World Journal of Science and Technology Research
Vol. 1, No. 9, December 2013, PP:205-214 , ISSN: 2329 - 3837 (Online)
Available online at www.wjst.org

Research article

EARTHQUAKE RISK FOR WIND PANELS IN TURKEY

Kubilay Kaptan, Ugur Kavlak, Onur Yilmaz

Disaster Education, Application And Research Center, Istanbul Aydin University
E-mail: kubilaykaptan@aydin.edu.tr, ugurkavlak@aydin.edu.tr, onuryilmaz@aydin.edu.tr

---

ABSTRACT

The year 2010 saw a significant increase in installed wind power. Contrary to historical trends where Europe dominates the market for wind power, much of this growth was concentrated in North America and Asia. Both regions periodically experience strong earthquakes that may impact the final turbine design. As the installed wind power in earthquake prone regions grows, so does the importance of appropriate consideration of seismic hazards. Under-predicting this hazard exposes the operators and the communities dependent on wind power to undue risk. On the other extreme, over-prediction of earthquake influence may lead to costly designs that place unjustifiable pressure on the economical feasibility of wind power. Thus, rational prediction of seismic considerations will maintain and enhance the ability of wind power to economically compete with other energy sources.

The purpose of this paper is to look at current practice for seismic loading determination for wind turbines, discuss the limitations of current design methods, and suggest some improvements to design procedures to better represent the behavior of wind turbines under seismic loading. This paper presents also an overview of the experimental program and associated preliminary analytical results and risk areas for wind panel applications in Turkey.

Keywords: Earthquake, Earthquake Risk, Wind Panels, Risk Areas, Turkey

---

INTRODUCTION

Current practices for seismic loading vary greatly, but generally fall into one or both of two categories: numerical (finite element) analysis; and analysis based on building codes such as the 1997 Universal Building Code (ICBO, 1997), [1]. Additionally, there are situations where the estimation of seismic loads is simply not preformed. It is widely recognized that the dynamic behavior of wind turbines is distinct from that of other building structures.

It is imperative that wind farms remain in operation immediately following an earthquake to provide power for rescue and recovery efforts. In contrast to a city comprised of many different structures, a wind farm consists of few types of unique structures. This homogeneity raises the problem that an earthquake with unfavorable characteristics may damage most of the turbines at a given wind farm.

The earthquake response of wind turbines is a topic of interest, relevant to installations in seismic regions such as Turkey. In recent years, researchers and practitioners have approached this problem through application of existing code for building structures as well as numerical and analytical modeling of wind turbines.

For wind energy projects located in seismically active regions, considerations for seismic forces often utilize criteria developed for building structures. The loads determined from building code procedures are then superimposed with operational turbine loads for turbine foundation design. Utilizing criteria developed for seismic evaluation of building structures raises questions of applicability for other structures such as conventional wind turbines. It is therefore important to understand seismic response behavior of wind turbines in order to appropriately apply building code procedures for seismic loading evaluation.

Table 1: Installed Wind Power Capacity in the World

No	Country	MW	No	Country	MW
1	Germany	11968	24	Costa Rica	71
2	Spain	5043	25	Belgium	45
3	USA	4674	26	Ukraine	44
4	Denmark	2880	27	Finland	39
5	India	1702	28	Latvia	24
6	Italy	806	29	Brazil	19
7	The Netharlands	727	30	Turkey	15
8	United Kingdom	570	31	Luxemburg	14
9	Japon	486	32	Argentina	12
10	China	473	33	Czech Republic	11
11	Greece	462	34	Iran	11
12	Sweden	372	35	Tunis	8
13	Canada	270	36	Israel	8
14	Portogal	204	37	Russia	7
15	France	183	38	South Korea	6
16	Ireland	167	39	Switzerland	5
17	Australia	143	40	Mexico	5
18	Austria	130	41	New Caledonia	7
19	Egypt	125	42	Sri Lanka	2
20	Norway	97	43	Jordan	1
21	New Zeland	82	44	Romania	1
22	Morocco	54	45	Rest Countries	12
23	Poland	54	46	Sum	32039

Turkey has plenty of great natural resources. Geographical location of Turkey is also a great advantage, especially its distance to industry demanding countries, European Union, Arabic states. In addition to that, climate is a varying factor depending on the landscape. Three sides of Turkey is surrounded by Mediterranean, Black and Aegean sea with the warm and nice weather and good amount of stable wind speeds. However, to use all these advantages, Turkey needs energy. Any country that cannot produce its own energy cannot improve and will always be dependent on other countries; will lack freedom [2].

Since wind energy is not a stable electricity source, it requires other sources of electricity production investments to different energy resources. In addition to that, the demand of Turkish Republic is much more than the amount that can be produced by wind energy. On the other hand, it is a free energy resource once all the investments are completed. Price of wind does not fluctuate and by the technological advancements in wind power engineering, repair costs, and efficiency levels (increased up to 33% compared to around 15%, 20 years ago.) it is a great way of producing energy.

HOW WIND TURBINES OPERATE

The main energy source for the wind turbines is air. Air is a fluid; it has its particles in the gas form instead of liquid form. When air moves quickly, its particles move fast, in the form of wind. Meaning of motion is derived from the kinetic energy, which can be easily captured and very easy to use. For instance, it is like the water can be captured by the turbines of a hydroelectric dam. In our case, the fluid is captured by a wind turbine. Speaking of wind power, it all starts from the sun. The wind is a form of solar energy: 1% to 2% of the solar energy is converted in wind. It's just air in motion which is caused by the rotation of the earth, the irregularities of the earth’s surface, irregularities of the temperature in the atmosphere. The wind is more important in coastal and mountainous regions due to the amplified effect of atmospheric pressure difference on wind velocity. When the sun heats up a certain area of land, the air around that land absorbs some of that heat coming from the sun. At a certain temperature, the hotter air begins to rise very quickly since the given volume of the hot air is lighter than the equal volume of the cooler air.

ON SHORE WIND TURBINE LOCATIONS

On-shore zones are mostly on top of hills or elevated lands that are almost 3 kilometers from the nearest shoreline. Theory behind this application is to obtain the maximum wind speed from the accelerating effect of hills and steep land on the coastal winds. Determining the exact location of greatest wind speed is crucial for maximizing output and the process is known as `micro-siting`. Detailed wind maps of the area are constructed with the help of anemometers since 20m of positioning difference could double or half the output numbers. Like every engineering problem, on-shore turbine installation has a drawback that has to be considered: effect on local habitat.

NEAR SHORE WIND TURBINE LOCATIONS

Near-shore locations are described as a hybridization of distance parameters. They are mostly considered to be within 3 kilometers of inland and 10 kilometers of offshore. Near-shore farms also hybridize the thermodynamic and aerodynamic properties of offshore winds and onshore winds. Shores are ideal places for turbine installation due to strong convection winds. Moreover, winds on sea surface carry much more energy at the same speed than the winds over mountains and elevated landscapes since the density of wind is higher on sea surface.

WIND ENERGY POTENTIALS IN TURKEY

Although the first Turkish wind turbine was constructed in at the Golden Dolphin Hotel by Vestas in 1985 (55 kW), the development of modern Turkish wind power engineering began from 21st of November 1998 when the first 3 Enercon E-40 wind turbines of 500 kW each began to operate at Alacati, Izmir. Then, the windfarm consisting of 12 Vestas V44/600 turbines was constructed at the same locality in November 1998 and the third wind farm with total installed capacity of 10.2 MW started to operate from June 2000 at Bozcaada Island. However, these capacities of constructed WPT do not reflect the real potential of Turkey.

There are many publications of Turkish researchers relating wind energy potentials in separate regions of Turkey. As a result of long-time work, in June 2002, Turkey's Wind Atlas [12] was assembled and published by the Turkish State Meteorology Organization (SMO) and General Directorate of Electrical Power Resources Survey and Development Administration of Turkey (EIE). Results of observations on 45 meteorology stations of Turkey are summarized briefly in *Table 2*. As seen from this table, it is impossible to draw conclusion on wind energy potentials in many regions of Turkey. The majority of meteorology stations of Turkey were established more than 50 years ago. As a result of urbanization, many meteorology stations found themselves in city boundaries.

Table 2: Wind Characteristics Registered at Some SMO Stations in Turkey

No.	**Station name**	**Altitude (m)**	**Anemometer height (m)**	**Observation period**	**Average wind speed (m/s)**	**Earthquake Region**
1	Afyon	1034	12	1989–98	1,8	2
2	Ağrı	1632	10	1989–98	1,7	2
3	Akçaabat	3	13	1989–98	1,9	4
4	Akçakoca	10	10	1989–98	1,8	1
5	Amasra	73	10	1989–98	5,2	1
6	Ardahan	1829	10	1989–98	1,9	2
7	Bandırma	58	11	1989–98	4,0	1
8	Bergama	53	12,5	1989–98	3,0	1
9	Bozcaada	28	10	1989–98	5,8	1
10	Bursa	100	11	1989–98	1,8	1
11	Cihanbeyli	969	10	1989–98	2,9	4
12	Çanakkale	6	10	1989–98	3,7	1
13	Çorum	776	10	1989–98	1,8	2
14	Dalaman	13	13	1989–98	2,6	1
15	Diyarbakır	677	15	1989–98	2,8	2
16	Elazığ	990	10	1989–98	2,7	2
17	Erzincan	1218	10	1989–98	1,7	1
18	Erzurum	1758	10	1989–98	2,8	2
19	Etimesgut	800	20	1989–98	2,2	4
20	Gönen	37	10	1989–98	2,4	1
21	Güney	805	10	1989–98	4,3	1
22	Iğdır	858	11	1989–98	1,0	2
23	İpsala	10	14	1989–98	2,9	3
24	Kangal	1512	10	1989–98	2,6	3
25	Karapınar	1004	10	1989–98	2,3	4
26	Karataş	22	10	1989–98	3,1	2
27	Kayseri	1093	10	1989–98	1,8	3
28	Kozan	109	10	1989–98	2,1	3
29	Kuşadası	22	14	1989–98	2,2	1
30	Malatya	948	13	1989–98	1,9	1
31	Mardin	1050	10	1989–98	3,9	3
32	Muş	1320	10	1989–98	1,1	1
33	Ordu	4	12,7	1989–98	1,5	3
34	Pazar	79	10	1989–98	2,0	4
35	Pınarbaşı	1500	10	1989–98	3,9	1
36	Polatlı	885	10	1989–98	2,5	4
37	Samsun	4	13	1989–98	2,4	2
38	Seydişehir	1131	10	1989–98	1,9	4
39	Siirt	896	10	1989–98	1,3	1

40	Silifke	15	10	1989–98	2,1	3
41	Sinop	32	10	1989–98	2,9	4
42	Siverek	801	14	1989–98	2,9	3
43	Suşehri	1163	10	1989–98	3,2	1
44	Şile	31	10	1989–98	3,4	2
45	Van	1661	10	1989–98	2,5	2

REPA (TURKISH WIND ENERGY ATLAS)

Repa is a specific kind of government program that was designed to include whole Turkish land and coasts, providing three different numerical atmosphere analysis model combined with meteorological data. This system is then run back in time in order to get a 200x200m resolution per point on Turkish map, providing specific detailed wind data. 700GB data, a supercomputer with 124 microprocessors, storage space of 5 terabytes is used to complete this project that included measurements from approximately 33million different points of data around Turkey. The outcomes of this project can be used by anyone interested or works in wind energy business, in addition to academic individuals or communities. Below are the capabilities of this model :

- Annual, monthly, daily or seasonal average wind velocity data for heights 30, 50, 70, 100m above ground.
- Annual, monthly or seasonal wind densities at 50 and 100m above ground
- Annual wind capacity factor at 50m
- Annual wind types at 50m
- Temperature data at 2m and 50m above ground
- Atmospheric pressure level at sea level and 50m above ground.

In order to find potential wind farm locations on Turkey REPA map shown in *Figure 1* is integrated to a geographical information systems models. (CBS) This map includes topography, rivers, lakes, civilization areas, special forest terrain, highways/freeways, railroads, harbors, airports, energy transmission lines and transformer stations. Most of this information is available on the free map tool provided by the website. However detailed descriptions and analysis of such specifics of land is only given as “unusable area”. REPA project decreases the time and costs of any basic feasibility analysis which needs to be done by individuals of such interest. Therefore it decreases the time needed to research and find a suitable and efficient location in Turkey in order to produce green energy. Just by investigating areas on this project, it even is possible to get the possible cost of electricity production for a wind farm production facility.

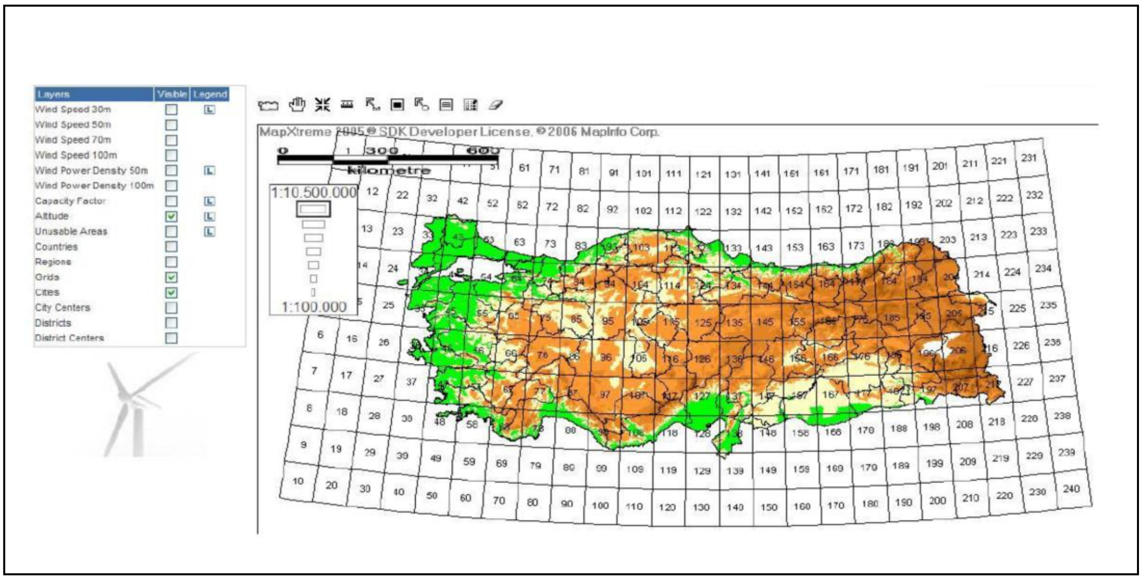

Figure 1: REPA Online Map Analysis Tool

World Journal of Science and Technology Research
Vol. 1, No. 9, December 2013, PP:205-214 , ISSN: 2329 - 3837 (Online)
Available online at www.wjst.org

The geographical map shown in *Figure 2 and 3* clearly shows the possible wind farm construction possibilities [4]. The most common chance of building a cost efficient wind farm is to build them at elevations from 0 to 500m or at most up to 1000m. Elevations higher than 1km might be dangerous for the Wind Farm and will drastically increase the cost of electricity production as a result of high maintenance costs. Inner parts of Turkey (the brown area) mostly face a territorial climate. Especially the addition of high elevation makes the winter tougher (colder with snow, blizzard etc.) and lack of transportation is additional trouble for such power generators to accomplish their job. Therefore the most efficient wind power plants would be to have them onshore or offshore where land elevation is close to 0m. Warm Mediterranean weather and stable wind speed is a good way to gain the wind energy and have less cost of production. In addition to that, transportation around the Mediterranean region is more advanced with plenty of highways and wide roads.

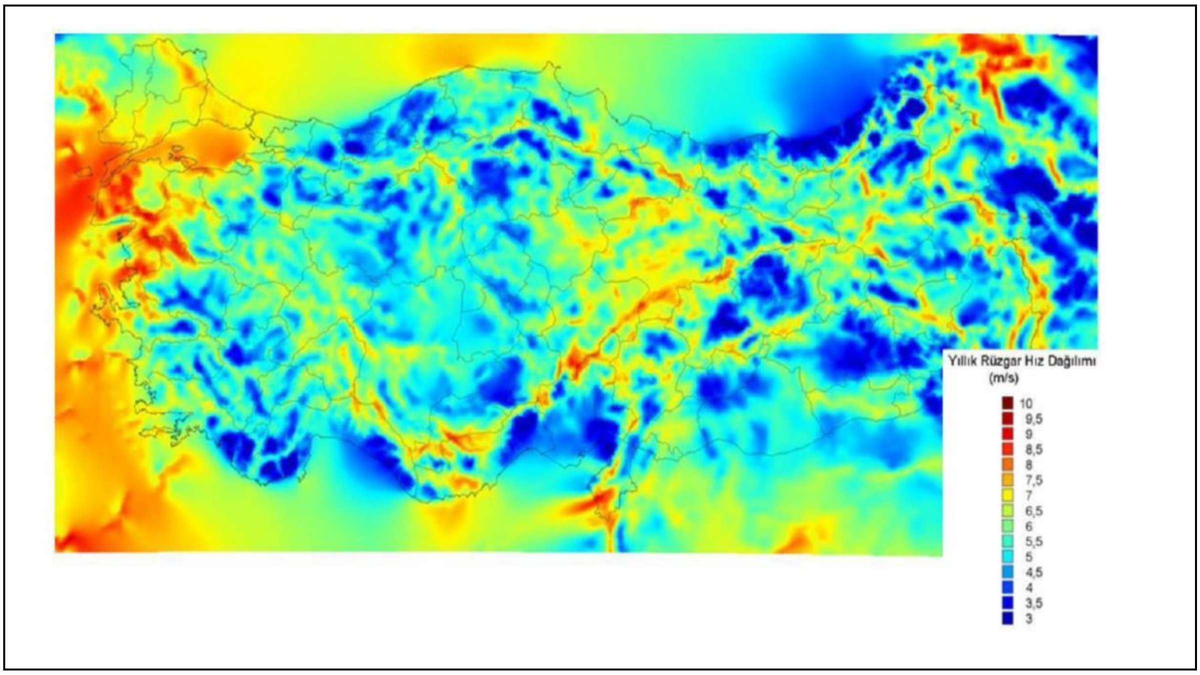

Figure 2: Annual Average Wind Speed Map of Turkey for Elavation 70m to 100m

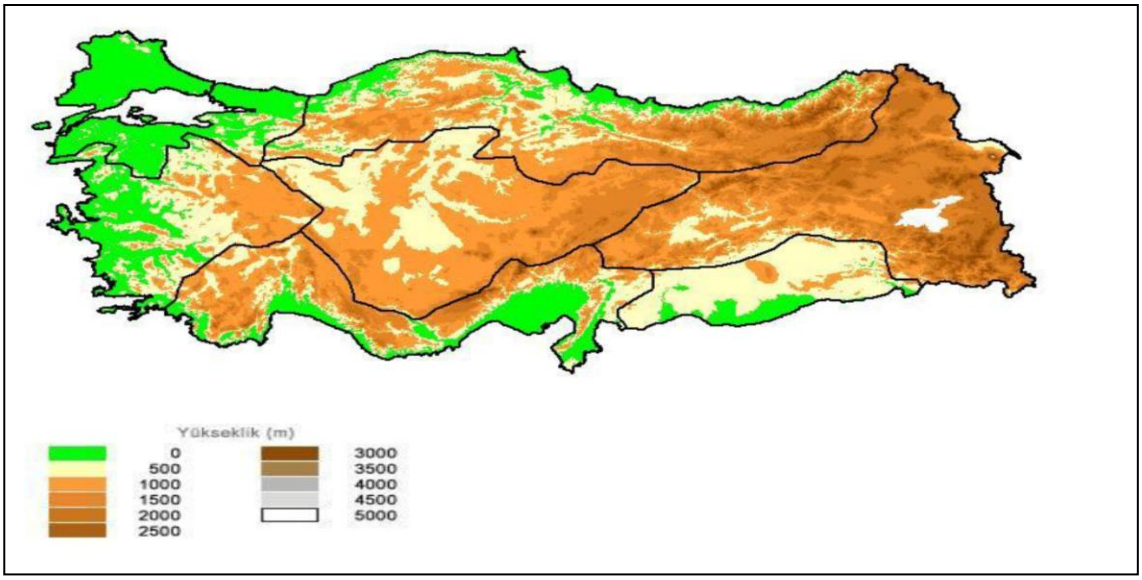

Figure 3. Elevation Color Key in Meters

ANALYSIS PROCEDURES

Several procedures are available for evaluation of seismic loading of buildings and other structures. The analysis procedures within the building codes are generally recommended based on the occupancy category, structural characteristics and the seismic setting of the given structure. The recommended analysis procedures can generally be categorized as consisting of modal response spectrum procedures and time history analysis procedures [5]. Modal (response spectrum/frequency domain) analysis can be utilized to determine seismic loads on a structure by evaluating loading contribution from all relevant modes of vibration during an earthquake. The evaluation requires determination of a response spectrum (from a building code source or site specific evaluation) that defines the spectral acceleration of a structure as a function of the structure period. Modal analysis can be implemented to account for all relevant modes of vibration of a structure but a simplified procedure is available in the code for evaluation of only the first mode of vibration. The simplified method is commonly referred to as the equivalent lateral force (ELF) procedure in which the seismic load is calculated as an equivalent horizontal base shear. The calculated base shear is then distributed to the structure being analyzed based on the mass distribution with height. The ELF procedure provides a first order estimation of the magnitude of seismic loads and can be used as a screening tool on whether more refined analyses are required. Seismic loading evaluation can also be performed using time history procedures (time domain analysis). The evaluation can be accomplished by analyzing representative time histories selected from earthquake records at a given site to more precisely model the interaction of seismic forces on the foundation, tower and turbine as the earthquake occurs. Time domain analysis is a more precise evaluation procedure since representative structural characteristics can be modeled and the response evaluated at specific time intervals during the earthquake. In the case of wind turbines, the calculated seismic loading can be combined with other concurrent loads depending on the turbine operational state.

MODAL RESPONSE ANALYSIS

Seismic Ground Motion Parameters

Seismic analysis procedures require defining ground motion parameter values and/or earthquake acceleration time histories. The ground motion parameter values may be determined from site-specific procedures or from the generalized procedure specified in building codes as described below. Building codes include spectral response acceleration maps developed by the United States Geological Survey that provide the required acceleration parameter values for evaluation of seismic loads for the U.S. and its territories. The maps consist of 0.2 (Ss) and 1 second (S1) 5% damped spectral accelerations that can more accurately be obtained from the USGS program Seismic Hazard Curves and Uniform Hazard Response Spectra available in public domain at http://earthquake.usgs.gov. The USGS ground motion mapping program provides a convenient tool for obtaining the mapped spectral response parameters for any location based on an input zip code or coordinates (Geographic or UTM), and also includes maps which can be reviewed for independent verification. Several analysis options are available within the program based on the code being applied for the evaluation (NEHRP, Probabilistic Hazard Curves, ASCE 7, IBC, NFPA 5000). The spectral response accelerations from the USGS maps were created assuming attenuation relationships for soft rock and therefore require correction if the subsurface conditions are different from these assumptions. Evaluation of site-specific subsurface conditions is therefore required in order to properly account for attenuation or amplification of the ground motions indicated on the USGS maps. Building codes generally require preparation of a geotechnical report which forms a basis for the design for most structures.

Response Spectrum

The design response spectrum is dependent on the mapped ground motion parameter values (i.e. seismic setting of the site) and the seismic site class (subsurface conditions), and is plotted as a function of the structure period. The subsurface conditions at a given site are an important part of the seismic load evaluation since the level of attenuation/amplification of the ground motion is dependent on the soil or bedrock characteristics. It is therefore critical that the subsurface conditions at a given location are well-defined in order to develop a representative response spectrum for any site. The resulting spectra for different assumed site classes clearly demonstrate the importance of utilizing representative subsurface conditions for a given location. Once a response spectrum is developed for a given site, the dynamic response of a structure can be evaluated based on the period of vibration of the mode(s) being considered.

Structure Period

US building codes require that a structure's fundamental period utilized in seismic evaluation be based on properly substantiated analyses. An approximate formula for calculating the fundamental period of a building based on the height and structural system is presented in the code as[5,6]:

$$Ta=C_t.h^x \quad (1)$$

Where h is the height of the structure and Ct and x are constants based on the structural system. It is clear from reviewing the structural system categories that none of the above are a good match for wind turbines and, if the formula was to be applied, turbines would fall into the "all other structural systems" category. However, the building code indicates that Equation 5 is not recommended for non building structures per section 15.4.4 of ASCE 7- 05. Prowell and Veers [10], conducted a study of published first fundamental mode periods for various wind turbines with differing hub heights and correlated the data with Equation1.

Equivalent Lateral Force Procedure

Vibration characteristics of a structure can be evaluated by constructing a linear mathematical model taking into account all relevant modes of vibration each with their own characteristic modal mass, frequency and damping. The vibration characteristics can be modeled in the frequency domain and combined using appropriate methods to obtain representative response for the entire structure. The building codes include specifications for implementing simplified modal analysis using the Equivalent Lateral Force (ELF) Procedure. The ELF procedure is effectively an application of modal vibration analysis but limited to the first mode of vibration (i.e. assumes all the structure's mass is mobilized in the first vibration mode). The ELF procedure consists of applying an equivalent static lateral force to a linear mathematical model of a structure with magnitudes and direction representative of the dynamic loading from earthquakes. The structure is assumed to be fixed at the base for application of the ELF procedure [7].
The total seismic force applied to a structure in the ELF procedure is calculated in terms of a base shear. The seismic base shear is calculated as the product of a site-specific seismic response coefficient and the seismic weight of the structure. The seismic response coefficient is based on the design short period spectral acceleration (SDS) adjusted by a structure response modification factor (R) and an importance factor (I). The calculated base shear can then be distributed over the height of the structure in consideration of the story weights and heights as a representative model of the equivalent floor level forces from earthquake loading. The basic seismic base shear calculation formula is as follows:

$$V= C_sW \quad (2)$$

Where

$$C_s=SDS/(R/I) \quad (3)$$

V =Seismic Base Shear
W =Effective Seismic Weight
C_s =Seismic response Coefficient
R =Response Modification Factor
I =Importance Factor

The seismic response coefficient can be adjusted to account for the structure period and has upper and lower bound limits depending on the seismic setting of the structure being considered. The reader is referred to the building code documents for additional details and recommended adjustments to the seismic response coefficient.

Response Modification Factor (R)

The R factor is an empirical reduction factor that is intended to account for damping, overstrength and ductility in a structural system for displacements approaching the ultimate displacement of the structure. The R factor for brittle structures with very low damping would therefore be close to about 1, which represents no reduction in the linear response of the structure. Ductile systems with significant inherent damping would conversely be able to withstand relatively large deformations in excess of the yield point and are therefore assigned a larger reduction factor (up to 8 for special moment resisting frames).

Importance Factor (I)

Each structure is assigned an importance factor (I) based on the occupancy category. The importance factor relates a structure's occupancy to hazard to human life and economic impact in the event of failure, and/or emergency response requirements. Low risk structures (e.g. agricultural facilities) are assigned an importance factor of 1.0 while structures such as residential and office buildings, schools, churches and power stations that are deemed to represent a substantial hazard to human life in the event of failure are assigned a value of 1.25. Structures that are designated essential structures which include facilities required for emergency response following an earthquake (e.g. fire stations, hospitals with emergency rooms, air traffic control towers) are assigned the maximum importance factor of 1.5. The value of I selected for a structure impacts the calculated seismic base shear since it effectively reduces the response modification factor (ductility), thereby increasing the computed base shear if a value other than 1.0 is selected. [8,9].

FUTURE RESEARCH NEEDS

In order to better understand the seismic response of a wind turbine, several aspects require additional research and validation:

- Further measurement and testing of damping of the wind turbine system under parked and operational conditions.
- An investigation of directivity of aeroelastic damping and seismic excitation to determine possible implications on wind turbine vibration.
- Impact of soil-structure interaction in the seismic response of the foundation and wind turbine.
- A determination as to whether wind turbine systems are considered "essential structures" by the building code, and validation of the appropriate building code Response Modification Factor for wind turbines.
- Probabilistic analysis of the interaction between extreme wind and seismic events.
- Evaluation of post buckling behavior of tube towers.

CONCLUSIONS

Based on the above review, commonly utilized building codes do not appear to consider wind turbine systems in a truly comprehensive manner. Several conclusions can be drawn with regard to current practices and understanding of wind turbine seismic loading as summarized below:

- Current practice in assigning importance factors and occupancy categories to wind turbine generators is not consistent with similar structures such as single pedestal water towers, or of similar importance to the electrical grid, such as a conventional power plant.

- Combinations of loads prescribed by the IEC and other standards appear appropriate provided that aeroelastic damping is present.
- If aeroelastic damping is not present (i.e. a parked condition), standard building code procedures do not allow for an adjustment in damping ratios different from those observed in conventional building systems, and therefore cannot take the low level of damping of a parked turbine into consideration. More refined analysis would need to be conducted to take the lower damping ratios into account.
- Building code procedures do not account for directivity of seismic loading and may not predict representative loading if the direction of earthquake loading is not parallel to the wind loading direction, thus potentially skewing the seismic + wind load combinations.
- Most of thw areas determined for wind panel systems are in either Earthquake 1 and 2 regions. All of the design procedure of the wind panel construction projects should take Earthquake Loads into account.

REFERENCES

[1] ICC (2006). *International Building Code 2006.* International Code Council, Country Club Hills, Il, USA.

[2] American Society of Civil Engineers, (2006) Minimum Design Loads For Buildings and Other Structures ASCE 7-05.

[3] Building Seismic Safety Council/National Institute of Building Sciences (2004). NEHRP Recommended Provisions For Seismic Regulations For New Buildings and Other Structures (FEMA 450).

[4] International Electrotechnical Commission (2005) 61400-1 Ed. 3: Wind Turbines – Part 1: Design Requirements.

[5] Germanischer Lloyd (2003). *Guideline for the Certification of Wind Turbines*. Germanischer Lloyd, Hamburg, Germany.

[6] DNV/Risø National Laboratory (2001) *Guidelines for Design of Wind Turbines*, Second Edition, Wind Energy Department, Riso National Laboratory, Denmark.

[7] Witcher, D, "Seismic Analysis of Wind Turbines in the Time Domain" *Wind Energy*, 8, pp. 81-91, © 2004 John Wiley & Sons, Ltd.

[8] European Committee for Standardization (2003) Eurocode 8, Design of Structures for Earthquake Resistance, prEN1998-1:2003.

[9] Prowell, I., Veletzos, M., Elgamal, E. (2008) "Full Scale Testing for Investigation of Wind Turbine Seismic Response", unpublished.

[10] Prowell, I., Veers, P. (2009) "Assessment of Wind Turbine Seismic Risk: Existing Literature and Simple Study of Tower Moment Demand, Sandia National Report SAND2009-1100.

[11] The Regents of the University of California (2005), Pacific Earthquake Engineering Research Center: NGA Database.

[12] Edremitoglu, H., Toydemir, C. K., Baskan., (2009) "Economical, Environmental Outcomes of Wind Energy Production in Turkey", WORCESTER POLYTECHNIC INSTITUTE.