Onshore and nearshore wind turbine foundation design and construction : *How can the designer optimize time and costs, based on International and Vietnamese experiences*

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Abstract.

According to the Vietnam National Power Development Plan VII with the vision 2030, the expected Vietnamese wind energy capacity will be six (6) GW by 2030. Wind energy is very new in Vietnam. Since 2018, only 300 MW of wind energy has been constructed. However, 4.900 MW of wind energy are today registered in Vietnams pipeline and are to be developed starting from 2021. This huge potential needs a lot of international experience mixed with the local companies and conditions to develop a sustainable and renewable energy industry.
This paper would like to share CTE Winds vision of wind turbine foundation design and construction for onshore and nearshore projects on how can the engineer optimize time and costs, based on our International and Vietnamese experiences with large scale wind power projects in Europe and Vietnam.

From the wind turbine foundation construction point of view the following factors listed below will affect the design and construction: technical specifications of wind turbines, construction site conditions, International and local standards, regulations and climate uncertainties. When starting a project, it shall be paid attention to choose the best construction site, the right wind turbine technology, the best design and construction for the project. This paper will point out some problems and theirs solution to optimize or reduce the risks for the construction of wind power projects.

Keywords: Wind power plant, wind farm, foundation design, wind turbine generator, onshore, nearshore foundation and foundation construction.

1 INTRODUCTION

Vietnam is considered to have the best wind resources in Southeast Asia. Located in the monsoon climate zone, and shaped by its over 3,000 km long coastline, Vietnam´s potential to develop and generate wind power is substantial. The huge potential wind energy leads to the increasing numbers of wind farms in Vietnam which complicated the foundation design and consequently placing a greater burden on the engineer to develop more innovative and cost-effective foundations as well as support structures. So, for Onshore and nearshore wind turbine foundation design and construction: how can the designer optimize time and costs?

With more than 20 years of experience in the wind energy market, 8 agencies on 4 continents and over 17.500 Wind turbine foundations performed worldwide, the CTE (Wind) group can proudly state that our core business is the foundation design for wind turbine generators (WTG). All civil engineering activities relevant in wind power projects are provided from establishing the master plan of wind farms,to the access road and public road designs, the crane pad and platform erection designs, anchor system and concrete tower designs, or even the geotechnical analysis and drainage systems structure designs, etc.

CTV Wind is the local representative of the CTE group in Asia, located in Vietnam. CTV Wind is the company who released the first wind power plant in 2007 and did almost all wind projects in Vietnam to this day. Especially noteworthy are Tuy Phong, Huong Linh, Dam Nai, Phu Lac… Simultaneously, with more than 30 senior engineers, CTV Wind is specialized in the wind power engineering and masters the local standards, technical regulations and international standards. Besides, CTV Wind works for the local market as well as in international projects. CTV Wind brings together its international experience and expertise on large scale wind farm projects, with the in-depth local

knowledge about the materials, culture, local supply chains, and local networking to create innovative, and engineering values for wind power projects.

With far more than 20.000 MW installed power in over 67 countries and 1000 MW in Vietnam, we have accumulated a strong know-how and experience in the design and construction of Civil BoP design for wind power plants.

2 FOUNDATION DESIGN CONSIDERATIONS

2.1 About the function of WTG foundations

The components of a wind turbine system (Figure 1) include the foundations, the tower, the wind turbine generator (rotors and nacelles). The WTG Foundation is the part of the wind turbine in which the tower is anchored and that transfers the loads to the soil. The foundation is a structural part that allows the turbine to function properly during its entire lifetime. The foundation system is a major and primary component of the wind turbine generator and is used to keep the turbine in its proper position while being exposed to the forces of nature. The foundation system is the only part of a wind turbine, which is not made by manufacturer. It shall be designed and build on the construction site. Therefore, it should be paid attention to avoid all risks of environment, weather and nature. In general, all of these factors represent significant challenges in the design and construction of wind turbine support structures and foundations. This paper provides advices for selecting and designing such foundations with optimal cost and schedule.

In the Wind Turbine foundation construction point of view, these several factors will affect the wind turbine foundations design and construction, we will list the main factors below: technical specifications of wind turbines, construction site conditions, International and local standards, regulations and the climate uncertainties.

Figure 1. Foundation on site

2.2 The input data of wind turbine manufacture.

First and foremost, the input data from wind turbine manufacturer is one of the most important information. Wind turbine manufacturers shall provide all input data such as foundation load, anchor cage, technical specifications before the foundation can be designed. While the anchor system plays a role for the connection between the foundation and the tower, all technical specifications of the wind turbine are the requirements of the wind turbine manufacturer to make sure that the WTG does operate well during its lifetime. For example: the dynamic resonance criteria or fatigues criteria.

However, foundation loads of WTGs are sometimes incorrect. The designer have to verify and

request the missing information in order to progress to the next step. Sometimes, the detailed construction site is modified, or the initial assumption of the foundation load providing by the OEM is not correct and the iteration calculation has to be done with the OEM to have the right foundation load, for example in the case high pedestal foundation, nearshore foundation where the preliminary foundations will be sent to the WTG manufacturer to take into account its influence on the load. This process can take time and influence the schedules of a project. The same problems can happen with the data of the anchor cage.

Figure 2. Anchor cage

2.3 Site conditions

The second factor are the site conditions, including geotechnical and topographical conditions, hydrology conditions or marine environmental conditions of nearshore projects (wave height, tidal, current velocity ...).

Understanding the geologic setting of the site, with its inherent complexities, represents the basis for formulating an accurate set of design documents and more importantly to allow the construction of a wind farm project. The geotechnical investigations should extend throughout the depth and areal extent of soils that affect or can be affected by the installation of the planned structure and foundation. The number of bore holes depends on the selected foundation type and the anticipated geologic conditions. In general, one bore hole per turbine foundation is recommended. Since the main expense of performing an offshore drilling program is the mobilization of the drill barge, performing fewer bore holes may not be as cost-effective. Moreover, obtaining geotechnical information at foundation location goes a long way in reducing risk.

Geotechnical investigation shall be carried out according to technical specifications for Wind turbine foundation design. In Vietnam and some other countries, civil engineer sometimes receives the geotechnical report given by the wind farm's owner. But the report cannot be applied in drawings, because of the missing information for the foundation design. The same work has to be done again, which leads to loss of time and money. The characteristic of the soil determines if there is a need to perform one or several bore holes to understand the soil conditions of each wind turbine position.

If the geotechnical condition is very complex and not homogenous, we can propose to change the position of the wind turbines from the beginning. For example, we have a foundation for a wind farm and the receiving soil is very complex, the foundation cost will increase about 60% in comparison to a

project with normal ground conditions, because we have to do additional works for pile foundations or soil improvement. The investor shall be advised to change the position after analysing the trend of soil. All in all, the investor can save up to 60% additional costs in comparison to the old position.

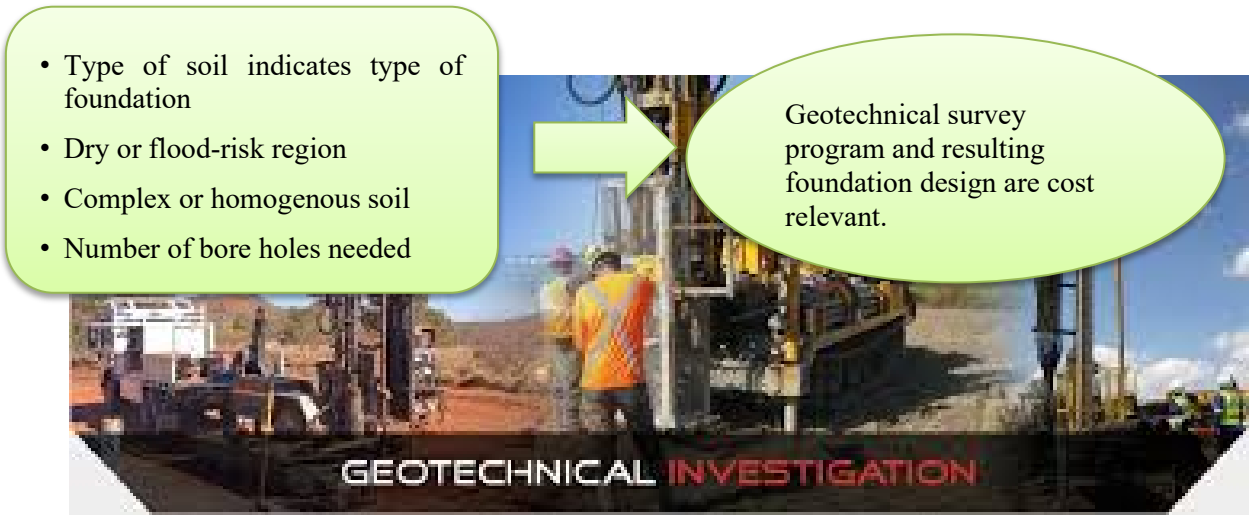

Figure 3. Geotechnical investigation on site

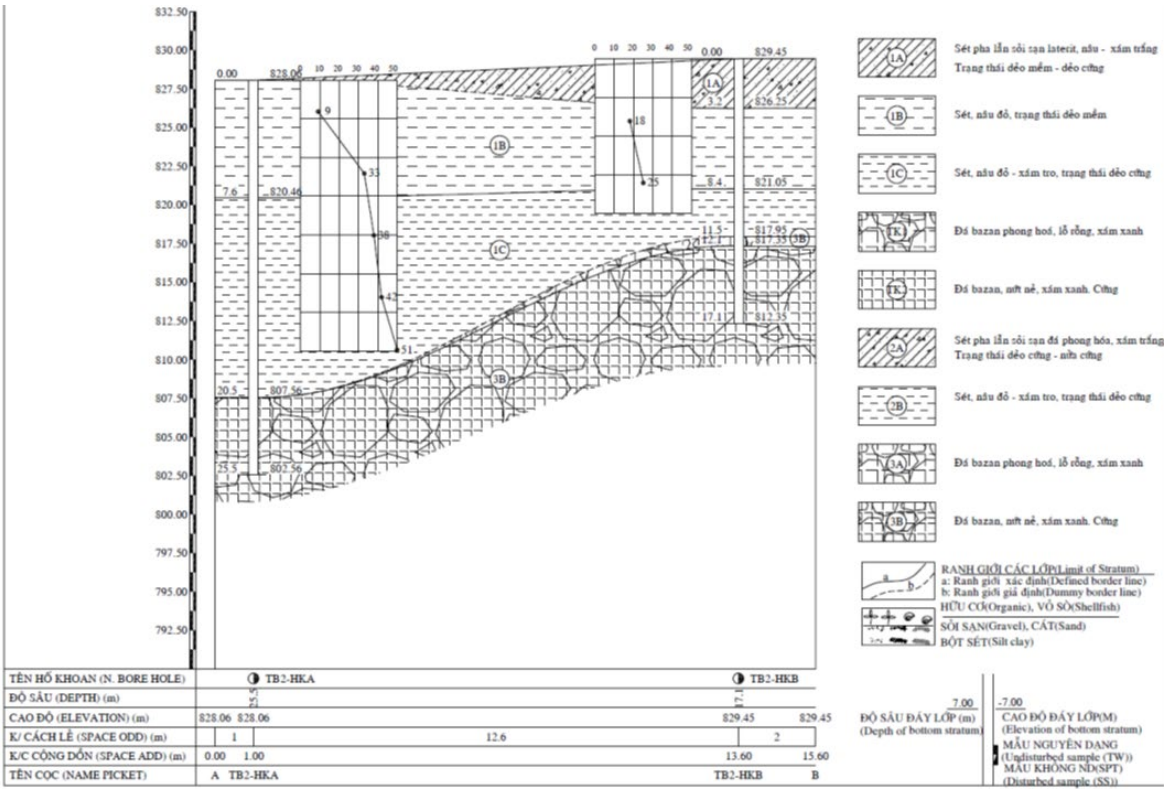

Figure 4. Geotechnical report

Hydrology conditions – determines the foundation level, the road level, the hydraulic structure. The hydrological survey is very important to determine the water level of foundations and roads. Sometimes, the wind power project influences the hydrology of the site. For example, the water level can increase more than usual due to the road system blocking the waterway. If the engineer does not pay attention to this possibility, it could lead to several sub-sequential and serious risks. With these

information, we can save about 20% of construction cost and evaluate the risk of flood affecting the construction site. Knowing the concrete site conditions, leads to choose the most suitable and reliable solution for the foundation.

Figure 5. WTG foundation construction on shallow water area

In the case of a nearshore foundation, all input data from the marine environment should be analysed such as the tidal, wave height, current velocities, etc... This is one of key factors to design and construct nearshore foundations. For each construction method and concrete site condition, there should be a suitable foundation solution. For example, in tidal zones like in Vietnam, the variation of the tidal is very high and the water depth is shallow. This makes it difficult for the big equipment of offshore industrial to reach the wind turbine position. Because the wave loads depend on the dimension and geometry of the foundation, a good foundation design optimizes the costs and the construction time.

2.4 International - local conditions

The third factor related to the local condition, includes the local law and regulation, the local material and the local construction method. Some countries require a professional engineering (PE) licenced to design the wind turbine Generator foundations. This is the case in the Asian countries, USA, Canada, China, Thailand. A PE is needed for the design documents and the construction permit. In Vietnam, governmental regulation requires a licence for the engineer but also for the company. For example, for an wind farm project within the category 1, with a total power of more than 50 MW, the company must have the compatible licence certificate in order to perform the category 1 project.

Several standards and regulations must be followed. For example: International standard IEC, Eurocode, national standards and technical regulations, WTG manufacturers technical specification, etc. The technical specification for the construction are needed for acceptation tests according to the international code. This is not really popular in local countries like Vietnam, so the designer has to find the equivalent test with the local conditions or find the similar regulations.

For example, according to Vietnamese standards, when CTV Wind designed the Phu Lac Wind Farm, the test for anchor bolt had been done. But if we had said that this was one of the components of a wind turbine, in this case there are CE certifications and there is no need to do the test.

As explained in the introduction, the foundation are made on site. The available local material has a strong effect on the foundation. It is important to know what materials are available on the local site

in order to decide the construction method. High concrete grades are used for wind turbine foundation construction. But this is not really popular in Vietnam. Therefore, construction contractor must have experience with the required high concrete grades on site.

Figure 6. Before and after casting

In Vietnam, many reinforced steel type can be found with strength ranging from 295 Mpa to 400 Mpa. It is better to use high strength grades - such as B500B - in the foundation construction. But reinforced steel with the strength of 500 Mpa is also not very popular on the local site. It is one of the difficulties of the construction contractor. In addition, the contractor must import the grouting. This progress can take a long time. It is better if the contractor have the plant to buy the grouting before the construction has started.

2.5 Weather

The last factor which has an impact on foundation design, is the unusual weather. All wind turbine foundations are always constructed on site. It is directly influenced by the local climate and the weather.

Figure 7. Road access and foundation in raining season

The weather forecast should also be studied before the construction of foundation start. For example, foundation in hot weather conditions, cold weather conditions or during raining seasons,etc. …

Depending on the weather, the planning and execution of the construction changes. The Figure 8 shows a *Road access to the construction site of a foundation during the rainy season*.

3 FOUNDATION DESIGN SOLUTION

These are different foundation types for wind turbines. Our R&D engineering team has developed many foundation types adapted to the specific site conditions and wind turbines. As a result, the construction time and costs have been reduced. The figure 5 shows some foundation solutions designed by CTE Wind.

Figure 9. Several type of foundation

In Vietnam, some unexpected problems on the site can appear. Especially, during the excavation work of the foundation, an heterogeneous mixture can be found in the ground, for instance, karst and geohazard are the evidence of heterogeneous mixture. Based on the realistic soil conditions, the designer must find an effective solution for the foundation design in order to achieve the desired results.

Buoyancy foundations

Buoyancy foundations have more advantages than traditional foundations. As researches have shown, designs with buoyancy can decrease the concrete volume from 25% to 50% (figure 8). The buoyancy raft works on a similar principle like a floating structure, where the support for the raft is mainly obtained by displacing the weight of the earthwork that is overburden by the volume of a large voided foundation. They tend only to be used where suitable bearing strata is at too great a depth for other more traditional alternative.

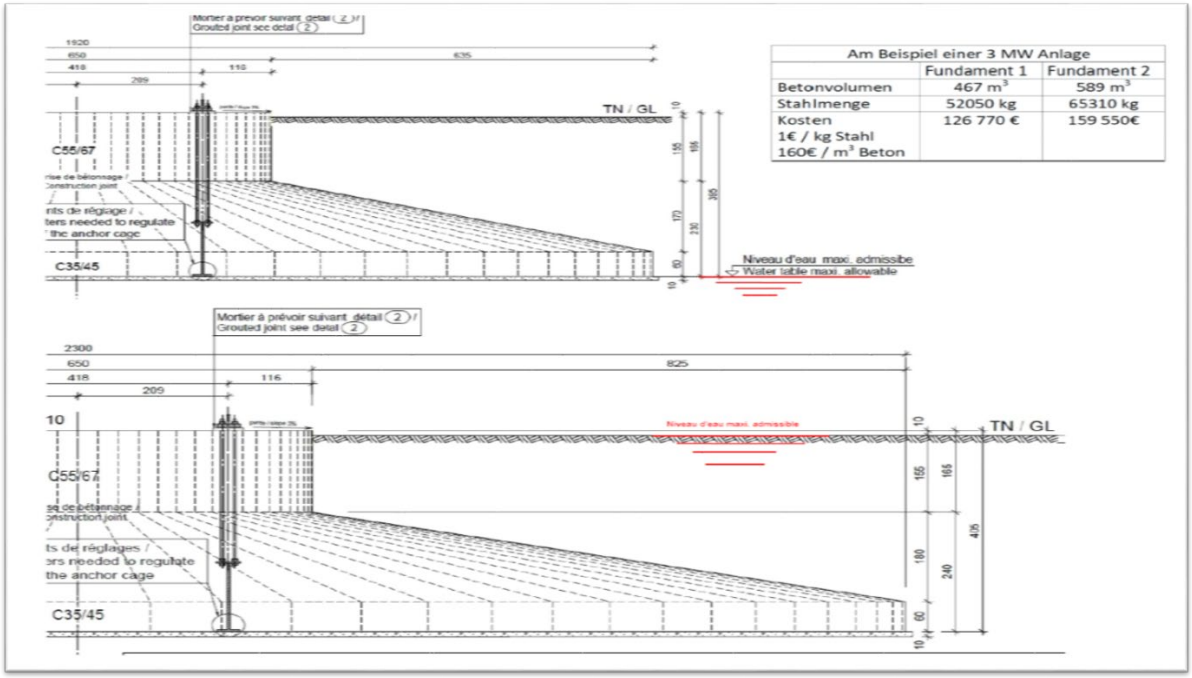

Figure 10. Compare between traditional foundation and buoyancy foundation

In Vietnam, the foundation needs a waterproof system in order to cope with buoyancy such as: underground waterway in foundation excavation and using material to protect the construction site to avoid problems during compaction works.

The SOFT-SPOT® solution

The SOFT-SPOT® foundation is another interesting technical solution that was invented by CTE Wind a few years ago. The SOFT-SPOT® was developed by CTE Wind's engineering team and has been implemented in various countries around the world. This foundation design optimizes the bill of quantities as it saves concrete, reinforcement bars and reduces the foundation diameter. It is easy to build and does not change the construction of the gravity foundation. A patent for the this design has been issued.

CTE Wind has already developed and implemented many projects with the SOFT-SPOT®since its launch. Several hundreds of the new foundation designs are built around the world: Brazil, France, Lithuania, Indonesia, Mexico, Netherland, Russia, Serbia, Sweden and Thailand to name a few. As a result of its astonishing design it allows savings in concrete volume up to 15%, reduction of foundation diameter and total weight of reinforcement bars of 5-7%. In some cases what is even more important than the material costs is the available space: with the SOFT-SPOT® you need less surface for the foundation. This reduces the time and excavation costs. An example of the benefits for this solution is the wind park - Thai Lan, following the information below:

Table 1. Benefit of the SOFT-SPOT® solution

Main Project Data & Conditions	
Location & year	Thailand, 2017-2018
Wind farm size	60 WTGs totaling 180 MW installed capacity
WTG model	Vestas V136 3 MW 157 m h.h.steel tower
Approx. driver loads	170000 [kNm]
Main soil conditions	Bearing capacity:220 kPa Buoyancy conditions: YES Seismic conditions: NO

RESULTS	***Foundation baseline***	***SOFT-SPOT® solution***	***Comparisson***
Type	*Circular gravity shallow foundation*	*Circular gravity shallow foundation with SOFT-SPOT®*	*Variation (%)*
Diameter (m)	*27.4*	*24.5*	*- 11 %*
Depth (m)	*3.68*	*3.68*	*0 %*
Concrete volume (m3)	*1190*	*980*	***- 18 %***
Steel quantity (kg)	*125000*	*114000*	***- 9 %***
EPS 100 (m3)	*-*	*28*	*NA*

Anchor cage design

Basically, an anchor cage is a set of bolts, kept together by inferior and superior steel rings. Normally the anchor cage arrives disassembled to the site and workers can mount it in a few hours. The main advantage of an anchor cage is a better transmission of loads to the concrete: sometimes a separation of the embedded ring from the concrete can be observed, although this leads to tower movements and possibly subsequent serious stability problems.

Choosing the right length and pre-stress loads of the bolts has an impact on the rebars section and also on the concrete resistance class.

Nearshore foundation

The nearshore foundation is a kind of foundation that can be used in intertidal zones with water depth from 2 to 15m. The water depth is very shallow which makes it very difficult for vessels or big offshore equipment to reach and work on ground. With all these factors to take into consideration, a classical solution for WTG foundation can lead to several additional cost, such as: high construction costs, pile sheets must be driven at first and water pumping during flood times. The quality of the construction cannot be assured and the duration of the construction can be quite long.

However, CTV Wind is also able to design a cost effective and reliable solution for intertidal zones. With the CTVs nearshore solution, the wind farm owner can save a large amount of material in his project. Below you can find a comparison table (2), which shows the percentage of saved material if CTV solution is applied in Vietnam. CTV solution is the most optimal solution for all kind of nearshore wind turbines.

Materials	**Existing project**	**CTV Solution**	**% saved**
Concrete Volume (m3)	662	400	39%
Reinforcement (tons)	70	55	21%
Piles (unit)	36	32	11%
Pile sheets	yes	no	

Table 2. Comparison table

4 REFERENCE

Figure 11. Dam Nai wind farm

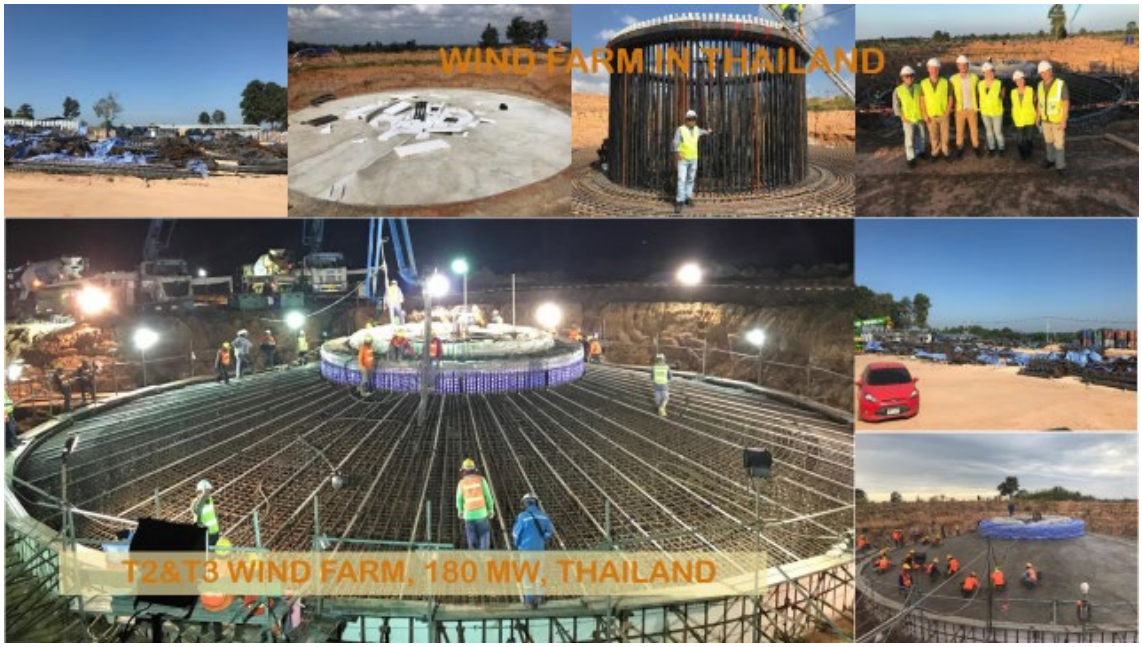

Figure 12. Wind farm in Thailand

Figure 13. Phu Lac wind farm

5 CONCLUSIONS

Increasing wind turbine and tower sizes and installations in deeper waters have clearly demonstrated a need for more innovative and cost-effective foundations. This paper summarizes basic relevant foundation and geotechnical issues for onshore and nearshore wind turbine tower foundations. The advantages and drawbacks of each type have been presented. Also exposed in this paper are the conditions for which each type of foundation is most suitable. Based on the information summarized in this paper a geotechnical engineer working for a wind farm developer should be able to perform preliminary sizing and selection.

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