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WIND RESISTANT DESIGN OF 2MW, E-82 WIND TURBINES IN EARTHQUAKE-PRONE AREAS IN ITALY

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1 INTRODUCTION

Within March 2008 the European Union will adopt the so-called “EUROPEAN STRATEGIC ENERGY TECHNOLOGY PLAN (SET-PLAN)” which will give the development lines for the extension of renewable energy. In the “COMMUNICATION FROM THE COMMISSION TO THE COUNCIL, THE EUROPEAN PARLIAMENT, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS”, one can read amongst the Key EU technology challenges for the next 10 years to meet the 2020 target: double the power generation capacity of the largest wind turbines, with off-shore wind as the lead application.

Looking forwards to this ambitious target, Italy is rapidly moving in wind energy development and several regions of Italy, mainly in the south, are recently developing many areas for wind parks of large dimensions (Puglia, Calabria, Campania, Sardegna) for a whole of about 130 towers (260 MW) within 2008.

This paper reports on a new technology developed by ENERCON GmbH for wind turbines of great power (so-called E-82, 2 MW nominally; s. Fig. 1) which have been studied and developed in Germany according to local standards. The rotor blades have a diameter of 82m, while the towers height varies from 83m to 97m

The tower technology consists in precasted, high-resistance RC ring elements, which are superposed and longitudinally prestressed. The implantation in Italy of the same technology for E-82 has required a deep analysis of the aeroelastic loads and wind loads, while considering the coexistence of the seismic action (I or II category according to Italian rule). The study was carried out for different heights of the towers as well as for different kinds of the foundation blocks, which can be realised on piles or without piles.

Figure 1: the 2MW wind turbine (ENERCON E-82)

Figure 2: The concrete part and the first steel segment have been assembled

2 WIND LOADS ON AN E-82 TYPE WIND TURBINE

Aeroelastic wind loads on the rotor E-82 are delivered by the constructor and certified by primary agencies (German Lloyd amongst others). Aeroelastic loads are delivered through a table-wise, according to format reported in Table 1.

Height [m]	CCE	Safety factor	Fx [N]	Fy [N]	Fz[N]	Mx [Nm]	My [Nm]	Mz [Nm]
0.00	6.2_w303	SFF = 1.1 SFM = 1.1	-6.25E+05	-4.92E+03	-7.91E+06	-6.35E+04	-3.83E+07	2.34E+04
19.13	1.5_w142	SFF = 1.35 SFM = 1.1	-4.30E+05	-1.16E+05	-6.22E+06	2.00E+06	-2.98E+07	-3.91E+05
38.26	1.5_w142	SFF = 1.35 SFM = 1.1	-4.09E+05	-3.95E+04	-3.80E+06	-2.02E+05	-2.16E+07	-3.47E+05
57.39	1.5_w142	SFF = 1.35 SFM = 1.1	-3.65E+05	9.92E+03	-1.85E+06	-5.15E+05	-1.38E+07	-3.49E+05
83.30	2.2_w102	SFF = 1.1 SFM = 1.1	-1.00E+05	1.12E+05	-1.30E+06	4.19E+05	-6.43E+06	-1.60E+03

Table 1: Aeroelastic loads on the wind turbine tower

All loads are provided, as a function of the height, in correspondence of 5 tower sections, including the resultant force and bending moment, on the top of the tower, due to the wind action on the rotor. These loads are derived from a three dimensional numerical model of the whole system which is able to take into account of the elasticity of both rotor blades and concrete-steel tower. This model has been analyzed in two configurations: the first one with a perfect restraint at the base, while the second one with an elastic spring at the base, simulating the elasticity of the system terrain-foundation. From a safety point of view, all internal forces are firstly provided in correspondence of the single elementary load conditions and then enveloped in order to obtain the maximum for the six characteristics of solicitation in the tower (Table 1).

3 THE PRESTRESSED TOWER TECHNOLOGY: MATERIALS AND BUILDING PROCESS

The tower is made by ring elements of high-resistance concrete (f_{ck} 45 ÷ 60 N/mm^2) with a steel segment on the top, which is hosting the flange to carry the nacelle and the rotor.
Foundations have been realized by means of a circular concrete crown which, in the inner part, host the anchorage devices for the prestressing system. The tower is made by 15-18 concrete segments and two steel segments, the first one allocating the top devices for the prestressing cables anchorages. The tower erection is carried out by superimposing each concrete segment by means of a special concrete mortar bed between segments. The tower prestressing is then performed only after the installation of the first steel segment. Hence the second steel cone reaches the maximum height, where the nacelle and the rotor are installed.

4 UPGRADING OF THE TOWER DESIGN: STRUCTURAL ANALYSES AND VERIFICATIONS

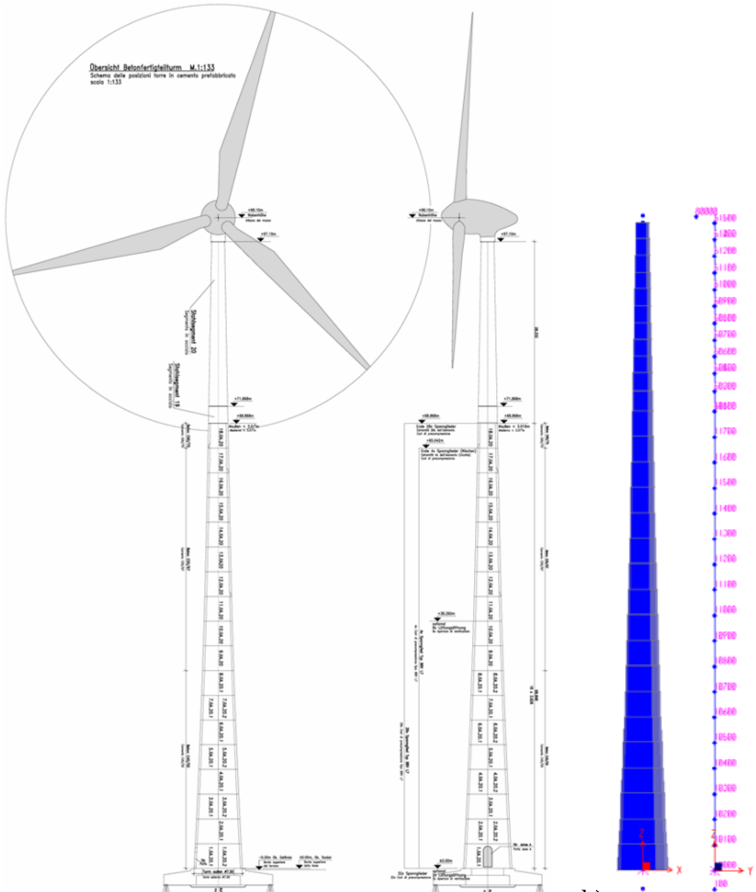
The upgrading of the design has consisted into a complete remodelling of the structure, by means of two Finite Elements (F.E.) Models: in the first one, the tower has been modeled by using beam elements, while in the two-dimensional shell elements have been used, in order to achieve a more detailed representation of the stresses distribution around the openings in the concrete shell. Static proofs on the whole structure have been evaluated by a set of load combinations, assuming the following partial safety factors for the wind and earthquake loads, according to the IEC-61400:2005:

		SLS			**ULS**	
		Rare	*Frequent*	*Quasi Perm.*	*Wind*	*Wind + Earthq.*
γ_G *Dead loads*	*Favorable*	1,00	1,00	1,00	0,90	0,90
	Unfavorable	1,00	1,00	1,00	1,35	1,35
γ_P *Prestressing*	*Favorable*	1,00	1,00	1,00	0,90	0,90
	Unfavorable	1,00	1,00	1,00	1,20	1,20
Wind loads		1,00	1,00	1,00	1,10	1.1 x 0,15 = 0,165
Seismic loads		-	-	-	-	1,00

Table 2: Partial safety factors assumed in the tower design

Elementary wind condition are evaluated according to following international standards: IEC 61400:2005 (Ref. [2]) and Dibt 2004 (*Richtlinie für Windenergieanlagen*) (Ref. [3]), the second ones being strictly lied to the first one. These Codes provide a complete set of elementary load condition to be analyzed and which cover a large amount of ultimate, serviceability and abnormal configurations where the wind generators can be found operating itself. Moreover they provide also the partial safety factors, both for the material and for the load, to be used for each wind load condition.
In the investigated case, a complete check has been performed in order to evaluate the tower safety when a seismic load has to be taken into account; because of the absence of seismic

loading in the aforementioned recommendations, during the design of these towers it has been assumed that 15% of the maximum wind load (corresponding to about 38% of the 50-year return period speed) can be considered as acting when the earthquake occurs. The chosen wind speed is very well within the operational wind speed range of the tower and it is above the average annual wind speed.



a) b)

Figure 2: Modelling of the E-82/97 tower: a) sketch of the concrete/steel segments; b) F.E. model

5 DYNAMIC ANALYSES AND FUTURE DEVELOPMENTS

Further analyses are in progress, aimed to investigate the dynamic behavior of the E-82 towers. The structural performance is being evaluated through a TD analysis of its response under turbulent wind, by taking care of soil-foundation interaction. The obtained results will be compared with those recorded during tests which will be performed during the checking process.

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