Peña Ventosa windfarm (Spain)

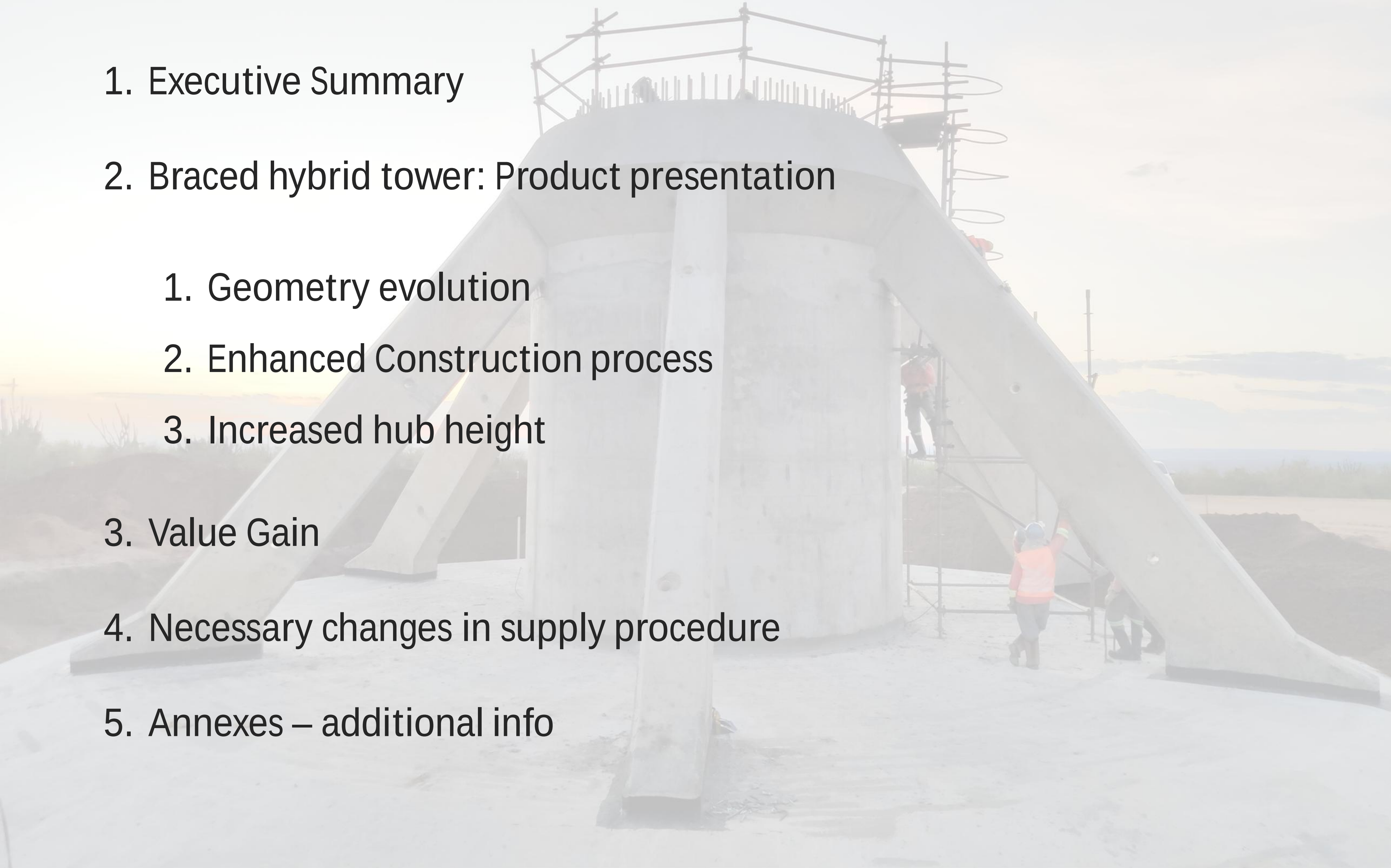
ESTEYCO

HYBRID TOWER based on BRACED FOUNDATION

Product Presentation

Feb 2024

CONTENT



1. Executive summary

- [x] Hybrid towers based on the use of braced foundation *generate Value in excess of 200keur/wtg*, mostly due to extra AEP because of extra hub height achieved. Its use can significantly improve the profitability of any given wind farm.

- [x] The technology is not new, but braced foundation has evolved to hybrid braced tower in two ways:

  + increasing hub height gains

  + improving the construction method, so that foundation + concrete part of the tower are now simpler to construct.

- [x] Braced hybrid tower implementation demands new interfaces with BoP and turbine OEMs, because some scope changes take place when it is used. Last minute adoption of the solution for a given windfarm is often not possible.

2. Braced Hybrid Tower: Product presentation

Hybrid towers based on Esteyco's proprietary Braced foundation allows a very efficient evolution of any given steel conventional tower into a hybrid tower with a height increase of 8 – 10 meters.

The resulting product is a true hybrid tower:

- First 8-10m from terrain level are concrete, followed by the existing conventional steel tower.
- Entrance door, elevator and ground level equipment (cabinet, switchgear…) located at terrain level, in the concrete part of the tower.

The foundation + concrete section of the tower saves ± 30% of concrete compared with a conventional foundation without any height gain, which implies remarkable CO_2 emissions reduction when summing up materials savings and extra green energy produced.

Validated technology: over 1 GW (337 wtgs) of wind power using braced technology since 2016, four certification processes passed with TÜV-Sud and GL.

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2.0 Certification and guarantees

Regarding certification and guarantees, the concrete part of braced hybrid towers are considered a foundation. They are, therefore, out of the Type certificate of the turbine, just like any other foundation.

Braced foundation is designed so that it fulfills the OEM requirements for the foundations. Th OEM scope starts in the steel part of the tower, on top of the bolt cage included in the foundation.

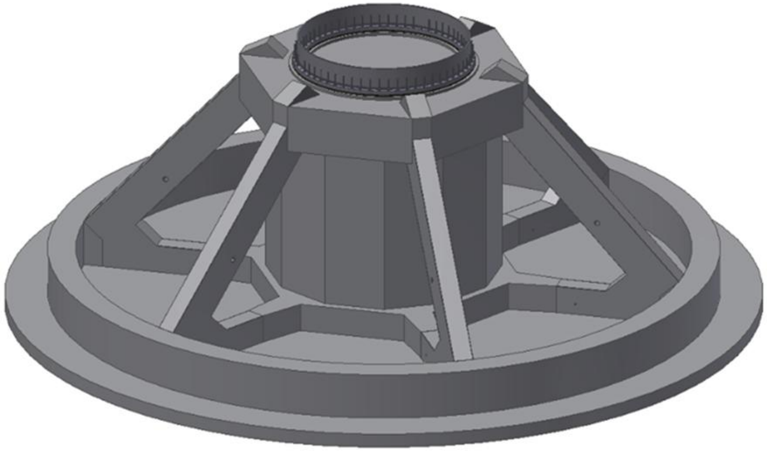
If desired, certification bodies can supply a Windfarm certification for the Braced foundation. Anyhow it will not go on the Type cert of the turbine because the boundary of that certification is the bolt cage.

Ventos de Serra do Mel windfarm (Brazil)

In Esteyco we have successfully windfarm - certified four designs, each time the customer has asked for it.

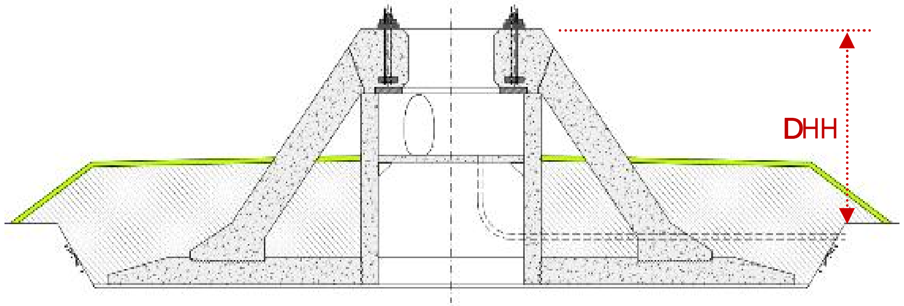
Turbine supply contracts and guarantee structures can therefore be identical when using conventional or braced foundations.

2.1. Product presentation – Geometry evolution



Former design

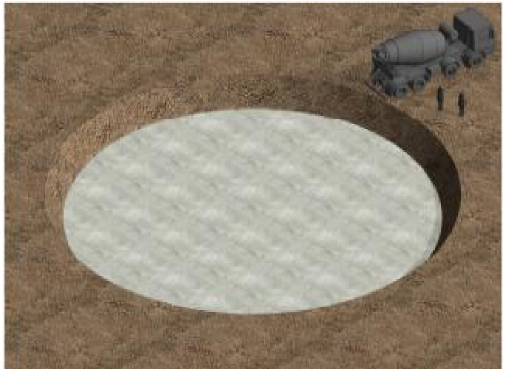
New design



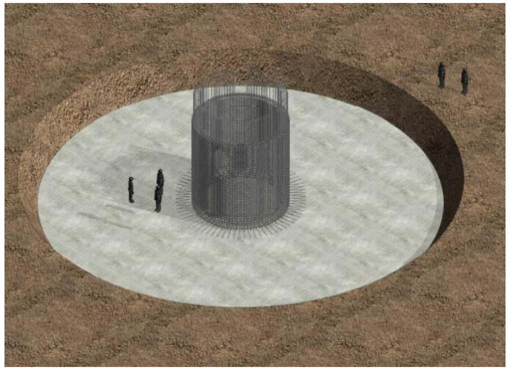
- Removal of all beams in slab
- Simplified, lighter braces
- Circular upper ring simplifies rebar
- Bigger upper ring hole allows for elevator access to entrance level

2.2. Product Presentation: Enhanced Construction Process (i)

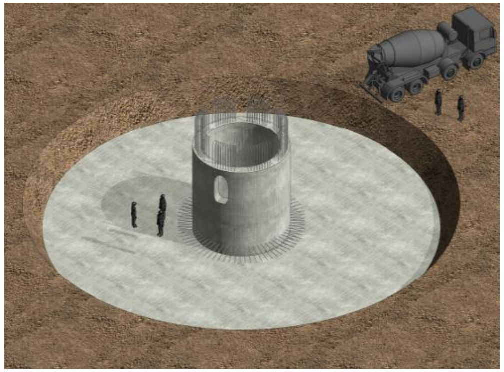
1 Excavation



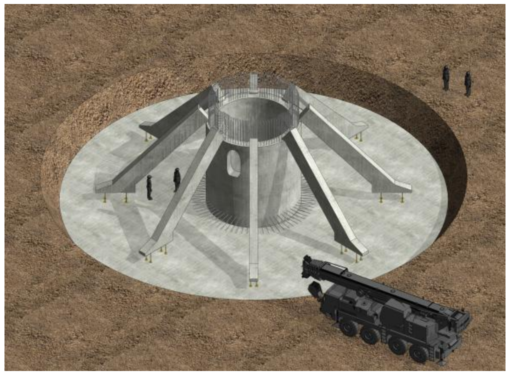
2 Blinding Concrete pouring



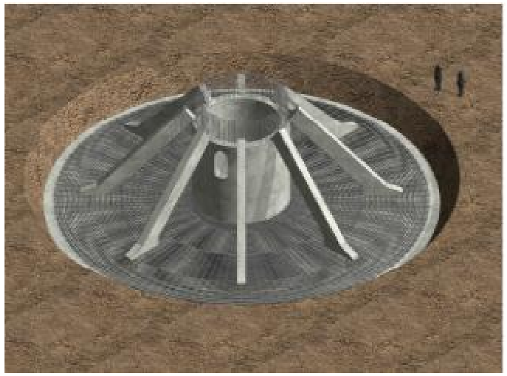
3 Central shaft reinforcement*



4 Central shaft pouring



5 Braces installation



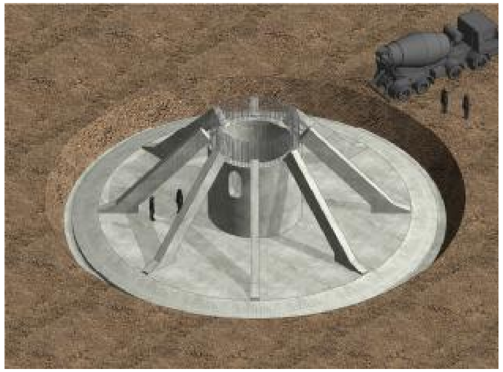
6 Lower slab reinforcement

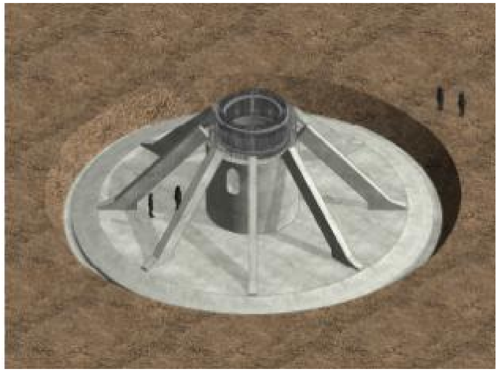
Construction order has been altered: Central shaft is the first element to be constructed

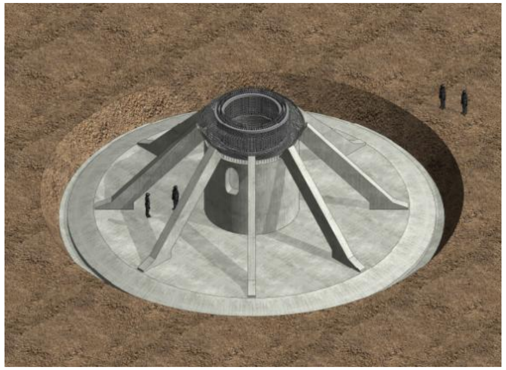
- Much simpler construction of the shaft, as nothing gets in the way when installing and removing the formwork
- Permits specialized company works without interferring with slab execution
- The finished shaft is the perfect support for the braces: braces are simpler, and braces positioning is much easier

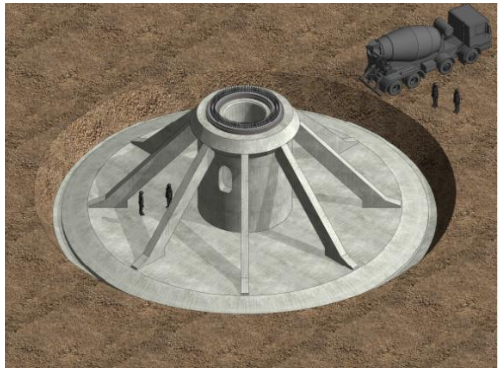
Shaft is constructed first, prior to lower slab and braces placing, enabling simpler foundation construction.

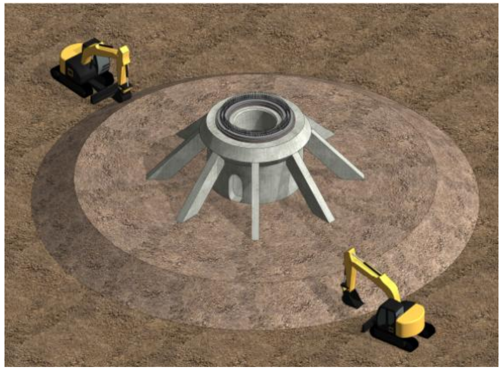
2.2. Product presentation: Enhanced Construction Process (ii)

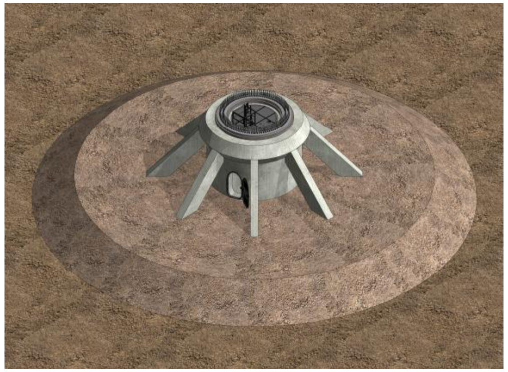

7 Lower slab pouring


8 Bolt cage installation


9 Upper ring reinforcement


10 Upper ring pouring


11 Earth refill

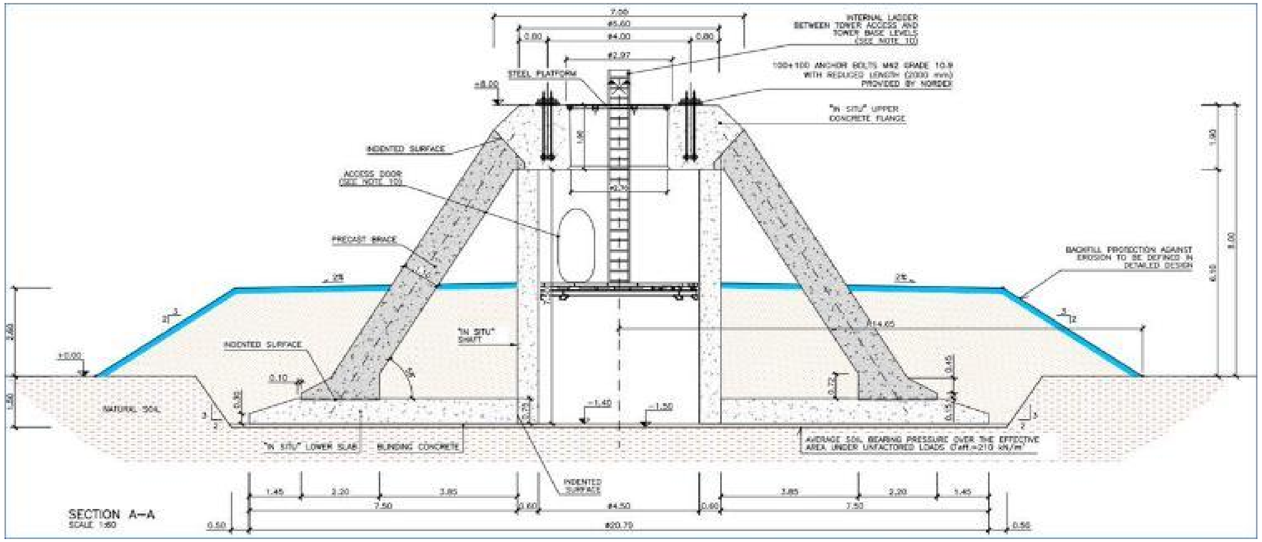

12 Door + internals installation

Upper ring execution is a simple phase, provided adecuate tooling is available:

- Internal and external platform on top of the central shaft, utilizing simple and cheap hanging mechanisms utilized in climbing formwork.
- Railings and specific ladders permit that bolt cage installation, reinforcement placement, and concrete pouring of the upper ring are performed with terrain-level construction regulations (no harness needed, no work-at-height rules).
- Height of the upper ring is 2m, bolt cage is 2.3m: bolt cage assembly and rebar placing is simpler than the corresponding assembly of bolt cage and central rebar of conventional foundations with 4m long bolts.

Adecuate, specific platforms and scaffolds are a must for construction

2.3. Product presentation: Increased Hub Height: + 8m height

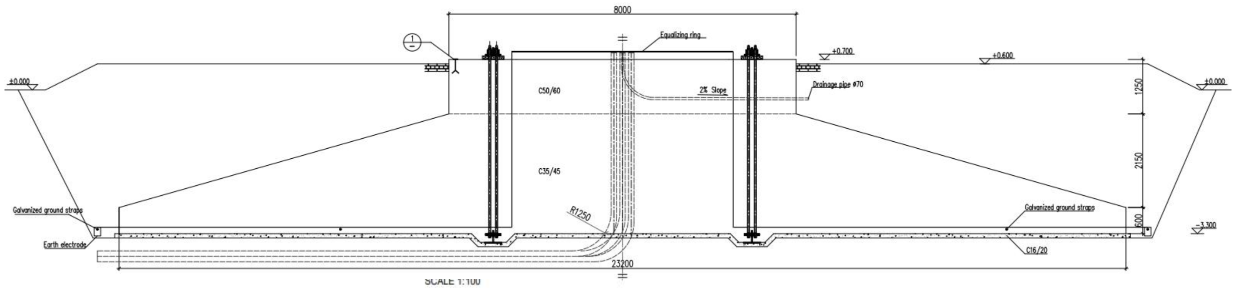


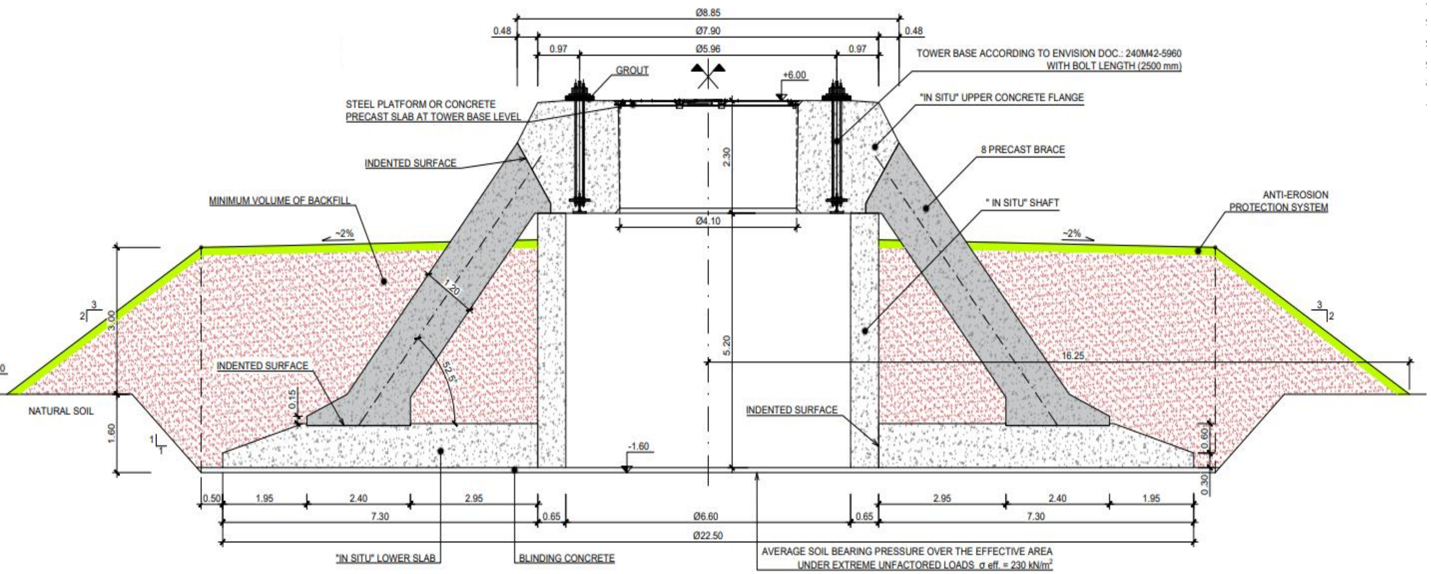
ALTERNATIVE 1: HH+8m	Braced	Conventi.	Savings braced found.	
Diameter (m)	20.70	22.30	1.60	7%
Pedestal base elevation (m)	+8.00	+1.10	6.90	
Concrete fck=30-35MPa (m3)	286	512	225.5	44%
Concrete fck=45-50MPa (m3)	91	19	-71.8	-378%
Concrete (total volume) (m3)	377	531	153.7	29%
Concrete fck=15MPa (m2)	370	400	30.16	8%
Reinforcing steel fyk=500MPa (kg)	54000	65000	11000	17%
Anchor bolt length (m)	2.000	3.590	1.590	44%
Anchor bolts grade 10.9 (2x100 M42) (kg)	4350	7809	3458	44%
Excavation (m3)	607	1173	566	48%
Backfill, including protection system (m3)	1582	1002	-580	-58%
Other costs of braced found. (moulds, cranes…)	0			

- Foundations compared are 5x MW turbines with 105m Hub height steel towers
- 30% reduction in concrete quantity
- Economical impact but also carbon footprint impact
- Bigger turbines should lead to higher savings.

Cimentación convencional +0,7m vs braced hybrid +6m
WTG: Envision E182 7.x MW HH130
Wfarm location: Saudi Arabia

		Convencional	Braced+6m	diferencia	
Diameter		23,20	22,50	-0,70	
Concrete C35/45 + C45/50	m3	764	486	-278	-36%
Reinforcement	kg	69000	65000	-4000	-6%
Excavation	m3	1769	793	-976	-55%
Refill	m3	1289	2109	820	64%





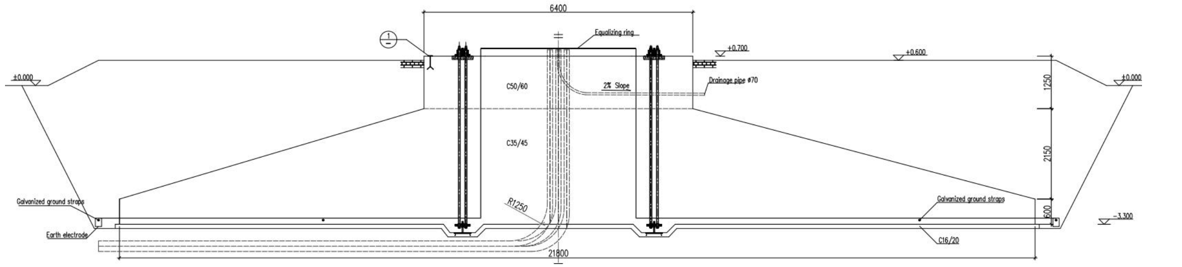
No entrance versions can use aditional refill height to shorten the access ladder height

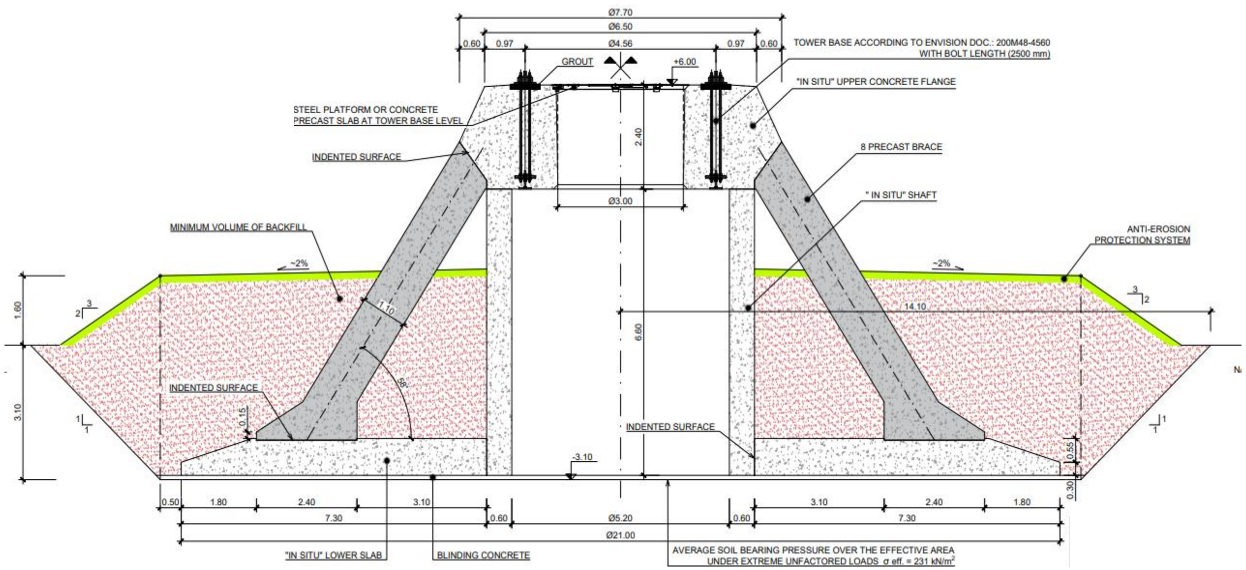
Refill over terrain level is NOT mandatory

2.3. Product presentation: Diverse examples

Cimentación convencional +0,7m vs braced hybrid +6m
WTG: Envision E182 7.x MW HH105
Wfarm location: Saudi Arabia

		Convencional	Braced+6m	diferencia	
Diameter	m	21,80	21,00	-0,80	
Concrete C35/45 + C45/50	m3	637	430	-207	-32%
Reinforcement	kg	57000	55000	-2000	-4%
Excavation	m3	1690	1542	-148	-9%
Refill	m3	1270	1861	591	47%





The bigger the foundation, the bigger the savings in BoP.

Commparing this desing for 105m tower with the design for 130m tower in the former slide:

- Conventional foundation is bigger by 127 m3 for the higher tower.

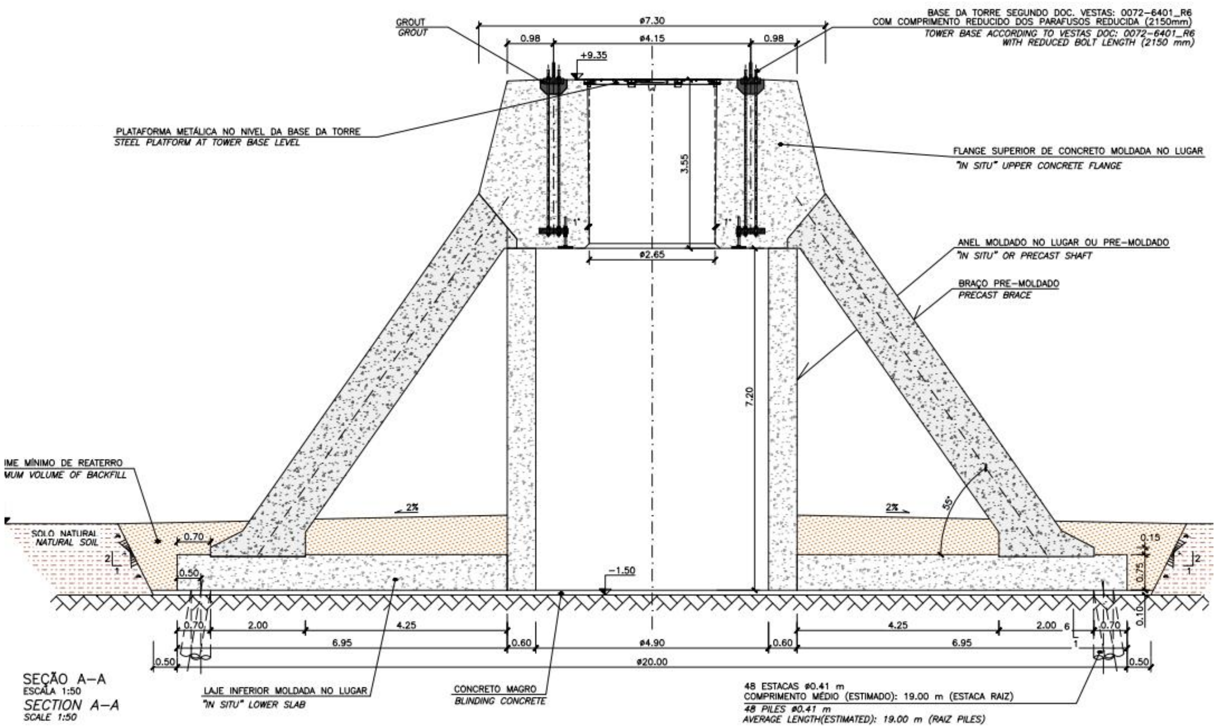
- Braced foundation is bigger by 56 m3.

2.3. Product presentation: Diverse examples

Cimentación micro-pilotada con Jaula de pernos +9,35m
WTG: Vestas V150 4.2 MW HH90
Wfarm location: Brazil

		Convencional	Braced+6m	diferencia
Diameter			20,00	
Concrete C35/45 + C45/50	m3		432	
Reinforcement	kg		64000	
Excavation	m3		558	
Refill	m3		282	

48 micropilotes de 0,41m Ø y 19m largo (120m3 hormigón, 12.100kg acero)



Refill height can be customized when designing.

No refill over terrain level is possible (with some extra foundation diameter or some extra central shaft + braces height)

Conventional lenght bolts can be used (extra hub height, but more complex upper ring execution)

Micro-piled example (foundation concept also valid when piles are needed due to soil characteristics).

3. Tower Value Gain vs conventional steel towers: overview

Value overview:

The total value gain of using this concept is the sum of three parts:

- ✔ Extra AEP value given by the extra hub height.
- ✔ Savings in lower part of steel tower that should revert in a lower turbine price, the same way as when a shorter tower is ordered.
- = No relevant difference in cost of construction – Materials are reduced but process and tooling costs are higher so that final result is not very different

The difference in cost of construction is minor compared with the value gained through AEP increase and steel tower savings.

3.1. Tower Value Gain vs conventional steel towers: AEP increase value

1.- Extra AEP production due to extra hub height +8m height increase

	SG170 6.6MW		SG145 5.0MW		SG132 3.465MW		G114 2,5MW		Vestas V100 2MW	
hub height	115 m	123,0 m	115 m	123,0 m	115 m	123,0 m	115 m	123,0 m	115 m	123,0 m
Gross AEP (MWh) *	25.101	25.594	18.621	18.995	13.927	14.185	10.497	10.693	7.970	8.120
Net AEP (MWh) *	22.592	23.035	16.759	17.096	12.535	12.767	9.448	9.624	7.174	7.308
Gross Eq. Hours *	4.049	4.128	3.724	3.799	4.019	4.094	4.199	4.277	3.985	4.060
Net Eq. Hours *	3.644	3.715	3.352	3.419	3.618	3.685	3.779	3.850	3.587	3.654
delta AEP hub height gain		1,96%		2,01%		1,85%		1,87%		1,88%
delta AEP hub height gain		443		337		233		176		135
delta NPV Eur/WTG **		194.393		147.956		102.017		77.367		59.090
delta NPV Eur/MW **		29.453		29.591		29.442		30.947		29.545

* Energy production for typical wind conditions: av. speed 7,2m/s at 100m; k Weibull 2,1; air dens 1,18kg/m3; α = 0,19; total losses 10%

** Net Present Value scenario: 50 eur/MWh constant tariff , Corp Tax 25%, Wacc 7,5%, 25 yr operation

Braced foundation height increase can increase WF value by 200k€/WTG due to the gain in hub height (for 6+ MW wtgs), even considering quite conservative assumptions (tariff, wacc, taxes)

3.2. Tower Value Gain vs conventional steel towers: Steel tower bottom section

2.- Steel section bottom savings:

- Shorter bolts: braced foundation uses 35% shorter bolts, saving 3 to 4 tons of bolts per tower. The bolts for a modern 6MW turbine cost circa 40keur, so usage of this solution implies savings of 12keur to 16keur per tower.

- Botton section to compensate for the weakness generated by entrance door: It can easily imply additional 4 tons of steel for reinforcements, plus a lot of additional welding and cutting operations in the lower part of the bottom steel section. Savings of 10keur/twr can be achieved if door entrance is removed from the steel section (very rough estimate).

- Door itself, bottom platforms and access ladder are also eliminated from the steel section, but they have to be added to the foundation, so minor cost changes in this scope. It can be important, anyhow, in case these components are not delivered by OEM, because then there are savings in OEM scope and extra costs in Utility/developer scope.

Simplification of steel tower bottom can sum savings up to 25 to 30 kEUR when ordering a turbine to be used with braced hybrid tower.

The extra hub height may demand a bigger turbine assembly crane if the baseline model can not cope with the extra height.

3.3 Tower Value Gain vs conventional steel towers: Extra construction cost

Regarding total construction costs the are several aspects to comment:

On the positive side, this solution saves materials compared to conventional foundations: see page 8 example for +8m solutions.

On the negative side, the process is more complex:

- precasting of braces,
- several concreting stages,
- need of specific formwork, platforms and tools,
- Crane needed to place braces in position

Construction process extra cost will exceed savings in materials, at least in the first units constructed.

After learning curve there may be a saving in BoP.

But, in any case, extra cost or additional saving will be very minor compared to value in hub height and tower bottom saving.

3.4 Braced additional advantages

- ü Concrete delivery amount is smaller (-30%) and divided in 3 different operations, so that the bigger concrete pouring operation is less than half the volume of conventional foundations. Concrete procurement is simplified, undesired cold joints risks are reduced significantly.

- ü Concrete curing process is simpler, because of volume and because the slab is thinner, so curing temperature is better.

- ü Entrance to the turbine at terrain level, no external ladder, wider door. Smaller ice falling risk or slipping risk. Wider door can help for certain operations (i.e switchgear maintenance/replacement).

- ü Tower bottom is concrete and is +- 1 meter wider. Additional space for equipment or even spares, less noise, less cold/hot.

- ü From the point of view of sustainability/environment, 30% smaller carbon footprint because of concrete quantity reduction, and 2% extra green energy production due to higher hub height.

4. Changes in supply procedure: overview

Using Braced hybrid tower, several supply scope changes take place. Beforehand, a series of actions must take place:

1.- BoP requires some *specific tooling* and know-how to make sure that concrete part of foundation+tower are correctly executed.

2.- *Turbine supplier* scope is changed:

- Steel tower bottom section is different (no door, no lower platform)
- Field pallet is different (shorter bolts, external ladder removed, door and internals for the concrete part of the tower are to be included).
- Crane reach has to be checked for the extra hub height.

3.- *Turbine supplier* will need a new site assessment for the extra hub height wind conditions.

If access door is maintained in steel tower, changes by OEM are significantly reduced, but still some changes remain (bolt lenght, site assesment, crane assessment, longer access ladder)

5. Implementation

Up until now we have been offering the technology for specific windfarms, as an opportunity to substitute conventional foundation with braced technology exclusively in that windfarm.

This has two problems:

- On one side, the schedule for the windfarm is already tight, so any changes in design, procurement or anything may not be feasible due to dates to be met in a windfarm already in its final execution phase.

- On the other side, the efforts to implement the technology are only compensated by the value gained in that windfarm.

We believe the correct way to approach the technology is not looking at a windfarm, but rather looking at the portfolio, launching a Plan to prepare to be able to use the technology and then defining which will be the first windfarm that can benefit.

5 . Annexes

I. Pictures from Previous Windfarms

II. Track Record of the solution

III. Internals Definition

5. Annex I.- Pictures from past experiences (i)






Braces for diverse windfarms, some precasted on-site, some precasted in precast plant facilities (but open air – upper left case)

5. Annex I.- Pictures from past experiences (ii)

All pictures from Canudos windfarm (Brazil) – First windfarm utilizing new design and process

5. Annex I.- Pictures from past experiences (iii)






All pictures from Canudos windfarm (Brazil) – First windfarm utilizing new design and process

5. Annex I.- Pictures from past experiences (iv)

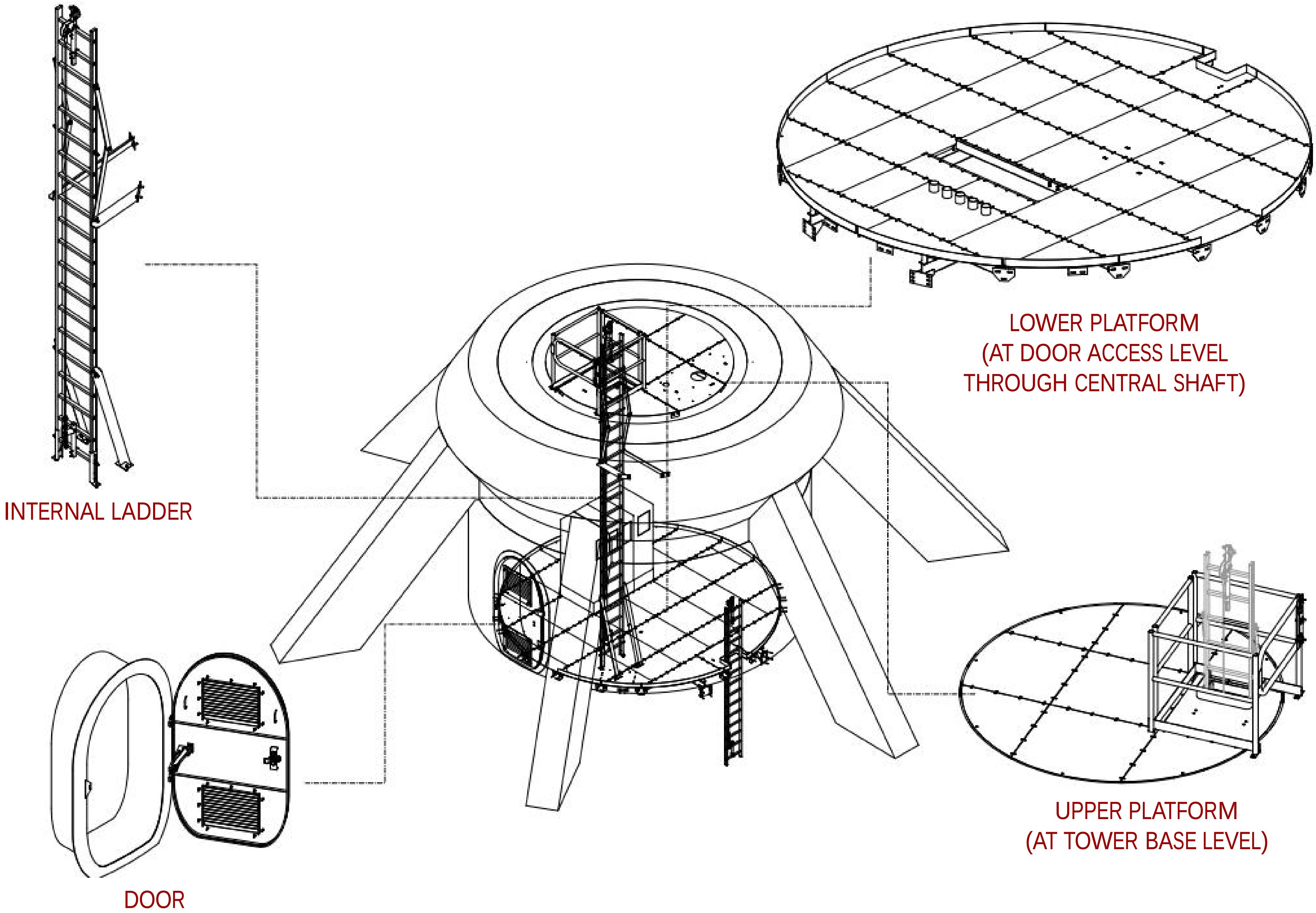
All but bottom right picture from Canudos windfarm (Brazil) – First windfarm utilizing new design and process.
Bottom right picture from Ventos do Serra do Mel WF (older design)

5. Annex II.- Braced foundation Track Record

WIND FARM	CLIENT	COUNTRY	WIND TURBINE GENERATOR	YEAR	WTG NUMBER	MW
BANZI	GAMESA	ITALY	GAMESA G97-2MW HH90 m +1.35	2015	15	30,0
KAYATHAR	GAMESA	INDIA	GAMESA G97-2MW HH100 + 4m	2016	3	9,0
SAN JACINTO	ALDESA	MEXICO	GAMESA G97-2MW HH80 + 4m	2016-2017	10	20,0
TIZIMIN	SMARTENER	MEXICO	GAMESA G114-2.1MW HH125 + 4m	2017-2018	40	84,0
BODENSEE	VESTAS	GERMANY	V136-3.45MW HH132 m + 2m	2018	1	3,5
BARKOW	VESTAS	GERMANY	V136-3.45MW HH132 m + 2m	2018	1	3,5
BEITASHAN	JINKE	CHINA	CSIC H136-2,2MW HH100 + 6m	2019	45	99,0
PEÑA VENTOSA	VESTAS/ENEL	SPAIN	V90 2.2MW HH72 + 6m	2019	4	8,8
VENTOS DE SERRA DO MEL I	DOISA/ VOLTALIA	BRAZIL	G132-3.465MW T114m + 6m	2019	47	162,9
VENTOS DE SERRA DO MEL III	DOISA/ VOLTALIA	BRAZIL	G132-3.465MW T114m + 6m	2019-2020	44	152,5
DUMAT AL JANDAL	TSK/EDF	SAUDI ARABIA	V150-4.2MW HH124m + 6m	2019-2020	99	415,8
CANUDOS I	GEL/VOLTALIA	BRAZIL	G132-3.55MW T84m + 6m	2020-2021	28	99,4

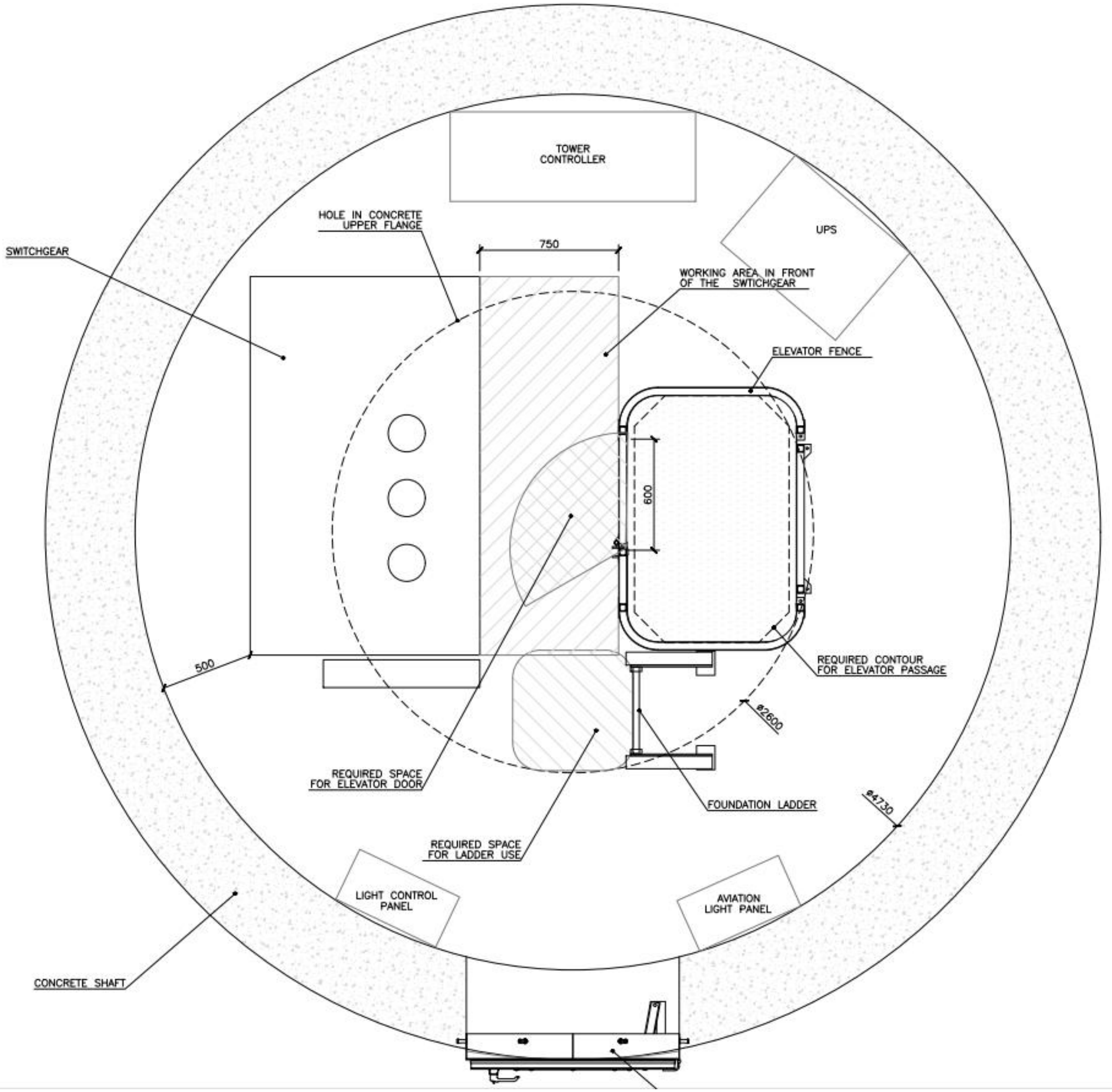
337 foundations fully finished (1088MW)

5. Annex III: Internal elements – General view and alternatives (i)

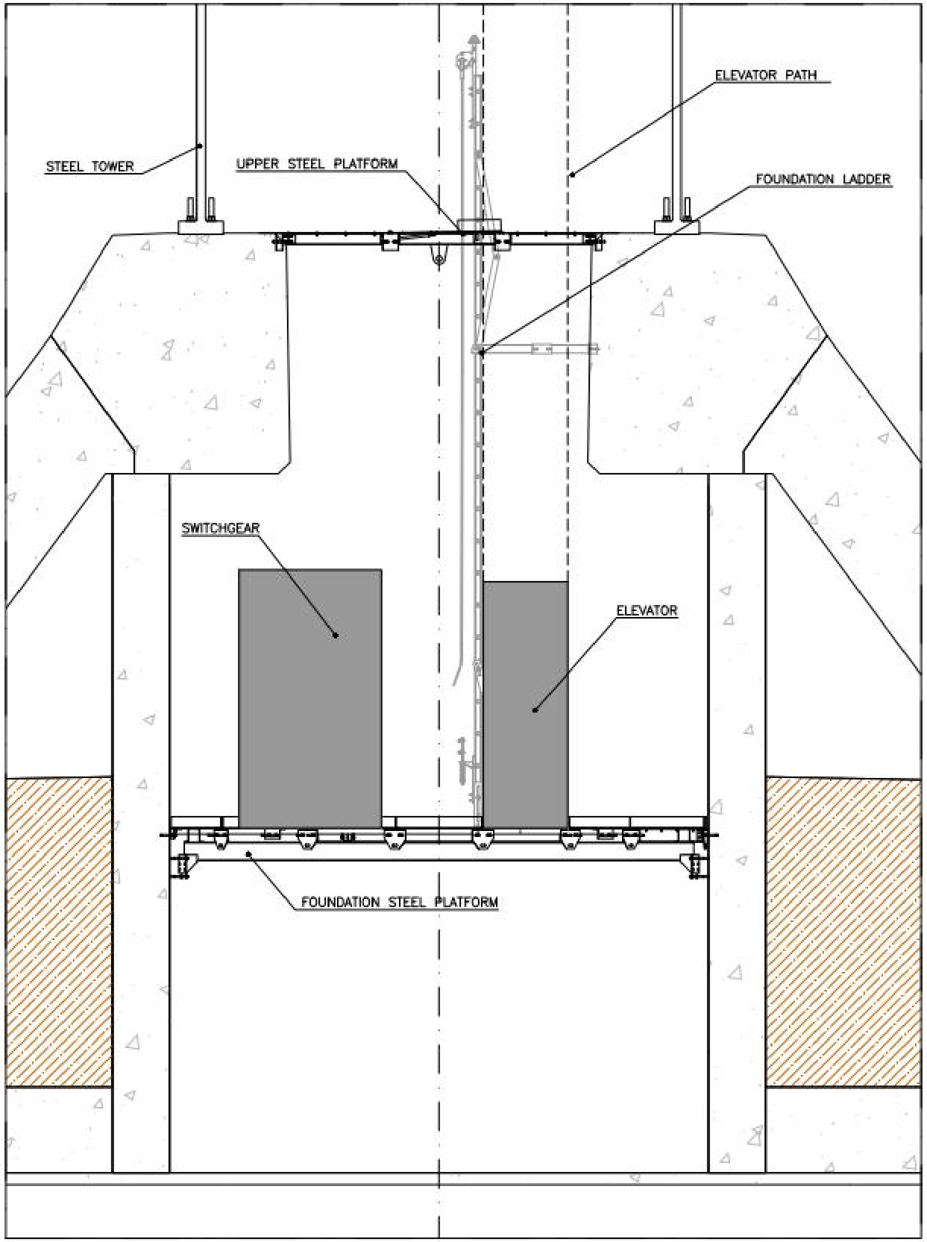


5. Annex III: Internal elements – General view and alternatives (ii)

A) Elevator at Terrain - Access level:



EQUIPMENT DISTRIBUTION – PLAN VIEW



EQUIPMENT DISTRIBUTION – ELEVATION

ESTEYCO