

Grout Cracks in WTG Foundation

How to tackle?



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Abstract

The study pertains to a proposal of manufacture of new grout material and a self-healing technology for the cracks developed in the grout based on the design experience and expertise on the grout subjected to fatigue loading for wind turbine foundation and based on the past failure analysis of these grout material. With bigger and larger turbines, the problem will further amplify and a remedial measure by producing an apt grout for the wind turbine generator should be taken to task so that the future of turbines is safeguarded. The investor of wind turbines should understand the sensitivity of this component as this might jeopardize the entire cash inlay strategy.

Introduction

Onshore wind turbines are enormously growing in renewable energy generation. As per IRENA 2019 report, there is an increase of 3.75 times of MW capacity over a decade (from 2009 to 2018) in global context, out of which India has increased to 3.23 times that of the MW existed in the year 2009 till 2018. As of 2019 report, onshore wind energy makes up 23% of the world's renewable energy capacity, and the same is 30% in India as per 2018 statistics, with no offshore energy installations in India (Renewable Energy Capacity Statistics 2019). Support structures for these onshore wind turbines are usually gravity-based or piled reinforced concrete foundations and these structures are considered as least importance for an onshore wind turbine regardless of being a critical structure. In renewable energy generation, almost 95% of wind turbine generator (WTG) failures are attributed to problems in gearbox, blades or generator, compared to failures of towers and foundations¹. Being a quite niche sector that involves multiple domain knowledge is sometimes far reached, there seems to be a lot of facts which do not come out in the public domain at ease as many operating

persons do not have domain expertise to tackle such problems with wind turbine foundations and the failures are generally hidden. The companies experiencing the grout cracks in WTG foundations should share their experience so that the studies and improvements can be made better in this regard. However, for continued investment and for maximization of environmental benefits, it is vital to extend the life of these support structures or to ensure their design life time at least.

Cracks in WTG foundations can happen either before hardening or after hardening of mortar. The cracks can be classified based on the structure of cracking, viz., physical (different types of shrinkages, accidental), chemical (corrosion, carbonation), constructional (movement of formwork), structural (design fault), thermal (seasonal temperature variation), etc. Among the types of cracks, cracks in foundation are the ones first initiated in the first 3 to 5 years of commissioning of a wind farm. This technical paper covers the importance of cracks in grouts which we have practically faced in the field and what should be the future research requirement to overcome this defective practice. The cracks in the grout can entirely jeopardize the load transfer mechanism causing undue stresses on the foundation concrete and the interface. The impact of grout cracks may not limit its residence within the grout but because of the crack openings in the grout its functionality is lost and the top concrete will receive the abnormal stresses which they are not designed for as the load transfer mechanism is further widened out surpassing the pedestal face.

Impact of Cracks in WTG Foundations

As per IRENA Renewable Energy Technologies: Cost Analysis Series, 2012 Report, the cost of the support tower with foundation is slightly more than one fourth of that of a WTG out of which, the contributing cost for foundation is around 5-6%, again a

quarter of the cost of the tower. Further, the report suggests that for onshore wind power projects, foundation is one of the key areas where cost reduction can be implemented. While trying to reduce the cost, the quality and the life of the structure cannot be forfeited. We should adhere to the Codal guidelines as well as come out with an economical design. Although in terms of the percentage of cost is least for foundation, but strength of the foundation is very important for the overall reliability of WTG. While failures often get widely reported in media simply because of the high visibility of turbines, the percentage of structures that break is low compared to failures of turbine blades as reported by US based insurance company (2015).

Successful and safe installation of wind turbines largely depend on the materials which connect the tower to its foundation. In general, loads transferred to foundation are of axial load, bending, torsion, rotation, vibrations and combined effects of all these, besides interaction of the soil and foundation (Standard Design Report of NeXHS 2019). Grouts play a major role in transferring these loads from the tower structure to the foundation. Hence, a careful design and selection of the grouting material is of utmost important.

Construction Manual (SOP) as prepared by NeXHS (2019) has the following guidelines for grouting process:

1. Selection of suitable formwork material (GI sheet/MS plate). Figure 1 shows the typical formwork using MS plate at a site.
2. Calculation of minimum gap required both inside and outside
3. Height of formwork above the grouting level
4. Ensuring the uniformity of the gap all around
5. Sufficient support to formwork
6. Surface preparation for grouting by suitable methodology
7. Surface treatment before grouting
8. Selection of adhesive bonding agent between concrete surface and grouting surface



Figure 1:
Formwork for Grouting

Understanding the Cracks in Grout

Cementitious and epoxy-based grouts are generally used for WTG foundations. Recommended ways and means as documented in the project manual are not religiously followed while executing

the construction and installation of projects and often result in deviations. Such field deviations lead to cracking in grouts in common as can be seen in Figure 2. Further, the types of cracks in grouts as experienced by us while executing and during the life of the project in the field are discussed in the following sections. The process of grouting at site is demonstrated in Figures 3 and 4.



Figure 2:
Radial Cracks on Tower Pedestal – Crack Expanded



Figure 3:
Process of grouting at site



Figure 4:
While and after grouting

Common Types of Cracks Observed in Grouts

The most common types of cracks observed in grouts based on visual inspection² are:

- Thin cracks including shrinkage and autogenous cracks
- Vertical cracks on the voids provided to allow access for grouting
- Horizontal cracks at the connection
- Thermal cracks while processing and due to improper curing especially in regions of water scarcity.
- Material cracks due to lack of strength or differential grouting material or metallic contents in the grout
- Corrosion cracks due to carbonation or at the connection
- Structural cracks due to poor design
- Cracks arising out of artisanship

Main Causes of Grout Cracks

To overcome these cracks, precautionary measures are necessary while and after the execution of project. Some of the main causes of grout cracks are listed below:

- Inappropriate selection of material
- Non-uniform grouting material
- Two different grouts for one pour in a site
- Insufficient injection of grout
- Lack of provision of expansion joints that don't permit breaks in between two successive pours
- More number of sharp corners or excess material at the edges as sharp corners tend to break and hence chamfered edges may be provided to limit stress-related cracking

- Weak grout as against equivalent strong grout
- Sequence of form release to avoid differential restraint on the grout during its cure
- Poor performance of workmanship
- Poor structural design

Research Requirement to Tackle Grout Cracks

Based on the pattern of failures from a survey on wind farms located in southern part of India by the authors, it is observed that in each wind farm, there are issues related to grout to the extent of 3% to 5% after commissioning. Figure 5 shows the location of wind farms considered for the selected study. Figure 6 shows the representative number of wind turbine foundations affected by the issues related to grout.



Figure 5:
Location of Wind Farms (■)

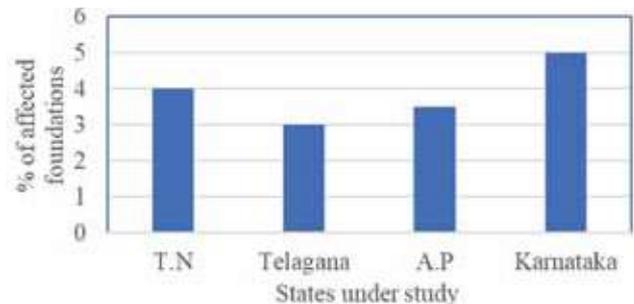


Figure 6:
Foundations Affected by Issues Related to Grout

Failure analysis

A preliminary research by us on cracks was initiated by considering the actual crack found practically in the field. By applying failure theory, propagation of cracks is further analyzed using Abaqus.

Mix Design of High Strength Grout

We have initiated a high strength grout, which would possess good mechanical and fatigue response, durability and long-term response to damages. Research is on-going at our R&D centre to possess a few superior properties for a high strength grout mix, such as:

- Should act as a transition material possessing extra high properties.

- Has to be designed to have a very high fatigue resistance.
- Should be capable of transferring or absorbing dynamic loads in a predictable and consistent manner.
- Grouts should have vibration damping capability, as well as adequate compressive strengths.
- Has to be a non-shrink grout and preferred to be cement based and should have a stable volume to maintain the bearing capacity.

Self-healing technology

Research has been initiated on self-healing technology especially for the grout and concrete so that any crack development in the grout can be addressed through the self-healing compound.

Conclusion

Recent studies in Germany, where more than 20,000 wind energy systems are in place, have found that up to 30 percent are affected by foundation damage within the first three to five years³. Causes of this damage include the high number of load changes (up to 7 million load changes per year). The loads must be transmitted through the anchors and through the grout bed that serves as the link to the foundation³.

According to American Wind Energy Association (AWEA), average hub height of utility-scale wind turbines installed in the U.S. jumped from 58 meters to 88 meters over a period from 2000 to 2018 and in global context it is aimed to build ultra-tall towers to the extent of 160 m height to boost the capacity factor (www.greentechmedia.com). However, while trying to expand the markets by reducing the tower costs perhaps by 15% to

20% by 2030 (IRENA 2019), use of lightweight materials, hybrid towers and other innovative technologies to achieve that height in-turn require a high strength grout to strengthen the foundation. Wind energy continues to grow, besides solar energy during this COVID-19 pandemic, even as global electricity demand has been declining in many regions (www.greentechmedia.com). A non-shrink cement-based high strength grout is the requirement at this moment of the time to tackle grout-based cracks. It is a challenge for the researchers in the field of renewable generation, which our R&D Centre has taken up. Preliminary mix design developed is a cement-based (OPC) non-shrinkable grout by using only high range water-reducing agent, aiming to achieve 150 MPa and further lab-scale mechanical tests are being continued.

References

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Renewables meet 46.3% of Germany's 2020 power consumption, up 3.8 pts

Renewable sources met 46.3% of Germany's power consumption in 2020, 3.8 percentage points more than in 2019, utility industry association BDEW said, adding that parts of the increase came from a drop in usage in the coronavirus crisis. Germany wants to raise the share of renewable in its power mix to 65% by 2030 and is just finalising a green law reform bill this week to step up its efforts.

(Source: Reuters, December 14, 2020)

Cabinet Approves CERC Proposal to Exchange Information with FERC, US in Electricity Sector

The Union Cabinet has approved the Central Electricity Regulatory Commission's (CERC) proposal to enter into a Memorandum of Understanding (MoU) with the Federal Energy Regulatory Commission (FERC), USA to exchange information and experiences in the electricity sectors. As per a statement, the MoU will help improve the regulatory and policy framework to develop efficient wholesale power market and enhance grid reliability.

Source: ANI, December 17, 2020

Tamil Nadu Owes Most to Power Generation Companies

According to a study released by ICRA, the state utility Tangedco has huge outstanding payments of Rs 18,520 crore, to power generating companies. In contrast, Gujarat discom's outstanding was Rs 448 crore, Maharashtra's Rs 7,358 crore and Karnataka's Rs 7,127 crores as of October 2020.

(Source: TNN, December 24, 2020)