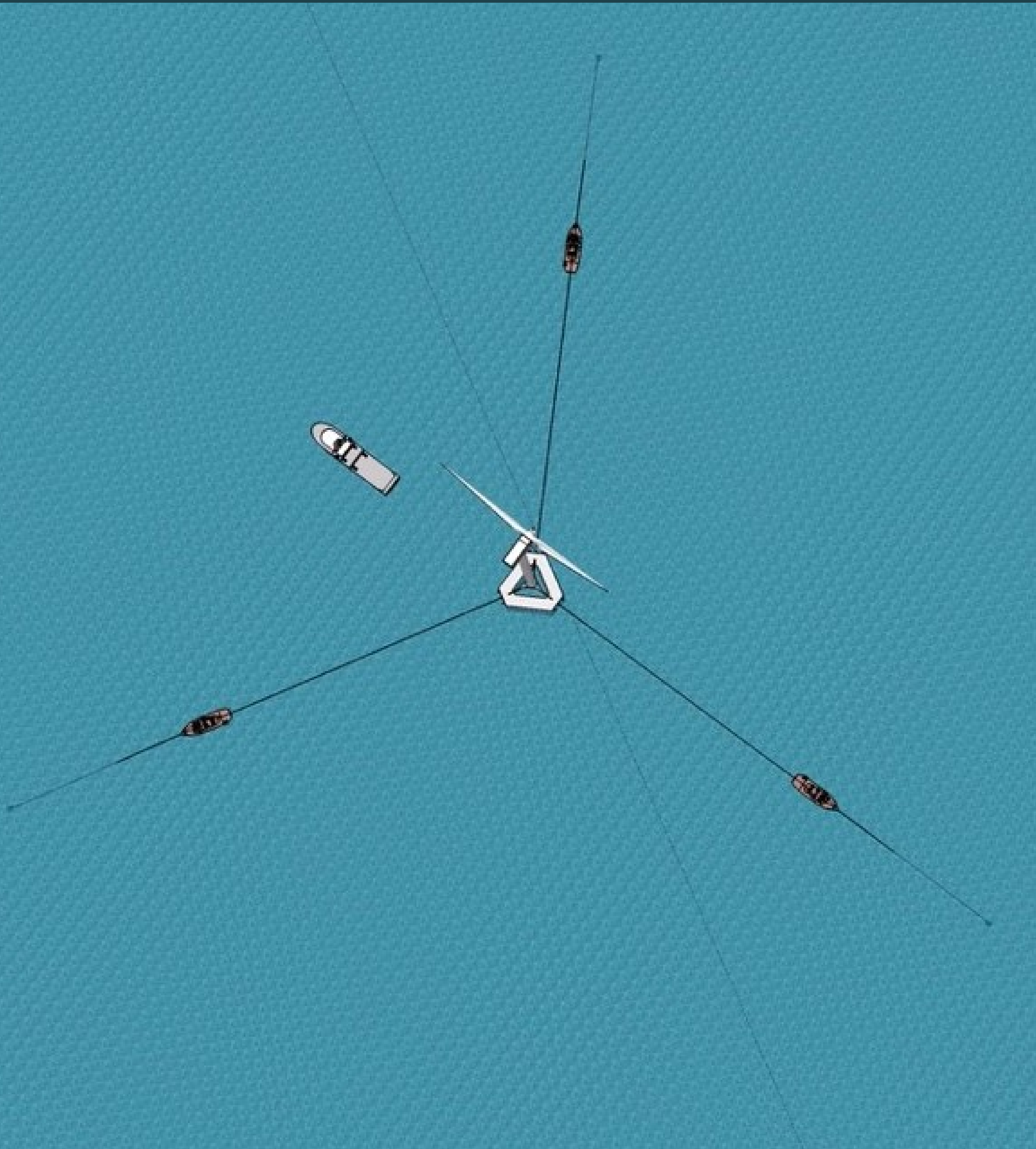
e-maritime

THE CAISSONS OF THE WIND TURBINE GENERATOR FOUNDATIONS

MAY 2023 SPECIAL EDITION



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Dear Readers

In this special edition of the e-maritime magazine, you can read about the caissons for the Türkiye Offshore Wind Project. The author of the article describes the project, the evolution of the proposed technical solution and some of its planned stages.

You can also read five Case Studies where the author explains, among other things, the methods of construction, handling, floating and installation of the caissons.

This whole edition comprises plenty of images, sketches, drawings and other materials that can help understand better what and how is done.

I would like to thank Erdal Ergül for providing the article and for his great cooperation during editing it and preparing it for publication, and David Stork for reviewing and proofreading this special edition.

The next e-maritime edition is not planned; when there is suitable content, we will do our best to prepare it for publication.

Magdaléna Sobotková
Chief Editor

May 2023

INTERNATIONAL PEER-REVIEWED ONLINE MAGAZINE
ABOUT PORTS, DOCKS, VESSELS, MARITIME EQUIPMENT
AND CONSTRUCTION AT SEA

e-maritime

The magazine **e-maritime** is an international peer-reviewed online magazine about ports, docks, vessels, maritime equipment and construction at sea.

It brings **original articles about design, construction, operation and maintenance of ports, docks, vessels, maritime equipment and construction at sea** from around the world.

Its electronic form enables publishing of high-quality photos, videos, drawings, links, etc.

We aim to include **all important and technical information** and show the grace and beauty of the structures and vessels as well.

It can be read free of charge and all magazines stay **available online** on our website as pdf.

From March 2019 to November 2021, it was regularly published three times a year. The September Issue was shared with the magazine e-mosty ("e-bridges"): "Vessels and Equipment for Bridge Construction", **www.e-mosty.cz.**

Since 2022, it has been released irregularly – when there is suitable content, we prepare a special edition.

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2 Thanks to OTOYOL YATIRIM ve İŞLETME INC. that is the Concessionaire of the Osmangazi Suspension Bridge for their kind permission to use Figures and drawings of this challenging project;

3 Thanks to Mr. Fatih Zeybek;

4 Thanks to Mr. Hasan Taşan who made a Peer Review of this paper (and where I used his personal photo also) and the Osmangazi Bridge Team Members;

5 Thanks to the Members of the Construction Companies of the Tenderer;

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10 Thanks to Mr. Arif Yeşiltepe who provided case Study 2 Caisson Construction on Barge Figures from his private archive;

11 Thanks to Mr. Erkan Çırak who provided Case Study 2 Caisson Tow and Submerging Operation Figures from his private archive,

12 Thanks to Miss Merve Türkkan who prepared the video and renderings;

13 Thanks to Mrs. Magdalena Sobotkova who edited and accepted to publish this article in her reputable e-maritime journal, and thanks to Mr. David Stork who kindly peer-reviewed and edited this article in order to prepare it fo publishing;

14 And finally, thanks to my Wife and Daughters who always support me.

THE CAISSONS OF THE WIND TURBINE GENERATOR FOUNDATIONS

Türkiye Offshore Wind Project

EUR ING Erdal Ergül, FICE

1. INTRODUCTION

The General Directorate of Turkish Renewable Energy (YEGM - www.yegm.gov.tr) declared its intention in 2018 that they diversify its Renewable Energy Investment Program and will support Offshore Wind Projects to use the country's know-how acquired from many Onshore Wind Energy Projects executed in Türkiye and use the capabilities of the country's maritime industry.

Amongst the others, one of the reputable Turkish Holding Companies (I will refer to it as the Tenderer from now on) having Construction Companies within its structures (one of them always cited in the ENR 250 list) has decided to show interest in investing in this sector and participate in forthcoming tenders.

I was then invited to join their tender team as Marine and Substructure Construction Advisor for Tender Preparation and Proposed Project Manager for the Project.

My most challenging project has been the Substructures of the Osmangazi Suspension Bridge Project in Izmit Bay in Türkiye, where I was the Marine Works Construction Manager of STFA Construction Company (a Reputable Turkish Marine Construction Company). This was the Nominated Subcontractor of the Main Contractor, IHI Infrastructure Systems Company (Japanese).

This project comprised two near-shore tower foundations at -40m CD (Chart Datum). We used our invention/development (know-how) of Roller Chain Stoppers for the mooring of Gravity Based Structures at Izmit Bay.

Therefore, Offshore Wind Farms, especially the ones that include Gravity Based Foundations (GBS), have become my special interest.

2. PROPOSED PROJECT LOCATIONS

The Client tendered an offshore wind power plant in the Marmara Region with 1,200 MW installed power. The first phase is 840MW, and the rest will be executed in the second phase.

Three alternative Project sites, namely, Saros (1), Şarköy (2), and Kıyıköy (3), see Figure 1, are considered for the Project development.

Figure 1: The Project Locations

Environmental factors significantly affect site selection, the interested Tenderer is committed to assessing the alternative sites in terms of their environmental conditions and therefore, commissioned Royal Haskoning-DHV-TR Engineering Inc. (RHDHV-TR), a company of Royal Haskoning-DHV, to undertake an Environmental Constraints Mapping for Offshore Wind Farm Sites.

RHDHV-TR has conducted a high-level review of the alternative Project sites based on publicly available information and has undertaken desktop bird research.

The environmental review focused on available data sources and engineering judgment.

The Tenderer made and signed a design and consultancy agreement with Ramboll, Denmark, since they have extensive experience in Offshore Wind Project Design.

3. TOPIC-BASED EVALUATION OF ALTERNATIVE PROJECT SITES

The site selection has been made in line with the consideration of several drivers i.e., "Detailed map of site area and site limit coordinates," "Site restrictions data", "Shipping routes" etc. which were prepared by Ramboll, and "Environmental restrictions" defined in the "Report for the Environmental and Social Constraints Mapping for Offshore Wind Farm Sites" prepared by RHDHV-TR.[1]

As I know the three sites very well, I provided extensive support in the selection process. The most important driving factor was the moderate/good wind speeds which would be the main driver for the power production and thus, return on Investment CAPEX during the operation period.

For this, the feasibility study was prepared by Ramboll with the help of Mesoscale wind resource modelling, which they created. Then the Saros site as an "Offshore Wind Farm Site" was selected, see Figure 2.

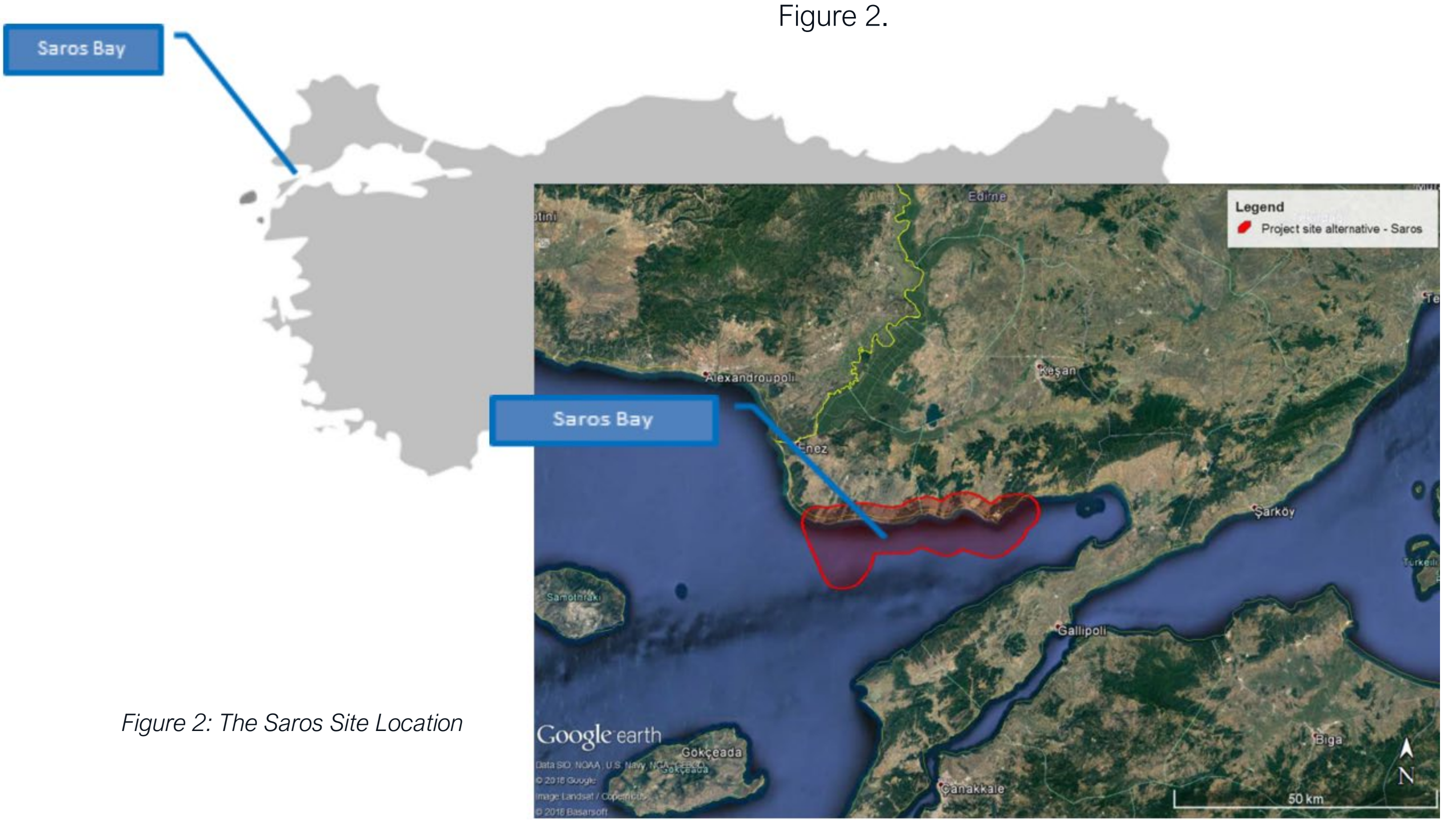


Figure 2: The Saros Site Location

[1] Royal Haskoning-DHV's "Environmental and Social Constraints Mapping for Offshore Wind Farm Sites", September 2018

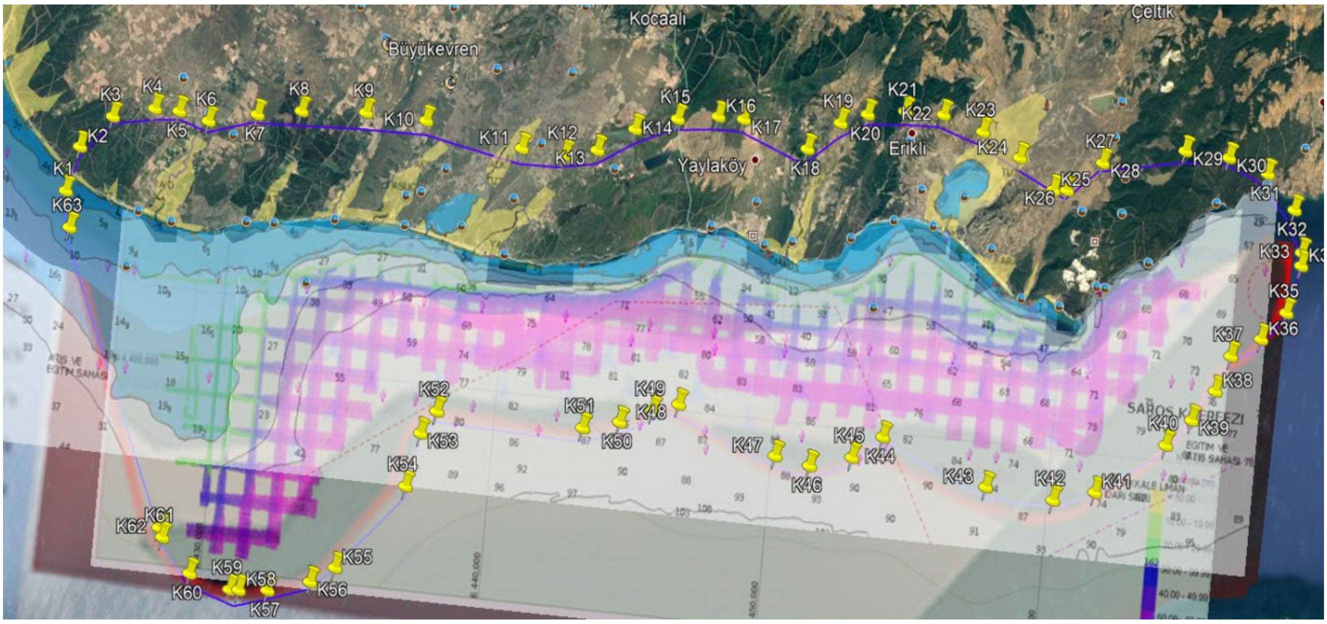


Figure 3: The Saros Site Location with boundary IPs (K##)

4. WIND TURBINE GENERATOR FOUNDATION SELECTION

Four alternative structure types (Monopile, Jacket, Suction Bucket and Gravity Based Structure) and two options (a Floating type and the Karehamn project foundation type) were compared in the detailed checklist, with my contribution.

Since the soil data was not known, we made our decision based on the general assumptions of Dr. Mustafa Serdar Nalçakan, Ramboll, and the Tenderer (in line with the papers named "Geological evolution of the Gulf of Saros, NE Aegean Sea"[2] "Plio-Quaternary history of the Turkish coastal zone of the Enez-Evros Delta: NE Aegean Sea"[3], and "Stratigraphy, sedimentology, and tectonics of the Gelibolu Peninsula and SW Thrace Basin"[4]), my own site and seashore observations and experience and finally, seismicity based on "Design Basis Ground Motions for the Preliminary Earthquake Resistant Design of the Wind Turbine Farms in Thrace, Türkiye[5]" which are defined below with contingency plan as follows:

- The soil is assumed to be the bedrock with sediments on top. Most likely sand with friction. No soil profile is available for this study.
- For the next phase of the project, more data on seabed/soil is required to reach a more detailed design level. For gravity structures, the soil conditions (strength, topography, etc.) are the main design parameter that has a significant impact on the total cost. This is valid for the substructure itself as well as seabed preparation and scour protection measures.

The foundation principles were chosen as concrete Gravity Based Foundation (GBF) due to the Geotechnical Conditions at the installation site. The most important reason is soil conditions, which is a hard stratum.

This would only allow the driving of monopiles (which is the most economical solution in these depths) if in combination with boring/shaft machines which would end up making it a more costly option.

[2] M. N. Cagatay, N., B. Alpar, R.Saatcilar, R. Akkok, M. Sakinc, H. Yuce, C. Yaltirak, and I. Kuscu: "Geological evolution of the Gulf of Saros, NE Aegean Sea", dated 14 February 1997. Revised: 12 November 1997

[3] B. ALPAR: "Plio-Quaternary history of the Turkish coastal zone of the Enez-Evros Delta: NE Aegean Sea", 2001

[4] M. Sumengen, I. Terlemez, K. Senturk, C.Karakose, EN. Erkan, E. Unay, M. Gurbuz, Z. Atalay: "Stratigraphy, sedimentology and tectonics of the Gelibolu Peninsula and SW Thrace Basin", in Turkish, 1987. Unpublished technical report

[5] Prof. Dr. Mustafa Erdik: "Design Basis Ground Motions for the Preliminary Earthquake Resistant Design of The Wind Turbine Farms in Thrace, Türkiye", August 2018

For Kıyıkoy Site, we considered Dolphin and Pile Combinations, however, the best wind-feasible area Saros Bay had already been chosen, and the dolphin piles would have to be driven by the reverse circulation method which is more expensive than the Floating Gravity Based Structure (GBS) Method.

Ramboll proposed two different types of fixed bottom GBF:

1) Fixed Bottom, Floating type GBS Concept;
2) Fixed Bottom, Karehamn project foundation type GBF.

The Tenderer's Marine Construction Company decided to use the Karehamn project foundation type GBF solution as they already have experience with this type of construction.

Respecting their patent and intellectual rights, I will just explain my solution which is the Floating type GBS Solution that I designed in line with the combination of Ramboll's proposal.

For this, I used my experience with the Osmangazi Suspension Bridge's Tower Foundations as it is suitable for a plinth for GE's 12MW Haliade-X WTG turbines.

I must mention that we studied both solutions in the end and we found the cost of both methods were similar to each other, however, we did not have many detailed discussions on this issue.

5. TÜRKİYE OFFSHORE WIND FOUNDATION STRATEGY

5.1 Fixed Bottom, Gravity Base Structure Solution (Floating)

I converted Ramboll's proposal of a Floating GBS solution to my design used in the Osmangazi Suspension Bridge Tower Foundations (OSBTF) experience. It will be a Crane-free GBS operation which was also advised in the Presentation "New Foundations for Deeper & Larger Offshore Wind Farms".[6]

As advised, this solution "*is suitable for 6 and 8 MW and depths greater than 30m*", whereas my experience was with -40m, and later we prepared the tender for the Dardanelles Suspension Bridge (1915Çanakkale Bridge) with -55m depth.

For the equipment requirements for the submerging operation (not sinking) such as clusters of cells*, pumps, valves, ballast water pipelines, and ventilation pipelines, I converted/downscaled the OSBTF Caissons to my design which is cited below.

On the other hand, in order to reduce the number of Anchor Handling Tugs (AHTs), I decided to use a Triangle Shape but with chamfered corners to make it a Hexagonal Shape.

* Clusters are cells (2,3,4 or 6) which are connected by pipes through caisson walls from bottom (for water ingress) and top for air transfer, therefore they are acting together as Submarine Ballast Tanks.

Figure 4: Fixed Bottom, Gravity Base Structure Solutions (Floating)

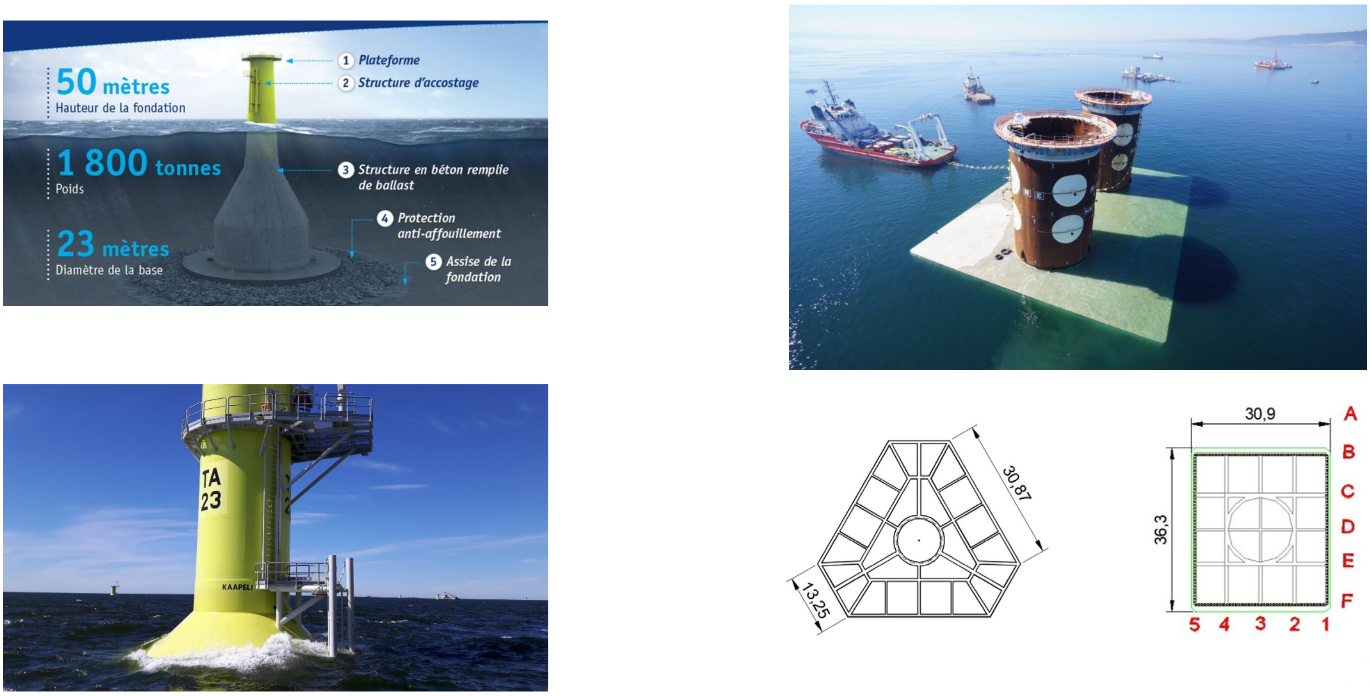


Figure 5: Fixed Bottom, Gravity Base Structure Solutions (Floating)

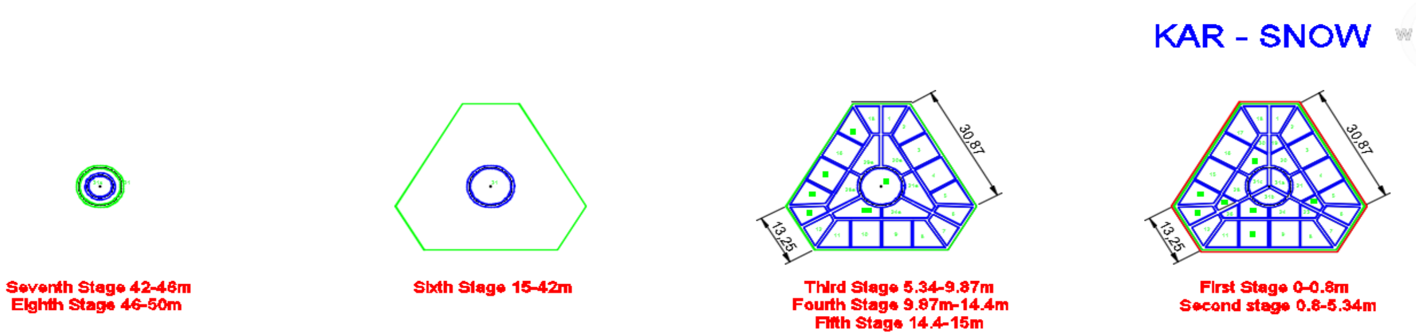


Figure 6: KAR-SNOW Fixed Bottom, Gravity Base Structure Solution (Floating) by Erdal Ergül

Elevations and Construction Phases of the KAR-SNOW Fixed Bottom GBS from 0,00 level to 50.00 level in plan and Cells locations of the Caisson Structure at each phase.

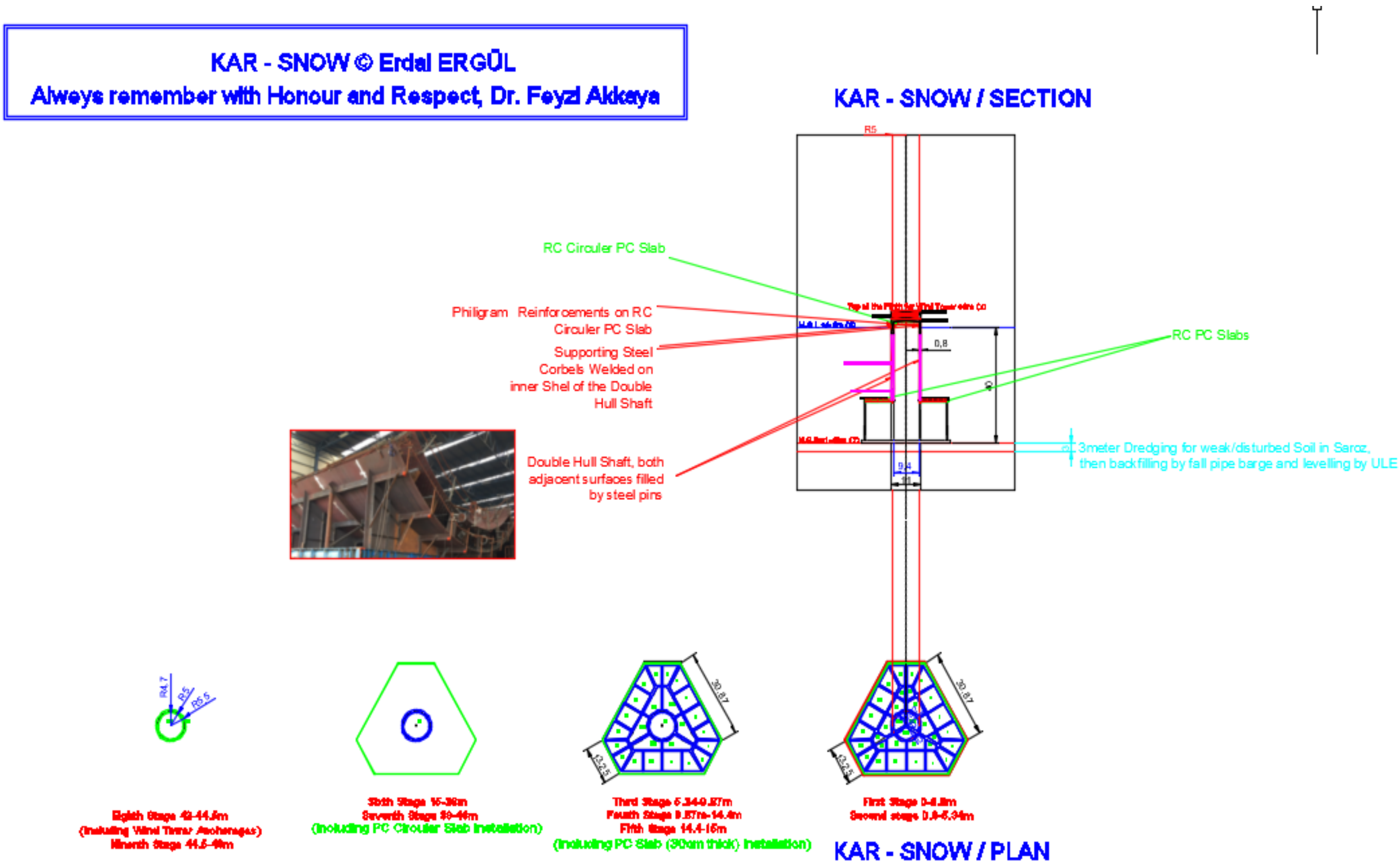


Figure 7: KAR-SNOW Fixed Bottom, Gravity Base Structure Solution (Floating) by Erdal Ergül.

Elevations and Construction Phases of the KAR-SNOW Fixed Bottom GBS from 0,00 level to 50.00 level in plan and section. Also shows Cells locations of the Caisson Structure at each phase and a picture of the combined Shaft Structure which will be the main part of the Sixth Stage (Level 15.00 to 42.00)

5.2 Submerging of Fixed Bottom, Gravity Base Structures (GBS) Floating

Figure 8: Submerging of Gravity Base Structure GBS Solution (Floating). Courtesy of STFA Construction Co. Osmangazi Suspension Bridge South Tower Foundation[8,9]

5.3 Floating Wind, Gravity Base Solution (Floating)

Figure 9: Floating Wind Farm. Esteyco – Elisa Project

[8] Paper of H. Tasan, E. Ergul, and B. Nacar. [9] Articles of E. Ergul and F. Zeybek in "e-mosty"
For more details please see full list of references on page 70

In my anchor handling experience gained in 1989-1990*, Zonguldak with a hollow-shaped Jack-up Barge "Hergeleci", Figures 10 and 11, creates difficulties when you need to tow it but while standing in its own place it is more durable compared to the Flat Top Barges.

Figure 10: Towage of Hollow-Shaped Hergeleci Jack-up Barge. Courtesy STFA Construction Co.

* 1350 MW Ambarli Natural Gas Combined Cycle Power Plant; Cooling Water Intake and Outfall Structures Const., Istanbul, and 1991-1994 Erdemir Capacity Improvement and Modernization Project (New Harbour, Diversion Channel of South Collector, New Gülüç Bridge)

Figure 11:

Left: Year 1989 Hergeleci at Ambarli Natural Gas Combined Cycle Power Plant, Istanbul/Türkiye

Right: Year 1983 Hergeleci at Erdemir New Harbour Project, Kdz.Ereglisi, Zonguldak/Türkiye. Courtesy of STFA Construction Co.

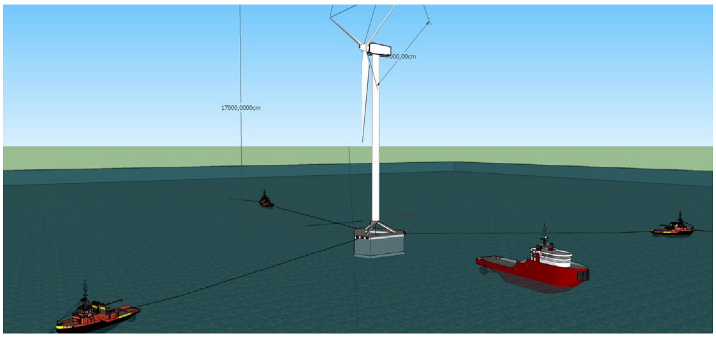
5.3.1 Installation of Floating Wind, Gravity Base Solution (Floating)

Finally, I designed Karbuke-I, see Figure 12, by emptying the inner part of KAR-SNOW and adding three mooring chains on each corner with roller chain stoppers (invented by myself) to make mooring/anchor handling operations easy, see Video 1.

We used the roller chain stoppers at the towing and installation operations of the Osmangazi Suspension Bridge Tower Foundations, and I am happy I could make one of the biggest contributions to solving the stopper part of it.

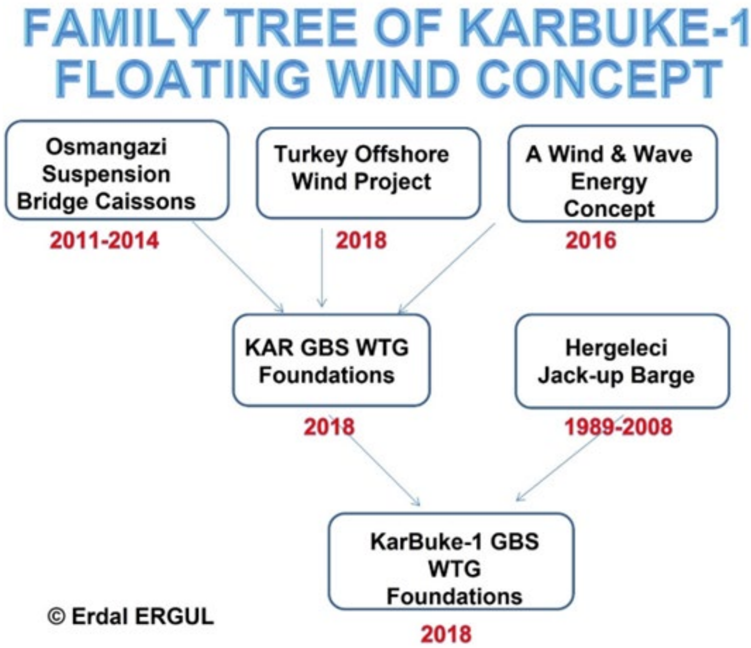
As a result of this emptying of the inner part of the Caisson Structure, in order to give more stability to the Floating Caisson Structure in the Open Seas, the floating capacity of the Caisson Structure was reduced.

Therefore, in line with the reduced capacity of the Floating GBS Caisson Structure, I also reduced the planned WTGs (Wind Turbine Generators) capacity from 12MW to 6MW, i. e. 12 MW for fixed bottom foundation (Kar-Snow), floating at the installation time. And 6 MW for floating foundation (KarBuke - a part of Snow).



Video 1: Karbuke-1 at installation stage. Credit: Merve Türkkan

Click on the image to play the video



→ *Figure 12: Family Tree of Karbuke-1 Floating Wind Concept*

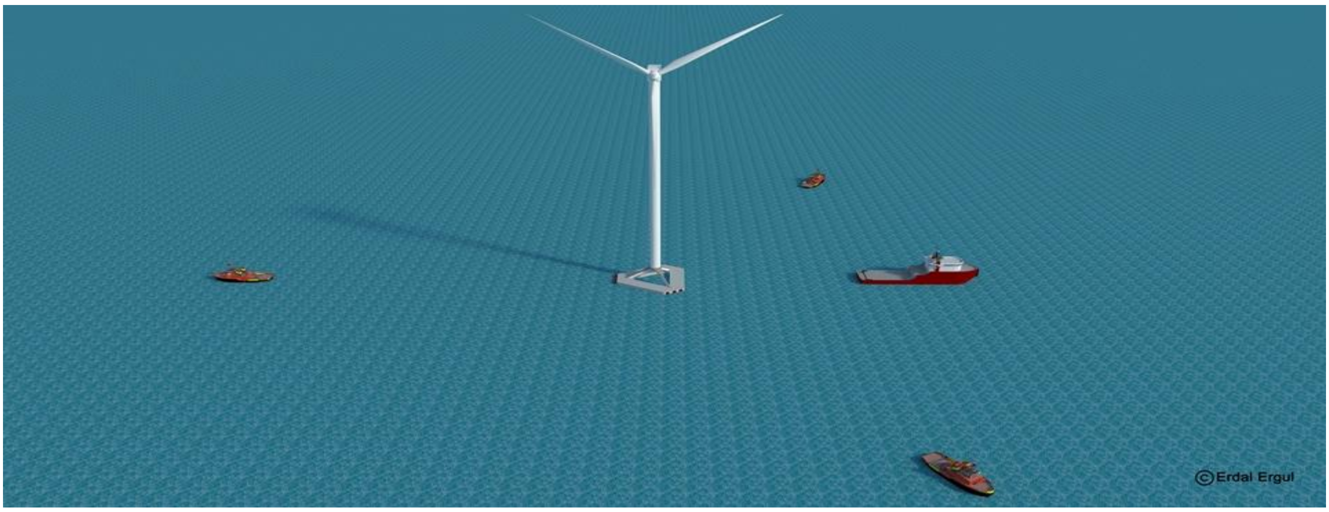


Figure 13: Karbuke-1 at installation stage; three AHTs and one assisting vessel/Diving Supply Vessel (DSV). Hook-up AHT is not shown, while the same rendering is also representative of the Fixed Bottom, Floating type GBS Concept Submerging Stage

6. TURBINE SELECTION

This solution is one of the more expensive options for the GBS foundations but in line with the soil conditions we had to choose the GBS solution.

Therefore, one of the main driving issues of the design was automatically solved - the most powerful WTG had to be chosen.

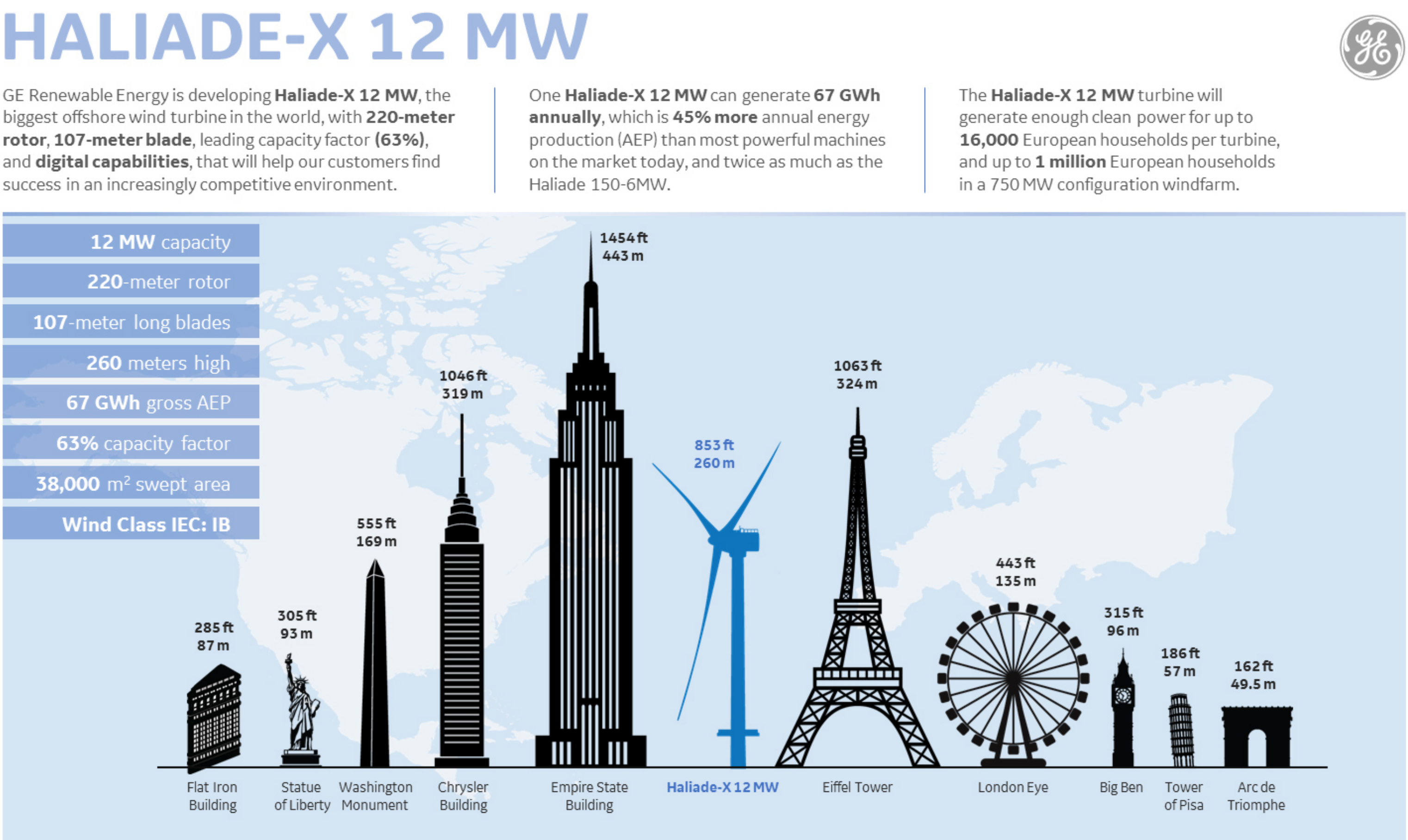
It is GE Haliade-X 12 MW, see Figures 14 and 15, and the Tenderer made necessary actions with GE accordingly.

At the same time, the required number of WTG locations was defined: for 840MW, 70 units each with 12MW are needed.

Therefore, by choosing the GBS caisson foundation made of reinforced concrete, we also completed the most important part of the project.

The main driving factors of the project were in line with the local content ratio of the Tender Specifications which must be 70% minimum, while 12MW WTGs (other than blades) and Electrical Cables (including cable laying vessels) have to be foreign-made, where reinforced concrete caisson will be made in Türkiye and with Turkish sourced material.

Figure 14: Illustration of the height of Haliade-X 12 MW compared to various structures



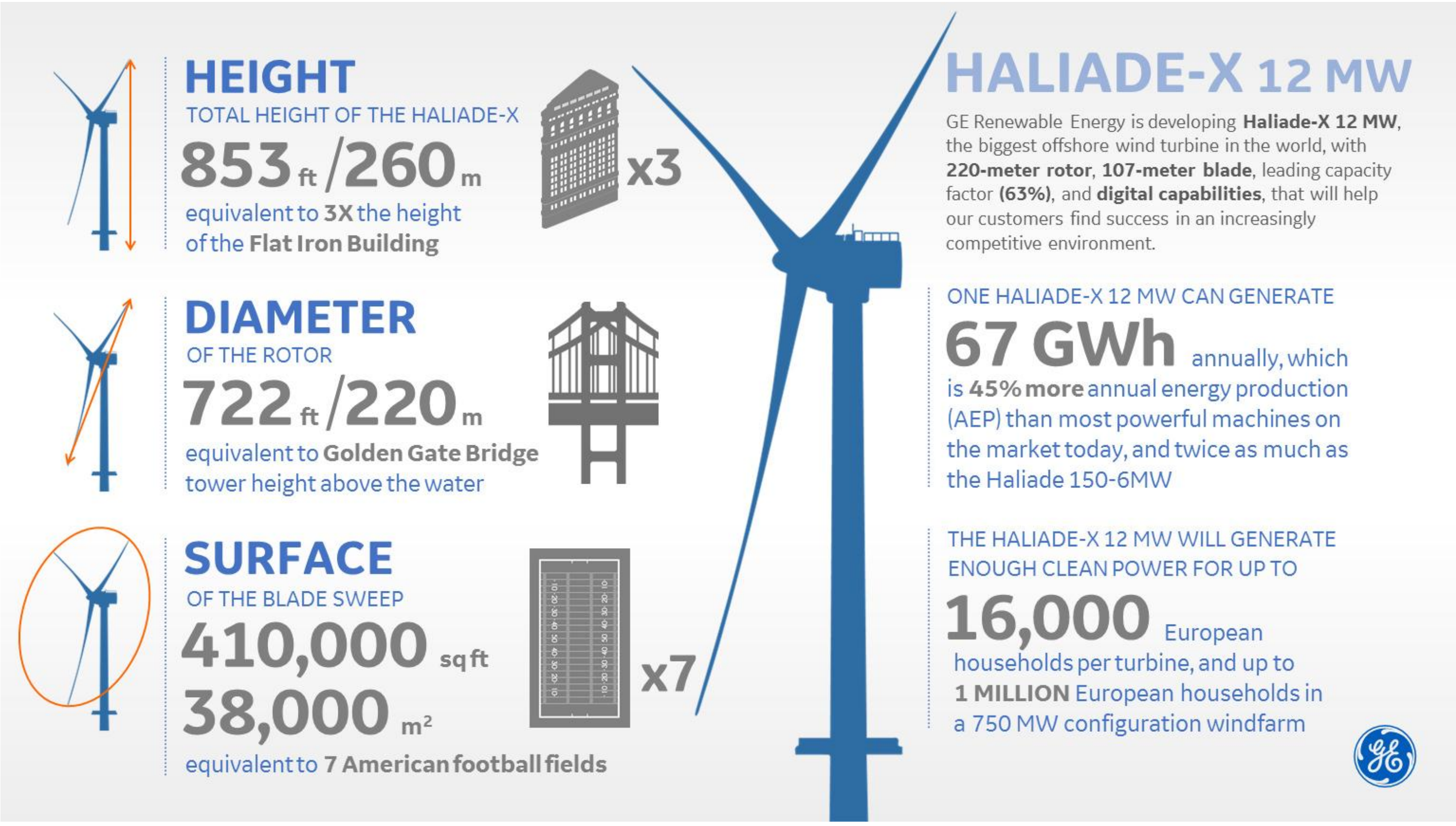


Figure 15: Key features of the Haliade-X 12 MW wind turbine

7. TYPICAL STAGES OF OFFSHORE WIND FARMS PROJECT EXECUTION

7.1. Seabed Preparation

7.2. Foundation Production and Installation

7.3. Complementary Works after Caisson Installation

7.4. Scour Protection

7.5. Superstructure Installation

7.6. Installation Contractors

7.7. Vessels (Lift, Transport, Cable Laying, Support Etc.)

7.8. Service/Construction Vessel Types

7.9. Weather Windows

7.1. Seabed Preparation for Türkiye Offshore Wind Project

Seabed preparation is a combination of two stages.

7.1.1 Dredging/Sweeping of Seabed

Since the hard strata is the expected soil condition of the Seabed at the Saros Location just dredging/sweeping of the Seabed is envisaged.

Using Back-hoe Deeper Dredgers up to -20m or clamshell barges beyond that level, I have proven experience down to -63m at Bosporus (Years 2001-2004; Küçüksu Water Treatment and Sea Outfall Project, STFA Construction Group), although other solutions may be proposed.

The dredging permit and disposal of dredging material permit have to be taken from the related authorities, and the regulations and requirements of them have to be strictly followed.

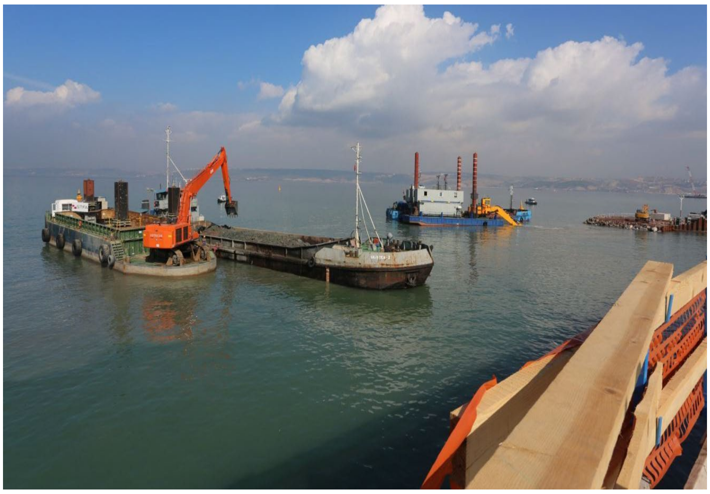


Figure 16: Dredging using Back-Hoe Deeper Dredger, Osmangazi Suspension Bridge Approach Channel Dredging. Courtesy of STFA Construction Co.

Dredging/sweeping of the Seabed has to be planned taking into account the chosen dredging equipment, mentioned above, and involves starting offshore and working towards the land side.

Dredging work is planned to be executed mainly using Back-Hoe Deeper Dredger and Split dump barges. The trench widths have to be in line with the requirements of the Tow & Installation Sub-Subcontractor.

Dredging materials have to be classified in accordance with the specifications and Environmental Laws and Regulations. Inspections are going to be made at the site and at the laboratory by the Ministry of Environment and Urbanization.

If there is no contaminated soil encountered at the dredging location, the dredged material will be loaded to split dump barges and dumped into the "Allocated Trench" in the Aegean Sea.

We did not expect any contamination in Saroz Area as there is no significant industry facility present in the location at the tender time.

7.1.2 Gravel Bedding with Fall Pipe and ULE Equipment for the WTG Foundations

The footings (caissons and steel shafts) of the WTG foundations are going to be designed to locate on a gravel bed at a maximum of 40m below sea level.

Although other solutions may be proposed in the same manner as at the Osmangazi Bridge, the gravel bedding is planned to be placed using a fall pipe continuously fed by Hopper & Conveyor combination mounted on a floating crane barge which will be allocated only for this job.

The main reason for this is that we do not want to use divers at -40 to -43 m depths as it means that, with no decompression time, they would have only a 5-minute bottom time when diving to reach the working depth.

It would be possible to increase the bottom time to 20 minutes, but it would mean 90 minutes of decompression in the water.

As a Feed designer of the fall pipe barge and underwater levelling equipment (ULE), I am able to comply with the Client´s (our) specifications such as the weight of ULE and connections of cables and hoses.

The surface of the gravel bedding is planned to be levelled by the specially designed and built hydro-mechanical ULE. This is to be transported and operated from a specially designed and constructed Catamaran Barge to handle the ULE.

Dumping

A fully donated floating crane barge, which can also be used for deep dredging operations, is planned to be used for the dumping of the gravel bedding material, see the visualization in Figure 18. The dimensions of the barge are approximately 73.20 x 21.34x 4.88m.

Figure 17: A Fall-Pipe Barge ´Alparslan-2´ in operation - Bedding Preparations for Osmangazi Suspension Bridge Caissons. Courtesy of STFA Construction Co.

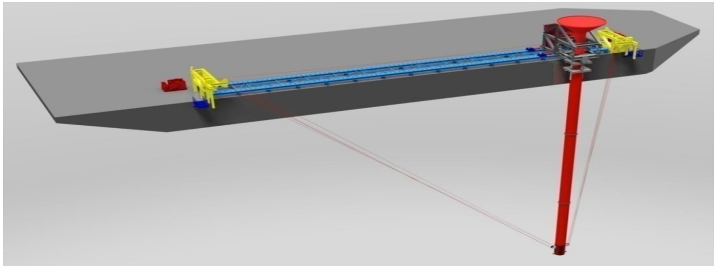


Figure 18: Visualization for Gravel Bedding Operation

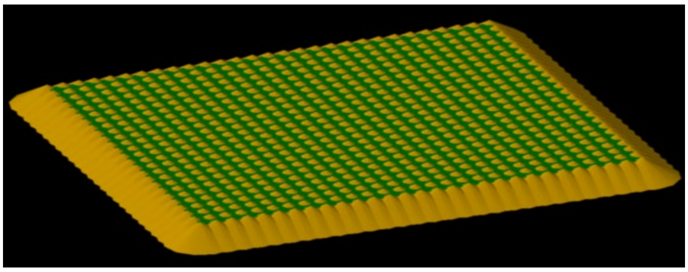


Figure 19: 3D View of the Mounds in the whole Section

A hopper with a 150m³ capacity is planned to feed the conveyor belt having a minimum 1m³/min capacity and is planned to be used for the continuous dumping operation.

A fully donated floating crane barge, having a minimum of one crawler crane and one long boom back-hoe, will feed the hopper continuously.

A clamshell attached to the crawler crane on the barge is planned as the backup for the Back-hoe excavator in case of any breakdown.

A small amount of bedding materials (~500 m^3) is planned to be always kept on the barge.

Figure 19 demonstrates the mounds, shown in yellow, to be applied to the whole section of the WTG foundation on a maximum -40 m Seabed.

← ↑ Figures 20 and 21: Bedding Preparations for Osmangazi Suspension Bridge Caissons - the Land Tests of ULE. Courtesy of STFA Construction Co.

Figure 22: Bedding Preparations for Osmangazi Suspension Bridge Caissons - the Land Tests of ULE. Courtesy of STFA Construction Co.

INTERIM BATHYMETRIC SURVEY

Before starting the levelling operation, an initial Bathymetric Survey has to be carried out by Survey Boat to get accurate data and provide certain levels and coordinates of the peak points to be levelled in the final stages.

This survey is very important to generate an as-built map for grading to compare with the theoretical one obtained by the computer as above and revise the levelling plans before the ULE operation.

Preparation of the Operation Barge for Levelling

Figures 23 and 24 show a Catamaran Barge to be used for carrying and handling the ULE.

Figure 23: Bedding Preparations for Osmangazi Suspension Bridge Caissons - Kaptan Aydemir Catamaran Type, ULE Carrier Barge (ULE in Operational Position). Courtesy of STFA Construction Co

The ULE is planned to be carried by using four lengths of sling wire which are fixed to an Assembly Beam.

It is also planned to be controlled by using a "Programmable Logic Controller" system on the operation barge.

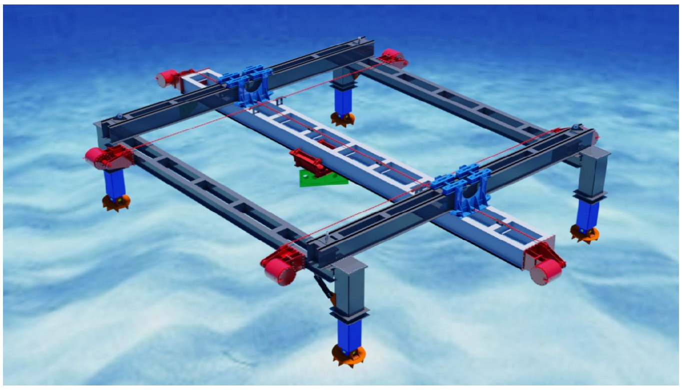


Figure 25: An Underwater 3DView of the ULE, the grader blade (scrapper) painted in green

This automation system also consists of encoders, switches, converters, scales, connection boxes, valves, transmitters, pressure sensors, a camera, a projector, a scanning sonar, an inclinometer, and the necessary electrical equipment.

Figure 24: Bedding Preparations for Osmangazi Suspension Bridge Caissons - ULE at Stand-By Position on Kaptan Aydemir Barge. Courtesy of STFA Construction Co.

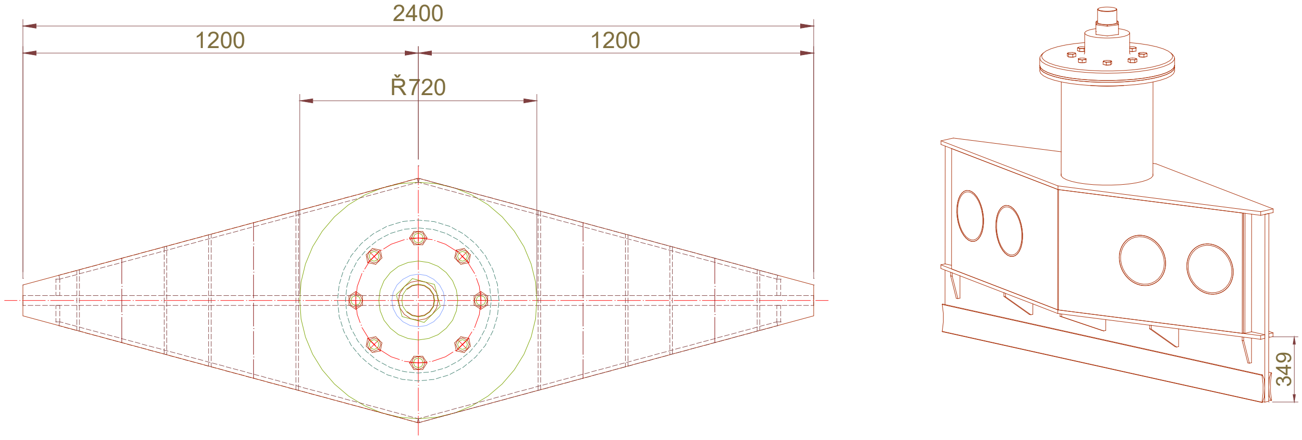


Figure 26: Grader Blade of ULE

After each sweep, the actual form and the elevation of the gravel bed are going to be observed by a scanning sonar and underwater camera mounted on the ULE.

Taking data with sonar provides much information about elevations, especially before each shifting/re-positioning of the ULE.

The ULE is to be controlled in an operation room on a screen panel for displaying all of the manoeuvres, motions, coordinates, and positions of the ULE, see Figure 27.

Figure 27: Bedding Preparations (The Land Tests of ULE) for Osmangazi Suspension Bridge Caissons - Operation Room. Courtesy of STFA Construction Co.

__Levelling Steps__

Levelling operations by ULE are planned to be completed in three steps:

- First layer sweeping, 38 cm, with a 45° angle of the blade.
- Second layer sweeping, 25 cm, with a 45° angle of the blade.
- Third layer cleaning, with a 0° angle of the blade.

__Levelling Plans__

Levelling plans, i. e. “Working zones” and the “Working direction” are planned to be selected in line with the ruling current direction and speed for Saros Fixed Bottom GBS Wind Farm Area WTG Foundations and have to be prepared separately.

The extensive material must be swept to the edges and the middle of the area, and the operation has to be conducted accordingly.

In case divers are needed, they will be equipped with headphones and helmets.

This also means an operational Decompression Chamber and related staff have to be present at all operational times at the site.

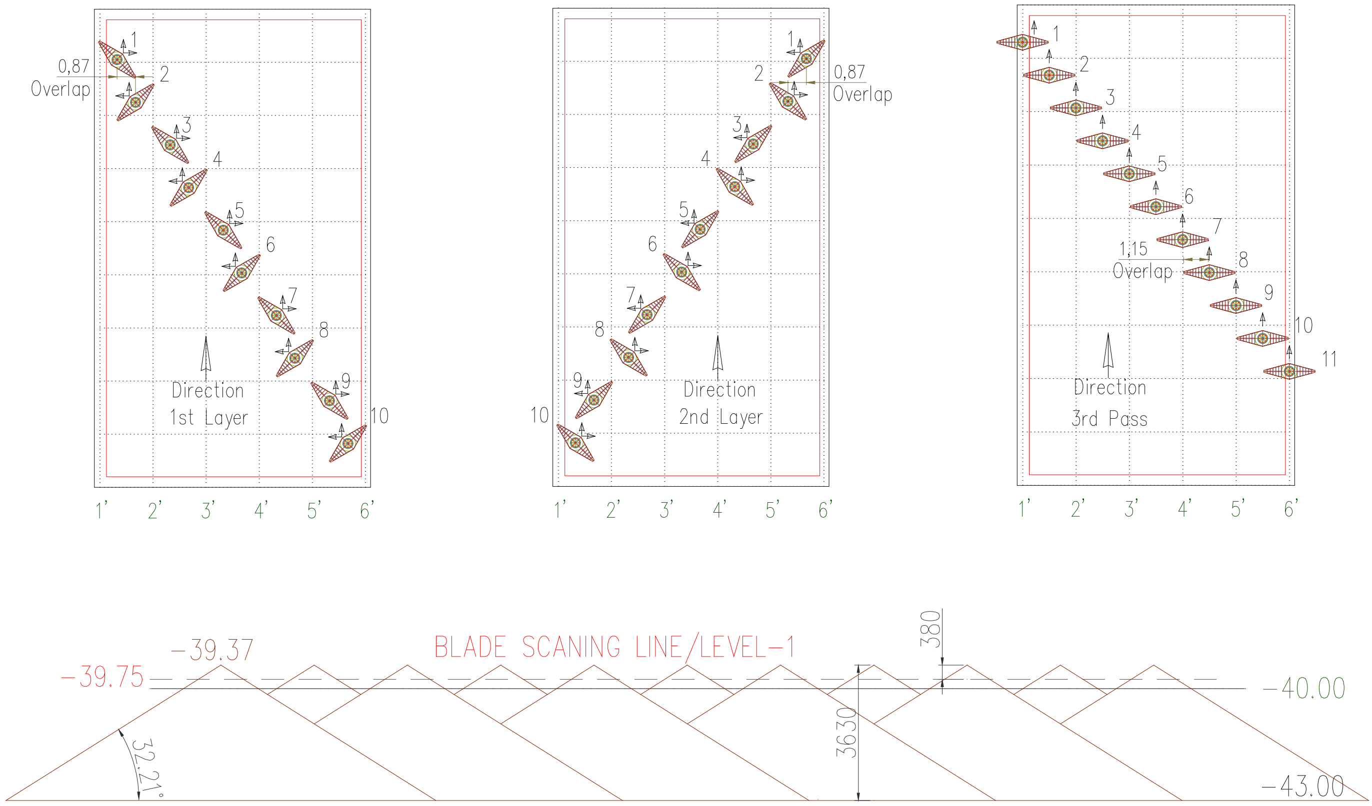


Figure 28: Levelling Layers

7.2 Foundation Production, Floating and Installation

Using my experience and my former company's, STFA Construction Group, experience gained by witnessing them or whilst searching the STFA Archives in order to prepare tender documents, I can summarize some of the different uses of caissons that can be used as follows:

Some Caisson Applications in Marine Engineering

- Berthing Facilities such as Quay Walls;
- Protection Structures such as Breakwaters;
- Supporting Structural Elements such as Bridge Piers;
- WTG Foundations for Offshore Wind Farms, either Floating Types or Fixed Bottom.

Main Features of Caisson-Type Structures

- Gravity Type Structures;
- Require higher bearing capacities of soil as foundation;
- Special Manufacturing, Handling and Placement Methods are required;
- Shapes vary due to the site conditions and available construction equipment (rectangular, circular, cloverleaf, etc.).

Technical and Economic Advantages of Caissons in Marine Engineering

- Fast production rate due to being able to prefabricate off-site;
- Suitable for a wide range of water depths;
- Reduces underwater work to a minimum;
- Higher positioning tolerances compared to blockwork or precast wall units;
- Flexibility regarding shape and incorporation of structural elements to improve hydraulic performance;
- Less maintenance and repair requirements;
- Better quality control is possible and removes the risk associated with deep piling operations.

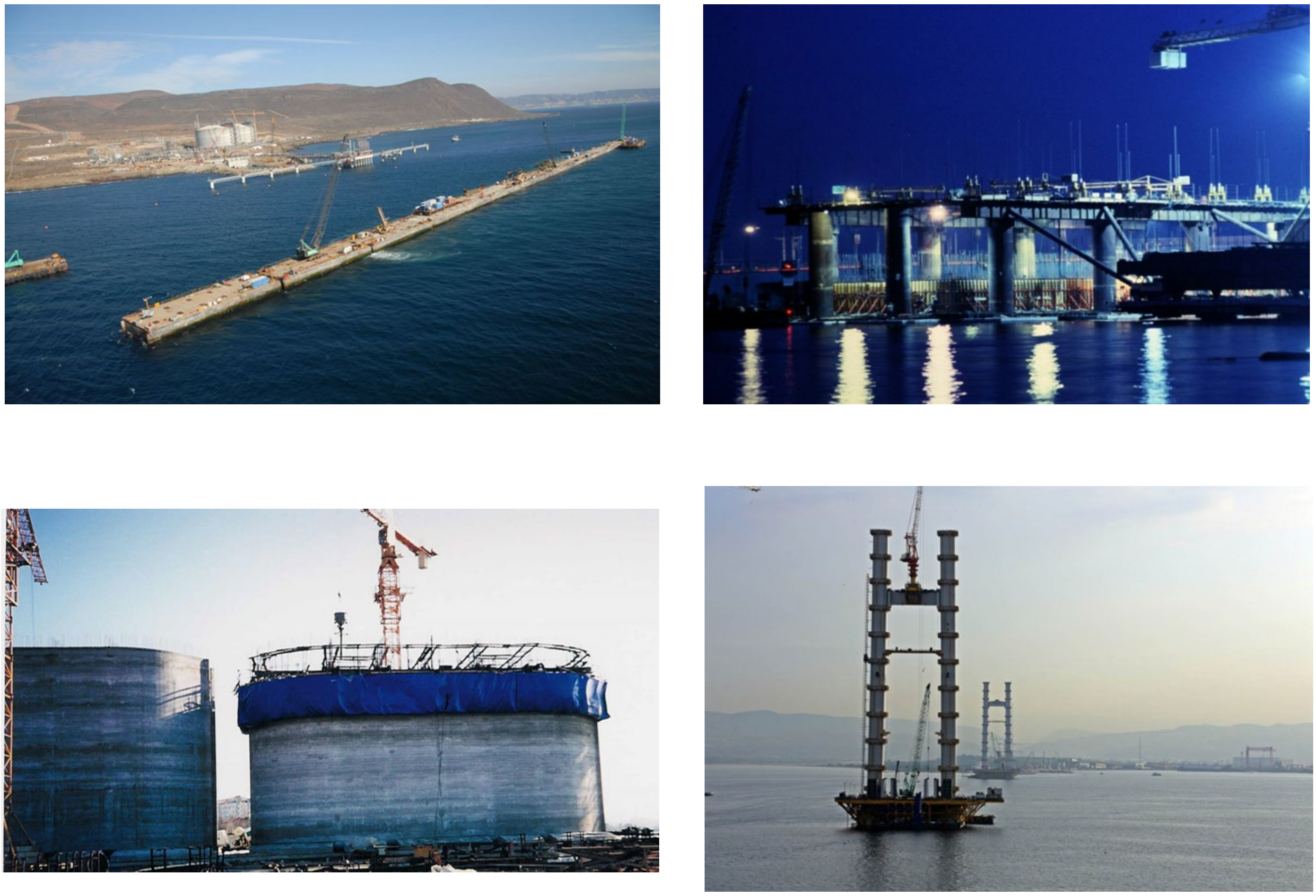


Figure 29: Caissons in Marine Engineering

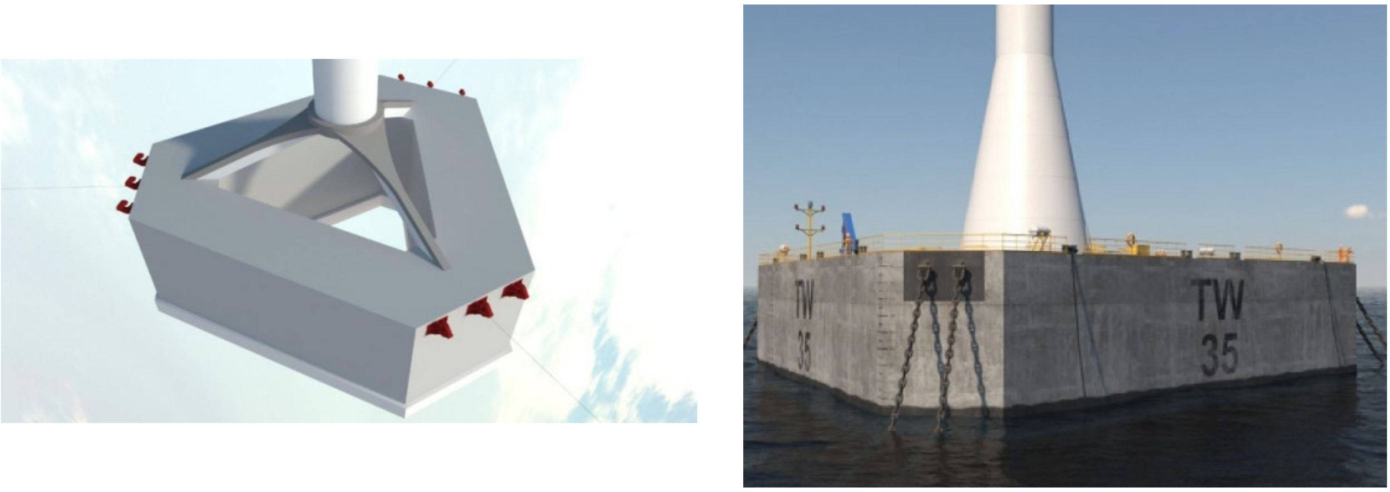


Figure 30: Floating Type WTG Foundations for Offshore Wind Farms

Left: Karbuke-1. Courtesy of Erdal Ergül (August 2018)

Right: ARCHIME3 floating platform project (Triwind floater) for the PLOCAN facilities (Gran Canaria), Beridi (November 2021)

CASE STUDIES

In order to explain Caisson Production, Lowering and Installation methods, I present here five case studies.

I wrote case Studies 1 and 3 based on Mr. Serkan Misirlioglu's Presentation "Caisson Applications in Marine Engineering"[10].

CASE STUDY 1

Galata Bridge at Golden Horn

ISTANBUL – TÜRKIYE

CASE STUDY 2

Marmara Ereğlisi LNG Terminal Project TEKIRDAG – TÜRKIYE

CASE STUDY 3

Belde Port Facilities

IZMIT – TÜRKIYE

CASE STUDY 4

Construction of Substructure Osmangazi Suspension Bridge Project

IZMIT / YALOVA – TÜRKIYE

CASE STUDY 5

New Nador Port Project

NADOR – MOROCCO

[10] H. S. Misirlioğlu: "Caisson Applications in Marine Engineering". Presentation, August 2011

CASE STUDY 1: CAISSON PRODUCTION, LOWERING AND INSTALLATION OF THE GALATA BRIDGE PIER FOUNDATIONS AT GOLDEN HORN, ISTANBUL

The Galata Bridge, one of the most prestigious projects in Türkiye, was constructed over the Golden Horn of Istanbul, see Figure 31 to replace the nearby old pontoon bridge built in 1912, see Figure 32.

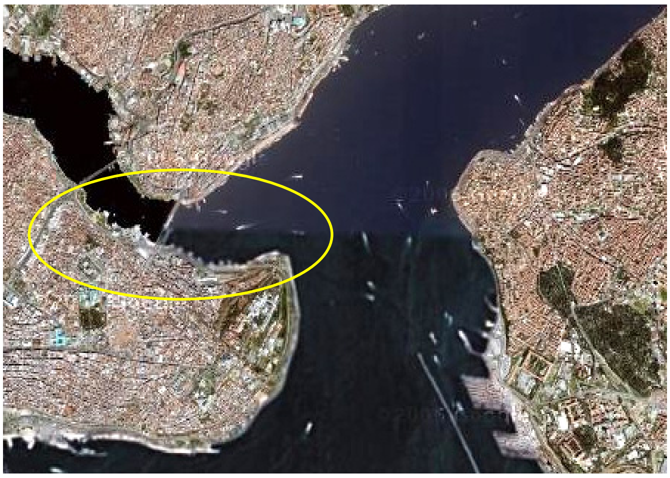


Figure 31: Location of New Galata Bridge at Golden Horn and Bosphorus

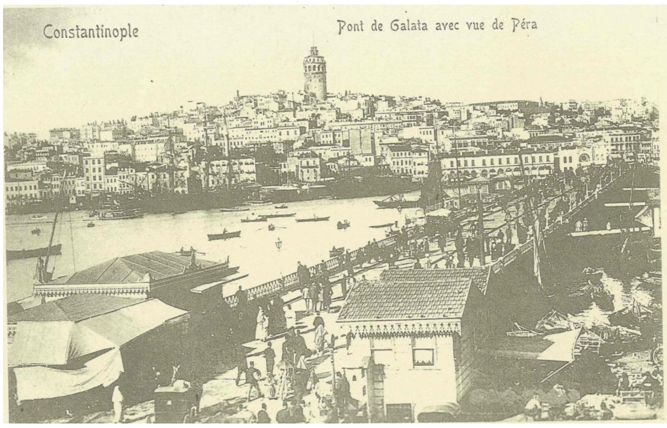


Figure 32: Old Galata Bridge at Golden Horn

The Galata Bridge is a low-profile bridge in harmony with its historical environment. It is, in fact, the combination of two types of bridges. The 80m wide central shipping channel is spanned by a two-flap structural steel Bascule Bridge.

Figure 33: New Galata Bridge at Golden Horn

Figure 34: Galata Bridge in Construction Stage

Figure 35: Night view of the New Galata Bridge

The bridge allows for the passage of ships up to 8,000 DWT.

The Bascule Bridge is supported by box-type piers of caisson construction on both sides of the shipping channel.

The 490m long and 42m wide bridge is used to serve 2 x 3 traffic lanes; 2 x 1 light rail railway and 2 x 1 pedestrian way

There are Shopping Mall & Restaurants on the lower deck which were built on the following main components:

- Abutments
- Pre-stressed concrete double-check approach bridge
- Caissons piers of the bascule bridge
- Bascule bridge

The fixed element of the bridge is supported by 144 steel (St 52.3) tubular closed-ended piles, 2,000mm in diameter and 80m each in length.

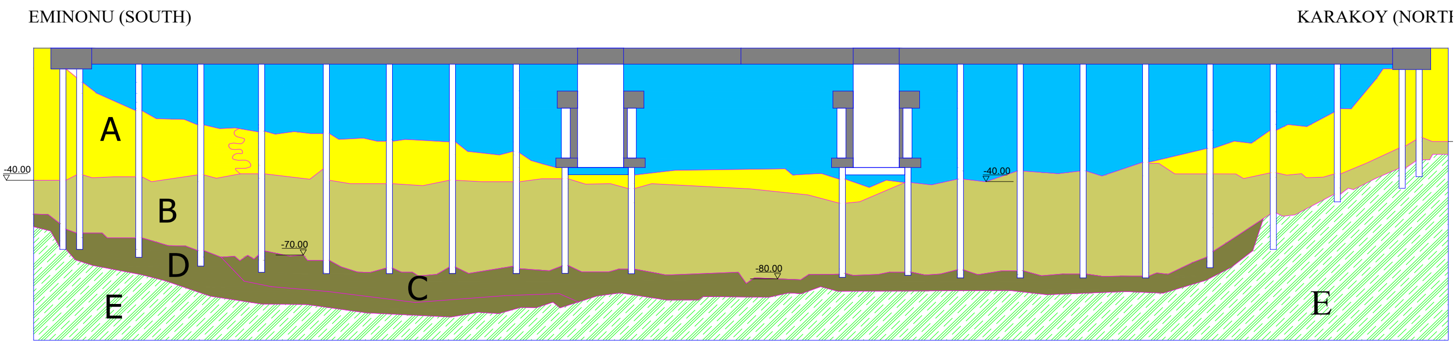
SOIL CONDITIONS

Soil profile of the bridge is shown in Figure 37 below.

Figure 36: New Galata Bridge at Golden Horn

Design Consideration

- Live Loads
- Dynamic Wave Affect
- Hydrostatic Lateral Loads
- Earthquake Loads
- **Ship Impact Criteria: 8,000 DWT ship, with 2,5 m/sec velocity** (Governing Load Effect calculated as per Nordic Road Council Regulations for Ship Impact)



A: MAN MADE FILL
B: ALLUVIUM
C: GRAVEL
D: WEATHERED SHALE
E: SANDSTONE BEDROCK

Figure 37: Soil Profile of the Galata Bridge

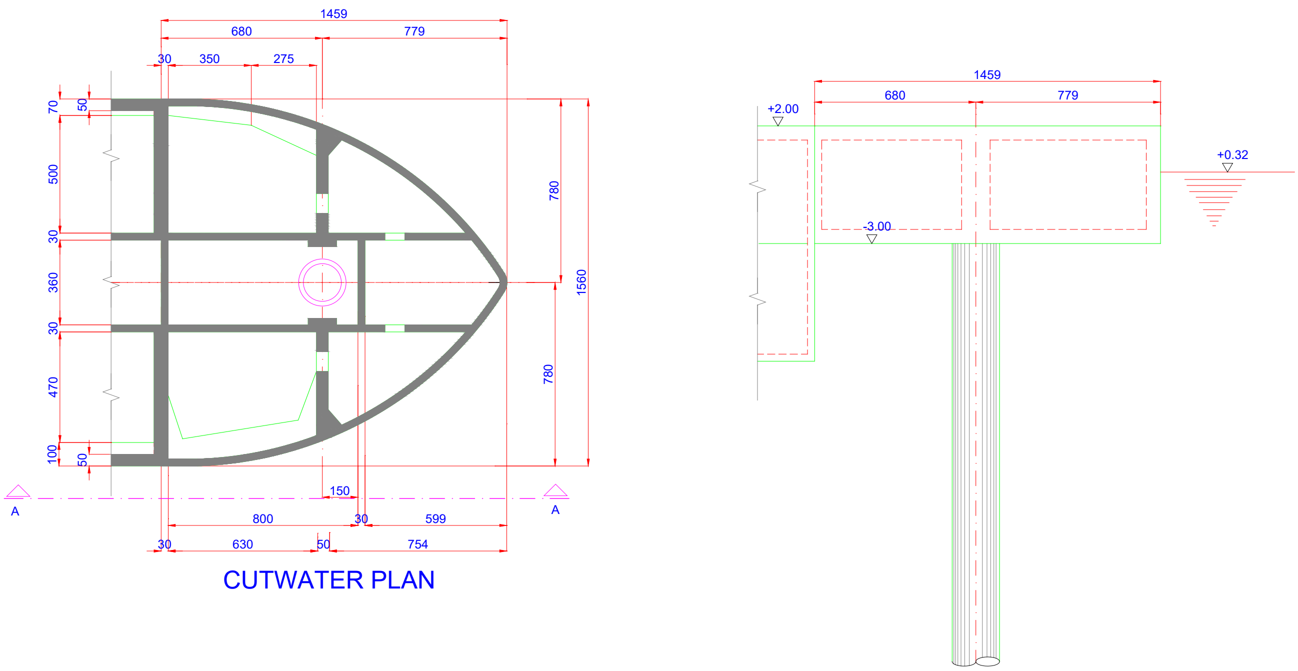


Figure 38: Ship collision protection structure of the Galata Bridge

Cutwaters are functioning as precaution barriers against ship collision.

They are constructed from reinforced concrete like a caisson itself and each part (shaped like ship bow) is supported by a permanent steel cased bored pile (similar to main caisson supportive piles).

Design of Caissons

The caissons are supported with 12 steel tubular piles with a diameter of 2,000 mm and fixed on piles at -13.00 m and -7.50m levels by reinforced collar beams, and fixed at -32.00 m level with elastic support.

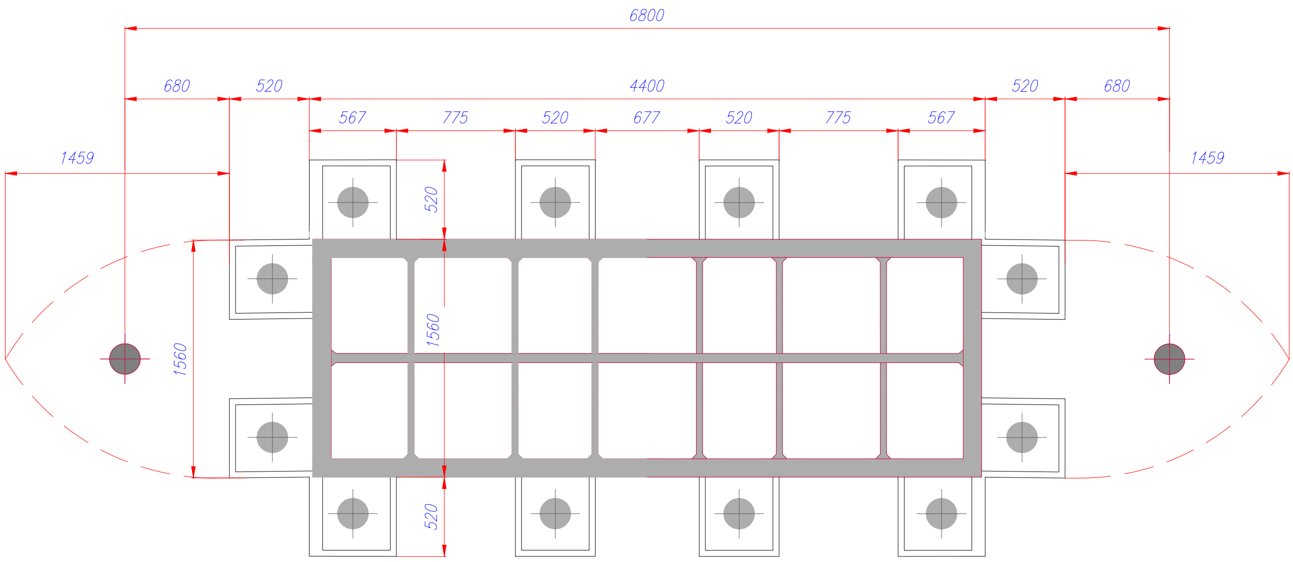


Figure 39: Ship collision protection structure of the New Galata Bridge

<u>Caisson Dimensions</u>

Width : 15.6 m

Length : 44 m

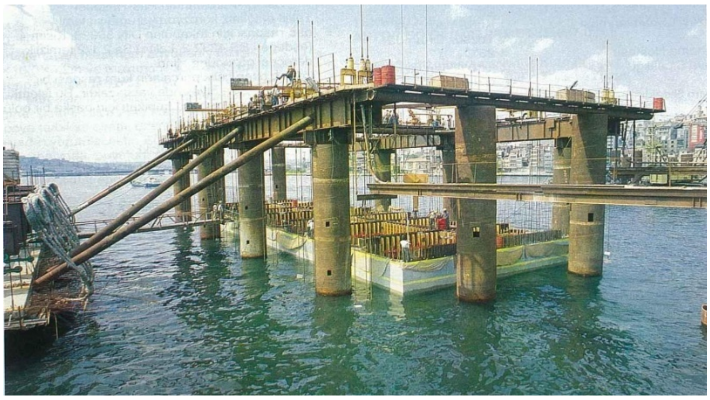
Height : 43 m

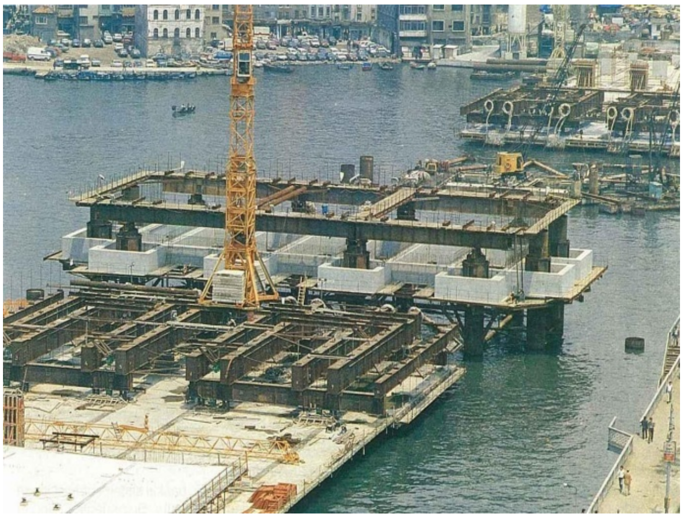
Concrete : 10,000 m³

Steel Bars : 1,300 tons

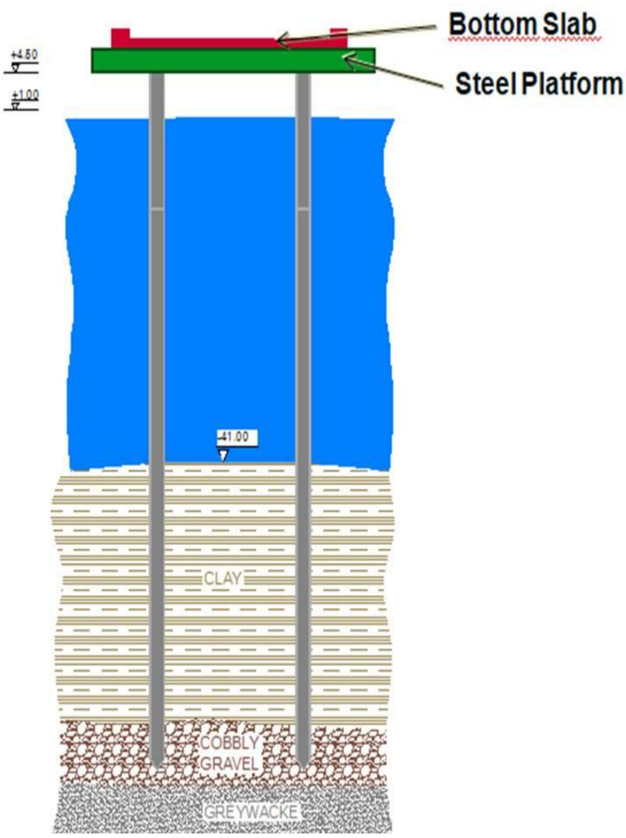
Total Weight : 29,000 tons (including mechanical equipment for the lifting of bascule)

<u>Construction of Caisson</u>





← ↑ *Figure 40: The Caisson construction started on the platform, created by 12 steel tubular pipes*



← ↑ *Figure 41: The lowering of Caisson started by Strand Jacks that used Dywidag Anchorage Rods*

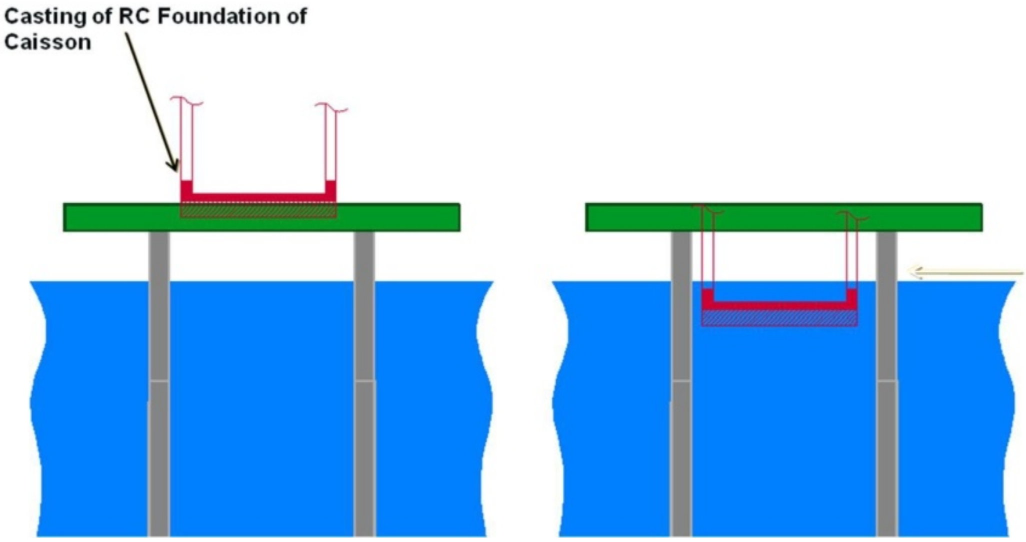


Figure 42: The lowering of Caisson started by using Strand Jacks

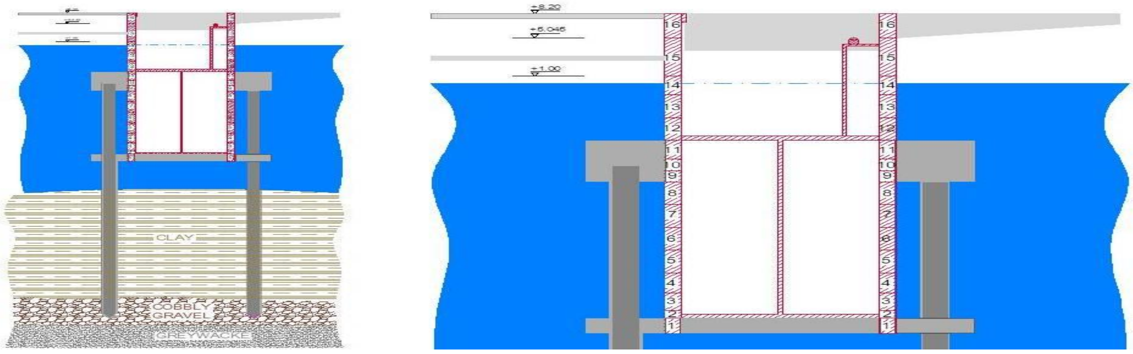


Figure 43: The Caisson Construction completed

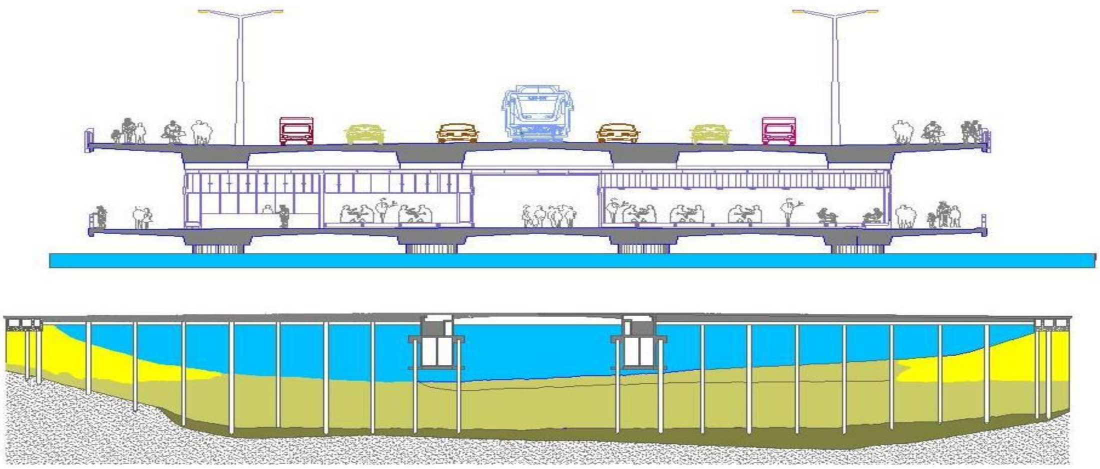


Figure 44: Section and Profile of Completed The New Galata Bridge

Figures 33 – 44: Courtesy of STFA Construction Co.

CASE STUDY 2: CAISSON PRODUCTION, LOWERING AND INSTALLATION OF THE MARMARA EREĞLISI LNG TERMINAL PROJECT AT TEKIRDAG

Figure 45: Location of the Terminal

Now let us view another Case Study. Although its execution looks very simple if you compare it with other case studies, it needed a huge submersible or semi-submersible barge, or a floating dock for quite a lot of time.

However, other requirements were mostly the same, such as an Equipping Jetty, Wharf or Pier and supporting marine vessels and equipment in combination with skilled (Marine & Construction) “Rainbow-Collar” workers (employees who combine work or experience on the assembly line with more technical or administrative duties) in order to execute this complex operation.

In this case, most of the cost came from the allocation of a submersible unit with sufficient capacity.

Practically, this method is chosen where the required amount of caissons is lower, and it is not necessary to set up a complex production plant.

As a result, you do not need to invest in establishing temporary yards.

There was only one caisson to be produced. As the company (STFA Construction Group) has its own Ocean Going Submersible Barge (Koca Yusuf-II), and also construction premises were not available at that time as New Galata Bridge Pier Foundations at Golden Horn were ongoing, this method was chosen by the Company Management.

I was the Site Chief of this Project in the beginning stage when we were constructing a rubble mound approach jetty structure, but I was not involved in dredging, gravel bedding, caisson construction, towing, floating, and sinking of it as I was transferred to another project of the company.

Figure 46: A view of The Marmara Ereğlisi LNG Terminal Caisson from the Construction Stage on the Ocean Going Submersible Barge of STFA (Koca Yusuf-II).
Courtesy of STFA Construction Co.(from CEng. Mr. Arif Yeşiltepe's Private Archive)

Figure 47: A view of The Marmara Ereğlisi LNG Terminal Caisson from the Construction Stage on the Ocean Going Submersible Barge of STFA (Koca Yusuf-II).
Courtesy of STFA Construction Co. (from CEng. Mr. Arif Yeşiltepe - standing on the left - Private Archive)

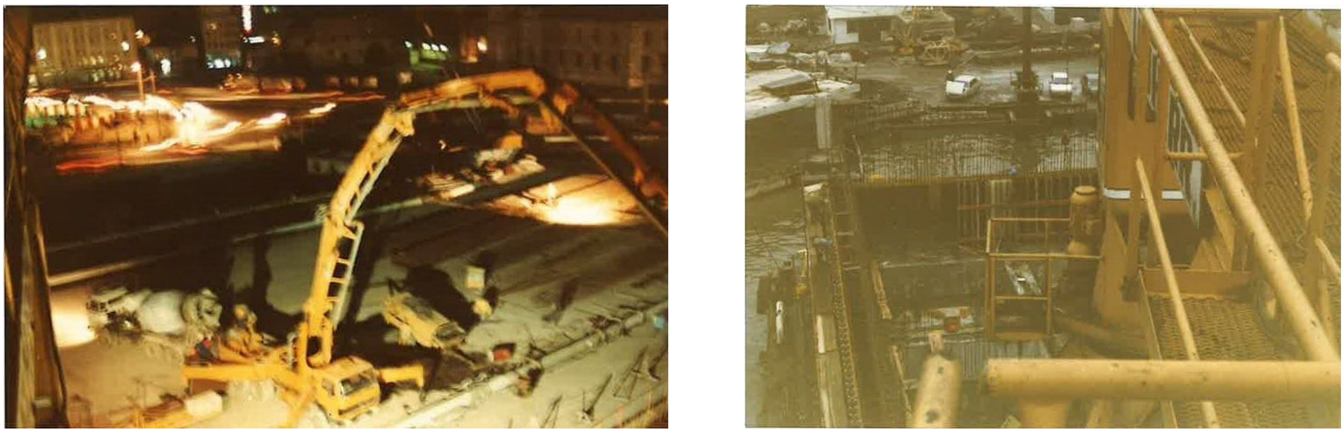


Figure 48: Concrete Casting Stage of M. Ereğlisi LNG Terminal Caisson on the Ocean Going Submersible Barge of STFA (Koca Yusuf-II). Courtesy of STFA Construction Co. (from CEng. Mr. Arif Yeşiltepe's Private Archive)

Figure 49: Towage of M. Ereğlisi LNG Terminal Caisson on the Ocean Going Submersible Barge of STFA (Koca Yusuf-II) by Ocean Going AHT of STFA(Yaşar Doğu-I).
Courtesy of STFA Construction Co. (from CEng. Mr. Arif Yeşiltepe's Private Archive)

Figure 50: The Water Intake Caisson cast on Submersible Barge (STFA's Koca Yusuf II) at Marmara Ereğlisi LNG Terminal, just before the submerging operation.
Courtesy of STFA Construction Co.

Figure 51: Submerging operation is started for STFA's Submersible Barge (Koca Yusuf II), therefore the Water Intake Caisson started to move towards to sea, where at its planned location at Marmara Ereğlisi LNG Terminal. Courtesy of STFA Construction Co. (from CEng. Mr. Erkan Çırak's Private Archive)

Figure 52: Submerging operation is ongoing for STFA's Submersible Barge (Koca Yusuf II), therefore the Water Intake Caisson is moving towards its planned location at Marmara Ereğlisi LNG Terminal.
Courtesy of STFA Construction Co. (from CEng. Mr. Erkan Çırak's Private Archive)

Figure 53: Submerging operation is completed for the Water Intake Caisson, and therefore the caisson is at its planned location at Marmara Ereğlisi LNG Terminal.
Courtesy of STFA Construction Co. (from CEng. Mr. Erkan Çırak's Private Archive)

CASE STUDY 3: CAISSON PRODUCTION, LOWERING AND INSTALLATION OF THE BELDE PORT FACILITIES QUAY WALL CONSTRUCTION PROJECT AT IZMIT

Figure 54: A view of The Belde Port Facilities Quay Wall Construction Project. Courtesy of STFA Construction Co.

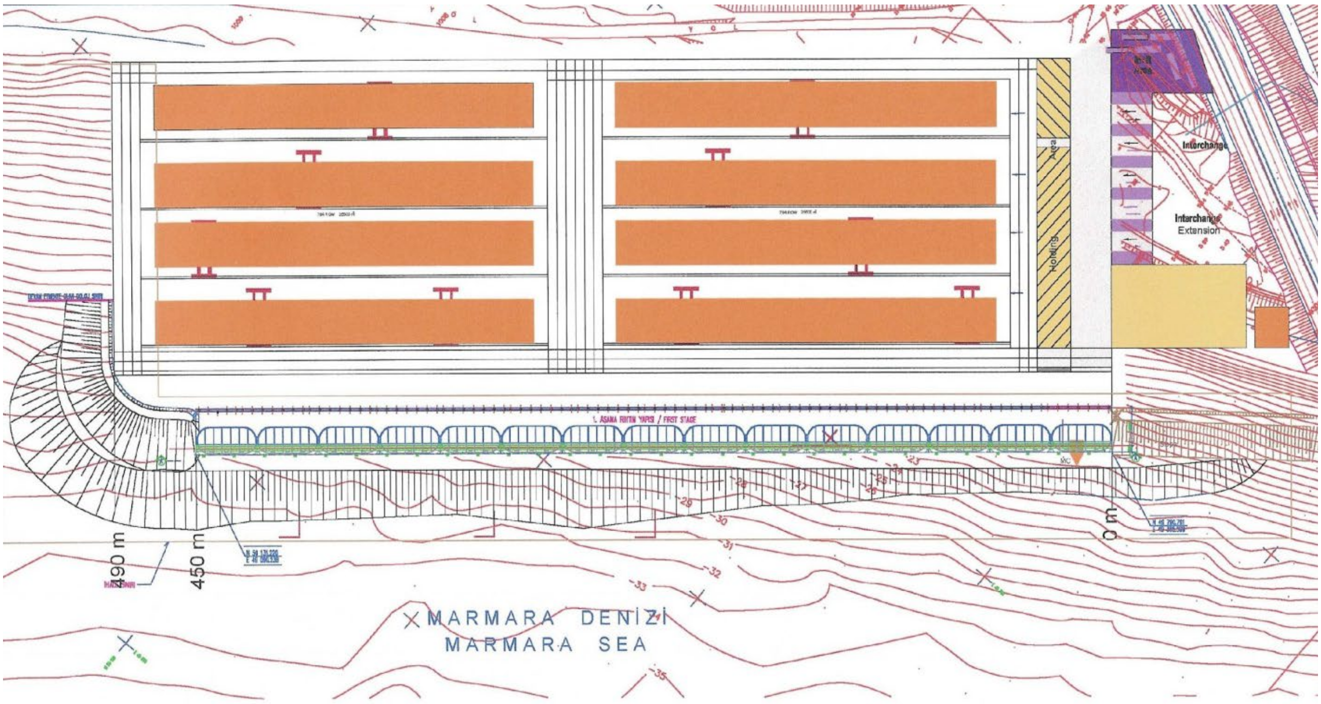


Figure 55: Plan View of the Belde Port Project

Figure 56: Plan drawing of the Belde Port Caisson, on the left the scaled Model of the Caisson and Capping Beam, and on the right the Caisson Construction stage

The Project consisted of:

- Construction of 15 gravity caissons with slip forming method.
- Lifting, floating, and towing of the caisson to the construction site by special vessels.
- Backfilling of the caissons and coastal protection of the seaside fill (earth filling and rubble mound slope, shore protection works).

Dimensions of Caissons

Width: 18 m

Length: 30 m

Height: 17 m

Weight: 2,380 tons

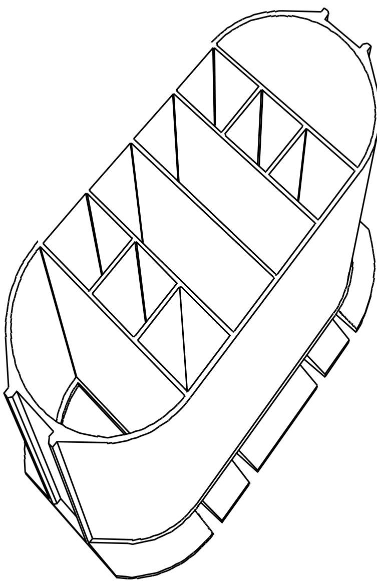


Figure 57: A 3D figure of the scaled Model of the Caisson

Design Considerations

- Hydrostatic Effect
- Surcharge Loads
- Live Loads
- Berth Crane Loads
- Ship Effect
- Dynamic Wave Effect
- Tide Effect
- Earthquake Load

Figure 58: A photograph from the Caisson Construction stage

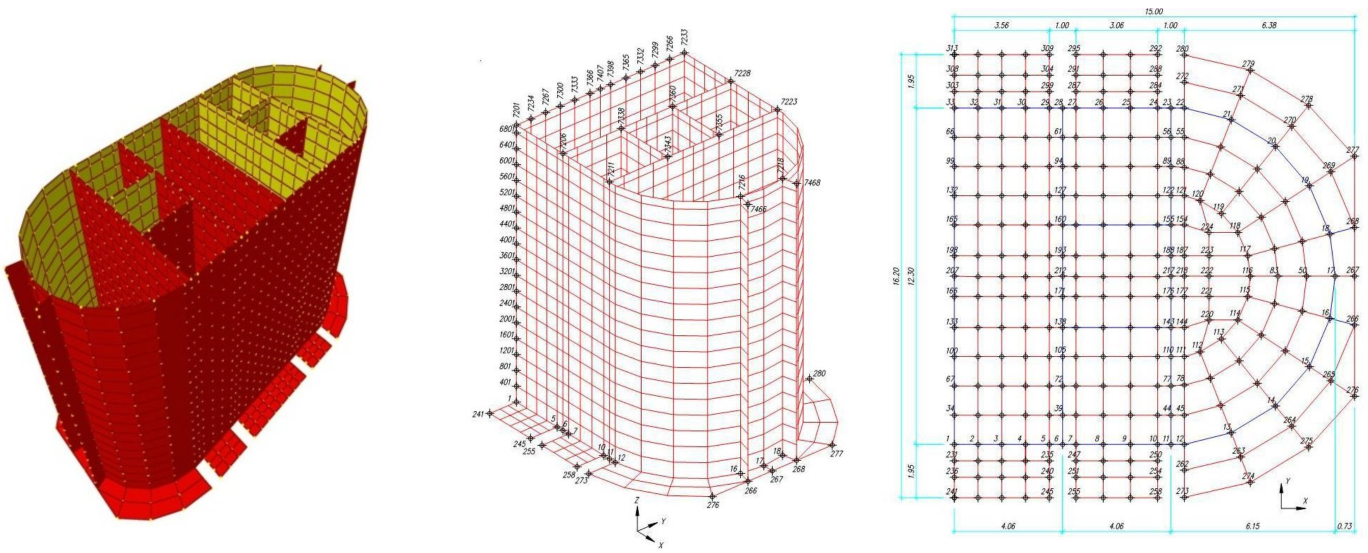


Figure 59: Design details of the Caisson

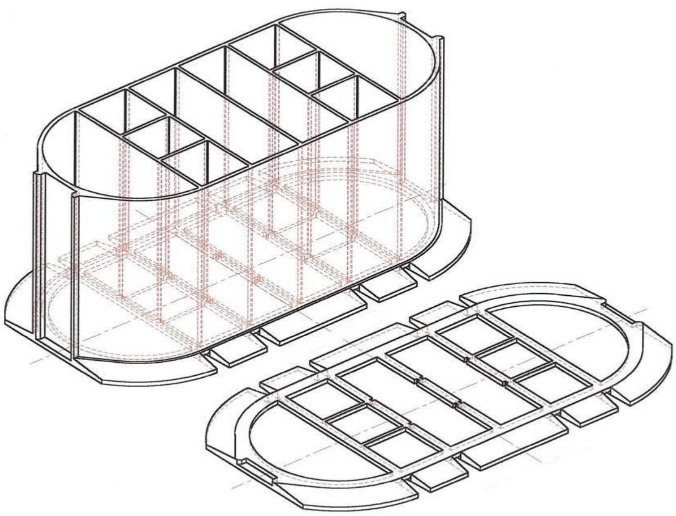


Figure 60: 3D model of the Caisson and the Caisson Foundation

Slope Stability

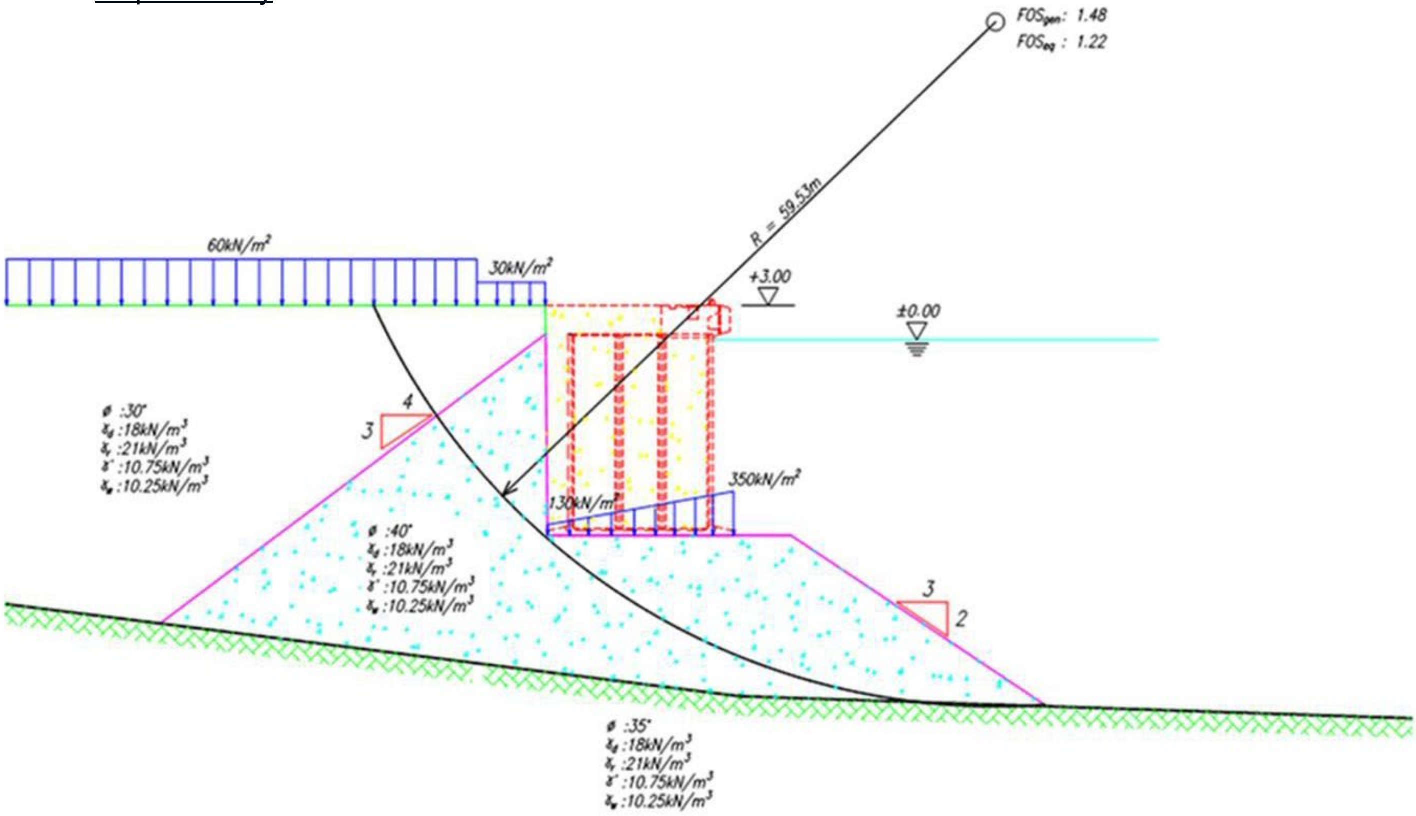
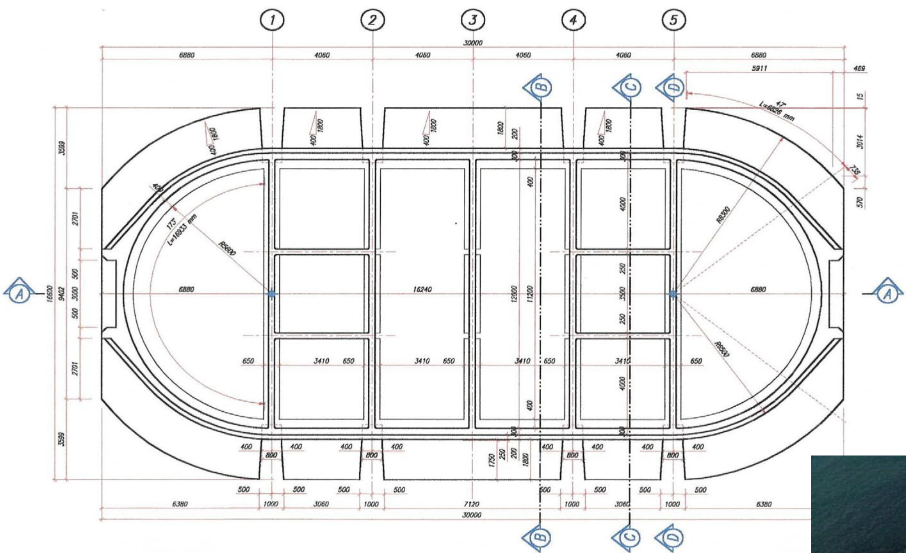
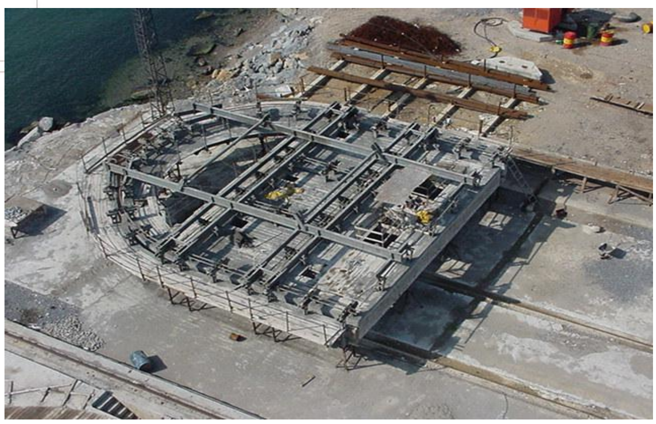


Figure 61: Slope Stability and Slide Circular Analysis



← Figure 62: Plan drawing of the Caisson

→ Figure 63: A Figure of the Caisson Foundation



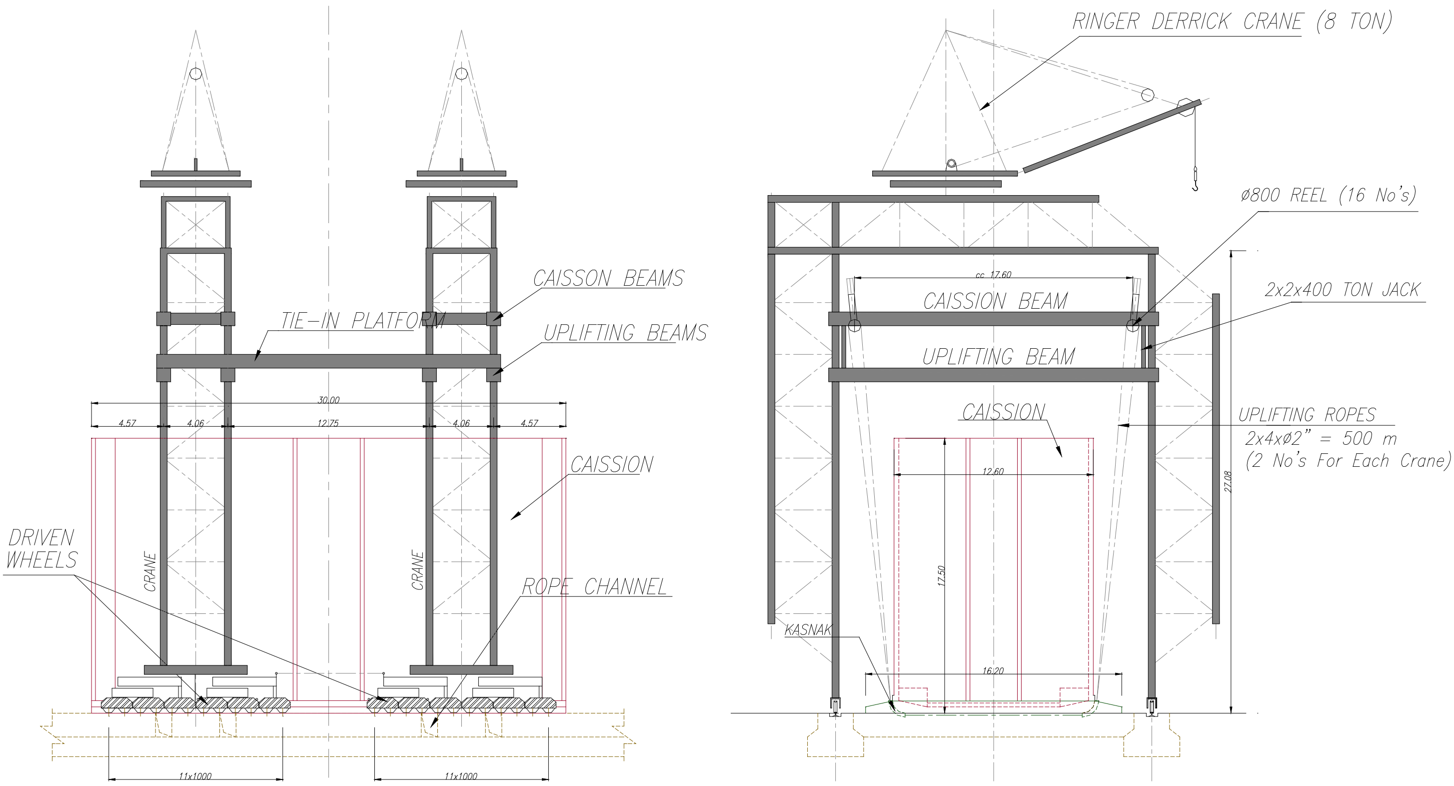


Figure 64: Plan and Section Drawings of the Caisson and the DEVE Heavy Crane

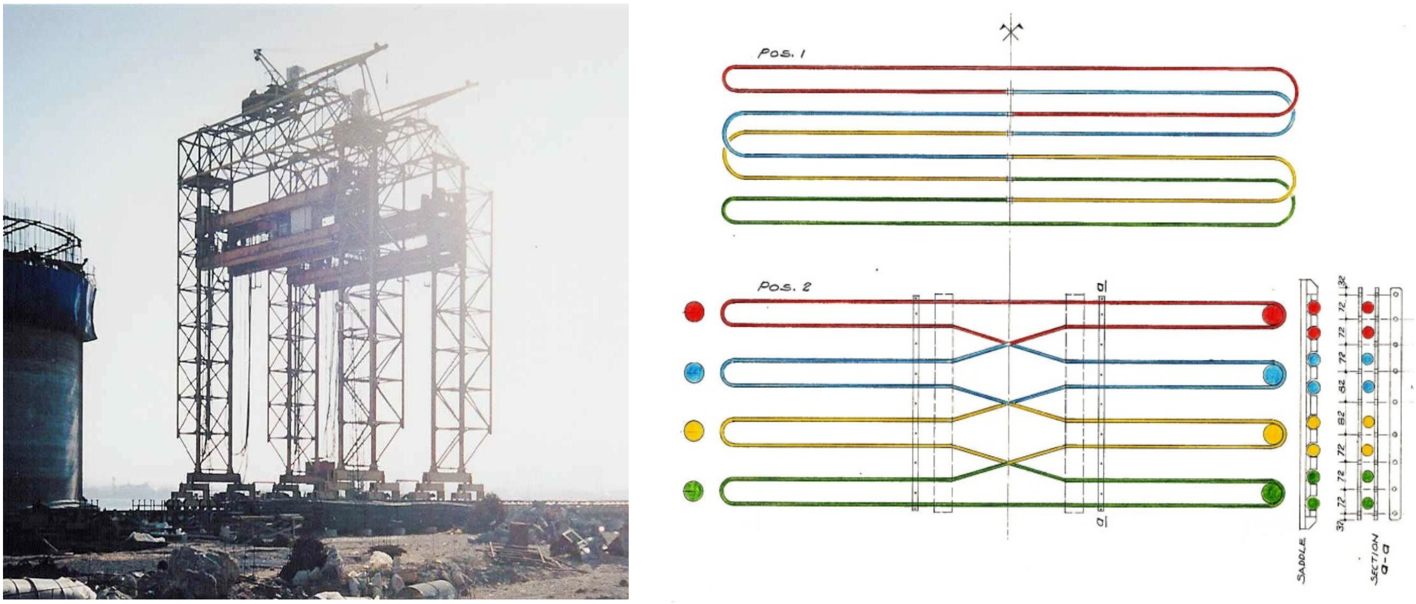


Figure 65: DEVE Heavy Crane from the Caisson Construction Yard, and Lifting Rope Configuration for the Caisson

Considerations for Floating of Caissons

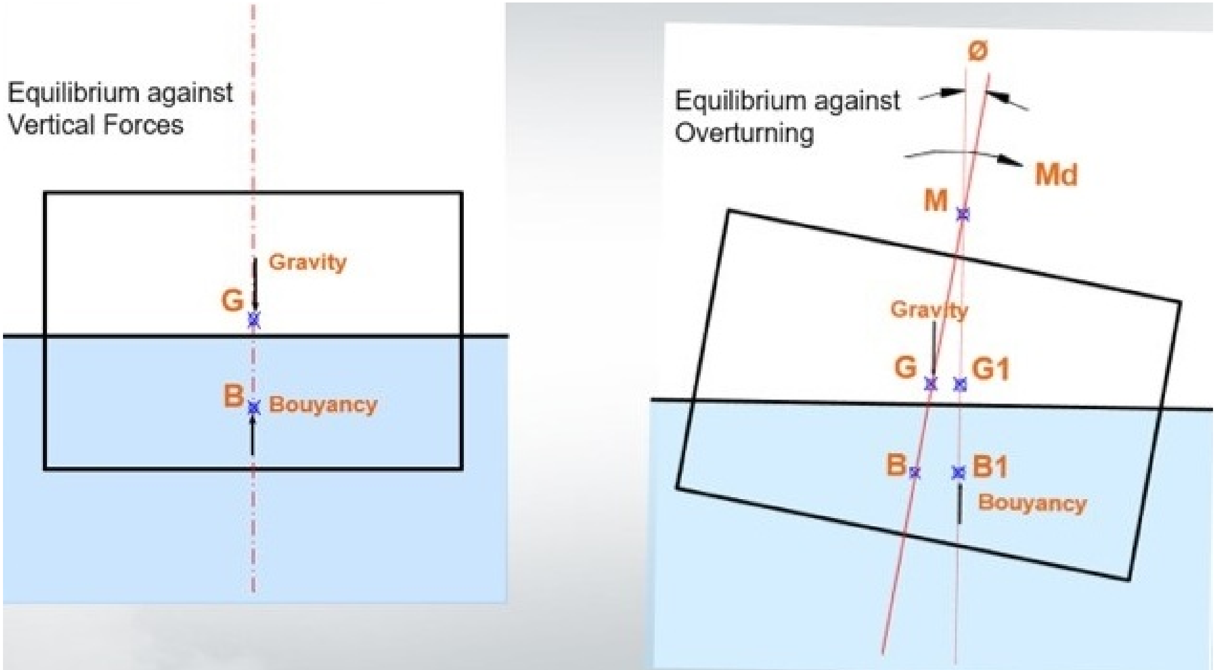


Figure 66: Images for the Equilibrium analysis

Floating Parameters

- Constrains Within the Port Basin
- Capacity of The Existing Pier
  - Handling Capacity of the Crane
  - Limited Water Depth

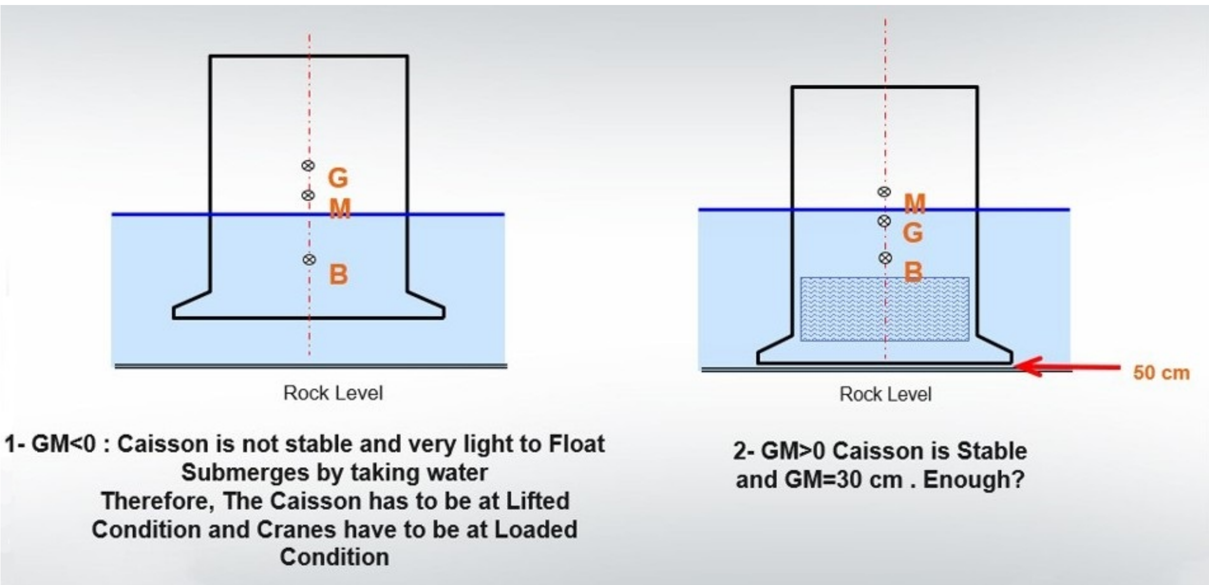


Figure 67: Images for the GM analysis

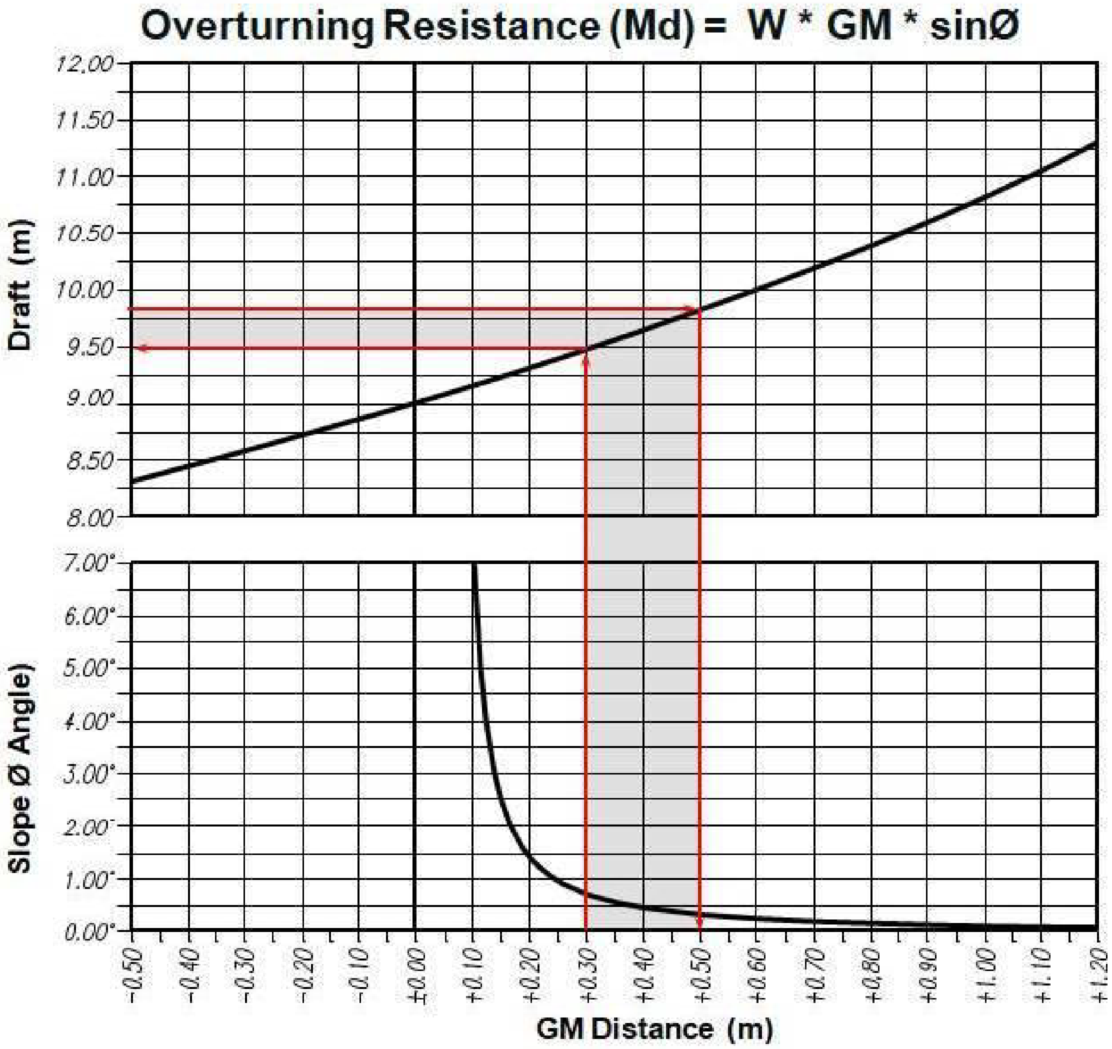


Figure 68: Overturning Resistance calculations

<u>Considerations for Towing of the Floating Caissons</u>

<u>Floating Parameters</u>

- Constrains In Deep Water
  - Wave Effect
  - Wind Effect

Impact on navigation was also considered.

For this case study, we communicated with Harbour Master and a warning was issued by Navtex.

Figure 69: Visualization of the Towing Route for the Caisson

The caissons were constructed at the STFA's own yard at Pendik Premises – the red dot on the left. (Today the premises belongs to DFDS company (https://www.dfds.com.tr/)

Method of Construction, Handling and Placement of Caissons

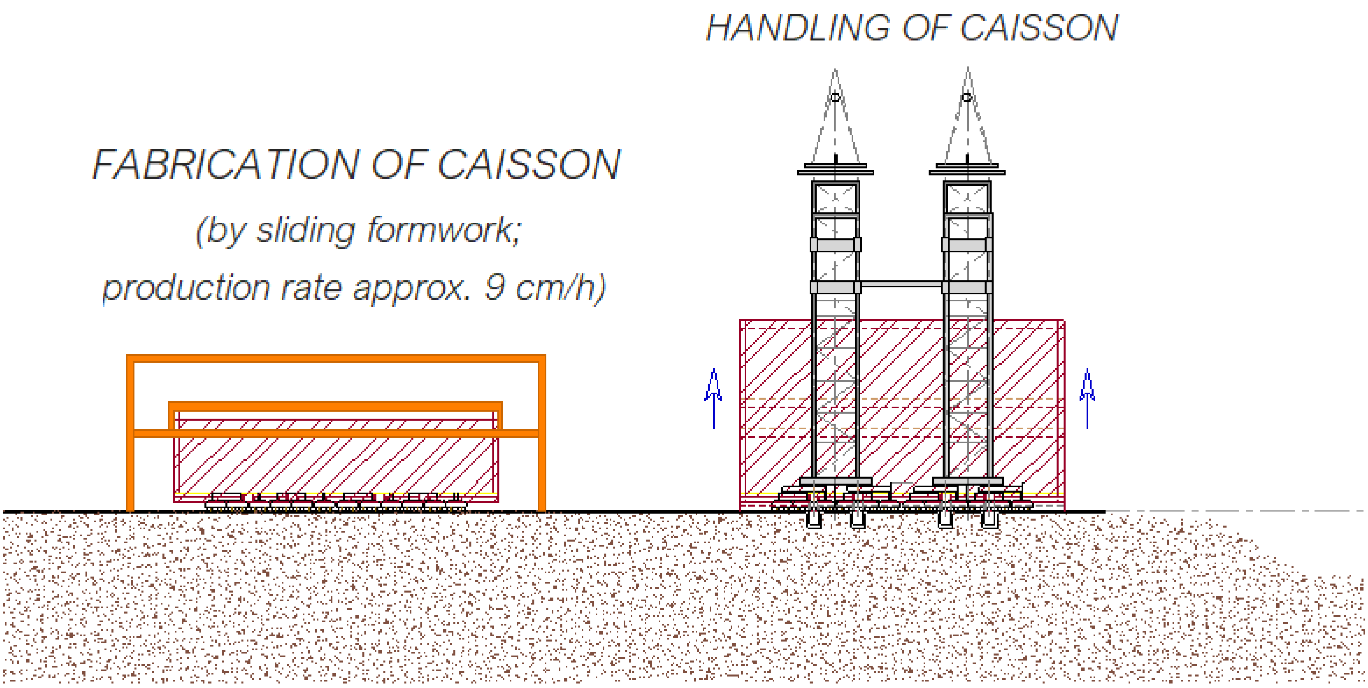


Figure 70: Visualization of the Fabrication (left) and Handling of the caisson – the caisson on the launching way by DEVE heavy gantry crane (right)

Figure 71: Figures of the Caisson Foundations

Figures 70, 73 – 76 show the handling and floating of the caisson. The caisson is moving forward and is lowered to relax the crane by the caisson's floating/buoyancy at the shallow drafted area.

The floating of the caisson is shown in Figures 73 and 75 – 79. The caisson is then moved forward to the deeper area, while the cranes are loaded. At the same time, water is taken inside of the caisson to fix the centre of gravity (gm). Subsequently, the caisson is lowered.

At the time of one of the operations, this subsequent caisson operation failed and as the caisson was continuously lowered, it overturned/toppled. Because of the changed centre of gravity, the crane overturned as shown in the Equilibrum sketches, Figures 65 and 66. It caused a devastating accident. We lost the crane, however, there were no injuries.

Figure 72: The Caissons under Construction. The blue canvas covers the upper moulds system

↓ Figure 73: Visualization of the Handling (left) and Floating (right) of the Caissons

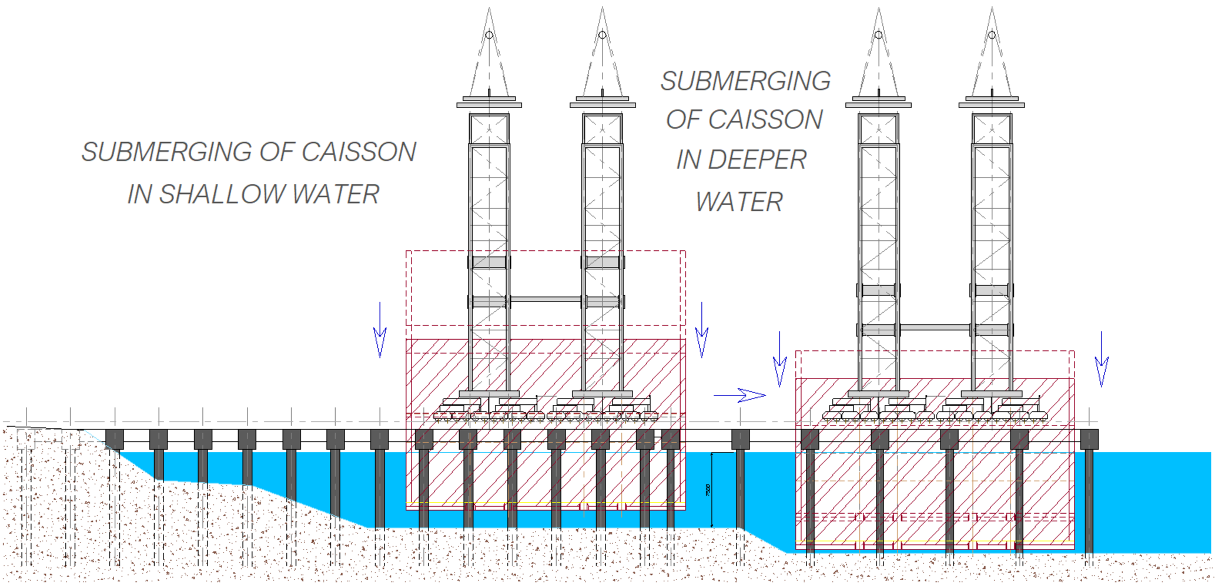
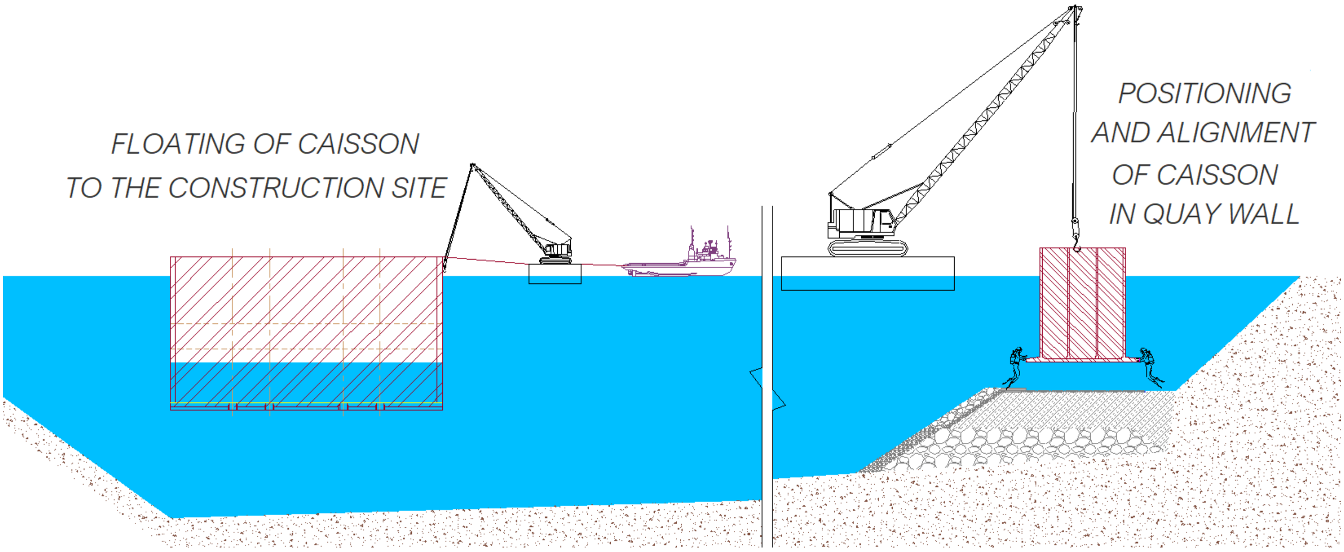


Figure 74: Handling of the Caisson

Figure 75: Handling and Lowering of the Caisson

← ↑ Figure 76: Lowering, Handling and Floating of the Caissons

Figure 77: Floating, Towing and Placement of the Caisson



↑ Figure 78: Drawings of the Floating, Towing and Placement of the Caissons

Figure 79: Backfilling of the Caissons

Figure 80: Placement of the Caissons

Figure 81: The Belde Port Facilities Quay Wall Construction Project

Figures 55 – 81:
Courtesy of STFA Construction Co.

CASE STUDY 4: CAISSON PRODUCTION, FLOATING, TOWING AND INSTALLATION OF THE CONSTRUCTION OF SUBSTRUCTURE WORKS - OSMANGAZI SUSPENSION BRIDGE PROJECT AT IZMIT AND YALOVA

PROJECT INFORMATION

The Project consists of:

- 2x55,000 t Caissons as Tower Foundations to be placed to a depth of -40m on seabed including dredging, driving of 380 No's of Inclusion Piles and Bedding works;
- Construction of Dry Dock and Wet Dock for Caisson Production;
- Diaphragm Wall Construction at South Anchorage Area;
- Anchorage Structures positioned on both sides of the Bridge;
- Approach Bridges Piers and Side Spans Piers for both North and South Sites;
- Reclamation and Revetment work for the South Anchorage Area.

Dimensions of Caissons

Length: 54 m

Width: 67 m

Total height: 42 m

Height of reinforced concrete footing: 15 m

Height of steel shafts: 27 m

Weights:

25.000 tons before Initial Launching

40.000 tons before Final Launching

70.000 tons after Submerging

100.000 tons after Plinth and Tie-Beam Construction

Figure 82: Initial Launching Stage of the Osmangazi Suspension Bridge's South Tower Foundation Caisson. Courtesy of STFA Construction Co.

Figure 83: Animated Figure from the Design Stage of the Osmangazi Suspension Bridge. Courtesy of Concessionaire OTOYOL YATIRIM ve İŞLETME INC.

Figure 84:

Map with the Location of the Osmangazi Suspension Bridge in Marmara Region, Türkiye

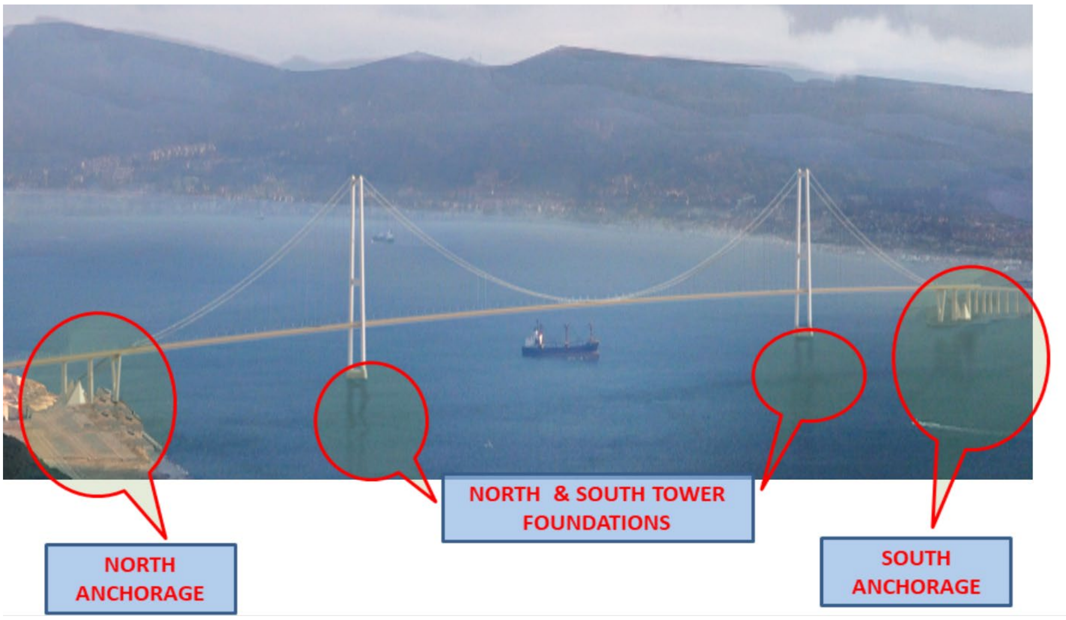


Figure 85:

Sectional View of the Osmangazi Suspension Bridge located in Izmit Bay. Courtesy of STFA Construction Co.

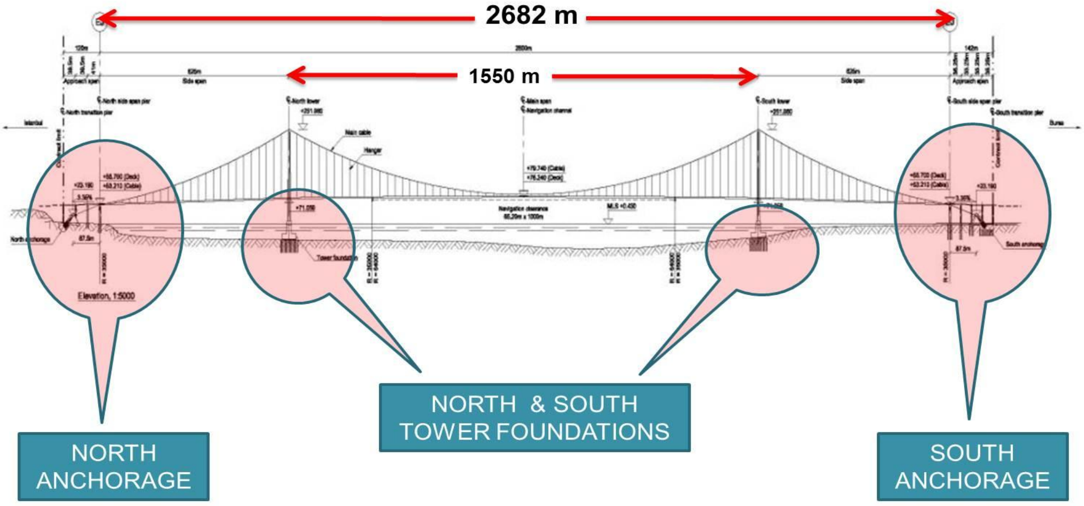


Figure 86:

Sectional View of the Osmangazi Suspension Bridge

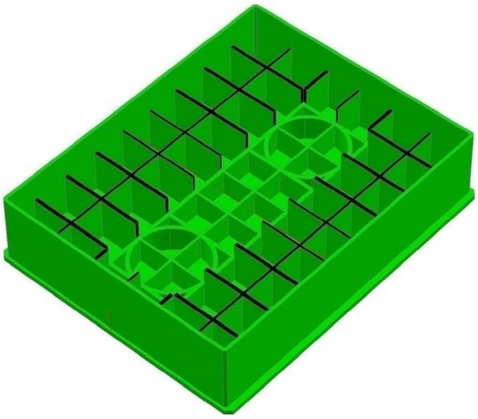


Figure 87: 3D model of the Caisson Construction at Dry Dock and water in-taking to the Dry Dock to prepare Caissons for Initial Launching. Courtesy of STFA Construction Co.

TOWING OF CAISSONS FROM THE DRY DOCK TO THE WET DOCK

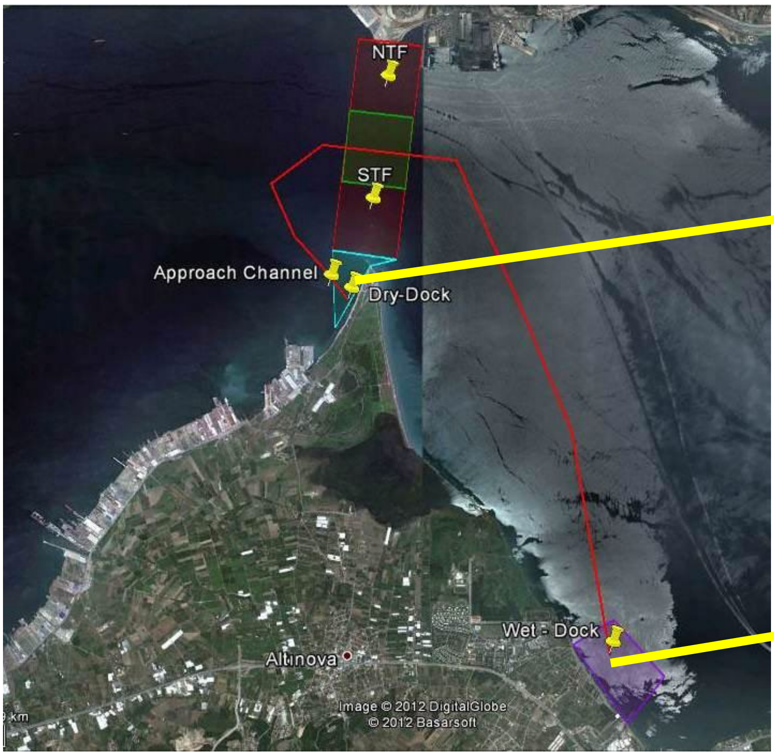


Figure 88: Towing of Caissons from Dry Dock (Hersek/Altınova/Yalova) to Wet Dock (Kaytazdere/Yalova); Initial Launching. Courtesy of STFA Construction Co.

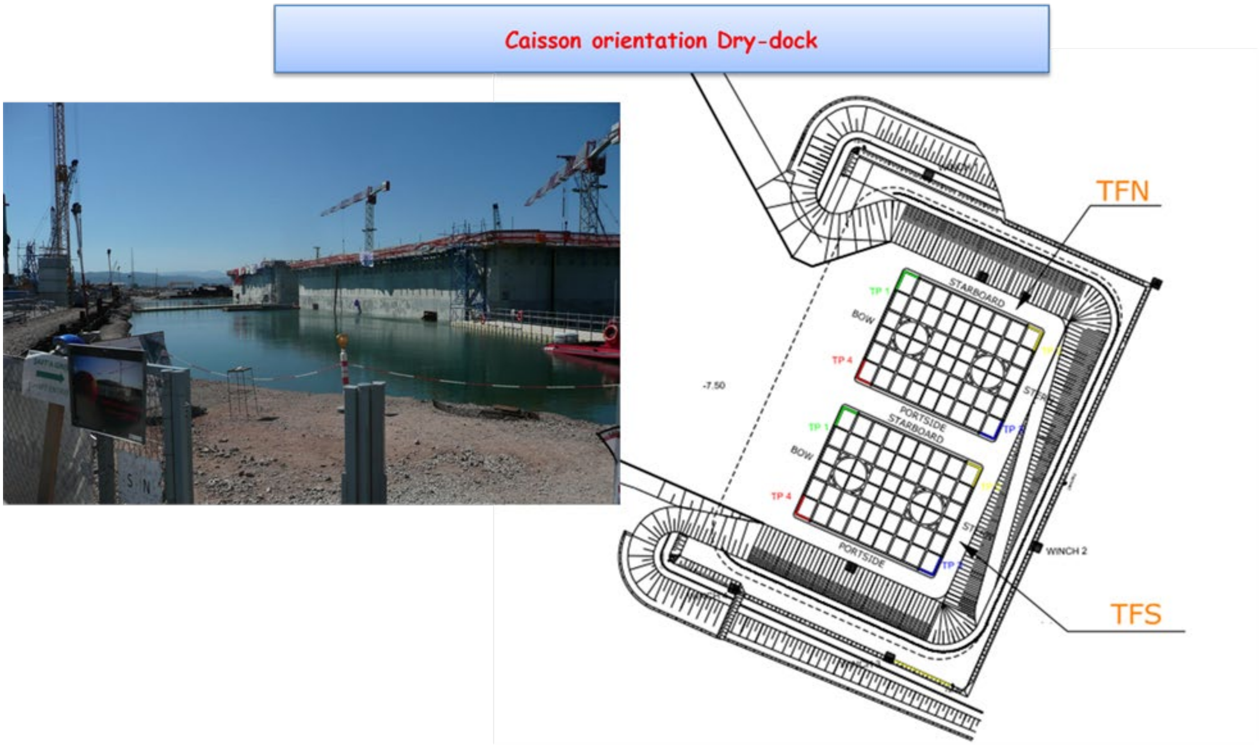
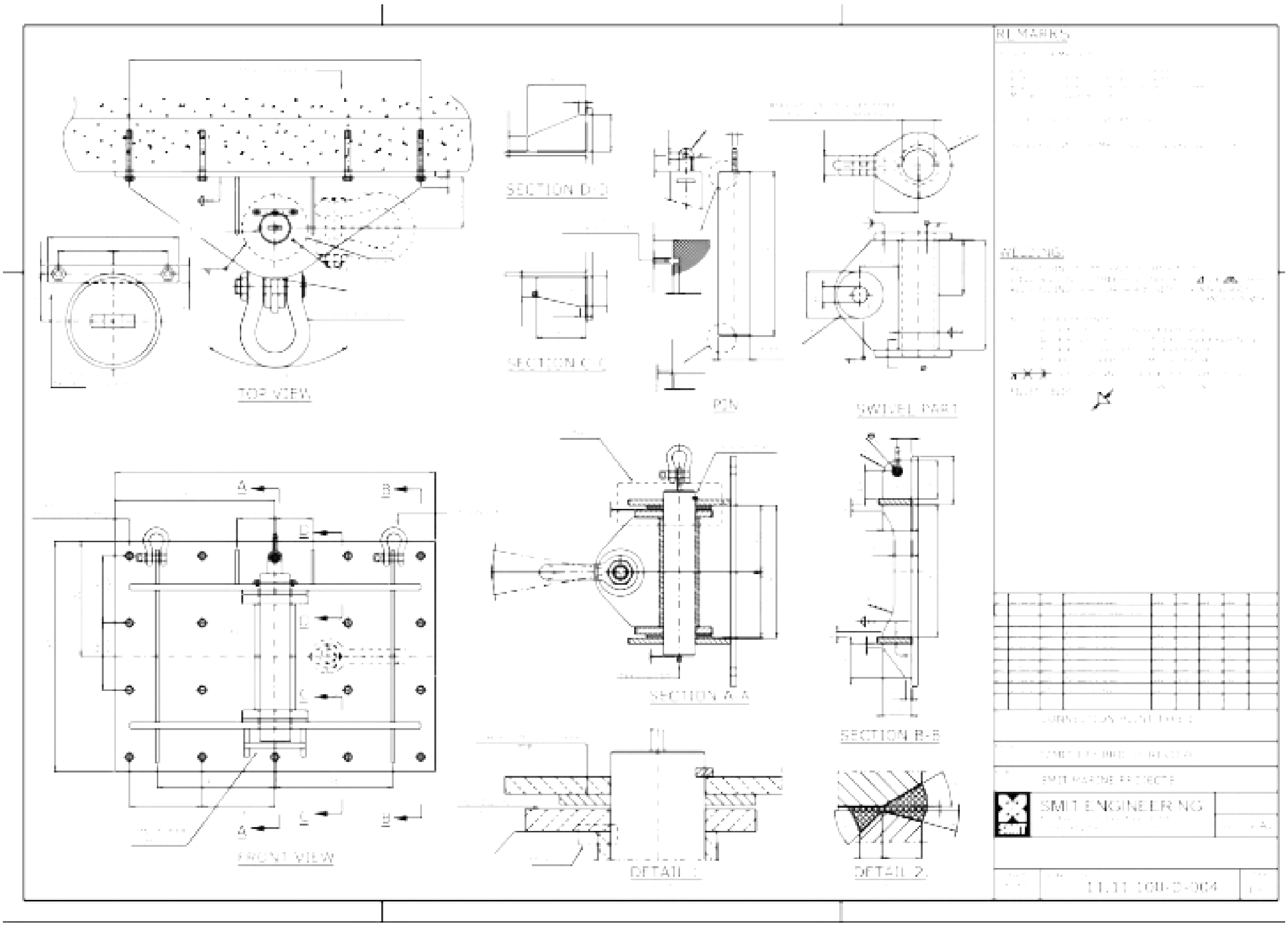
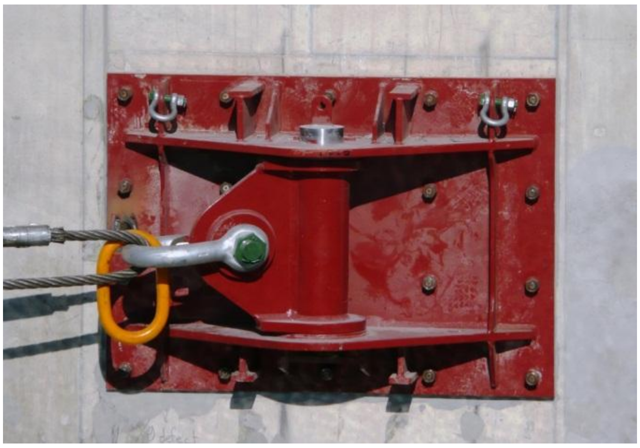


Figure 89: Caisson orientation at Dry Dock (Hersek/Altınova/Yalova); Initial Launching. Courtesy of STFA Construction Co.





Figures 90 – 95: Two tow points and winches at Dry Dock (Hersek/Altınova/Yalova); Initial Launching. Courtesy of STFA Construction Co.

Figures 96 – 99: Initial Launching Towing Vessels; Upper Left: KURTARMA-5, Upper Right: KURTARMA-8, Bottom Left: KURTARMA-9, and Bottom Right: KURTARMA-10. Courtesy of Directorate General of Coastal Safety (Türkiye)

Figures 100 and 101: Hooking-up of Towing Vessels; in front Diana-II (STFA's Work Boat) in the centre and behind KURTARMA-9 and KURTARMA-10. Courtesy of STFA Construction Co.

Figure 102: Initial Launching; KURTARMA-9 and KURTARMA-10 are towing the South TF Caisson and KURTARMA-5 is hooking up as Trailing Tug Boat. Behind is Diana-II (STFA's Work Boat) assisting with the Hook-up Operation. Courtesy of STFA Construction Co

Figure 103: Initial Launching; KURTARMA-9 and KURTARMA-10 are (front) towing the South TF Caisson and KURTARMA-8 and KURTARMA-5 as Trailing Tug Boat. Courtesy of STFA Construction Co.

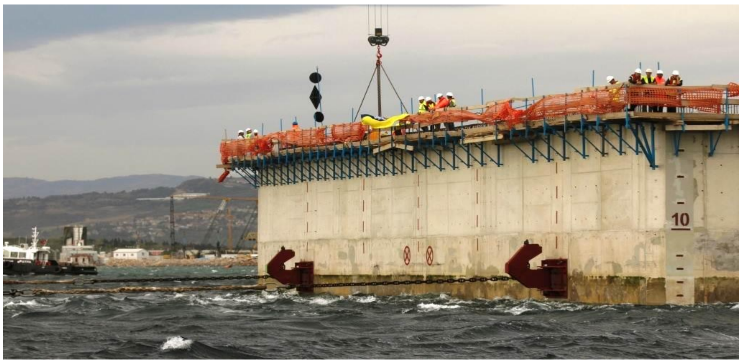
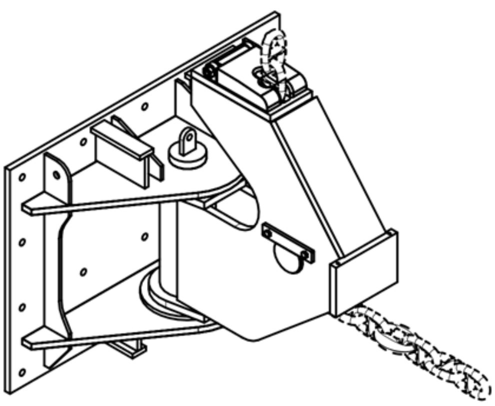
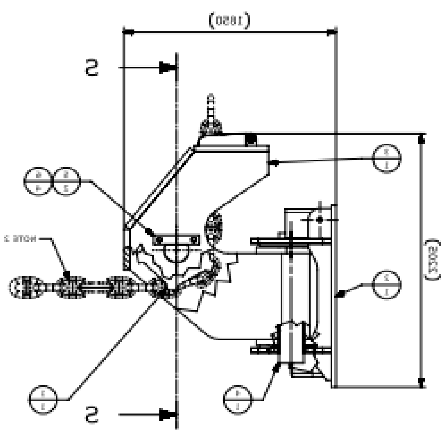


Figure 104: Initial Launching of North TF Caisson, on the left is 'ServetKaradağ' (STFA's Assisting Tug Boat). Courtesy of STFA Construction Co.

Figure 105: Initial Launching of North TF Caisson; on the right (distant two) KURTARMA-9 and KURTARMA-10 are towing the North TF Caisson, and KURTARMA-8 (right) and KURTARMA-5 (left) as Trailing Tug Boats. Courtesy of STFA Construction Co.

MOORING AT THE WET DOCK





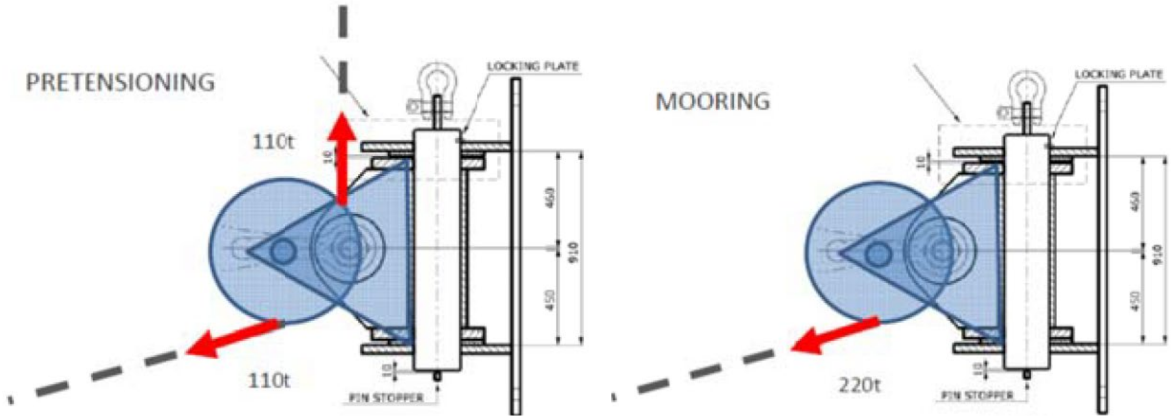


Figure 106: Drawings of mooring at Wet dock; Tensioning Mooring wires by the means of our invention Roller Chain Stopper. Courtesy of STFA Construction Co.

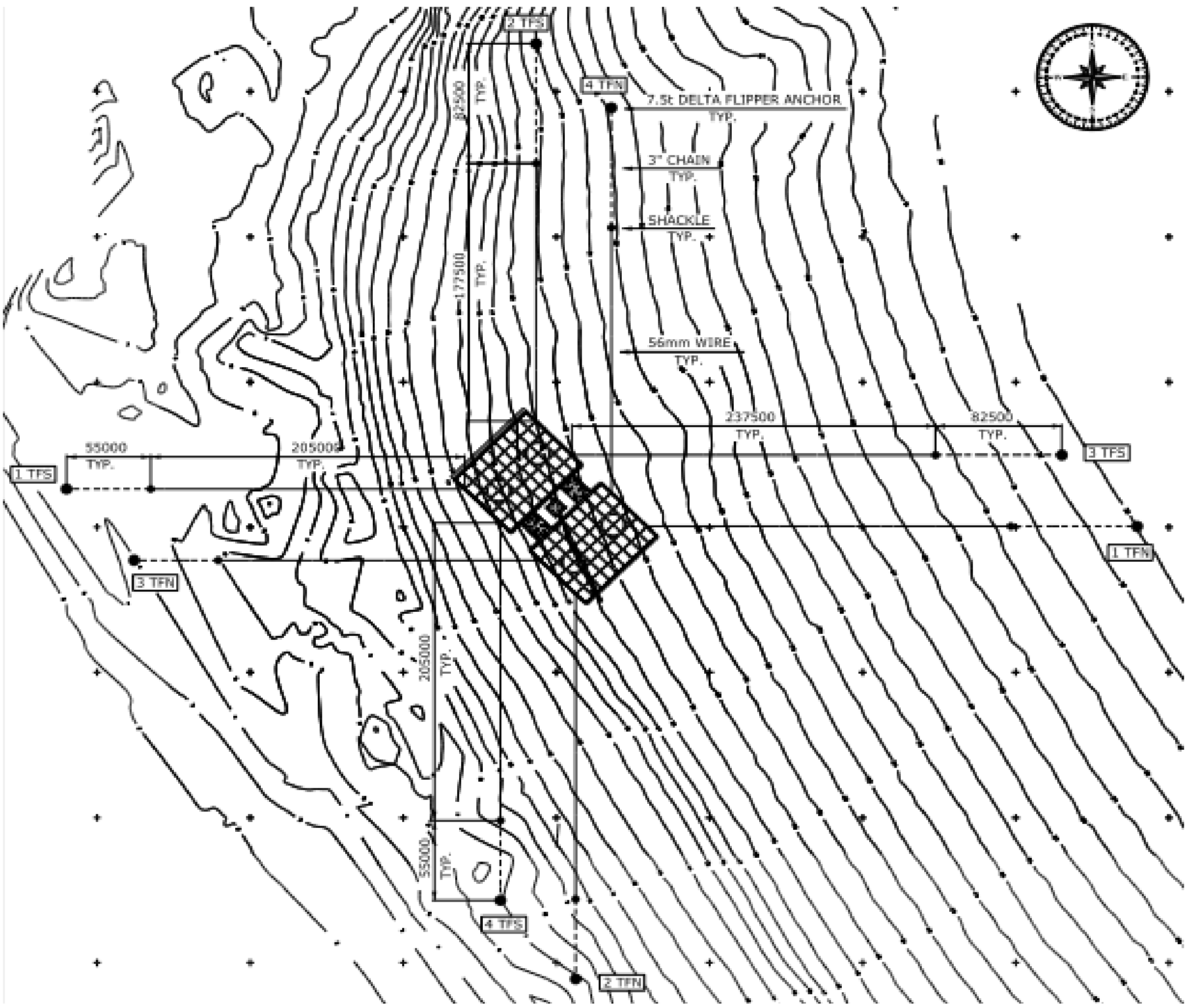
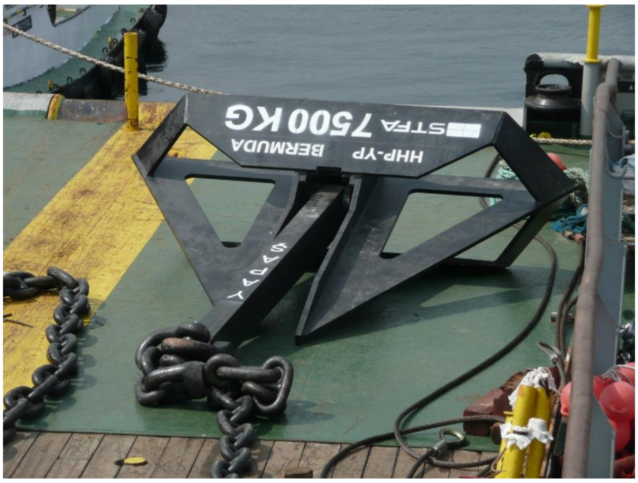
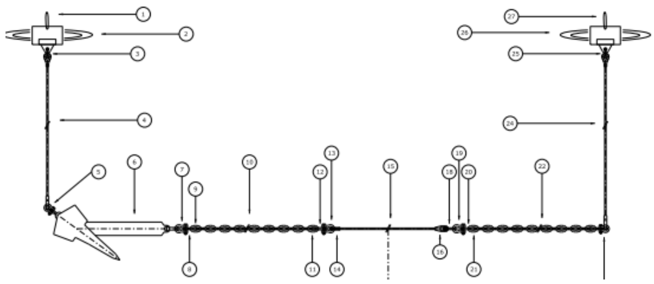


Figure 107: Mooring at Wet Dock; Mooring layout at Wet Dock. Courtesy of STFA Construction Co.





Figures 108 – 111: Mooring at Wet Dock; Mooring layout at Wet Dock. Courtesy of STFA Construction Co.

Figure 112: Mooring at Wet dock; Tensioning of Mooring Chains using Roller Chain Stopper and Floating Cranes. Left side Kazıkçı Ibrahim (STFA's Floating Crane), Right Side Doğa-I Floating Crane (STFA is operator).

Courtesy of STFA Construction Co.

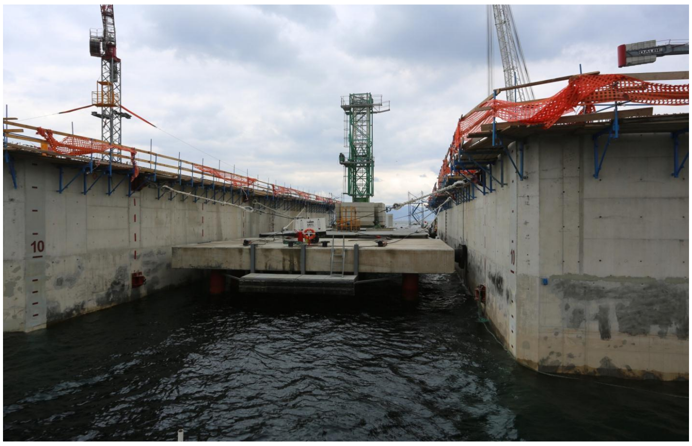


Figure 113: Soft Mooring of Caissons at Wet Dock, and Tower Crane under Erection (left), and Anchoring of Caissons at Wet Dock and Starting of Wet Dock Concreting Operation with Kazıkçı İbrahim (STFA's Barge) equipped with Concrete Pumps and ready to receive (STFA's) Concrete Mixer Carrier Barges (Towed by STFA's Tug Boats). Courtesy of STFA Construction Co.

CAISSON CONSTRUCTION - CONCRETE WORKS AT WET DOCK

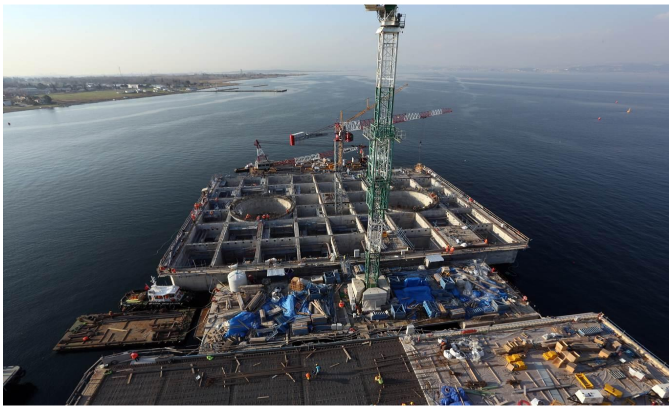
Wet Dock Production

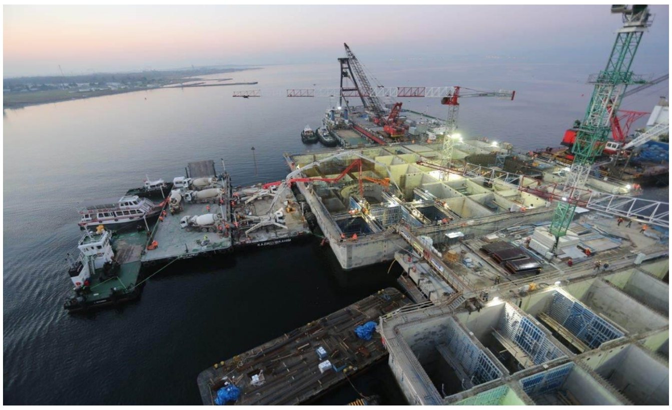
Concrete: 5,500 m^3

Reinforcement: 1,500 tons

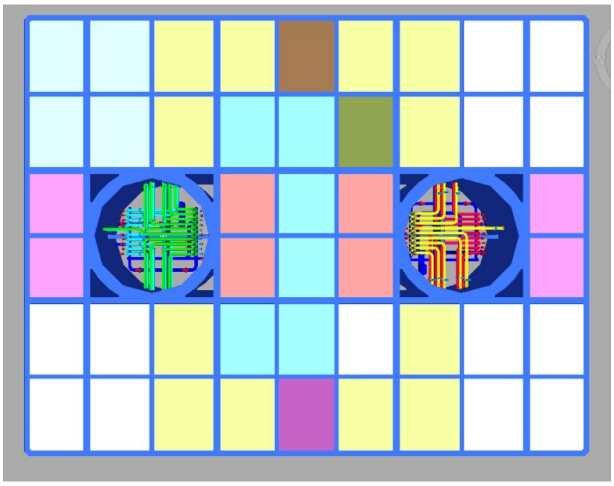
↓ *Figure 114: Wet Dock Concreting Works.*

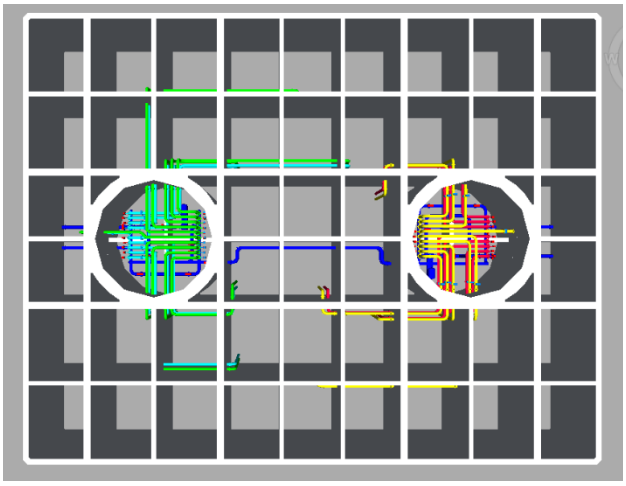
Courtesy of STFA Construction Co.

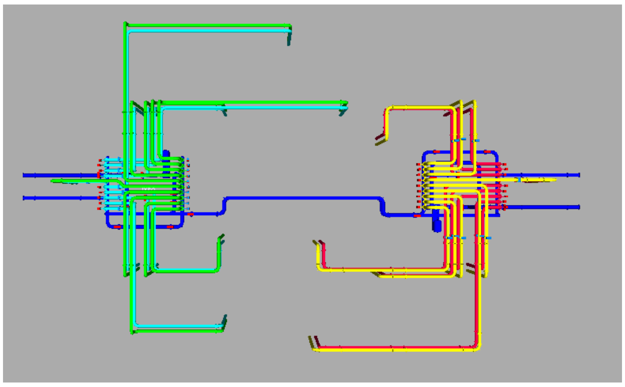


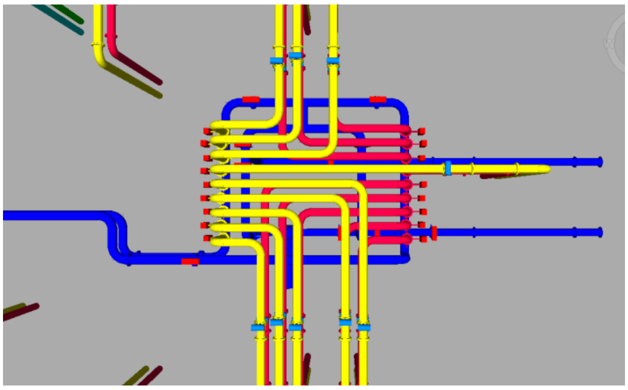


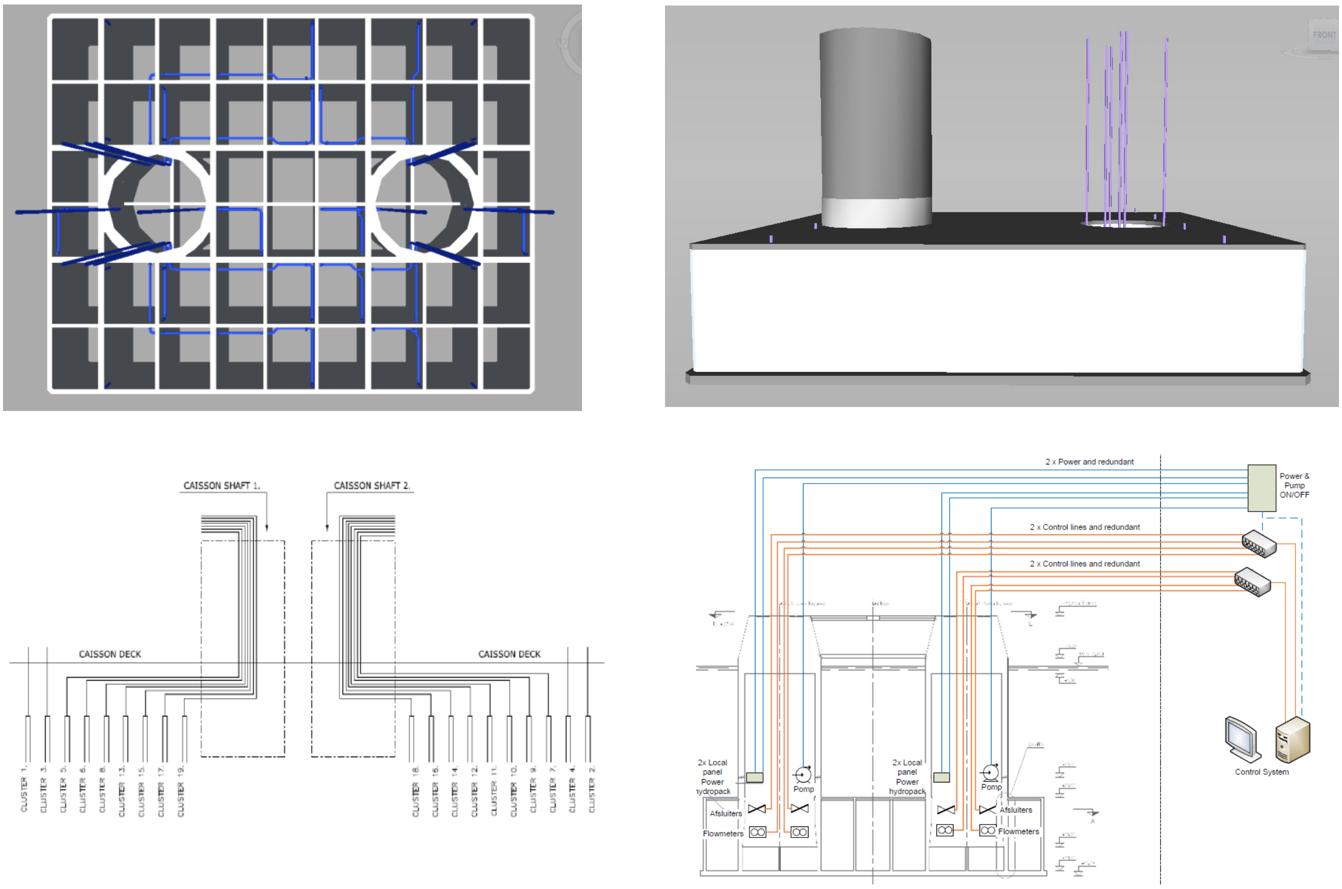
BALLAST SYSTEM DESIGN











Figures 115 - 120: Ballast System Design. Courtesy of STFA Construction Co.

SUBMERGING OF CAISSONS AT THE TOWER FOUNDATIONS

Figure 121: Wet Dock Location, SHA (Safe Holding Area), and Caisson Deployment Locations.

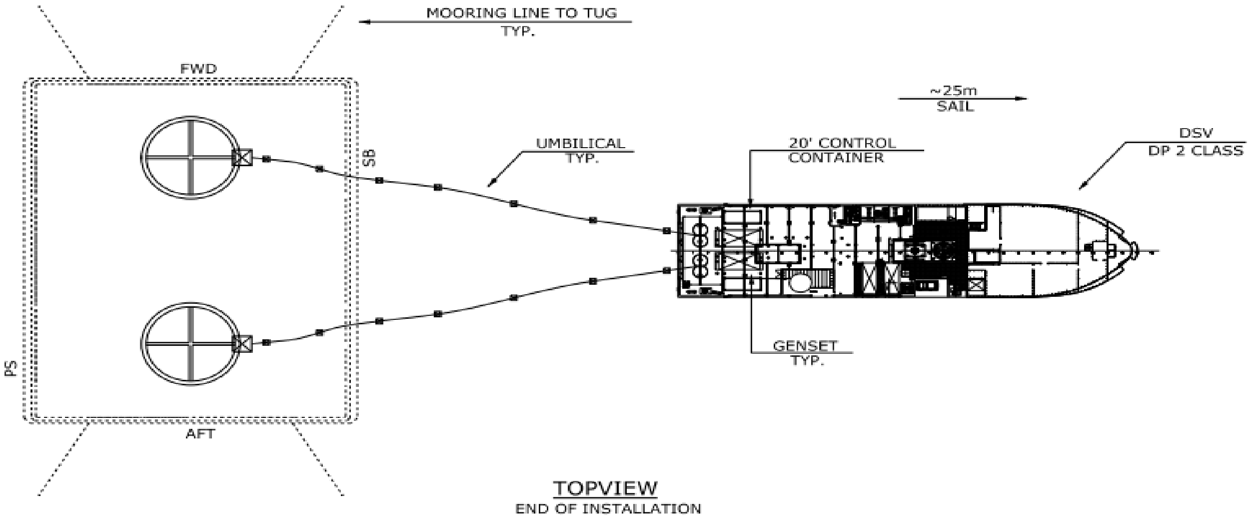
Courtesy of STFA Construction Co.

SUBMERGING OF CAISSONS AT THE TOWER FOUNDATIONS

Dynamic Positioning Vessel, Class 2 (DP 2) Diving Supply Vessel (DSV) ´ASTREA´

Figure 122: Submerging of Caissons at the Tower Foundations, Installation Vessel ´SPS ASTREA´.

Courtesy of STFA Construction Co.



Final Launching: Guard /Hooking-up Vessel

Figure 123: Guard / Hooking-up Vessel ´YaşarDoğu-I´ (STFA's AHT).

Courtesy of STFA Construction Co.

Final Launching: Towing vessels

Figures 124 – 127: Submerging of Caissons at the Tower Foundations, Installation Vessels. ´EMRE OMUR´, ´VOS ATLANTICO´, ´KURTARMA-9´, and ´KURTARMA-10´.

Courtesies of STFA Construction Co. and Directorate General of Coastal Safety (Türkiye)

Tow Rigging

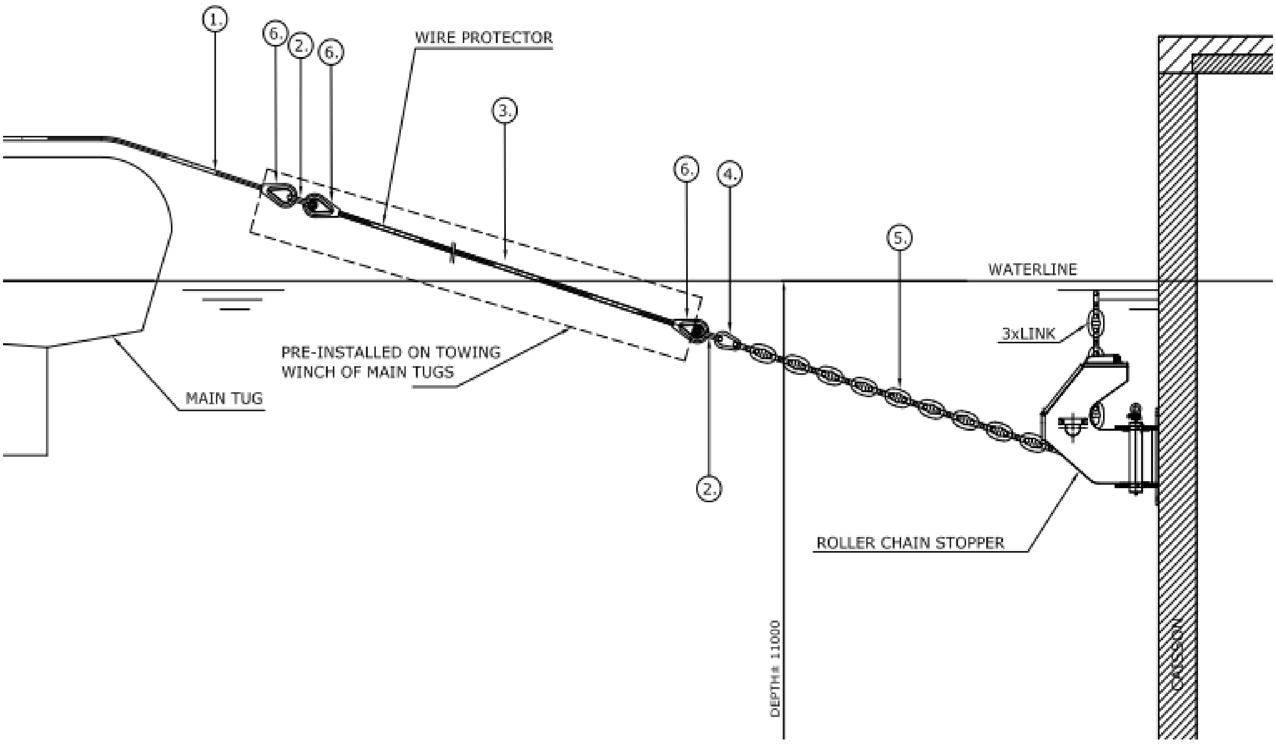


Figure 128: Tow Rigging at Wet dock. Courtesy of STFA Construction Co.

Mooring Layout TFN (North Tower Foundation)

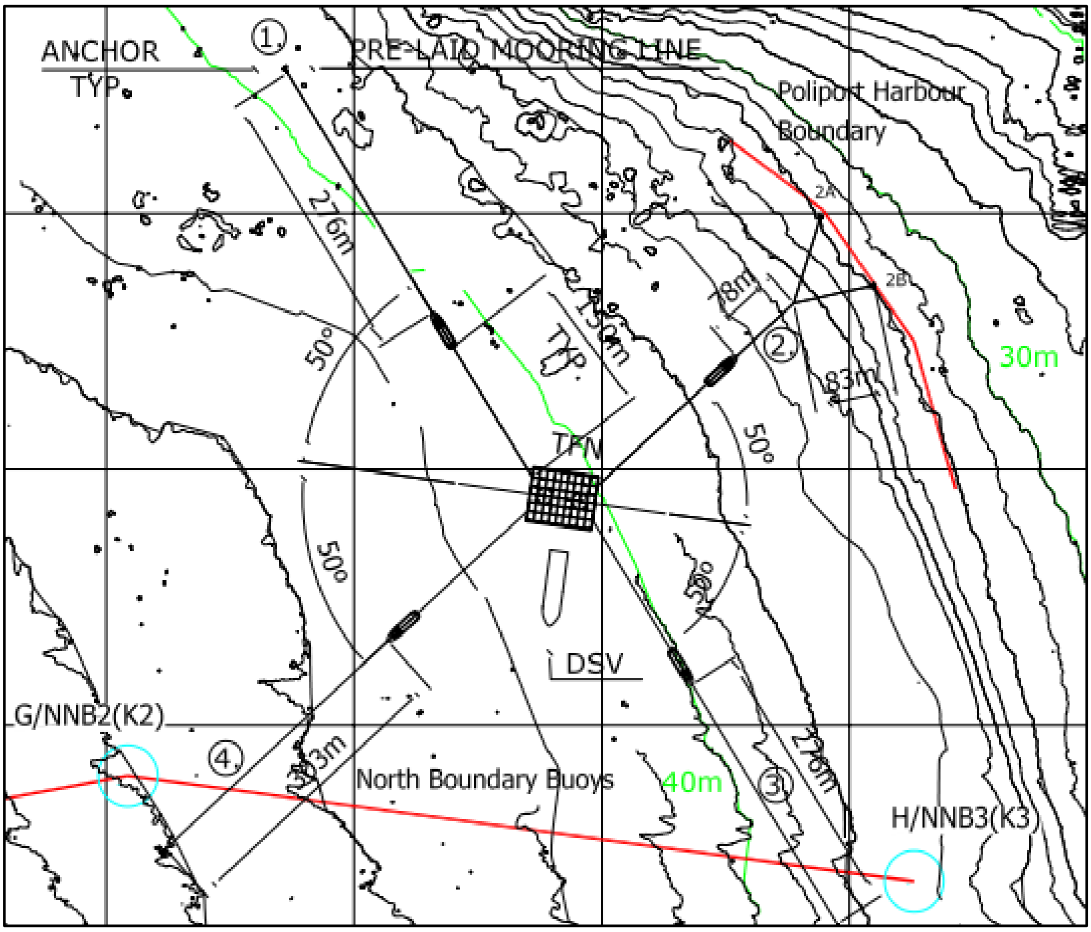


Figure 129: Mooring Lay out North TF. Courtesy of STFA Construction Co.

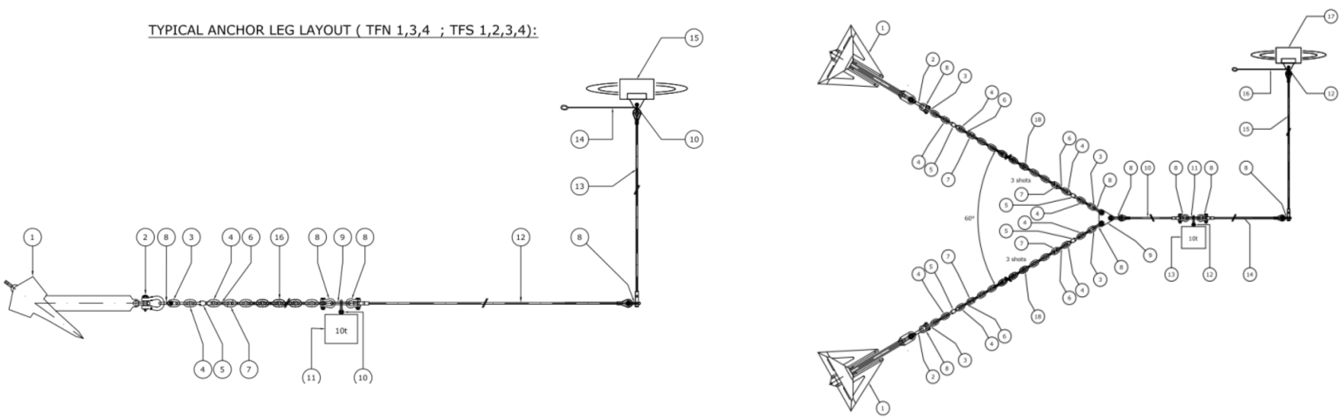


Figure 130: Anchor Leg Mooring Layout North TF 1,3,4 and South TF 1,2,3,4; Right Side: Anchor Leg Mooring Layout North TF 2 (Delta Anchoring). Courtesy of STFA Construction Co.

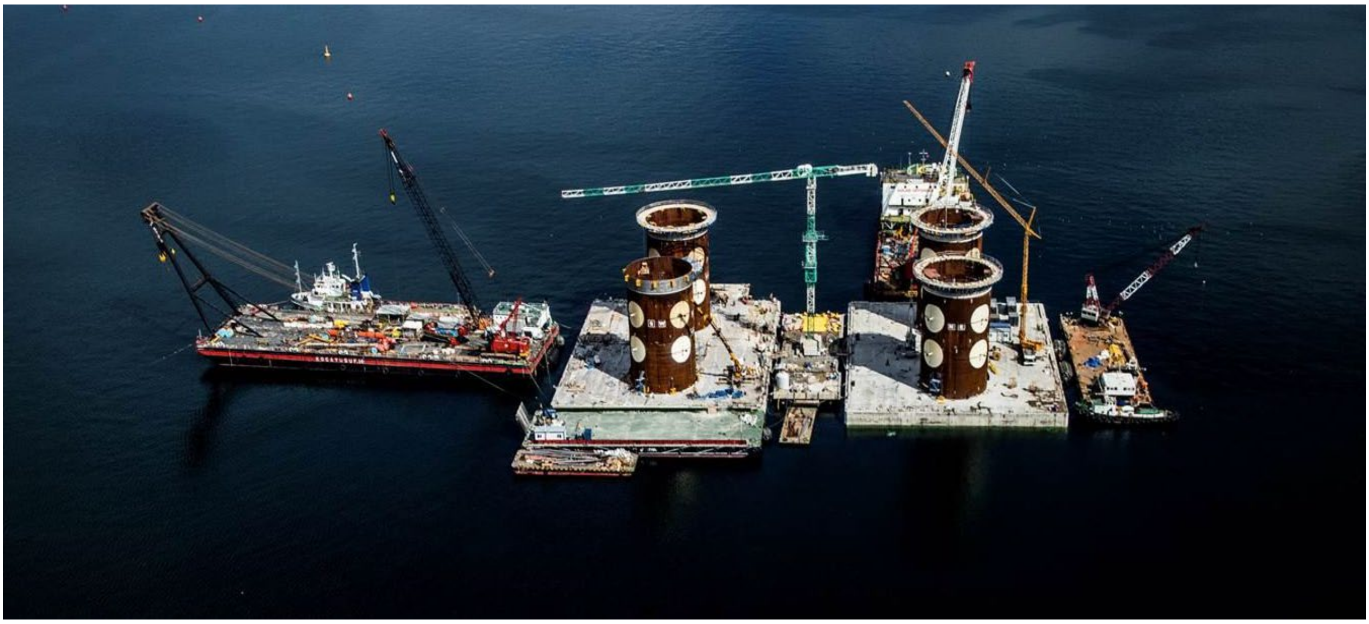


Figure 131: The Caissons are ready to Hook-Up and Tow at Wet Dock. Courtesy of STFA Construction Co.

Towing of Caissons from Wet-Dock to Tower Foundations

Figure 132: The Caissons are ready to Hook-Up and Tow at Wet Dock.

Courtesy of STFA Construction Co.

Figure 133: Installation Scheme; Installation Vessels are Moored to Anchor Legs which are previously installed by the means of 'YaşarDoğu-I' (STFA's AHT) Guard / Hook-up Vessel at North TF and DSV (DP2 Diving Supply Vessel) 'SPS Astrea' (Behind the Caisson) is located at its planned position to control to Submersion Operation.

Courtesy of STFA Construction Co.

Installation / Submerging of Caisson at the North Tower Foundation Location

First, coarse gravel is placed by fall pipe, then fine tuning with fine gravel and ULE is done as explained above.

After caisson installation, scour protection (5-60Kg of Rock) is executed by a fall pipe barge and clamshell equipped floating crane barge

Figure 134: Installation / Submerging of Caisson at the North Tower Foundation Location. Courtesy of STFA Construction Co.

e-maritime

CASE STUDY 5: CAISSON PRODUCTION, LOWERING, TOWING AND INSTALLATION OF THE NEW NADOR PORT PROJECT

NADOR – MOROCCO

<u>Dimensions of Submersible Barge EIDE-33</u>

Length o. a.: 100 m

Beam o. a.: 45 m

Dwt: 14,900 mt

Lightship: 6,000 mt

Deck load: 15->20T/m²

Deck area: 4,120 m²

Submersible (submersion draft):

19.9 m water on deck

Figure 135: 8,000-ton Caissons are cast by Portal Crane Combined Slipform Method of BYGGING-UDDEMANN AB and Submersible Barge – Eide Barge 33 (Operated by STFA-SGTM JV) is to receive caisson for lowering it to the Sea. Courtesy of STFA Construction Co.

May 2023

CAISSON PRODUCTION, LOWERING/FLOATING, TOWING, AND INSTALLATION OF THE OFFSHORE WIND PROJECT

SAROS BAY, ENEZ – EDIRNE, TÜRKIYE

Similar to my proven experience at the Osmangazi Suspension Bridge Project in which I personally knew the chosen Project Site, the project site was just nearby our Summer Camp and I knew the shore, nearby places, man-made and natural structures, geotechnical data, marine and weather conditions, and even the near-shore sea bed since I am also a PADI licensed recreational 'Open Water Diver.'

I decided to use the Case Study of the Osmangazi Suspension Bridge to follow and even design the WTG Foundation caissons similar to it, which I already explained in Section 4. WIND TURBINE GENERATOR FOUNDATION SELECTION, and here I will only explain Fixed Bottom, Floating type Gravity Based Structure (GBS) Concept.
At this stage, in order to be given a competitive offer, the Marine Construction Company's Istanbul team and I worked on two alternatives for the Cast and Lower or Cast and Float the Caissons.

ALTERNATIVE I: CASTING GBS ON LAND AND LOWERING IT

As already explained in Case Study 5, we worked with BYGGING-UDDEMANN AB on the New Nador Port Project in Morocco with their BYUM Single Gantry Slipform and IP-CCV Transfer System Method from the Tender Stage of the Project where the Marine Construction Company's Istanbul Team mostly consisted of STFA's Tender Preparation Team for this project, including myself.

Then we submitted my Caisson design including all drawings and calculations to BYGGING-UDDEMANN AB to prepare our casting yard and to cast our 70 caissons in the first phase by "BYUM Single Gantry Slipform and IP-CCV Transfer System Method", while we were working at the New Nador Port Project in Morocco.

Heavy Lowering experience of the Marine Construction Company's Team (Ex. STFA)

On the other hand, we planned one alternative method for the Lowering of Caissons for the Nador Port Project which is in line with Case Study 1: Galata Bridge at Golden Horn, Istanbul – Türkiye.

However, to provide the best economical offer to the Client, the solution presented in Case Study 5 was chosen at the tender time as mentioned above.

ALTERNATIVE II: (CASTING GBS IN DRY-DOCK) AND FLOATING IT

This alternative was based on the experience of the Marine Construction Company´s Istanbul Team (Ex. STFA) with the Osmangazi Bridge Construction, as presented in Case Study 4.

Figure 136: Production at the Casting Yard

Kar-Snow type WTG Foundation Caissons will be cast by Portal Crane Combined Slipform Method of Bygging Uddemann AB and a Submersible Barge will be ready to transport and lower the caisson in the Sea similarly to STFA's MANNP Nador Port Project. 8,000-ton Caissons planned to be cast on land, and lowered by Strand-Jack pistons using 'Freyssinet Anchorage Ropes' which were used as an alternative for Nador in Morocco Tender in line with Case Study 1

Construction of Dry Dock

To construct and float the caissons that form the footings of the Tower Foundations, a Dry Dock was planned at the tender stage.

For constructing a dry dock and to create a construction area for the GBS Structures of WTG foundations at dry conditions, there is a need for an area to be reclaimed at the Project Area, and this was incorporated into the tender design temporarily.

Dry Dock Construction works comprise:

- Construction of retaining bund and revetments for both the temporary and permanent sections;
- Driving Sheet Piles;
- Dewatering and Excavating the existing land down to the specified bottom level of the Dry Dock;
- Compaction of the bottom of the Dry Dock Area;
- Provision of surface drainage system;
- Road Construction;
- Dredging of Approach Channel;
- Removal of Temporary Bund;
- Final Sweep;
- Final Removal of Temporary Bunds and the Dry Dock.

← Figure 137: 25,000-ton Caissons (Initial Launching Weight) are cast in Dry Dock by Standard Climbing Shattering Method. Courtesy of STFA Construction Co.

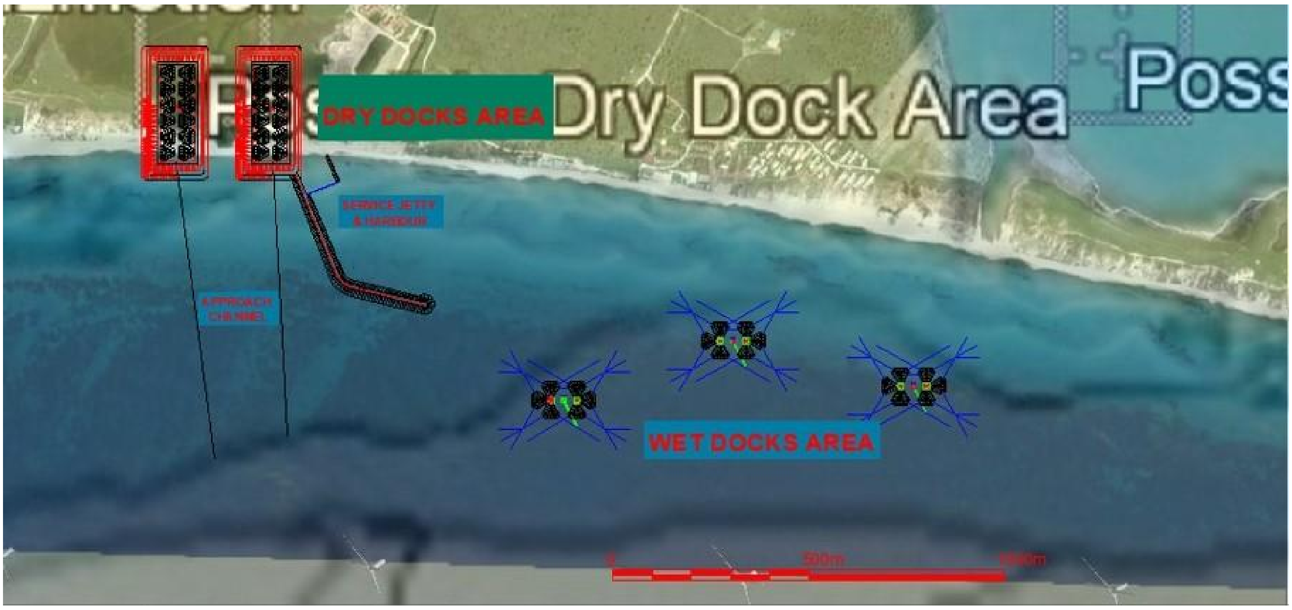


Figure 138: Türkiye Offshore Wind Project - Saros Dry and Wet Docks Locations

Dry Dock Construction

Bund Construction around Dry Dock

The temporary bund constructions and a temporary Harbour with Service Jetty are planned to be started.

There are several alternatives planned as measures to solve private land issues that may occur at the construction stages.

Driving Sheet Piles

For the inner sides of dry dock retaining bunds, a granular fill bund is planned to be constructed in the full section up to elevation +0.6 m CD level with a 12.3 m width and 1.6 m CD level with a min. 6.5 m width at the top respectively.

This can be done by dump trucks and a bulldozer or a loader in the first stage.

Following the completion of temporary revetments, steel sheet piles are planned to be driven along the perimeter of the Dry Dock as shown in Figure 119.

The sheet piles prevent the flow of seawater into the excavation pit, i. e. dry dock, to provide a dry working environment.

In the second stage, granular fill bunds are laid on the inner side of the (temporary) bunds constructions and completed in the full section up to +1.6 m CD level with Quarry Run (0-400kg) material.

Dewatering and Excavation

Submersible pumps are planned to be utilized for the discharge of seepage water.

Following the completion of the sheet pile cofferdam, the inner portion of the plot is planned to be excavated up to the calculated (-) level.

Following the completion of Dry Dock construction, construction of GBS Caisson Structures for WTG Foundations can be started.

Figure 139: Driving of the Sheet Piles. Courtesy of STFA Construction Co.

Figure 140: Dewatering and Excavation of Dry Dock. Courtesy of STFA Construction Co.

Figure 141: Preparation of the base of the Dry Dock for GBS Caisson Construction. Courtesy of STFA Construction Co.

Dredging for Approach Channel

Since the temporary Dry Dock is planned to be constructed in shallow waters there is a need for an approach channel to be formed by dredging.

As the dredging permit and disposal of dredging material permit have to be issued by related authorities, the regulations and requirements set by them shall be strictly followed.

Dredging for Approach Channel trenches is planned to be performed by dredging equipment, starting from the offshore end towards the land side.

Dredging work is planned to be executed mainly by a Back-Hoe, Deeper Dredger, and Split dump barges. The trench widths will be adjusted as per the Tow and Installation requirements of MWS (Marine Warranty Surveyor) in line with the 'New Panama Channel Studies' (Reference: Port Engineering, 3rd Edition – 1981, Part Brunn, Gulf Publishing).

Dredging materials have to be classified in accordance with the specifications and Environmental Laws and regulations.

In line with the wide site and laboratory, inspections that are going to be done by the Ministry of Environmental and Urbanization, if there is no contaminated soil found at the dredging location, the dredged materials are going to be loaded to split dump barges and will be dumped to the "Allocated Place by Ministry of Environmental and Urbanization" in the Aegean Sea.

Removal of Temporary Bund

When the caisson production in the Dry Dock is completed and the caissons are going to be floated, fully moored and anchored at Dry Dock, the removal of the temporary bunds will be started.

Both land and sea equipment are planned to be used for the removal of the temporary bund.

Figure 142: Dredging by Back-Hoe Deep Dredger. Courtesy of STFA Construction Co.

Figure 143: Taking Water to the Dry Dock, after the completion of the Caisson Construction. Courtesy of STFA Construction Co.

Figure 144: South TF Caisson Floated, Moored at North TF and submerged to the bottom of the Dry Dock temporarily. Courtesy of STFA Construction Co.

<u>Final Sweep</u>

After the dredging operations, the final sweep of post trenching is planned to be executed by Harrowing method which is towing an I-Beam behind an AHT Tug Boat.

<u>Final Removal of Temporary Bunds</u>

After the completion of the Project and when all caissons are out from the Dry Dock through the approach channel and moored to the Wet Dock, the final removal of the temporary bunds and cofferdam will be started.

Temporary bunds around the Dry Dock area will be removed and the permanent bund will be completed in accordance with the design drawings.

<u>Towing of Caissons from Dry Dock to Wet Dock</u>

First, the caissons will be towed out from the dry dock through the approach channel and to be moored to the designated mooring location (wet dock) approximately 1 Nm from the dry dock (Phase A) as explained in detail in Case Study 4 above.

<u>Shaft Installation at Wet Dock</u>

The remaining part of the WTG footing will be completed at Wet Dock as explained in detail in Case Study 4 above, the Tower part of the WTG construction is planned to be executed in the same manner as the Osmangazi Suspension Bridge Tower Foundations using Double Hull Pinned Shaft to create a composite structure for Tower Part of the WTG Foundation.

Figure 145: Removal of the Sheet Pile Cofferdam and Temporary West Bund. Courtesy of STFA Construction Co.

Therefore, Double Hull Pinned Shaft is planned to be installed on top of the WTG Foundation by using a floating crane, and SCC (Self Compacted Concrete) will be cast by tremie pipes to the inner part of the shaft to create a composite structure between WTG footing and Wind Tower Generator.

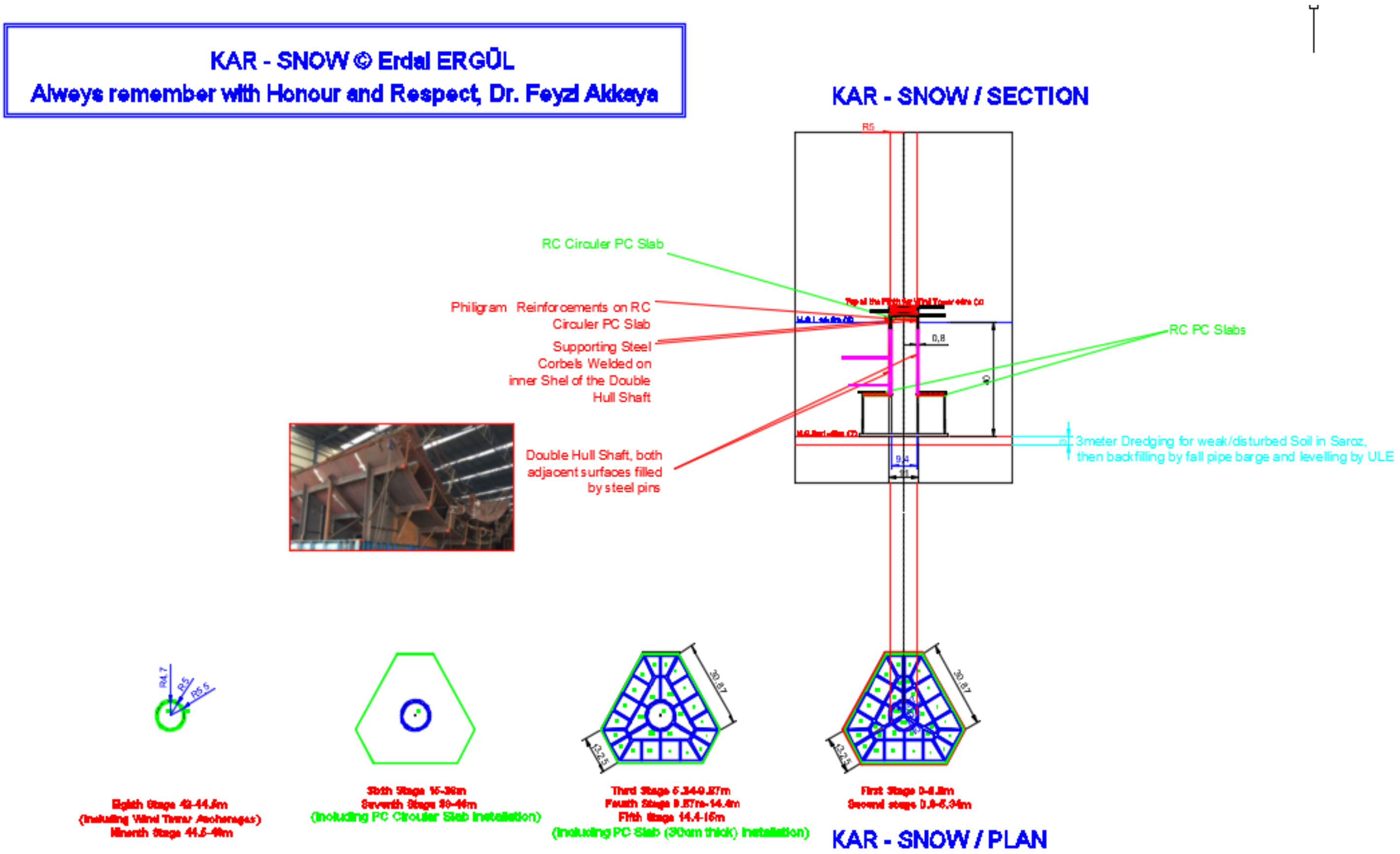


Figure 146: KAR – SNOW GBS Gravity-Based Offshore Wind Foundation

Figure 147: Double Hull Pinned Shaft

Figure 148: Casting of SCC with Tremie Pipes

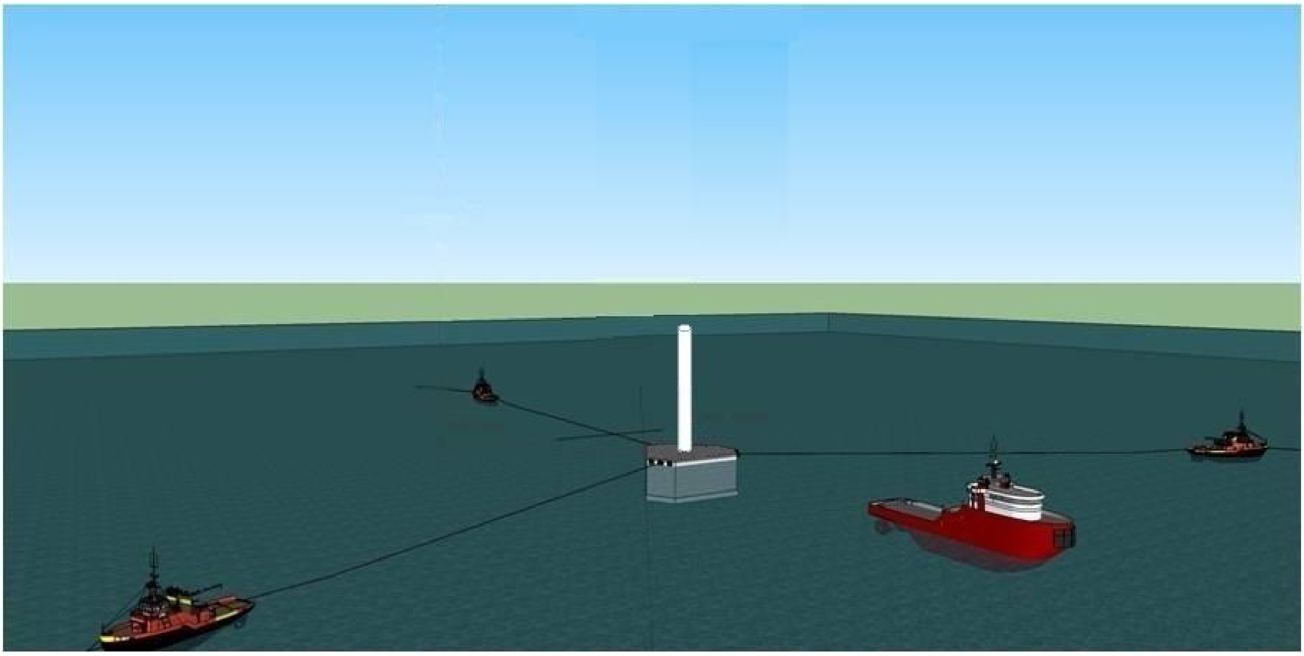


Figure 149: Submersion of the Fixed Bottom (Floating) Type, GBS Caisson Structured WTG Foundations named "Kar-Snow" for Offshore Wind Farms

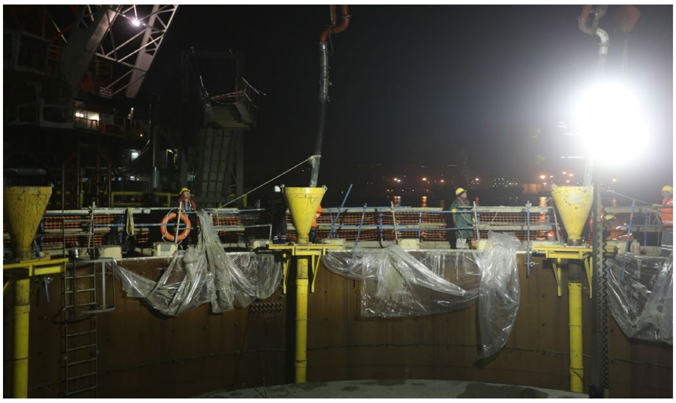
Towage and Submerging of Caissons

After the completion of the construction and the levelling, the foundations will be ready for installation of the caissons that will be towed from the Wet Dock to the permanent location (Phase B).

They will be installed/submerged in a controlled manner as explained in detail in Case Study 4.

COMPLEMENTARY WORKS AFTER CAISSON INSTALLATION

As soon as a caisson is satisfactorily installed, the inner voids between the steel shafts are cast-in-situ with self-compacted concrete using the tremie method.



Figures 150 and 151: Cast-in-situ (SCC) concrete in a shaft by Tremie Pipes and a Floating Crane. Courtesy of STFA Construction Co.

Scour Protection with Fall Pipe using Clamshell and Grab Equipped Floating Equipment

Figure 152: Anti-Scour Rock Placement - Filter Layer (Crushed Stone) by Fall Pipe Barge. Courtesy of STFA Construction Co.

Figure 153: Anti-Scour Rock Placement by Grab-equipped Floating Crane. Courtesy of STFA Construction Co.

Scour Protection of Caissons

After the completion of the submerging operations of the Caissons, anti-scour rock placement is planned to be done by a floating crane with a fall pipe attachment.

Scour protection materials are planned to transport to the WTG Foundations area either by Split Dump Barges or Flat Top Barges.

After completion, some of the below stages of the project will follow (as specified on page 17):

7.5. SUPERSTRUCTURE INSTALLATIONS

7.6. INSTALLATION CONTRACTORS

A Joint Venture of the Construction Companies of the Tenderer is planned to be as an Installation Contractor

7.7. VESSELS (Lift, Transport, Cable Laying, Support Etc.)

7.8 SERVICE/CONSTRUCTION VESSELS

7.9. WEATHER WINDOWS

We deem the Mediterranean Sea and Black Sea as Mare Nostrum in "**Abilik (Brotherhood)" culture** in STFA. This company culture is explained on its website as a ***culture crafted jointly by the founders*** (Dr. Sezai Türkeş MSc. CEng (R.I.P), and Dr. Feyzi Akkaya MSc. CEng (R.I.P)), ***and employees of STFA*** (with me as one of the hundreds of thousands of employees, serving in a total of 25 years between 1989 - 2008 and 2011 - 2017 proudly).

To honour Dr. Feyzi Akkaya MSc. CEng (R.I.P) who created the Marine Calendar and used Acem Naci Bey (Fersiye Hanım)'s Calendar incorporation with Turkiye's SHODB (Office of Navigation, Hydrography and Oceanography - ONHO) data, while most of the Mariner (Seafarer) and Marine Construction People proven its correction (including myself), please see Figure 154.

I used his Marine Calendar and his Guidelines given in "*Şantiye El Kitabı (Construction Site Handbook)*", pp 41 - 50[11] with the incorporation of ONHO (SHODB) below-mentioned data and reports[12, 13] to prepare Project (Saros) Marine Calendar and Downtime Analysis.

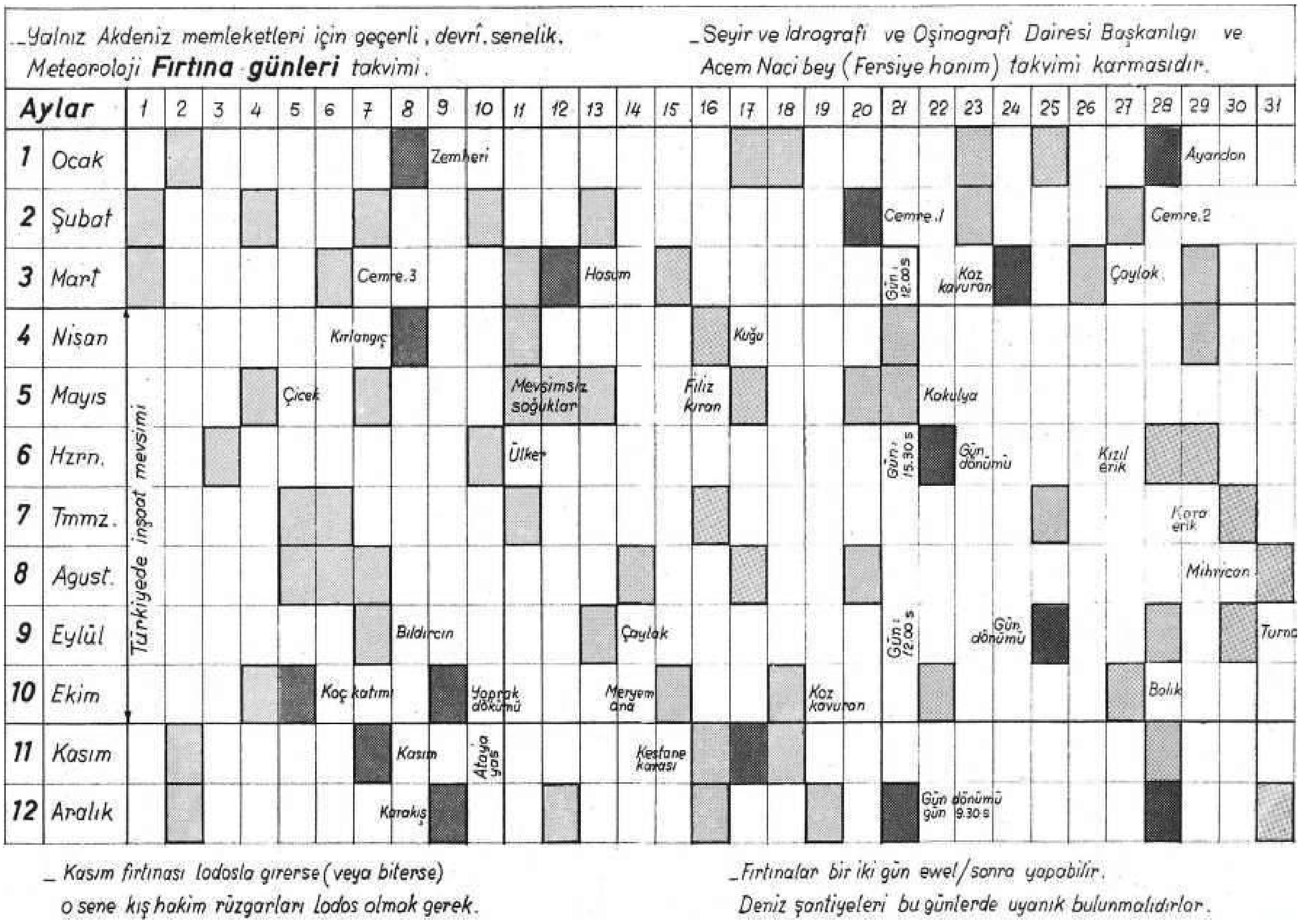


Figure 154: Feyzi Akkaya's Marine Calendar from Şantiye El Kitabı (Construction Site Handbook), page 46. Courtesy of Temel Vakıf (Temel Foundation)

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11 Feyzi Akkaya's Şantiye El Kitabı (Construction Site Handbook) Courtesy of Temel Vakıf (Temel Foundation)

12 DS 22 – O/Ş G Deniz Kuvvetleri Komutanlığı Hidrografi Yayınları (Turkish Navy – Hydrography Publishing), Rüzgar - Deniz – Ölüdeniz ve Dalga Atlası (Wind – Sea –Swell and Wave Atlas) (Çubuklu- July 1984, Second Edition) Dz.K.K. (SHODB) Seyir, Hidrografi ve Oşinografi Dairesi Başkanlığı (Turkish Navy (ONHO) Office of Navigation, Hydrography and Oceanography).

13 Seri No: 83-17 Deniz Kuvvetleri Komutanlığı Hidrografi Yayınları (Turkish Navy – Hydrography Publishing), Ege Denizi Meteoroloji Atlası (Meteorological Atlas of the Aegean Sea) (Çubuklu- 1983) Dz.K.K. (SHODB) Seyir, Hidrografi ve Oşinografi Dairesi Başkanlığı (Turkish Navy (ONHO) Office of Navigation, Hydrography and Oceanography) Agean Sea Wave Height & Surface Currents and Visibility Data of ONHO (1983).

14 Türkiyedeki Rüzgar Santralleri Ocak 2018 (Turkish Wind Power Plant Atlas) (TWPPA 2018) by Türkiye Rüzgar Enerjisi Birliği (Turkish Wind Energy Association) / Türkiye Rüzgar Enerjisi Kurumu (TÜREK)

FULL LIST OF ALL REFERENCES

1 Royal Haskoning-DHV's "Environmental and Social Constraints Mapping for Offshore Wind Farm Sites.pdf" (September 2018)

2 Paper of M. N. Cagatay, N. Gorur, B. Alpar, R.Saatcilar, R. Akkok, M. Sakinc, H. Yuce, C. Yaltirak, and I. Kuscu's, and dated 14 February 1997 (Revised: 12 November 1997), named " Geological evolution of the Gulf of Saros, NE Aegean Sea"

3 Paper of B. ALPAR's, and dated 2001, named "Plio-Quaternary history of the Turkish coastal zone of the Enez-Evros Delta: NE Aegean Sea"

4 Unpublished technical report in Turkish of M. Sumengen, I. Terlemez, K. Senturk, C.Karakose, EN. Erkan, E. Unay, M. Gurbuz, Z. Atalay 's, and dated 1987, named "Stratigraphy, sedimentology and tectonics of the Gelibolu Peninsula and SW Thrace Basin"

5 Paper of Prof. Dr. Mustafa Erdik "Design Basis Ground Motions for the Preliminary Earthquake Resistant Design Of The Wind Turbine Farms In Thrace, Turkey.pdf" (August 2018)

6 Ramboll's "Offshore Wind Project in Turkey - Proposal to Tenderer_1.pdf" (July 2018)

7 Poster of Hina Varshney, Jacob Jensen, and Sidharth Jain's New Foundations for Deeper & Larger OW for MEC Intelligence EWEA Offshore 2015 – Copenhagen – 10-12 March 2015

8 Paper of H. Tasan, E. Ergul, and B. Nacar, The Caissons of The Tower Foundations / Izmit Bay Suspension Bridge Project, dated August 2014, presented at MWWD MWWD 2014 Engineering, Construction, Supervision and Monitoring of Sealines and Coastal Works Seminar

9 Articles of E. Ergul (Vessels for Substructure) and F. Zeybek (Vessels for Superstructure), for "Vessels and Maritime Equipment Used for Construction of Osmangazi Bridge" published at "e-mosty" (International Online Peer-Reviewed Magazine About Bridges "https://e-mosty.cz/" in 20th September 2018

10 Presentation of H. S. Misirlioğlu's dated August 2011, named "Caisson Applications in Marine Engineering"

11 Feyzi Akkaya's Şantiye El Kitabı (Construction Site Handbook) Courtesy of Temel Vakıf (Temel Foundation)

12 DS 22 – O/Ş G Deniz Kuvvetleri Komutanlığı Hidrografi Yayınları (Turkish Navy – Hydrography Publishing), Rüzgar - Deniz – Ölüdeniz ve Dalga Atlası (Wind – Sea –Swell and Wave Atlas) (Çubuklu- July 1984, Second Edition) Dz.K.K. (SHODB) Seyir, Hidrografi ve Oşinografi Dairesi Başkanlığı (Turkish Navy (ONHO) Office of Navigation, Hydrography and Oceanography).

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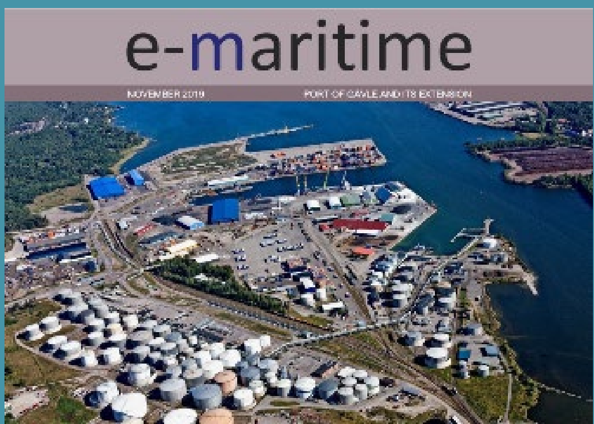

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