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C-WET
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EDITORIAL

We are entering an era of optimism with order books full until 2008. The desperate search is on for suitable land to set up not a few machines but hundreds of megawatts. The new customers are independent power producers and masters in business administration and experts in preparing scenarios with available information. At this stage, I thought we should remember one lady who, perhaps, never thought that her efforts would launch thousands of MW of wind power.

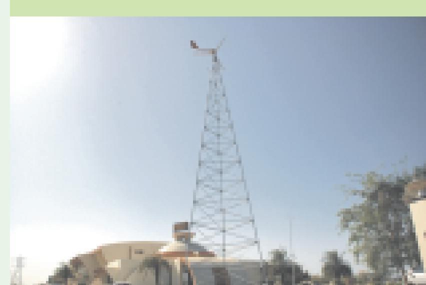
When I joined NAL in 1979 under Dr.S.K.Tewari as a scientist, I used to hear of a Miss Mani who was a terror among meteorologists and weathermen. One story goes like this: This assistant meteorologist in the Palace Road office was holding forth on the next few days' weather to unsuspecting visitors when suddenly the phone rang and this chap lolling in his seat casually picked up the phone and "halloo..."ed into it. Next moment he was standing in attention and looking shell shocked started mumbling "yes madam... no madams..." in to the phone in a most reverential manner. Later mopping his brows he confessed it was Miss Mani herself. Such was the effect she normally had on people. During late seventies, her Wind and Solar Data hand books was hugely popular among the new RE technology enthusiasts. It was during this time an idea started by Dr.S.K.Tewari about need for a nation wide wind resource assessment got fillip from the Ministry and to a very large extent by Miss Mani. In fact, she had, by then, retired from active service (India Meteorological Department) and was associated with Raman Research Institute. She had the courage and ability to run a seemingly dangerous program of running wind monitoring stations in remote areas. Normally in Government run establishments the fear of audit paras prevent faint hearted scientists and engineers from venturing into such activities. But with Miss Mani there was no such thing as fear. She just went ahead and implemented the program with an Iron hand. Dr.Tewari and I were consultants to the program on different aspects. Therefore there used to be considerable interaction with the team and we were invited to the review meetings. In those initial review meetings with state nodal agency officers, she just would order what needs to be done and things were as good as done. We were quite young in those days and I remember, even Shri A.K Gupta of the Ministry, who was himself well known for his firm hand in the field, would agree with many of the recommendations (more like commands!). Today India possesses one of the most carefully documented wind resource information due to her.

On a personal front, with her almost abrasive approach to the younger generation, she had a healthy disdain towards engineers in general. I still remember the first wind monitoring station installation at Sultanpet in Tamilnadu. There were about three hundred people gathered at the project site and Madam promptly took up her position at the site. A straight backed office chair was installed and her assistants complete with umbrellas and thermos stood in attendance. Mr.Ramalingam of Tamilnadu Energy Development Agency was coordinating with Tamilnadu Electricity Board to get the mast installed. As it should happen, TNEB could not get the pulling and lifting machine to site in time. We had to think of an alternate method on the spot. It was a challenge to me and to engineers in general. It was eventually decided to use TNEB jeep to haul the mast up through a pulley system. The action plan was explained in detail to each of the riggers first in English and then translated to Tamil for clarity. I can tell you they were some of the most anxious moments for me. Perhaps there was a change of opinion about engineers after this event. Today it seems child's play and we may tend to laugh at it all.

Just to remember her for the great contributions that she made, the Governing Council of Centre for Wind Energy Technology decided to name the library after her. Nothing very significant, but this was long over due. This was CWET's way of saying thank you. Her greatness lies in the fact that she did all this with no expectations.

Contents

Editorial Board

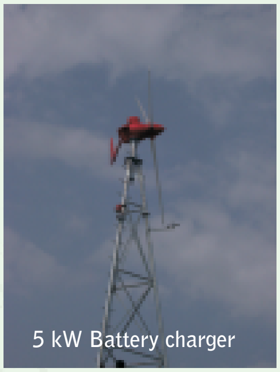


DEVELOPMENTS IN R&D UNIT

Wind-Solar –Pungham oil trigeneration system at C-WET campus.

With a view to use renewable energy devices to the maximum extent in C-WET campus, R&D Unit has set up a 45 kW Wind-Solar -Pungham oil trigeneration system to meet the load demand partially and also to undertake R&D studies on the system. Towards this end a 15 kW single crystal photovoltaic array, 10 kW wind turbines and a 20 kW straight vegetable oil engine- generator system has been deployed. The output of these devices supplies energy to the uninterrupted power supply system


Power Conditioning Unit


5 kW Battery charger

at the campus. The system generates about 60kWh per day and is used as a technological demonstrator. The system integration is underway.


Solar Photovoltaic Panels

Figure: Wind-Solar–Pungham oil trigeneration system

Development and validation of design methodologies & design tools for low and moderate wind regimes

R&D Unit has undertaken development and validation of design methodologies & design tools for rotor / blades for low and moderate wind regimes in association with National Aerospace Laboratories, Bangalore.

Analytical design methodologies have been developed and validated using the experimental data from an available 300 kW, 2-bladed, downwind, stall-regulated, horizontal-axis wind turbine. Based on these validations design of a similar 500 kW turbine has been completed. Experimental data will be gathered from the demonstrator wind turbine (500 kW) to validate the methodologies evolved.

Also, aerodynamic performance studies will be carried out on augmentation devices like Gurney Flaps, which will be employed in actual field trials.

MOVE ON IN WRA UNIT

Presently, forty-one wind monitoring stations are operational under various wind monitoring projects sponsored by the MNRE. Five wind monitoring stations have been established and operational at Karnataka for M/s.MSPL Ltd., Hospet under consultancy projects.

Three verification procedures for wind monitoring have been taken up for M/s. Enercon India Ltd., Mumbai and M/s. Vestas Wind Technology India Pvt. Ltd., Chennai under consultancy Projects.

The unit has completed due diligence for wind farm, for the proposed wind farm in Gadag Dist. in Karnataka for M/s. Enercon India Ltd., Mumbai during this quarter.

One feasibility study of wind farmable area in Maharashtra for M/s. Southern Wind Farms Ltd., Chennai has also been completed.

Two scientists and one meteorologist of the unit have undergone a course on the background and application of Karlsruhe Atmospheric Mesoscale Model (KAMM)/WAsP methodology as a part of the preparation of numerical wind atlas of the country. Objective of the course was to gain an in-depth knowledge of the KAMM/ WAsP numerical wind atlas methodology.

STEPS FORWARD IN TESTING UNIT

The measurements for Suzlon 1500 kW wind turbine in Gujarat are ongoing since March 2007.

Provisional Type Testing of Enercon 800 kW E53 wind turbine at Jodhpar, Gujarat is in progress.

Provisional Type Testing of IWPL 250 kW wind turbine at Navadra, Gujarat, is in progress since April 2007.

The instrumentation of Siva 250 kW wind turbine at WTTS, Kayathar, has been completed. The measurements are expected to start during the last week of July 2007.

An agreement has been signed between C-WET and Suzlon to test their new variant of 350 kW wind turbine in Gujarat and the measurements are expected to start in the first week of August 2007.

MARCHING AHEAD IN S&C UNIT

Renewed Provisional Type Certificate of the wind turbine model V39 – 500 kW with 47 m rotor has been issued to M/s. Vestas RRB India Limited.

The review of documentation for Provisional Type Certification of Pawan Shakthi – 600 kW wind turbine model under Category II as per TAPS – 2000 (amended) has been almost completed. The Provisional Type Certificate will be issued shortly.

Technical specification verification and verification of safety and function test of Elecon T600-48 wind turbine model, installed at site has been carried out as part of Provisional Type Certification under Category – I, as per TAPS – 2000 (amended).

Internal Audit findings for S&C unit have been successfully closed. The status of Quality Management System of the unit has been presented and discussed during the Management Review meeting.

Revised List of Models and Manufacturers of Wind Electric Generators / Wind Turbine Equipment (RLMM) has been issued on 02-04-2007.

The certification projects, taken up as per TAPS – 2000 (amended), are under progress.

The continual improvement and maintaining the Quality Management System are ongoing.

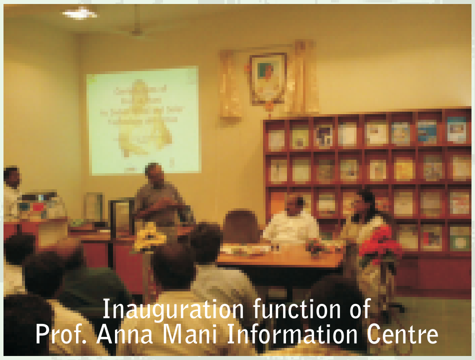
HIGHLIGHTS FROM ITCS UNIT

Upcoming International Training Course:

Preparatory works for organising the Third international Training Program on "Wind Turbine Technology and Applications" from 8th to 17th August 2007 is in progress.

Prof. Anna Mani Information Centre:

C-WET library has been named as "Professor Anna Mani Information Centre" on 21st May 2007. The inaugural function was attended by the various personnel from State Nodal Agencies, Industries and Association of wind energy sector.



Inauguration function of Prof. Anna Mani Information Centre

E-Security:

Firewall with E-security features has been installed to strengthen the e-security of C-WET.

Fifth National Training Course on "Wind Farm Development and Related Issues" on 6th and 7th December 2007 at C-WET:

C-WET is organising its fifth national training course for technical persons and field engineers in the wind power sector on 6th & 7th December 2007 at C-WET, Chennai.

Course Fee

The course fee is Rs. 2000/- (Rupees Two Thousand Only) per participant and for student Rs. 1000/- (with the supporting covering letter by the Head of the Institution). The demand draft should be drawn in favour of "Centre for Wind Energy Technology", payable at Chennai. The course fee includes course material, lunch and coffee / tea. A copy of the registration form is given here and photocopies of the same can be used for registration. The application should be received on or before 20th November 2007. Detailed timetable will be sent alongwith confirmation letter.

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REGISTRATION FORM

Full Name : ....

Position : ....

Organization : ....

Sponsoring Agency : ....

(Supported by a covering letter from the Head of institution)

Contact Details :

Phone : .... FAX : ....

E-mail : ....

Postal address : ....

....

....

Details of Registration fee

Amount ....

Demand Draft No. .... Date : ....

Bank : ....

Signature ....

Essentials of Structural Design of Wind Turbine Tower Components

In most wind turbines (Wind Electric Generators, WEG), only 10% to 20% of the total cost is consumed for the support tower and foundations. Nevertheless, the tower's function as a machine-foundation supporting costly and heavy rotating equipment cannot be overlooked in terms of its fractional cost. Generally the close interaction of operational characteristics of turbine and the structural response of the supporting tower warrant mutual technical coordination of aero and structural engineers. Hence in most cases, the design of support towers have been provided by turbine manufacturers considering the static, dynamic and fatigue nature of operational loadings. Efforts are still needed for the development of comprehensive codal specifications and standardization of designs of support towers for various environmental and soil conditions of the user-countries.

Many industries in India have attempted to indigenise the manufacturing of possible components of a WEG installation and the first choice is the support tower and its foundation, using Indian materials and fabrication technologies. The proprietary nature of aerodynamic loading data for the tower design is an unavoidable bottleneck in developing national standards for structural specifications of the support towers. However, the overnight collapse of over 130 wind mills in one of the major wind farms (Table-1) in India due to cyclonic wind forces has raised the importance of understanding the underlying codal provisions of design and installation methods in terms of the overall structural stability and quality assurance. The tower design and erection practices vary considerably depending upon the wind characteristics, terrain conditions and the type of WEG. Further the site-specific soil properties used for the design of foundations are based on assumed data or on limited measurements. This article examines the options and issues in structural design of these towers.

Learning from failures: Right step for perfection

The post disaster damage documentation of wind mill failures after the June 1998 cyclone at Lamba in Gujarat indicated foundation pullouts, total collapse of lattice towers, shearing and twisting of lattice towers as well as shell-buckling of cylindrical towers, and de-lamination and fibre separation in rotor blades. One of the main reasons as explained by Lyn Harrison et.al[1], is that the cyclone winds of a millennium storm, that crossed Gujarat coast has far exceeded survival margins (Table-1) of most of wind mills. Further, failure of brakes of rotors, uncontrolled wheeling of rotors at higher RPM, inoperability of yaw motors due to Grid failure have increased the incidence of total collapse of towers. It is also observed that high frequency contents in the cyclone winds would have resonated the tower with the free wheeling rotors which will result in high stress ranges and lower fatigue cycles for the failure. When an extreme event occurs the failure is coupled with excessive oscillations, dynamic buckling, faster rate of fatigue crack growth and progressive collapse of joints. However it is the concerted effort of the wind energy research group spread all over the world that has left more than 60% of the wind turbines (Table-1), in Gujrat, which stand to tell the tale of design adequacy close to or at the survival wind loads. Many lessons could be learnt, by carrying out simple indicative short term on-site full scale ambient wind vibration tests on these surviving support towers and components.

Loads on towers supporting wind turbine

Wind mills/wind farms are located at sites where there is wind energy, with high availability throughout the year. In addition, the available energy should also be usable, within the operating limits of the turbine. Most turbines have cut-in, cut-off, and operating wind speeds. The wind load effect is random and dynamic and is referred in the wind turbine industry as shown in Fig.1. For the ease of design comprehension the mean wind loads are considered as STATIC, and the fluctuating wind loads as DYNAMIC.

The static loads on the tower are due to:

i) Self weight / dead weight of turbine located on top of tower including nacelle .

ii) Mean wind loads acting on the tower and on the turbine (stalled out-of-wind or parked in-wind).

Mean wind loads under normal operating wind conditions, pose no severe static stress peaks. However, when the wind speed is well over the cut-off wind speed of the turbine, also during cyclonic storms or hurricanes the extreme winds cause high static stresses in parts of the tower of cylindrical shell or lattice type, even though the rotor is stopped. These loads are called survival wind loads. Different countries specify different survival wind speeds which are in the range of 50 to 70 m/sec for different regions.

Dynamic operating loads on the tower are due to:

i) Fluctuating component of wind (gust).

ii) Differential wind velocities in upper and lower blade positions of the rotor due to wind velocity profile along height

iii) Tower torsion due to differential lateral correlations of wind velocities on the exposed blade area.

iv) Variation of gravitational acceleration of blade mass while in operation, causing gyroscopic effect.

v) Manufacturing or erection induced imbalance in the rotor mass and associated dynamic amplification of stresses.

vi) Continuous fluctuations in Yaw mechanism and so on.

Apart from the normal dynamic loads, there are other situations which will have dynamic transient loads such as:

i) Application of sudden brakes.
ii) Continuous manual yawing in-wind to out-of-wind and vice-versa.
iii) Resonant vibration at the natural frequency, f_1, of the tower.
iv) Wake induced cross wind oscillations of cylindrical shell type towers (amplitude dependent).
v) Stiffness reduction due to bolt snapping or pull out at a connection and so on.
vi) Blade mode and higher order blade frequencies which might trigger tower resonance.
vii) Blocked (accidental) pitch or yaw mechanism either during operation or under high winds.
viii) Grid disconnection or rotor jamming with gear during operation.

Because of the complexities involved in the load characterisation of (i) aerofoil in turbulent wind, (ii) blade loads to overall rotor loads, (iii) rotor loads to hub loads, and finally (iv) hub loads to tower loads, most of these towers are designed using some approximations so that rational but fairly safe designs are obtained

Basic design criteria for towers

Based on the mechanical and aerodynamic characteristics of the wind turbine, and depending on the site conditions (corrosive or non-corrosive) and aesthetics of design, the choice of tower is made. In addition, choice of the type of tower is also governed mainly by the type of wind energy generator that is supported, whether it is slow or fast and for what purposes. The usual purposes are pumping water, battery changing, grain processing or power generation and grid connection. The classification of wind turbines and the wind energy availability are sufficiently addressed by C-WET. In this article structural design of towers of wind energy converters used as wind electric generators (grid-connected) are only covered.

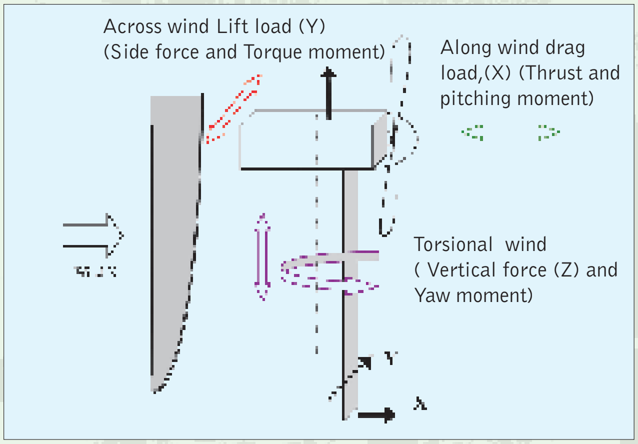

Fig.1 Dynamic wind load effects on wind turbine towers

Classification of tower

As a practice, the towers supporting wind electric generators are classified according to:

I. Rated thrust at maximum rated power (capacity of tower to resist extreme stress).
II. Natural frequency of the tower in relation to rotor RPM (geometric and dynamic characteristics of tower).
III. Type of design and construction.

I. Rated thrust

The manufacturers specify with certain partial safety factors, that the tower should resist a minimum rated thrust based on aerodynamic characteristics of the rotor/blade under critical high wind conditions, at the hub height of the cantilevered tower. Being the tip load on the cantilever tower, its effect is significant in terms of response stresses. The hub height of wind turbines used in India vary from 20 m to 80 m with rated power ranging from 50 kW to 1500 kW depending on the location of the wind form.

II. Natural frequency of tower

There are two types of wind turbines adopted in practice one is with constant speed rotor, the other is variable speed rotor. In the field, it is obvious that constant wind speed is difficult to achieve, as wind is naturally a random process. In the case of constant speed rotor, the aerodynamic characteristics are so controlled (by pitch/stall regulation) and the gear transmission systems are so designed to provide a constant RPM (Revolutions Per Minute) of the rotor, i.e. the rotor operates more or less in a single frequency, and the generator delivers power close to 50 Hz (in India, ±5), which is the normal grid electric supply frequency. In the case of the variable speed rotor, there is a rated wind speed at which it produces maximum rated power, however the rotor would be able to capture some additional wind power (usually about 10 to 15%) from a wider band of wind velocities above and below rated wind velocity. This additional power comes with a trade-off in cost of power electronics involving DC/AC conversions.

Now, if 'N' is the rated RPM of the rotor, its frequency $p = N/60$ Hz. This is normally called 1 p vibration frequency, or shaft frequency. The interaction of tower's natural frequency f_1 with p gives the kind of classification of towers based on frequency, which is given typically for a n-bladed turbine by:

(i)	very soft	$f_1 < p$
(ii)	soft	$f_1 < (n)p$
(iii)	stiff	$f_1 > (n)p$

'(n)p' will be exciting frequency for a 'n' bladed rotor under well balanced operating conditions. In the case of variable speed rotor this classification is rated at the nominal RPM of the rotor. The very soft tower oscillates more and vulnerable for shortening of fatigue life of tower, but is slightly less costlier. Whereas the stiff one, most of the times is not economically viable.

III. Type of design/construction

Easiness of fabrication, transport, erection, corrosion protection, installation and operation and maintenance (O&M) drives the choice of a tower such as:

(i) Cylindrical chimney like shell, closed type, has an advantage of inner side being protected and provides easier access control equipment and to top during emergency and bad weather conditions. Yet, in a tropical country like India, working inside a metallic tower during summer is a bit uncomfortable. With either welding or bolted connections even at the foundation level, these shells are subjected to buckling and fatigue very easily. Costly high quality metal, and sophisticated fabrication and assembly techniques need to be used. However, this is widely used due to its aerodynamic advantages as well as axi-symmetric cross sectional properties, which reduce the wind directional effects on the tower design. Being slender circular, tapered cylinder, vortex shedding cannot be avoided, under certain steady critical mean wind velocity conditions. This causes undesirable cross wind oscillations and stresses.

(ii) Lattice towers, drag dominated towers, are vulnerable for member buckling and fatigue, but are easy to fabricate, transport and erect. It needs very careful dynamic design of members, as well as joints and bolting systems. It is less costlier when compared to cylindrical towers. Unless pre-tensioned friction grip bolts are used, fatigue design should be examined, not only for all the members but for all the joints too. Fatigue being a local phenomena local strengthening could be carried out during maintenance, including replacement of damaged members.

(iii) Prestressed concrete towers are not widely used in practice, because of high as well as low, cyclic vibratory loading due to wind and machinery and also due to the longer construction time and sophisticated construction equipment.

(iv) Tilt-up/down guyed tubular towers, are used for compact, low mass fully integrated (rotor+gear+generator) wind turbines for ease of maintenance. These occupy more land space for guy cable anchorage. One major advantage will be to design the tower for lower survival wind, so that the tower can be brought down for safety either in the event of cyclone or for routine maintenance without cranes. These types of towers are generally classified as soft based on frequency, and thus have excessive oscillations due to guy-compliance.

Analysis and design for extreme buckling stresses/tensile yield stresses

Most of the adopted designs being out of steel as fabrication material, the stresses both in angular (rolled steel) sections, and in sheet/plate shells are limited by permissible stress in compression depending on the slenderness ratio. Steel also needs to be checked for permissible tensile stress, which is a factored value of yield stress. Most often this criteria must have to be satisfied in the extreme survival non-operating condition of the wind turbine.

Analysis and design for fatigue damage

Fatigue can be defined as an insidious process, which occurs over a period of time due to repetitive (cyclic) loading on structures. There are mainly two factors involved, one is the expected number of load effect (in-service stress) cycles in the structure, the other is the material strength of structural element, component, or part for a given stress range. The material strength of structure, is expressed in terms of the permissible number of cycles for a given stress range through a series of controlled laboratory experiments. The curve is known as S-N curve (Fig.2), with stress range(S) versus number of cycles(N) to failure in fatigue. It is important to note that as the stress range increases the permissible number of cycles decreases significantly. A power-cut or Grid-failure (a frequency of occurrence of one per year, is assumed in the western countries) which causes an impulsive load such as a brake event for the WEG, enhances the stress range several fold. Typical measured time histories of strain in four legs of a lattice tower during a brake event are shown in Fig.3, with a jump in strains. The stress enhancement ratios (SER) based on full scale measurement for special operating conditions of a WEG are given in Table 2. This shows that how these events can drastically reduce the fatigue life of towers. In reality, most of the dynamic stress ranges that occur in a wind turbine tower are highly random and contain multiple stress ranges, with varying degree of exposure during the entire design life of the structure. The design life is usually 20 to 50 years depending on the importance. Most of the designs are based on a simple damage index d_i, evaluated under constant amplitude loading conditions, which can be defined for a given stress range $_{si}$, according to Palmgren-Miner's rule as,

$$d_i \quad \frac{n_i}{N_i}$$

Here n_i is the actual number of cycles (in-service load effect) experienced by the designed structure and N_i is the permitted number of stress cycles at the given stress range ' $_{si}$', under laboratory (constant amplitude) test conditions for material fatigue and fracture characteristic evaluation. For a random excitation, the total damage index can be defined as a sum of individual damages d_i:

$$D \quad {}_{i} \; d_i$$

This total damage over the design life of the tower should be less than '1' for safety against fatigue damage.

Fatigue cycle counting from measured stress ranges

The actual number of cycles for any typical wind turbine for a given site/wind conditions have to be measured and counted from field measurements. Using the measured stress ranges in various bins of wind speeds, fluctuating cycles of the stress ranges in the operating conditions can be evaluated, using rain-flow counting technique (Table 3). Even though the tail ends of the wind speed bins had lesser number measured data, the nominal rated operating range had sufficient number of records to get an on the spot assessment of the possible fatigue damage. These wind speed bins repeat in various seasons of each year in the entire design life of tower during turbine operations. So the fatigue cycles are cumulative. If the number of cycles "Ns" permitted (Fig.2) in a specific stress range $_{si}$, then the value of measured number of cycles "n_{si}" can be taken from the respective wind speed bin for the leg. Then the following equation can be used to estimate the annual occurrence of fatigue damage, which is cumulative sum of all the operating range of wind speed. Damage in one year D_{annual}, is given as

$$D_{annual} = \sum_{i=1}^{Ws} Di = \sum_{i=1}^{Ws} \sum_{s=1}^{Ts} (ns/Ns) * (Hi)$$

Where, Di is fatigue damage in ith wind speed bin

n_s is number of cycles per hour for the stress range $_s$ in the i^{th} bin

W_s is the number of operating wind speed bins

T_s is the number of active stress ranges in i^{th} bin

H_i is the number of hours of operation in the i^{th} bin

N_s is the number of permissible cycles for stress range $_s$

Some useful tips for tower-like structures Analysis

- Finite Element Modeling (FEM) of tower like structures should avoid local modes which may involve a few plan-braces.
- The frequency used in GRF must be for the first global bending mode and should be used in "Hz" units (cycles/second) in the given formula. It is essential to verify the mode shape for global bending mode before the frequency is used, for dynamic amplification effects.
- While using GRF method we must bear in mind that only first (that too a linear mode) mode is used for the derivation of the codal expressions, which is unrealistic for a tip massed cantilever.
- While analyzing for operational dynamic loads on rotor, the wind loads on tower for the corresponding wind speed bin must be adopted.

Design

- Design of steel sections should be as per working stress design using IS 800 for latticed towers, guyed towers and other tower like tubular support structures.
- For important towers in cyclone prone areas additional factor of safety may be exercised.
- Wind mill tower designs should aim at tuning the fundamental frequency (by choice of geometry, sections and adjusting the mass and stiffness) for avoiding resonance due to the proximity of tower frequency not only to rotor RPM but also to blade passing frequency.
- Fatigue of wind mill towers under operational loads must be checked for the design life, for Indian turbulent wind conditions.

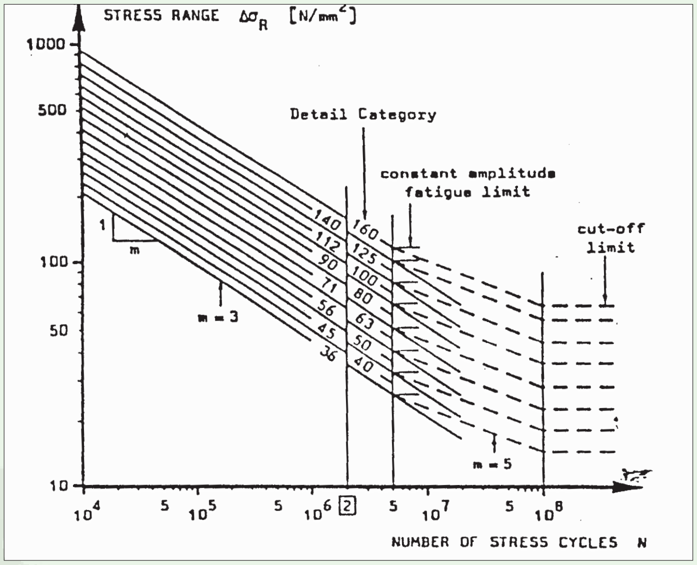

Fig.2 Typical S-N Curves (ECCS)

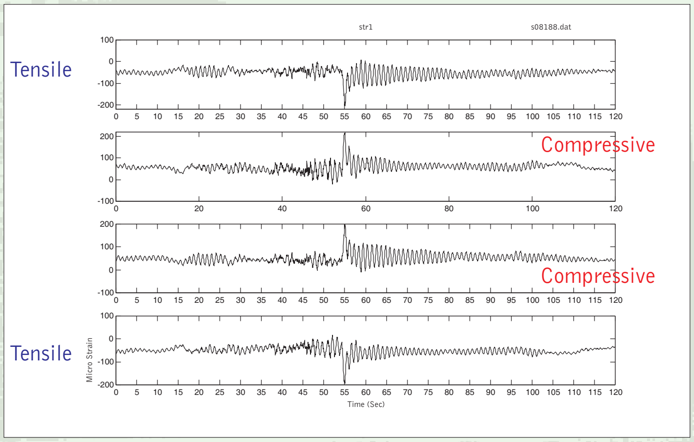

Fig.3 Typical jump in measured strains during turbine brake event

Table 1. Wind mills that survived a millennium Gujrat- Cyclone [1]

Turbine Manufacturer	Total turbines	Turbines destroyed
NEPC	83	18
BHEL-Nordex	52	2
Suzlon(SuedWind)	38	24
BEPL-Bonus	34	34
Vestas	50	18
Elecon	14	14
Enercon	15	0
NEG Micon	7	7
TTG-Husumer	6	0
Vestas-RRB	5	5
AMTL(Wind World)	4	2
Tackie	4	0
RES(AWT)	2	2
Chase	3	3
Total	**315**	**129**

Table 2. Stress-range Enhancements Ratios (SER) in special operating conditions.

Sl. No.	Special Operation	Ratio of mean Wind Speed	Leg1 SER= Spl/ Normal base	Mid	Leg2 SER= Spl/ Normal base	Mid	Leg3 SER= Spl/ Normal base	Mid	Leg4 SER= Spl/ Normal base	Mid
1	Braking with WEG-on	0.78	2.04	2.16	3.50	3.34	1.59	1.47	4.09	2.47
	Starting with WEG-off	0.98	3.67	2.68	3.39	5.59	3.75	3.29	3.95	3.47
2	Pitching with WEG-on	1.00	2.76	2.27	4.74	3.54	2.30	1.92	5.20	3.84
3	Yawing with WEG-on	0.78	1.96	1.29	1.13	1.64	1.58	2.23	1.24	1.28

Table 3. Measured cycles of dynamic stress ranges per hour for leg 3

	Mean wind speed Bins (m/s)								
Stress Range MPa	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16
3.2	4623	4796	4652	4330	3948	3910	3436	3180	3204
9.5	56	126	226	387	508	592	745	796	820
12.6	20	42	72	138	211	275	374	416	428
15.8	8	18	27	53	83	127	165	162	216
22.1	3	3	4	8	12	23	28	20	36
28.4	1	1	1	1	2	2	4	6	4
31.5	0	1	1	1	1	2	3	2	0
34.7	0	0	0	1	0	0	1	2	4
37.8	0	0	1	0	0	0	0	0	0
41.0	0	0	0	0	0	0	1	0	0

[1] Lyn Harrison, Sara Knight and Torgnt Moller, " Cyclone winds exceeded survival margins", Wind Power monthly, Sept 1998, pp 20-21

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Shri. S.Sivakumar
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Expired on 24.06.2007

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CENTRE FOR WIND ENERGY TECHNOLOGY (C-WET)
An autonomous R&D institution established by the Ministry of New and Renewable Energy (MNRE), Government of India
To serve as a technical focal point of excellence to foster the development of wind energy in the country
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