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“Deep Sea No.1” Energy Station

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Project owner: China National Offshore Oil Corporation (CNOOC) Limited

Overall design: CNOOC Limited

Basic design: CNOOC Research Institute Co., Ltd.

Detailed design: Offshore Oil Engineering Co., Ltd.

Construction: Offshore Oil Engineering Co., Ltd.

1 Overview of the “Deep Sea No.1” Energy Station

The “Deep Sea No.1” gas field lies in the northern South China Sea, approximately 150 km north of Sanya, Hainan Province, at a water depth of 852–1560 m. The field comprises multiple reservoirs with proven natural gas reserves of 1.79799 × 10^{11} m^3 and proven condensate reserves of 1.85048 × 10^9 m^3. “Deep Sea No.1” is China’s deepest offshore gas field and has the largest reservoir span, the highest formation temperature and pressure, a high condensate content, and some of the most challenging marine conditions encountered in domestic offshore development.

The “Deep Sea No.1” Energy Station is a large offshore oil and gas production complex constructed to develop the “Deep Sea No.1” gas field. It consists of Phase I and Phase II. Phase I develops the eastern reservoirs (east–west span 70 km; north–south span 30 km), and Phase II develops the western reservoirs (east–west span 25 km; north–south span 20 km). Phase I includes the world’s first 100,000-t semisubmersible production, storage, and offloading platform; the mooring system; the steel catenary riser (SCR) system; the subsea production system; the umbilical system; and the subsea pipeline network. It uses an efficient configuration in which the subsea production system is tied back to the semisubmersible production and storage platform. Phase II lies approximately 70 km from the production and storage platform and is operated remotely. It employs an economic and safe configuration that includes a subsea production system, a shallow-water jacket platform, and a deepwater semisubmersible production and storage platform equipped for remote control. Both configurations represent industry firsts.

The field is designed for 23 production wells. Deepwater oil and gas are transported through the subsea production facilities, umbilicals, subsea pipelines, and SCRs to the production and storage platform. After processing, sales-quality gas is exported through subsea pipelines to the onshore export pipeline, whereas condensate is stored in the columns of the “Deep Sea No.1” Energy Station and periodically offloaded by shuttle tankers to downstream users (Fig. 1). Because of export pipeline constraints, the current annual production is approximately 5.0 × 10^9 m^3 of gas and 5.0 × 10^5 m^3 of condensate.

The main facilities of the “Deep Sea No.1” Energy Station include a 105,000-t-displacement semisubmersible production, storage, and offloading platform (Fig. 2). The platform provides natural gas processing and condensate storage and export, integrating production, storage, living quarters, and remote-control functions. It consists of an upper topside module and a lower hull. The topside module uses a truss structure with a main deck and a production deck and houses the gas compression and export system, the condensate processing system, and emergency evacuation equipment. The lower hull measures 91.5 m in length and 91.5 m in width and adopts a four-column, ring-shaped pontoon design. Each column has a cross section of 21 m × 21 m and a height of 59 m, with 49.5 m spacing between columns. The pontoon cross section is 21 m × 9 m, and the hull weight is 33,000 t. The total platform weight is 52,000 t, with a full-load displacement of 105,000 t, an operating draft of 35–40 m, and a design service life of 30 years.

For station keeping, “Deep Sea No.1” uses a permanent mooring system. Each mooring line is anchored on the

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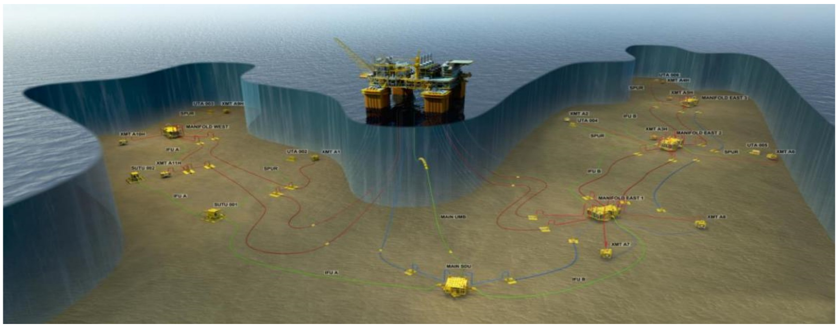

Fig. 1 Schematic view of the overall project.

Fig. 2 Semisubmersible production, storage, and offloading platform.

seabed at a depth of 1500 m, with the opposite end connected to one of the platform’s four columns. Each column is equipped with four mooring lines, forming four groups with a total of 16 lines longer than 2500 m. Each line includes an upper R4S-grade Φ157 chain, a Φ274 polyester rope, and a lower R4S-grade Φ157 ground chain. Each polyester segment measures close to 1 km. Polyester rope has higher strength than steel wire, resists seawater corrosion, and weighs approximately one 40-third as much as steel cable.

The subsea production system includes production risers, subsea trees, subsea umbilical termination units (SUTUs), subsea distribution units (SDUs), and manifolds (Fig. 3). The production risers use SCRs as flow paths for wellstream transport and natural gas export between the subsea facilities and the platform. The SCRs are fabricated from API 5L PSL2 X65 seamless pipe. A total of six risers are installed, with a combined length of 12.62 km, including flexible hoses, pipeline end terminations (PLETs), and jumpers (Fig. 4).

2 Key technological innovations

The main innovations of the “Deep Sea No.1” Energy Station lie in two economic, safe, and efficient development configurations. The first is a subsea production system tied back to a semisubmersible production, storage, and offloading platform. The second combines a subsea production system, a shallow-water jacket platform, and a deepwater semisubmersible platform equipped for remote control. Together with the design, construction, and installation technologies developed for the 100,000-t semisubmersible multi-column production, storage, and offloading platform, these approaches form an integrated ultra-deepwater oil and gas development technology system. They provide a new technological and managerial pathway for China’s ultra-deepwater exploration and development and meet the requirement for 30 years of operation without dry-docking.

2.1 Deepwater gas field development model

Construction of the “Deep Sea No.1” Energy Station faced multiple challenges, including dispersed reservoirs, high condensate content, large well spacing (> 5 km), flow assurance difficulties during long-distance multiphase transport, numerous and complex subsea facilities requiring substantial investment, and the requirement for 30-year operation without dry-docking. The field also

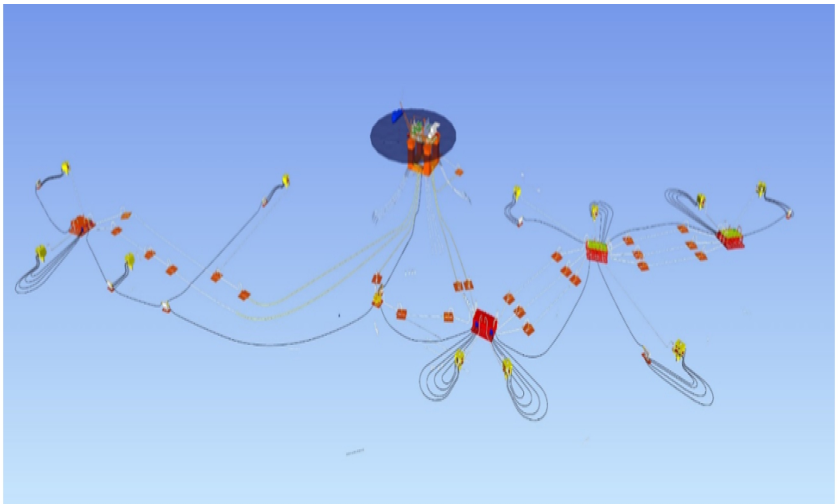

Fig. 3 Subsea production system.

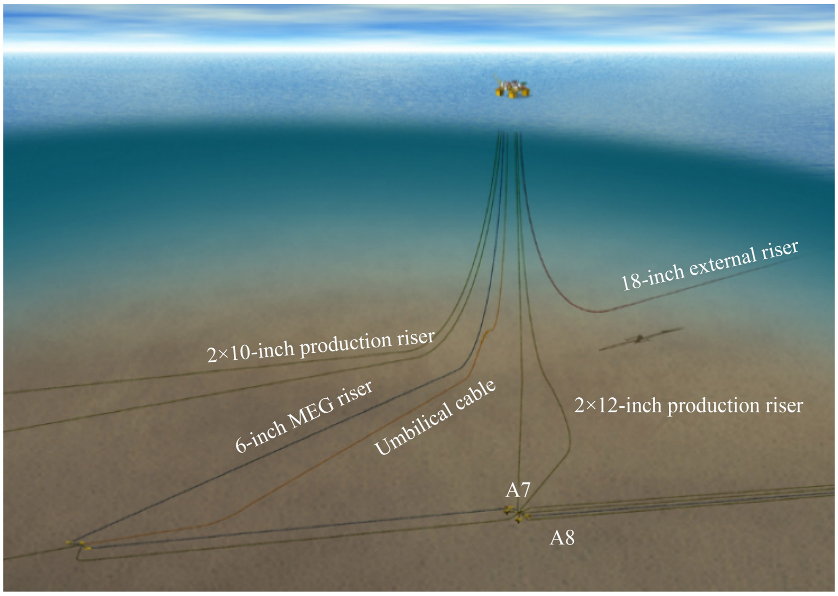

Fig. 4 Steel catenary riser and subsea pipeline transportation system.

produces 1250 m^3 of condensate per day, which introduces storage and export safety risks. In response, “Deep Sea No.1” adopted an innovative deepwater development model, establishing the world’s first configuration that combines deepwater subsea wellheads with a semisubmersible, column-type production, storage, and offloading platform. This configuration replaces the traditional model with laying out oil pipelines and floating production storage and offloading vessels and addresses the difficulty of economically developing deepwater gas fields with dispersed reservoirs and high condensate content. Fluids from the subsea system are transported to the platform for processing; stabilized condensate is stored within the platform columns and exported periodically by shuttle tanker, and natural gas is delivered by pipeline. This approach enables economic development of the field and provides a new model for deepwater oil and gas projects.

2.2 Design and construction technology system for the semisubmersible production and storage platform

Conventional semisubmersible platforms lack storage capability, as their columns are generally configured as ballast tanks, empty tanks, and passageways. Column-based condensate storage had no prior engineering precedent. To address this challenge, the “Deep Sea No.1” project established a design and construction technology system for a semisubmersible production and storage platform suited to 1500-m water depth in the South China Sea. The project developed design methodologies, workflows, and standards for this platform type. A multi-opening, span-reducing bulkhead design was created for the condensate storage tanks, optimizing column structural configuration, maintaining fluid flow continuity, and significantly enhancing structural integrity. This produced one of the industry’s most complex multi-column semisubmersible structures. Structural stress was reduced by 17%, fatigue life was increased from 30 to 84 years, and steel usage was reduced by 11%. The project resolved the engineering challenge of accommodating 20,000 m^3 of condensate storage within the columns, achieving the world’s first multi-column condensate storage solution and increasing the platform’s load-to-displacement ratio from 1/3 to 1/2.5, thereby adding approximately 7000 t of variable deck load.

2.3 Motion control technology for variable-draft semisubmersible production platforms

Construction of “Deep Sea No.1” faced severe ocean conditions, including frequent typhoons and strong monsoon and internal-wave currents. These conditions placed stringent requirements on the design and material selection of the mooring system and created significant challenges for the strength and fatigue performance of the SCR system. To address these factors, the project developed motion control technology for a variable-draft semisubmersible production platform and resolved key design challenges for the SCR system. Using long-term measured data from multiple offshore platforms in the South China Sea, particularly research results from the past decade, the team established deepwater wave spectra, wind spectra, time-domain models, and refined metocean parameters specific to the region. These results filled gaps in domestic and international technical standards and provided a quantitative basis for optimizing hull form, mooring orientation, and SCR fatigue prediction and mitigation. The project also developed key equipment, including deepwater risers, polyester mooring lines, suction piles, and riser limiters, as well as supporting systems such as gravity anchors, self-balancing pipe racks, and printed-circuit heat exchangers. These advances substantially enhanced domestic deepwater equipment manufacturing capability.

2.4 Efficient construction, precision integration, and long-distance wet-tow technology

Construction of “Deep Sea No.1” also faced limited onshore fabrication space, as no domestic shipyard fully met the requirements for building the platform. This required coordinated work across multiple facilities and engineering disciplines, with precise adaptation among different construction sites. To address these constraints, the project developed technologies for efficient fabrication, precision integration, and long-distance wet towing. These advances enabled safe and efficient completion of the full sequence of onshore construction, integration, long-distance transport, installation, and commissioning of the semisubmersible production, storage, and offloading platform. They also marked a domestic breakthrough in end-to-end construction of deepwater semisubmersible production systems.

The team established a precision-control methodology that integrates full-process deformation prediction, digital measurement, computer-based mating simulation, precision regression analysis, and pre-deformation adjustment. This methodology enables coordinated, dynamic control of the 50-m-span topside module’s global pre-deformation and the localized deformation of mating interfaces. It also supports an array-based segmentation method compatible with skidway construction and multi-dimensional assembly, and techniques for transverse skid-on integration of large open-hull structures with pre-tilt correction and high-elevation float-off. These advances enabled rapid onshore construction, transverse load-out, and nearshore float-off of the open-hull structure for “Deep Sea No.1.”

Through these innovations, the team completed the assembly of 28 column sections totaling approximately 1.7×10^4 t in 70 days with a mating accuracy of ± 6 mm. The 3.35×10^4-t semisubmersible hull was constructed in less than 15 months. The overall construction time represents 79% of the benchmark for leading international performance and about 40% of the typical duration at domestic shipyards. This achievement set a world record for construction speed for platforms of this type and advanced national manufacturing capability. The team also executed the transverse skid-on operation for an ultra-large, heavy structure. The structure weighed 3.35×10^4 t and measured 91.5 m × 91.5 m × 59 m. This operation set a world record for the largest transverse load transfer.

The project resolved deformation-control challenges in dual-beam lifting of large-span flexible truss modules and developed deformation-control and capture systems for semi-floating integration of the large open-hull structure. A real-time computational method was established using a human-in-the-loop framework that integrates nearshore sea states, platform–module–crane coupled dynamics, and visualization-based calculation. This method resolved challenges associated with semi-floating, low-draft hulls and high-precision mating of large structures. It enabled the world’s first semi-floating precision integration of a 50,000-t-class structure, comprising a 3×10^4-t semisubmersible hull and a 2×10^4-t module (Table 1).

Using a motion-coupling analysis method for multiple floating bodies and towing lines, the project developed three-vessel coordinated control technology for a high-inertia, square semisubmersible platform. This resolved the challenges of towing an ultra-large floating structure during winter monsoon conditions from Yantai in the Bohai Sea to the Lingshui area of the South China Sea, across varied environments including the Bohai Sea, Yellow Sea, East China Sea, the Taiwan Strait, and the South China Sea. The project established a long-distance

Table 1 Comparison of integration tolerances

Tolerance item	“Deep Sea No.1” Energy Station requirement	Conventional domestic requirement
Adjacent columns	± 10 mm (spacing 49,500 mm)	± 10 mm (spacing 48,000 mm)
	± 6 mm (spacing 21,000 mm)	± 19 mm (spacing 79,624 mm)
Diagonal columns	± 13 mm (spacing 70,004 mm)	± 10 mm (spacing 48,000 mm)
	± 10 mm (spacing 60,000 mm)	± 19 mm (spacing 79,624 mm)
Column relative position tolerance	13 mm	N.A
Column inclination	1 min	N.A.

wet-towing scheme for a 10 × 10^4-t-class semisubmersible platform, enabling safe and efficient towing of the world’s first 100,000-t semisubmersible production and storage platform. The full towing distance was 1600 nautical miles (nm), with a total towing duration exceeding 400 h and an average speed of approximately 4.0 konts (Fig. 5).

2.5 Installation technologies for ultra-deepwater polyester mooring systems, SCRs, and subsea production facilities

Construction of “Deep Sea No.1” faced challenges posed by great water depth and complex seabed terrain. Water depth exceeds 1500 m, and the seabed includes developed channels and irregular topography, making mooring foundation selection and riser touchdown-zone crossing difficult. The design and fabrication of ultra-deepwater (> 1500 m) SCRs and polyester mooring lines, together with installation of mooring systems, risers, and subsea structures under these conditions, were key technical challenges.

To address these challenges, the project developed installation technologies for ultra-deepwater polyester mooring systems, SCRs, and subsea production facilities. Tackling the application and installation challenges associated with polyester mooring lines and SCRs under such complex conditions had no precedent in China.

Ultra-deepwater (1500 m) multi-point mooring installation technology was developed for the South China Sea. The region’s harsh conditions required the mooring system to be installed rapidly and efficiently while meeting strict accuracy and quality requirements to ensure 30-year operational safety. Given the advantages of polyester lines over conventional steel-wire systems, such as better control of platform offset and lower cost, the project developed technologies for mooring-leg twist control, polyester-line installation protection, dual-winch synchronous tensioning, and rapid reconnection of the mooring system. Installation accuracy for all 16 mooring legs exceeded design requirements, and installation efficiency was higher than expected. The rapid-reconnection method alone reduced the installation schedule by 5 days, saving more than 30% of the planned time.

Ultra-deepwater (1500 m) SCR installation technology was also developed. SCRs are critical to deepwater floating platforms, forming the transport link between topside processing facilities and subsea production systems. Fatigue resistance is essential, as riser integrity directly affects field safety. Using *in situ* simulation of riser configurations, the engineering team identified the mechanical characteristics of the touchdown zone and developed technologies for passive riser-limiter installation, fatigue-resistant weld quality control, reverse-pull subsea riser crossing, tension transfer, and riser lift and landing. The team completed S-shaped installation of 6-inch SCRs and ensured installation quality consistent with a 30-year design life under harsh South China Sea conditions, achieving China’s first autonomous installation of SCRs.

Ultra-deepwater installation technologies for multiple subsea production facilities were also developed. In addition to the semisubmersible platform and mooring system, the field includes a production system comprising 11 subsea trees located at 1500 m depth, one SDU, two SUTUs, 10 suction anchors, 28 rigid jumpers, and multiple umbilical flying leads. The largest subsea structure measures 21.2 m × 11.9 m × 8.7 m, with a maximum weight of 242 t and a maximum installation depth of 1526 m. Through simulation of real-sea conditions, the team established installation methods suited to complex metocean environments and developed technologies for ultra-deepwater lifting of large subsea structures, dynamic resonance analysis for deepwater lifting systems, vertical installation of large-diameter umbilicals, and precision positioning of flexible pipelines. These advances enabled efficient completion of all subsea production facility and pipeline installations and strengthened China’s capability in independent design and construction of subsea production systems.

2.6 Operational assurance system for production under complex marine conditions

To address challenging sea conditions, “Deep Sea No.1” established an operational assurance system tailored to the complex marine environment of the South China Sea and built China’s first intelligent maintenance system for a semisubmersible column-type production, storage, and offloading platform. The project developed intelligent

Fig. 5 Three-vessel wet-tow operation of the semisubmersible production and storage platform.

fatigue detection and monitoring software for deepwater risers and platform structures, together with a digital twin system. It also created an integrated platform for monitoring, maintenance, and production data management, enabling capabilities for data acquisition, transmission, foundational analytical computing, and digital-twin–based assessment.

3 Conclusions

The completion of the “Deep Sea No.1” Energy Station and the successful development of the “Deep Sea No.1” gas field have strengthened China’s capability for independent offshore oil and gas development. They have also advanced domestic high-end marine equipment industries, including polyester mooring systems, SCRs, and subsea production systems. As China’s deepwater development and engineering capabilities continue to progress, new offshore production platforms, such as cylindrical FPSOs, FLNG units, SPAR platforms, and TLPs, will be developed to support efficient production across fields of different scales and marine environments. These advances will further drive technological progress in offshore engineering and help establish an integrated engineering and management system for shallow-water, deepwater, and ultra-deepwater oil and gas development with Chinese characteristics.