Gravity substructures of offshore oil and gas facilities

Oleg Finagenov[1], *Viacheslav* Glagovsky, and *Vladimir* Shtilman

All-Russian Vedeneev Hydraulic Engineering Research Institute, Saint Petersburg, Russia

Abstract. The article presents a review and analysis of using gravity substructures as supports for various offshore oil and gas facilities. It gives examples of oil and gas producing platforms with steel and reinforced concrete substructures. It also describes a modern offshore facility, a process line of the liquefied natural gas and stable gas condensate production, storage and shipment plant based on a reinforced concrete gravity foundation.

1 Introduction

The continental shelf occupies more than 6% of the entire Earth surface. It concentrates about 20% of the global oil reserves and 30% of the global natural gas reserves. The share of the global production on the shelf is about 30% for oil and 27% for gas [1].

Almost entire Russian shelf is located in cold seas of the Arctic Ocean and in the Sea of Okhotsk. It provides more than two thirds of all hydrocarbon resources of the global arctic shelf [1]: the initial total oil in place on the Russian continental shelf is about 234 Bbbl o.e., of which 80% is gas. Currently, more than 30 fields located in the arctic and subarctic continental shelfs are operated.

Historically, the first stages of shelf oil and gas field development down to 100 m employed offshore fixed platforms that accommodated drilling and production rigs. The latter includes wellheads of producing and injection wells, gas, oil and water treatment systems. One field was developed by a number of platforms that fed hydrocarbons prepared for transportation to the central gathering station. This field development scheme is individual, and the development method is above-water. It should be noted that the above-water development method is widely used in development of arctic shelf fields [2].

Gravity substructures are often used as supports for well-heads and process equipment.

Apart from platforms designed for oil and gas production, gravity substructures can be used as supporting and other offshore oil and gas facilities. Currently, the first process line of the liquefied natural gas and stable gas condensate production, storage and shipment plant based on a reinforced concrete gravity foundation is designed, built and installed.

This article considers the use of gravity substructures for the above-mentioned offshore oil and gas facilities.

[1]Corresponding author: finagenovom@vniig.ru

2 Materials and methods

Various types of supports are used as foundations for well-heads and process equipment:

- concrete gravity base structure;
- steel gravity base structure.

The existing experience shows that this development method in freezing sees is widely used down to 50 m where the ice situation shows a continuous ice cover formed by one-year ices (the Sea of Okhotsk).

The major advantage of this development method is using technologies and equipment in onshore fields by slightly modifying them. First of all, this makes it possible to condition both liquid and gaseous hydrocarbons for transportation in a single-phase condition. A fixed platform also provides all-year-round maintenance, which greatly reduces the period to achieve the design annual production by the field located in the freezing sea, and ensures faster project payback.

For example, this development method was used in development of Sakhalin-2 fields. The project provides development of two fields: Piltun-Astokhskoye (mainly oil field with associated gas) and Lunskoye (mainly gas condensate field with oil rim). In 1998, the Molikpaq platform (Fig. 1) was installed at the Piltun-Astokhskoye field 16 km from shore 30 m deep, the first Russian offshore drilling and producing ice-class platform.

In 2007, the second Piltun-Astokhskoye-B (PA-B) platform was installed at the Piltun-Astokhskoye oil and gas condensate field 12 km from the shore, 32 m deep. In 2008, this platform started oil production (Fig. 2).

The platform has equipment for drilling, hydrocarbon, liquid/water treatment, and chemicals storage. To ensure the maximum safety, process equipment, auxiliary systems and accommodation modules are located in various zones. The primary working areas are closed type. They are used to control temperature and ventilation with local protection against winter conditions for outdoor equipment. Accommodation modules are designed for 100 permanent workers and 40 temporary workers.

Platform PA-B oil is fed via a system of offshore and onshore pipelines to the oil loading terminal in the south of Sakhalin. The PA-B capacity is more than 70,000 bbl (11,100 m^3) of oil and 2.9 mln m^3 of associated gas per day.

It should be noted that the Molikpaq is based on a steel gravity base structure, while PA-B is based on a reinforced concrete bas structure.

Fig. 1. Molikpaq offshore ice-resistant fixed platform (OIFP).

Fig. 2. Piltun-Astokhskoye-B platform.

In 2006, the Lunskoye-A platform was installed at the Lunskoye gas condensate field 15 km from the shore 48 m deep (Fig. 3).

Gas and liquid hydrocarbon production started in 2009. The Lunskoye field wells have the largest in Russia tubing diameters of 24 mm, which greatly increases their flow rates and, therefore, reduces the payback. The design capacity of these wells is 9-10 mln m^3/day.

The platform has equipment for drilling, hydrocarbon, liquid/water treatment, and chemicals storage. The primary working areas are closed type. They provide temperature control and ventilation with local protection against winter conditions for outdoor equipment. Accommodation modules are designed for 90 permanent workers and 36 temporary workers. The Lunskoye-A platform design capacity (Lun-A) is more than 50 mln m^3 of gas, with the associated condensate and oil production of about 8000 m^3 (50,000 bbl) per day.

This platform is also supported by a reinforced concrete base structure.

Fig. 3. Lunskoye-A platform.

It should be noted that the Lun-A and PA-B platform substructures were built simultaneously [3] in 2004–2006 at the dry dock in the Vostochny port (Fig. 4).

Fig. 4. Substructures of Lun-A and PA-B platforms.

The shelf of the island of Sakhalin provides two more platforms with gravity substructures. These are Orlan and Berkut platforms of the Sakhalin-1 project.

The Orlan platform was initially called Glomar Beaufort Sea I and was built in 1983–1984 in Japan. In 1984, the platform was towed and mounted in the Beaufort Sea (USA, Alaska). The platform was operated for exploration drilling. It proved in practice that the platform design is suitable for all-year-round operation in severe arctic conditions. The platform drilled 6 exploration wells from 1984 to 1997. The platform was then purchased for the Sakhalin-1 project and re-equipped for production.

Fig. 5. Orlan platform.

After global retrofitting when the newest drilling equipment was mounted on the platform (only the substructure left from the old platform), Orlan was towed to the permanent location (Fig. 5). Its pontoons were filled and the platform was permanently placed on the prepared bottom of the Sea of Okhotsk. The sea depth at the Orlan site (with drilling and accommodation modules) is 15 m. The Orlan steel (reinforced concrete) substructure can resist ice and giant ice block as high as a six-story building.

The gravity substructure of the Berkut platform is reinforced concrete just as PA-B and Lun-A, and they were also built from 2009 to 2012 in dry dock of the Vostochny port (Fig. 6).

Another example of individual above-water development method is the Prirazlomnoye field located on the Pechora Sea shelf 65 km north-west from the village of Varandey. Its region is characterized by extreme meteorological conditions, severe ice conditions, low sea depths (19-20 m) and poorly developed onshore infrastructure. Currently, the field is actively drilled and produces oil.

Fig. 6. Berkut platform substructure under construction.

Prirazlomnoye OIFP overview is given in Fig. 7. The OIFP is a gravity structure made of steel structures using concrete as ballast.

All-Russian Vedeneev Hydraulic Engineering Research Institute has a unique experience in shelf operations. Out specialists took part in development of all Russian oil and gas field platforms on gravity substructures [4-9].

These operations are related with offshore geological and hydrographic surveys.

They include:

- hydraulic effects of waves and currents,
- substantiation of bottom protection against scours using a hydraulic model,
- concrete testing for frost resistance,
- measurement of regulatory and design parameters for B70 and B80 concretes for gravity substructures (GSSs),
- dynamic properties of subsoils.

Project activities include:

- development of project documentation,
- verification of design basis and feasibility studies (project),
- development of special specifications (SSs),
- analysis of discrepancies between design and detailed documentation and development of proposals to eliminate them for the gravity substructure,
- designer supervision over the substructure manufacturing.

Fig. 7. Prirazlomnoye OIFP

Calculation and theoretical support includes:

- measurement of loads (wind, waves, currents, ice, seismic) acting on the substructure,
- calculations of substructure strength,
- design surveys of stability and load-bearing capacity of the substructure [5-7, 10].

All the above activities and surveys were done as per the applicable Russian regulations. It should be noted that the experience with the gravity substructure at oil and gas field platforms was used by the All-Russian Vedeneev Hydraulic Engineering Research Institute in the development of SP 369.1325800.2017 [11].

3 Results and discussion

All-Russian Vedeneev Hydraulic Engineering Research Institute developed a GSS for the liquefied natural gas (LPG) and stable gas condensate (SGC) production, storage and shipment plant consisting of three process lines with a total capacity of 19.8 mln tons LPG per year and stable gas condensate with a total capacity up to 1.6 mln ton per year of SGC. Process lines will have a total storage capacity for 687,000 m^3 for LPG and 255,000 m^3 for SGC.

Three process lines will jointly use onshore facilities including the central control room, onshore pipeline racks, the electrical substation, the high-pressure flare, the glycol aqueous solution startup boiler, the ice formation control system, etc.

Each process line consists of:

- a gravity-type concrete base structure including LPG and condensate storage tanks, and auxiliary systems;
- superstructure modules for feed gas and condensate treatment, LPG and SGC production including facilities for shipment, special systems of primary power supply and emergency generation.

The gravity substructure includes slabs, walls, baffles, stiffening ribs in premises containing LPG and SGC tanks, storages for superstructure consumers and ballast system.

The GSS includes:

- GSS foundation slab;
- lower GSS tank slab;
- upper GSS slab;
- upper slabs of GSS cantilevers.

The GSS is divided by walls and stiffening ribs. This is necessary to ensure the GSS structural strength. Moreover, the internal volumes can be used as storages for various products and as ballast tanks.

GSS walls are divided into:

- external walls;
- internal walls;
- walls of stiffening ribs.
- transverse and longitudinal walls of cells between the GSS foundation slab and lower slab of the GSS tank (apart from transverse and longitudinal walls of the central wall);
- cantilever walls;

Concrete walls and GSS walls enable segregation and creating accumulator tanks. The following concrete tanks store products within the GSS (tank parameters are based on the requirements of the storage procedure):

- LPG storage tanks (a membrane protection system is required for the concrete);
- stabilized gas condensate (SGC) storage tank;
- off-spec gas condensate (OSGC) storage tank;
- coolant storage tank (ethane, etc.; a membrane protection system is required for the concrete);
- service water tank;
- industrial/drain water tank;
- open drainage system tank;
- glycol solution storage tank;
- diesel fuel storage tank;
- hot oil storage tank.

The membrane protection system is used in LPG and coolant (ethane) tanks.

The membrane protection system ensures safe storage of LPG and ethane in GSS tanks in all operating conditions (heat insulation and tightness).

Gravity substructures are made in dry docks of the construction center of large-capacity offshore facilities (CCLCOF) located in the immediate vicinity to the village of Belokamenka (Murmansk region) (Fig. 8).

In parallel to each GSS, superstructure (SS) modules were manufactured at the production sites in Asia and Russia. The ready-made modules at the CCLCOF will be installed at the GSS using a lifting and launching system, after which SS modules will be connected to each other and to the GSS.

The ready-made process lines will be towed to the Gydan peninsula where they will be installed on a prepared offshore base structure in the coastal zone (the first process line was installed in August 2023). This will be followed by their connection to onshore facilities, firing of gas turbines, final commissioning before start-up.

Fig. 8. Construction of the natural gas liquefaction line on a gravity substructure.

The first process line is planned to be launched before the end of 2023.
The specialists of the All-Russian Vedeneev Hydraulic Engineering Research Institute took part in

- the development of SSs for geological surveys and a documentation package for such surveys,
- development of geotechnical design basis,
- laboratory tests of soils as part of complex surveys,
- development of design documentation (including determination of load and effects on the substructure, calculations of GSS strength and stability) on the fixed offshore terminal.
- development of light concrete (as a new material) and all necessary laboratory tests,
- development of specifications for GSS manufacturing.

4 Conclusion

The continental shelf of the World Ocean concentrates large hydrocarbon resources. They are distributed in the World Ocean in an irregular manner. Major hydrocarbon resources on the shelf are concentrated in the Arctic Ocean, in the Mexican and Persian Gulfs, in the North Atlantic, on the shelf of Brazil and Venezuela, on the shelves of West Africa, Australia, Sakhalin Island, as well as in the Caspian Sea.

Despite the potentially high resources and already discovered hydrocarbons of the Arctic Ocean, the production is low there due to difficult climatic conditions and remoteness. Nevertheless, the production in this region is being developed, and in the future, it will become one of the largest sources of hydrocarbons.

The platform types ensuring operation stability are limited by perceiving ice loads. The key difference of ice-resistance structures is an ability to resist ice loads and possible iceberg loads. For a sea depth of 100 m, the primary recommendation in selecting a platform concept is a fixed platform, while the gravity substructure is recommended as its base structure.

The existing practice (operating platforms in the Sea of Okhotsk and the Pechora Sea, Orlan, Berkut, Molikpaq, PA-B, Lun-A, Prirazlomnaya) supported this conclusion.

The experience in construction and operation of reinforced concrete base structures of platform made it possible to take a decision on using this type of structures for another kind of offshore oil and gas facilities – a liquefied natural gas and stable gas condensate production, storage and shipment plant. The first line is already built and installed on the shelf of the Kara Sea near the Gydan peninsula.

Further development of the Arctic shelf must result in developed and improved gravity substructures of offshore facilities of various kind and purpose.

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