Tri-Suction Pile Caisson Foundation Concept

Final Report

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Notice

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Acronyms and Abbreviations

BoD	Basis of Design
CC	Central Column
DEME	Dredging, Environmental and Marine Engineering
DSJ	Double Slip Joint
FID	Financial Investment Decision
ft	feet
HLV	Heavy Lift Vessel
JUP	Jack-Up Vessel
kWh	kilowatt hours
LCOE	Levelized Cost of Energy
MIV	Main Installation Vessel
m/s	meters per second
mT	metric ton
MW	megawatts
MWh	megawatt hours
NDT	Non-Destructive Testing
NID	Nature Inclusive Design
NM	Nautical mile
NYSERDA	New York State Energy Research and Development Authority
OWF	Offshore Wind Farm
PAM	Passive Acoustic Monitoring
PSO	Protected Species Observer
PSV	Platform Supply Vessel
SPMT	Self Propelled Modular Transporter
SP	Suction Pile
SPT	Suction Pile Technology
SWOT	Strength Weaknesses Opportunities Threats
SWP	Self Weight Penetration
T&I	Transport and Installation
TSPC	Tri Suction Pile Caisson
W	watts
WTG	Wind Turbine Generator

Executive Summary

DEME Offshore US LLC (DOUS), with its sister company SPT Offshore, are developing a new foundation type for the US offshore wind industry. The development was funded by a grant from the Department of Energy (DOE) and the New York State Energy Research & Development Authority (NYSERDA) through National Offshore Wind Research and Development Consortium (NOWRDC). The innovative TSPC foundation concept is considered a more technically and commercially attractive alternative for US wind farms than traditional concepts such as monopiles and jackets, particularly for larger turbines and in deeper water. The benefits of the TSPC include a more environmentally friendly installation due to the noiseless and vibration-free suction pile installation method and therefore opening the possibility for year-round installation program. This would allow projects to be completed in one season, resulting in lower mobilization costs and early generation of revenues.

S.1 Initial Market Analysis

DEME started this study by conducting an initial market assessment for a 15MW TSPC in the US Market and assessing any constraints from the US supply chain and port infrastructure along the US East Coast. A comprehensive SWOT analysis was executed, delving into the strengths, weaknesses, opportunities, and threats associated with the TSPC concept. The main advantage in the TSPC lies in its noiseless installation capabilities, made possible through its innovative suction pile technologies. This not only minimizes noise pollution but also opens up environmentally friendly opportunities for transportation and installation (T&I) methods, including the possibility of free-floating the TSPC base instead of relying on traditional barges. However, a notable impediment persists in the form of the lack of readiness within the supply chain, given that offshore wind represents a relatively new market in the United States.

S.2 Basic Design

Chapter 2 delves into the foundational design aspects of the TSPC. This chapter encompasses an analysis of various soil conditions, including uniform sand and layered soil with sand and clay, as well as an evaluation of the stability of the suction piles. Additionally, it addresses the installation capacity, encompassing the required pressure levels, and incorporates Load Resistance Factor Design considerations. The design of the TSPC is predicated on a survival load case scenario with a return period of 500 years. The study examines two distinct types of TSPC: one fabricated from steel and the other partially constructed using concrete, with comprehensive dimensional analyses conducted for both variants.

S.3 Fabrication

The fabrication process has been studied for both steel and concrete versions of the TSPC. The TSPC mainly consist of a central column, equipped with auxiliary secondary steel structures, such as access platform and boat landing, an integration section, being the connection between the suction piles and the central column, and 3 suction buckets. To reduce the crane capacity requirements for installation, another option would be to split the TSPC in 2 pieces and add a double slip-joint to integrate the central column and the base. According to preliminary analysis, the TSPC concept requires an integrated and complex fabrication capacity for structural primary steel and secondary steel with a combination of automated and manual labor-intensive manufacturing processes, however to a lesser extent than jacket fabrication.

S.4 Transport and Installation

In the context of offshore wind, the Jones Act has implications for the transportation of components, such as wind turbine components and foundations, between US ports during the construction and maintenance of offshore wind farms. Ports also need sufficient acreage, quayside length, quayside bearing capacity, navigation channel depth and air draft to safely fabricate, maneuver, load out and transport components to offshore areas. Two T&I methods were defined for the TSPC concept: one utilizing a Heavy Lift Vessel, and the other leveraging the free-floating capacity of the TSPC base. Four scenarios were discussed to transport and install the TSPC:

1) Utilizing feeder barges for transport and a Heavy Lift vessel for installation
2) Utilizing a Jones-Act compliant Heavy Lift vessel for both transport and installation
3) Free-floating de TSPC base, utilizing feeder barges to transport the central column and a Jack-Up vessel for installation.
4) Free-floating the full TSPC and utilizing a smaller Jack-Up vessel for installation.

S.5 Qualitative Cost Analysis

At this stage, the efficiency in the manufacturing process gained by experience is very limited, leading to direct cost-related consequences. In fact, fixed costs such as investments and management costs are negatively impacted at early stages of technologies and manufacturing plants. The preliminary evaluation shows potential costs to manufacture a full TSPC foundation in USA in the range of 2x the costs foreseen in the more mature market of Europe. From a labor perspective, the disparity in costs can be attributed to variations in labor costs between the US and EU regions. Regarding T&I costs, since TSPCs produce no disruptive noise during installation, posing no threat to marine mammals, they are supposed to be exempt from piling restrictions, enabling 24/7 year-round installation in the United States, which creates the prospect of constructing larger wind farms within a single year, thereby accelerating the generation of electricity income. Although the fabrication cost of the TSPC is higher than monopile foundations, the overall LCOE has the potential to be lower when taking into account a single installation season and early revenue generation. Furthermore, the overall LCOE of TSPC is expected to be lower than any other types of noiseless foundations such as suction pile jacket. The innovative nature of the TSPC technology, in the early stages, results in higher risks and greater CAPEX compared to conventional foundations. Notably, while monopiles represent advanced technologies, TSPCs have not even reached the development phase yet. In the long term, when the supply chain is well established on US ground, a higher convergence to the costs of a mature market such as EU is expected. The TSPC concept opens an opportunity for US 'home build' industry of foundations, as this has not matured yet elsewhere in the world and fits well in the US specific regulation (piling ban) and environmental protection (whale friendly).

S.6 Optimizations

Optimizations can be carried out alongside the full EPCI process. The design can be further investigated to create a US supply chain-specific design that comply with near-future capabilities and will reduce both costs and duration of fabrication and of Transport and Installation. In parallel, the supply chain for serial production of large foundation structures would need to be further developed in the US. It is imperative to ensure that both fabrication and marshaling of the product occur at a unified location. Improvements in the T&I methods can be explored through the free-floating tow-out methodology.

S.7 Commercialization Roadmap

A comprehensive roadmap for commercialization has been devised, starting with the research and development phase, progressing through testing and enhancements, and finishing with the full-scale commercialization and expansion of the TSPC.

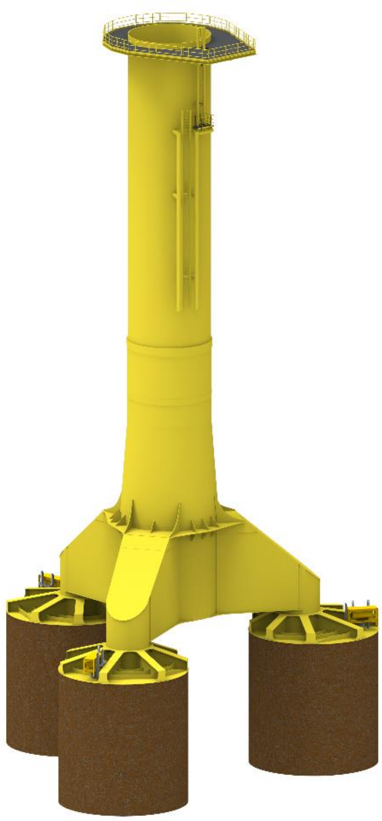
Market Analysis

1.1 Company background

DEME Offshore US and SPT Offshore are developing this revolutionary solution that includes the engineering expertise of SPT with the significant EPCI experience of DEME Offshore. Additionally, the team leverages the considerable resources of the DEME Group, which has over 140 years of experience in the maritime industry and is a world leader in Offshore Wind and one of the world leaders in the Dredging industry. The DEME Group has a highly experienced team of engineers, marine architects, and specialist to complement their significant operations team and fleet of over one hundred vessels. DEME has a proven track record of investing in innovative solutions that create a brighter tomorrow.

Figure 1. Tri-Suction Pile Caisson

Source: DEME Offshore



1.2 The Tri-Suction Pile Caisson (TSPC)

The Tri Suction Pile Caisson or TSPC is a novel foundation type that shares some common characteristics with a traditional monopile foundation. However, the TSPC is installed by a noiseless suction installation process instead of utilizing the piledriving process found in traditional monopile and jacket foundations. The TSPC consists of, see Figure 2 and Figure 3:

- The central column has a similar design as a monopile, including similar secondary steelwork. Similar to a monopile, fabrication cost/mT is low due to the fully automated welding process.
- Split joint (double or single), the connection between the upper part and the lower part of the central column.
- Suction Pile-to-Column interface, the integrating steelwork. This part is envisaged to be made of steel, but in the NOWRDC study, utilization of reinforced concrete is also considered.
- Suction piles that anchor the foundation into the seabed.

Figure 2. TSPC – terminology of components – steel version

Source: DEME Offshore

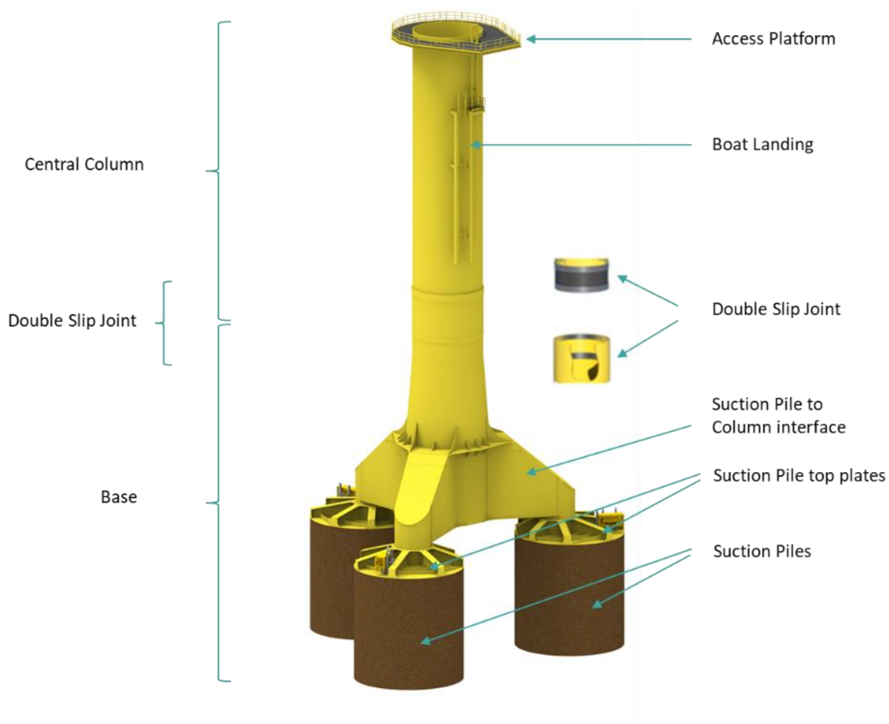
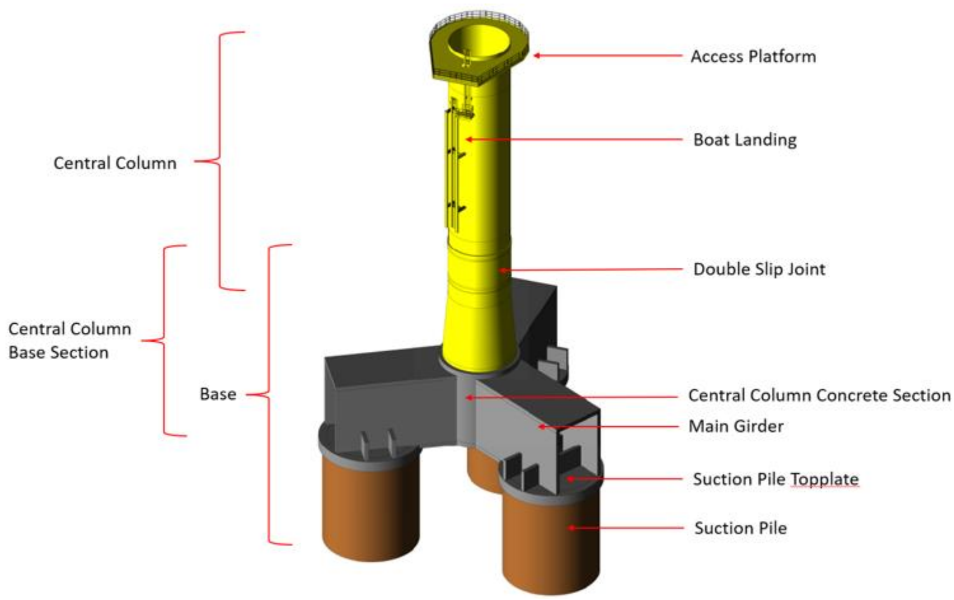


Figure 3. TSPC – terminology of components – concrete version

Source: DEME Offshore



DEME Offshore - SPT sees a growing concern over the underwater noise levels generated by the conventional piledriving process, which poses a hazard to marine mammals (underwater noise) and migrating birds (airborne noise). Recently in Europe (specifically Germany and the Netherlands), projects are subjected to more stringent adherence to the noise level criteria, which in some instances has led to the need to increase the number of noise mitigations systems operating in parallel, leading to costly project delays and the need to hire additional noise mitigation means. The US government has already implemented very restrictive measures such as visibility (night & fog) piling restrictions and seasonal piling bans (November till May) for hammered foundations, thereby protecting the marine mammals again noise emissions from these works. The suction pile foundation is an efficient solution to overcome this noise impact problem. The TSPC can be considered a cost-effective alternative to the conventional suction pile jacket.

1.3 SWOT Analysis

We identified several strengths and opportunities while also highlighting some of the weaknesses and threats to the TSPC concept. The major strength of the TSPC lies in its ability to be installed silently thanks to the suction pile technology. The TSPC concept is considered environmentally friendly compared to other foundation types that generate sound pollution during installation and require more marine assets and larger vessels. This allows for a more flexible all-year installation season as it would not be subject to a piling ban. Opportunities are present within the supply chain's growth potential. Given the expected advances in the coming decade, the onshore and port infrastructure could prove to be sufficient to fabricate the foundations in the US without the significant investment in large steel rolling infrastructure, expensive factories, and the need to retrain an entire workforce. Today, we have seen a limitation to workability and downtime for traditional foundations such as monopiles and jackets due to local legislation and environmental requirements for protected species. Furthermore, existing US manufacturing facilities, port and vessel infrastructure are inadequate to reach the 2030 offshore wind goals set by the Biden administration. The limited availability of installation vessels is partly due to the worldwide growth in demand for offshore wind coupled with technological advances in the industry. As technology improves, larger turbines with higher capacities are being installed, necessitating bigger installation vessels which remain scarce on the market. Finally, developing the supply chain will certainly create jobs but it will be crucial to properly train and certify these workers.

Table 1. Recap of SWOT analysis for TSPC

o Noiseless Installation o Free-floating structure allowing environmental friendly transportation o Suction Pile Technologies time-tested and already present in the industry o Pre-installed secondary steelwork o Pre-installed NID o Compatible with East Coast conditions o Recycling and Circularity **Strengths**	o Currently low TRL and CRL levels o Supply chain constraints o Nascent US market **Weaknesses**
Opportunities o US offshore wind ambitions o Innovation, Future IP, and Potential for Government and Industry Involvement o Local Content and Job Creation o Noise level constraints o CO2 and NOx emission reduction o Supply chain development o Potential lower procurement and fabrication costs compared to SBJ	**Threats** o Price Volatility in the industry o Higher unit prices for fabrication in the US compared to EU, Middle East and Asia o Limited Availability of: ▪ Marine assets ▪ Manufacturing facilities ▪ Ports infrastructure

1.3.1 Strengths

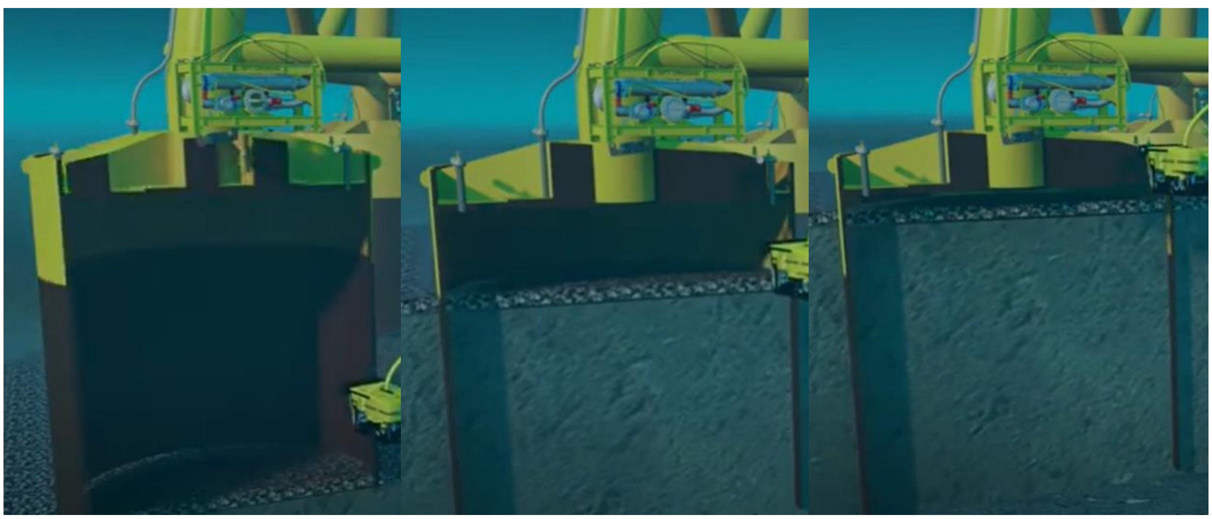
The following section will develop the numerous strengths of the TSPC.

1.3.1.1 Noiseless installation

The TSPC is designed to be noiseless as it is driven/sucked/pumped into the seabed by pumps, see Figure 4. Since the foundation does not require piling, it is not subject to strict noise restrictions and piling bans faced by traditional fixed foundations. Therefore, there would be no schedule constraints during the offshore installation campaign (24 hrs./day, 365 days/year). The 24/7 operations during installation cut down on cycle times, thus reducing prices of the costly MIV, reducing overall emissions. In practice, the underwater noise levels are dictated by the noise of the installation vessel's propulsion system. Likewise, the airborne noise of the generator set of the pump is negligible compared to the noise levels generated by the part of the hammer above water for traditional piling.

Figure 4. Artist impression of the installation process of a suction pile into the seabed in 3 stages

Source: DEME Offshore



1.3.1.2 Free-floating TSPC Base

The particularity of the TSPC design is that it can be split into 2 pieces: (i) a central column, and (ii) a base, connected by a double slip joint. The hydrostatic stability of the free floating TSPC base has been analyzed, based on creating buoyancy in the 3 suction piles. The central column and the main girders, however, have been assumed to be non-buoyant. The suction piles are closed off at the top, by the pre-installed suction pumps and additional valves between the pump and the pump-interface on the suction piles top plate. The bottom of the suction piles is open to sea and therefore the water surface is free to move. Due to the buoyancy of the TSPC base, it can be towed to the offshore site using tugs, offering a more environmentally friendly transportation option as it eliminates the need for a barge. The central column, however, must still be transported on a barge. Nonetheless, since it is similar to a monopile, multiple central columns can be efficiently transported on a single barge.

1.3.1.3 Suction Piles, time-tested technologies

The Suction Pile concept has been widely utilized in the offshore Oil and Gas industry for decades. SPT Offshore installed over 1000 suction piles and anchors since 1997[1]. The TRL of suction pile technology, as the main technology for the TSPC, is TRL 9. However, the combination of various sub-technologies, while envisaging fabrication, transport & installation, and application in the US, is deemed to reduce the Technical Readiness Level (TRL) of the TSPC as a whole.

[1] https://www.worldexpro.com/contractors/drilling-and-well-completion/spt-offshore/#:~:text=Worldwide%20we%20installed%20over%20450,all%20sedimented%20type%20of%20soils.

Figure 5. Legacy Suction Pile Jacket for Oil and Gad Market

Source: SPT Offshore

1.3.1.4 Pre-installed secondary steelwork

The TSPC is installed into the seabed by the suction process, which is a very gentle method to establish penetration of the foundation into the seabed; the accelerations imposed on the structure during installation are negligible. Conversely, piledriving monopiles introduces very high accelerations to the structures, which therefore hardly allow any structures to be welded to the monopile, unless specifically design to sustain these loads.

The absence of high accelerations (and fatigue due to hammer impact) during TSPC installation allows pre-installation of secondary steelwork on the assembly yard; as a rule of thumb, the cost of installing structures onshore is around $^{1}/_{10}{}^{th}$ of the cost seen for installation of the same component offshore. This will result in a significant reduction of installation costs. In addition, due to reduction of offshore time for the main HLV and the absence of additional installation vessels, greenhouse gas emissions will be reduced.

Secondary steelwork involves inter alia the access platform, internal platforms, boat landing, crane, internal- and external ICCP system, temporary TP cover. Pre-installation of these items, prior to transport to the OWF, saves a significant amount of offshore vessel time.

1.3.1.5 Pre-installed Nature Inclusive Design (NID)

Likewise, the suction process allows pre-installation of Nature Inclusive Design (NID) on the TSPC structure, aiming at improving the marine habitat by attracting particular species of fish, shellfish, and marine growth. NID could consist of inter alia, specific coatings, fish shelter spaces, crab cages, and oyster breeding nets. By pre-installing the NID, no separate installation vessel is required for this task, and as consequence CO2, and NOx emissions are minimized.

1.3.1.6 Compatible with US East Coast conditions

The TSPC solution optimizes its potential in the target market by relying on specific soil conditions (sand and clay) abundant along the US East Coast and harnessing time-tested suction pile technologies.

1.3.1.7 Recycling and Circularity

Suction pile foundations are completely removable at the end of life (by pumping out), which allows recycling of the steelwork or even circularity by partially re-using components of the TSPC, such as the suction piles. Compared with monopiles, portions of the structure could stay on the seabed indefinitely. During decommissioning, the foundations will not be left behind like traditional piled solutions. This leaves the seabed similar to its original condition and allows for upcycling and recycling of metals that are becoming increasingly difficult to mine and environmentally unsustainable. Therefore, from an environmental and sustainability point of view, the TPSC is the optimal solution to meet growing market demand while facing a scarcity of resources.

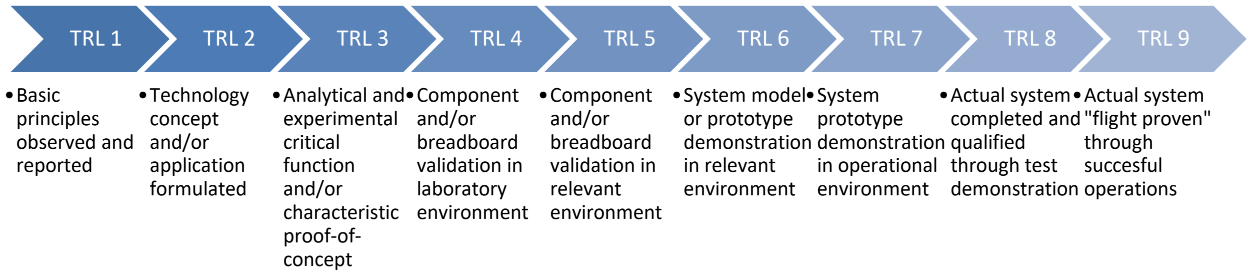
1.3.2 Weaknesses

This chapter lists some of the potential weaknesses of the TSPC foundation concept for the US offshore wind market.

1.3.2.1 Low Technical Readiness Level (TRL)

The Technology Readiness Level (TRL) scale provides an indication of the maturity of a certain technology. The generally accepted TRL scale covers nine levels as schematically depicted in Figure 6.

Figure 6. Definition of TRL



Although the Technical Readiness Level (TRL) of the different sub technologies, where the TSPC is based upon, are relatively high, the combination of these sub technologies is deemed to have a TRL of around 2 at the start of this study.

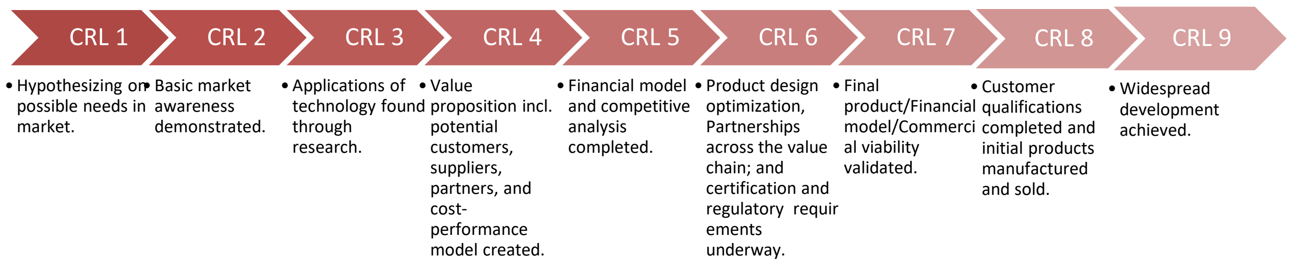
Table 2. TRL status per TSPC sub-technologies

Sub technology	Status	TRL
Suction pile installation	SPT has successfully installed over 1000 suction piles, without any single failure.	9
Suction pile as foundation for WTGs	Up to today around 250 suction pile foundations for WTGs or substations have been installed. In the coming 2 years another 200 pcs are anticipated to be installed and ready for operation.	9
Split Joint	Approval in principle from Lloyd's granted for the Double Slip Joint (KCI the engineers). The single slip joint has been tested offshore by a consortium of i.e., TU-Delft, Van Oord, Heerema Nov 2021.	6-7
Free floating tow out	In principle tow out of floating structures is well proven. In case of a TSPC-shaped vessel, tow out of Floating wind semi-subs can be regarded as an analogy. Nevertheless, stability and dynamic behavior are to be model tested for better understanding.	3-4
TSPC, as a combination of existing techniques	Innovative technology in study phase	2-3

1.3.2.2 Commercial Readiness Level (CRL)

The Commercial Readiness Level measures how a new product/technology is ready to be made commercially available, starting from the belief a new technology could be commercially successful all the way through to full regulatory compliance, commercial availability, and wider acceptance within the target market. The different levels are illustrated in Figure 7.

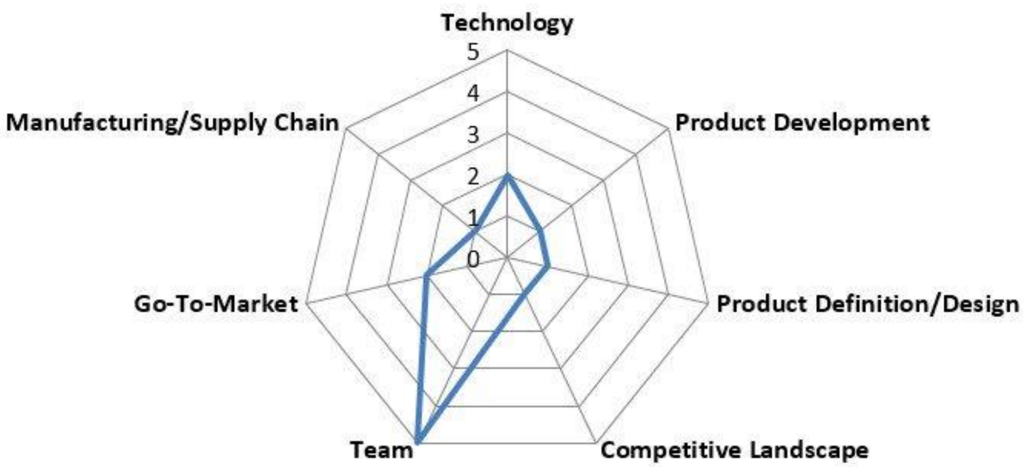
Figure 7. Definition of CRL



Prior to start of the NOWRDC TSPC development, the CRL of the TSPC foundation concept and the transport and installation methodology were calculated at CRL 1, see also the TRL/CRL radar plot from the calculator in Figure 8.

Figure 8. TRL and CRL radar plot

Source: ARPA-E model



1.3.2.3 Supply chain constraints

Today, there are still numerous supply chain challenges hindering the development of TSPC in the United States. This is partly because it's a new market and benefits from experience in manufacturing processes and standardization are still be materialized, compared to more mature markets such as Europe. Currently, conventional monopiles serve as the predominant foundations for installation, and as TSPC represents an innovation, it will only become competitive as it reaches a more -advanced development stage. Additionally, the TSPC is a substantial structure, necessitating large installation vessels with ample crane capacity for its installation. Such vessels are presently unavailable in the US and are in short supply globally due to high demand. It is safe to assume that there is ample time to develop the supply chain before the TSPC can commercially enter the market. it can be expected that, in the near term, many of the

European fabricators will establish themselves in the US and develop a supply chain for large steel rolling (2-4 inches and above) to support monopile production. This supply chain will thus benefit the TSPC and increase the commercial viability of serialized production.

1.3.3 Opportunities

The section outlines both the opportunities the TSPC could bring to the US market, and opportunities for US offshore wind supply chain.

1.3.3.1 US Offshore Wind ambitions

As widely recognized, the Biden Administration has set ambitious goals for the offshore wind industry in the US, aiming to achieve 30 GW of installed capacity by 2030. In addition, many states have set their own very optimistic goals and have begun to significantly invest in infrastructure, training, and the supply chain to bolster the Offshore Wind industry.

This new industry which is set to construct several wind farms per year, opens infinite possibilities to all the players – from designers to contractors, fabricators, O&M specialists, small fleet owners, and environmentalists. Moreover, many of the large international companies and market leaders on a global scale have established themselves in key geographic locations in the US to support the burgeoning industry. This allows for a jumpstart in the sector as companies with decades of experience bring their knowledge and expertise to the local supply chains allowing the industry to bypass some of the growing pains of a new market.

Furthermore, it presents significant prospects for the local workforce, as it is poised to generate numerous employment opportunities in the coming years. It also opens a door for innovation through research and development initiatives, where the TSPC could potentially have a crucial role in the future.

1.3.3.2 Innovation, Future IP and potential for government and industry involvement

The TSPC is an amalgamation of time test technologies utilizing cutting-edge engineering to harness environmentally friendly, fully capable, and economical solutions. Although the design of this concept is currently in its early stages, it is poised for further developments in the next decade. As is typical with any innovative design, progress takes time as new technologies, tools, materials, and other tangible advancements emerge. This gradual evolution will enable the TSPC to expand into alternative foundation forms or potentially be utilized in ways that are presently beyond our imagination.

1.3.3.3 Local Content and Job Creation

For both traditional foundations and the TSPC concept, there are many opportunities for supply chain development that maximizes local content in the Engineering, Fabrication, Transportation & Installation and maintenance stages. The current generation and next generation XL monopiles serve as the building blocks for the US to develop a local supply chain, train tradespeople and fully develop a labor force of skilled workers. Experienced fabricators, leaders in the EU market, are already busy or looking to create US based fabrication facilities, which will also create numerous job opportunities[2].

Building the TSPC in the US will require extensive amounts of raw steel, rolling, welding, and construction. Moreover, extensive labor force will be required to coordinate onshore activities with regards to logistics and final assembly in the marshaling facilities. Figure 9 provides a list of potential identified services available nationally and locally. Some services may be too specific to source within a limited area, so they may need to be outsourced from subcontractors and vendors located elsewhere in the U.S. This variability creates a grey area between the two Local Content classifications; for example, feeder barges, assist tugs, and maybe scour protection can be sourced on both the State and National level. Some of the locally available services also refer to services that are more applicable for further specialization through Diverse Supplier classification, encouraging efforts to strengthen support of small and diverse subcontractors, vendors, and suppliers.

[2] https://eew-group.com/company/our-facilities/eew-aos-philadelphia/

Figure 9. List of offshore wind potential local and national services

Furthermore, there are plans for US Flagged Jones act support vessels to be built in addition to the current fleet of Barges, Tugs, PSVs, and AHTs, creating opportunities for US based maritime companies and further utilizing local ports, bunkering, vessel agents and suppliers. The first Jones Act-compliant, US based installation vessel, the Charybdis, is currently being built in Texas. Completion of vessel construction and sea trials are expected to take place in 2025. The vessel will feature a main crane with a boom length of 130 meters and an expected lifting capacity of about 2,000 mT. Compared to the world market, these US build marine assets are more expensive and, in some cases, less technologically advanced than the vessels available in Europe or Asia. However, much like the onshore infrastructure needed to support the industry, we foresee new assets being built to support the industry by the time the TSPC is commercially available.

It is also important to note that as the market gravitates toward XL Monopiles in the near future, it is safe to assume that much of the required infrastructure to facilitate commercial scale use of the TSPC will be built out, and sufficient capacity for raw materials, fabrication, marshalling, and installation will already be established. Given that the TSPC requires a significant amount of rolling, welding, and onshore assembly, we foresee that the economic impact from local content will be a major advantage for the TSPC and allow for significant job creation during the fabrication stage and progressive lower cost over time. The current US projects will not only lead the way for the nation's offshore wind industry as "First Movers" into the industry where significant gains will be made, but also significant challenges will have to be overcome. As such many of the major challenges that must be addressed before a fully operational industry can thrive, will have already been confronted, and innovative ideas such as the TSPC will be able to serve as a second mover and capitalize on the lessons learned by the current generation of wind farms. This opportunity requires both the cooperation of the federal government and state governments. Moreover, a unified approach to the supply chain from a regional consortium of states would be ideal. Thus, each state could capitalize on the strengths of services, infrastructure and natural resources needed to support the industry. Whereas the current trajectory at the time of writing is that each state (while working with others and communicating with others) wants to host the "National Hub" for the whole industry.

1.3.3.4 Noise level restrictions

As noise levels are becoming an increasing concern (see Marine Technology News), the increased interest by governments to protect marine mammals from waterborne noise and migrating birds from airborne noise is an excellent opportunity for the noiseless suction pile technology of the TSPC.

The main wind turbine foundation concepts used worldwide in the offshore wind industry are monopiles and pre-piled jackets. For both concepts, piles need to be driven into the soil up to a specific target depth, which results in very high Sound Pressure Levels. To protect marine life from this emitted noise, government agencies have imposed limits on Peak Sound Pressure levels (LPeak) and Sound Exposure Levels (SEL05).

For driving the piles to target depth, the main solution today is using a large size impact hammer. The emitted Sound Pressure Level is depending on several parameters (driving energy, water depth, soil properties, pile dimensions, etc.). The most dominant parameter to predict the emitted Sound Pressure Levels is the pile diameter, as it is directly linked to all other parameters. The more the pile diameter increases, the more the measured noise level values increase.

Reflecting on projects undertaken during the latter half of the 2010s, the prevailing norm for monopile diameters stood at 6 meters. At present, the prevalent monopile design entails a foundational diameter of 9.5 meters. Looking ahead, the trajectory indicates an inevitable progression toward even more expansive dimensions. This shift is propelled by the swift advancement in wind turbine size, ensuring that the market will soon witness further amplification in monopile proportions.

Today the United States have introduced a range of strategic measures introduced to ensure the harmonious coexistence of offshore wind projects and marine ecosystems. These measures encompass diverse approaches, including the imposition of vessel speed limitations and a seasonal prohibition on turbine pile driving activities typically spanning December 1 to April 30, which directly affects the progress of the installation work. This strategic window avoids the period when right whales exhibit their highest concentration in the project vicinity. In addition to the ban, the project developer must deploy qualified specialists such as protected-species observers during pile driving operations. These observers are to be stationed on the pile driving vessel, with a minimum of two observers present at all times. Furthermore, in a bid to comprehensively monitor the potential impacts of the project on marine life, Passive Acoustic Monitoring has also been mandated. This method involves the recording of both ambient noise levels and the vocalizations of marine mammals within the lease area—prior to, during, and subsequent to construction activities. The overarching goal is to meticulously assess the ramifications of vessel noise, pile driving noise, operational noise from wind turbines, and to systematically document instances of whale detection within the designated wind development zone.

However, using impact piling for installing monopiles above 10m diameter will create an uncomfortable situation whereby the noise emissions, even with several abatement systems working in parallel, is expected to reach the noise limits imposed by the authorities. As previously detailed, currently fixed bottom foundations include the installation of monopiles or pin piles via impact hammer, with the implicit noise emissions created with this methodology.

The TSPC emerges as a remarkable catalyst, holding substantial potential for the offshore wind sector's environmental footprint. This innovative design, rooted in suction pile technologies, offers an elegant remedy to the prevailing challenges concerning noise limitations in offshore wind operations. Concurrently, it stands as a solution to mitigate the distress inflicted upon marine mammals due to the conventional piling of foundations. The unique characteristic of this novel foundation lies in its gentle noiseless installation process, whereby it is delicately lowered onto the seabed by activating a series of pumps, minimizing adverse impacts on marine ecosystems. The noiseless installation procedure inherent in TSPCs grants them the flexibility to operate throughout the entire year, avoiding the necessity for impact hammer-driven piling. Consequently, both nighttime and winter operations can be seamlessly executed without disruptions. The quiet anchoring process, achieved through suction, ensures the TSPCs' connection to the seabed without causing disturbances to marine wildlife or impairing the auditory faculties of marine mammals. Likewise, the noiseless decommissioning process leaves the seabed unaltered —a swift reversal of pressure retrieves the complete suction piles, leaving behind an undisturbed underwater landscape.

1.3.3.5 CO2 and NOx emission reduction in installation phase

Worldwide, governments focus on the reduction of Green House Gas emissions, like CO2 and a reduction of NOx in relation to avoiding endangering biodiversity. Overall, although offshore wind operations have significantly lower CO2 and NOx emissions compared to traditional fossil fuel-based energy sources, there are some indirect emissions associated with offshore wind operations, such as those related to manufacturing, installation, maintenance, and decommissioning of wind turbines and associated infrastructure. These emissions can include those from the production of materials like steel and concrete, transportation of components to offshore sites, and the energy required for construction and maintenance activities. NOx emissions can also occur during certain phases of offshore wind operations, such as during the manufacturing of turbine components and vessels, transportation of materials and equipment, and operation of support vessels and machinery.

Regarding the manufacturing phase of the TSPC, it is not anticipated to yield lower CO2 emissions compared to other traditional foundations, primarily because of the substantial size and thus the requirement for a significant amount of steel during fabrication. Nevertheless, no studies have been conducted to date to quantify this impact, and as such, we cannot confirm any specific emission figures at this time.

The decommissioning phase of the TSPC is expected to have lower emissions compared to foundations using non-suction pile technology. This is because the entire structure is pumped out of the ground, leaving no residual impact on the soil, and enabling a potential recycling of the steel components.

Concerning the installation of the TSPC, opportunities exist to reduce those emissions in the following cases:

- The use of a smaller offshore installation fleet will burn less fuel.
- 24/7 Operations will reduce overall installation time and use of offshore fleet.
- If fabrication yards are developed near offshore windfarms in the US, mainly the East Coast, no need for cross-Atlantic shipment.
- Reduction of transportation spread of all the components if fabrication centralized.
- No double big bubble curtain vessel and -compressors are needed since installation is noiseless.
- Depending on the installation method, more onshore than offshore works.

1.3.3.6 Supply chain development

Figure 10 below shows the investments required in the supply chain to meet the annual demand for major components in 2023, according to NREL's latest report, *A Supply Chain Road Map for Offshore Wind Energy in the United States* published in January 202 . These domestic developments naturally come with job creation.

Figure 10. Cumulative investment over time in the major components of a domestic offshore wind energy supply chain, retrieved from NREL's 2023 report on A Supply Chain Road Map for Offshore Wind Energy in the United States

Source: Shields, Matt, Jeremy Stefek, Frank Oteri, Sabina Maniak, Matilda Kreider, Elizabeth Gill, Ross Gould, Courtney Malvik, Sam Tirone, Eric Hines. 2023. A Supply Chain Road Map for Offshore Wind Energy in the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-84710. https://www.nrel.gov/docs/fy23osti/84710.pdf.

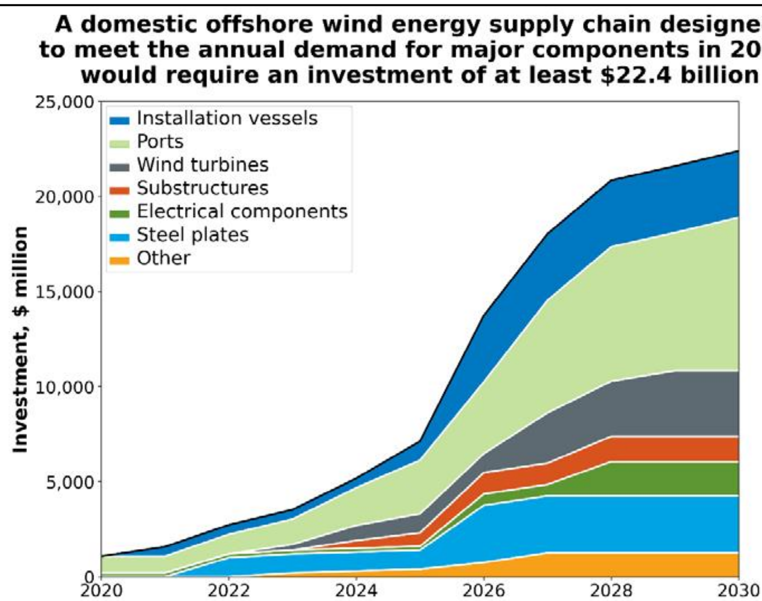


Figure ES2. Cumulative investment over time in the major components of a domestic offshore wind energy supply chain.

Note: Installation vessels include wind turbine installation vessels and heavy-lift vessels, which could be U.S.- or foreign-flagged[2], and specialized feeder barges, which must be U.S.-flagged. Ports include fabrication and marshaling ports.

The TSPC has the potential to create local jobs and positively impact local economies in the Engineering, Fabrication, and Transportation & Installation and maintenance stages. With regards to the TSCP fabrication on US ground, it will require extensive amounts of raw steel, rolling, welding, and construction. Moreover, regarding logistics and final assembly in the marshaling facilities, we foresee the need for a labor force to coordinate onshore activities. Additionally, there will be a need for Jones Act compliant vessels to tow the structures; a supply chain built around supporting the marine spread (Pilots, provisions, bunkers, agents) will also contribute to the local economy and employment. In general, we have found several aspects of the supply chain to be sufficient in supporting growth within the US Market.

For both traditional foundations and the TSPC concept there are many opportunities for supply chain development that maximizes local content. The current generation and next generation XL monopiles serve as the building blocks for the US to develop a local supply chain, train tradespeople and fully develop a labor force of skilled workers. Experienced fabricators, leaders in the EU market, are already busy or looking to create US based fabrication facilities, which will also create numerous job opportunities[3]

However, as depicted in Figure 10, substantial investments in fabrication facilities, providers of premium raw steel, and steel rolling facilities (with a diameter of 4 inches or more) within the US region will be imperative to meet the market demand for both the present and forthcoming generations of Monopiles and Jackets. Without such investments, a considerable portion of the required resources will likely have to be procured from foreign suppliers. Fortunately, the Biden Administration is actively promoting the advancement of clean energy manufacturing while simultaneously fostering job creation, as indicated in a press release from the White House on July 20th, 2023. The release states that "Since President Biden took office, companies have announced 18 offshore wind shipbuilding projects as well as investments of nearly $3.5 billion across 12 manufacturing facilities and 13 ports to strengthen the American offshore wind supply chain, representing thousands of new jobs".

Following conversations with various US fabricators, it can be inferred that the successful fabrication of a TSPC, which necessitates a greater amount of steel compared to a monopile for equal turbine capacity, within the United States will also be contingent upon the extent of national investments directed towards offshore wind fabrication facilities. Concrete fabricators also stand to benefit from potential opportunities, as the integration piece of the TSPC can also be constructed using concrete. Presently, to the best of our knowledge, the number of concrete fabricators in the US that possess the necessary expertise to undertake the construction of such a sizable structure on a commercial level is rather limited.

It is also important to note that as the market gravitates toward XL Monopiles in the near future, it is safe to assume that much of the required infrastructure to facilitate commercial scale use of the TSPC will be built out, and sufficient capacity for raw materials, fabrication, marshalling, and installation will already

[3] https://eew-group.com/company/our-facilities/eew-aos-philadelphia/

be established. Given that the TSPC requires a significant amount of rolling, welding, and onshore assembly, we foresee that the economic impact from local content will be a major advantage for the TSPC and allow for significant job creation during the fabrication stage and progressive lower cost over time.

The current US projects will not only lead the way for the nation's offshore wind industry as "First Movers" into the industry where significant gains will be made, but also significant challenges will have to be overcome. As such many of the major challenges that must be addressed before a fully operational industry can thrive, will have already been confronted, and innovative ideas such as the TSPC will be able to serve as a second mover and capitalize on the lessons learned by the current generation of wind farms. This opportunity requires both the cooperation of the federal government and state governments. Moreover, a unified approach to the supply chain from a regional consortium of states would be ideal. Thus, each state could capitalize on the strengths of services, infrastructure and natural resources needed to support the industry. Whereas the current trajectory at the time of writing is that each state (while working with others and communicating with others) wants to host the "National Hub" for the whole industry.

As a summary of this overview, a brief SWOT analysis on the supply chain in presented below:

Strengths • Project Management and integration capabilities (also from other mature industries) • Logistics and site proximity	**Weaknesses** • US emerging market - long-lead set-up (id, permitting, etc) • Long learning curves are expected. • High level investments affecting FOU costs
Opportunities • Leverage on existing capacity – available from other industries • Labor market – job creation	**Threats** • Alternative foundation concepts competition • Market capacity saturated with mature foundations

It is expected that the supply chain will benefit from the leverage on the existing local capacity gained in other manufacturing industries such for example Oil & Gas and related subindustries, shipbuilding, and civil construction.

The offshore wind market is expected to create new job opportunities in the future to complement the required skills. The US market is currently perceived as an emerging market, several players are setting up their yards which is considered as a long-lead process considering the location identification, permits approval, investment plans' actualization and related activities. It is also expected that the fabrication yards will undergo a long learning curve process before significant cost improvement can be seen in the manufacturing processes. Today, offshore wind foundations for offshore wind farms are manufactured overseas and transported to the US[4]. In the future, when fabrication yards are operational and learning curves effects embedded in the fabrication processes, it is expected that the US market will be able to satisfy the domestic demand.

It is possible that alternative foundation concepts are going to be deployed to serve the offshore wind industry, therefore close attention should be addressed to the available capacity on the market. Further analysis on the US market considering raw material supply, manpower and labor costs, governmental subsidies and import duties is recommended.

1.3.3.7 Potential lower procurement and fabrication costs compared to suction pile jackets

Due to the significant noise pollution generated during monopile installations, there is a chance that next generation monopiles might not be able to meet the current noise regulations. In that case or when site conditions do not allow for an efficient or practical monopile design, the exploration of alternative, quieter solutions for offshore wind development will be necessary. At present, the primary alternative available is the deployment of suction pile jackets, which have already seen successful implementation in Europe and Asia. When comparing the intricate design, including nodes, of suction pile jackets with that of TSPC structures, it becomes evident that TSPCs are expected to offer cost advantages in procurement and fabrication. This cost-efficiency is primarily attributed to their simpler structure, which closely resembles that of a tripod and monopile. In fact, the complexity of the jacket is governed by the number and size of nodes, where bracings interface with the jacket legs, which requires complex 3D dressing and manual welding of the interface. The TSPC, and particularly the central column and the central part of the base, consists to a large extent of steelwork that is completely similar to that of a monopile, which allows fabrication in a fully automated rolling line in horizontal position without the risks embedded in working at height.

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[4] https://www.vineyardwind.com/

1.3.4 Threats

This section lists the (external) threats that the US conditions can bring for the introduction of the TSPC in the US market. Threats to the TSPC mirror those of the current overall industry with supply chain constraints, limited infrastructure, shortages of vessels, and raw material price volatility. However, given the order book of wind farms that will be installed over the next two to five years and the learning curve that will have already occurred for the local industry, we feel confident that many of these will turn into strengths or opportunities. However, at the time of writing, there has been a lack of tangible investments into the supply chain and critical infrastructure. Specifically, port development (dredging to proper water depths and laydown areas with sufficient load-bearing capacity), advances in technology and ability for fabrication facilities and adequately training a labor force. While many states and localities have developed programs to address this, each state has its own goals and metrics. Thus, a unified approach to the industry at the federal/industry level as a whole is needed to properly allocate resources to not only benefit the development of the TSPC but also - the greater industry as a whole.

1.3.4.1 Price volatility in the industry

As seen recently with global events, we are experiencing extreme price volatility, inflation, and a lack of raw materials. While the present is not necessarily an indicator of what is to come for the industry, it is essential to note the increased demand for renewable energy with a disproportionate investment in building infrastructure and support systems to advance the supply chain, including but not limited to raw materials, fabrication facilities and technology, and installation asserts.

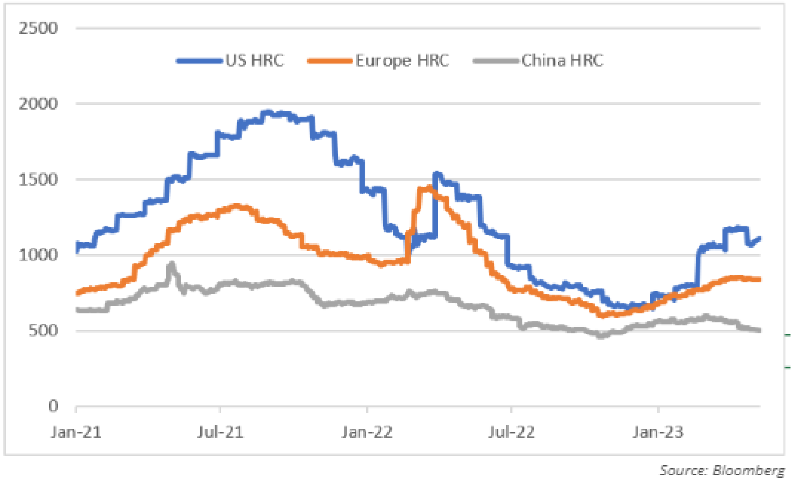
1.3.4.2 Higher unit prices for fabrication compared to the EU, Middle East or Asia

Figure 11 shows the steel price evolution in Europe, the US, and China from 2021 to 2023. Steel cost has risen by 180% compared to pre-pandemic levels.

Several reasons explain this trend. Firstly, there is a shortage of raw materials essential for constructing wind turbines. As the global shift towards achieving net-zero emissions gains momentum, the demand for materials crucial to renewable energy sources is on the rise, resulting in price hikes. Secondly, the escalating cost of oil has had a cascading effect on raw material prices. Geopolitical events, such as the turmoil in Eastern Europe since February 2022, caused a significant surge in oil prices. Elevated oil prices inevitably lead to an increase in the costs of raw materials. Moreover, the conflict in Ukraine has directly disrupted supply chains, impacting the availability of crucial materials like steel, which are vital for manufacturing wind turbines. Lastly, the expanding global energy infrastructure gap is a contributing factor to the surging costs of raw materials. Governments worldwide have invested billions in energy infrastructure development, further driving up the demand for raw materials required for these projects. Unfortunately, the raw material market is presently unable to meet the infrastructure demand, as it takes up to a decade to establish new material mines. Consequently, the prices of currently available raw materials continue to rise.

Figure 11. Steel prices evolution 2021-2023

Source: Ryerson, https://www.ryerson.com/resource/the-gauge/global-steel-prices-2023



1.3.4.3 Limited availability of Marine Assets, Manufacturing facilities, Ports

Marine Assets

Currently, we are facing a shortage of available vessels not just in the US but at the global level. The demand for offshore wind farms is increasing worldwide as countries, and entire regions begin to invest in developing renewable energy further. Moreover, the technology is advancing at such a pace that current assets will not be viable for the next generation of turbines and foundations as they increase in size. Additionally, with the required lead time to develop a new vessel, it is incredibly difficult to predict if the vessel would be sufficient for the next generation of technology. Fortunately, the TSPC mitigates this by harnessing the bouncy of the structure when floating to lower the required crane strength and vessel size. This means that the number of vessels capable of installing the TSPC is significantly increased. However, given the current demand and projections for the future there will need to be a significant investment made into building up not just the US but the worldwide fleet of installation vessels.

Manufacturing facilities

As identified in NREL's latest report, *A Supply Chain Road Map for Offshore Wind Energy in the United States* published in January 2023, it is imperative to develop manufacturing facilities on coastal sites with a laydown area (storage and facility footprint) of over 40 acres and quayside infrastructure for loading and unloading of finished components and materials. This holds particularly important for the TSPC structure, which boasts a substantial weight of 2,450 mT, depending on specific site conditions. Due to its size, it cannot be efficiently transported overland and must instead be assembled at facilities situated on coastal sites.

Ports infrastructure

Water depth

To allow free floating tow out of the TSPC, with a minimum under keel clearance of 2 m to avoid contact between the seabed and the bottom rim of the suction pile, the water depth in the port and waterways from the port to deeper waters offshore is required to be minimum:

- For the steel version: 10+2 = 12 m
- For the concrete version: 14+2 = 16 m

To avoid the need to schedule on tides and thereby avoid schedule constraints, the minimum water depths listed above are to be taken Lowest Astronomical Tide (LAT). Unfortunately, the available water depth in US ports will pose a limitation to the possibility for free-floating the TSPC to deeper waters.

Quay space

The space consumption of one TSPC, incl. corridors for mechanical handling, is expected to be around 2500 m² for each TSPC and thus for a typical offshore windfarm of 68 pcs this would amount to 170,000 m². To allow for storage area of components, assembly, inspection, offices, logistics, load out space, it is expected that the required space for marshalling is assumed to be approx. double, thus 350,000 m².

Bearing capacity

The required bearing capacity for the TSPC depends on load spreaders used at site and the capacity of the SPMTs, but generally, 15 t/m² is deemed sufficient.

Air draft

The required air draft for the free floating TSPC is around 35 m, whereas for a typical oceangoing tug this will be around 25 m (down ended nav mast); thus the TSPC defines the minimum required air draft along the tow route.

Other boundary constraints

When developers look for suitable areas for offshore wind, several factors are considered such as distance to shore – the nearest, the better – water depth – the shallowest, the better – and nominal wind speed – the highest, the better – among others. While a shallow water depth is beneficial due to shorter foundations and therefore, less fabrication costs, several restrictions apply for extremely shallow areas offshore. While this factor is usually not a problem – most wind farms are deep into the ocean such that water depth is greater than the maximum draught for installation vessels – several considerations must be taken into consideration related to the draught of the installation vessels.

In particular, two situations are of special consideration:

- Port facilities: although the Jones-Act creates a situation on which the installation vessels will not sail to an US port to load either foundations or wind turbine generators, these installation vessels must come onshore several times during the execution of an offshore wind farm to load goods (water, food), perform crew transfers and to refuel (bunkering).
- En-route: due to the above, specifications of the access channels must also be taken in consideration. In this regard, to factors are of importance:
    - Water depth → draught
    - Air-draft → clearance with regards to vessel height

Therefore, port authorities, local stakeholders, and governmental authorities must ensure that water depths in both the port and the access channel are suitable for the fleet required for the offshore wind installation fleet. While there is only one Jones-Act compliant vessel in the pipeline (Charybdis, Dominion) which will be able to load out wind turbine components and foundations at the port and install them at the offshore wind farm, the industry is planning to 'feed' the foreign installation vessels via Jones-Act compliant spread, including barges and supply decks. Regardless of the selected transport spread, air-draft limitations are of utmost importance. In particular, transition pieces ranging between 14-17 meters and wind turbine towers ranging between 125 - 160 meters when transported in a vertical position offer a challenge when sailing across the access channels since most of these channels are crossed by highway bridges. The air-draft is therefore compromised, altering either the sailing routes – longer sailing distance, implying more spread required to feed the main installation vessel constantly – or the methodology – components transported in a horizontal position instead of standard, vertical position. This potential issue applies to all foundation concepts, including fixed bottom (monopiles, jackets), floating concepts, and innovation concepts such as TSPC.

2 Basic Design

2.1 TSPC design

2.1.1 Design Basis

For the design of the TSPC, the following has been assumed as basis:

2.1.1.1 General

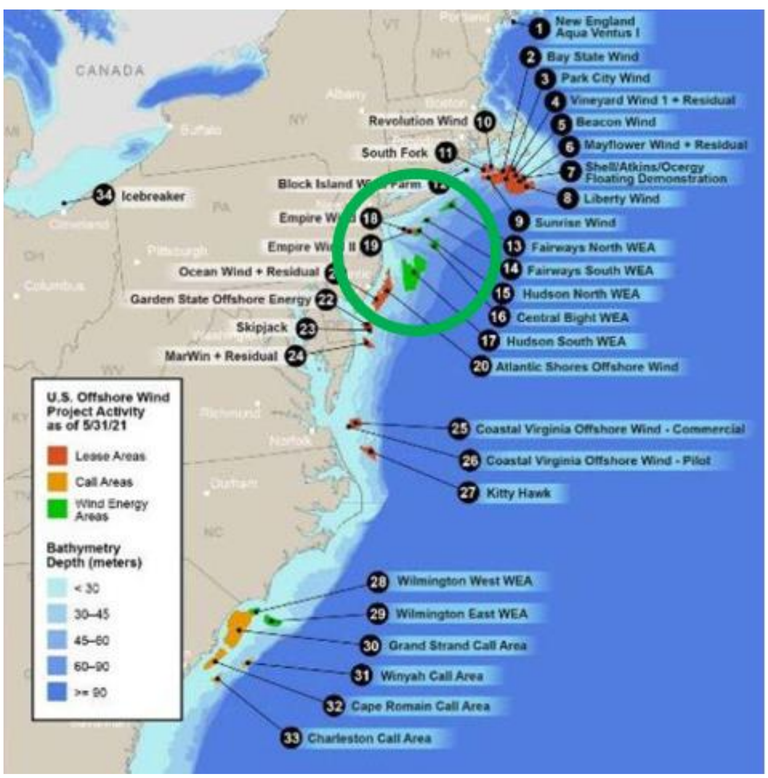
- Wind Turbine generator size: 15 MW, 240 m rotor diameter, hub height 150 m Lat
- Water depth:40 m
- Design Codes and Guidelines: the DNV codes and Recommended Practices, Combined with ABS, Bottom Founded Offshore Wind Turbines

2.1.1.2 OWF location

Location: East Coast US, specifically New York Bight Area, see Figure 12 for the indicative location of the New York Bight OWF area.

Figure 12. Indication location of New York Bight area

Source: https://cleanenergy.org/



2.1.1.3 Environmental data

For the environmental data used for design of the TSPC, see table below.

Table 3. Environmental conditions

Variable	1-year extreme	50-year extreme	500-yr survival	Units
Water depth high	40 + 2.2 = 42.2	40 + 2.7 = 42.7	40 + 3.0 = 43.0	mLAT
Water depth low	40 – 0.5 = 39.5	40 – 1.1 = 38.9	40 – 1.5 = 38.5	mLAT
Significant wave height	6.0	10.0	11.0	m
Wave period	11.0	14.0	15.0	s
Current speed surface	1.0	1.2	1.2	m/s
Current speed seabed	0.4	0.5	0.5	m/s
Wind speed, 100mMSL, 10-min	32.0	44.0	63.0	m/s

2.1.1.4 Soil data

For the soil data, two soil cases have been studied, covering about 50% of the area, see Table 4 and Table 5. The first profile resulted in the larger and heavier Suction pile and thus the results shown further are conservatively based on this profile.

Table 4. Soil Case 1: Uniform sand profile

Formation	**Unit**	**General Description**	**Deposition Environment**
Late Holocene	A	Medium to Dense SAND	Marine
Early Holocene	B	Very Dense SAND	Marine
Late Pleistocene	C	Medium SAND	Estuarine

Table 5. Soil Case 2: Layered profile

Formation	**Unit**	**General Description**	**Deposition Environment**
Late Holocene	A	Medium to Dense SAND	Marine
Paleochannel Infill	D	Stiff to very Stiff CLAY	Fluvial
Early Holocene	B	Very Dense SAND	Marine
Late Pleistocene	C	Medium SAND	Estuarine

2.1.2 Design scope

The TSPC design presented in this report has been checked for the following load conditions:

- Suction Pile Installation
  - Stress check
  - Buckling check
- Ultimate Limit State extreme 1-yr and 50-yr environmental loads
  - Stress check
  - Buckling check
- Survival Load Case storm 500-yr environmental loads
  - Plastic strain
  - Buckling check
- Stress Concentration Factor calculation of the most critical welds
- Eigenfrequency check of total system

2.1.3 In place capacity analysis summary

The soil material factors 1.15 for Sand and 1.25 for Clay were used for in-place capacity analyses, for monotonic and static loading. To account for cyclic soil degradation and strain accumulation, a cyclic factor of 1.1 was used as contingency, based on SPT project experience. As a result, the unity check (UC) was defined as:

$$\boldsymbol{UC = FoS/(\gamma_{m,sand} * 1.1)}$$

For the selected suction pile dimensions (after several iteration steps) and TSPC configuration, in-place capacity verification checks were conducted, based on the Mudline loads. The HSM-ss and NGI-ADP models were used in the detailed design phase for Soil Cases 1. The final In Place Capacity (IPC) Unity Check is presented below:

Table 6: Optimized Suction Pile Dimensions for Soil Cases 1

Soil Case	Pile Dimensions			Thickness		IPC
	Outer Diameter	Minimum Embedded Length	Total Shell Length	Shell	Top Plate	UC
#	[m]	[m]	[m]	[mm]	[mm]	[-]
1	12.5	12.5	14.0	45	40	0.95

2.1.4 Installation analysis summary

Installation verification was conducted for the final TSPC suction pile dimensions. The most probable (MP) and maximum expected (ME) installation under pressure, removal overpressure and self-weight penetration (SWP) depth are summarized in Table 7.

Table 7. Installation Verification

Soil Case	Self-Weight Penetration		Installation Pressure		Removal Pressure	
	MP	ME	MP	ME	MP	ME
#	[m]	[m]	[kPa]	[kPa]	[kPa]	[kPa]
1	0.67	0.49	169	312	236	431

Figure 13 presents the expected and limit pressure profiles during installation and Figure 14 presents the expected removal pressure profiles. Installation under pressures is within buckling and available maximum pressure limits. Self-Weight Penetration is higher or close to 0.5 m which is the required length for successful sealing.

Figure 13. Required MP and ME installation underpressure, buckling limit and maximum achievable underpressure

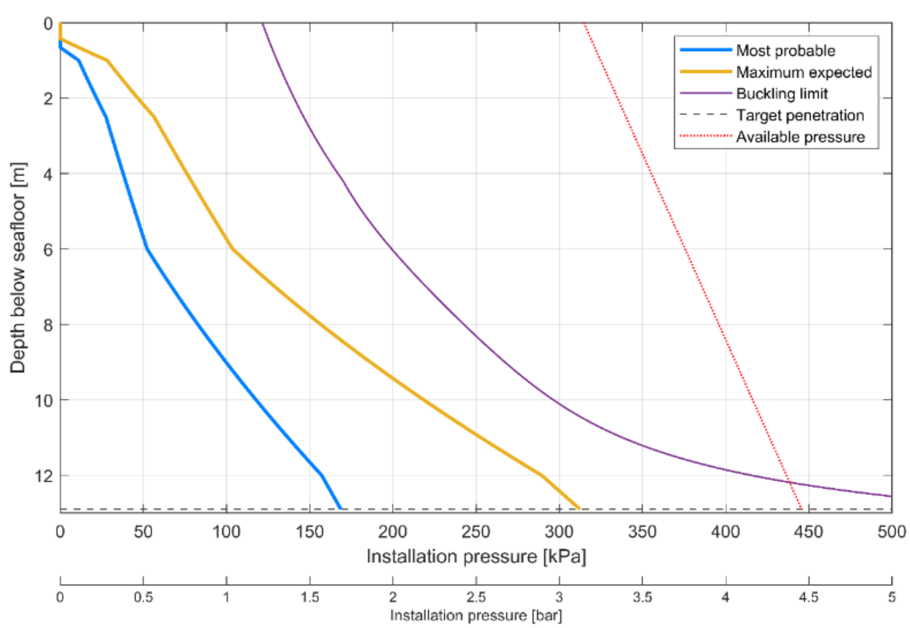
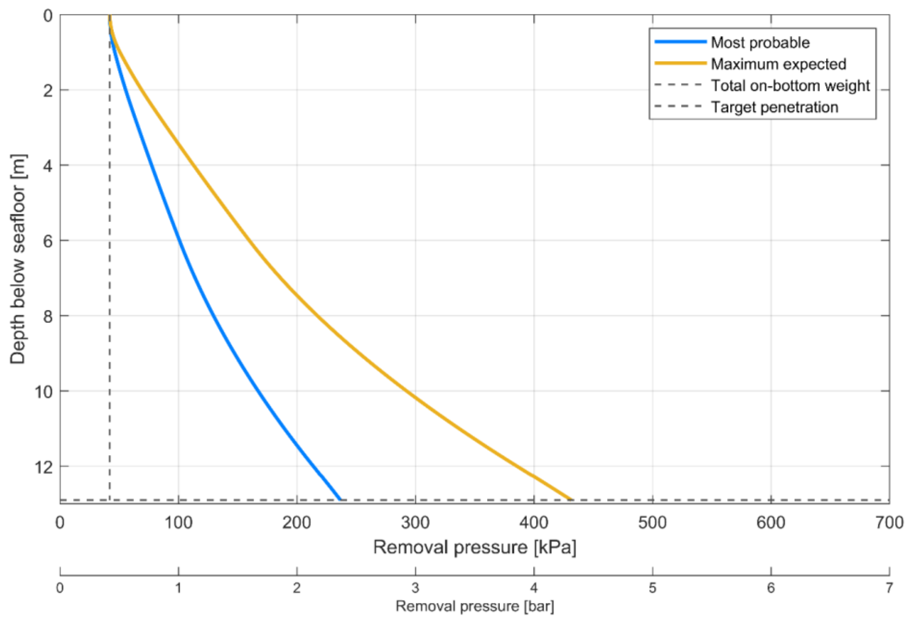


Figure 14 Soil Case 1 (Sand): Required MP and ME removal overpressure



2.1.5 Stress check summary

Load Resistance Factor Design (LRFD) methodology has been followed. An overview of combined Unity Check (UC) of the central column for both stress and buckling for the Ultimate Limit State load cases can be found in Table 8 for the five highest Unity Checks. For definitions of the analyzed sections of the TSPC, see Figure 15.

Figure 15. Analyzed sections of the TSPC

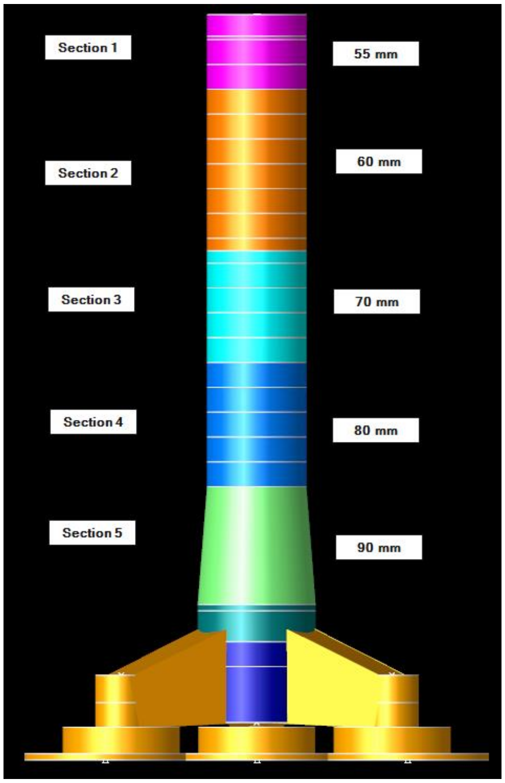


Table 8. TSPC UC overview for ULS LCs in SACS

Section	Thickness [mm]	Max combined UC
Section 1	55	0.79
Section 2	60	0.79
Section 3	70	0.71
Section 4	80	0.67
Section 5 (cone)	90	0.64

An overview of combined Unity Check (UC) of the central column (CC) for both stress and buckling for the ULS load cases can be found in Table 9 for the seven highest Unity Checks. Eigenfrequency calculation was only done for the Survival Load Case.

Table 9. TSPC UC overview for SLC in SACS

Section	Thickness [mm]	Max combined UC
Section 1	60	1.00
Section 2	65	0.98
Section 3	70	1.00
Section 4	80	0.94
Section 5.1 (cone)	98	0.95
Section 5.2 (cone)	91	0.95
Section 5.3 (cone)	90	0.84

2.1.6 TSPC overall dimensions – steel version

For the steel version of the TSPC, see General Arrangement and MTO 20204001—SPT-STR-DRA-1001 in Appendix A.

The overall dimensions are in summary:

- Overall system height: 73.5 m
- Extreme width: 49.5 m
- Suction pile spacing: 24.5 m (center to center)
- Suction pile dimensions: 12.5 m dia x 14.0 m height x 45 mm thickness
- Overall Dry Nett Weight: 2433 mT (incl secondary steel and Double slip joint)

2.1.7 TSPC overall dimensions – concrete version

For the concrete version of the TSPC, see General Arrangement and MTO 20204001-2-SPT-STR-DRA-1101, 20204001-2-SPT-STR-DRA-1102, 20204001-2-SPT-STR-DRA-1103, 20204001-2-SPT-STR-DRA-1104 in Appendix B.

The overall dimensions are in summary:

- Overall system height: 73.5 m
- Extreme width: 51.5 m
- Suction pile spacing: 24.5 m (center to center)
- Suction pile dimensions: 12.5 m dia x 14.75 m height x 45 mm thickness
- Overall Dry Nett Weight: 4516 mT (incl secondary steel and Double slip joint)

2.2 Recommendations

2.2.1 Structural Steel version TSPC

2.2.1.1 Structural steel weight

Reduction of the overall weight of structural steel, by:

1. Structural optimization of the main girders:
    a. The length/width/height ratio to be optimized for the same capacity.
    b. Consider the option to taper the width of the Main girder towards the tip.
    c. Analyze the effect of incorporating openings in the main girder web plates and girder tip in low stress areas.

d. Investigate the option to introduce automated welded stiffeners to allow reduction of wall thickness of flanges and webs.

2. Optimization of the central column (CC):
    a. Study option of reducing the size of the bottom plate CC.
    b. Analyze the potential benefit of a straight CC, instead of a conical section (which is approximately twice as expensive compared to straight)
    c. Improve central column sizing more efficiently based on mono-pile design with thickness steps of 1mm instead of 5mm and maximizing OD/t ratios that are acceptable based on manufacturing capabilities.
3. Optimization of Suction Pile wall thickness over height (currently uniform).
4. Fatigue analysis to be reviewed to see if conservatisms could be reduced safely and base the analysis on actual WTG load data from the supplier. Further, reduce critical weld SCFs presented in this report, by local adjustments in the design.
5. Optimize nesting of plates (mainly applicable to Main girders and suction pile top plate and -girders)
6. Seek an alternative for the Double Slip Joint; analyze cost of the Single slip joint, grouted connection, and the option to separate between SP and Main girder.
7. Optimize the coating specification / number of coating layers, in relation to increasing the ICCP system capacity to minimize corrosion protection system costs.

2.2.1.2 Secondary steel weight

Cost reduction of secondary steel:

1. Re-design the supports for the Internal platforms without taking into account the pile driving loads; this will lead to less and less complex supports.
2. Re-design the internal platforms for onshore installation (instead of offshore), to eliminate guides and installation features.

2.2.1.3 Labor

Reduction of labor cost, by:

1. Minimizing weld volume
2. Design for automated welding of certain details, with specific focus on the Main girders, SP top plate incl girders and the SP shell.
3. Optimize assembly method to maximize horizontal welds during the fabrication and assembly.
4. Design for fillet welds instead of full penetration welds where possible

2.2.2 Structural Concrete version TSPC

1. The steel version TSPC design has been taken as a basis for the design of the concrete version. The loads on the structure (interface loads), the central column dimensions, the Suction Pile dimension, and the soil stiffness reactions (FSM) are all based on the steel version design. A further finetuning by considering the impact of the overall dimensions and weight of the concrete connection element is recommended.
2. The TSPC may include a double slip joint from an installation and stability perspective. The installation and stability aspects of the TSPC with concrete base are quite different due to the increased weight and dimensions. Due to this, the advantage of a double slip joint in comparison to a conventional above water bolted connection might be different as well.
3. The Concrete base showed different loading behavior of the Suction Piles compared to the steel base, dominantly in horizontal direction. Further finetuning by formulating the Foundation Stiffness Matrix using a load path more consistent with the concrete base structure loads is recommended.
4. The higher submerged weight of the concrete connection element is expected to result in potentially smaller diameter and shorter suction piles.
5. Only the critical cross sections are verified at this stage of design, resulting in typical concrete reinforcement and connection details. It shall be noted that these sections typically represent the maximum reinforcement layouts whilst less critical sections are of relevance for the average and minimum layouts. Further analysis of all sections is required to provide an overall realistic reinforcement layout.
6. The full main girder cross section is extended to the end of the suction piles in order to keep several installation options open. By adding a closure structure, the box elements could add buoyancy during installation. Omitting parts of the top plate and walls of the box at the free end of the beam is possible from a structural perspective. Recommended is to investigate whether additional internal buoyancy is required for increasing the hydrostatic stability in free floating mode.
7. The connection between the concrete lid (ring beam) and the suction pile shells is designed with a double-sided joint consisting of dowels and brackets. Further finetuning by more detailed analysis (structure-soil interaction) is required to verify the anticipated load paths in more detail. Potentially, the brackets can be omitted, reducing the overall connection height.
8. Interaction of the steel central column and the concrete base has not been analyzed in detail. Recommended is to check the steel central column for buckling at the transition from steel to concrete. In addition, potential wall thickness reduction of the steel central column at the bottom is to be investigated.

9. The overall corrosion protection strategy is not considered in detail at this stage of design. A concrete reinforced structure has good corrosion resistance properties compared to steel structures, potentially lowering the use of cathodic protection systems.
10. No FLS and eigenfrequency analysis are performed. Further investigation is required to assess the impact of the concrete base on the overall eigenfrequencies and structural responses.

2.2.3 Geotechnical aspects

2.2.3.1 Suction pile dimensions

Optimization of the suction piles dimensions by geotechnical analysis:

1. Perform cyclic analysis, instead of using an assumed cyclic factor (of 1.1) for in-place capacity checks. Given the predominantly cyclic nature of offshore wind turbine foundation loads, a more detailed incorporation of soil stiffness degradation and strain accumulation is to be performed. Model testing can be considered for confirmation of the analysis.
2. Analyze the effect of increasing Suction Pile interspacing on the weight of the Main girder plus Suction Pile for sandy soils; the lower tensile loads on the luff side is expected to result in a reduction in Suction Pile overall size.
3. Conversely, for clayey soils, it could be considered to reduce the suction pile centre-to-centre distance, resulting in a more clustered suction pile formation and, potentially, a global failure mechanism (suction piles and inner soil plug) and a reduction in TSPC overall weight.
4. Perform an independent SLS check (with unfactored loads) to allow decoupling from the ULS safety factor; potentially this would result in a more optimized and less conservative geotechnical TSPC design. (a serviceability limit state (SLS) loading condition check was not part of the study scope, and thus the safety factor for in-place capacity ultimate limit state (ULS) checks was determined based on a maximum suction pile top plate displacement criterion, in order to provide a certain level of confidence that the proposed concept TSPC design can accommodate deflection limitations for offshore wind turbine support structures).

2.2.3.2 Suction pile grouting

Analyze the effect of short duration upward loading, as well as long duration downward load (weight) on the Suction Pile capacity in both directions; this may potentially eliminate the need for Suction Pile top plate grouting for certain soils.

2.2.3.3 Scour protection

1. Consider taking into account effect of the weight of the rock-based scour protection on increased capacity of the soils surrounding the suction pile.
2. Reduction of potential scour by reducing local water particle velocity around the structure by including suppression members on the Main girders and around the SPs (check by CFD).
3. Analyze technical and commercial viability of pre-installed frond mats systems (either the rigid steel frame, or the pump deployed design) v/s conventional rock placed scour protection.

3 Fabrication

3.1 Market assessment

With the aim of understanding the readiness of the US market to manufacture the TSPC foundation concept, a preliminary market investigation was conducted utilizing large fabricators capable of managing the complex requirements and sophisticated supply chain required to fulfill the fabrication processes.

During our communications with the supply chain and potential fabricators, we were able to only secure high-level replies to our RFQs. We understand the reasons for this to be two-fold. Much of the data would be made public as the activities around our request corresponded to a government funded grant. Furthermore, there was no guarantee of an immediate financial benefit for the supply chain to invest substantial resources in conducting their own research and development on an innovative concept that had not yet been introduced in the US market. These factors were not the only drivers to our lack of response. Our evaluations have revealed that the ability to manufacture even basic and well-established offshore wind structures in the US is still at an early stage and requires more time for development. Hence, the initial hesitation from potential vendors to share information can be attributed, in part, to limited resources, current capabilities, and the absence of any contractual or financial incentives.

The US market is in its earlier stages of manufacturing structural steel components to feed the Government plan of deploying 30GW by 2030 and 110GW by 2050[5]. Stronger engagement and active participation are to be expected from the supply chain when the permit processes and US State-wide auctions are officially launched for specific offshore wind sites. (See article: Smoother Sailing To 30 Gw By 2030: Proposed Enhancements To Offshore Wind Permitting Process)

The considerations above clearly underline the US supply chain for offshore wind farms as an emerging market with the related implications linked to new technologies, manufacturing learning curves and amortization of investment and fixed costs. The US market is not yet at the level of maturity required to deliver complex foundations, such as the TSPC. However, we did find interest from a few select fabricators who provided preliminary feedback. Thus, we would take a positive outlook toward the future viability of the local supply chain as fabrication shifts to the US from developed markets such as the EU, Middle East and Asia.

In order to create trust by the US market in the TSPC concept a demonstration project is key.

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[5] https://www.utilitydive.com/news/department-energy-strategy-offshore-wind-plan/ .

3.2 TSPC fabrication analysis

3.2.1 Process

As previously mentioned, the design of the TSPC can be adapted to project specific needs and thus the fabrication process will depend on whether the structure will be made in 1 piece or 2 pieces.

If it's made in 1 piece, the TSPC will be composed of, see Figure 2 in section 1.2:

- A central column, equipped with auxiliary secondary steel structures, such as access platform and boat landing.
- Integration section, being the connection between the suction piles and the central column, made in steel or, as alternative, in concrete.
- Suction buckets, for a total of 3 pieces per foundation.

To reduce the crane capacity requirements, another option would be to split the TSPC in 2 pieces and add a double slip-joint to integrate the central column and the Base. In this case the TSPC would be split into:

- A central column, equipped with auxiliary secondary steel structures, such as access platform and boat landing.
- A base, consisting of the three suction buckets, and the integration structure.

Based on preliminary analysis, the TSPC concept requires an integrated and complex fabrication capacity for structural primary steel and secondary steel with a combination of automated and manual labor-intensive manufacturing processes.

From a fabrication point of view, the TSPC concept design considered in this study can be analyzed as follows:

Item	**Main dimension**	**Weight (mT) – per foundation**
DWG ID: dry net weight contingency not included		
Central column – primary steel	H 35.8m; Diameter: 8m, No conical sections	520 mT
Integration structure – primary steel	H 27.1m	983 mT of which Shell: 386.65 mT (incl. 50% weight for Conical section)
Suction piles – primary steel	Shell H16m; Diameter: 12,5m	3*296 mT of which Shell: Approx. 65% weight
Secondary steel	---	42 mT of which boat landing: 24 mT; Access platform: 18 mT
TSPC	**Overall height: 73.5m**	**2,433 mT**

	Footprint 37m	

This type of foundation requires ability from the supply chain to:

- manufacture primary steel tubulars up to 15m diameter which is considered a technological challenge from the start of the art monopile fabricators in Europe and Asia where offshore wind farms are an established market;
- In relation to the integration structure sections, to build a complex primary steel structure around a small section of the monopile and extending its structural steel arms to the suction buckets;
- make available sufficient manpower with manufacturing skills and large fabrication space to accommodate a structure that could reach a footprint of approx. 25m
- locate a convenient and well-equipped offloading facility for further integration of the TSPC with heavy lifting capabilities.

3.2.2 Fabrication methodology for steel version

From a fabrication methodology perspective, the TSPC combines the application of serial production with highly automated machinery and labor-intensive manufacturing processes as summarized below:

Section	**Fabrication processes**
Central column (CC)– primary steel	highly automated, fast serial production, horizontal construction
Integration structure – primary steel	use of prefabricated components such as shell, manual labor intensive
Suction piles – primary steel	highly automated, serial production, vertical construction, manual labor intensive for the top shell; possible internal reinforcement needed
Secondary steel	use of prefabricated components, manual labor intensive

The central column will be fabricated in a serial production environment with a fully automated manufacturing growing lines in horizontal position.

The secondary steel structure such as access platform and boat-landing will be fabricated and assembled on ground and mounted on black steel before undergoing the application of necessary painting layers.

The suction piles will be fabricated in a serial production environment with fully automated manufacturing growing lines in vertical position due to the different ratio between diameter and height of the section to avoid deformations in the manufacturing process. The top-plate section that will accommodate the base of the integration section requires intensive manual labor and painting application, and it does not involve the use of rolling equipment.

The integration structure can be seen as a steel column with conical and cylindrical sections, and 3 girder arms connecting to the main body. The column sections will be fabricated in a serial production environment with fully automated manufacturing growing lines in horizontal position. The three girder arms will require an intensive manual labor process before being mounted to the steel column in horizontal or vertical position. The integration structure will then be painted according to design specification and requirements.

Joining together, raising, and final assembly of the 3 main components, namely central column, integration structure and suction piles, is to be performed in a yard capable to accommodate the final product (bearing capacity – ground) and equipped with heavy lifting cranes. The assembly consists of 5 main steps (including primary and secondary steel):

For the base structure:

1) Build the individual suction piles with top plate and girders (3x)
2) Assemble the 3 suction piles with the central sub-column into 1 base unit.
3) Mount all the secondary steel (anodes, suction interface, grout piping, etc.)

For the central column:

1) Fully automated welding and NDT in horizontal orientation
2) Mount all the secondary steel (boat landing, platform, anodes, Davit crane, etc.)

The structure will have to be built on blocks or grillage to allow SPMT's to transport the items to the quayside. The final assembly of the TSPC foresees the lifting of the integration structure of approx. weight 1,000 mT on the suction piles (see Figure 16), and consequently central column of approx. weight 600 mT (including the secondary steel) on the integration structure and suction piles previously assembled (see Figure 17).

The final product is then ready to be transported via SPMT onto the barge and sail to the final destination.

Figure 16. Final assembly process of TSPC base

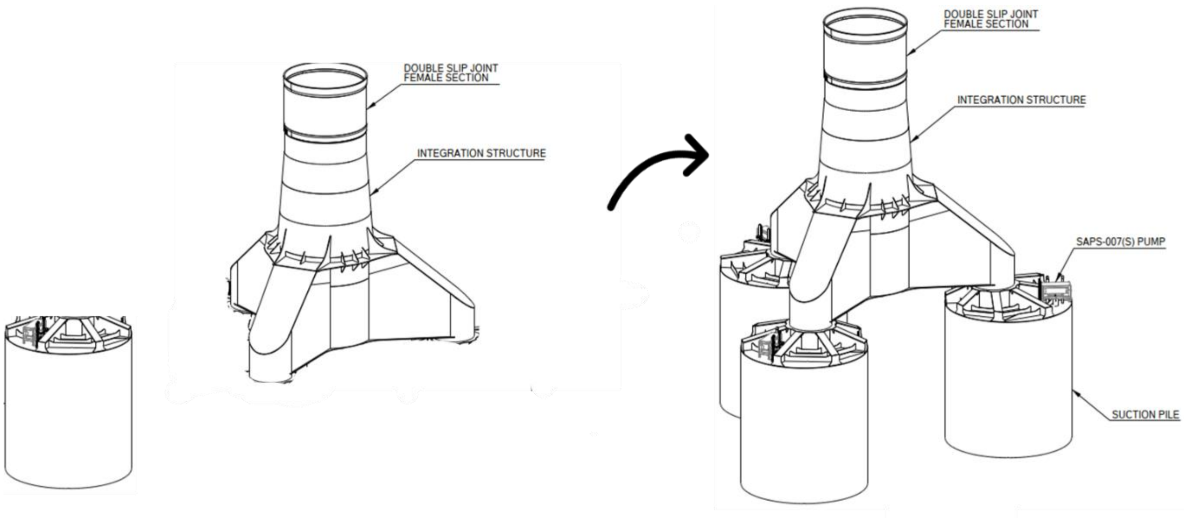
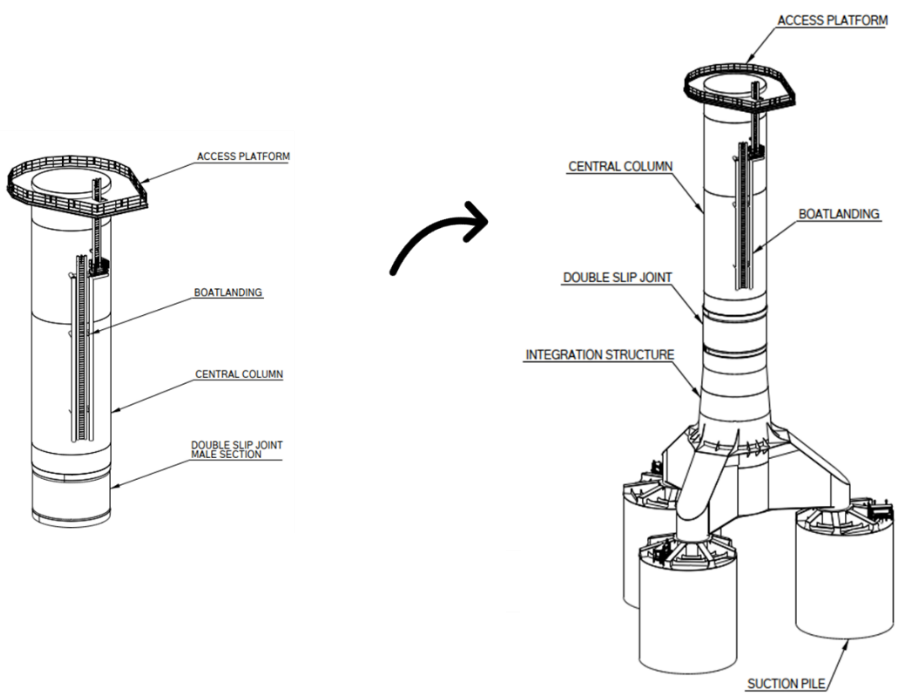


Figure 17. Final assembly of central column



Currently, in order to have a preliminary estimation, the following approximative indications have been considered as basis of the planning:

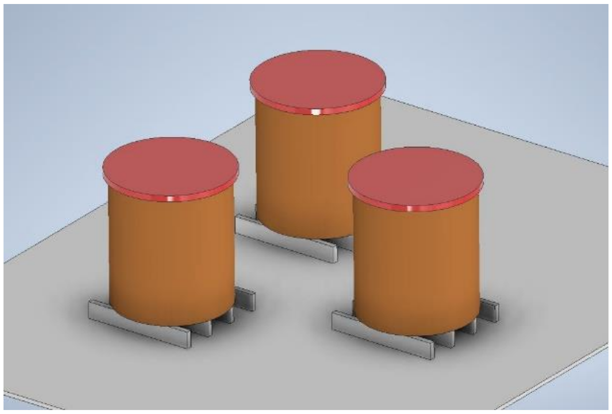
- 2x Tier 1 Fabricators to serve the installation planning
- lead time of 6 months for engineering, primary steel ordering and 1st pieces ready
- approximately 24 months of fabrication and assembly
- TSPC output rate fully assembled: 2 Foundations ready to pick-up per month.

3.2.3 Fabrication methodology for concrete version

Coastal Precast Systems was consulted regarding the specific details of the concrete version, and they offered a comprehensive explanation of the manufacturing procedure.

Initially, the cylinders (orange colored) will be placed up on 1.5 m tall dunnage for easier transportation later. The red section in the below picture are concrete lids. These lids will have seven permanent 24x84WF beams welded to the top for added strength and to make the forming and pouring process easier.

Figure 18. 3 suction piles made of steel

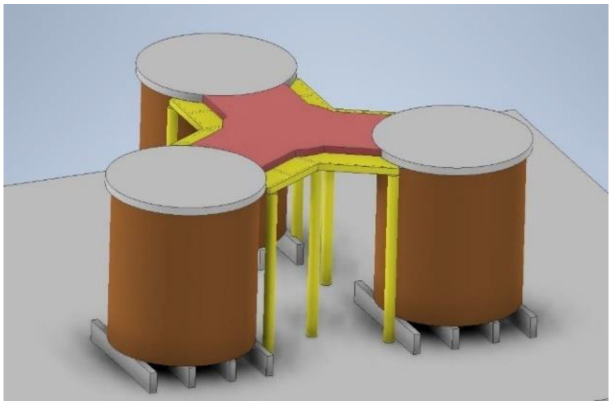


After the completion of cylinder lids a bracing system will be set into place. This bracing system will be made up of the same 24x84WF beams and have smaller stringers in-between. This will be set 15 m in the air with nine 0.9 m steel cylinder pipes. There will be additional support between the posts and some between the posts to the cylinder for rigidity purposes.

A 5 cm thick decking will be placed on top of the bracing to make for easy movement and added strength for forms. This whole area will be equipped with 1 m handrails and a construction elevator for moving the crew and material.

After the supports are all set up, the base slab will be formed up and poured. This is the highlighted red section in Figure 19.

Figure 19. Base slab formed

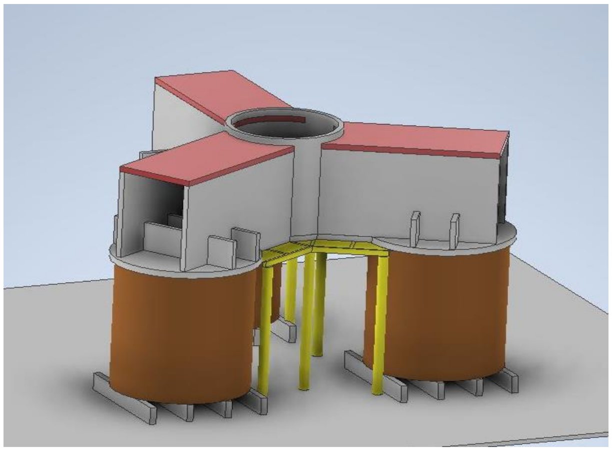


The middle concrete cylinder (highlighted in red) will be formed up with an inside form, the cage premade on the ground will be lifted into place, the outside form would be set, and the cylinder poured. After being poured the forms will be stripped and removed.

Following the completion of the middle cylinder the 3 m tall transverse beam will be formed up and poured. These will be basic wall forms. The cages will be premade and set in and the forms set up with the appropriate spacings and poured. These will be done in three groupings of two.

The Main Girder Wall will be formed up around the transverse beam with the exterior form first. The cage for this will be brought up in sections and the inside form brought in last. This will also be done in three groups of two. These will attach into the installed rebar couplers cast in the concrete cylinder.

Figure 20. Final TSPC concrete base



The Main Girder Top Plate will need to be built in precast sections. The issue with forming up the top plate in place is there would be no way to get the scaffolding out. Instead, each of these panels will be made in two parts and raised into place. These will all be held on with a closure pour.

There will be 0.76 m steel pipe welded in between each of the bottom cylinders for structural integrity for moving and transportation.

4 Transport and Installation

4.1 Market assessment

The US coastline varies in water depths which range from shallow waters to deeper offshore areas. Each site presents unique challenges and considerations for foundation transport and installation. One of the big challenges in the advancement of offshore wind projects is the Jones-Act. The Jones Act requires that all goods transported between US ports be carried exclusively on vessels that are built, owned, operated, and crewed by US citizens or permanent residents. This law aims to protect and promote the domestic maritime industry, ensuring a stable workforce and fostering national security by maintaining a strong maritime presence.

In the context of offshore wind, the Jones Act has implications for the transportation of components, such as wind turbine components and foundations, between US ports during the construction and maintenance of offshore wind farms. Compliance with the Jones Act can present challenges due to the limited availability of US-flagged vessels capable of handling the large-scale equipment required for offshore wind projects.

To navigate the requirements of the Jones Act, project developers in the offshore wind industry have pursued different strategies. This includes utilizing US-flagged vessels for installation, maintenance, and other project-related activities, establishing partnerships with US maritime companies, and exploring options for vessel construction and modification within the US.

As the offshore wind industry in the US continues to evolve and expand, ongoing discussions and considerations regarding the Jones Act are likely to continue to evolve and potentially shape the regulatory landscape. Balancing the objectives of promoting domestic maritime industry and fostering the growth of offshore wind energy will require the offshore wind industry to revisit its logistics for T&I that are consistent with the requirements of the Jones Act.

4.1.1 Ports & facilities

As mentioned in the latest NREL report *A Supply Chain Road Map for Offshore Wind Energy in the United States* published in January 2023, the current port facilities in the U.S. don’t have sufficient capabilities to meet the US goals to install 30 GW of offshore wind energy by 2030. As the size and weight of wind turbines are rapidly increasing and are too big to transport on land, manufacturing facilities need to be located near ports. The ports also need sufficient acreage, quayside length, quayside bearing capacity, navigation channel depth and air draft to safely fabricate, maneuver, load out and transport components to offshore areas.

Significant investments have been planned and will be needed in the coming years to meet the requirements for component manufacturing facilities. Channel dredging and the permitting requirements for building offshore wind energy manufacturing facilities will be particularly challenging as they fall under specific US regulations which may vary from state to state.

Due to the TSPC size and weight, the port will have to meet the following criteria to marshal a TSPC foundation:

- Water depth: ± 12 m
- Quay space: ± 170,000 m^2
- Bearing capacity: 15 t/m^2
- Air draft: ± 55 m

The ports listed below have announced construction developments in the coming years.

Figure 21. US Marshalling ports' investments status

Source: Shields, Matt, Jeremy Stefek, Frank Oteri, Sabina Maniak, Matilda Kreider, Elizabeth Gill, Ross Gould, Courtney Malvik, Sam Tirone, Eric Hines. 2023. A Supply Chain Road Map for Offshore Wind Energy in the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-84710. https://www.nrel.gov/docs/fy23osti/84710.pdf.

Asset	State	Primary Sponsor(s)	Announced Investment To-Date ($ million)	Status
		Marshaling Ports		
New Bedford Marine Commerce Terminal	MA	Massachusetts Clean Energy Center, U.S. Department of Transportation, Vineyard Wind	128	Operational (minor upgrades ongoing)
New London State Pier	CT	Connecticut Port Authority, Ørsted, Eversource	255	Finishing upgrades in 2023
Portsmouth Marine Terminal	VA	Virginia Port Authority, Ørsted	243	Upgrades beginning in 2022, to be completed in 2025
New Jersey Wind Port	NJ	State of New Jersey	540	Phase 1 under construction Phase 2 planned
Tradepoint Atlantic	MD	US Wind, Ørsted	37.2	Not announced
South Brooklyn Marine Terminal	NY	State of New York, Equinor, bp	287	Not announced
Port of Salem	MA	City of Salem, Crowley Maritime Corporation, Avangrid	33.8	Not announced
Arthur Kill Terminal	NY	Not announced	48	Not announced
Port of Humboldt	CA	State of California	11	Planning and design underway

The U.S. Department of Transportation's Maritime Administration (MARAD) has announced in February 2023 a $660 million funding for ports through the Port Infrastructure Development Program (PIDP)[6]. This investment will help improve ports and related freight infrastructure to ensure US ports can meet anticipated growth in freight volumes.

4.2 T&I Method Statement

DEME engaged in collaborative brainstorming sessions with internal experts in transport and installation to determine the most effective solutions for our project. Two T&I methods were defined: one utilizing a Heavy Lift Vessel, and the other leveraging the free-floating capacity of the TSPC base.

[6] https://www.transportation.gov/briefing-room/usdot-announces-more-660-million-available-through-port-infrastructure-development

Four scenarios were discussed to transport and install the TSPC:

1) Utilizing feeder barges for transport and a Heavy Lift vessel for installation
2) Utilizing a Jones-Act compliant Heavy Lift vessel for both transport and installation
3) Free-floating de TSPC base, utilizing feeder barges to transport the central column and a Jack-Up vessel for installation.
4) Free-floating the full TSPC and utilizing a smaller Jack-Up vessel for installation.

Please be aware that the barge sizes indicated in the drawings are approximate and will be further specified based on stability requirements and the space requirements of the SPMT.

4.2.1 Scenario 1: HLV + Feeder Barge

The first scenario consists of using feeder barges and a HLV with a 5,000-t crane capacity (e.g., DEME's Orion heavy lift vessel, see Figure 22).

Figure 22. Orion, one of DEME's HLVs

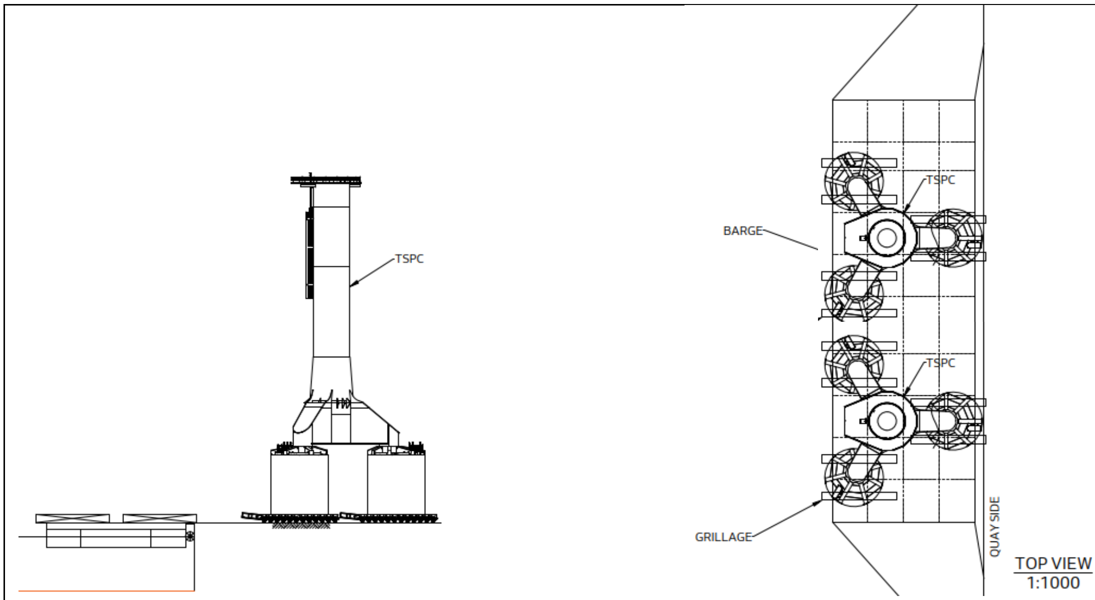
Source: DEME Group

At this stage, the full TSPC is assumed to be stored in the marshalling port. The first step is to load out two fully assembled TSPC structures on the US-flagged feeder barge with SPMT's and seafasten the TSPC onto the grillages of the barge. The barge can then be towed with tugs to the designated offshore windfarm location.

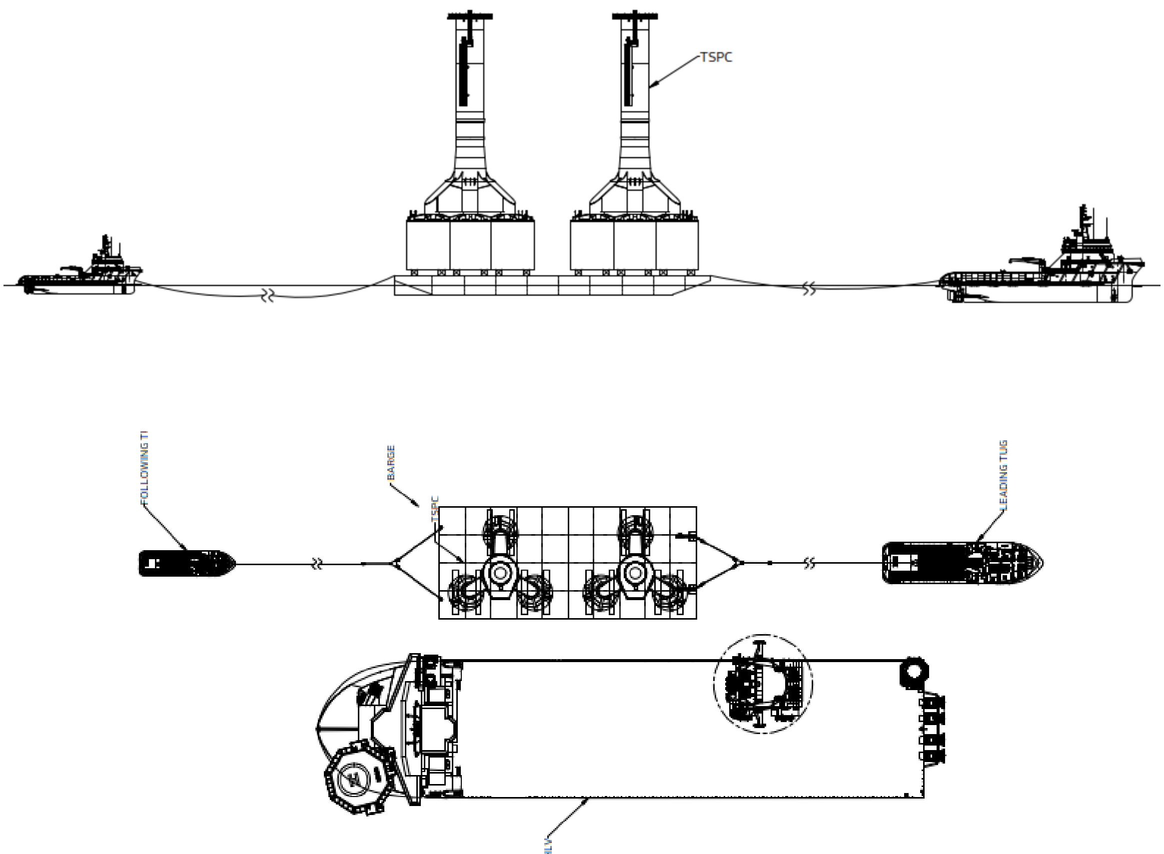
In the field, HLV Orion will carry out the installation of the TSPC foundation, including the suction operations.

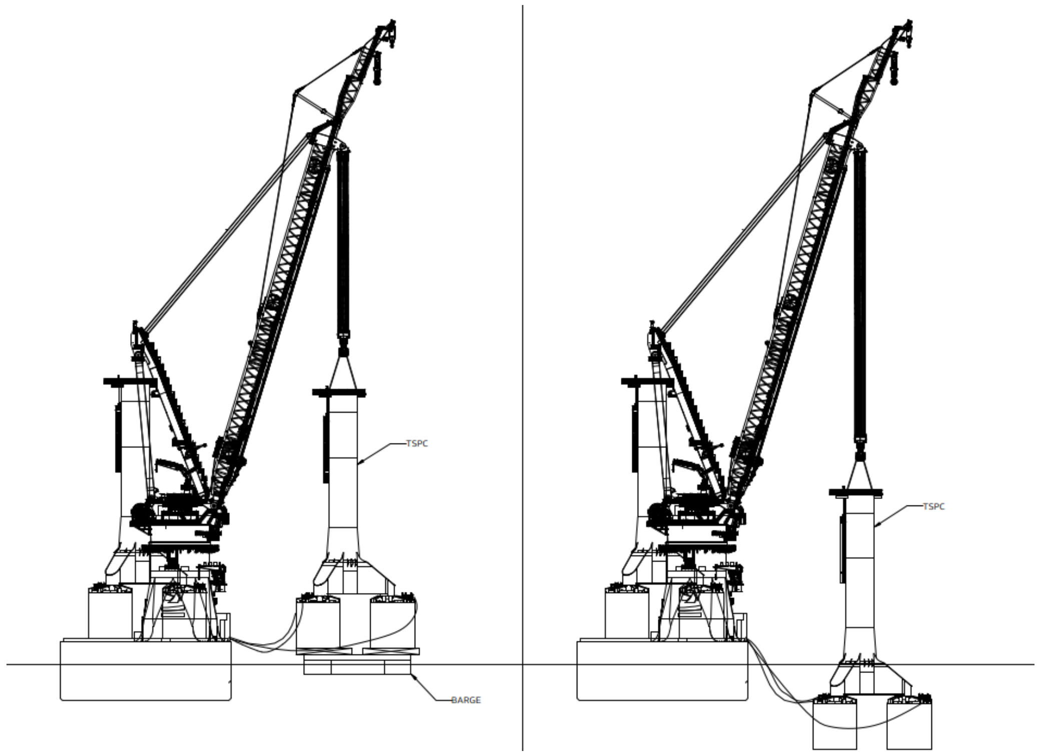
At this moment we anticipate executing the grouting works from a separate vessel, a US-flagged PSV.

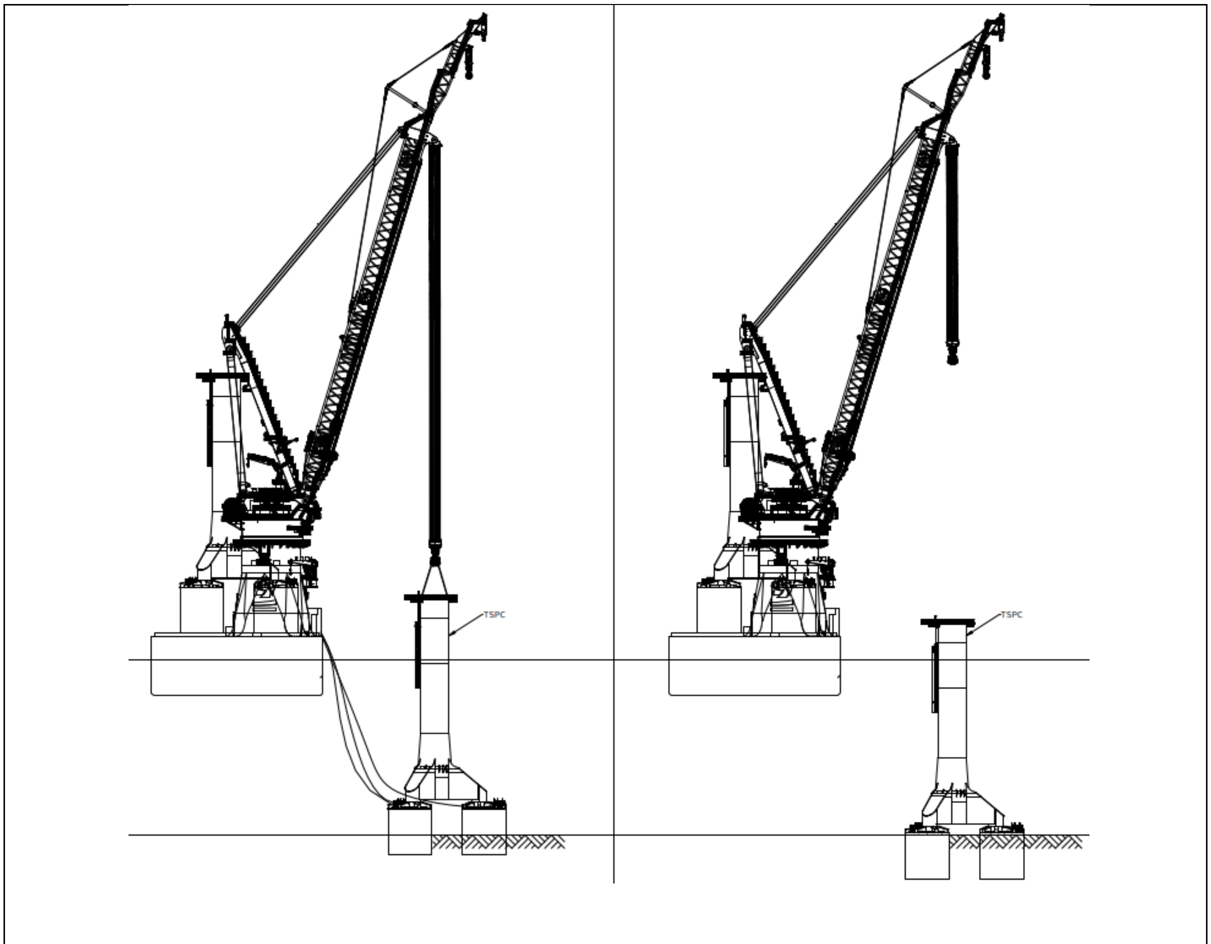
Step 1: Load out 2 fully assembled TSPC from quay onto barge and seafasten.



Step 2: Bring barge to field.



Step 3: Lift TSPC off barge and lower TSPC till self-weight penetration reached. Disconnect hoses. Start suction operation.

Step 4: Suction operation completed. Disconnect rigging, retrieve air hoses and suction pumps.



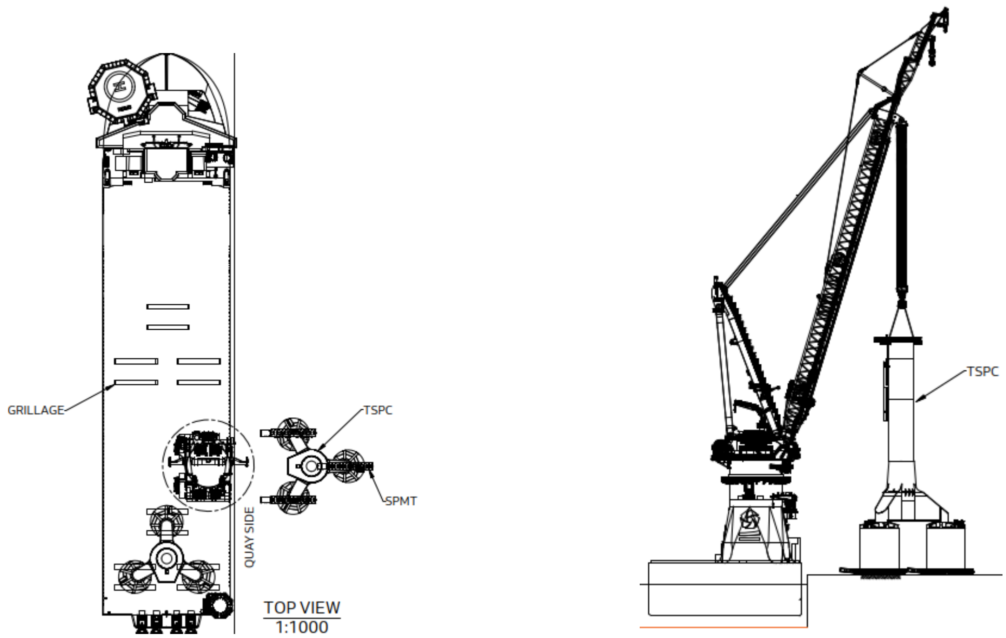
Step 6: Sail HLV to next location and sail barge back to port.

Regarding demobilization, TSPC can be retrieved relatively easily by applying a reverse effect on the suction buckets, allowing the structure to be fully removed, minimizing the environmental impact compared to other foundation types.

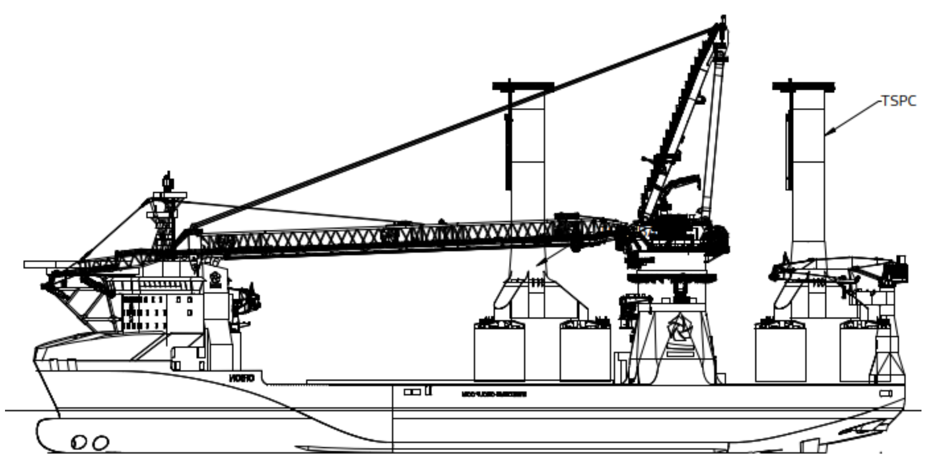
4.2.2 Scenario 2: Jones-Act compliant HLV

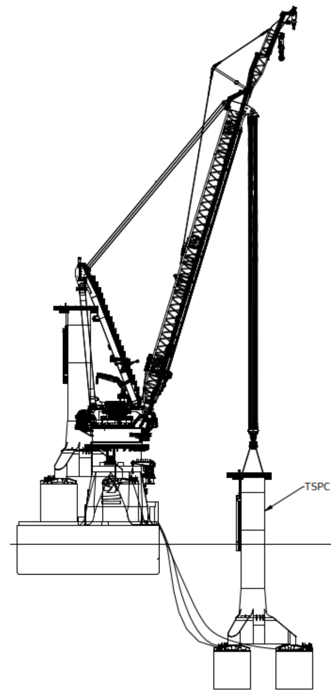
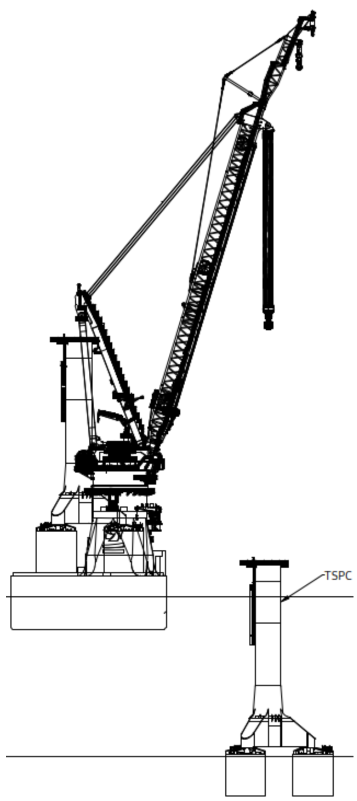
The second scenario consists of using a Jones-Act compliant HLV with a 5000t crane capacity, going to port to load out the fully assembled TSPC, load it on its deck and sail to the offshore location to install it.

Step 1: Load out 2 fully assembled TSPC's from quay onto HLV.



Step 2: Sail HLV to field.



Step 3: Lower TSPC till self-weight penetration reached. Disconnect hoses. Start suction operation. 
Step 4: Suction operation completed. Disconnect rigging, retrieve air hoses and suction pumps. 
Step 5: Sail HLV directly to next location

4.2.3 Scenario 3: Free-floating base + JUP

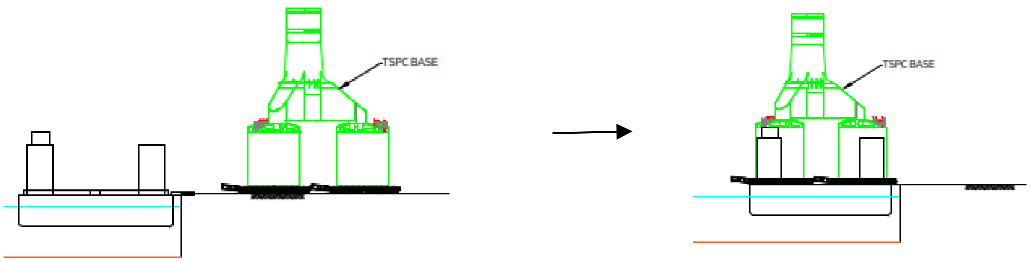
The third scenario is based on the free-floating capacity TSPC base. The base will be loaded out in port on a semi-submersible barge using SPMT. Depending on the water depth in port, the semi-submersible barge is either (i) directly submerged in port allowing the Base to free-float thanks to the buoyancy in the suction piles and then be directly towed out to site with oceangoing tugs, or (ii) towed-out to site with tugs where it will then be submerged.

Once in the field, a Jack-Up Vessel with estimated crane capacity of 1,500 t will first lower the TSPC base onto the seabed.

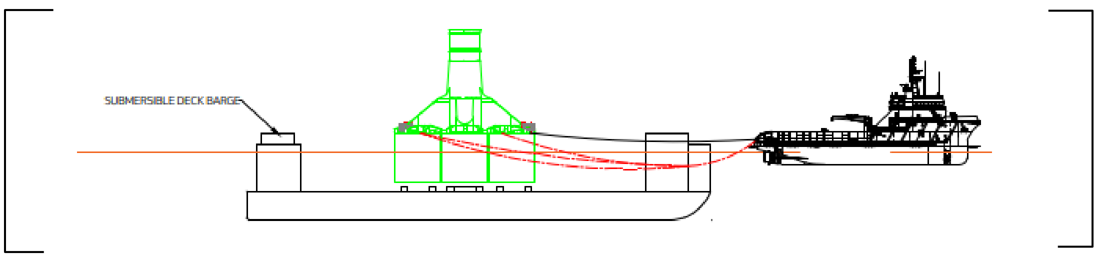
Figure 23. Apollo, one of DEME's JUP vessel

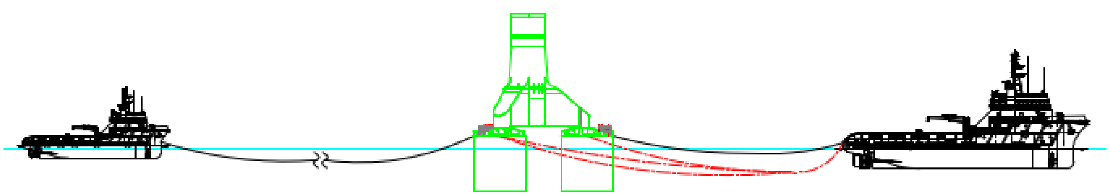
Source: DEME Group

Step 1: Load out TSPC base from quay on a US-flagged semi-submersible barge.

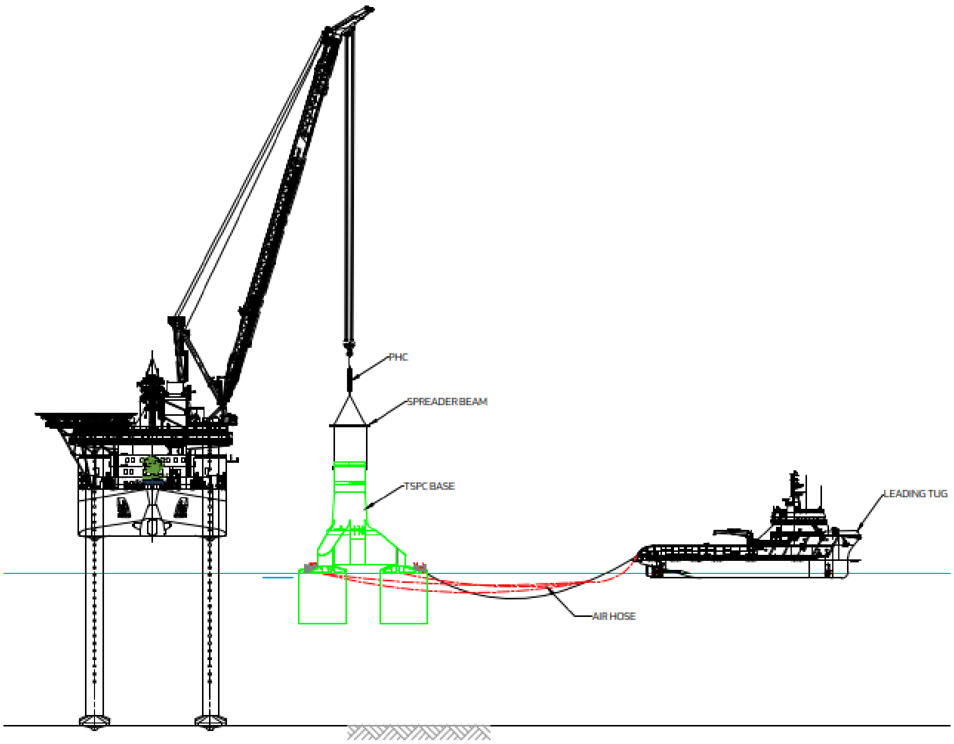


Step 2: Tow out the free-floating base with tugs directly to field OR tow out semi-sub barge to deeper waters, submerge the barge and tow out free-floating TSPC base.

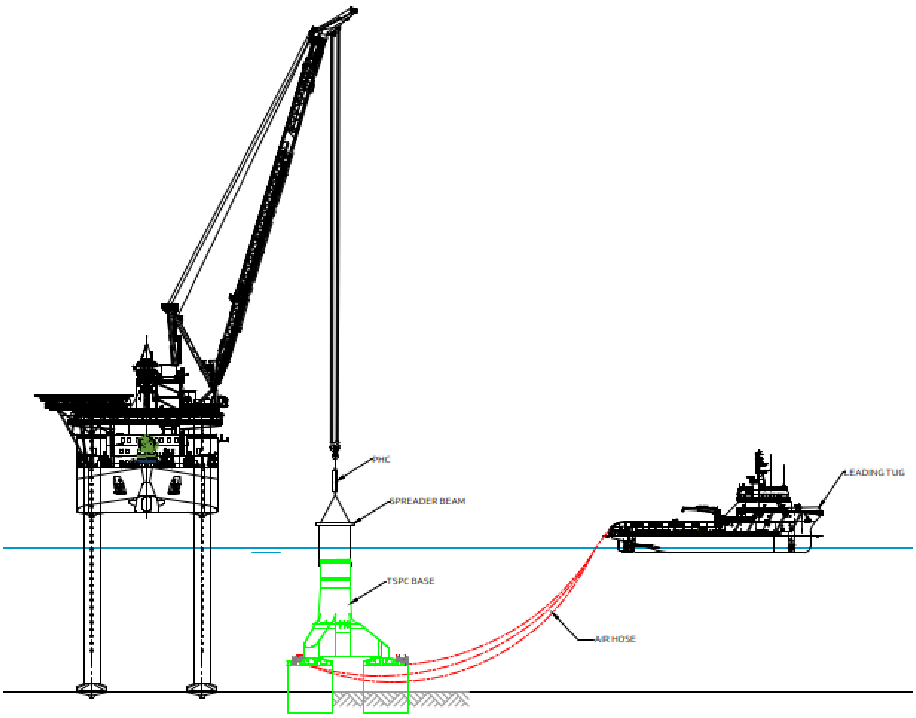




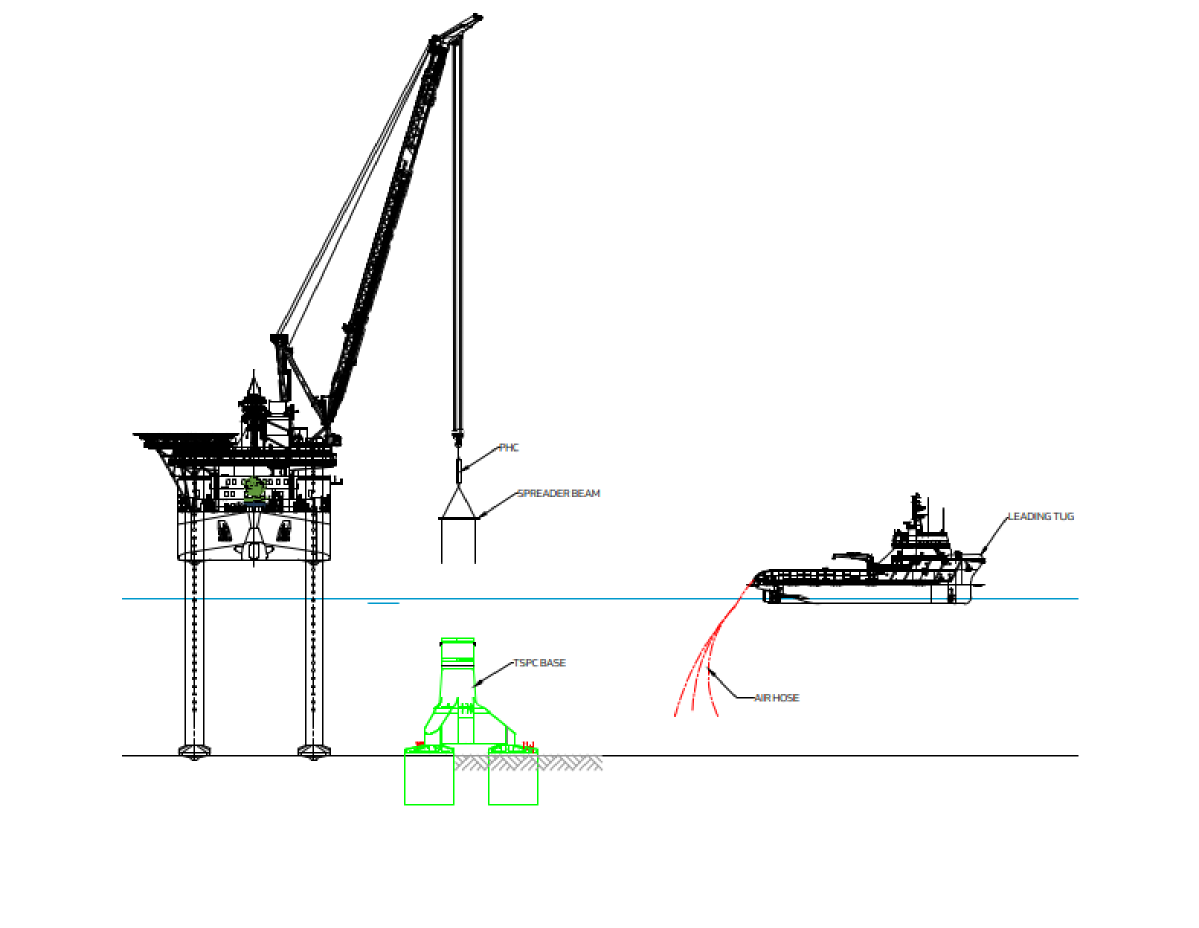
Step 3: Install TSPC base with JUP.



Step 4: Lower TSPC base till self-weight penetration reached. Disconnect hoses. Start suction operation.



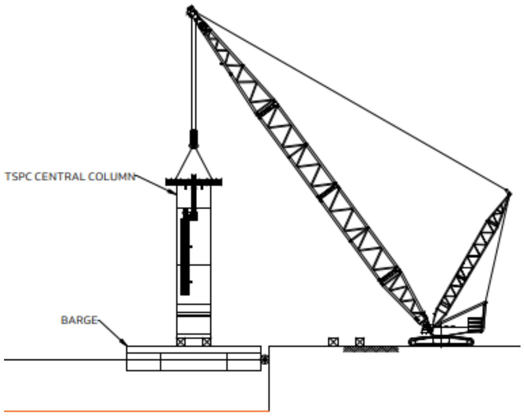
Step 5: Suction operation completed. Disconnect rigging, retrieve air hoses, suction pumps.

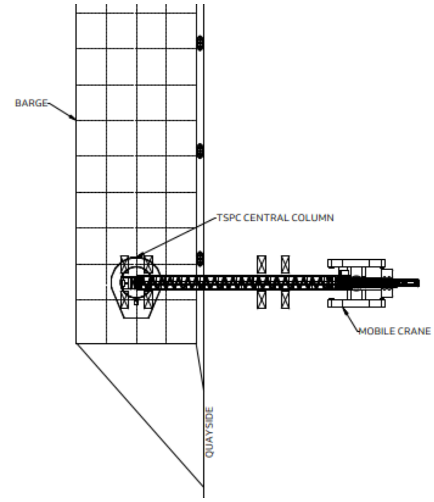


Step 6: Sail JUP vessel to next location.

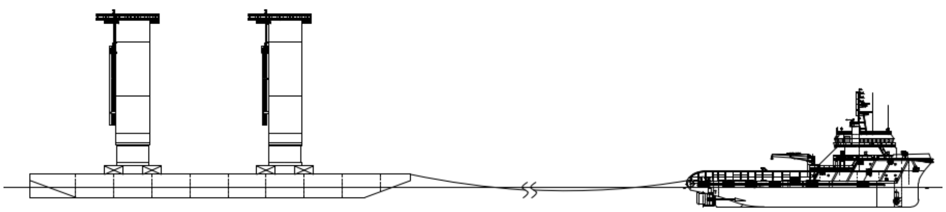
In parallel, barges will be loaded with the central column and towed to the field. Upon arrival of the barge carrying the central column, the JUP will lift the central column off the barge and lower it onto the Base to engage the Double Slip Joint.

Step 1: Load central columns onto barge with onshore crane.

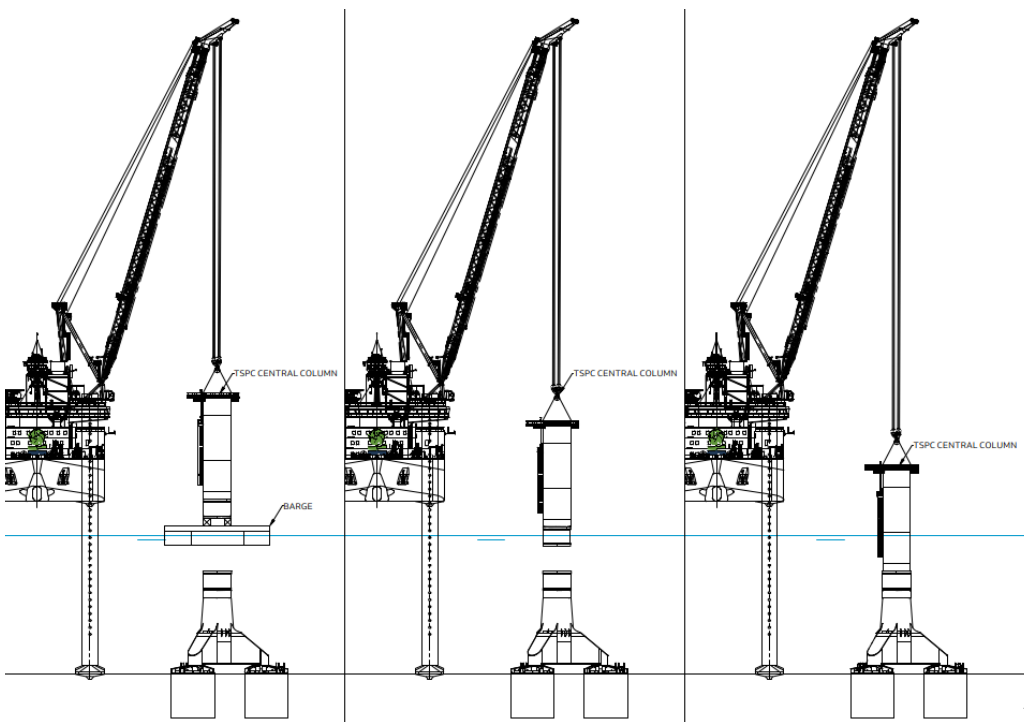




Step 2: Tow out barge with tugs to field.



Step 3: Lift central column off barge and install it on TSPC base, engaging double slip joint.



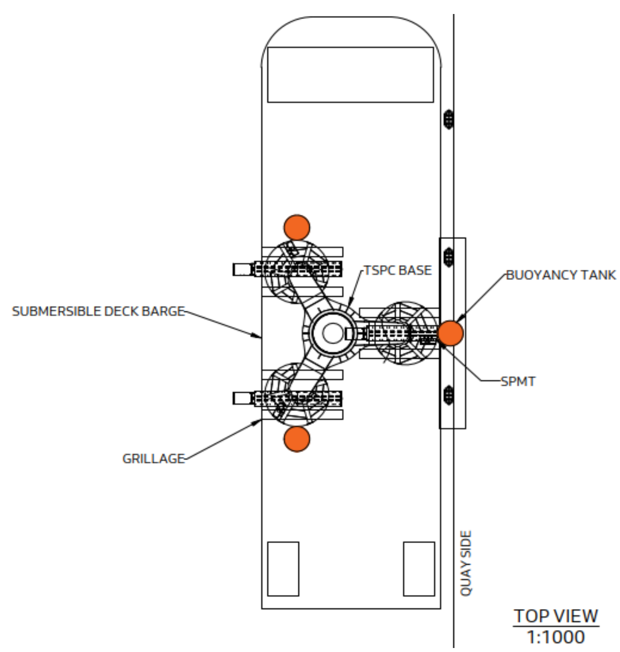
Step 4: Sail barge to next location.

4.2.4 Scenario 4: Free-floating full TSPC

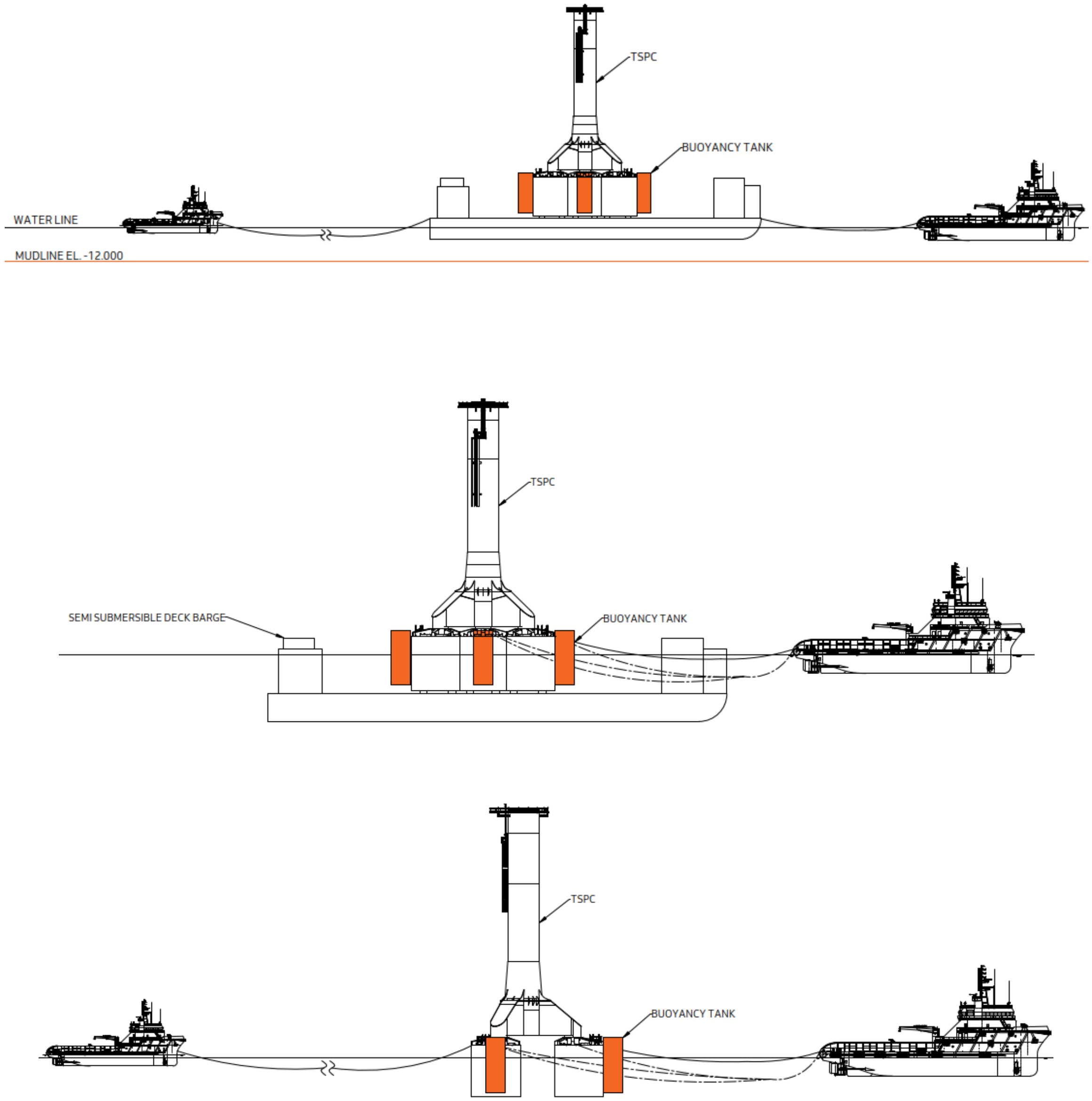
The fourth scenario is similar to the previous one and is also based on the free-floating capacity of the TSPC. However, this goes one step further and considers the floating capacity of the full structure and not only the base. In this case, the use of innovative tools is required to increase the stability of the full structure while it's floating (e.g., much bigger buoyancy tanks)

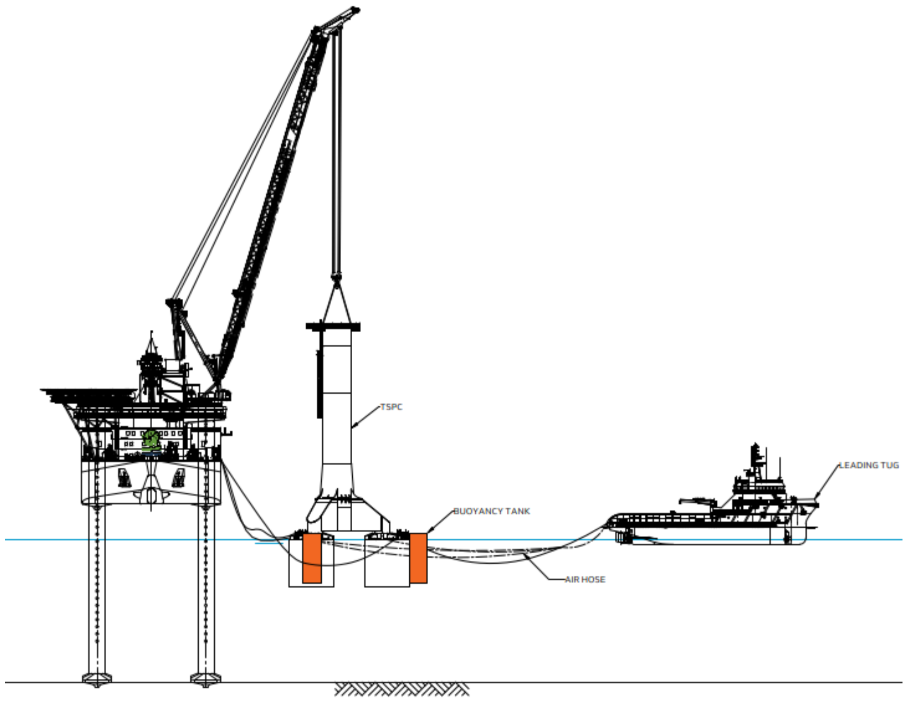
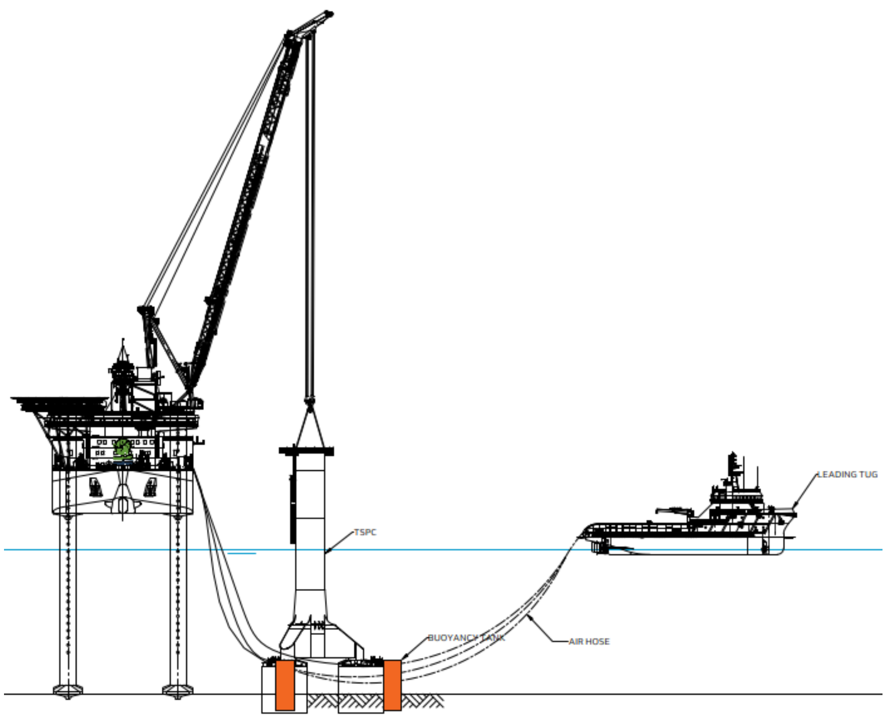
In this scenario, the full TSPC will be loaded out in port on a semi-submersible barge using SPMT. The barge will then be towed to deeper sheltered waters before being lowered allowing the TSPC base to free float. The TSPC will be towed out with tugs until the offshore wind farm site. Once in the field, a Jack-Up Vessel with estimated crane capacity of 1,500 t will first lower the full structure onto the seabed.

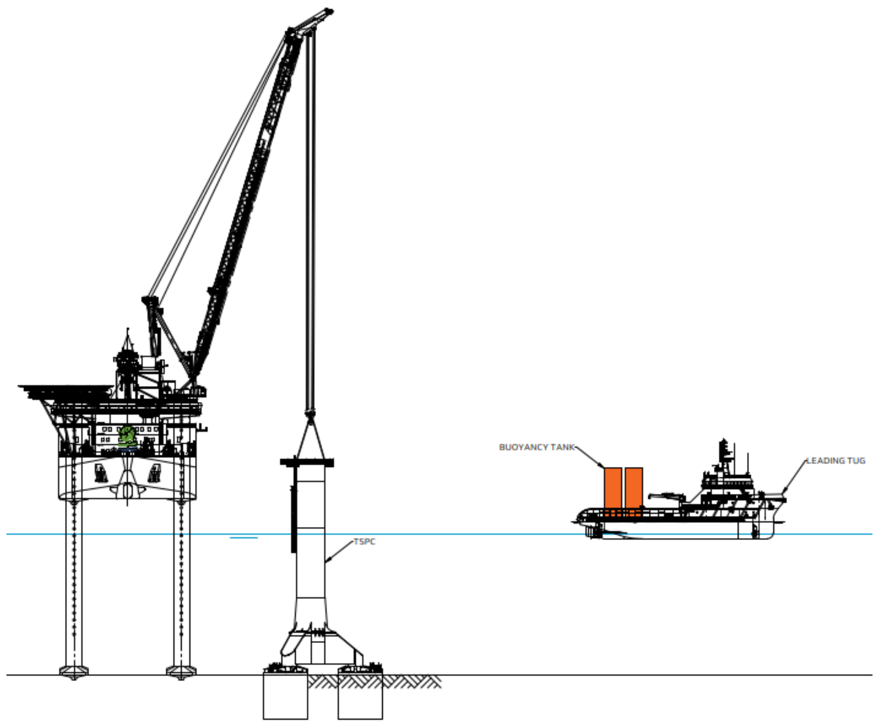
Step 1: Load out fully assembled TSPC with buoyancy tanks from quay onto semi-submersible barge.



Step 2: Tow out the free-floating base with tugs directly to field OR tow out semi-sub barge to deeper waters, submerge the barge and tow out free-floating TSPC base.



Step 3: Connect TSPC to JUP crane hook and lower TSPC till self-weight penetration reached. Disconnect hoses. Start suction operation. 
Step 4: Suction operation completed. Disconnect rigging, retrieve air hoses, suction pumps and buoyancy tanks. 



Step 5: Sail tugs back to port and JUP to next location

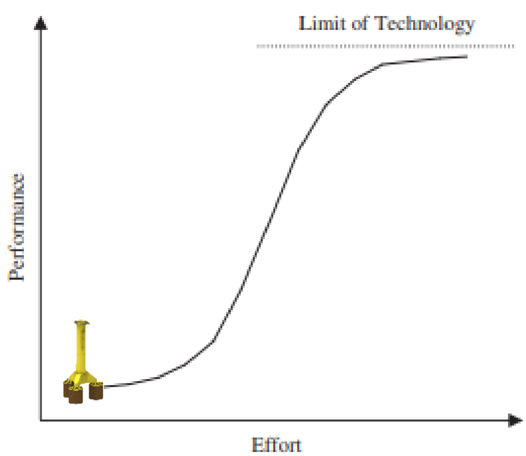
5 Qualitative Cost Analysis

5.1 Fabrication Costs

Whilst major developers are looking into eco-friendly foundations to serve part of the offshore wind farms by the end of this decade, innovative structures are introduced as demonstrator concepts in consolidated markets such as in Europe to be fabricated by 2026-2028[7]. At this stage, FID for these projects have not been reached. Under this frame, a one-off TSPC would be manufactured with the aim of incorporating the lessons learned from engineering, construction, and installation back into the design and manufacturing processes.

From this perspective, the TSPC can be seen as novel technology, even if it represents the combination of cost efficient monopile and suction pile processes. In relation to technologies and their cost evolution over time, when the performance of a technology is plotted against the amount of effort and money invested, it typically shows slow initial improvement, then accelerated improvement, then diminishing improvement.

Figure 24. Performance improvement



The initial performance of a novel technology is low in the early stages because lessons learned from experience are not yet included in the cycle. At this stage, the efficiency in the manufacturing process gained by experience is very limited, leading to direct cost-related consequences. In fact, fixed costs such as investments and management costs are negatively impacted at early stages of technologies and manufacturing plants.

[7] https://english.rvo.nl/information/offshore-wind-energy/hollandse-kust-west-wind-farm-zone

Raw materials and semi-finished components are likewise adversely affected, as their demand remains low in the early stages, resulting in higher prices. Given the nascent state of the US market in establishing the offshore wind supply chain, it's reasonable to anticipate significantly higher costs compared to more mature markets like Europe, where the industry has already benefited from manufacturing experience and increased demand. As later demonstrated in this paper, labor costs play a substantial role in determining the total production cost of steel structures.

The qualitative costs analysis reported below considers the high-level data received from the market and the costs analysis for similar structures in consolidated market such as EU waters. To understand the nature of the TSPC cost level, it is important to highlight its main cost drivers, namely steel plate and semi-finished products, labor, and fixed cost.

The preliminary evaluation shows potential costs to manufacture a full TSPC foundation in USA in the range of 2x the costs foreseen in the more mature market of Europe.

From a raw material perspective, the difference can be explained considering the average steel plate supply in the US, approx. 2,200-2,500 Eur/mT, compared to the one in Europe, which stands at the level of approx. 1,500-1,600 Eur/mT. There is an approximate 40% cost difference in raw materials between the two geographical regions, without considering the technical specifications of the steel plates. Further analysis is required to assess the steel plate market and its availability for offshore wind farms. Additionally, a thorough investigation into potential enhancements in raw materials should be undertaken, especially considering the greater availability of concrete slabs in the US market which could lead to cost improvements.

From a labor perspective, the disparity in costs can be attributed to variations in labor costs between the US and EU regions. The average US blue-collar hourly rate is twice that of the EU blue-collar hourly rate. Additionally, it is assumed that facility investments and depreciation costs will have a substantial impact on the emerging US market.

Further analysis must be conducted on the market, with particular attention to:

- importation and custom duties for raw material
- labor unions and any eventual collective bargaining agreement
- possible subsidies at governmental level

In the future, we can anticipate positive impacts stemming from the learning curve in fabrication on serial production and the economies of scale in purchasing.

In the medium term, significant costs improvement might be seen as a general assumption in the following areas:

- Material cost level is improved due to economy of scale on larger sourced steel quantities;
- Labor and Equipment cost levelized to account for efficiency improvement in the production;
- Project management & Overhead Costs reduced due to the larger scope over time;

In the long term, when the supply chain is well established on US ground, a higher convergence to the costs of a mature market such as EU is expected.

5.2 Transport & Installation Costs

The costs associated with Transportation and Installation will fluctuate depending on the duration of the cycle time and the vessels utilized, with larger Heavy Lift Vessels (HLVs) often commanding higher day-rates. The following factors are considered when investigating these costs:

- Project Preparation: Expenses related to project planning, engineering, and logistical preparations.
- Procurement: Costs associated with procuring necessary equipment, materials, and services for transportation and installation activities.
- Mobilization of Vessels: Expenses related to mobilizing the vessels to the project site, including fuel, crew, and equipment transportation.
- Execution: Costs incurred during the actual transportation and installation processes, including vessel operations, crane usage, and labor.
- Weather Delays: Potential additional expenses resulting from project delays caused by adverse weather conditions.
- Efficiency and Breakdown: Considerations for the efficiency of operations and the potential for equipment breakdown or downtime, which may lead to increased costs.
- Insurances: Costs associated with insurance coverage for transportation and installation activities, including liability and asset protection.
- Demobilization of Vessels: Expenses related to demobilizing the vessels after completing the transportation and installation tasks.
- Operations and Risks: Ongoing costs and potential risks associated with the operational phase of the wind farm, such as maintenance, repairs, and any unforeseen events.

Since TSPCs produce no disruptive noise during installation, posing no threat to marine mammals, they are supposed to be exempt from piling restrictions, enabling year-round installation in the United States.

DEME's tender experts have calculated that approximately 100 TSPC foundations could be successfully installed within a single year, further optimization might lead to higher numbers. In comparison, current offshore wind farm projects in the US typically comprise 60 to 80 wind turbines annually (subject to seasonal and visibility restrictions). Taking a conservative approach, this implies that a TSPC-based wind farm can generate the energy equivalent of 30 to 40 additional turbines and achieve this 1 year sooner than if it was a monopile-based project as 100 monopiles would require 2 years to install due the piling ban.

5.3 Levelized Cost of Energy (LCOE)

For many years the cost of wind power has steadily come down, but the aftermath of COVID19 and the war in Ukraine has changed the landscape.

Besides the impacts of the Ukraine war, the energy industry faces challenges as increasing interest rates, raising inflation, supply chain constrains, shortages of people and disruptions. However, “the last few years of turmoil have been an exception to otherwise consistent project cost declines over a longer time period”, according to BloombergNEF article dated June 7, 2023, “Cost of Clean Energy Technologies Drop as Expensive Debt Offset by Cooling Commodity Prices”. “The LCOEs of utility-scale solar, onshore and offshore wind have fallen by 58-74% over the decade to 2023, and BNEF expects these cost reductions to continue in the long run thanks to continuing technology improvements, greater economies of scale and reduced financing costs.”

Between 2010 and 2021, the global weighted average LCOE of offshore wind fell 60%, from USD 0.188/kWh to USD 0.075/kWh. The latter, 2021 figure was 13% down on its 2020 value of USD 0.086/kWh. From its peak in 2007, the global weighted average LCOE of offshore wind had fallen 65% by 2021. The future is hard to predict, but it’s likely that the trend of cost reduction is stabilizing and might even go up in the near future to find a new stable level.

Especially the US Offshore Wind market shows a significant upswing in CAPEX, for several reasons. One of the contributing factors is the (night) piling ban / restricted piling season for ‘traditional hammered Monopile foundations” which is creating a slow construction schedule, a multiple season installation approach and requires additional mobilizations of expensive installation vessels. The underlaying cause is the noise generated by monopile hammering, for which piling restrictions are introduced to protect sea mammals, a sensible and justified measure.

If it would be feasible to install foundations without or with very limited noise emissions, this might open the possibilities to lift the piling restrictions and thereby leading towards a more efficient installation set-up and cost reduction. One promising innovative solution is the deployment of TSPC foundations, which are not only noiseless but also “whale friendly”, particularly benefiting the US market by offering substantial opportunities for local involvement.

Examining the current the LCOE of TSPCs today reveals that its innovative nature results in higher risks and greater CAPEX compared to more established foundations like monopiles. However, while monopiles represent advanced technologies, TSPCs have not even reached the development phase yet. Consequently, it would be unfair to directly compare the LCOE of TSPCs with that of monopiles. Instead, a more reasonable approach would be to compare TSPCs’ LCOE with other suction pile technologies, such as suction pile jackets, where TSPC has the potential to be more competitive in terms of cost-effectiveness and advantages.

An additional crucial factor to consider is decommissioning costs, which are significantly lower for TSPCs, nearly 10 times lower than those associated with monopiles. As TSPC matures in the offshore wind market, CAPEX expenses are anticipated to decrease, along with reduced uncertainty regarding risks. These trends are expected to lead to a declining LCOE over the years, mirroring the historical pattern seen with other foundation technologies.

6 Optimizations

Optimizations can be undertaken with the entire Engineering, Procurement, Construction, and Installation (EPCI) process.

To advance the TSPC design, our primary focus must center on the development of innovative tools aimed at cost reduction and optimization for the US market. Specifically, we are exploring novel methodologies for Transport and Installation (T&I) and advancing alternative structural materials for the foundation, such as pre-cast concrete and additive building technologies. We also anticipate the emergence of entirely new technologies in the longer term. It's essential to ensure that the TSPC concept matures fully before entering the market, as numerous opportunities for innovative solutions are yet to be discovered and developed.

One of the main priorities moving forward will be to create US supply chain-specific designs that comply with near-future capabilities and will reduce both costs and duration of fabrication and of Transport and Installation to improve the overall efficiency of the project. Thus far, our design was based on the technical constraints of the US soil and environmental conditions and not on the U.S. supply chain capabilities and limitations. By adding the fabrication constraints as a factor to the design we would co-operate with the supply chain and designers to further develop the design of the TSPC to better accommodate serial production and the current constraints of the fabrication capabilities in the US. In parallel, the supply chain for serial production of large foundation structures would need to be further developed; a significant need was identified for the industry to invest in the advancement of:

- Serial fabrication and handling capacity for heavy steel structures (over 1,500 t) and concrete structures (over 3,000 t)
- Port and Marine infrastructure capacity (both in numbers, size, strengthened quays, handling equipment, channel water depth, air draft)
- Marine transport and installation vessels (floating cranes specialized in both inshore- and offshore operation, tugs, flattop- and semi-submersible barges, subsea construction vessels)

Moving forward as an industry, it is imperative to ensure that both fabrication and marshaling of the product occur at the same location. This approach will streamline the fabrication, assembly, transportation, and installation processes, ultimately reducing unnecessary logistics expenses.

To improve the TSPC commercial competitiveness even further in comparison to suction pile jackets, being the main ‘competitor’ in the field of noiseless foundations, several non-comprehensive recommendations are put forth:

1. Fabrication costs are the largest components of the total EPCI cost of the TSPC. Achieving cost savings in fabrication primarily involves the generic development of the supply chain. Feedback from the US steel and concrete structure fabricators was rather limited, while price levels generally appeared to be significantly higher compared to European, Middle East and Asian prices for a similar scope. At this stage of market maturity, the procurement from outside US plus transport to the US is considered by most developers, however fabrication in the US at market-conform price levels should be envisaged. In the latter case, the supply chain, spanning construction companies, yards, port- and marine infrastructure, onshore craneage, marine equipment and engineering services need to be developed to a level of efficiency where it can compete with similar services outside the US (with the transport costs as the only difference).

2. Subsequently, transport and installation costs typically constitute around one-fifth of the total EPCI expenses for the TSPC. Enhancements can be explored through the free-floating tow-out methodology:
    a. Investigate the technical and commercial implications of increasing the hydrostatic stability by increasing the SP interspacing for the free floating a fully assembled TSPC (no DSJ), combined with crane assisted lowering.
    b. Investigate the technical and commercial implications of increasing the hydrostatic stability by outfitting the SPs with additional buoyancy tanks for the free floating fully assembled TSPC (no DSJ), combined with crane assisted lowering.
    c. Investigate the technical and commercial implications of lowering the TSPC to the seabed without crane assistance by utilizing buoyancy tanks (to be sized and disconnection and logistics to be studied).

   Another approach to enhance transport and installation, occasionally hampered by the Jones Act, involves the separate installation of Suction Piles apart from the TSPC main body. This strategy aims to decrease Heavy Lift Vessel (HLV) and feeder barge specifications, consequently reducing associated costs. The split between the suction piles top and the main girder can result in a more balanced weight distribution, thus lowering the required crane capacity. Additionally, this separation reduces the width of the upper structure, alleviating barge width constraints.

Furthermore, the utilization of suction pumps with a higher flow rate can significantly decrease offshore installation time.

7 Roadmap to commercialization

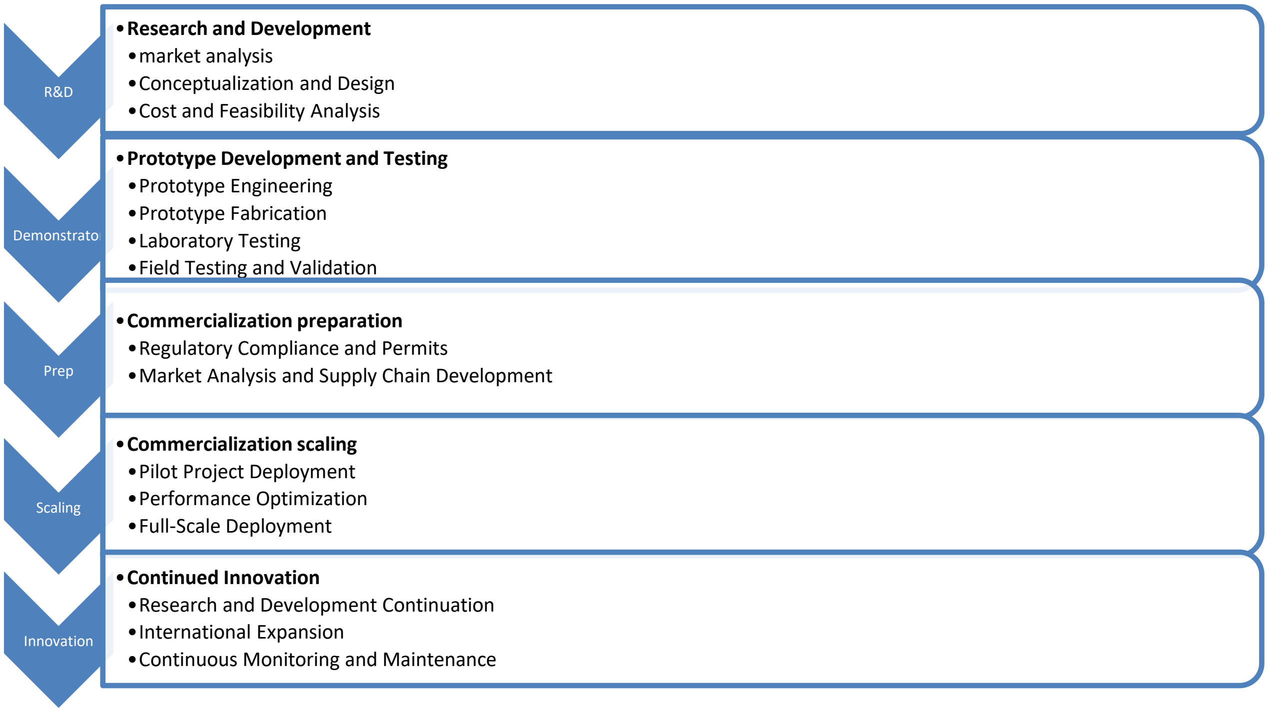
7.1 Introduction

This roadmap outlines the strategic steps and considerations necessary to transition from a research study to the successful commercialization of a new offshore wind foundation. The process encompasses various phases, including research and development, prototype development and testing, commercialization preparation, commercialization and scaling, and continued innovation and expansion.

DEME Offshore's strengths lie in its unrivalled track record of performing Transport and Installation assignments and complex EPCI or BOP projects for foundations, WTG and offshore substations. With its specialist installation vessels, equipment and highly skilled teams, all aspects of a wind farm project can be performed in-house, from the initial seabed preparation to the turbine and substation installation and including the inter-array and export cables. DEME also specialize in suction pile anchors and foundations through its subsidiary SPT Offshore.

The roadmap for development of the TSPC is schematically represented in Figure 25.

Figure 25. Roadmap for development of the TSPC



7.2 Phase 1: Research and Development

7.2.1 Market Analysis

We started by conducting an exhaustive market analysis employing the SWOT methodology. This approach aimed to assess the viability of introducing the TSPC product into the US market, evaluating its potential to address prevailing challenges within the offshore wind industry. As part of the SWOT analysis, also the US maritime- and construction supply chain was analyzed, to gain a better understanding on the constraints the offshore wind sector in general and the TSPC specifically would be subjected to.

7.2.2 Conceptualization and Design

We then developed a conceptual design of the TSPC for a virtual site at the East coast of the US, based on realistic assumptions for soil data and environmental data. The design of the TSPC is based on the industry standards from DNV-GL for offshore wind turbine foundation design, in combination with ABS Survival Load Case (SLC) with 500-yr storm conditions is analyzed to cover for potential presence of topical hurricane traveling Northwards – which is typical for US East Coast conditions.

Both a TSPC constructed from steel and a TSPC with the integration piece between the central column and the Suction pile for concrete were made.

Several transport and installation methodologies for both the steel version and the heavier concrete version were devised, based on locally available equipment and being compliant with the Jones Act.

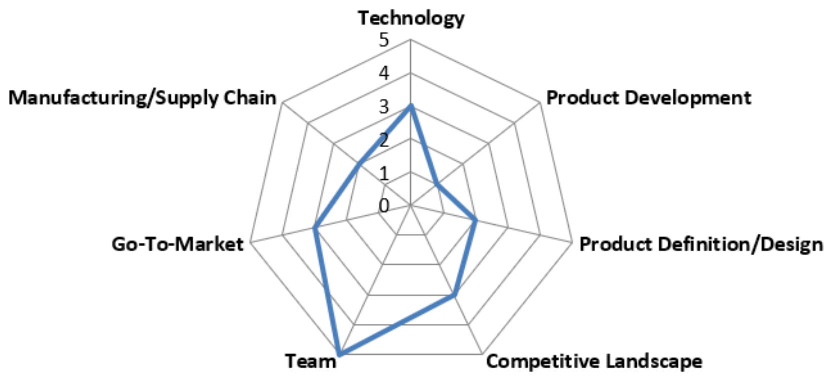
The result of the Concept design was confirmation of the technical feasibility of fabrication and transport and installation of the foundation, as well as the General arrangement for both designs, including the structural weight; this was input to the Cost and Feasibility analysis.

7.2.3 Cost and Feasibility Analysis

Following the design phase, we conducted a comprehensive cost analysis, comparing the Tri Suction Pile Caisson with conventional foundation options like monopiles. Additionally, we formulated distinct transport and installation cycle timelines, factoring in various scenarios and circumstances, such as the capacity of the TSPC to free float, which would enable the utilization of smaller HLV during the installation operations.

At the end of the NOWRDC TSPC development, the TRL and CRL of the TSPC foundation concept and the transport and installation methodology were calculated at TRL 3 and CRL 3, see also the TRL/CRL radar plot from the calculator in Figure 26.

Figure 26. Radar plot showing scoring on TRL- and CRL aspects – at the end of the NOWRDC development.



7.3 Phase 2: Prototype Development and Testing

7.3.1 Prototype Engineering

Small scale laboratory tests are to be performed for analysis of aspects like:

- Hydrostatic and -dynamic behavior of the free-floating TSPC during tow out
- Drag- and Mass coefficients to determine the hydrodynamic loading
- Scouring of the seabed
- Hydrodynamic loading on the Nature Inclusive Design (NID)

These tests will confirm the technical feasibility of the transport method, inform on the operational load assumptions, enable validation of the CFD analysis and allow optimization of the TSPC structure design, as well as the scour protection design and potential incorporation of Nature Inclusive Design elements.

7.3.2 Prototype Fabrication

The next phase would be to build scaled prototype(s) of the TSPC based on the conceptual design and develop a test program. Typically, the prototype has a scale of 1:40 to 1:50 depending on the size of the water basin, resp. the wave flume. Possibly the model can be (re)used for the various tests, but the different test requirements may result in cost reductions when utilizing bespoke models.

7.3.3 Laboratory Testing

The different aspects that are input to the design(optimization) of the TSPC, as listed in 3.4.1 will require the conduction of a rigorous test program in controlled laboratory settings to validate the feasibility of the transport methodology, the input to the structural integrity analysis, hydrodynamics loads on the external structures (like NID) and optimization of the Scour protection design.

In this iteration, the design of the TSPC, appurtenances and scour protection will be optimized based on test results.

At the end of the laboratory tests the TRL will be in the range of TRL 4 to 5.

7.3.4 Field Testing and Validation

Installation of a prototype in a controlled offshore environment to simulate real-world conditions can be considered.

Depending on the objective of the mid/full scale protype tests, the following tests could be considered:

1. The fabrication method, yard logistics, methods for automated fabrication, for component-based fabrication and -assembly. This would require a direct role for potential fabricators.

2. Load out method from the quay into the water. This would require input from the operators of vessels, cranes, and logistical handling equipment.

3. The dynamic behavior of the TSPC during free floating tow out.

4. The dynamic behavior and crane loads during installation of the free floating TSPC by ballast-controlled lowering by a lower tier HLV.

5. The feasibility of the suction process in the local soils; it could be considered to test this on various locations in the area with an existing test pile.

6. Underwater noise level measurement during the suction process, to confirm the noiseless characteristics of the method.

7. The feasibility of pumping out the TSPC to confirm the feasibility of decommissioning; again, several locations could be considered as well as including underwater noise measurements.

8. Operational behavior, including WTG. This would provide information on the excursions, rotations, stresses in the structure, stiffness, structural response, etc. of the TSPC under realistic WTG loading. Involvement of a WTG supplier would be necessary. Power offtake would need to be organized. Permitting required.

9. Operational behavior, excluding WTG. The behavior of the structure, subjected to hydrodynamic loads (only) could be monitored.

10. Operational behavior for the scour behavior with and/or without scour protection; this does not necessarily need to be rock based protection. Interface with scour protection installation contractor needed.

11. Operational behavior of Nature Inclusive Design (= artificial reefs). The different species attracted by the NID could be monitored DNA sampling.

For the above tests, to reduce procurement costs, it could be considered to utilize a 'simplified' design of the TSPC, omitting the secondary steelwork and possibly considering reducing the interface level and reduce the wall thickness of certain members (depending on the objective listed above). A corrosion protection system may not be required.

For several of the above listed tests, the duration of the TSPC staying on location would be in the order of several hours, up to days. In case of testing the operational behavior, a full year would typically be recommended to cover seasonal effects, should be considered. After retrieval, the TSPC prototype is transported back to shore for scrapping, recycling, or re-use.

At the end of testing a full-scale prototype, the TRL would be TRL 6.

7.4 Phase 3: Commercialization Preparation

7.4.1 Regulatory Compliance and Permits

In this 3rd phase, the first step towards commercialization is to navigate regulatory requirements and obtain necessary permits for large-scale deployment, as well as addressing environmental impact assessments and safety regulations.

The development of offshore wind energy in the United States is guided by federal and state permitting processes designed to ensure the responsible siting, planning, construction, operation, and decommissioning of projects. Securing permits is one of the big issues in the US offshore wind deployment because of regulatory uncertainty and slow approval processes. According to project developers, the insufficient number of regulatory personnel is causing delays in the swift approval of projects, and this meanwhile projects are currently facing rising installation costs due to high inflation.

The responsibility is in general directed towards a complex regulatory structure involving numerous authorities assigned to distinct phases of the permitting process. The absence of federal coordination result in significant delays in issuing Environmental Impact Statements—federal documents that assess the impact that a project might have on the surrounding environment—preventing the deployment of these projects.

In addition, connecting offshore wind power to the onshore electricity grid is still a work in progress in the United States, necessitating huge infrastructure development. The environmental impact of expanding transmission infrastructure is largely unknown and will undergo its own regulatory process.

As stated in the EnergySource US Offshore wind's growing pains: Permitting and cost inflation article of June 26, 2023: "To address the bottlenecks in issuing permits, the United States should learn from German and British offshore wind strategies by housing permitting authorities within a single agency and staffing regulatory bodies appropriately to enable large-scale, strategic approval processes. Cost inflation remains a problem for US offshore wind. Steel prices remain elevated, there are a limited number of available service vessels, and transmission challenges will loom larger as projects move closer to deployment."

7.4.2 Market Analysis and Supply Chain Development

The TSPC is an opportunity for the foundations market as it offers an environmentally friendly installation technology together with the combination of cost efficient monopile and suction piles processes. From a fabrication perspective, the TSPC combines the application of serial production with highly automated machinery and labor-intensive manufacturing processes.

Being the US offshore wind market in its emerging phase, potential challenges can be found in the supply chain establishment. In fact, the TSPC foundation requires a large range of steel fabricators and construction yards able to support the serial production and the main components and erection and final mating processes.

From a market analysis and supply chain development, a potential roadmap which takes into consideration the US market encompasses the following steps:

1. Mapping the demand for offshore wind farm steel foundations forecasted over a timeframe of 3 to 5 years to scale up the necessary investment and optimize the most advanced technologies.

2. TSPC design progress to identify applicable standards to facilitate a local supply chain development and potential cost optimizations of new technologies and processes.

3. Actively monitoring the market capacity available to fulfill the current and future projects in the US and complementary capacity from international market, from raw material sourcing to fabrication and assembly processes.

4. Request feedback from the supply chain throughout the product development phases in order to assess benefits in the manufacturing processes for serial production. With this approach, technical and commercial aspects would be further investigated based on market consultation. This would allow to better understand the cost drivers and leverage on efficiencies that could have larger positive impact on fabrication processes, manufacturing lead-times and overall costs.

5. Investigate the raw material processes at the bottom of the steel supply chain. Ideally the supply chain should be supported by domestic steel mills to minimize transport and logistics

impacts, CO_2 footprint, etc. with substantial capacity for large steel plate suitable for offshore wind farms according to market fabrication standards.

6. Investigate labor market wages, skills and required qualification and seek for potential development of workmanship or migration from other sectors to fulfill the industry demand.

7. Actively scout potential new entrants willing to enter the foundation market, also established in other sectors such as Oil & Gas and related subindustries, shipbuilding, etc. giving the potential cross functional expertise in the field of steel fabrication, manpower and required skills for welding and steel manufacturing.

8. Establish communication channels with suppliers and perform site visits at their manufacturing sites and / or having planned investments to enter the offshore wind farm industry to verify their capacity and capability (potential and actual) to meet the offshore wind demand for steel foundations.

DEME owns a dedicate team with expertise on supply chain assessment and development to verify fabricators' capability to undertake a scope of work in compliance with project requirements and standards in relation to final and constituent products.

These assessments are beneficial for all stakeholders in the industry, and they can be used from a value engineering perspective to optimize processes and costs, risks profiling of the supply chain, decision making by developers, etc.

7.5 Phase 4: Commercialization and Scaling

7.5.1 Pilot Project Deployment

Deploy one or a limited number of TSPC foundations, probably as part of an Offshore Wind Farm development. Test the fabrication method, the logistical method, load-out, transport and installation of the TSPC in the field, including installation noise measurements. During the operational life, monitor the structural behavior (overall stiffness, local stresses at point of interest), the status of the scour protection and surrounding seabed by frequent monitoring and the attractions of marine species. The TSPC design is validated at a larger scale.

This would bring the TRL to 8.

7.5.2 Performance Optimization

The data from the pilot project is analyzed to identify areas for optimization and improvement of the fabrication method, logistics and the structure- and appurtenances design. Refine the design and manufacturing processes based on lessons learned.

7.5.3 Full-Scale Deployment

Gradually increase the deployment of new foundations in offshore wind farms, using the lessons learned from the pilot project. Collaborate with energy companies to integrate the technology into their projects.

The TRL in this phase is 9.

7.6 Phase 5: Continued Innovation and Expansion / Optimization

7.6.1 Research and Development Continuation

Maintain a commitment to ongoing research and innovation to enhance the technology's performance and efficiency. Explore opportunities for using advanced materials, automation, and improved installation methods.

7.6.2 International Expansion

Looking at the international market, there is potential for future viability. This phase is about exploring partnerships and collaborations to introduce the technology to global offshore wind markets. However, it is essential to note that the TSPC design will require adaptions to suit different environmental and regulatory contexts. The TSPC designs examined in this study have been explicitly tailored for use in the U.S. market, meeting both the physical environment and regulatory requirements.

7.6.3 Continuous Monitoring and Maintenance

Implement a robust monitoring and maintenance strategy to ensure the long-term reliability and efficiency of the foundations.

8 Conclusion

Today, fixed bottom foundations, which involve the use of impact hammers for installing monopiles or pin piles, inherently produce noise emissions. Aside from their impact on marine mammals and sea life, these noise emissions lead to delays in construction for two main reasons:

- Night Pile Ban: as it is impossible to identify if marine mammals are present in the vicinity of the main installation vessel, piling operations are prohibited during the night.
- Winter Pile Ban: the migration of marine mammals closer to shore during the colder months (November to April), where offshore wind farms are situated, results in a ban on piling operations and, consequently, offshore activities related to fixed bottom foundation installation during this period.

The adoption of an alternative foundation concept, such as the TSPC effectively circumvents the need for identifying marine mammals during the night or disrupting their migration. In both scenarios, as there are no noise-producing impact hammer operations, installation work can proceed during nighttime and winter periods without disturbance. The noiseless and vibration-free suction process employed to secure the TSPC to the seabed doesn't disrupt marine life or negatively affect the hearing abilities of marine mammals.

Nevertheless, it's important to note that TSPC is still in its early development stages and currently cannot compete with driven monopiles in terms of cost efficiency. However, it's worth noting that not all sites are suitable for pile driving. The TSPC can compete effectively on sites with limited overburden and where drilling is necessary for monopiles. Additionally, the TSPC proves to be more cost-effective than other noiseless WTG foundations, such as suction pile jackets. Ongoing research aims to streamline the TSPC design for easy installation. The free-floating approach, relying on the buoyancy of suction piles, could also revolutionize the transportation and installation process.

Furthermore, to fully commercialize TSPC, substantial growth in the US supply chain is necessary, along with investments in marine assets, ports, and manufacturing facilities. While this innovative foundation offers significant environmental benefits, its development also creates new job opportunities in the United States. As offshore prices continue to rise, the reliance on pioneering technologies like TSPC becomes more critical than ever before. The next crucial step towards advancing TSPC development involves executing a demonstration project featuring 2 or 3 TSPC foundations.

9 References

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Appendix A : TSPC dimensions – steel version

I. GENERAL
1. THE FOLLOWING GENERAL NOTES SHALL APPLY TO ALL STRUCTURAL DRAWINGS, U.N.O..
2. ALL STEEL WORK (FABRICATION) ETC. SHALL BE IN ACCORDANCE WITH DNVGL-OS-C401

II. DIMENSIONS AND SIZES
1. ALL DIMENSIONS SHOWN ARE IN MILLIMETERS (U.N.O.)
2. ELEVATIONS IN MILLIMETERS. ELEVATIONS ARE REFERENCED TO WATERLINE
3. ANGLES ARE IN DEGREES (360°)
4. ALL TUBULAR SIZES SHOWN ARE OUTSIDE DIAMETER x WALL THICKNESS IN MILLIMETERS, EG. Ø 1829 x 50 W.T.
5. ALL PLATE (PL) THICKNESS SHOWN ARE IN MILLIMETERS (U.N.O).

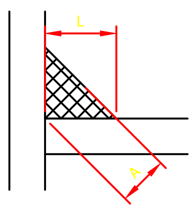
III. MATERIALS
1. ALL STEEL PARTS TO BE DELIVERED ACCORDING TO THE TABLE BELOW U.N.O. ON THE DRAWINGS.

TYPE	STRUCTURAL CATEGORY	INSPECTION DOCUMENT (EN 10204 REFERENCE)	GRADE	APPLICATION
1	SPECIAL	TYPE 3.2	VL EW36 - Z35	- CC STUB - MAIN GIRDER STUB - MAIN DIAMOND PLATE - SP TOPPLATE - SP DIAMOND PLATE - SP INLET TUBE - SP INLET PADEYE
2	PRIMARY	TYPE 3.1	VL E36	- CENTRAL COLUMN - CC BOTTOM PLATE - MAIN GIRDER BOTTOM PLATE - MAIN GIRDER WEB - MAIN GIRDER TOP FLANGE - MAIN GIRDER STIFFENER - TOP STIFFENER - SP GIRDER WEB - SP GIRDER FLANGE
3	PRIMARY	TYPE 3.1	VL D36	- INNER RING STIFFENERS - STUB INTERNAL RING STIFFENER - SP SHELL - SP STUB - SP GIRDER END PLATE - SP TOPPLATE STIFFENER - SP TOPPLATE STIFFENER - SP DIAMOND PLATE STIFFENER - SP STUB STIFFENER - SP INLET
4	SECONDARY	TYPE 2.2	VL D27S	- SP GUIDE

IV. PAINTING AND PROTECTIVE COATING
1. PAINTING AND PROTECTIVE COATINGS SHALL BE IN ACCORDANCE WITH NORSOK STANDARD M-501 - SURFACE PREPARATION AND PROTECTIVE COATING
2. DAMAGE OF ANY KIND TO THE PERMANENT STRUCTURE PAINTING / COATING BEFORE AND DURING INSTALLATION PRIOR TO HANDING OVER THE FACILITIES TO THE COMPANY SHALL BE REPAIRED BY AN APPROVED METHOD AND TO THE FULL SATISFACTION OF THE COMPANY.

V. WELD CONNECTIONS
1. WELDING SYMBOLS ACCORDING TO AWS 2.4
2. ALL WELDS SHALL BE FULL PENETRATION WELDS IN ACCORDANCE WITH AWS D1.1, LATEST REVISION U.N.O.
3. ALL WELDS SHALL BE CONTINUOUS (U.N.0).
4. FILLET WELDS WITH NO SPECIFICATION OF DIMENSIONS ARE MADE ACCORDING TO THE TABLE, U.N.O.

PLT THICKNESS	MIN (A)	MIN (L)
T ≤ 8MM	4MM	6MM
8 < T ≤ 12MM	6MM	8MM
12 < T ≤ 15MM	7MM	10MM
15 < T ≤ 20MM	9MM	12MM
20 < T ≤ 30MM	13MM	18MM
30 < T ≤ 40MM	16MM	22MM



5. ALL FILLET WELD SIZES SPECFIED ON DRAWINGS ARE LEG LENGTH.
6. IF PARTS FROM DIFFERENT STEEL TYPES ARE WELDED TOGETHER THE REQUIREMENTS OF THE STRICTEST PREVAILS.
7. ALL WELDS TO BE CONTINUOUS AROUND ENDS AND EDGES OF PLATES TO PREVENT CORROSION.
8. SEAL WELDS SHALL BE A MINIMUM 3 MM FILLET, U.N.O.

VI. PLATE JOINING
1. WHEN JOINING TWO PLATES OF DIFFERENT THICKNESS THE THICKEST PLATE MUST BE BEVELED 1:4 TO THE THICKNESS OF THE THINNER PLATE U.N.O. ON THE DRAWINGS.

VII. HOLES
1. ALL EDGES AND HOLES CUT IN SPECIAL STEEL AND PRIMARY STEEL (INCLUDING THOSE TO BE REINFORCED) ARE TO HAVE ALL BURRS REMOVED BY GRINDING TO A MINIMUM RADIUS OF 3 MM.

VIII. RATHOLES
1. RATHOLES WITH NO SPECIFICATION OF DIMENSIONS ARE MADE ACCORDING TO THE TABLE U.N.O.

WEB OR STIFFENER THICKNESS (T) IN MM	RATHOLE RADIUS (R) IN MM
T < 20MM	R = T + 15MM
T < 35MM	R = T + 10MM
T ≥ 35MM	R = T + 5MM

2. THE SURFACE OF THE HOLES SHALL BE SMOOTH AND WITHOUT ANY INDENTATION.
3. NO RATHOLES PERMITTED IN TUBULAR MEMBERS.
4. NO RATHOLES PERMITTED IN OUTER PLATES OF ENCLOSED AREAS.
5. RATHOLES IN BRACKETS AND BEAM-TO-BEAM CONNECTIONS MAY STAY OPEN U.N.O.
6. ALL EDGES OF THE RATHOLES SHALL BE GROUND SMOOTH.

IX. NON DESTRUCTIVE TESTING
1. TEST AND ACCEPTANCE CRITERIA ACCORDING DNVGL-OS-C401
2. ALL WELDS SHALL BE 100% VISUALLY INSPECTED AND ACCEPTED PRIOR TO CARRYING OUT NDT
3. ALL WELDS SHALL BE TESTED ACCORDING TO TABLE BELOW AND SHALL FULFILL THE CLASS B ACCORDING TO EN 5817:2014

STRUCTURAL CATEGORY	INSPECTION CATEGORY	TYPE OF CONNECTION	TEST METHOD			
			VISUAL	MAGNETIC 1)	RADIOGRAPHY 2)	ULTRASONIC 3)
SPECIAL	I	BUTT WELD	100%	100%	100%	-
		CROSS- AND T-JOINTS, FULL PENETRATION WELD	100%	100%	-	100%
		CROSS- AND T-JOINTS, PARTLY PENETRATION WELD AND FILLETS	100%	100%	-	-
PRIMARY	II	BUTT WELD	100%	20% 4)	-	-
		CROSS- AND T-JOINTS, FULL PENETRATION WELD	100%	20%	-	20%
		CROSS- AND T-JOINTS, PARTLY PENETRATION WELD AND FILLETS	100%	20%	-	-
SECONDARY	III	BUTT WELD	100%	SPOT 5)	SPOT 5)	-
		CROSS- AND T-JOINTS, FULL PENETRATION WELD	100%	SPOT 5)	-	SPOT 5)
		CROSS- AND T-JOINTS, PARTLY PENETRATION WELD AND FILLETS	100%	SPOT 5)	-	-

- 1) PENETRANT TESTING TO BE ADOPTED FOR NON-FERRO-MAGNETIC MATERIALS.
- 2) MAY BE PARTLY OR WHOLLY REPLACED BY ULTRASONIC TESTING UPON AGREEMENT.
- 3) ULTRASONIC TESTING SHALL BE CARRIED OUT FOR PLATE THICKNESSES OF 10MM AND ABOVE. TESTING OF PLATE THICKNESSES 10 TO 8MM MAY BE AGREED IF SPECIAL QUALIFICATION IS CARRIED OUT.
- 4) FOR WELD CONNECTIONS ON SHELL NOT SUBJECTED TO HIGH RESIDUAL STRESS, SPOT CHECK WILL BE ACCEPTABLE
- 5) APPROXIMATELY 2% TO 5%

4. ALL INSPECTION AND NDT OF STRUCTURAL STEEL WELDS SHALL BE DONE AFTER GRINDING, IF APPLIED REPAIRING OF WELDS SHALL BE CARRIED OUT ACCORDING TO A QUALIFIED WELDING PROCEDURE WHICH SHALL BE DOCUMENTED
5. REPAIRED WELDS HAVE TO BE INSPECTED BY NDT AND HAVE TO FULFILL THE SAME REQUIREMENTS AS STIPULATED FOR THE ORIGINAL WELD SEAMS

ABBREVIATIONS

BTM	: BOTTOM	R	: RADIUS
CJP	: COMPLETE JOINT PENETRATION	SPF	: SUCTION PILE FOUNDATION
CL	: CENTERLINE	TKY	: T-, K- & Y- JOINT
D	: DIAMETER	T.O.B.	: TOP OF BEAM
EL.	: ELEVATION	T.O.S.	: TOP OF STEEL
IAW	: IN ACCORDANCE WITH	TP	: TARGET PENETRATION
ML	: MUDLINE	TYP	: TYPICAL
MPI	: MAGNETIC PARTICLE INSPECTION	U.N.O.	: UNLESS NOTED OTHERWISE
MRP	: MINIMUM REQUIRED PENETRATION	UT	: ULTRASONIC TESTING
MSL	: MEAN SEA LEVEL	WP	: WORK POINT
MTO	: MATERIAL TAKE OFF	WPS	: WELD PROCEDURE SPECIFICATION
NDT	: NON DESTRUCTIVE TESTING		
N.T.S.	: NOT TO SCALE		
OD	: OUTER DIAMETER		
PJP	: PARTIAL JOINT PENETRATION		
PL	: PLATE		

NOTES:
1. CONCEPTUAL TENDER DESIGN ONLY

REFERENCES:
1. 20204001-SPT-STR-DRA-1001 GENERAL ARRANGEMENT

REV.	DATE	DESCRIPTION	PREP.	CHK.	APPR.
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Tel. +31 (0)88 220 21 21
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CLIENT:
PROJECT: TSPC NOWRDC
TITLE: GENERAL NOTES

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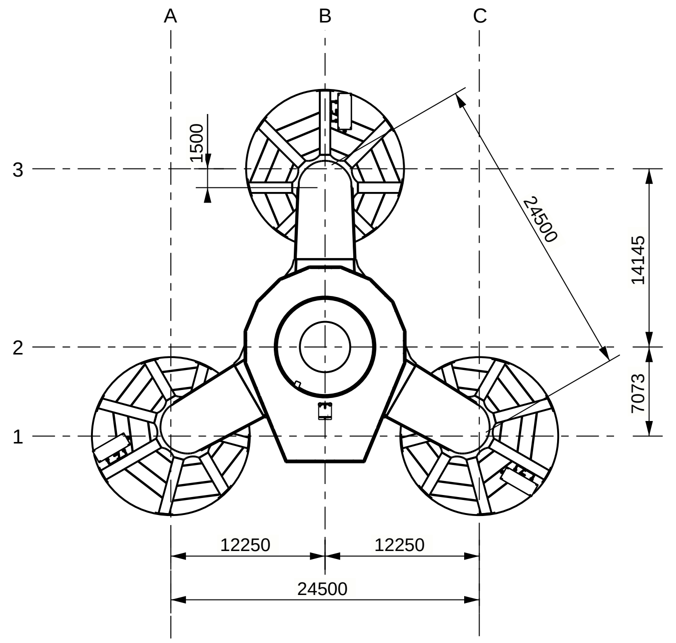
SHEET: 1/1 | DRAWING No. 20204001-SPT-STR-DRA-0000 | REV: A1



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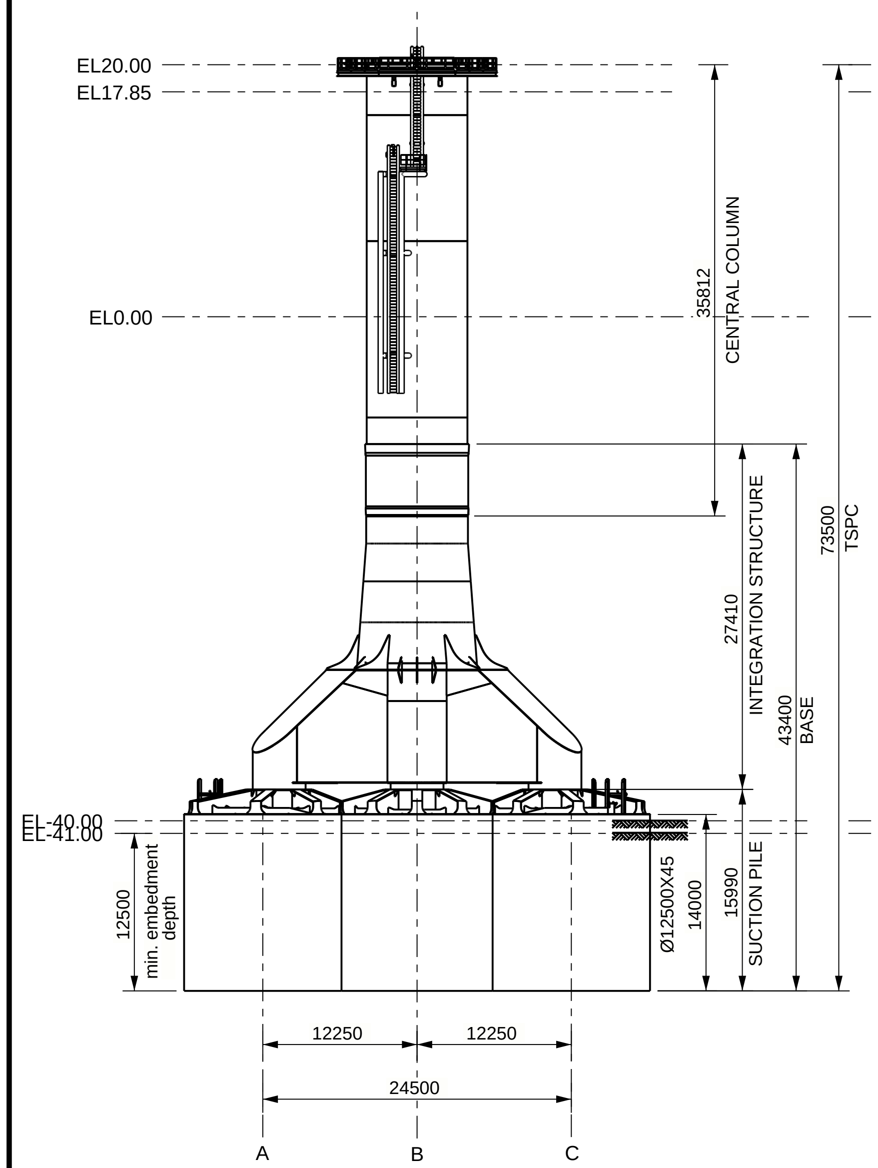

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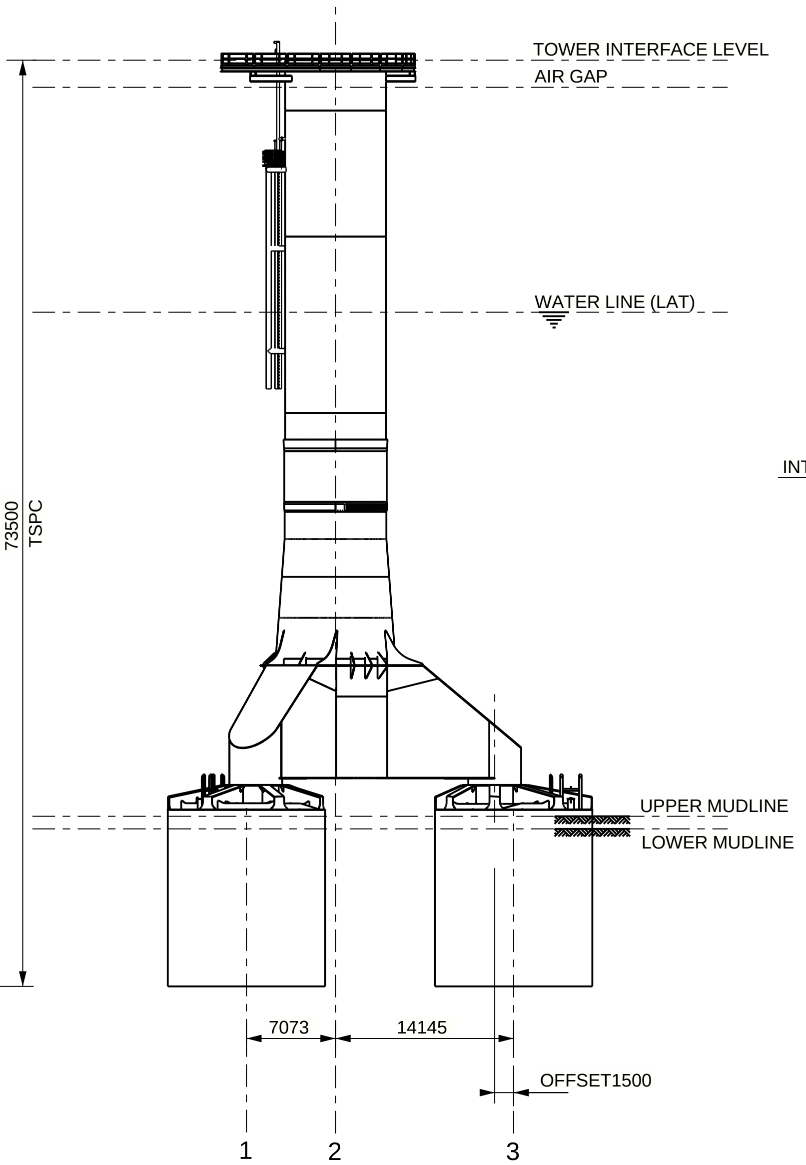

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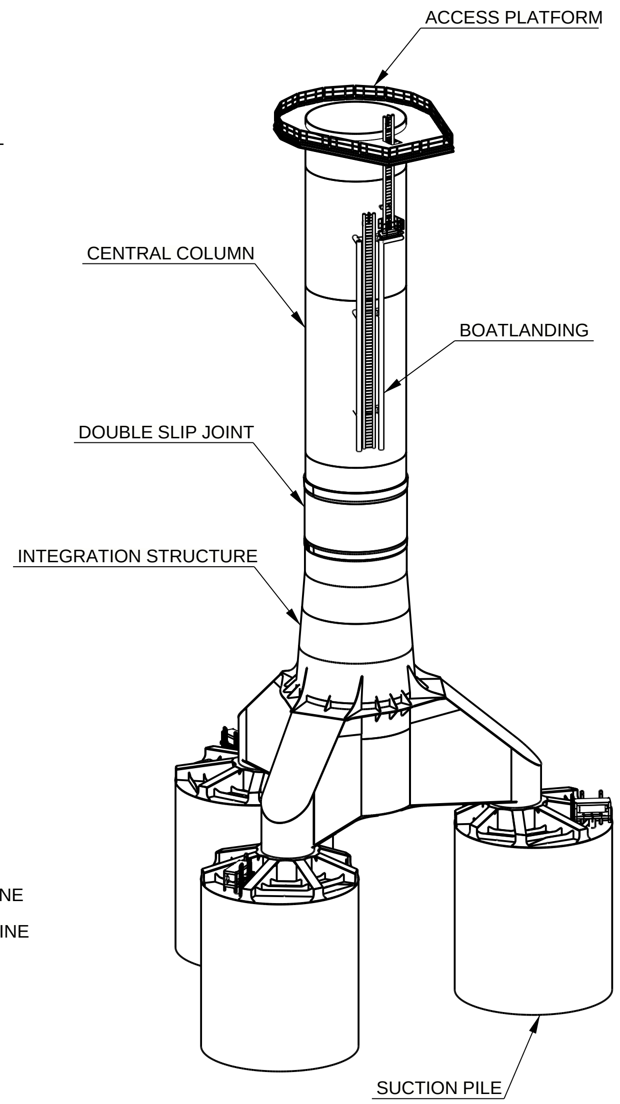

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NOTES:

1. CONCEPTUAL DESIGN ONLY
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2. FOR GENERAL NOTES SEE DRAWING : 20204001-SPT-STR-DRA-0000
3. DRY NET WEIGHTS:
   - SINGLE SUCTION PILE (3x) = 296 mT
   - INTEGRATION STRUCTURE = 983 mT
   - CENTRAL COLUMN = 520 mT
   - BOATLANDING = 24 mT
   - ACCESS PLATFORM = 18 mT
   - TSPC = 2433 mT

REFERENCES:

1. 20204001-SPT-STR-DRA-1002 MTO

REV.	DATE	DESCRIPTION	PREP.	CHK.	APPR.
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TITLE: GENERAL ARRANGEMENT TSPC

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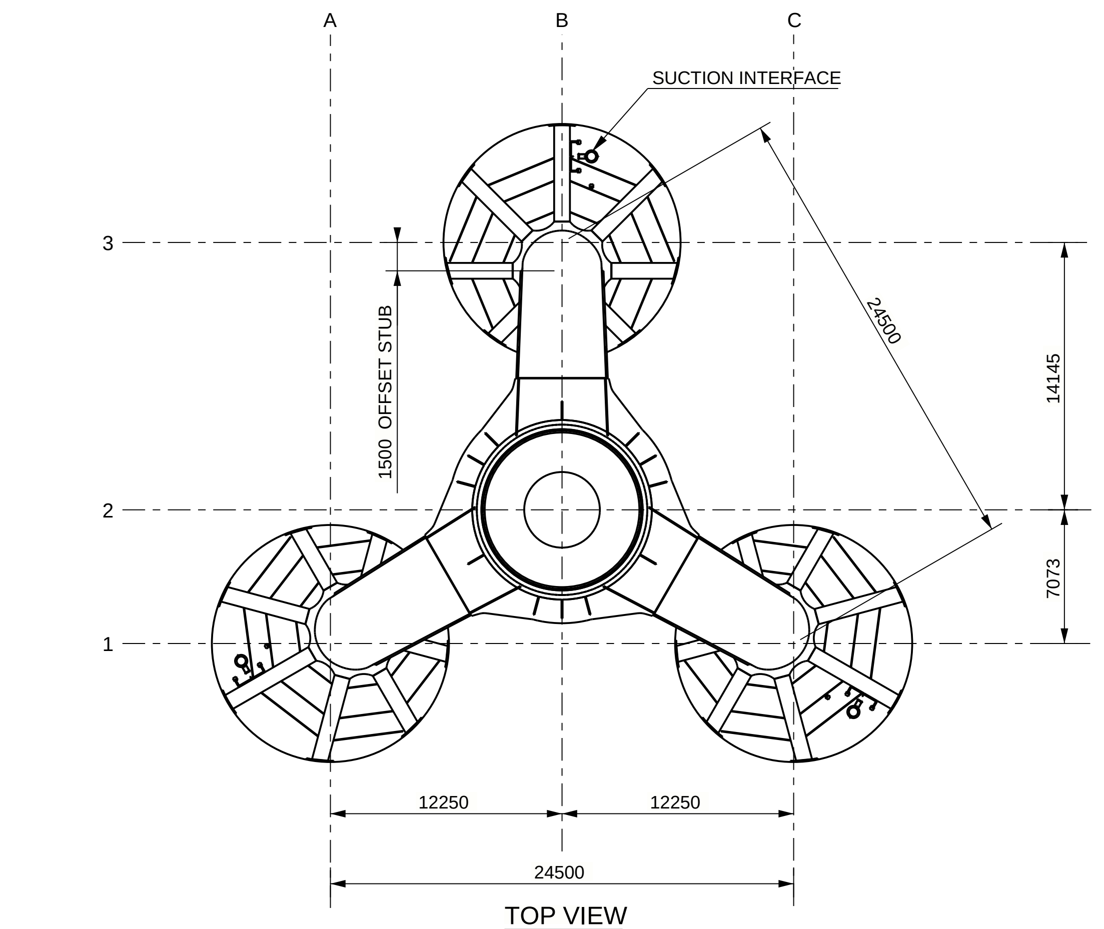

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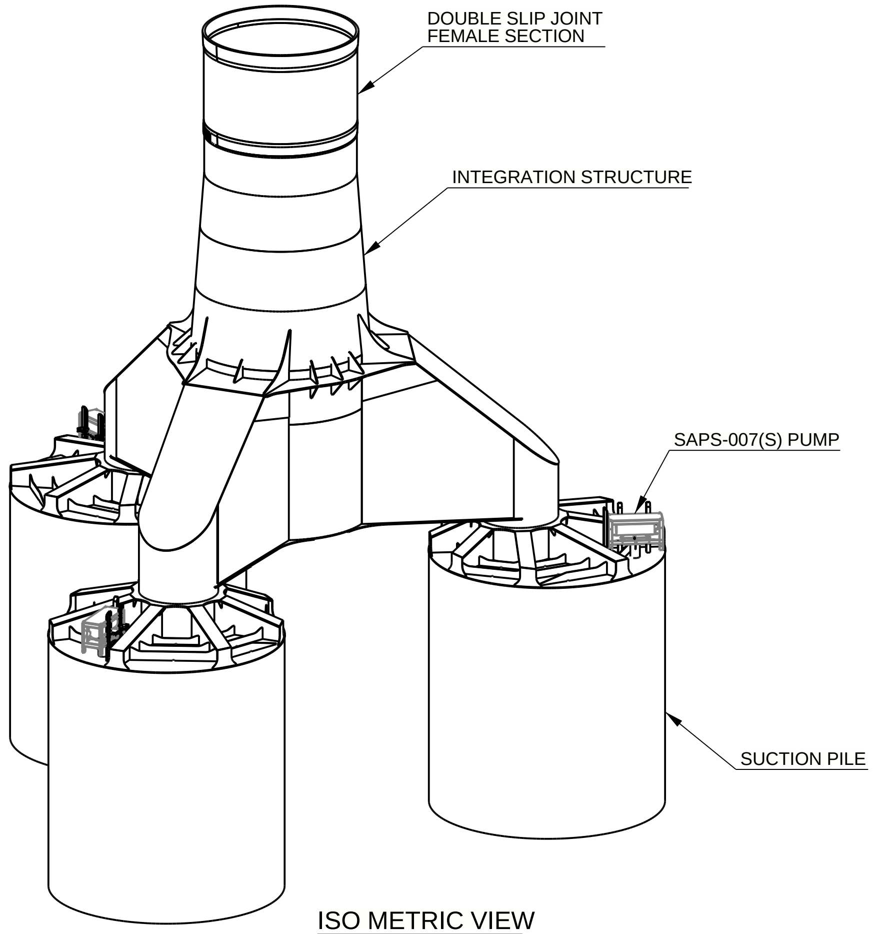

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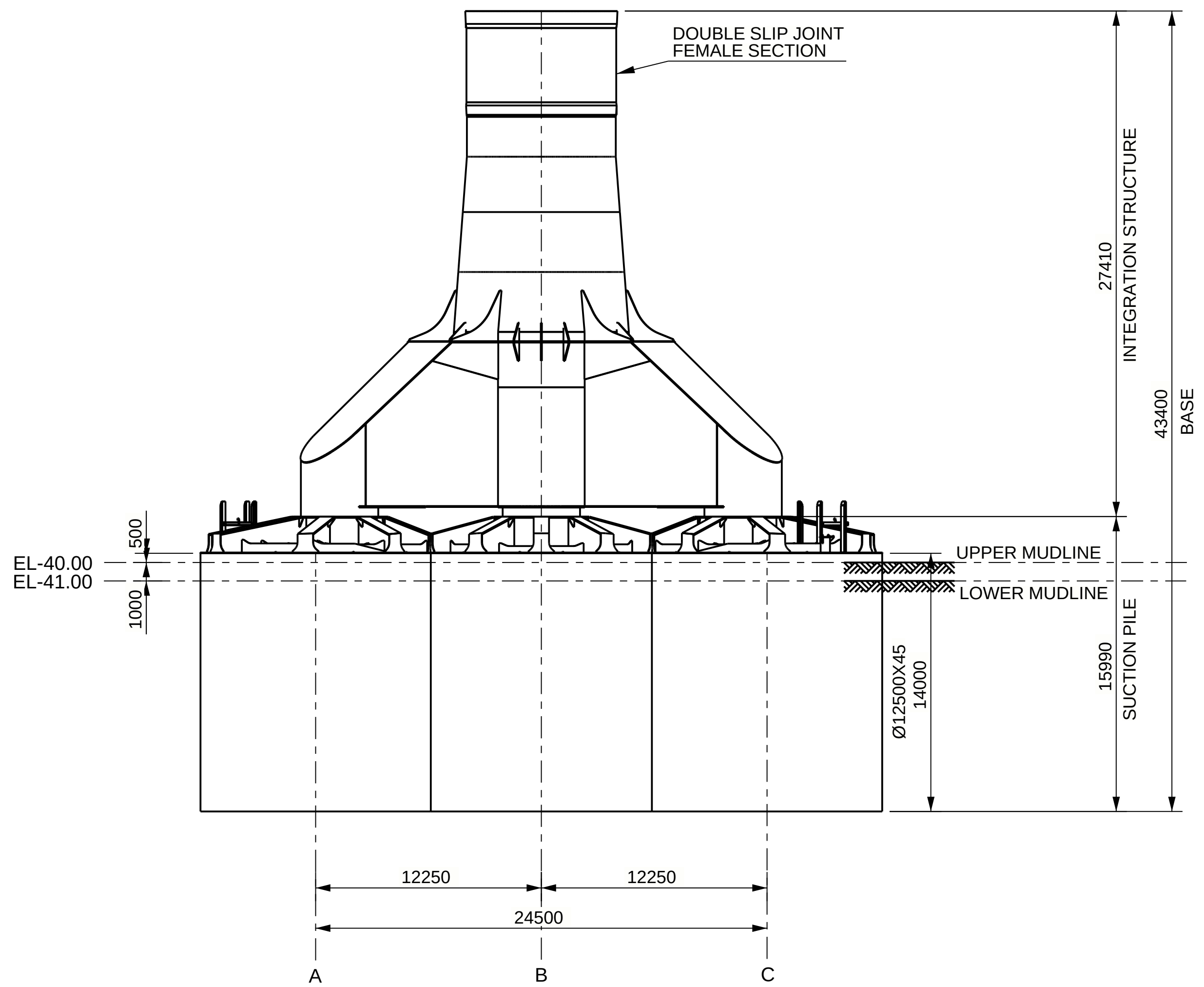

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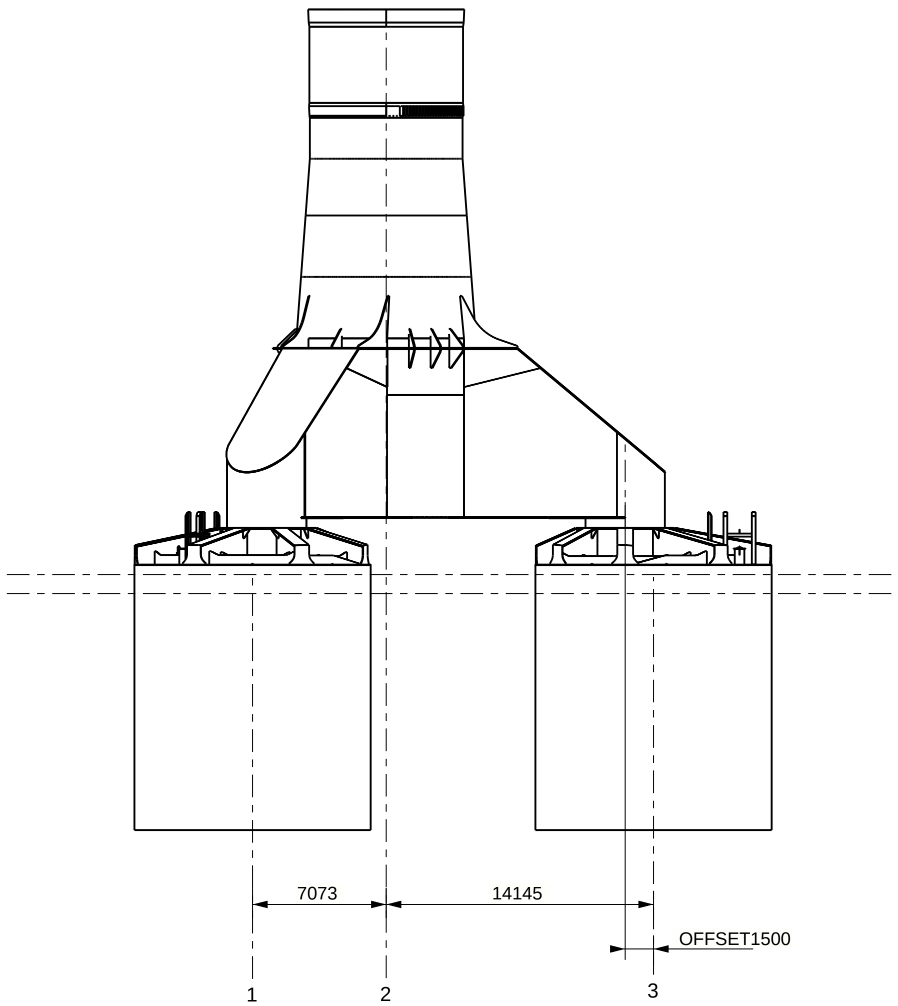

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NOTES:

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2. FOR GENERAL NOTES SEE DRAWING : 20204001-SPT-STR-DRA-0000
3. DRY NET WEIGHTS:
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   - INTEGRATION STRUCTURE = 983 mT
   - BASE WEIGHT = 1871 mT

REFERENCES:

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TITLE: GENERAL ARRANGEMENT BASE

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REV:

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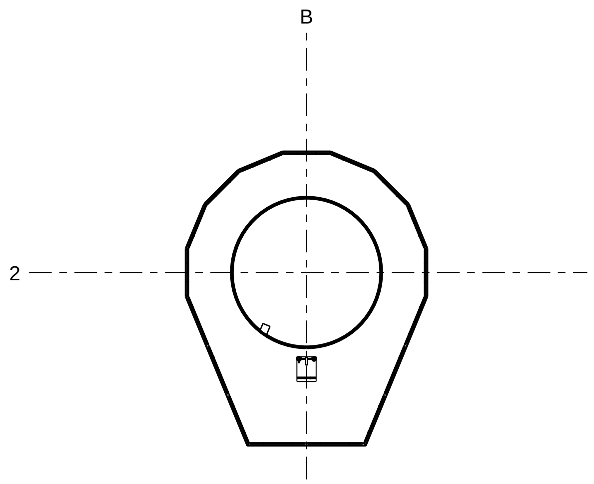

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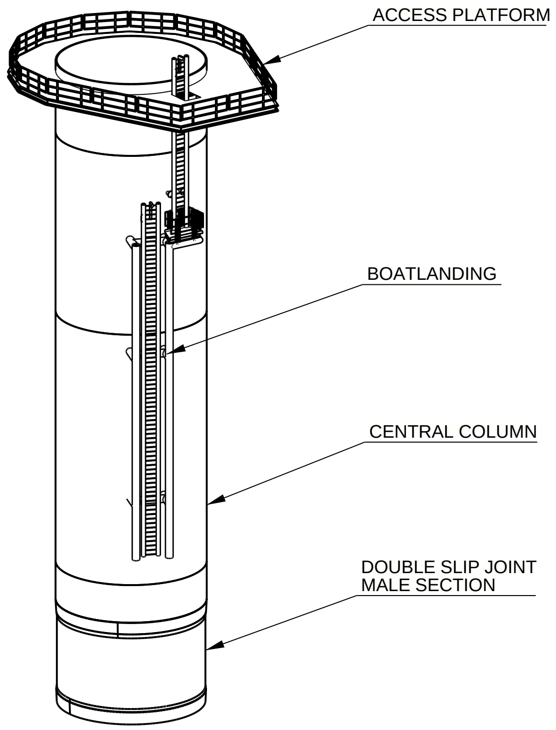

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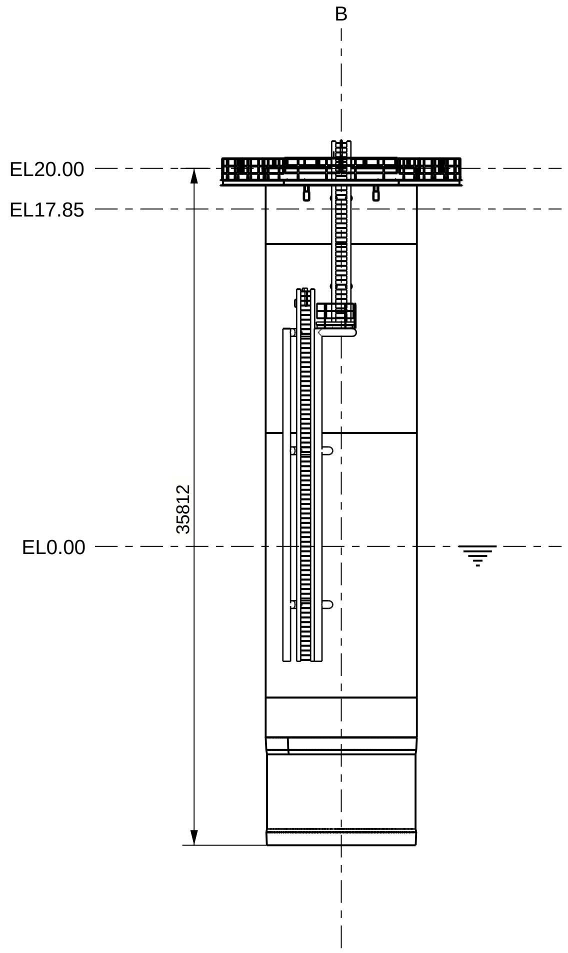

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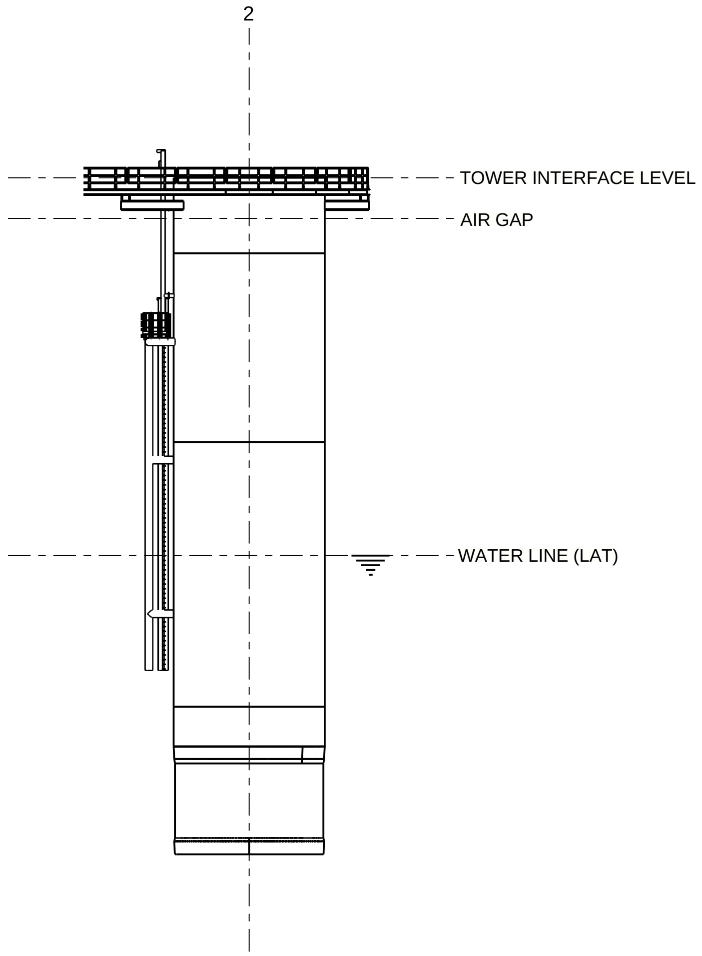

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NOTES:

1. CONCEPTUAL DESIGN ONLY
   (boatlanding+access platform for indication only)
2. FOR GENERAL NOTES SEE DRAWING : 20204001-SPT-STR-DRA-0000
3. DRY NET WEIGHTS:
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   - BOATLANDING = 24 mT
   - ACCESS PLATFORM = 18 mT
   - COMBINED WEIGHT = 562 mT

REFERENCES:

1. 20204001-SPT-STR-DRA-1002 MTO

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CLIENT:

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TITLE: GENERAL ARRANGEMENT CENTRAL COLUMN

SCALE: 1:400 (A3)

CLIENT DOC. No. -

REV:

SHEET: 3/4

DRAWING No. 20204001-SPT-STR-DRA-1001

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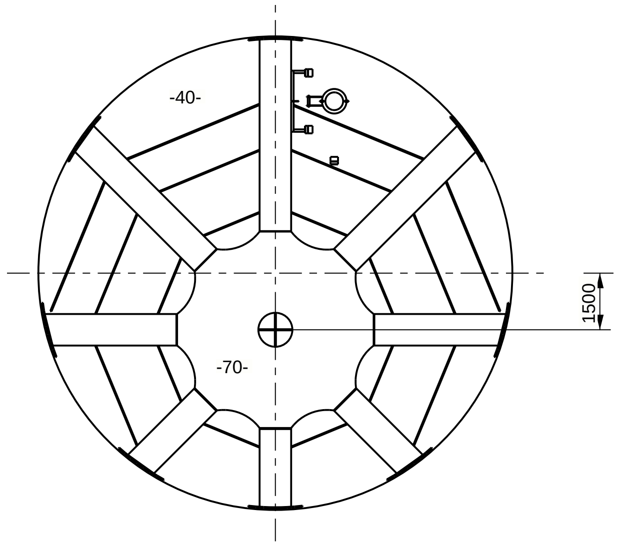

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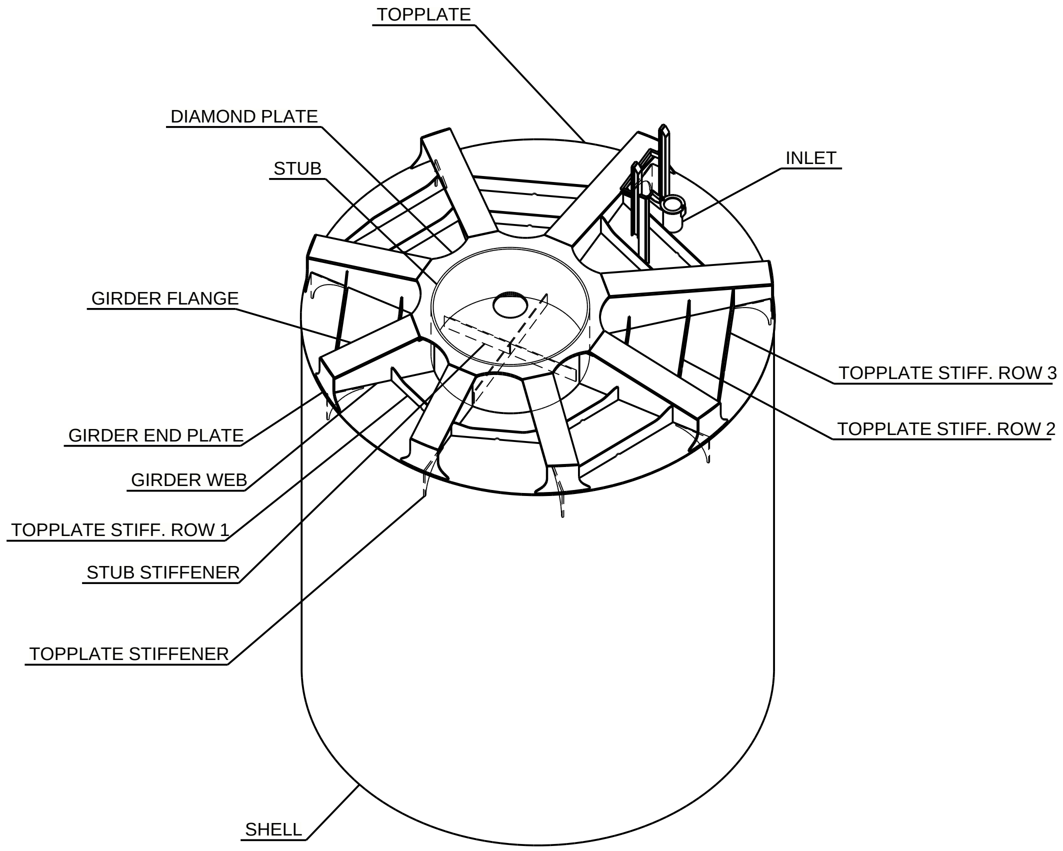

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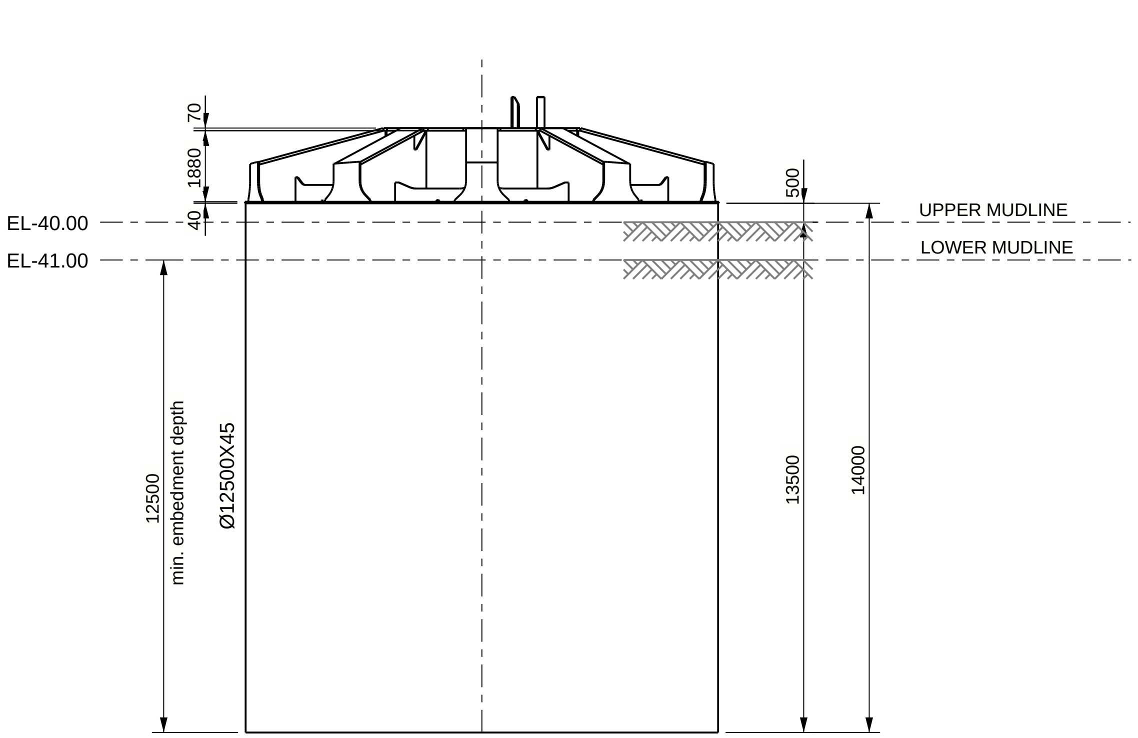

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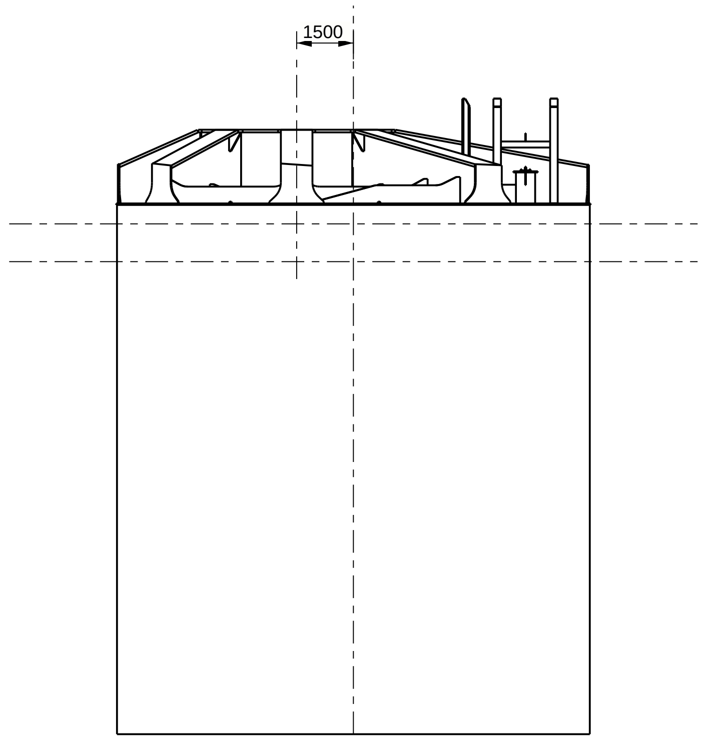

SIDE VIEW
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NOTES:

1. CONCEPTUAL DESIGN ONLY
2. FOR GENERAL NOTES SEE DRAWING : 20204001-SPT-STR-DRA-0000
3. DRY NET WEIGHTS:
   - SUCTION PILE = 296 mT

REFERENCES:

1. 20204001-SPT-STR-DRA-1002 MTO

REV.	DATE	DESCRIPTION	PREP.	CHK.	APPR.
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CLIENT:

PROJECT: TSPC NOWRDC

TITLE: GENERAL ARRANGEMENT SUCTION PILE

SCALE:	CLIENT DOC. No.	REV:
1:200 (A3)	-	
SHEET: 4/4	DRAWING No. 20204001-SPT-STR-DRA-1001	REV: A1

Item no.	Profile	Length(mm)	Material	Qty	Item Mass(kg)	Total Mass(kg)	Total Area(m²)	Item Designation
1	Ø9500X60	6440	TYPE 1	1	89931	89931	194	CC STUB
2	Ø9500X90	3000	TYPE 1	1	62641	62641	92	CC STUB
3	Ø9500X9014X90	3250	TYPE 1	1	66292	66292	97	CC CONE SECTION
4	Ø9014.21X8528X91	3250	TYPE 1	1	63468	63468	92	CC CONE SECTION
5	Ø85268X8080X98	3000	TYPE 1	1	59635	59635	81	CC CONE SECTION
6	Ø4200X80	6427	TYPE 1	3	37948	113844	189	MAIN GIRDER STUB
7	Ø9320	45	TYPE 3	1	19653	19653	113	CC INTERNAL RING STIFFENER
8	PL75X12950	14510	TYPE 1	1	37679	37679	134	MAIN DIAMOND PLATE
9	PL30X4040	4040	TYPE 3	3	2601	7802	68	MAIN STUB INTERNAL RING STIFFENER
10	Ø9500	45	TYPE 2	1	25029	25029	143	CC BOTTOM PLATE
11	PL80X6084.6	6084	TYPE 2	3	7227	21679	74	MAIN GIRDER BOTTOM FLANGE
12	PL50X7256.1	7538	TYPE 2	3	8109	24327	128	MAIN GIRDER BOTTOM FLANGE
13	PL50X7865	8101	TYPE 2	6	21505	129028	666	MAIN GIRDER WEB
14	PL80X2000	4035	TYPE 2	6	3425	20552	71	MAIN GIRDER WEB
15	PL50X4643	10227	TYPE 2	3	16442	49327	255	MAIN GIRDER TOP FLANGE
16	PL60X2750	3051	TYPE 2	6	1271	7626	36	MAIN TOP STIFFENER
17	PL60X1000	1039	TYPE 2	12	277	3318	17	SECONDARY TOP STIFFENER
17	PL60X1000	1000	TYPE 2	9	280	2522	13	SECONDARY TOP STIFFENER
18	PL60X867	5835	TYPE 2	6	2017	12102	59	MAIN GIRDER STIFFENER
19		2165	TYPE 1	1	36278	36278	57	CC STUB
20			TYPE 2	1		130000	162	DSJ FEMALE
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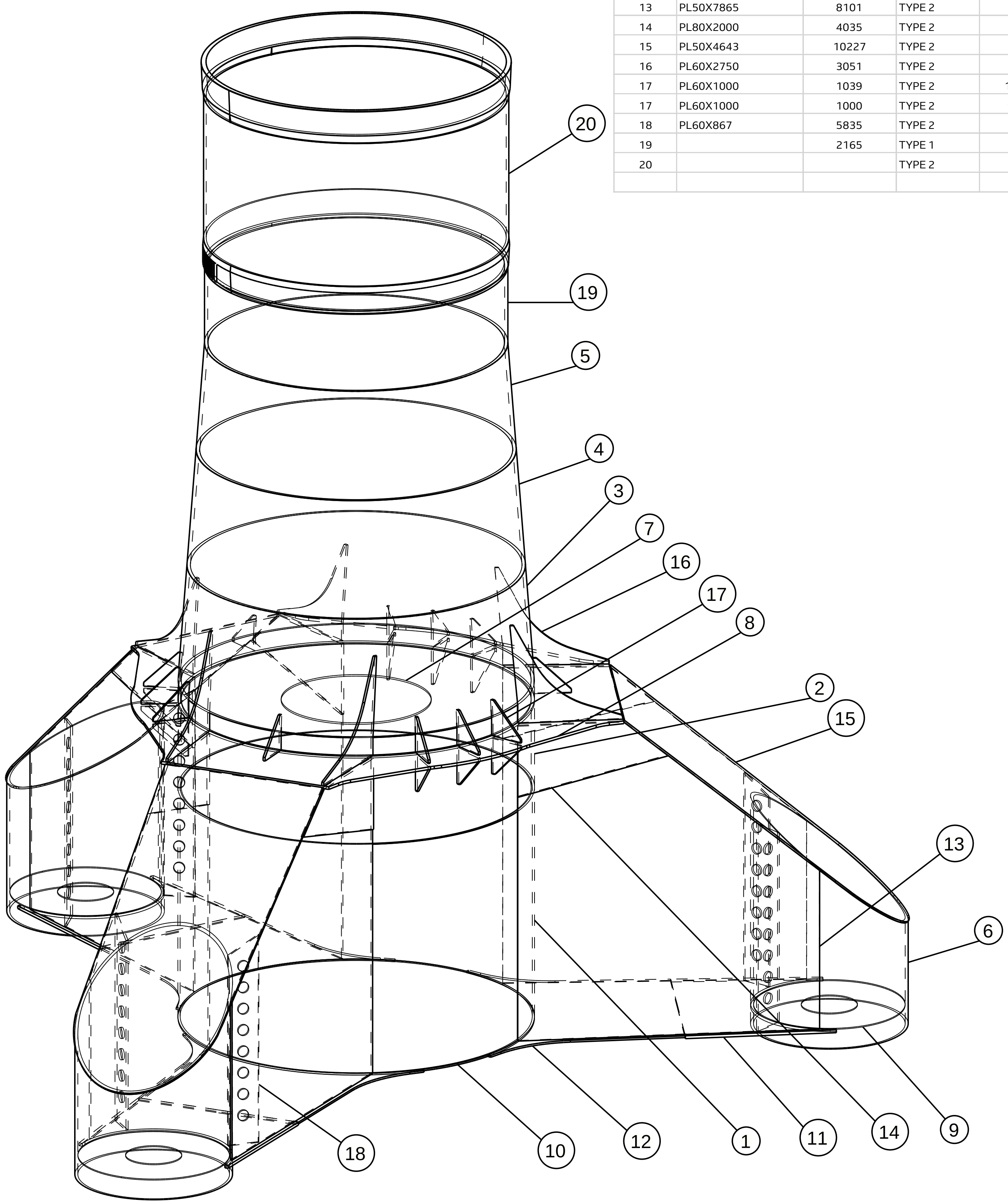

ISO METRIC VIEW
1:150

NOTES:

1. CONCEPTUAL DESIGN ONLY
2. FOR GENERAL NOTES SEE DRAWING : 20204001-SPT-STR-DRA-0000
3. DRY NET WEIGHTS:
   - INTEGRATION STRUCTURE = 983 mT

REFERENCES:

1. 20204001-SPT-STR-DRA-1001 GENERAL ARRANGEMENT

REV.	DATE	DESCRIPTION	PREP.	CHK.	APPR.
B1	28-02-2023	CONCEPTUAL DESIGN	RPI	ADB	PKR

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SPT OFFSHORE

CLIENT:

PROJECT: TSPC NOWRDC

TITLE: MTO INTEGRATION STRUCTURE

SCALE: 1:150 (A3)

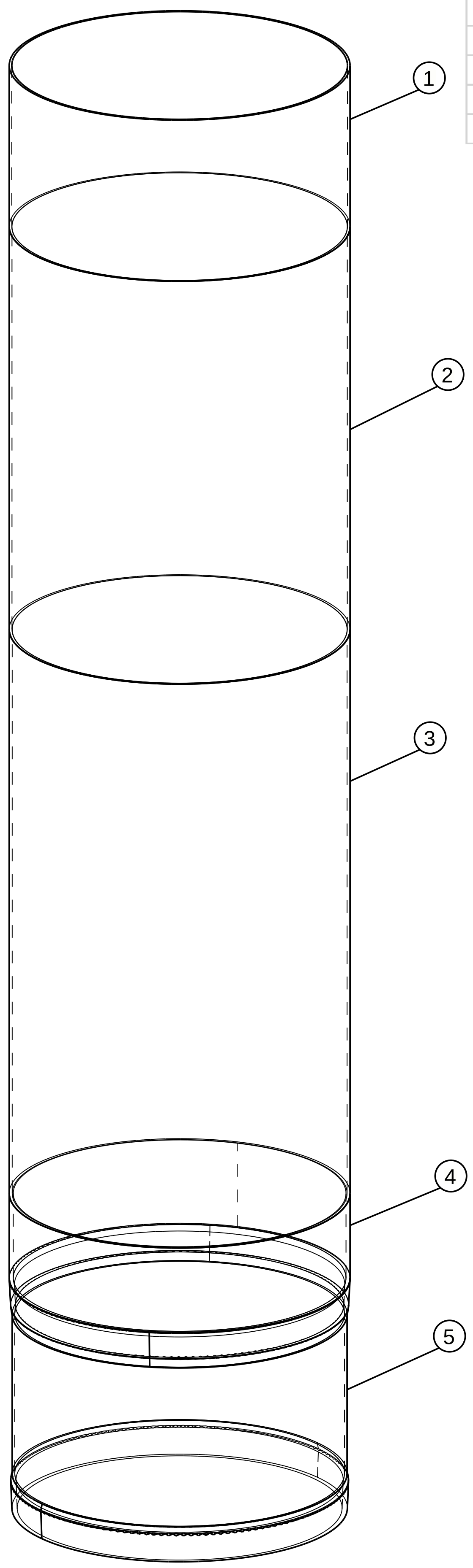
CLIENT DOC. No.: -

REV.:

SHEET: 1/3

DRAWING No.: 20204001-SPT-STR-DRA-1002

REV.: A1



ISO METRIC VIEW
1:150

Item no.	Profile	Length(mm)	Material	Qty	Item Mass(kg)	Total Mass(kg)	Total Area(m²)	Item Designation
1	Ø8000X60	4000	TYPE 3	1	46980	46980	102	CENTRAL COLUMN
2	Ø8000X65	10000	TYPE 3	1	127158	127158	253	CENTRAL COLUMN
3	Ø8000X70	14000	TYPE 3	1	191594	191594	354	CENTRAL COLUMN
4	Ø8000X95	2100	TYPE 3	1	38884	38884	55	CENTRAL COLUMN
5	Ø8000X144		TYPE 2	1		115000	150	DSJ MALE
					Total:	519616	914	

NOTES:

1. CONCEPTUAL DESIGN ONLY
2. FOR GENERAL NOTES SEE DRAWING : 20204001-SPT-STR-DRA-0000
3. DRY NET WEIGHTS:
   - CENTRAL COLUMN = 520 mT

REFERENCES:

1. 20204001-SPT-STR-DRA-1001 GENERAL ARRANGEMENT

REV.	DATE	DESCRIPTION	PREP.	CHK.	APPR.
B1	28-02-2023	CONCEPTUAL DESIGN	RPI	ADB	PKR

Korenmolenlaan 2
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www.sptoffshore.com

CLIENT:

PROJECT: TSPC NOWRDC

TITLE: MTO CENTRAL COLUMN

SCALE: 1:150 (A3)

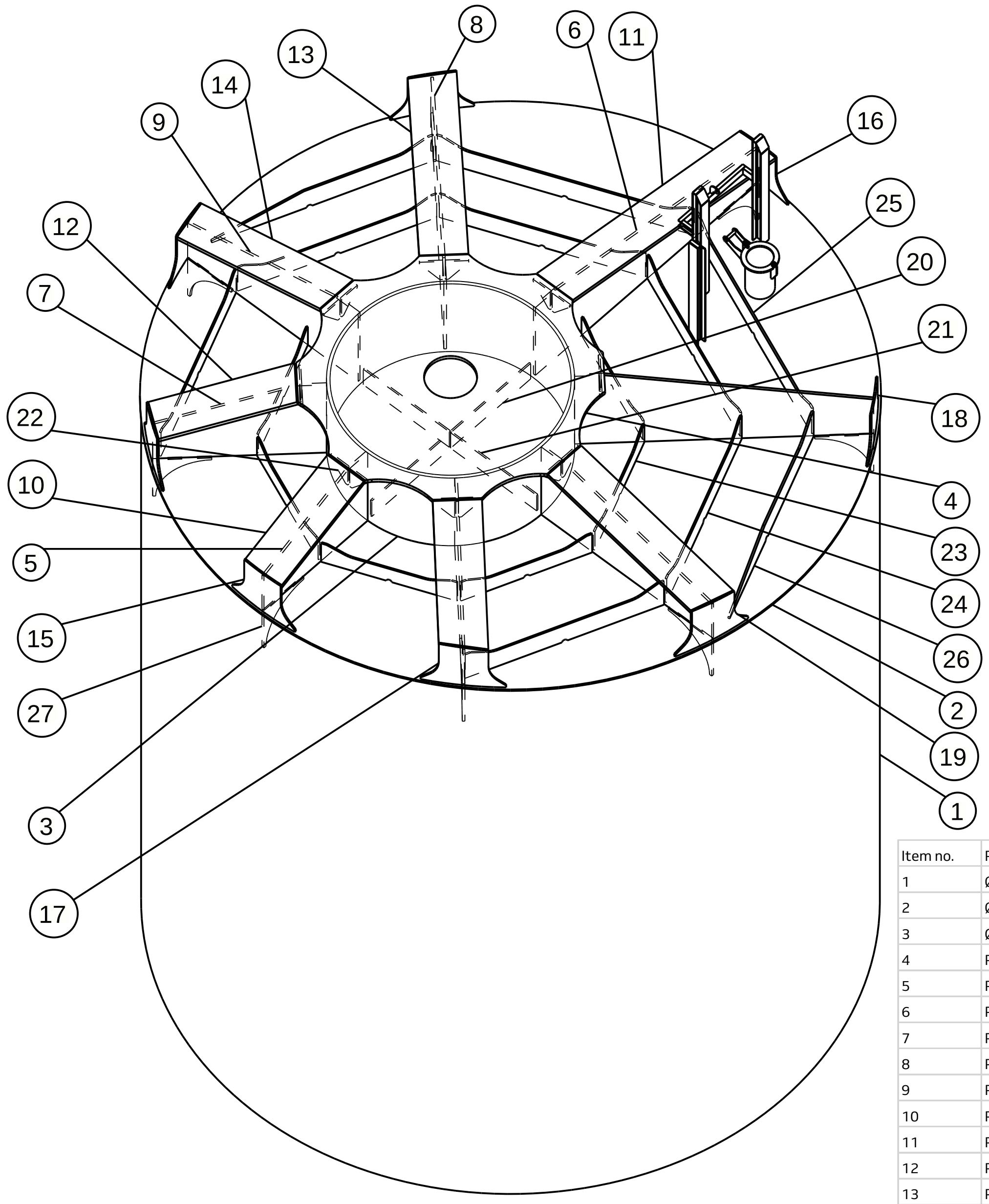
CLIENT DOC. No. -

REV:

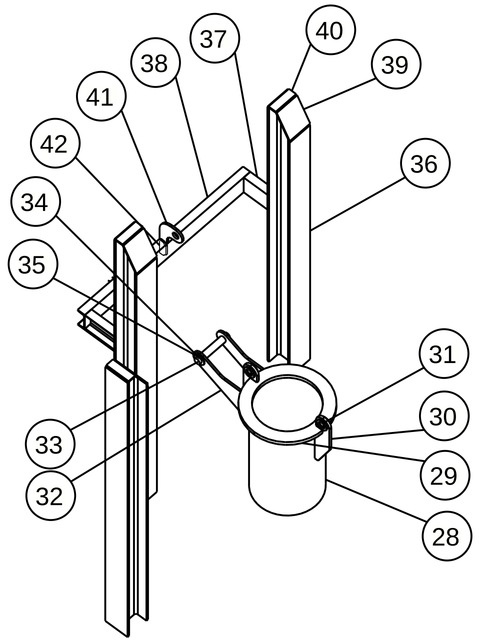
SHEET: 2/3

DRAWING No. 20204001-SPT-STR-DRA-1002

REV: A1



ISOMETRIC VIEW
1:125



ISOMETRIC VIEW
1:50

Item no.	Profile	Length(mm)	Material	Qty	Item Mass(kg)	Total Mass(kg)	Total Area(m²)	Item Designation
1	Ø12500X45	14000	TYPE 3	1	193471	193471	552	SHELL
2	Ø12540	40	TYPE 1	1	38705	38705	248	TOPPLATE
3	Ø4200X60	1880	TYPE 3	1	11510	11510	26	STUB
4	PL70X5123.7	5124	TYPE 1	1	10685	10685	40	DIAMOND PLATE
5	PL45X1880	2598	TYPE 2	1	1381	1381	8	GIRDER WEB
6	PL45X1880	5598	TYPE 2	1	2880	2880	17	GIRDER WEB
7	PL45X1880	2946	TYPE 2	2	1555	3109	18	GIRDER WEB
8	PL45X1880	5066	TYPE 2	2	2615	5229	31	GIRDER WEB
9	PL45X1880	3914	TYPE 2	2	2038	4077	24	GIRDER WEB
10	PL70X835	2294	TYPE 2	1	1043	1043	4	GIRDER FLANGE
11	PL70X835	5181	TYPE 2	1	2372	2372	9	GIRDER FLANGE
12	PL70X835	2676	TYPE 2	2	1187	2375	10	GIRDER FLANGE
13	PL70X835	4717	TYPE 2	1	2128	2128	9	GIRDER FLANGE
13	PL70X835	4717	TYPE 2	1	2128	2128	9	GIRDER FLANGE
14	PL70X835	3629	TYPE 2	2	1611	3223	13	GIRDER FLANGE
15	PL30X1040	1442	TYPE 3	1	235	235	2	GIRDER END PLATE
16	PL30X1025	1442	TYPE 3	1	232	232	2	GIRDER END PLATE
17	PL30X1060	1461	TYPE 3	2	236	473	4	GIRDER END PLATE
18	PL30X1040	1461	TYPE 3	2	235	469	4	GIRDER END PLATE
19	PL30X1060	1487	TYPE 3	2	239	478	4	GIRDER END PLATE
20	PL30X430	3980	TYPE 3	1	403	403	4	STUB STIFFENER
21	PL30X430	1975	TYPE 3	2	200	400	4	STUB STIFFENER
22	PL30X395	500	TYPE 3	16	28	452	5	DIAMOND PLATE STIFFENER
23	PL30X510	2448	TYPE 3	8	224	1791	17	TOPPLATE STIFF. ROW 1
24	PL30X650	3713	TYPE 3	6	418	2506	23	TOPPLATE STIFF. ROW 2
25	PL35X700	4638	TYPE 3	2	664	1329	10	TOPPLATE STIFF. ROW 3
26	PL35X700	4140	TYPE 3	2	464	928	7	TOPPLATE STIFF. ROW 3
27	PL45X1000	1000	TYPE 3	8	103	827	6	TOPPLATE STIFFENER
28	Ø508X12.7	860	TYPE 1	1	133	133	1	INLET
29	PL30X650	650	TYPE 3	1	37	37	0,4	SUCTION INLET FLANGE
30	PL20X131	490	TYPE 1	2	7	15	0,2	INLET PADEYE
31	PL10X90	90	TYPE 1	4	0,3	1	0,1	INLET PADEYE
32	PL15X314.9	504	TYPE 3	2	9	18	0,4	INLET
33	D50	295	TYPE 3	1	4	4	0,1	INLET
34	Ø90X20	5	TYPE 3	2	0,2	0,3	0,01	INLET
35	D10	80	TYPE 3	2	0,0	0,1	0,01	CLAMPING BUSHING
36	HEB200	2760	TYPE 4	3	158	473	10	GUIDE
37	UNP160	300	TYPE 4	2	6	11	0,3	GUIDE
38	UNP160	1620	TYPE 4	1	30	30	1	GUIDE
39	PL10X200	235	TYPE 4	3	4	11	0,3	GUIDE
40	PL10X65	200	TYPE 4	3	1	3	0,1	GUIDE
41	PL15X203.5	220	TYPE 4	1	3	3	0,1	GUIDE
42	PL15X57.5	144	TYPE 4	1	1	1	0,02	GUIDE
					Total:	295579	1123	

NOTES:

1. CONCEPTUAL DESIGN ONLY
2. FOR GENERAL NOTES SEE DRAWING : 20204001-SPT-STR-DRA-0000
3. DRY NET WEIGHTS:
   - SUCTION PILE = 296 mT

REFERENCES:

1. 20204001-SPT-STR-DRA-1001 GENERAL ARRANGEMENT

REV.	DATE	DESCRIPTION	PREP.	CHK.	APPR.
B1	28-02-2023	CONCEPTUAL DESIGN	RPI	ADB	PKR

Korenmolenlaan 2
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SPT OFFSHORE

CLIENT:

PROJECT: TSPC NOWRDC

TITLE: MTO SUCTION PILE

SCALE: 1:50 (A3)

CLIENT DOC. No. -

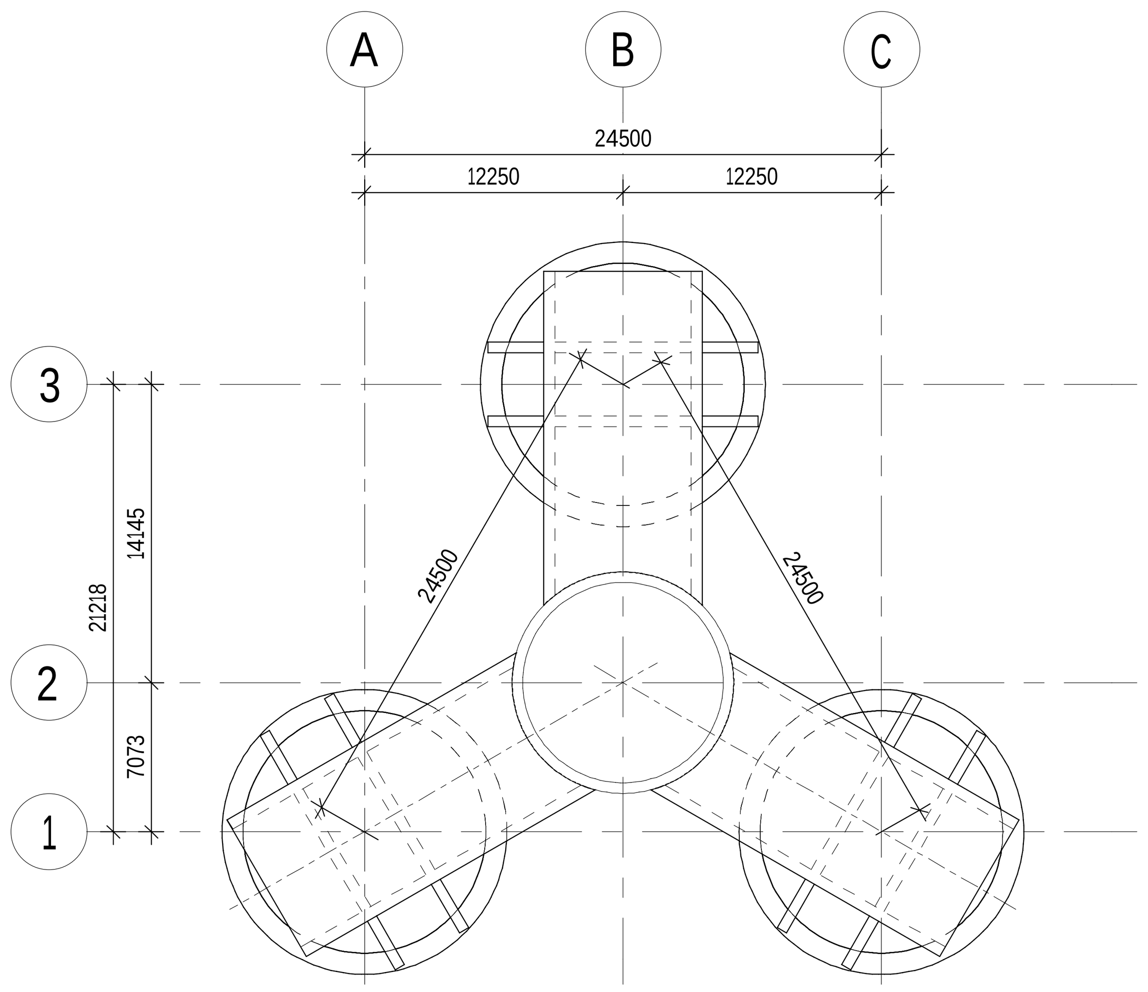
REV:

SHEET: 3/3

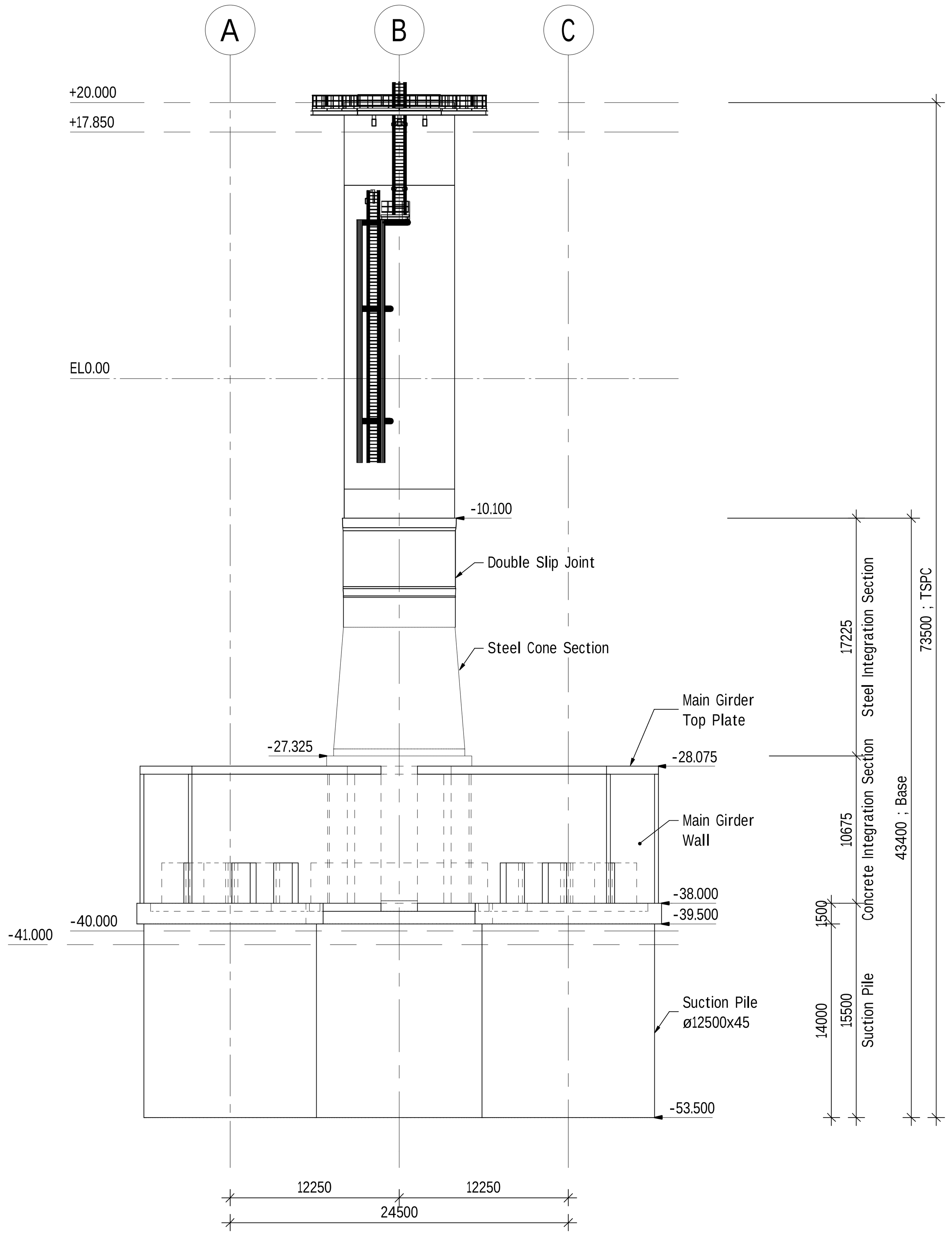
DRAWING No. 20204001-SPT-STR-DRA-1002

REV: A1

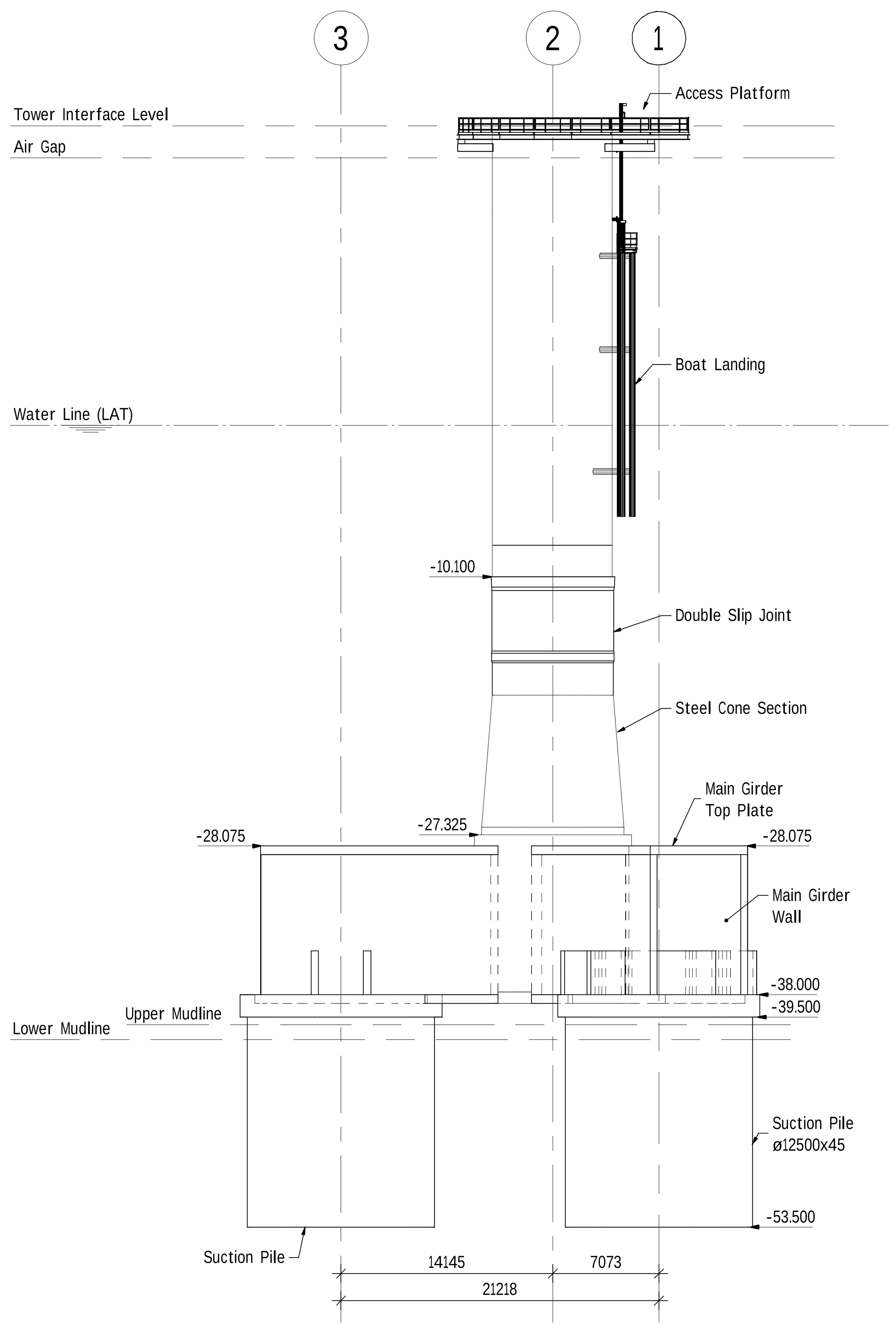
Appendix B. TSPC dimensions – concrete version



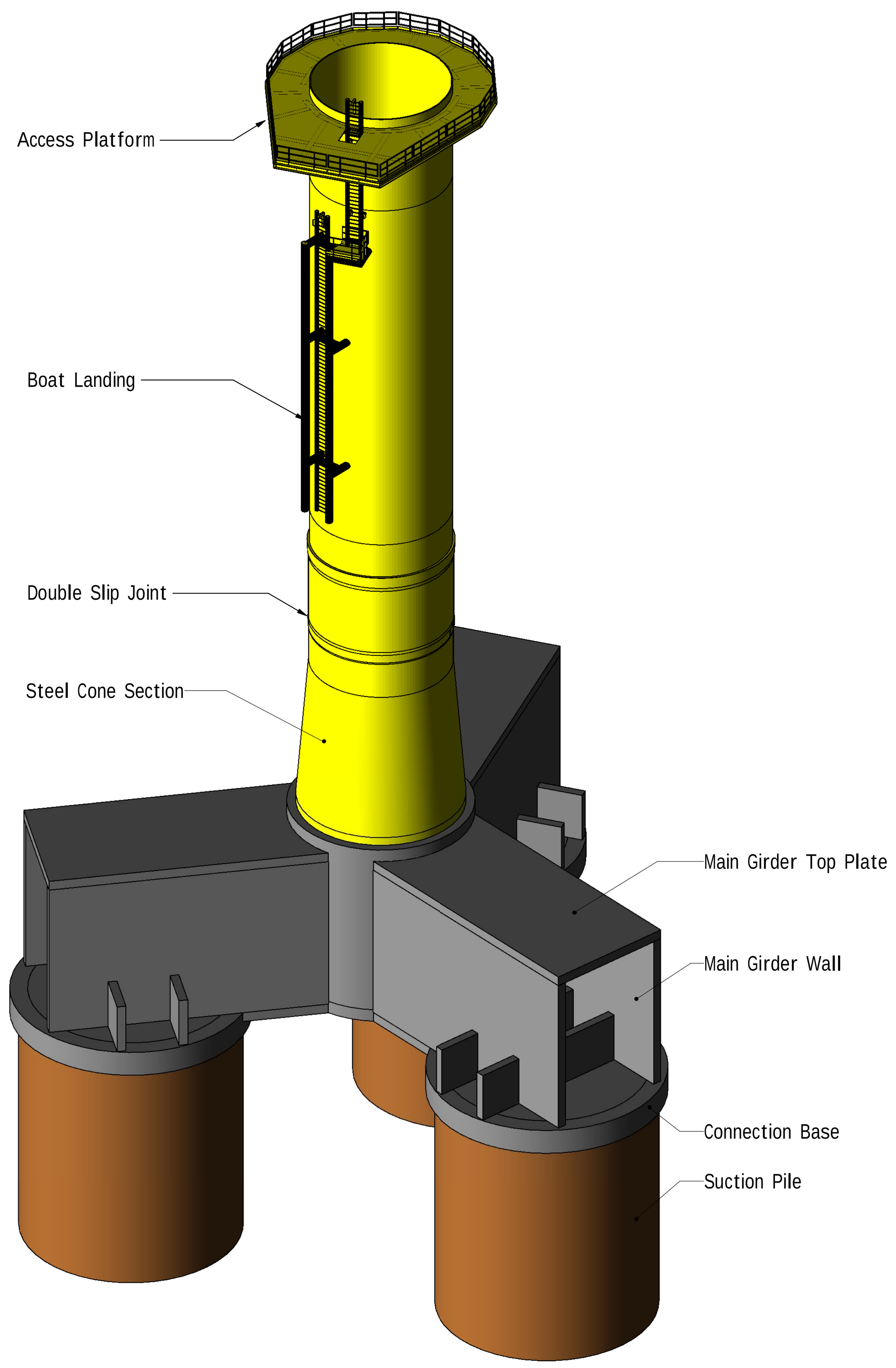
TOP VIEW
SCALE 1 : 300



FRONT VIEW
SCALE 1 : 300



SIDE VIEW
SCALE 1 : 300



ISOMETRIC VIEW

Notes:

- Conceptual Design Only
- All dimensions shown are in millimeters (U.N.O.)
- Angles are in degrees (360°)

References

20204001-2-SPT-STR-DRA-1102	Structural Drawing Concrete TSPC
20204001-2-SPT-STR-DRA-1103	Typical Details Reinforcement
20204001-2-SPT-STR-DRA-1104	MTO Concrete Integration Section

Rev.	Date	Description	Drawn	Chkd
E				
D				
C				
B	03-03-23	Second Issue	JWHO	JOHD
A	21-02-23	First Issue	JWHO	JOHD

PHASE: STATUS:

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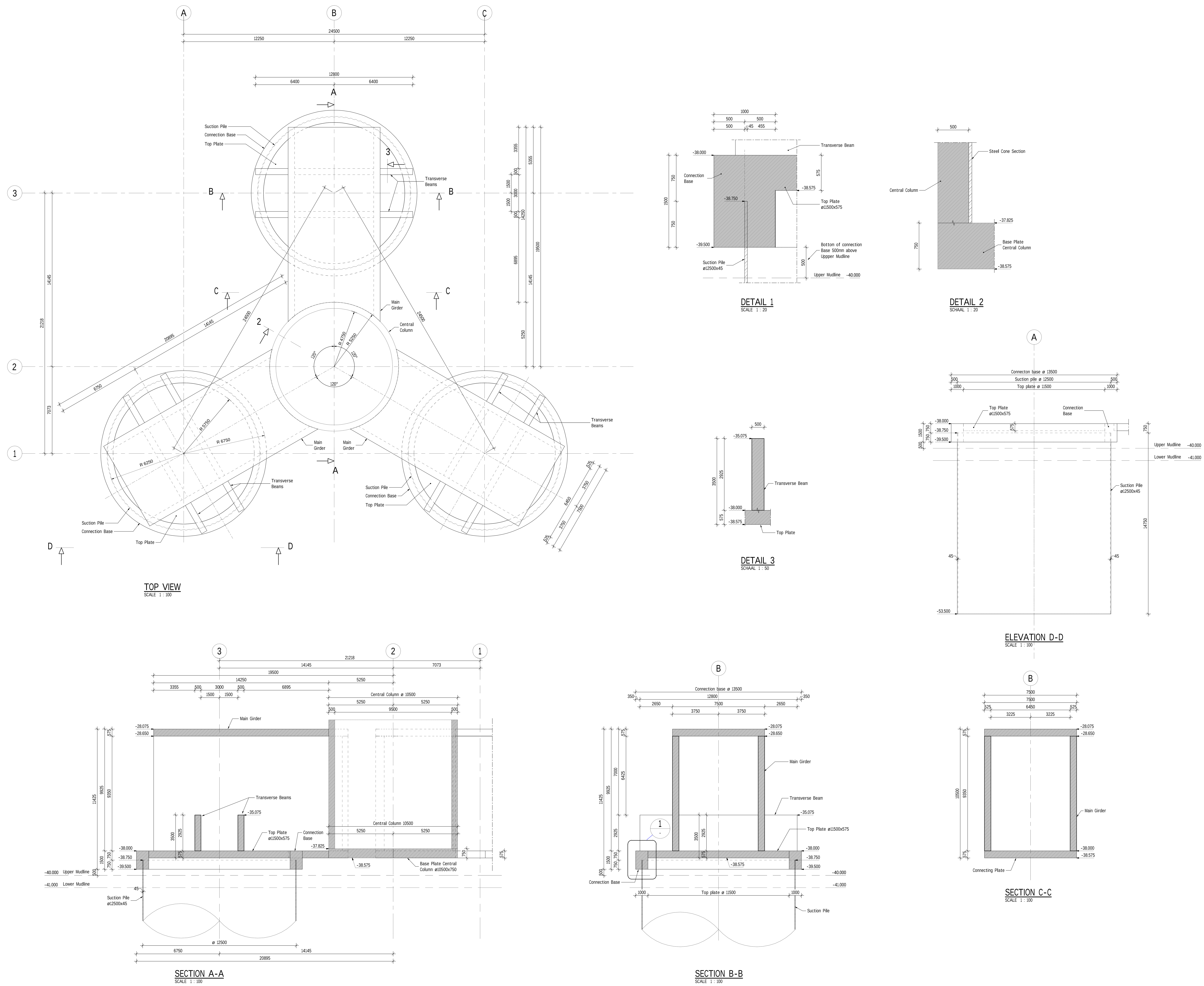
Client

Project: TSPC NOWRDC

Subject: General Arrangement
TSPC - Concrete Integration Section
Conceptual Design

Drawn	Checked	Date	Scale	Size
J.W. Hoekstra	J. de Haan	03-03-2023	1:300	A1

Project no.	Drawing no.	Rev.
20204001	20204001-2-SPT-STR-DRA-1101	



Legend

- Reinforced Concrete
- Structural Steel

Notes:

- Conceptual Design Only
- All dimensions shown are in millimeters (U.N.O.)
- Angles are in degrees (360°)
- All tubular sizes shown are outside diameters x wall thickness in millimeters, eg. ø10500x500
- All Plate thickness shown are in millimeters (U.N.O.)

Materials

- Concrete cover: 50mm
- Concrete class: C45/55

References

20204001-2-SPT-STR-DRA-1101	General Arrangement TSPC Concrete Integration Section
20204001-2-SPT-STR-DRA-1103	Typical Details Reinforcement
20204001-2-SPT-STR-DRA-1104	MTO Concrete Integration Section

Rev.	Date	Description	Drawn	Chkd
E				
D				
C				
B	03-03-23	Second Issue	JWHO	JOHD
A	21-02-23	First Issue	JWHO	JOHD

PHASE: Conceptual Design STATUS: DRAFT

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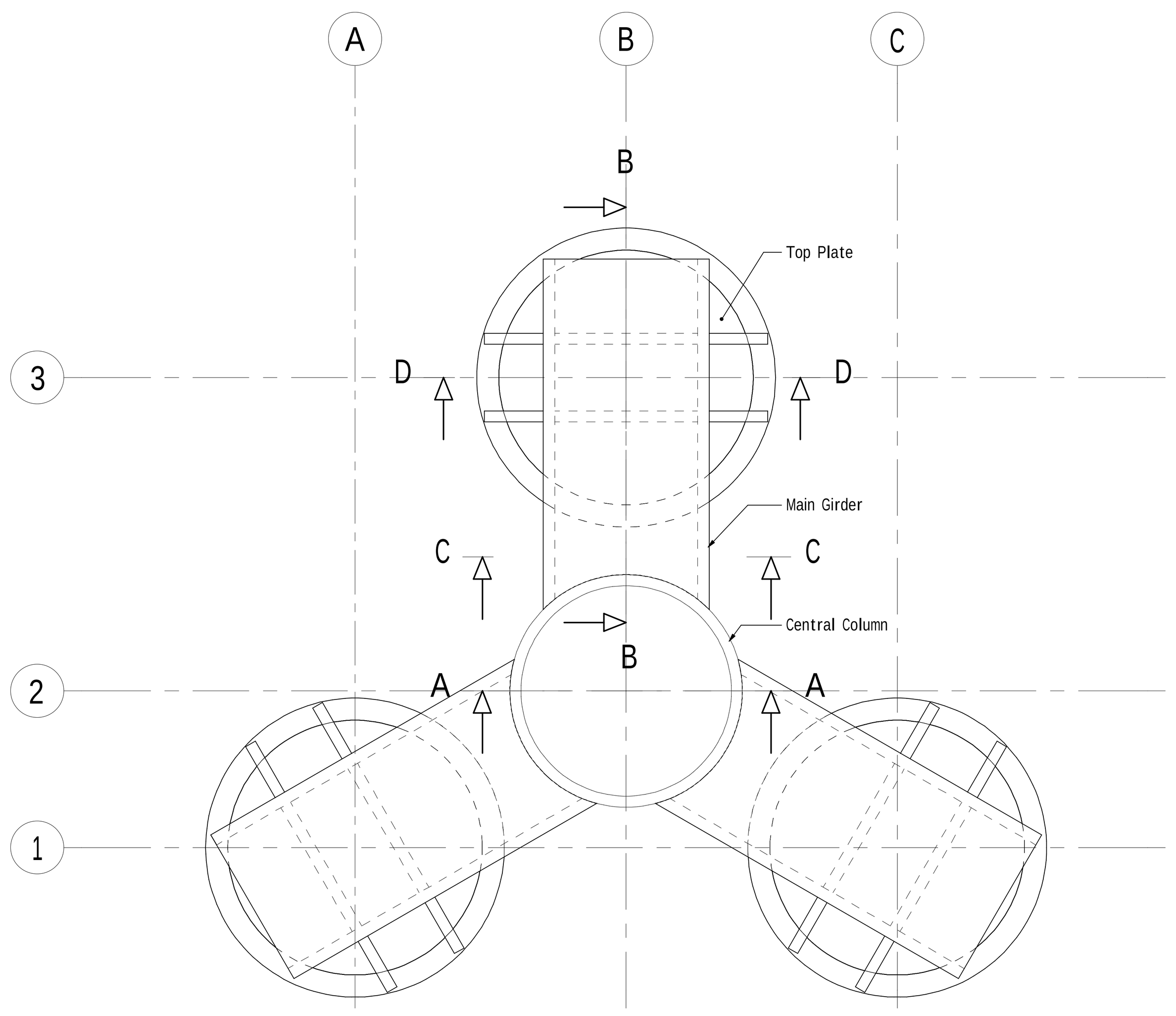
Client

Project: TSPC NOWRDC

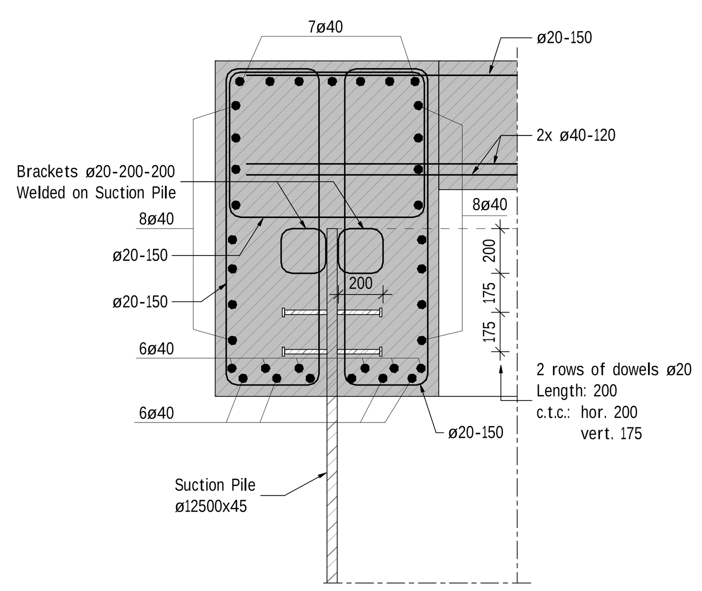
Subject: Structural Drawing
TSPC - Concrete Integration Section
Conceptual Design

Drawn	Checked	Date	Scale	Size
J.W. Hoekstra	J. de Haan	03-03-2023	1:100 1:50	A0

Project no.	Drawing no.	Rev.
20204001	20204001-2-SPT-STR-DRA-1102	

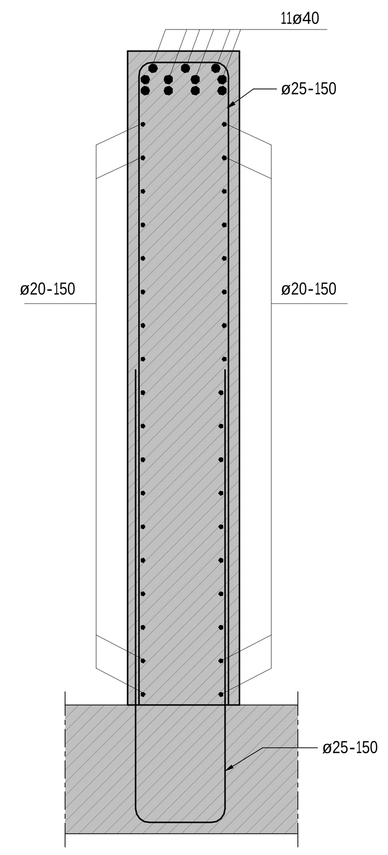


TOP VIEW



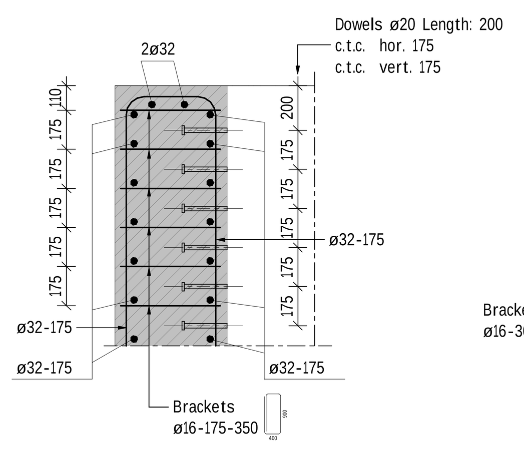
DETAIL 1

SCHAAL 1 : 20



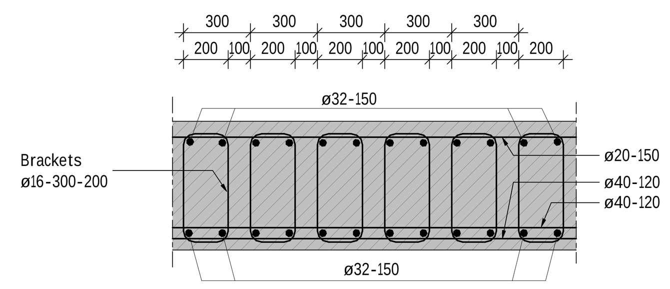
DETAIL 2

SCHAAL 1 : 20



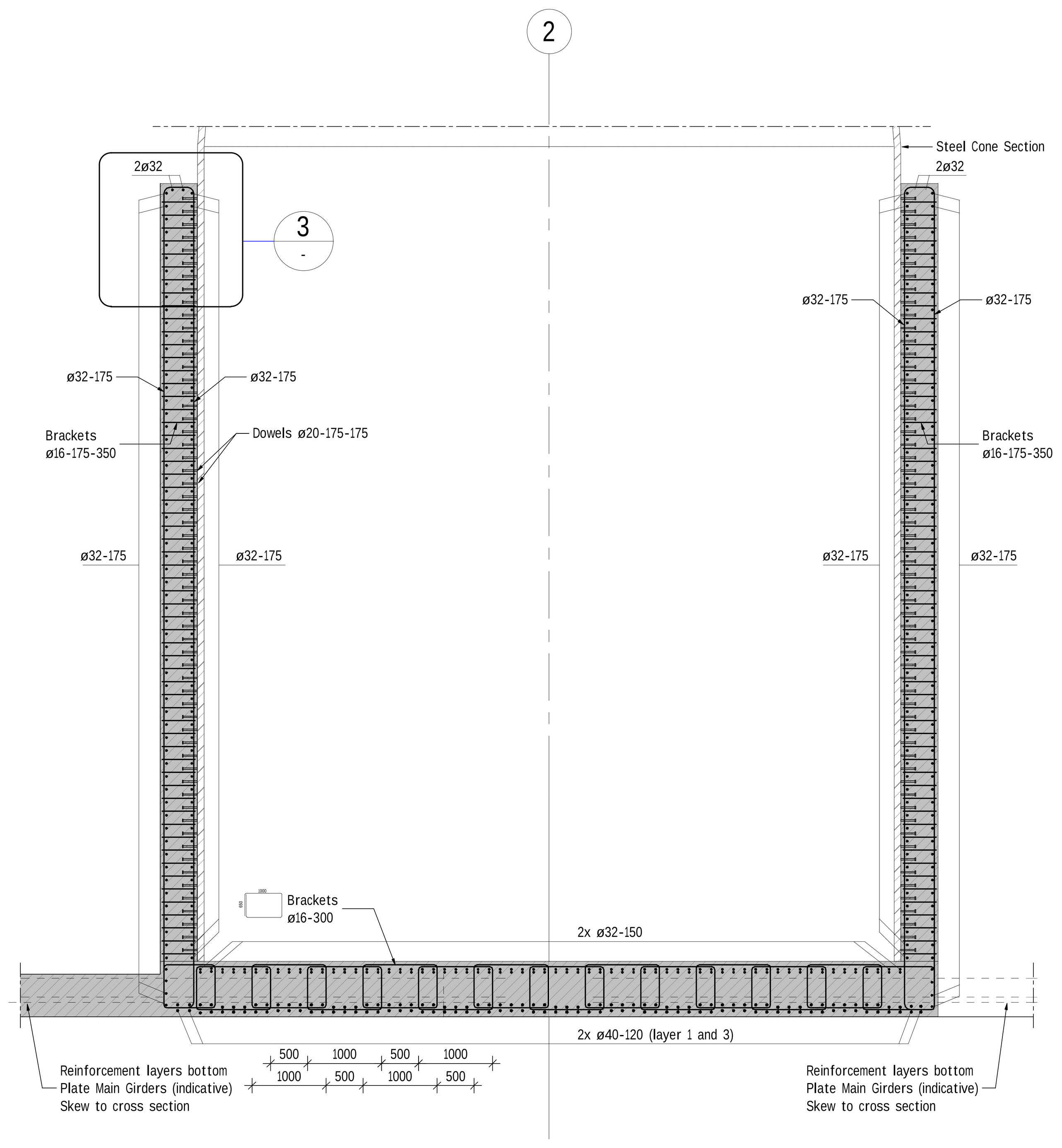
DETAIL 3

SCALE 1 : 20



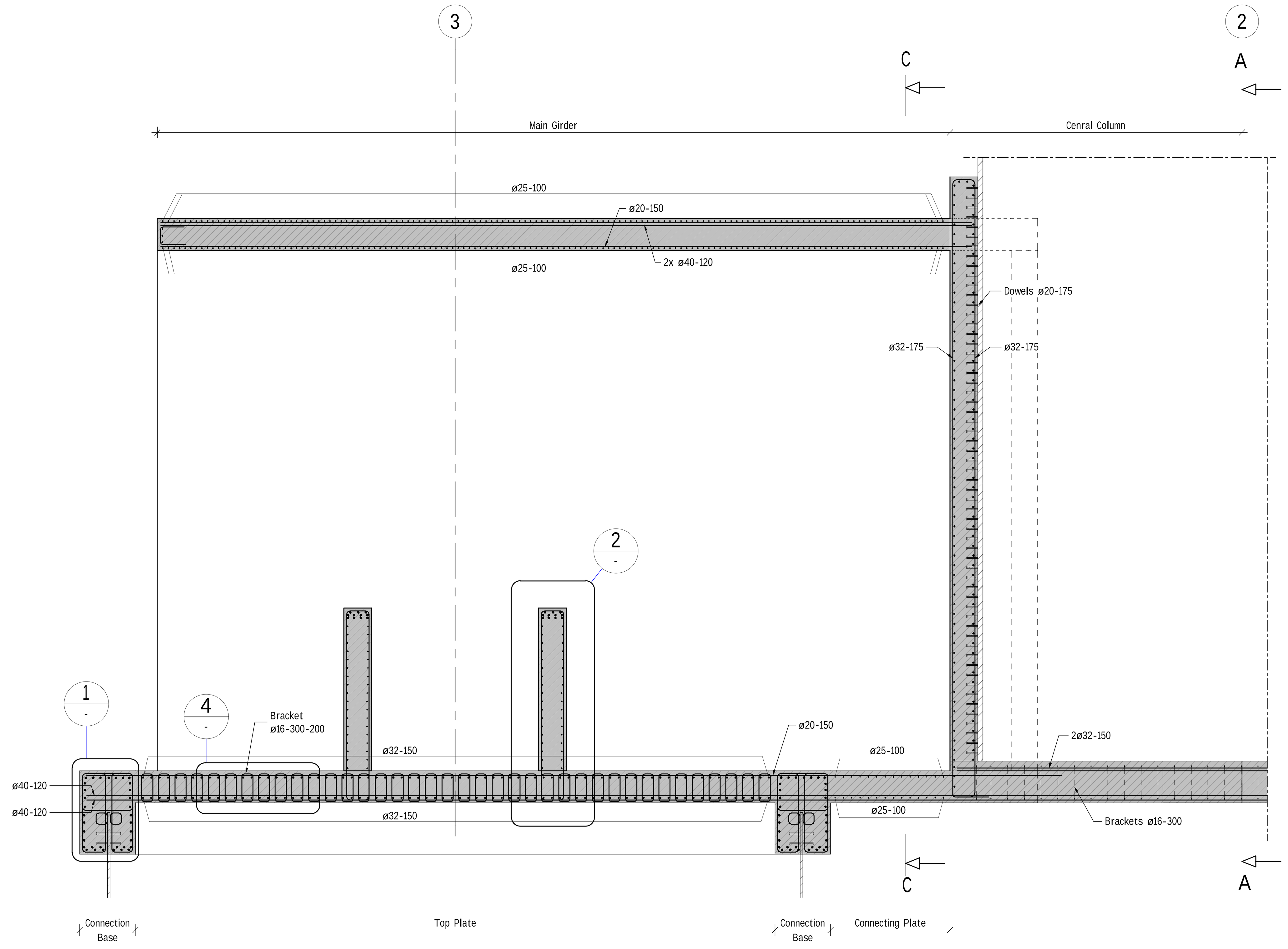
DETAIL 4

SCALE 1 : 20



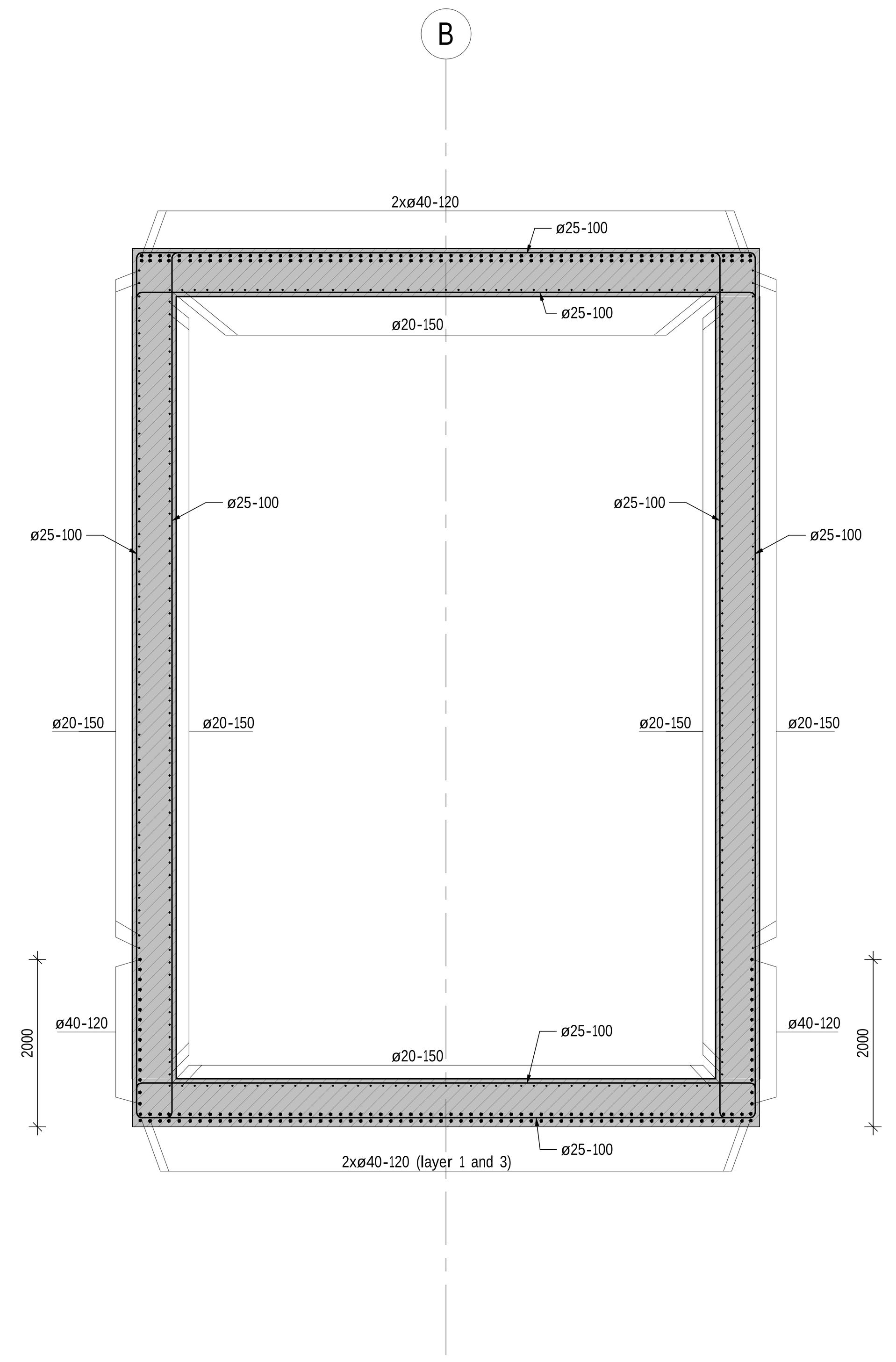
SECTION A-A; CENTRAL COLUMN

SCHAAL 1 : 50



SECTION B-B

SCALE 1 : 50



SECTION C-C; MAIN GIRDER

SCHAAL 1 : 50

Legend

- Reinforced Concrete
- Structural Steel

Notes:

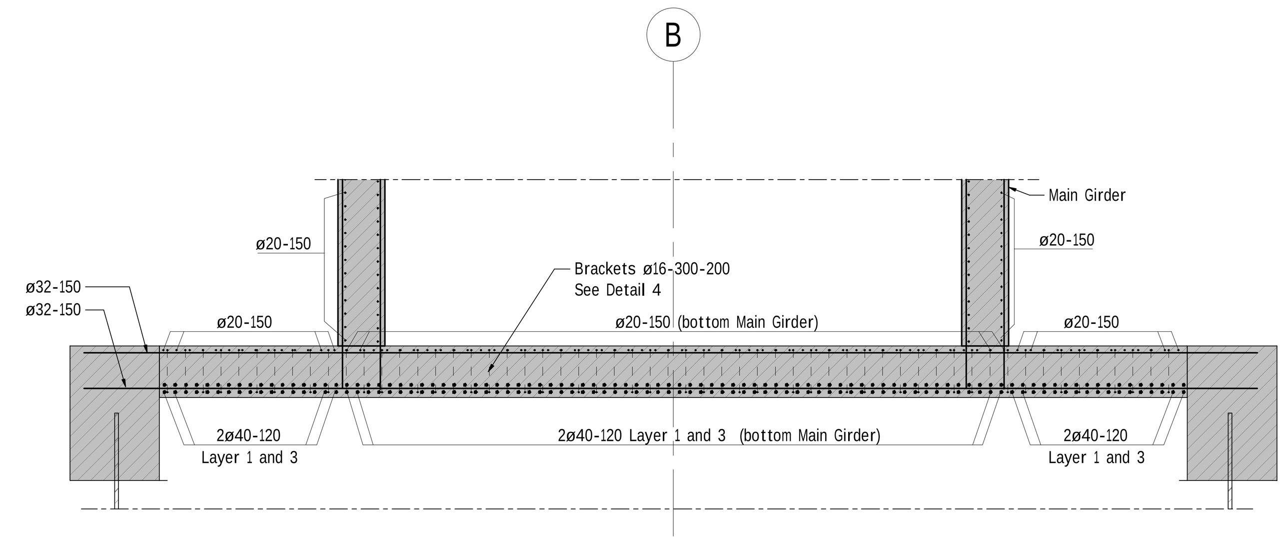
- Conceptual Design Only
- All dimensions shown are in millimeters (U.N.O.)
- Angles are in degrees (360°)
- All tubular sizes shown are outside diameters x wall thickness in millimeters, eg. ø10500x500
- All plate thickness shown are in millimeters (U.N.O.)

Materials

- Concrete cover: 50mm
- Concrete class: C45/55
- Reinforcement Steel: B500B

References

20204001-2-SPT-STR-DRA-1101	General Arrangement TSPC Concrete Integration Section
20204001-2-SPT-STR-DRA-1102	Structural Drawing Concrete TSPC
20204001-2-SPT-STR-DRA-1104	MTO Concrete Integration Section



SECTION D-D; TOP PLATE SUCTION PILE

SCHAAL 1 : 50

Rev.	Date	Description	Drawn	Chkd
E				
D				
C				
B	03-03-23	Second Issue	JWHO	JOHD
A	21-02-23	First Issue	JWHO	JOHD

PHASE: Conceptual Design STATUS: DRAFT

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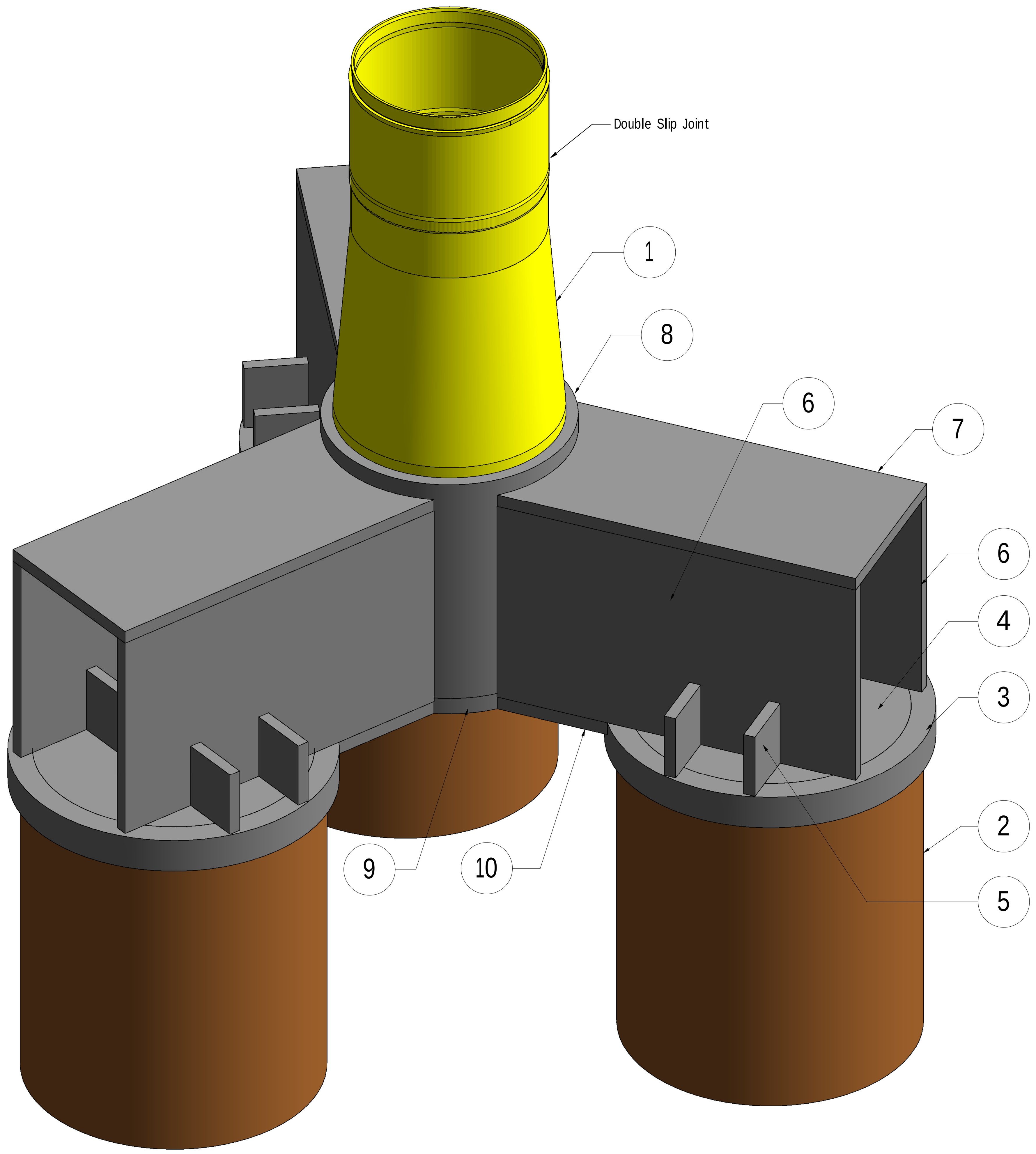
Client

Project: TSPC NOWRDC

Subject: TSPC - Concrete Integration Section Typical Details Reinforcement Conceptual Design

Drawn	Checked	Date	Scale	Size
J.W. Hoekstra	J. de Haan	03-03-2023	1:50 1:20	A0

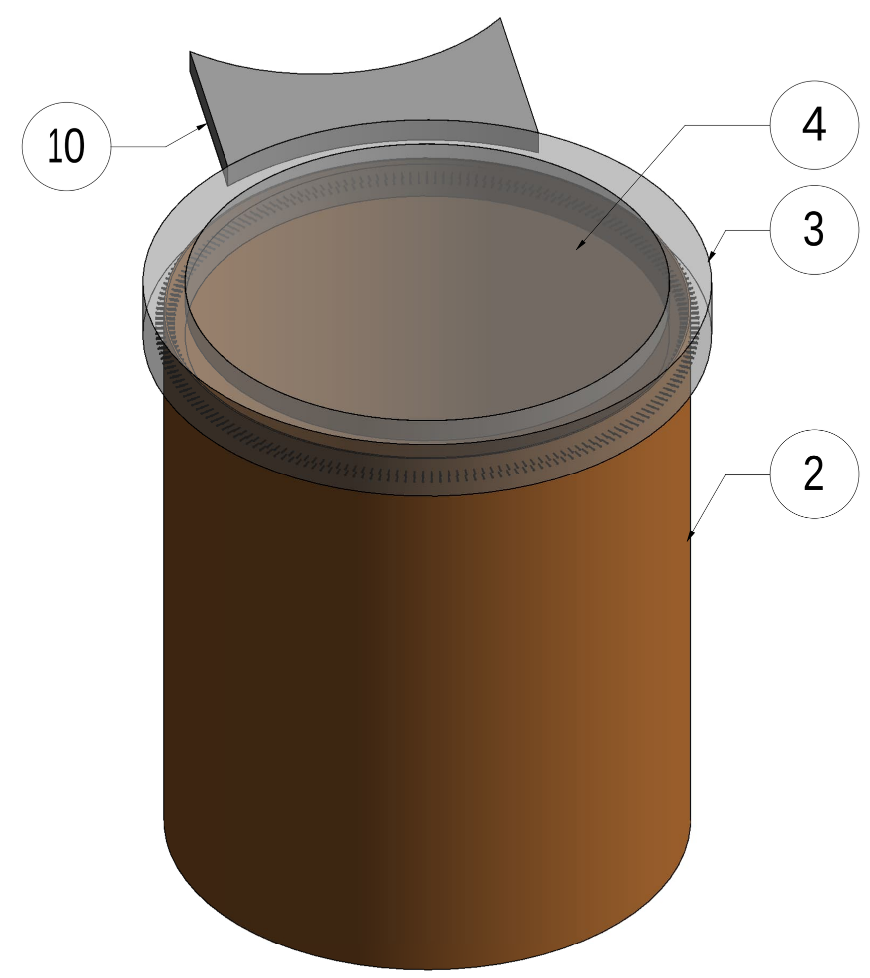
Project no.	Drawing no.	Rev.
20204001	20204001-2-SPT-STR-DRA-1103	



ISOMETRIC VIEW BASE

Item no.	Profile	Quantity	Material: Description	Volume (m3) (per elemnent)	Weight (t) (per element)	Weight (t) (total)
1	Steel Cone Section	1	Steel	62.35	489.40	489.40
2	Suction Pile ø12500x45	3	Steel	25.97	203.9	611.70
3	Connection Base	3	Reinforced concrete	58.90	147.25	441.75
4	Top Plate	3	Reinforced concrete	59.73	149.31	447.93
5	Transverse Beam	6	Reinforced concrete	18.72	46.80	280.80
6	Main Girder Wall	6	Reinforced concrete	74.91	187.29	1123.74
7	Main Girder Top Plate	3	Reinforced concrete	63.54	158.85	476.55
8	Central Column	1	Reinforced concrete	164.80	412.00	412.00
9	Base Plate Central Column	1	Reinforced concrete	64.93	162.32	162.32
10	Connecting Plate	3	Reinforced concrete	12.94	32.33	96.99

Total 4516 t



ISOMETRIC VIEW SUCTION PILE

Reinforced Concrete

Structural Steel

Notes:

- Conceptual Design Only
- All dimensions shown are in millimeters (U.N.O.)
- Angles are in degrees (360°)

References

20204001-2-SPT-STR-DRA-1101	General Arrangement TSPC Concrete Integration Section
20204001-2-SPT-STR-DRA-1102	Structural Drawing Concrete TSPC
20204001-2-SPT-STR-DRA-1103	Typical Details Reinforcement

Rev.	Datum	Omschrijving	Getekend	Gec.
E				
D				
C				
B	03-03-23	Second Issue	JWHO	JOHD
A	21-02-23	First Issue	JWHO	JOHD

FASE: Conceptual Design STATUS: DRAFT

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Opdrachtgever

Project: TSPC NOWRDC

Onderdeel: MTO Concrete Integration Section Conceptual Design

Getekend	Gecontroleerd	Datum	Schaal	Formaat
J.W. Hoekstra	J. de Haan	03-03-2023		A1

Werknummer	Tek. nummer	Rev.
20204001	20204001-2-SPT-STR-DRA-1104	