Engineering Design for an Offshore Wind Turbine Farm

Project Background

This project centers on the engineering design for the construction of a 180-megawatt offshore wind turbine farm and operations facility in a south-central region of the USA. The purpose of the project is to provide low-cost, renewable energy to help local utilities and their customers reach their carbon emission reduction goals and diversify their generation portfolio.

A Request for Proposals (RFP) provided by a university-based energy research institute included several key engineering services components:

- Approximately 12 wind turbines (enough to reach 180 MW).
- A collector system, transmission substation, and transmission line to connect and convert the electrical output of the wind turbines to the high-voltage transmission grid.
- A LEED Gold Certified wind farm power monitoring and teaching facility.
- Site improvements for the new facility including walkways, driveways, parking, underground power and data lines, and other site amenities.

The total budget for all activities associated with the project is $700,000,000.

A team of five students responded to the RFP with a formal engineering proposal. Study emphasis of the student team spanned construction management, structural engineering, geotechnical engineering, and environmental engineering. The students were mentored by five licensed engineers during the process with expertise in the noted engineering areas. Additional guidance was provided by three class instructors, all of whom were licensed engineers.

Existing Substation and Land Area (top right) and Wind Farm Lease Blocks (bottom left).

Preliminary Design

The team was faced with multiple constraints in their approach to this project. In particular, the client desired to reduce the Levelized Cost of Energy (LCOE); meaning the design must be as cost efficient as possible without reducing integrity of the system. The team developed three alternative design options for the client to consider. Conceptual designs were created for each, using three-dimensional Computer Aided Design (CAD) models. An opinion of probable cost was calculated for each alternative and projected operating expenses and revenues were developed.

The team created a slide show that illustrates the designs and the pros and cons of each option. The presentation included a decision matrix that reflects the client's priorities. It was presented to a panel of judges that included engineers, research scientists, and members of the public.

Design Alternatives

Two offshore lease blocks, the wind turbine type, and the location of the onshore substation were previously selected by the client. Each turbine operates at a hub height of 150 meters with a rotor diameter of 240 meters. The turbines are based on the IEA Wind TCP Task Force's definition of the 15-MW reference turbines. The two lease blocks are located 24.85 miles offshore. Additional analysis was required by the student team to optimize the location of the wind turbines to minimize wake loss and cable length.

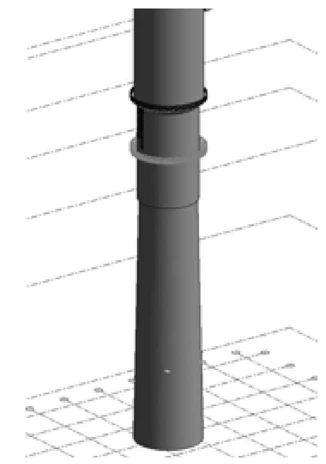
Three alternative design concepts were developed by the team. All three designs included an operations and maintenance facility with differing approaches for the offshore subsurface system. Each alternative was analyzed with respect to structural, environmental, geotechnical, and construction engineering considerations.

The first alternative considered was a gravity-based foundation (GCF). This would be designed from precast concrete with steel reinforcements and is suitable for sites with depths of up to 30 meters.

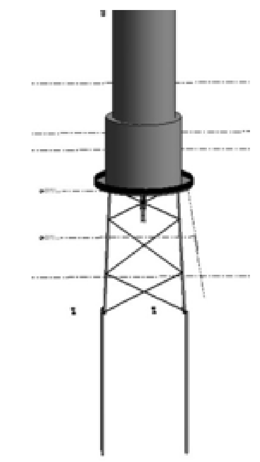
The second alternative considered was a monopile foundation. This would be designed as a long, single slender steel member typically installed at a water depth of 10 to 25 meters.

The third alternative considered was a jacket foundation. This would be designed as a lattice-truss structure that can be installed using piles or suction caissons typically installed in depths of 30 to 35 meters.

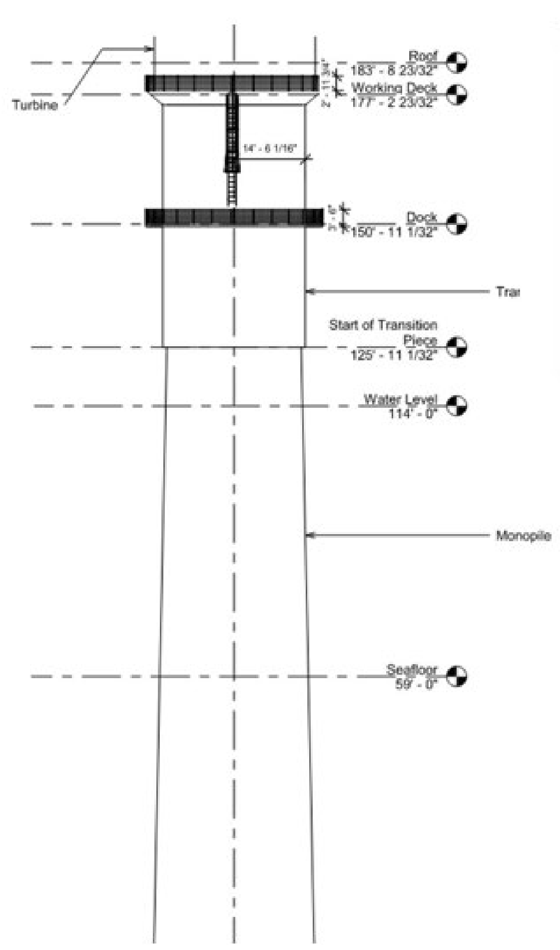
Alternative 1: Gravity Base



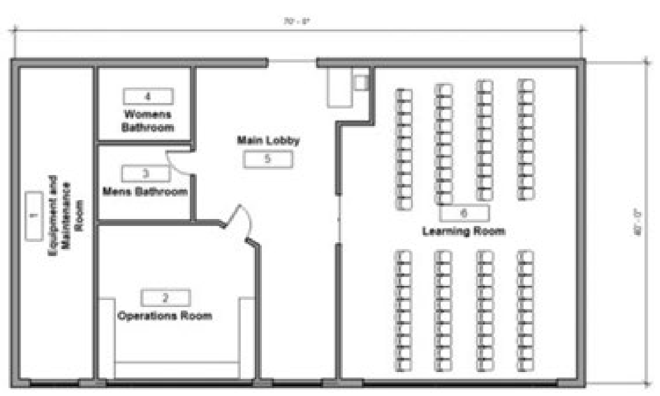
Alternative 2: Monopile



Alternative 3: Jacket



Final Design of Alternative 2: Monopile Foundation



Plan View of O&M Building

Evaluating the Design Alternatives

An evaluation matrix was developed to quantify the merits of each design alternative. The factors that were evaluated included environmental sustainability, social sustainability, economic sustainability, the project schedule, and the team's opinion of probable cost.

Offshore wind energy, while having existed since 1991, is a new industry in the USA. As such, the student team was also challenged to identify the various sources of uncertainty for the site evaluations and the preliminary design. These included data-based uncertainty, knowledge-based uncertainty, uncertainty in the estimate of probable cost, and the importance of uncertainty in design.

The student team ultimately recommended Alternative 2, the monopile foundation, as the best option to meet the client's goals. This foundation will achieve the lowest estimated cost and a longer lifespan without having to sacrifice structural integrity.

Criteria	Goal	Weight	Alternative 1	Alternative 2	Alternative 3
Approximate Construction Cost [$]	Min	23%	684,000,000	682,000,000	727,000,000
Transportation Cost [$]	Min	19%	64,320,000	50,400,000	105,600,000
Installation Time [weeks]	Min	21%	13.7	8.9	18.9
Impact of Benthic Habitat [ft^2]	Min	13%	415.5	70	12.5
Depth of Foundation Embedment [m]	Min	16%	3.5	28	23.5
30 m Sound Pressure Level	Min	8%	128	112	94
Total		100%	32.54%	**35.50%**	31.96%

Decision Matrix for All Three Alternatives

Final Design

With the client's approval, the team proceeded with the final design. Their work product includes a geotechnical report, verification of compliance with applicable codes, structural calculations, drawings, and specifications. The Moment Foundation Analysis and Design (MFAD) software package was used for the foundation analysis. Specifications included bid forms, terms and conditions, and technical sections for key project elements. A student serving as the project manager tracked and coordinated the team's effort and project schedule.

A formal presentation of the final design was made to the client and a panel of judges. The entire student team participated and explained the details of their design and the considerations used in establishing final configuration. A projected construction schedule and final opinion of probable cost were delivered. Copies of the plans, specifications, and a project manual were included in the presentation materials.

This successful design project presented the students with a real-world, open-ended, multidisciplinary project that pushed them to creatively problem solve while employing civil engineering best practices.

Final design of the operations and teaching facility.