Submarine Oil and Gas Pipeline Technology

Science & Technology Management Department, CNPC

2015

CHINA NATIONAL PETROLEUM CORPORATION

Submarine Oil and Gas Pipeline Technology :

Laying Submarine Oil and Gas Transmission Expressway!

Contents

China National Petroleum Corporation (CNPC) is a state-authorized investment agency and a state holding company. On July 1998, with the implementation of the Institutional reform of the State Council, CNPC was reorgnized to become an integrated oil company of cross-regions, cross-industries and cross-countries, it adopts modern enterprise system to realize the integrations of upstream and downstream operations, internal and external trade, production and marketing. CNPC's business covers six main sectors: oil and gas operations, petroleum engineering service, petroleum engineering construction, petroleum equipment manufacturing, financial services and new energy development. In 2014 CNPC produced 113.67 million tons of crude oil and 95.46 billion cubic meters of natural gas, while crude processing volume reached 150.2 million tons. The total revenue of RMB 2,730 billion with a profit of RMB173.4 billion had been achieved the same year.

CNPC was ranked 3th among the world's largest 50 oil companies and 4th in Fortune Global 500 in 2014.

CNPC strictly follows by the combined strategies of increasing resource capacity, expanding market shares and consolidating the international role, and persists in regarding technical innovation as a key framework to advance technological progress. To develop its core businesses, focuses will be placed on the solutions of key bottleneck technologies and key proprietary technologies. Thanks to continuously improving of the technical innovation system, optimizing the configuration of technological resources and strengthening the construction of strong talent teams, CNPC’s technological creativity has been considerably upgraded. Consequently, a large number of technologies have been developed independently, with its own intellectual property.

The submarine oil and gas pipeline technology is one of representatives for major innovations of CNPC.

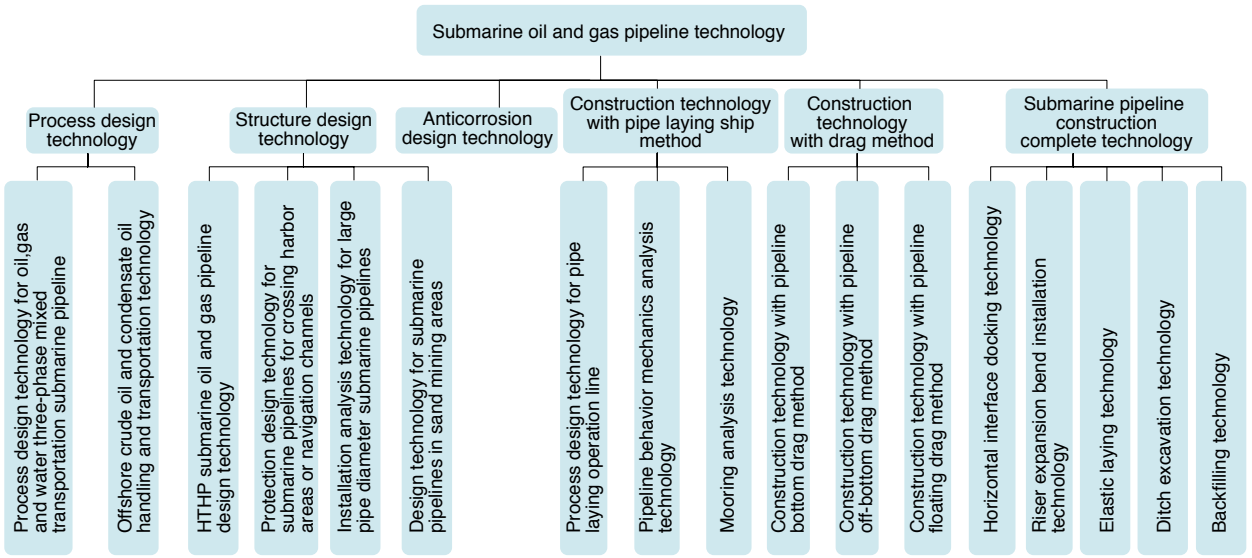
OFFERING ENERGY SOURCES, CREATING HARMONY

1 INTRODUCTION

Submarine pipelines have become important offshore oil and gas field production facilities and are the “artery” of offshore oil and gas production systems. Since the first submarine pipeline was laid in 1954, the length of submarine pipelines laid in the world has exceeded more than one hundred thousand kilometers.

CNPC has greatly increased its offshore engineering service capacity based on the technical development concept “perfecting beach fields, development shallow sea fields and reserving deep sea fields”. In terms of submarine oil and gas pipeline technology, CNPC has formed totally 6 major technology series such as submarine pipeline process design, structure design, anticorrosion design, construction with pipe laying ship method, construction with drag method and submarine pipeline construction complete technology and 17 characteristic technologies.

CNPC has steadily developed its comprehensive offshore engineering service capacity. CNPC has the capacity of independently undertaking the design and installation of pipelines of 80m in water depth and submarine pipelines. CNPC has successfully carried out the design and construction of large submarine pipelines such as Hong Kong branch of West-East NG Transmission Line II, Jidong Nanpu oilfield, foreign oil and gas fields, etc.



2 CHARACTERISTIC TECHNOLOGIES

2.1 Process design

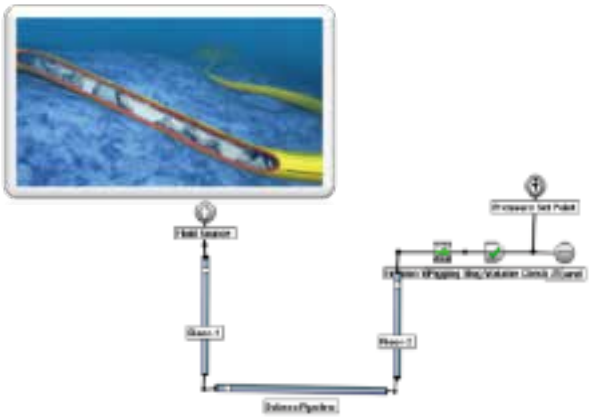
Submarine pipeline process design: determine the submarine pipeline transportation process scheme according to the basic data including oil and gas field development scale, physical properties of oil and gas, natural conditions, etc. as well as the overall development layout; through simulation and calculation in different operating modes, determine the best design and running data and ensure economic and reasonable running of pipelines.

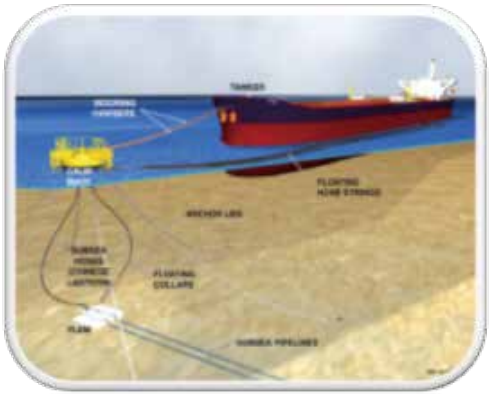
◆ Process design technology for oil, gas and water three-phase mixed transportation submarine pipeline

Serious slug flow is easily generated in an oil, gas and water mixed transportation submarine pipeline due to being affected by complex topography variation or operating conditions; drastic flow rate variation and pressure fluctuation will lead to closing and shutdown of downstream equipment and even destroy the pipeline. The fluid flow pattern and slug forming along the pipeline can be analyzed to predict and control slug flow in the pipeline and provide downstream slug flow capture design by establishing multiphase flow transportation software or numerical model and using reasonable pressure drop empirical formula.

◆ Offshore crude oil and condensate oil handling and transportation simulation technology

During handling of offshore crude oil and condensate oil, leakage and pressure over-limit of transported oil products occur easily, thus affecting normal running of submarine pipelines. By establishing the simulation model for the whole transportation system, analyze and predict the part of the transportation system where the pressure exceeds the limit more easily, provide pressure protection design of the over-pressure link, and ensure safe running of the transportation system.





2.2 Structure design

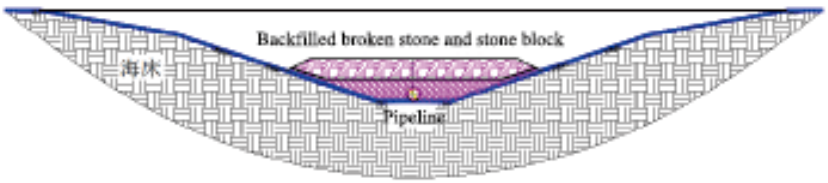
Submarine oil and gas pipeline structure design technology: calculate and analyze a submarine pipeline according to the route information on the submarine pipeline, the environmental conditions of the sea area including wind, wave and current, soil and geology conditions, pipelined media, anticorrosion data, platform displacement data, etc., thus ensuring that the submarine pipeline runs safely in its whole life cycle. Conventional calculation and analysis generally involve pipeline stability, on-bottom strength, riser strength, crossing, installation, etc.

◆ HTHP submarine oil and gas pipeline design

When a submarine pipeline and especially a long-distance submarine pipeline transports HTHP medium, it is easily buckled integrally, thus having an adverse impact on safe operation of the pipeline. In the event of failure by buckling, the problems will be come out, including oilfield shutdown, underwater maintenance, environmental pollution, etc. By establishing a pipeline model under the action of HTHP, accurately calculate the deformation and temperature stress of the pipeline, judge the position of lateral buckling or vertical buckling of the pipeline, and work out control measures to avoid lateral buckling or vertical buckling. Ensure safe operation of the pipeline by prohibiting buckling deformation.

◆ Protection design technology for submarine pipelines for crossing harbor areas or navigation channels

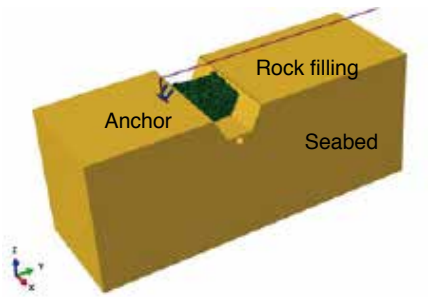
The route of a submarine pipeline will often inevitably cross harbor areas and navigation channels. In this case, anchor falling and anchor dragging in the event of accidental anchoring of a ship will impact or drag the submarine pipeline and thus damage it; seriously, the submarine pipeline will be broken. According to the protection requirements of harbor areas and navigation channels for the pipeline, obtain the best thickness, width and block stone grain size of rock-mound protection layer and ensure the safety of the pipeline crossing harbor areas and navigation channels by designing the buried depth of the pipeline, rock-mound protection section and size grading of backfilling rock blocks.



Typical pipeline protection section

Lateral buckling

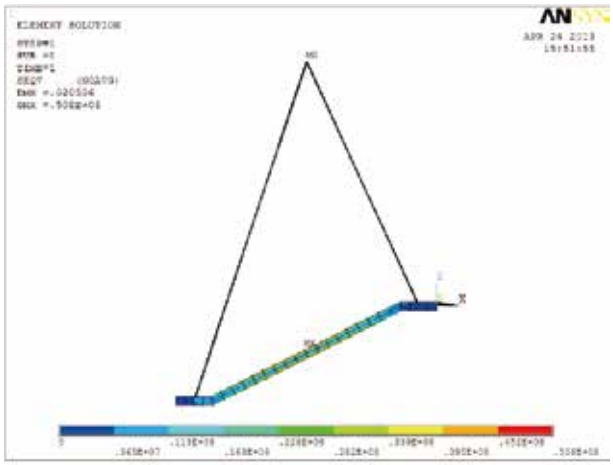
Vertical buckling



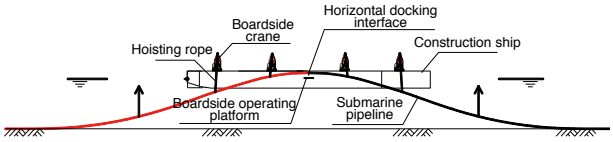
Anchor damage analysis model

◆ Installation analysis technology for large pipe diameter submarine pipelines

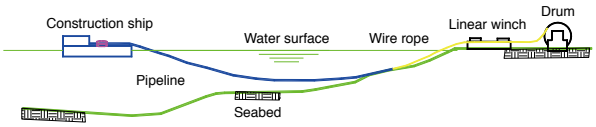
The installation analysis technology for large pipe diameter submarine pipelines includes the analysis of pipeline laying stress, riser installation, horizontal interface docking, nearshore dragging, etc. Calculate and simulate the construction process of a pipeline according to the selected construction ship and construction machines and tools, and ensure the installation scheme is feasible, thereby understanding construction operation. The installation analysis of a submarine pipeline is the necessary premise for ensuring the installation scheme is feasible. In addition, an appropriate installation method can control cost, ensure progress and reduce risks.



Riser hoisting



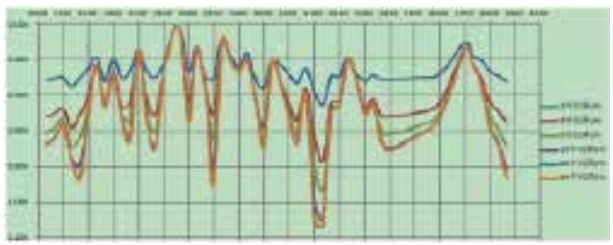
Horizontal interface docking



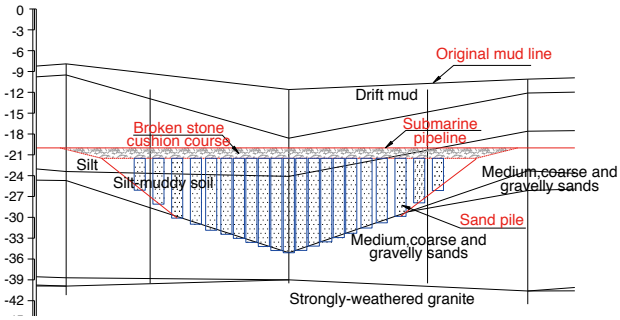
Shore towing construction of submarine pipeline landing section

◆ Design technology for submarine pipelines in sand mining areas

Nonuniform consolidation settlement of the seabed in a sand mining area will result in over-large local bending stress on a submarine pipeline, thus damaging it. When the route of the submarine pipeline inevitably crosses a sand mining area, the geologic conditions of the crossing section after sand mining shall be investigated to acquire soil data, thereby determining foundation treatment scope, working out an appropriate foundation treatment scheme and ensuing safe operation of the pipeline by analyzing foundation settlement and the stress impact of nonuniform settlement on the pipeline.



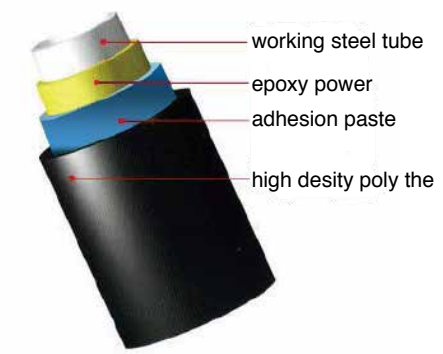
Variation of foundation settlement along the route



Foundation treatment in the sand mining area

2.3 Anticorrosion design

The anticorrosion design technology for submarine pipelines is the key technology for ensuring long-period safe operation of submarine pipelines in severe corrosive environment. For long-distance oil and gas pipelines or water transportation pipelines with various pipe diameters and operating conditions, select a correct and effective internal and external anticorrosion scheme, determine reasonable pipeline materials, coating systems, patching materials and corrosion inhibitors, and take some measures like corrosion monitoring device design and other ways to ensure long-term effective and stable running of pipelines.

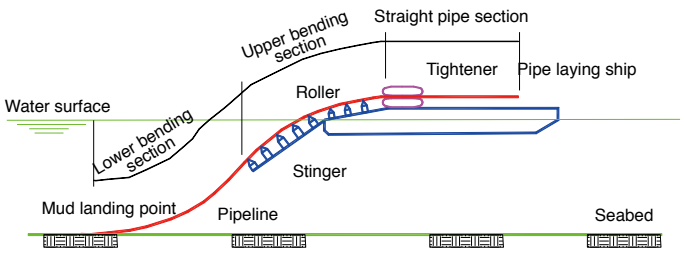


2.4 Construction and installation technology with pipe laying ship method

The construction and installation technology with pipe laying ship method includes process design technology for pipe laying operation line, pipeline behavior mechanics analysis technology and mooring analysis technology.

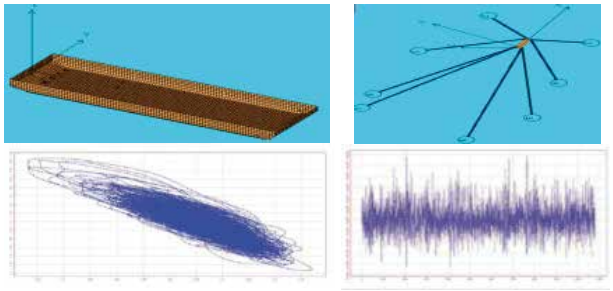
◆ Pipeline behavior mechanics analysis technology

Simulate a submarine pipeline into a series of continuous beam elements using international standards and specifications and the elastic finite element method; simulate the tightener, support roller and submarine boundary condition into rigid or elastic supports. The pipeline forms an S curve between the pipe laying ship and the mud landing point, and the curve is divided into upper bending section and lower bending section. In addition, the bending moment at the mud landing point of the pipeline is set as zero. On this basis, carry out stress analysis and checking of the pipeline to provide a basis for the adjustment of the parameters of the equipment including pipe laying ship tightener, running roller, stinger, etc.; simulate the submarine pipeline laying process and determine various optimal working states in the pipe laying operation period. On this basis, work out various operation procedures as site of construction guidance documents.

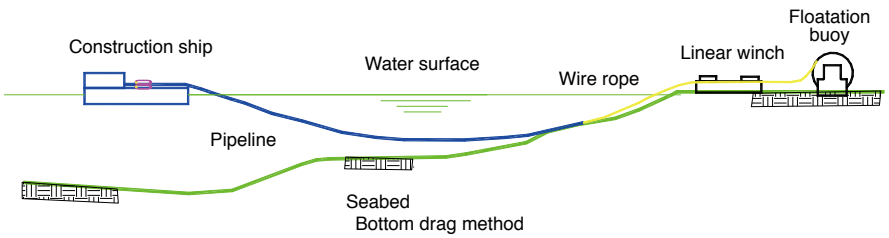


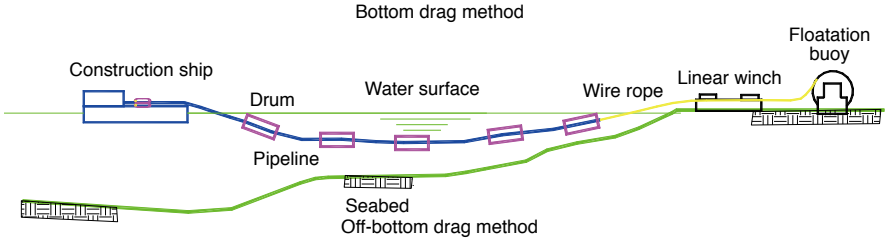
Typical S-shaped curve of pipe laying

◆ Mooring analysis technology



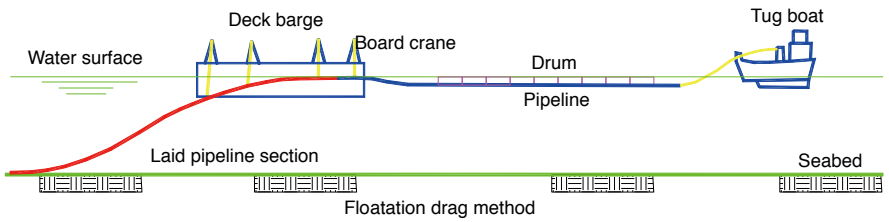
The mooring analysis process includes static analysis and dynamic analysis. Static analysis makes allowance for the average force load of the wind force, flow force and drift force on a ship and its mooring line, and then the average deviation position of the ship mooring system and the tension of the mooring line are worked out. Dynamic analysis makes allowance for the dynamic effect of a ship, its mooring line and external load, and then the time domain analysis result of ship displacement and mooring line tension is worked out. By using the mooring analysis technology, check anchor layout schemes, determine the mechanical highlights of each anchor layout scheme, and provide correct guidance to actual anchor layout.





2.5 Construction with drag method

The construction technology with drag method: bind a flotation buoy on a pipeline and make it float in water; then drag the pipeline to the pipeline design route using the tools such as ship and others; finally place the pipeline to the seabed. According to the state of the pipeline during towing in water, the drag method is divided into bottom drag method, off-bottom drag method, floating drag method, etc.



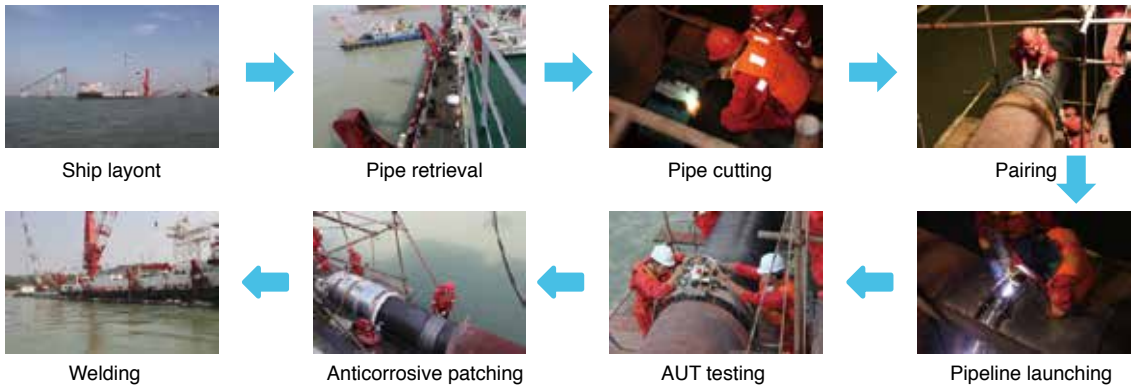
Bottom drag construction in the landing section

2.6 Submarine pipeline construction complete technology

The submarine pipeline construction complete technology includes horizontal interface docking technology, riser expansion bend installation technology, elastic laying technology, etc.

◆ Horizontal interface docking technology

The horizontal interface docking technology includes surface welding and integral lowering technology and underwater flange connection technology. The surface welding and integral lowering technology uses OFFPIPE software to analyze the pipeline stress problem during pipeline lifting and lowering, thus ensuring construction safety and that the pipeline stress during construction is within the permissible range. The technology has been successfully used in the submarine pipeline engineering of Hong Kong branch of West-East NG Transmission Line II, and horizontal interface docking at 25m water depth has been completed favorably.



◆ Riser expansion bend installation technology

The riser expansion bend installation technology refers to the construction technology where the flat pipe section of a submarine pipeline is connected with a platform or a land process line using riser and expansion bend. The riser expansion bend installation technology includes integral installation technology and underwater flange connection technology. The integral installation technology uses ANSYS software to make a mechanical analysis of the hoisting and lowering process of the riser and expansion bend, thus ensuring that the pipeline stress in the whole process is controlled within the permissible range. A construction scheme is worked out through analysis and calculation. The technology has been successfully used in the submarine pipeline engineering of Hong Kong branch of West-East NG Transmission Line II, and riser landing in Hong Kong section has been favorably completed.

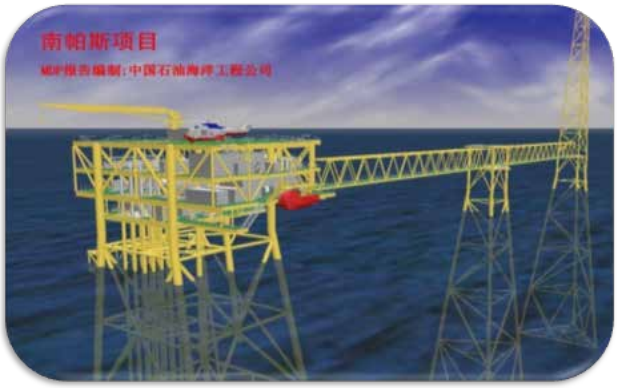
◆ Elastic laying technology

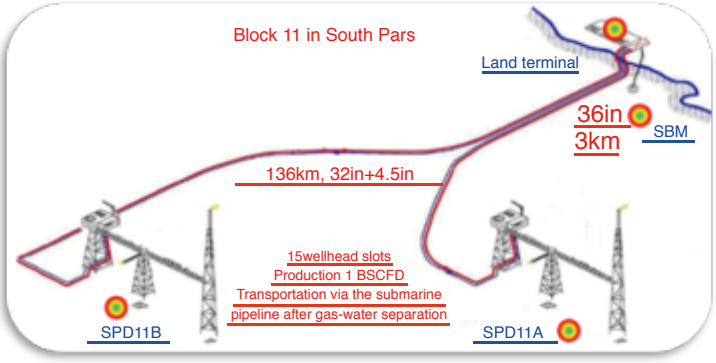
The elastic laying technology: lay the arc section designed in the middle of a submarine pipeline, analyze the stress on the anchor chain of the pipe laying ship under the joint action of external loads, and evaluate its operation safety or not. Use relevant software for checking; consider wind force, flow force and other possible external acting forces, evaluate the performance of the ship anchoring system under the comprehensive action of various loads, check the anchor layout scheme, and ensure safe and favorable construction.

3 TYPICAL CASES

3.1 Design of the gas field in block 11, in South Pars, Iran

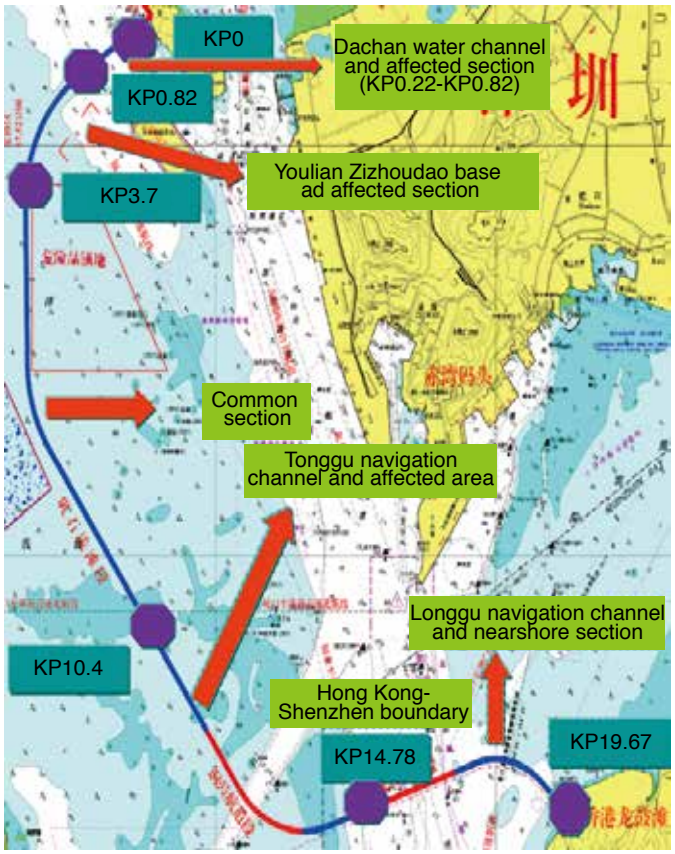
The gas field in block 11 in South Pars, Iran includes 2 wellhead platforms and their matching facilities, 6 submarine pipelines and optical cables and 1 set of single-point mooring transportation system. The water depth of the project is 70m and the annual gas production $200\times10^8m^3$ containing H_2S. The gas transportation pressure of the pipelines is 13.8MPa and the temperature 105 ℃. CNPC completed the basic design of the submarine pipelines and single-point mooring transportation system of the project within half a year. The design has been reviewed and approved by BV. The main technology difficulties is comprehensive simulation water hammer calculation of condensate oil transportation pipelines in multiple operating modes; structure design technology for long-distance transportation pipelines with large pipe diameter, high temperature and high pressure and complex route; lateral buckling design and analysis of HTHP pipelines; 30×10^4t oil transportation terminal design technology.





3.2 Hong Kong branch of West-East NG Transmission Line II

Hong Kong branch of West-East NG Transmission Line II is an important component of West-East NG Transmission Line 2 Project. Hong Kong branch begins with Dachandao terminal station and is laid via the seabed to Hong Kong Longgutan gas transmission station. The outer diameter, wall thickness and design pressure of the pipeline are 813mm, 22.2mm and 7.0MPa respectively. The operating pressure of the pipeline doesn't exceed 6.3MPa, and its designed annual gas transmission capacity is $60\times10^8 m^3/a$. The total length of the submarine pipeline is 19.67km, including about 14.78km of Shenzhen section of it. The designed service life of the submarine pipeline is 30 years. CNPC has undertaken the design and construction of the project and successfully completed the protection design of the submarine pipeline crossing harbor areas and navigation channels, the treatment design of local sand mining areas along the route, and horizontal interface docking design and construction at over 20m water depth.



4 ANCILLARY EQUIPMENT

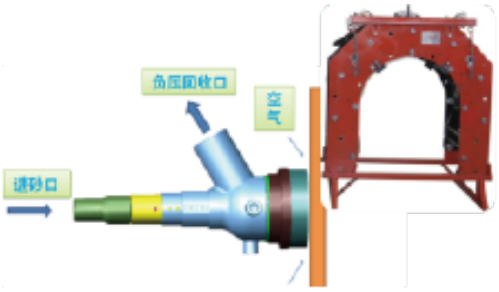
4.1 CPOE 101 pipe laying ship

The applicable water depth of “CPOE 101” pipe laying ship is 2.5~40m, and the maximum pipe diameter 60in. The ship is fitted with internationally advanced pipe laying operation line and 400t full-rotation crane. The designed maximum pipe laying speed is 2.5km/d. The total length, molded breadth and molded depth of the ship are 123.85m, 32.2m and 6.5m respectively. The ship is one of pile laying ships with the strongest pipe laying capacity and the most advanced equipment in shallow water areas.

4.2 Key laboratory

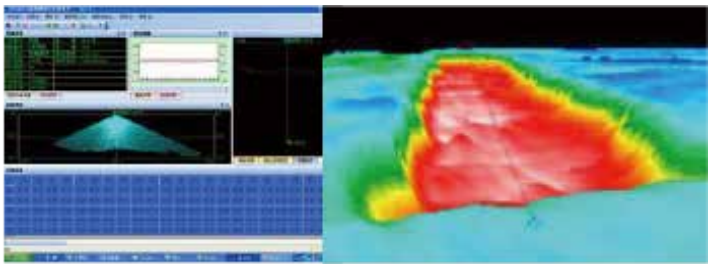
The building area of the key offshore engineering laboratory of CNPC is 5000m^2. The laboratory has over 100 pieces (sets) of various test equipment. The laboratory has the research capacity in the fields involving underwater equipment engineering, offshore engineering structure subgrade and foundation, deepwater structure engineering, etc. and can perform wave current water trough experiment, structural mechanics experiment, special material experiment and numerical simulation analysis on offshore engineering structures.

Full-scale fatigue testing machine



Automatic sand blasting equipment

Submarine bundle of pipes



Submarine 3D topographic mapping

4.3 Professional software

CNPC has over 10 sorts of internationally advanced offshore engineering software, which can be used in submarine pipeline structure analysis, process design and pipeline installation design. This has provided a technical guarantee to integrated design, construction and installation of submarine pipelines.

Autopipe

AGA

ANSYS

Pipeflo

Moses

SAGE Profile

5 QUALIFICATION STANDARDS

5.1 Enterprise qualification

CNPC has qualifications including grade A offshore petroleum engineering design, grade I offshore petroleum engineering contracting, grade B engineering consultancy as well as special equipment licenses including harbor operation license, pressure pipeline and pressure vessel license, etc., and is a national high-tech enterprise.

5.2 Technical standards

The Guide to Design of Offshore Oil and Gas Field Engineering has been published; multiple relevant offshore engineering standards and specifications have been quoted, including those of DNV, API, ASTM, GB, CCS, SY, etc., thus ensuring bases for all work and providing a powerful guarantee to design and installation of submarine pipelines.

Name of part standards and specifications	No. of standards and specifications
Specification for Submarine Pipeline System	DNV-OS-F101
Risk Assessment of Submarine Pipeline Protection	DNV RP-F107
Free spanning of submarine pipelines	DNV RP-F105
On-bottom stability design of submarine pipelines	DNV RP-F109
Specification for pipeline welding and relevant equipment	API RP 1104 Version 20
Seismic technical code for oil and gas transmission pipeline engineering	GB50470
Specification for steel pipes of pipelines	API SPEC 5L
Code for Design of Oil Transportation Pipeline Engineering	GB 50253
Code for Design of Gas Transportation Pipeline Engineering	GB 50251
Code for design of oil and gas gathering and transportation in oil fields	GB 50350
Code for design of oil and gas gathering and transportation in beach oil fields	SY/T 4085
Guide to pressure relief and reduction systems	API 521
Recommended method for design and installation of offshore production platform piping systems	API 14E
Sacrificial anode and cathode protection of submarine pipelines	DNV-RP-F103
External anticorrosive pipeline coatings painted at factories	DNV-RP-F106
Site rehabilitation of pipeline joint coatings and pipe body coatings	DNV-RP-F102

6 EXPERT TEAM

Tang Rongyu

Senior engineer, member of CSNAME, Deputy Director of Shallow Sea Central Station of CPS Engineering Committee, Deputy Secretary-General of Offshore Petroleum Engineering Specialized Standardization Committee, member of CCS Offshore Engineering Committee, member of Editorial Committee of China Offshore Platform and Petroleum Engineering Construction. He is mainly engaged in design and R&D of offshore oil and gas fields as well as construction, design and management of equipment base. As project manager or principal, he has taken charge of over 30 offshore engineering projects. He has chiefly formulated and has participated in formulation of 4 industrial specifications. Over 20 papers written by him have been published.

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Liu Jieming

National grade I registered structure engineer, member of Production, Learning and Research Committee of CSTAM, member of Beijing Society of Theoretical and Applied Mechanics, member of CPS, member of Offshore Engineering Specialized Standard Group of CNPC Standardization Committee. He has taken charge of over 50 offshore engineering designs. Over 10 papers written independently by him or co-authored by him (ranking first) and other persons have been published in national journals or at international conferences. As the industrial standard invitee, he has formulated 1 industrial standard and 1 enterprise standard. As the industrial standard chief reviewer, he has chiefly reviewed 4 industrial standards or enterprise standards.

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Guo Hongshen

Senior engineer. He has occupational qualification in US PMP project manager. He is mainly engaged in the study and design of offshore petroleum engineering equipment as well as the design and management of offshore engineering structures and submarine pipelines. He has participated in and taken charge of completing R&D of multiple national and ministerial key scientific research subjects, platforms and ships.

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Senior engineer, national grade I registered structure engineer, national stage II registered architect. He is mainly engaged in the construction of oilfield mining areas, surface engineering and offshore engineering as well as design and management of submarine pipelines. He has taken charge of over 20 surface engineering construction and submarine pipeline projects. Over 10 papers written by him have been published.

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Qin Yanlong

Senior engineer, member of CSNAME Offshore Engineering Branch, member of Offshore Engineering Work Department of CPS Petroleum Engineering Specialized Committee, member of Offshore Engineering Equipment Overall Technology Expert Panel and Offshore Engineering Equipment Special System and Equipment Expert Panel of the Ministry of Industry and Information Technology. He is mainly engaged in the study and design of offshore petroleum engineering development technology and equipment. He has taken charge of and participated in completing over 20 national, provincial and ministerial key scientific research subjects. He has obtained 2 grade II provincial and ministerial science and technology advance prizes and 1 grade IV provincial and ministerial science and technology advance prize. 53 papers written by him have been published. He has obtained 25 patents.

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Li Chunrun

Senior engineer, member of CWA, Deputy Director of Welding Professional Committee of China Petroleum Engineering Construction Association. He is mainly engaged in the study, development and management of offshore and land petroleum engineering construction and installation technology and special equipment. He has taken charge of and participated in completing over 20 ministerial key scientific research subjects and national key projects. He has obtained 2 grade II provincial and ministerial science and technology advance prizes and 3 grade IV provincial and ministerial science and technology advance prizes. Over 40 papers written by him have been published. He has obtained over 20 patents.

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Zheng Li

Senior engineer, grade I national architect. He is engaged mainly in construction and installation of offshore structures. He has organized the construction and installation of over 50 offshore structures including PY30-1 jacket, Yuedong module and jacket, etc.
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Gao Zhaoxin

Senior engineer. He has occupational qualification in US PMP project manager. He is mainly engaged in construction and installation management of offshore structures as well as laying management of submarine pipelines and submarine cables. He has participated in construction and installation of multiple topside modules and jackets of jacket platforms as well as laying of multiple submarine pipelines such as Hong Kong branch of Xier Line.
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