopic joint, in order to compensate for the vessel’s vertical displacement. The inner part of the joint is connected to the rig and moves with it, whilst the outer part is integral with the riser and is firm in relation to the seabed. The hydraulic seal between the two parts in relative motion is provided by packing that is activated pneumatically. Above the telescopic joint there is a diverter, connected to the riser by means of a knuckle and socket joint, the function of which is to drive any gas flow from the well to a safe position.

For drilling operations in very deep waters, the dead weight of the body of the riser can cause stability problems. It is recalled that the body of a typical riser with a diameter of 22 inches (55.88 cm) has a linear mass in water of about 240 kg/m. In such cases, it is possible to provide the sections of the riser with external floats made of synthetic, plastic-based foam. If the use of floats is not sufficient, to limit the compression stress that tends to destabilize the pipe, it is necessary to put the riser under tension from the surface. The requisite tension is supplied and kept constant by pneumatic tensioners on the vessel, located at the corners of the moon pool, and anchored by cables to the riser under the telescopic joint.

**Mechanisms for motion compensation**

A floating rig must be able to operate with the vessel in motion. In fact, it has been seen that the mooring and dynamic positioning systems are not rigid, and permit even quite considerable movements, both horizontally and vertically. Vertical motion is particularly prejudicial to drilling operations, as it modifies the tensions acting on the drill string. Motion compensators are therefore necessary, to guarantee a constant tension both on the drill string and on the marine riser. If mechanisms to offset the motion were not foreseen, the vertical movement of a floating rig, generated by waves and tides, would transmit dangerous stresses to the drill string and to the bit. During the upward motion of the vessel, the bit would become detached from the bottom hole, making drilling impossible, while during the downward motion it would bounce against the bottom of the hole, causing damage to the bit and transmitting an anomalous compressive force to the drill string. Two variants of motion compensators these exist, based on different

![Fig. 7. The marine riser.](image)
principles: the bumper sub (or telescopic joint) and the heave compensator.

The bumper sub, little used nowadays, is a sliding joint in a hydraulically sealed oil bath, located in the drill string above the drill collars. It also allows for rotation, thanks to its grooved profile. The elongation of each single joint is around 1.5 m, which means that several joints are necessary to offset the expected vertical movements of the rig.

The system to offset heave, on the other hand, involves the use of oleodynamic or pneumatic tensioners which balance the vertical shifts of the rig by means of special pistons, acting both in tension and in compression, which keep the upper part of the drill string at a constant tension (Fig. 8).

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Fig. 8. The system to offset heave.