Project Report

Application of Prestressing Technology in Ultra-large LNG Storage Tanks at the "Green Energy Port" Project in Yancheng, Jiangsu Province

Zhichao Wang [1], Chaochen Wen [2] and Yedong Jiang [2,*]

[1] Tongji Architectural Design (Group) Co., Ltd., Shanghai 200092, China;
[2] Liuzhou OVM Machinery Co., Ltd. Liuzhou 545006, Guangxi Province, China.
* Correspondence: dutwzc@163.com

Abstract: The Yancheng "Green Energy Port" is an important project planned under the National Natural Gas Production, Supply, Storage, and Sales System Construction and Interconnectivity program, and it is also the largest liquefied natural gas (LNG) reserve base currently under construction in China. In the first phase of the "Green Energy Port" project, 10 large LNG storage tanks were built, including 4 tanks with a capacity of 220,000 m^3 and 6 tanks with a capacity of 270,000 m^3, the latter of which are currently the largest storage tanks with a single-tank capacity in the world. This report provides a brief introduction to the project context, outlines the layout of the prestressed system in the LNG storage tanks and the construction phases, and summarizes the critical tests for the prestress system in cryogenic tanks.

Keywords: LNG storage tank; prestressing system; cryogenic storage tank; test

Citation: Wang, Z.; Wen, C.; Jiang, Y. Application of Prestressing Technology in Ultra-large LNG Storage Tanks at the "Green Energy Port" Project in Yancheng, Jiangsu Province. *Prestress Technology* **2024**, *3*, 57-70. https://doi.org/10.59238/j.pt.2024.03.006

Received: 07/08/2024
Accepted: 08/09/2024
Published: 30/09/2024

1 Project Overview

The "Green Energy Port" project in Binhai district, Yancheng, Jiangsu Province, China, can be traced back to September 2004, when the China National Offshore Oil Corporation (CNOOC) signed the "Agreement between the People's Government of Yancheng City and CNOOC Natural Gas and Power Generation Co., Ltd. on Jointly Promoting the Construction of the Jiangsu Binhai LNG Project" with the Yancheng Municipal Government. In August 2013, the Binhai LNG project received preliminary approval from the National Energy Administration. However, owing to the weak domestic demand for LNG, the project was put on hold and delayed [1]. On June 28, 2018, the Binhai LNG project was restarted [2]. The initial plan for four 160,000 cubic meter LNG storage tanks was upgraded to 220,000 cubic meters each, with the total investment increasing from 11.5 billion yuan to 17 billion yuan [3]. The first phase, consisted of four 220,000 cubic meter tanks, was constructed in May 2019 (Figure 1), and the roof-raising operation was successfully completed in September 2020 [4]. On June 9, 2021, construction began on an expansion that included six additional 270,000 cubic meters of full-containment LNG storage tanks, which were built in addition to the initial four tanks. After the expansion was completed, the annual handling capacity of the Jiangsu Binhai LNG receiving terminal reached 6 million tons, making it the largest LNG reserve base in China [5]. In September 2022, the first four LNG storage tanks were officially put into operation, and by the end of that month, all six expanded LNG storage tanks had successfully undergone roof-raising operations [6]. On April 24, 2024, the perlite filling for the six storage tanks of the first-phase expansion project was completed, marking the completion of the main construction of the storage tank group [7], which is planned to be fully operational by 2024 [8].

Figure 1 First-phase project park of the "Green Energy Port" in Yancheng [9].

The "Green Energy Port" in Yancheng is located in Binhai Port Industrial Park and is an important planned project for the production, supply, storage, marketing and interconnection of national natural gas. The six 270,000 cubic meter full containment tanks that were expanded in the first phase are currently among the largest single-tank capacity storage tanks in the world [10].

The full-containment LNG storage tank has two layers. The inner tank is a fully closed tank where liquified natural gas is usually stored, and is formed by welding a low-temperature-resistant, 9% nickel steel. The outer tank is a concrete tank that protects the inner tank and prevents the leakage of natural gas. The typical structure of an LNG storage tank is shown in Figure 2, The outer tank consists of a pile foundation, a pile cap, a tank wall (including a ring beam), a dome and related auxiliary equipment.

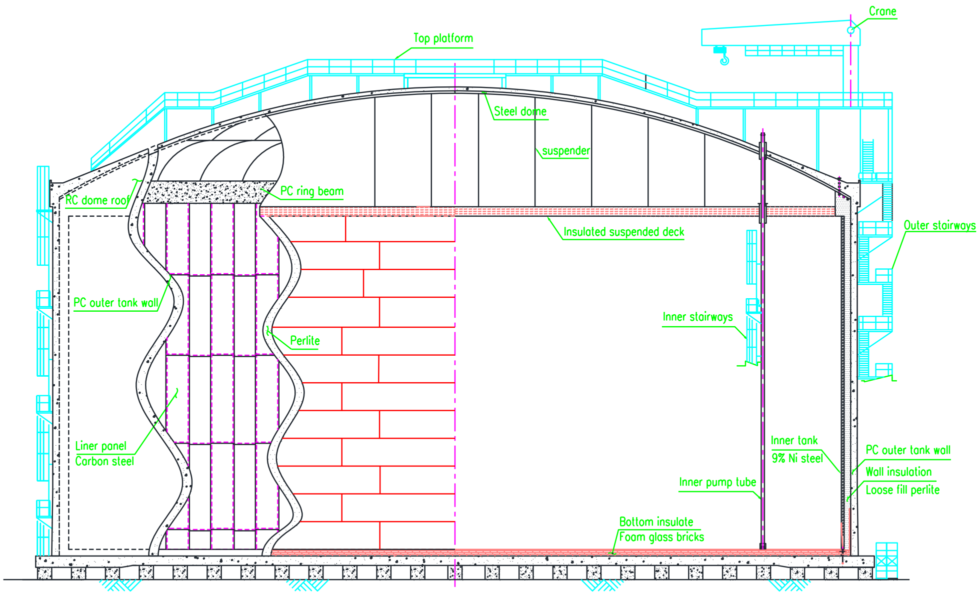


Figure 2 Schematic diagram of a typical full-containment tank

2 LNG Outer Tank Design

The design service life of the LNG outer tank is 50 years, and it has a Class B seismic defense category. Design calculations should be carried out in detail on the basis of the construction requirements and site data. The dimensions of the tank bottom, tank wall, and dome should all be calculated.

https://doi.org/10.59238/j.pt.2024.03.006

2.1 Outer Tank Loads

The main loads in the design of the LNG outer tank can be divided into permanent loads, variable loads, seismic loads, and accidental loads.

(1) Permanent loads: structural dead weight, prestress
(2) Variable loads: live load on the tank roof, snow load, internal pressure, internal negative pressure, pressure of the insulation layer, settlement, dead weight of liquefied natural gas, wind load, water pressure test, air pressure test, and thermal effect
(3) Seismic and accidental loads: seismic load, explosive load, fire, internal tank leakage load

2.2 Bottom Plate Design

The outer tank bottom plate (pile cap) generally adopts a reinforced concrete structure, which is thick at the edge and thin at the center. The outer tank wall is rigidly connected to the bottom plate. An elevated pile cap footing is usually used due to the high requirements for settlement of the storage tank structure, and because the pile body and cap can be rigidly connected. When the seismic acceleration is high, isolation bearings should be set between the pile top and the tank bottom plate. The tank bottom plate should meet the control requirements of uneven settlement.

2.3 Tank Wall Design

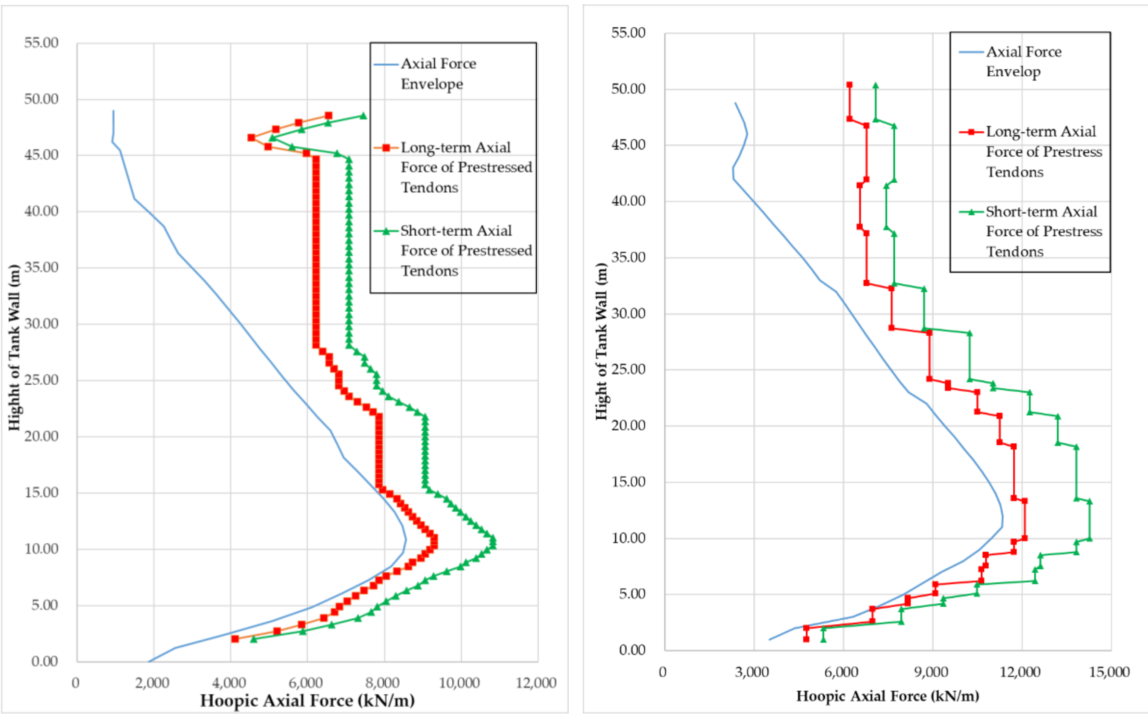
The tank wall is typically a circular prestressed concrete structure, with prestressing applied both horizontally and vertically via posttensioning. The hoop reinforcement and the inner side of the tank wall primarily use low-temperature reinforcement, whereas the outer side uses ordinary reinforcement. When designing the tank wall, it is necessary to ensure that the ultimate bearing capacity of the tank wall meets the requirements under various conditions and satisfies the corresponding crack control criteria and the maximum internal pressure stress conditions for the concrete. Under the maximum design load, the average compressive stress in the horizontal and vertical compression zones of the concrete should be at least 1 MPa. At least 10% of the wall thickness must be under compressive stress, and the thickness of the compressive stress zone should be greater than 100 mm.

2.4 Dome Design

The dome consists of a reinforced concrete shell cast in place on top of a steel shell, with the two shells connected by shear stud bolts. The steel dome shell is installed via a pneumatic lifting method, after which the concrete is cast in place on top of the steel dome. During the curing period of the concrete, a specific air pressure should be maintained inside the tank to support the weight of the newly poured concrete.

2.5 Prestressing System Design

The arrangement of prestressing in the tank should be determined on the basis of the forces involved. An axial force demand envelope is formed by calculating the axial tensile force generated by the load on the tank wall under various working conditions. The arrangement of the prestressing tendons is then determined on the basis of various factors, including the demand envelope, the anchorage space requirements, the construction tensioning scheme. The following figure (Figure 3) shows a typical axial force demand envelope in the circumferential direction and the corresponding circumferential axial force provided by the prestressing tendons arranged on the tank wall.



a) 220,000 cubic meter full containment tank b) 270,000 cubic meter full containment tank

Figure 3 Axial force demand envelope of the storage tank and the circumferential axial force provided by the prestressing tendons

2.6 Buttress Column Design

The design of the buttress columns in the storage tank is a critical aspect of the detailed prestressing design. This requires consideration of the compressive capacity of the local anchorage zone and the crack resistance of the general anchorage zone. A typical buttress column anchorage design is shown in the Figure 4.

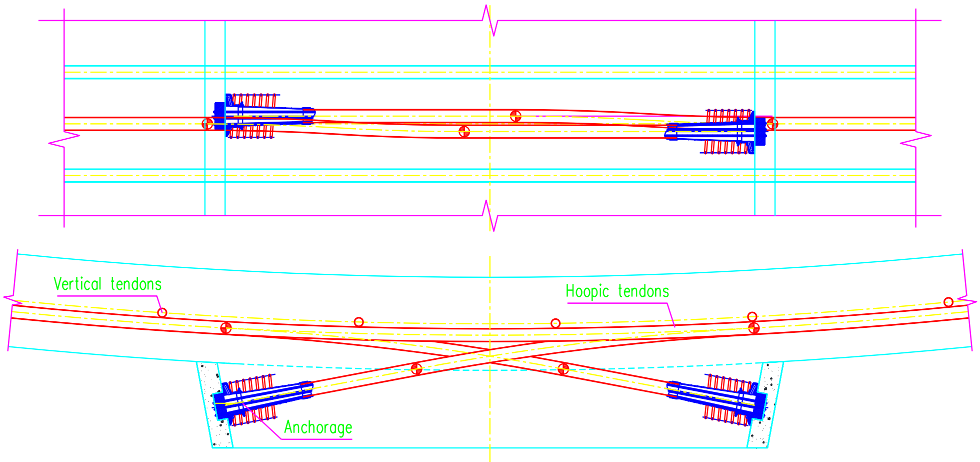


Figure 4 Typical buttress column detail drawing

The calculation of the bearing capacity of the local anchorage zone can be referenced from the design in the "Code for Design of Reinforced Concrete Structures" (GB 50010—2010) [11]. The bearing capacity must be analyzed in combination with the tank structure due to the irregular structure of the general anchorage zone. The strut–tie model method or finite element method can be used to calculate the overall force distribution and reinforce the tension zones. The anchor sealing structure should be considered when performing a detailed design of the prestressing system for the storage tank, in addition to considering the reinforcement in anchorage zones, since different anchor sealing structures can impacts construction efficiency.

2.7 Design Parameters of the Yancheng "Green Energy Port" Storage Tanks

The concrete outer tanks of the Jiangsu Binhai (Yancheng "Green Energy Port") liquefied natural gas (LNG) project are full-containment tanks. The main technical parameters of the storage tanks are listed in Table 1.

Table 1 Main technical parameters of the LNG storage tanks

Project of Storage Tank		**Unit**	**220,000 m³ LNG Tank**	**270,000 m³ LNG Tank**
Outer tank inner diameter		m	88	94.2
Height of the tank wall (from the top of the pile cap to the bottom of the dome)		m	45.2	48.8
Pile cap dimensions	Thickness of the central zone	m	1.2	1.4
	Thickness of the edge zone	m	1.4	1.6
	Outer diameter of the pile cap	m	94	100.6
Thickness of the outer tank wall	Variable thickness segment	m	1.0–0.8	1.2–0.9
	Standard segment	m	0.8	0.9
	Ring beam segment	m	1.1	1.2
Dome thickness		m	0.5	0.5
Number of buttress columns		/	4	6
Number of circumferential prestressing tendons (including ring beam segment)		group	98	117
Number of vertical prestressing tendons		bundle	136	156
Maximum design pressure		kPa·G	29	29
Pressure of air pressure test		kPa·G	36.25	36.25
Concrete grade of the tank		/	C50	C50
Concrete grade of the pile		/	C40	C40
Piles	Pile number	/	360	406
	Average pile length	m	73	73
	Pile diameter	m	1.5	1.5

3 Construction Process of the Prestressed System for the Storage Tank

The construction of the prestressed system for the storage tank runs through the entire construction process of the storage tank. Intervention is needed from the time of load-bearing construction until the temporary opening is closed after the completion of the water pressure and air pressure tests. Afterwards, the prestressing tendons near the temporary opening need to be tensioned. A typical construction process of the prestress system of the storage tank is shown in the following figure.

The construction of the prestressing system for the storage tank spans almost the entire construction process of the tank, starting from the pile cap construction phase. This process continues until after the water pressure and air pressure tests are completed, when the temporary openings are sealed and the prestressing tendons near these openings are tensioned. A typical construction process for a storage tank's prestressing system is shown in the Figure 5.

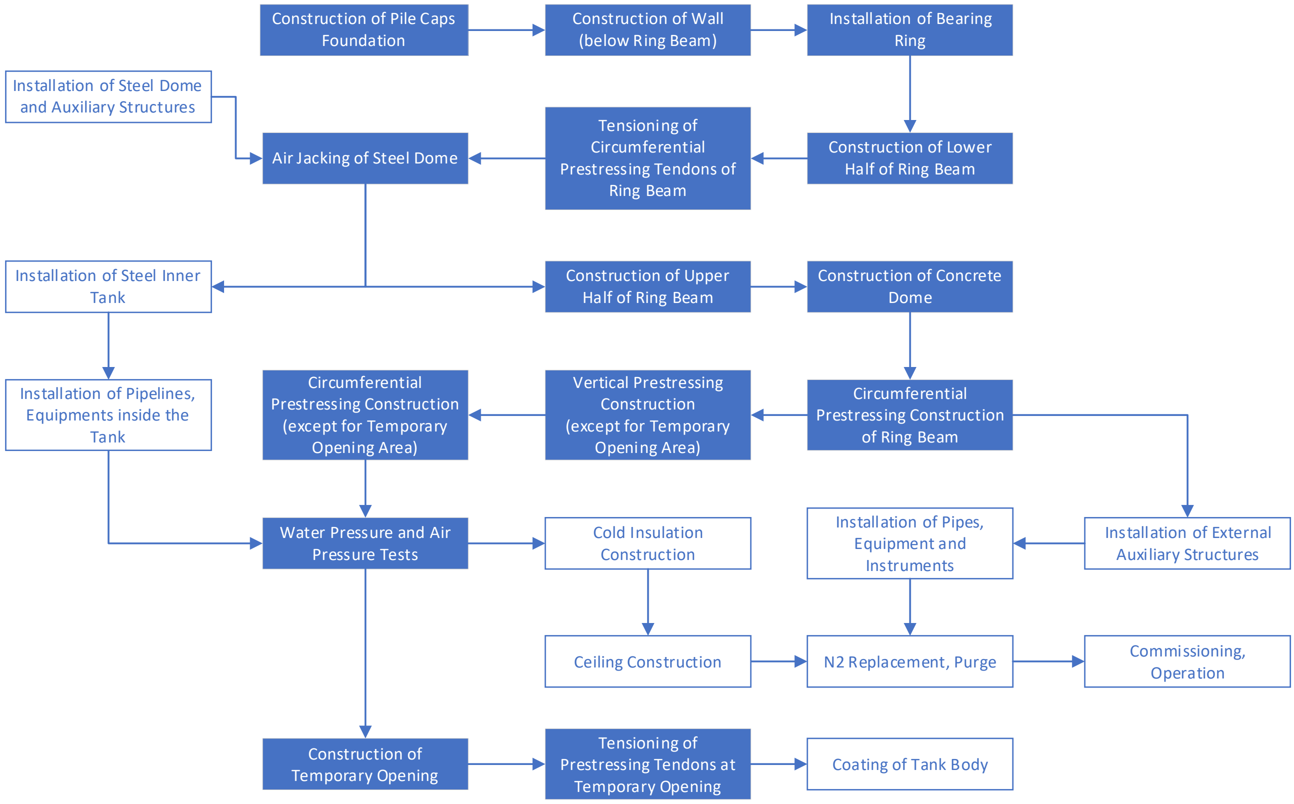


Figure 5 Construction process of the prestress system of the storage tank (simplified)

The Yancheng "Green Energy Port" project has been under construction for approximately three years. Thus, most of the construction process for the storage tanks has been completed. Figures 6 to 19 provide photographs of the key stages of the construction process for the storage tanks.

Figure 6 Pile foundation construction [12]

Figure7 Pile cap construction [13]

Figure 8 Tank wall construction [14]

Figure 9 Dome module hoisting [15]

https://doi.org/10.59238/j.pt.2024.03.006

Figure 10 Tank wall construction

Figure 11 The lower half of the ring beam prestressed tendon tensioning

Figure 12 Steel dome roof pneumatic lifting

Figure 13 Concrete dome roof construction

Figure 14 Installation of external equipment of tanks

Figure 15 Tensioning of vertical prestressed tendons

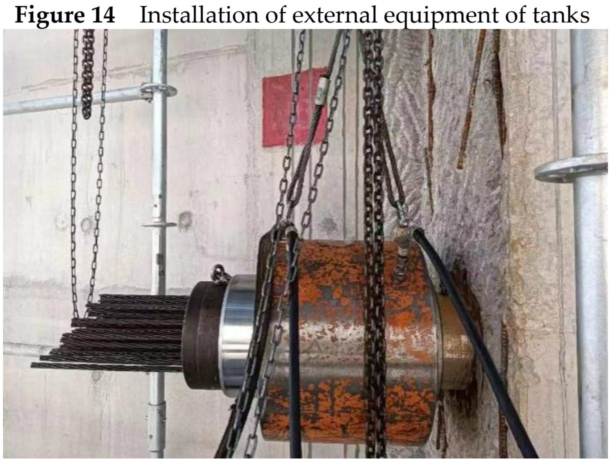


Figure 16 Tensioning of circumferential prestressed tendons

Figure 17 Installation of equipment in the tank

Figure 18 Water pressure test[16]

Figure 19 Prestressed tendon tensioning at the temporary opening

4 Main Tests of the Prestress System

4.1 Test of Corrugated Metal Ducts

Corrugated metal ducts are among the most commonly used types of ducts in posttensioned prestressed structures. Their primary purpose is to form specific ducts during the pouring of concrete, facilitating the insertion of prestressing tendons later. Therefore, the two most important indicators for corrugated metal ducts are the mechanical properties of the material and the liquid-tight properties. The standard "Corrugated metal ducts for prestressed concrete" (JG/T 225—2020) [17] requires anti-external-load performance tests and anti-leakage performance tests. The main purpose of these tests is to verify the strength and liquid-tightness of the corrugated metal duct structure.

The anti-external-load performance test is divided into an anti-local transverse load performance test (see Figure 20) and an anti-uniform load performance test (see Figure 21). During the test, the corrugated metal ducts should not crack or detach, and the deformation should not exceed a certain range. The antileakage test (see Figure 22 and Figure 23) is divided into an antileakage test after bearing a local transverse load and an antileakage test after bending; it requires no measurable leakage of clear water within 30 minutes after grouting.

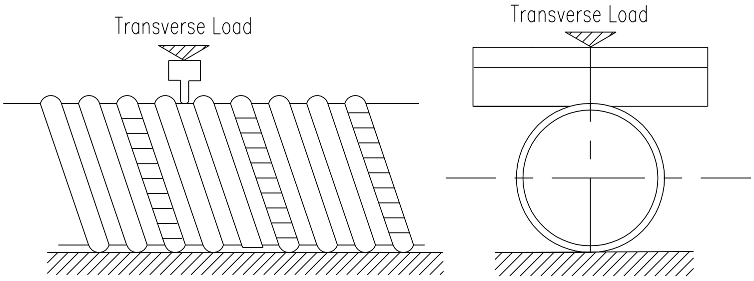


Figure 20 Anti-local transverse load performance test

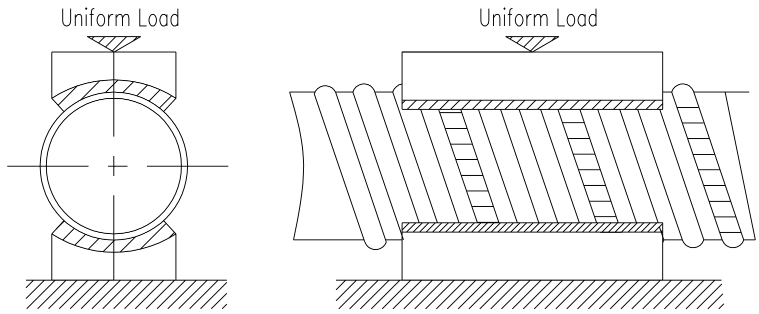


Figure 21 Anti-uniform load performance test

Figure 22 Pouring clear water into the ducts

Figure 23 Anti-leakage performance test

4.2 Slip Test of the Central Wire of Steel Stranded Wires for LNG Storage Tanks

Unlike ordinary prestressed concrete structures, the LNG storage tank needs to detect the amount of slip of the central wire of steel stranded wires in a cryogenic environment. The test verification is carried out according to the "Steel for the reinforcement and prestressing of concrete—Test methods Part 3: Prestressing steel" (ISO 15630—3: 2010) [18] standard. The main purposes of the test are as follows:

(1) To measure the slippage of the central wire of the steel stranded wires during loading at normal temperature in the cryogenic anchor system.

(2) To measure the slippage of the center wire of the steel stranded wires at -196°C ± 5°C, they were loaded to $0.8F_{ptk}$ and held for 15 minutes. The slippage of the central wire of the steel stranded wires was subsequently measured during further loading to $0.95F_{ptk}$, where F_{ptk} is the nominal breaking load of the prestressing tendon.

The slip test (Figure 24) of the steel stranded wire central wire needs to detect the entire anchoring assembly, and its test process is as follows:

(1) The test specimen, equipment and related instruments were installed according to the test outline.

(2) The initial tension of the steel stranded wire anchorage assembly was $0.1F_{ptk}$.

(3) The steel stranded wire anchorage assembly was gradually loaded at rates of $0.2F_{ptk}$, $0.4F_{ptk}$, $0.6F_{ptk}$ and $0.8F_{ptk}$, and the slippage of the center wire at each level of loading was recorded via digital displacement gauges.

(4) After loading to $0.8F_{ptk}$, the liquid nitrogen pump began to fill the sealed cylinder with liquid nitrogen. Once the temperature stabilized at -196°C ± 5°C, the load was held for 15 minutes, and the slippage of the center wire was recorded.
(5) Loading was increased slowly to $0.95F_{ptk}$, and the slippage of the center wire was recorded.
(6) The test instrument and equipment were removed, and the test ended.

The acceptance criteria for the test are as follows: when the test sample is loaded to $0.8F_{pk}$ force value in a normal-temperature environment, the slippage of the steel strand central wire is to be 0 mm; when the test sample is under $0.8F_{ptk}$ load in a cryogenic environment, the slippage of the steel strand central wire is to be 0 mm after the load is held for 15 min; and when the test sample is loaded to $0.95F_{ptk}$ in a cryogenic environment, the slippage of the steel strand central wire is to be less than 0.5 mm.

Figure 24 Slip test of the steel strand central wire in a cryogenic environment

4.3 Test of the Cryogenic Anchorage of LNG Storage Tanks

In accordance with the requirements of the "Anchorage, grip and coupler for prestressing tendons" (GB/T 14370—2015) [19] standard, in general, the anchorage needs to be tested via static load anchoring performance tests, fatigue load performance tests, anchoring zone force transmission performance tests, anchor plate strength tests, draw-in tests, anchorage head friction loss tests, and tension and anchoring process tests. Unlike ordinary anchorages, cryogenic anchorages for LNG storage tanks also need to pass cryogenic anchoring performance tests to verify their anchoring performance in a low-temperature environment of -196°C.

The test process of the cryogenic anchoring performance test (see Figure 25) is as follows:

(1) The test specimen, equipment and related instruments were installed according to the test outline.
(2) The construction jack is used to initially tension the steel stranded wire anchorage assembly to $0.1F_{ptk}$, where F_{ptk} is the nominal breaking load of the prestressing tendon.

(3) The construction jack was used to gradually load the steel strand anchorage assembly at rates of $0.2F_{ptk}$, $0.4F_{ptk}$, $0.6F_{ptk}$, and $0.8F_{ptk}$. After reaching $0.8F_{ptk}$, the anchor continues loading via the loading jack until the load reaches $0.8F_{pk}$, after which it is held for 1 hour.

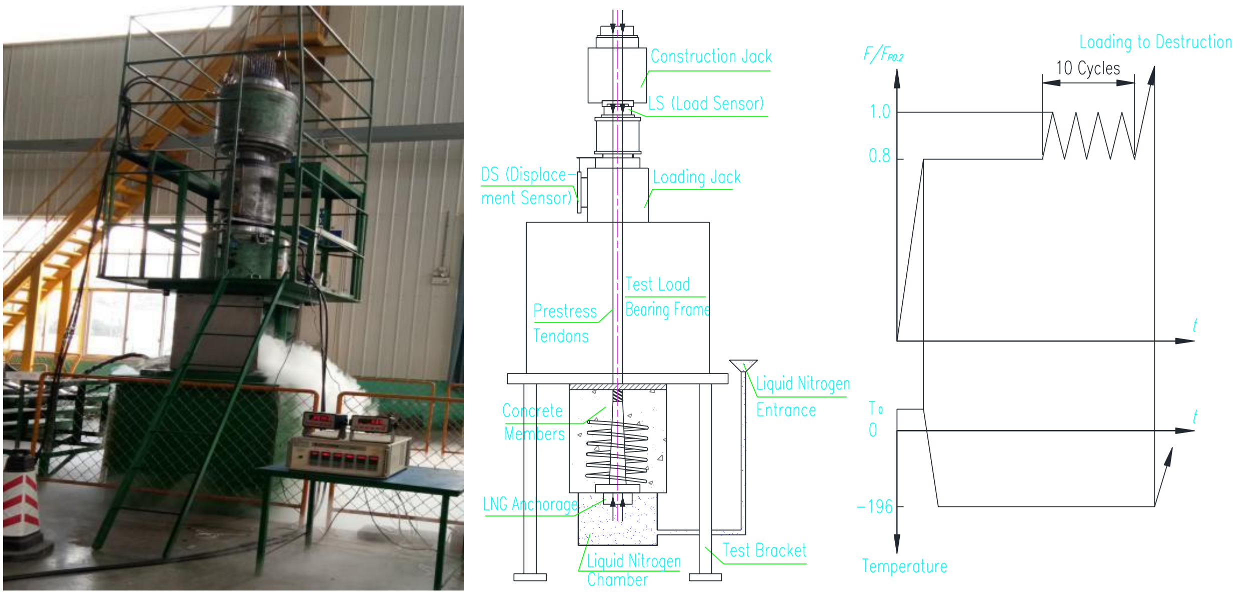
(4) Liquid nitrogen was injected into the low-end anchorage seal cap. Once the temperature stabilizes at -196°C ± 5°C, ten cycles of tension are performed between $0.8F_{ptk}$ and $F_{p0.2}$, where $F_{p0.2}$ is the tensile yield force F_{Tu} at a nonproportional extension rate of 0.2% at room temperature.

(5) After cyclic loading is complete, the tensile force is gradually increased at a speed of $0.002F_{ptk}$ per minute until the assembly breaks.

The acceptance criteria for the test are as follows:

(1) The measured ultimate tensile force F_{Tu} of the prestressing tendon–anchorage assembly at low temperature should not be less than 95% of the average ultimate tensile force nF_{pm} measured at room temperature.

(2) The failure mode should be the breakage of the prestressing tendon rather than the failure of the anchorage causing the termination of the test.



a) Test photographs b) Schematic diagram of the test device c) Loading history

Figure 25 Anchoring performance test in a cryogenic environment

4.4 Full-Scale Grouting Test in Prestressed Ducts

The full-scale grouting test (Figure 26) for prestressed ducts is an important test for evaluating the grouting process. Its main purposes are as follows:

(1) To verify whether the pressure of the grouting pump meets the working requirements.

(2) To test the mix proportion and flow properties of the grouting material.

(3) To calculate the volume of grouting material required to fill the duct completely.

(4) To inspect the density of the grouting material within the duct.

The relevant procedures and requirements for the grouting test according to the standard "Prestressing technology specification for safety containments of PWR nuclear power plants. Part 2: Test" (NB/T 20325.2—2014) should be followed [20].

Figure 26 Full-scale grouting test in a prestressed duct

4.5 Friction Test in Prestressed Duct

The prestressed duct friction test (Figure 27) is used to determine the friction coefficient between the tendons and the ducts. Its main purposes are as follows:

(1) To quantify the prestress losses that occur due to friction between the prestressing tendons and the duct walls by ensuring the effective application of prestress in the final structure.

(2) To validate the accuracy of the friction coefficients used in the design stage, the design calculation model should be evaluated, and a more accurate calculation of the prestress values should be measured.

The relevant procedures and requirements for the prestressed duct friction test can be followed according to the standard "Test method for friction loss in posttensioned prestressed concrete beams of railways" (Q/CR 566—2017) [21].

Figure 27 Friction test in the prestressed duct

https://doi.org/10.59238/j.pt.2024.03.006

5 Conclusions

This report provides a brief overview of the construction history of the Yancheng "Green Energy Port" project and summarizes the basic design parameters for the 220,000 and 270,000 cubic meters storage tanks. Through the proper arrangement of prestressing tendons, the design and construction of the world's largest single-tank LNG storage facility was accomplished.

Analysis of the LNG storage tank construction process reveals that specialized prestressing construction essentially runs throughout the entire construction process of the outer tank, making the detailed design of the prestressing system crucial. This report briefly summarizes the specialized construction process for the prestressing system of the LNG storage tank and summarizes important prestressing-related tests, providing valuable insights for similar projects.

Conflict of interest: All the authors disclosed no relevant relationships.

Data availability statement: The data that support the findings of this study are available from the corresponding author, Wang, upon reasonable request.

References

1. Yang, Y. CNOOC Binhai LNG Project to Start Construction, "Gas Shortage" After the LNG Receiving Terminal Construction Speed Up. Available online: https://www.sohu.com/a/239512838_260616 (accessed on 2018-07-02).
2. Xinhua Daily Newspaper. CNOOC Invests 14.4 Billion Yuan to Start Construction of Jiangsu Binhai LNG Project. Available online: http://www.cpcif.org.cn/detail/862193 (accessed on 2018-07-02).
3. China News Service Website. Jiangsu Binhai LNG Project "Capacity" to Prepare for the Yangtze River Delta Natural Gas Consumption Upgrade. Available online: http://www.cpcif.org.cn/detail/860567 (accessed on 2018-10-09).
4. Wu, L. China's Largest Independently Designed and Built Lng Storage Tanks Successfully Lifted the Roof, Kicking Off the Construction of Ultralarge Lng Storage Tanks! Available online: https://www.thepaper.cn/newsDetail_forward_9359287 (accessed on 2020-09-26).
5. Qu, Y. 270,000 Cubic Meters! China's Independent Research and Development of the World's Largest Volume of LNG Storage Tanks to Start Construction. Available online: https://new.qq.com/rain/a/20210610A02ZGO00 (accessed on 2021-06-10).
6. Zhao, J. CNOOC Yancheng Green Energy Harbor Phase I Expansion Project Successfully Completes Lifting of Tank No. 10. Available online: https://baijiahao.baidu.com/s?id=1744811371154980206&wfr=baike (accessed on 2024-09-24).
7. Xu, S.; Li, Y. CNOOC Yancheng "Green Energy Harbor" Completes Main Construction of 6 of the World's Largest LNG Storage Tanks. Available online: https://mp.weixin.qq.com/s/HI6UzCHbCWva15qBIcoIKg (accessed on 2024-04-25).
8. Yancheng News. CNOOC's Yancheng "Green Energy Harbor" Has a Record-High Supply Protection Capacity. Available online: http://www.yancheng.gov.cn/art/2024/5/31/art_33925_4195270.html (accessed on 2024-05-31).
9. Xu, S.; Chen, J.; Chen, L.; Yiting, L. CNOOC Yancheng "Green Energy Harbor" Completes Lifting of Vault Modules for 6 of the World's Largest LNG Storage Tanks. Available online: http://chinacpc.com.cn/info/2022-05-17/news_6364.html (accessed on 2022-05-17).
10. Yancheng News. Yancheng "Green Energy Harbor" Project Construction Speeds Up. Available online: http://www.yancheng.gov.cn/art/2022/9/5/art_49_3903092.html (accessed on 2022-09-05).
11. Ministry of Housing and Urban–Rural Development of the People's Republic of China. GB 50010—2010 Code for Design of Concrete Structures. China Architecture Publishing & Media Co., Ltd.: Beijing, 2011.
12. Yang, Y.; Zhang, L.; Bin, X. CNOOC Yancheng "Green Energy Harbor" Binhai 110kV Transmission Project Successfully Receives Electricity. Available online: http://www.ycnews.cn/p/543555.html (accessed on 2022-03-22).
13. Li, G.; Yu, Y.; Zhang, L. CNOOC Yancheng "Green Energy Harbor" Completes Pouring of Bearing Platforms for Six of the World's Largest LNG Storage Tanks. Available online: https://gaspower.cnooc.com.cn/art/2022/2/21/art_24741_15323145.html (accessed on 2022-02-21).

14. Xu, S. Six World's Largest Liquefied Natural Gas Storage Tanks Completed the Pouring of the First Layer of Outer Tanks at Cnooc Yancheng "Green Energy Port". Available online: https://gaspower.cnooc.com.cn/art/2022/4/1/art_24741_15325696.html (accessed on 2022-04-01).
15. Xu, S.; Chen, J.; Chen, L.; Li, Y. CNOOC Yancheng "Green Energy Harbor" Completes Lifting of Vault Modules for 6 of the World's Largest LNG Storage Tanks. Available online: http://chinacpc.com.cn/info/2022-05-17/news_6364.html (accessed on 2022-05-17).
16. Xu, S.; Li, G. CNOOC Yancheng "Green Energy Harbor" Completes Hydraulic Tests on Six 270,000 Cubic Meters LNG Storage Tanks. Available online: https://mp.weixin.qq.com/s/qI2zx57Kmk8doX7pqQyauQ (accessed on 2024-01-23).
17. Ministry of Housing and Urban–Rural Development of the People's Republic of China. JG/T 225-2020 Corrugated Metal Ducts for Prestressed Concrete. China Architecture Publishing & Media Co., Ltd.: Beijing, 2020.
18. International Organization for Standardization. ISO 15630-3: 2010 Steel for the Reinforcement and Prestressing of Concrete — Test Methods Par3: Prestressing Steel. International Organization for Standardization: Switzerland, 2010.
19. Ministry of Housing and Urban−Rural Development of the People's Republic of China. GB/T 14370-2015 Anchorage，Grip and Coupler for Prestressing Tendons. China Architecture Publishing & Media Co., Ltd.: Beijing, 2015.
20. National Energy Administration (NEA). NB/T 20325.2-2023 Prestressing Technology Specification for Safety Containments of Power Nuclear Power Plants — Part2: Test. Beijing, 2023.
21. China Railway Corporation. Q/CR 566—2017 Friction Test Method for Prestressed Concrete Beam by Railway Post-Tensioning Method. Beijing, 2017.

AUTHOR BIOGRAPHIES

	**Zhichao Wang** M.E, Engineer. Working at Tongji Architectural Design (Group) Co., Ltd. Research Direction: Prestressed Structure Design. Email: dutwzc@163.com		**Chaochen Wen** Senior Engineer, Working at Liuzhou OVM Machinery Co., Ltd. Research Direction: R&D of Prestressed products. Email: wencc@ovm.cn
	**Yedong Jiang** Senior Engineer, Working at Liuzhou OVM Machinery Co., Ltd. Research Direction: R&D of Prestressed products. Email: jiangyd@ovm.cn		