Statement of Company Experience In Wind-Turbine Structures

General Qualifications

Ensoft, Inc. dba Lymon C. Reese & Associates (LCR&A), was established in Austin, Texas, in 1985 with the principal aim of developing and applying computer-based solutions to complex engineering problems and has since built a strong reputation as a leader in this area. The principal and senior managers of Ensoft, Inc., who specialize in soil-structure interaction, full-scale loading tests, and instrumentation services for more than 30 years, have been invited to provide engineering consulting and design services around the world.

The firm has applied advanced technology, much of it based on recent research, in the writing of engineering software for the solution of complex problems that arise in geotechnical and structural engineering. Notable among Ensoft's computer programs are those that address the analysis and design of foundations, employing piles and drilled shafts in nonlinear soil strata. Over 5,000 companies, government agencies, and universities worldwide use Ensoft's software. The success and well-recognized reputation of this company is based on the quality of company's engineers and their unique knowledge and experience in deep foundations. LCR&A is the consulting department of Ensoft and provides the Wind Turbine Industry with a team of experienced professionals, dedicated to delivering expertise in the areas of geotechnical engineering and structural mechanics, with special reference to deep foundations.

Members of the firm have a close connection with the College of Engineering at The University of Texas. We are staying abreast of research being undertaken on many aspects of foundation design with the view of taking advantage of advances in practice to benefit the projects undertaken by the Wind-Turbine industry. In regard to research that will enhance the ability of the firm to design project that will perform in a superior manner and at lower cost. The firm has developed computer codes that take advantage of these new and improved methods; specifically, we have in-house computer programs to design a variety of reinforced-concrete members, retaining structures, foundations to sustain dynamic loads, foundations using new construction techniques, and supports for transmission towers.

LCR&A has positioned itself to respond very well to the needs of the wind-turbine industry, incorporating high-quality designs, frequently employing innovative techniques, keeping costs in mind and responding to specific requirements from various projects.

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SPECIAL QUALIFICATIONS

Members of the firm have had broad experience in the design, construction, and installation of remote-reading instrumentation systems for determining the performance of wind-turbine structures subjected to static and cyclic loads. Our involvement of many years in response measurements provided us with unique and extensive knowledge about the foundation structures for wind turbines.

UNIQUE FEATURES ON THE DESIGN OF WIND-TURBINE FOUNDATIONS

Features that are unique in the design of foundation structures for wind turbines are a special type of loading and the limitations on the movements/rotations of the foundation. Furthermore, there is usually no significant structural redundancy in the behavior of these foundations.

Many structures are subjected to wind loads but (1) wind causes a principal load on the wind-turbine structure; (2) the main portion of the wind load is applied at a considerable distance above the foundation; (3) the loading is repeated with varying magnitudes, and (4) engagement of emergency stops –due to high winds or other conditions– introduce significant design loads during wind storms. The wind produces a shear and a relatively large moment at the foundation, and the axial load due to the weight of the foundation is also significant.

Most offshore wind turbines are supported on deep foundations where piles may be subjected to tensile as well as compressive loading. In more competent soils and/or for lower loads the wind turbines at onshore locations are mostly supported on spread footings. If the piles are spread widely the load due to moment is reduced, the shear and axial load on the foundation are essentially unchanged, but the cost of the pile cap can be higher than closely-spaced piles.

If a shallow foundation is employed for the wind turbine, the design must address bearing capacity due to eccentric loading and must also consider the stiffness of the foundation. If the stiffness is weak, the rotation of the structure will be greater and could be unacceptable. Therefore, from the standpoints of both bearing capacity and settlement, the shallow foundation must have sufficient plan dimensions to yield an adequate factor of safety.

With the increase of the capacity and size of modern wind turbines, the design of their most suitable foundation becomes a challenging task. Modern analyses and designs for wind-turbine foundation structures must take into account concepts of soil-structure interaction that include the nonlinear behavior of the soil and rock strata.

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PROJECTS IN WIND-TURBINE FOUNDATION STRUCTURES

Structural and Geotechnical Design of Repaired Foundations for Mountain View I Wind Farm, Palm Springs, California (2012)

Owner: AES Wind Generation, Inc.

Completion: Ongoing in 2012

Project Description:

An older P&H Foundation system suffered damages due to loads arising from extreme occurrences of scour. LCR&A engineers evaluated and designed a strengthening system consisting of new drilled shafts and pile cap built around the existing foundation structure. The system is believed to provide safe response for the design life of the structure and at competitive costs when compared to the limited alternatives.

Services Provided:

1. Conducted soil-structure-interaction analysis for foundation behavior and dynamic stiffness;
2. Designed drilled shafts and pile cap along with detailing;
3. Provided final drawings for certification and construction permit;
4. Evaluated shop drawings and other engineering requests for construction; and
5. Provided field inspection and QA during construction (ongoing in June 2012).

Structural and Geotechnical Design of Drilled-Shaft Foundations for Mountain View IV Wind Farm, Palm Springs, California (2010-2011)

Owner: AES Wind Generation, Inc.

Completion: Late 2011

Project Description:

The Mountain View IV wind farm has a total of 49 Mitsubishi Heavy Industries (MHI) Model 1000A 1.0 MW generators with 60-m hub heights. The turbine towers were constructed on cylindrical steel monopoles supported by a unique foundation system with closely-spaced drilled shaft and tight pile cap.

The wind farm is located in Palm Springs, California, in an area that is subject to high seismic loading from the nearby San Andreas Fault Zone and severe scour (10 to 12 ft) due to the project location in a floodplain. The new drilled shaft foundation (under patent

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application) has unique features and special design to meet the performance requirement from the turbine manufacturer and the environmental challenges. The project involved a thorough design with specialized software products, including analysis of seismic loading, dynamic stiffness, soil-structure interaction, concrete and steel fatigue and drilled shaft capacity.

An evaluation of the actual response of this innovative foundation system is currently ongoing using specialized instrumentation that were placed in selected drilled shafts and pile caps.

Services Provided:

1. Conducted soil-structure-interaction analysis for foundation behavior and dynamic stiffness;
2. Designed drilled shafts and pile cap along with detailing;
3. Designed and installed instrumentation system for structural monitoring during operation;
4. Provided final drawings for certification and construction permit;
5. Evaluated of shop drawings and other engineering requests during construction; and
6. Provided field inspection and QA during construction.

Long-Term Foundation Monitoring for 3.0 MW Turbine Towers (105 M) at Snyder Wind Farm at Snyder, Texas (2008-2012)

Owner: Enel North America, Inc.

Completion: Ongoing in 2012

Project Description:

Developed an instrumentation system and monitoring program for the behavior of P&H Pier Foundations at the Snyder Wind Farm in Texas. Various types of sensors (including electronic displacement gauges, tilt meters, accelerometers, velocity transducers and resistance-type strain gauges) were installed on a total of 5 nominated turbine foundations during December 2008 and May 2009. Measurements from each of the electronic instruments are recorded automatically in the field and periodically transmitted to a server on the web performing data reduction and presentation through a wireless network system. The interpreted measurements are easily available on a secured internet server so LCR&A engineers and clients can make observations of the automatically-collected data.

Services Provided:

1. Design, evaluation and update of the performance of the instrumentation system;
2. Collection and interpretation of field measurements,

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3. Provision of quarterly reporting related to the measured performance of the foundations,
4. Provision of field inspections and recommendations.

Investigation of Cracks in Foundation Soils for 1.8 MW Turbines at Buffalo Gap Wind Farm, Taylor County, Texas (2008)

Owner: Buffalo Gap Wind Farm, LLC

Completion: 2008

Project Description:

Studied and investigated the performance of the as-built Patrick & Henderson (P&H) pier foundations at Buffalo Gap Wind Project, Taylor County, Texas. The wind farm comprises of 67 Vestas V-80 1.8 MW wind turbines. The hub height of the wind turbine is 256 ft (78 m) and the diameter of the tubular tower at the foundation level is 12.1 ft (3.692 m). Each wind turbine is supported by a single P&H pier, which was installed by P&H in 2005. Circumferential cracks were found in the soil near the perimeter of the P&H pier foundations at the Buffalo Gap Wind Farm. According to subsequent field inspections, the openings of the circumferential cracks in the soil around the perimeter of the concrete piers were plainly noticeable during operation at several P&H pier foundations at this site.

Services Provided:

1. Review the existing geotechnical information, loading data, and original documents pertaining to foundation design;
2. Identify possible causes for the observed excess movements on some foundations;
3. Study long-term effects on the foundation stiffness due to the degradation at high strain level of the foundation soil under cyclic loads;
4. Conduct field inspections and provide recommendations on remedy plans for foundations.

Review of Foundation Design for V90 80-Meter Wind Turbines, Fermeuse, Newfoundland (2008)

Lymon C. Reese and Associates, Inc. (LCR&A) was asked by Sigma Energy Solutions in New York to review the foundation design for V90 wind turbines, which consists of an octagonal concrete base with a cylindrical central pedestal. The central pedestal has an outer diameter of 4.8 m and a height of 1.1 m. The width of the octagonal concrete base is 17 m. The proposed development for the site consists of nine (9) wind turbines and one substation.

Services Provided:

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1. Critical review of geotechnical report to extract data needed for the analyses to be performed.
2. Selection of parameters describing the properties of the soil needed in the computations. A significant number of parameters describing the soil are needed, including the properties related to the shear strength of the soil, the unit weight, information related to settlement and the expected position of the water table during the life of the structure.
3. Computation of the bearing capacity of the foundation under both service and maximum loads.
4. Computation of the lateral resistance against the foundation using both service and maximum loads.
5. Computation of the rotation of the structure due to the wind load. The short-term stiffness of the soil must be estimated on the basis of the available data. Gapping between the foundations and the soils should not be developed during operation. Any potential deterioration in the contact surface due to gapping was investigated.
6. Computation of the settlement of the foundation under long-term loading. The settlement might be caused by the ejection of water from the soil due to vertical loading and to the possible re-orientation of the grains of soil.

Review of Two P&H Pier Foundations for SMUD Wind Energy Project at Solano County, CA (2008)

The P&H pier foundation typically consists of a large diameter, cast-in-place reinforced-concrete pier with an outside diameter of 13 to 18 ft and the inside diameter of 10 to 14 ft. The length-to-diameter ratio typically is 2 to 4. Therefore the behavior of this type of foundations is not similar to those of the traditional deep foundations. One unique characteristic of this type of foundation is that the rotation of the foundation may generate significant resistance from the soil against the overturning moment. This rotation may lead to the soil cracking at the interface between soil backfill and the undisturbed soil at the edge of the original foundation excavation. Sigma Energy Solution (SES) retained Lymon C. Reese and Associates, Inc. (LCR&A) in Austin, Texas to review the measured field data and the original design of foundations for evaluation of the serviceability of the foundations.

Services Provided:

1. Critical Review of Selected Soil Parameters.
2. Evaluation of Deflection and Rotation under Extreme Loads and Service Loads for V-90 Foundations
3. Investigation of Stress-Distribution by Using 3-D Finite-Element Model.

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4. Stability Study Under Extreme Loads.

Review of P&H Pier Foundations at Snyder Wind Farm, Texas (2007)

Sigma Energy Solution (SES) retained Lymon C. Reese and Associates, Inc. (LCR&A) in Austin, Texas to review the design documents and the geotechnical investigation report for P&H Pier Foundations at Snyder Wind Farm, Texas. The focus of this review is on professional opinions regarding the validation of modification factors applied by the designer on P&H piers, which in general have an outside diameter ranging from 14 ft to 18 ft.

Services Provided:

1. Critical Review of Representative Soil Strength Parameters based on the Geotechnical Investigation Report.
2. Comments on Scaling Factors in LPILE (Beam-Column Model) Analysis.
3. Model Including Tip Resistance and Side Friction for Large Piers.
4. Stability Study Under Extreme Loads.

Review of P&H Pier Foundations at Crescent Ridge, Illinois (2005)

Earth Systems Southwest (ESSW) retained Lymon C. Reese and Associates, Inc. (LCR&A) in Austin, Texas to provide professional opinions regarding the safety factor and its relationship with the appropriate design strength selected for the soil. The focus of this review is on the validation of modification factors applied by the designer on P&H piers.

Services Provided:

1. Critical Review of Representative Soil Strength Parameters based on the UU Triaxial Tests.
2. Comments on Reasonable Factor of Safety under Extreme Loads.
3. Size Effects on Soil Lateral Resistance (p-y curves).
4. Comments on Remediation Plan on Foundation.

Review of P&H Pier Foundations at Crescent Ridge Wind Farm, Tiskalwa, Illinois (2004)

Lymon C. Reese and Associates, Inc. (LCR&A) was retained by Eurus as the third-party reviewer in resolving outstanding issues between the foundation designer, Earth System Southwest (ESSW), Patrick & Henderson (P&H), and the bank's engineer – Garrad Hassan (GHA) with respect to the engineering design for the wind turbine foundations at Crescent

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Ridge Wind Farm, Tiskalwa, Illinois. The focus of this review is regarding to the methodology applied by the designer on P&H piers.

Services Provided:

1. The Acceptable Factor of Safety for Overturning Stability.
2. The Method Selected for Estimation of Rotational Stiffness.
3. The Effectiveness of the Bottom 2 feet of the Plain Concrete Section to Resist Moment.

Summary Comments on Wind-Turbine Projects

LCR&A treated each one of these projects in a manner that achieves the highest quality of design, bringing to bear the years of education and experience of members of the firm, taking advantage of applicable innovations reported in technical literature, designing to ensure constructability and always being aware of the necessity of keeping cost down. Furthermore, LCR&A has also been aware of the need of maintaining good environmental quality in each design.

Wind-Turbine-Related Publications and References

Rogers, M., Ntambakwa, E., Wang, S.T. and Crook, T., "Application of Drilled Shaft Foundations for Utility Scale Wind Turbines in a High Seismic Environment," 2012 ASCE Geo-Congress, Oakland, California, March 25-29, 2012.

Reese, L.C. and Wang, S-T, "Design of Foundations for a Wind Turbine Employing Modern Principles," ASCE Geotechnical Special Publication No. 180 – From Research to Practice in Geotechnical Engineering, edited by Laier J., Crapps D., and Hussein, M. 2008, pp. 351-365

DNV, "Guidelines for Design of Wind Turbines," published by DNV/Riso in Technical Cooperation, Denmark 2001, pp.193-200 (Pile-Supported Foundations partially from Ensoft Manuals).

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