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Energo Project No.: E08147

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Mineral Management Service
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Subject: MMS TA&R Project 627 – Inspection Methodologies for Offshore Wind Turbine Facilities – Final Report

Dear Lori:

The following is our Final Report documenting the development of the Offshore Wind Turbine Inspection Guidelines (attached). This revision includes modifications based on comments received at our final meeting on January 27.

This report and attached guidelines are the final deliverables for this project along with the management summary presentation delivered on the 27th.

Please let us know if you have any questions or comments.

Sincerely,
Energo Engineering, Inc.

A handwritten signature in blue ink, appearing to read "R. Sheppard".

Robert Sheppard, P.E.
Principal Consultant

A handwritten signature in black ink, appearing to read "Frank J. Puskar".

Frank Puskar, P.E.
Principal Investigator

TABLE OF CONTENTS

Executive Summary	3
1.0 Development Approach	4
2.0 Survey of Existing Data	4
3.0 Subject Matter Expert Input	11
4.0 Recommended Inspection Guidelines	12
5.0 References	12

Attachment A – Inspection Guidelines for Offshore Wind Turbine Facilities

EXECUTIVE SUMMARY

With the expected introduction of wind turbine facilities for the generation of electricity in US Offshore Continental Shelf (OCS) waters, there is a need to evaluate how the long term operations of these facilities can be ensured through Integrity Management (IM) activities, particularly inspection. There is a long operational history of IM in the Gulf of Mexico, offshore California, offshore Alaska and around the world for fixed and floating oil and gas platforms for drilling and production. Both prescriptive and Risk-Based Inspection (RBI) programs have been implemented to direct inspection operations for these facilities. This experience provides a foundation for developing inspection guidelines for offshore wind turbine structures and systems.

Current offshore practice is to use prescriptive or risk-based methodologies for inspections of both above and below water components. The latter is now allowed under new Code of Federal Regulations (CFR) language and has been used for both fixed and floating assets. While still evolving, the process of developing these inspection programs has worked successfully for offshore platforms and can be applied to wind turbine facilities.

This report documents the development of an IM methodology, including inspection and monitoring, for wind turbine structures operating in the US OCS. The approach combines existing methodologies used for wind turbine structures in other regions, current practice for fixed platform structures, and input from a panel of industry experts focused on evaluating specific parts of the wind turbine facility.

Attached to this report are inspection guidelines developed following the approach documented herein. These guidelines identify inspection priorities, inspection frequencies, data management and other factors necessary for implementing an efficient and effective inspection program for offshore wind turbine facilities.

1.0 DEVELOPMENT APPROACH

The development of the inspection guidelines was divided into three tasks:

1. Survey of Existing Data
2. Subject Matter Expert Input
3. Recommended Inspection Guidelines

The concept was to integrate the extensive experience of both above and below water inspection of offshore oil and gas platforms, especially in the Gulf of Mexico, with inspection practices that are unique to wind turbine facilities both in the US and in other parts of the world where these turbines are already operating offshore.

Part of the initial task was to gather data on the range of technologies incorporated in wind turbine facilities both onshore and offshore. Evaluation of existing regulatory and industry practice for inspecting these facilities was a useful guide to framing the guidelines being developed.

This initial framework was then augmented using input from industry experts familiar with the design and operation of wind turbine facilities. This expertise highlighted critical inspection locations and identified practical inspection realities (e.g., what can be accessed and how can areas be inspected) important to developing a useful set of guidelines.

This combination of established offshore inspection practice with the unique aspects of wind turbine facilities resulted in a set of inspection guidelines that can be used to effectively monitor the condition and proactively address anomalies that may occur during the service life of these facilities.

2.0 SURVEY OF EXISTING DATA

This task focused on a literature search and a survey of existing guidelines and regulations currently used for inspecting the structural and mechanical systems involved in the wind turbine facilities. Part of this effort included attending the 2008 Windpower conference held in Houston in early June. The conference proved a useful place to gather data on the wind industry in general, offshore specific information related to areas of concern and research (e.g., design parameters and seabed scour), and identify key players for inclusion in the expert panel.

2.1 Wind Turbine Facility Technology

A combination of data gathered at the conference and data obtained via the internet or through purchasing publications was evaluated to develop an understanding of important areas related to inspection and current industry practice.

As to the technology currently employed to install wind turbine facilities offshore, they are, from the tower structure and above, much the same as wind turbine facilities onshore. The

supporting substructure and subsea equipment are where the primary differences occur. Figures 2.1 and 2.2 show the various parts of typical offshore wind turbine facilities that are likely to be installed offshore in US waters.

The facilities can be divided into specific areas from a structural integrity management standpoint: subsea structure, subsea equipment, above water structure, above water equipment, and blades. The subsea structure supports the tower, turbine, blades and other equipment and is generally piled into the seafloor. Subsea equipment generally consists of cables and j-tubes or other structure to protect the cables, buried cables between facilities or to the shore, junction boxes and other equipment. The above water structure consists of the tower structure mounted on the subsea structure and the nacelle which houses the turbine and other equipment, and may include a helicopter abseil platform. Cables/J-tubes run up the tower to the nacelle. The blades are attached to the turbine equipment outboard of the nacelle. Access systems include boat landings, stairs, platforms, handrails, etc.

Existing installations favor the monopile subsea support system though there are design concepts that use a more traditional braced frame jacket support system. In either case, these subsea systems are similar to designs used for offshore oil and gas platforms and experience from that industry is directly applicable.

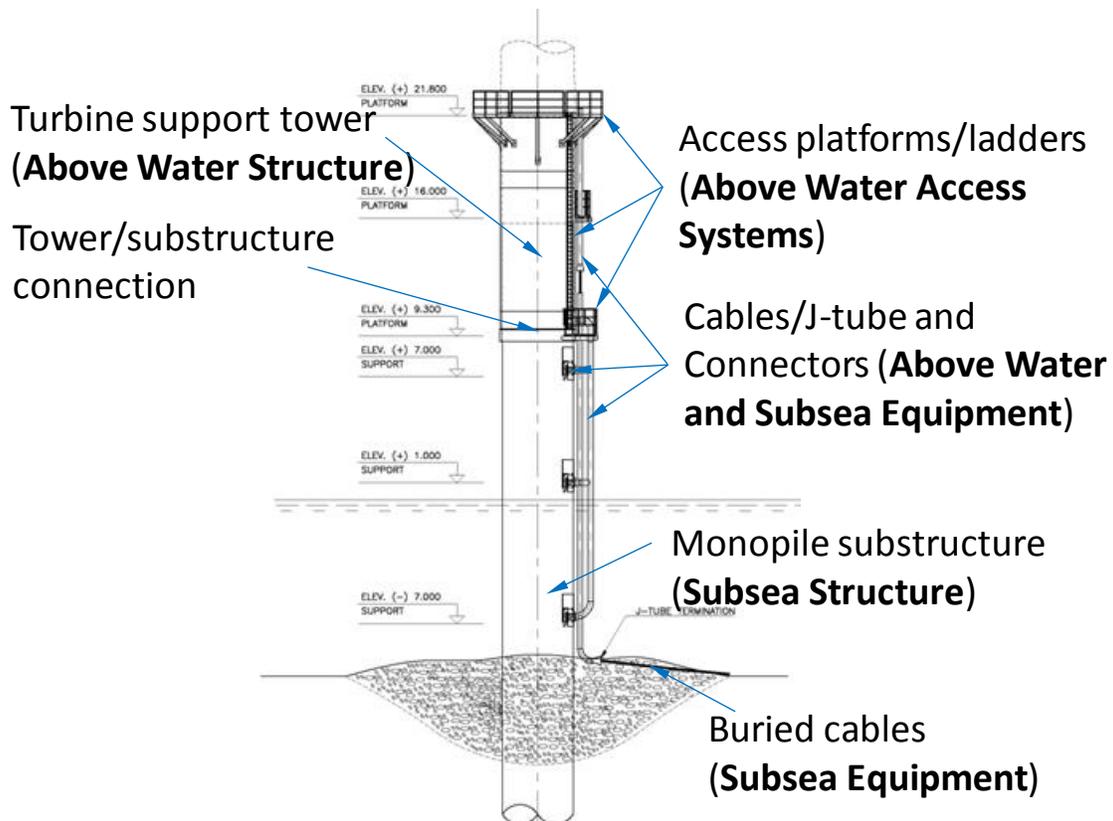


Figure 2.1 – Typical Offshore Facility from Mudline to Tower Structure

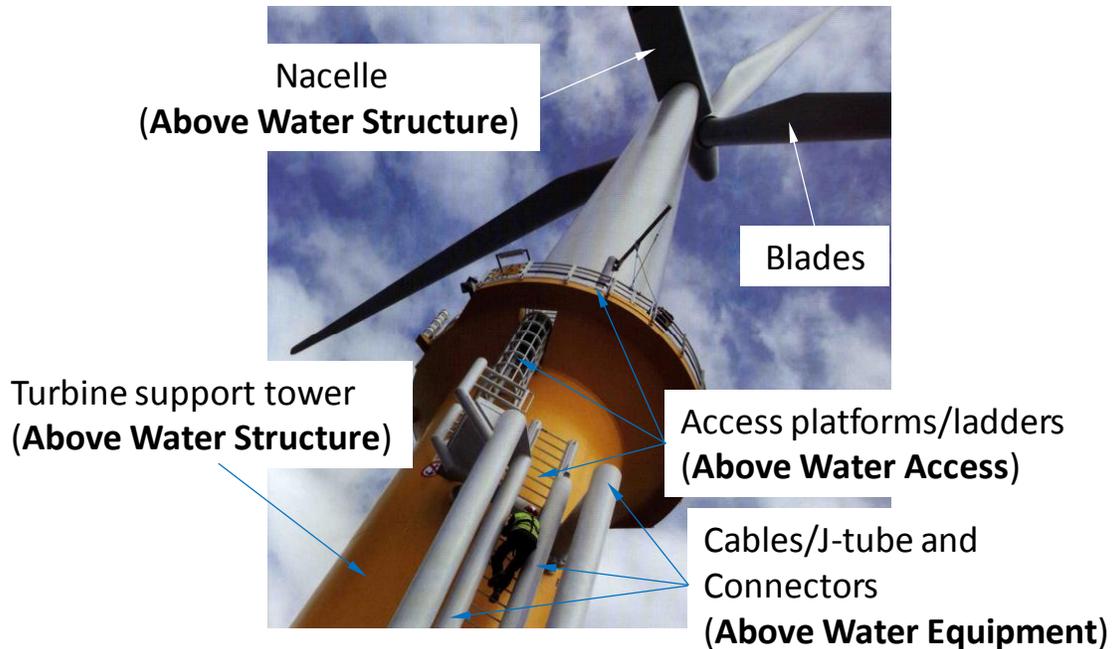


Figure 2.2 – Typical Offshore Facility from Tower Structure to Blades

A range of generation capacity is available for each turbine, from a few kilowatts to several megawatts per facility. It is expected that units in the megawatt generating capacity will be used primarily for most significant offshore wind farms to maximize their power generation capacity. Regardless of the capacity of the generation equipment, all the previously discussed parts of the facility are required.

Of particular interest is how blades respond to an offshore environment and what degradations affect them. Figures 2.3 through 2.5 demonstrate the kind of mechanisms that affect blades leading to erosion and other blade damage that should be identified as part of an inspection program.



Figure 2.3 – Leading Edge Erosion



Figure 2.4 – Severe Blade Damage and Delamination



Figure 2.5 – Lightning Damage to Blade

For multiple unit wind farms it is expected that there will be a service platform to which all the turbines will send their generated electricity. From there, equipment and cables will send the power to shore-based equipment. These service platforms will be similar to existing offshore oil and gas platforms and their inspection requirements will likely be addressed via the same guidelines used for those facilities (e.g., API RP 2A [Ref. 7]).

2.2 Offshore Oil and Gas Industry

Because of similarities of design and materials, it is expected that experience with offshore oil and gas facilities will be directly applicable to especially the subsea portion of offshore wind turbine facilities. In US waters there is significant operational experience for Gulf of Mexico structures but also for platforms offshore the West Coast and Alaska.

Issues such as corrosion, fatigue, mechanical damage (e.g., from dropped objects and vessel impact), and structural response to extreme events (e.g., hurricanes) is fairly well understood. Guidance found in API RP 2A and 2-SIM is directly applicable for the supporting structures of wind turbine facilities.

The following figures show examples of the kind of damage and anomalies found in offshore oil and gas structures that can be expected for wind turbine facilities as well. In Figure 2.6 the kind of cracking that can occur due to fatigue damage is shown (along with typical marine growth prevalent in shallower portions of the submerged structure). Inspections of subsea structure are intended to locate these kinds of issues so that remedial action can be taken before the joint fails and the structural strength is compromised.

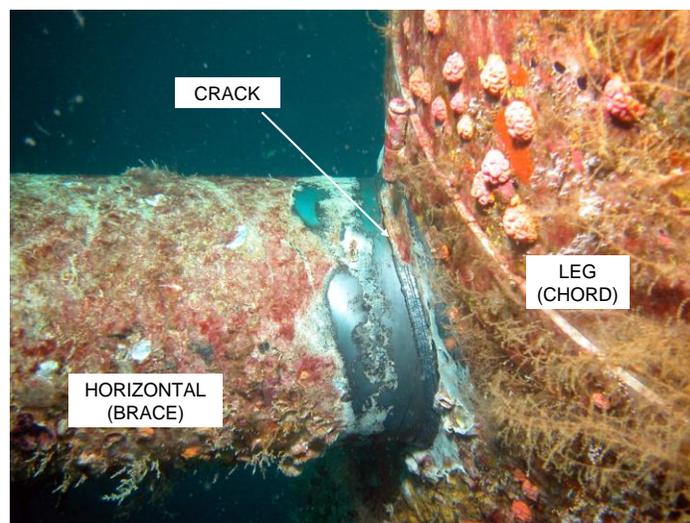


Figure 2.6 – Typical Fatigue Crack at Welded Connection



Figure 2.7 – Typical Separated Brace

Figure 2.7 shows a typical subsea k-brace that has separated from the main horizontal member. This is typical of storm damage at a vertical brace and would be identified by a post-event inspection.

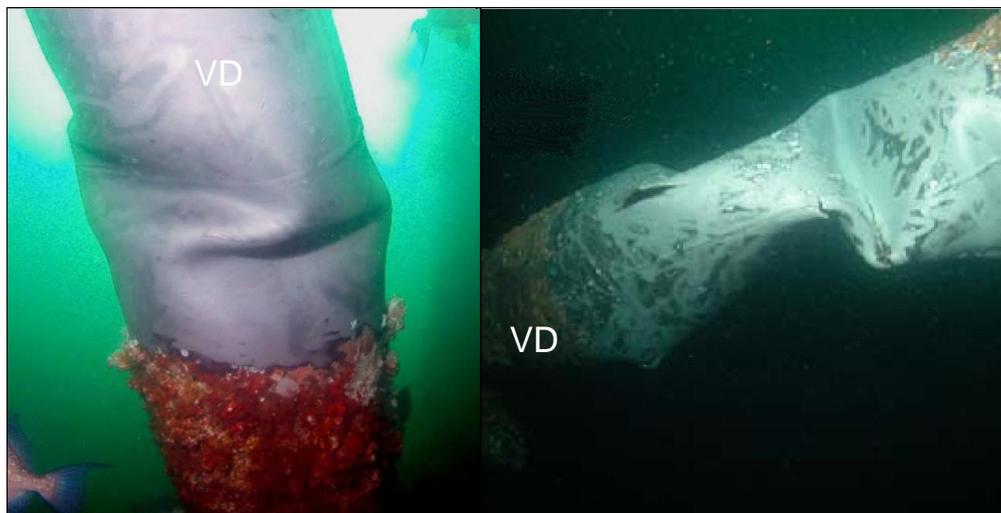


Figure 2.8 – Buckled Braces

The strength of environmental forces is demonstrated in Figure 2.8. This figure shows two different vertical braces that have been buckled by storm loads. Post-event inspections should identify these kinds of issues.

In Figure 2.9 a hole caused by corrosion damage can be seen. Properly maintained cathodic protection systems do a good job of preventing corrosion damage underwater, but the

topsides structures depend on properly maintained coating systems. In the splash zone near the water line that is constantly wetted and dried by waves and spray, coating systems are challenged. Corrosion is the most prevalent topsides degradation that can be identified via inspection programs. Figure 2.10 shows what can happen when maintenance is ignored for an extended period and corrosion is allowed to spread.



Figure 2.9 – Typical Corrosion Damage (especially in splash zone)



Figure 2.10 – Extensive Corrosion Damage

2.3 Classification Societies

Various Classification Societies are developing or have developed guidelines or rules related to onshore and offshore wind turbine facilities. The American Bureau of Shipping (ABS) is in the process of developing guidelines and have a representative on the panel of experts involved in this project. Other guides and standards reviewed were developed by Det Norske Veritas (DNV), Germanischer Lloyd (GL), and the International Electrotechnical Commission (IEC).

Two DNV documents were obtained: DNV-OS-J101, Design of Offshore Wind Turbine Structures and DNV-OS-J102, Design and Manufacture of Wind Turbine Blades, Offshore and Onshore Wind Turbines. Together, these documents provided an overview of design parameters recommended for wind turbine facilities, including those to be installed offshore, as well as guidance on inspection intervals, techniques and areas to inspect.

Three GL documents were obtained: Guideline for the Certification of Wind Turbines, Guideline for the Certification of Offshore Wind Turbines, and Guideline for the Certification of Condition Monitoring Systems for Wind Turbines. These documents provide guidance from a second classification society on the design and ongoing monitoring of wind turbine facilities, including specific guidance for offshore installations. The GL documents were more focused on maintenance of the equipment systems rather than integrity of the structures.

The IEC document, IEC 61400-3, Ed. 1, Design requirements for offshore wind turbines, was also reviewed. While this document does not contain specific guidance on ongoing inspections (though it does contain some general information), it does have useful information on the design parameters to be addressed which is useful in identifying important degradation mechanisms and in-service events.

These documents provided both background data on the systems to be included in the inspection guidelines and information on current inspection practices including frequency of inspection and inspection techniques.

3.0 SUBJECT MATTER EXPERT INPUT

In order to expand on information available from Task 1, a panel of subject matter experts was solicited to provide input from their own perspective on the wind turbine industry. The panelists volunteered their time in this effort. The panel includes:

Sandy Butterfield	Chief Engineer	National Renewable Energy Laboratory
Walt Musual	Principal Engineer	National Renewable Energy Laboratory
Jim Manwell	Professor & Director of RERL	University of Massachusetts
Gary Kanaby	Director of Business Development	Knight & Carver Wind Group
Dr. Roger Basu	Director, Research & Product Devel.	American Bureau of Shipping
Dr. Malcolm Sharples	President	Offshore Risk and Technology
Morten Andersen	Senior Engineer	DNV Global Energy Concepts

All panelists were provided with a survey to solicit specific feedback in the following areas:

- critical inspection areas for all parts of the facility,
- inspection frequencies,
- inspection techniques,
- regional variations,
- other data sources and
- post-event inspections.

These surveys were seeded with data gathered from the Task 1 results to prompt their feedback. This was intended to make the best use of their time and focus their efforts. Additionally, the panelists were provided with an outline of the guideline document so they could comment on the layout and content of the final document.

The input from the panelists was then used to take the guideline outline and expand it into the inspection guidelines attached to this report. Further, the panelists were asked to provide further review and comments on the draft guidelines before they were finalized.

4.0 RECOMMENDED INSPECTION GUIDELINES

Information from the data survey and the expert panel was used to develop the inspection guideline document. This document provides data to guide an operator through the process of developing an inspection program for their offshore wind turbine assets from the standpoint of structural integrity. It also provides guidance on overall integrity management including data collection and interpretation, and response to anomalous conditions and events (e.g., hurricanes).

The guidelines have been organized in the form of other guideline documents used for integrity management programs for offshore facilities. They are included in this report as an attachment since they are presented in a standalone document format.

5.0 REFERENCES

1. DNV-OS-J101, *Design of Offshore Wind Turbine Structures*
2. DNV-OS-J102, *Design and Manufacture of Wind Turbine Blades, Offshore and Onshore Wind Turbines*
3. GL Wind 2003, *Guideline for the Certification of Wind Turbines*, Edition 2003.
4. GL Wind 2005, *Guideline for the Certification of Offshore Wind Turbines*, Edition 2005.
5. GL 2007, *Guideline for the Certification of Condition Monitoring Systems for Wind Turbines*, Edition 2007.
6. IEC 61400-3, Ed. 1, *Design requirements for offshore wind turbines*
7. API Recommended Practice 2A, RP-2A, *Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms*, 21st Edition.
8. ISO 19902, Petroleum and Natural Gas Industries, Fixed Steel Offshore Structures.

Attachment A

Inspection Guidelines for Offshore Wind Turbine Facilities

Table of Contents

Acronyms, Abbreviations and Definitions	2
I. Overview and Scope	4
II. Frequency of Inspections	4
III. Subsea Structure	5
IV. Subsea Equipment	8
V. Above Water Structural and Access Systems	9
VI. Above Water Electrical and Mechanical Systems	10
VII. Blades.....	11
VIII. Post-Event Inspections.....	12
IX. Engineering Evaluation.....	13
X. Data Requirements.....	13
XI. Regional Variations	14

Appendix A: Sample checklists and data reporting

Acronyms, Abbreviations and Definitions

CP	Cathodic Protection
CVI	Close Visual Inspection
GVI	General Visual Inspection
MMS	Minerals Management Service
MPI	Magnetic Particle Inspection
NDE	Non-destructive Examination
NDT	Non-destructive Testing
OSTS	Office of Structural and Technical Support
ROV	Remotely Operated Vehicle
RVI	Remote Visual Inspection
UT	Ultrasonic Testing

Anomaly: An observed or measured condition which is outside the threshold considered acceptable from the design or most recent fitness-for-purpose assessment.

Condition Assessment: Information that should be gathered on the facility's present condition to perform a fitness-for-purpose assessment.

Corrosion: A component defect categorized as either general or local that manifests itself as either pitting, hole, fretting and/or crevice.

CP measurement: A measurement to determine the effectiveness of the CP system by measuring the cathodic potential at a location typically using a probe held by a diver or ROV system or using a drop cell device from above water.

Defect: An imperfection, fault, flaw or blemish in a component that can include mechanical damage, corrosion and weld defects.

Design Life: The planned time period from initial installation or use until permanent decommissioning.

Deterioration: The reduction in the ability of a component to provide its intended purpose.

Extreme Event: An extreme metocean, seismic and/or ice condition, which a structure may be subjected to during its operational life.

Fitness-For-Purpose: An existing structure is considered fit-for-purpose if it can be demonstrated that it has adequate strength to resist the imposed assessment loads (functional, metocean, seismic and/or ice).

Inspection: The visit to the facility for purposes of collecting data important to its structural integrity and continued operation.

Mechanical damage: A defect type that includes dents, bows, gouges, holes and separated or severed members.

Mitigation: Strengthening, modification or repairs and/or operational procedures that reduce loads or increase capacities.

Mudline: The sea floor.

Nacelle: The structure that houses the generating components, gearbox, drive train, etc. of a wind turbine facility.

OCS: Outer Continental Shelf, a term used primarily in the U.S. for the offshore areas under federal jurisdiction.

Operator: Those employed by the Owners to conduct operations.

Owner: A party who owns physical infrastructure assets and/or a party who owns capacity rights in those physical assets but does not own the asset itself.

Prior Exposure: The historical exposure of a facility to the design metocean, seismic or ice loading.

Repair: The work necessary to restore a facility to a condition deemed fit-for-purpose.

Risk-Based Inspection: The development of inspection strategies based an assessment of the facility's risk.

Splash Zone: The area of the structure that is intermittently wet and dry due to wave and tidal action.

Survey: A specific visual or non-destructive examination of one or more components. Collectively, the surveys make up the complete inspection.

I. Overview and Scope

These guidelines provide a framework for developing and implementing an in-service inspection program for offshore wind turbine facilities either as individual installations or as a group of turbines making up a wind farm facility. Specific inspection plans should be developed based on these guidelines by a qualified engineer, and these plans should be implemented by qualified personnel with adequate training and equipment for the defined inspection tasks.

The scope of these guidelines encompasses the structural integrity of the support structure (above and below water), blades and nacelles (including any helicopter abseil platforms), appurtenances, cables and access structures such as walkways, stairways and platforms. Normal maintenance items such as keeping walkways clear, as well as signage and safety-related items are not part of this scope though inspectors are encouraged to report any issues in these areas to the responsible parties. Also, inspections conducted according to individual manufacturer's specifications are not part of the scope of this document.

This document is divided into sections corresponding to specific areas of the facility containing data on critical inspection areas, inspection frequencies, inspection techniques and other guidance. There is also information on data gathering and retention guidelines as well as regional variations to consider.

II. Frequency of Inspections

Within the following sections reference is made to various inspection cycles: annual, three to five year cycle, etc. When a range is given, it is intended that the engineer responsible for developing the inspection program consider the following when determining where within that cycle the inspection should be scheduled:

Condition: As a facility ages its condition will change as degradation mechanisms affect the various structural systems (e.g., corrosion, marine growth), and modifications are made to the structure (e.g., new walkways, damage repairs). An accurate assessment of the current condition of the facility is necessary to define how often various inspection activities need to occur. If the operation of a facility has shown that corrosion is a problem or scour is a concern, then it is prudent to have a more frequent inspection cycle than a facility with more benign conditions or where historically there have been no issues.

Consequence of failure: Some units may be installed near shipping lanes or near environmentally sensitive locations. It is not anticipated that these units will be manned, so factors such as personnel safety will not typically affect the consequence of structural failure. However, impacts on other activities in the surrounding waters should be considered. Consequence of failure levels should be considered when defining inspection intervals for facilities, with greater

frequency of inspection given to those facilities with higher consequence of failure.

The following table (Table II.1) contains an overview of the suggested inspection cycles for different parts of the offshore wind turbine facilities. These cycles and the inspections are described in more detail in the following sections. Note that Annual Inspections are required even in years when Intermediate or Extended Inspections are completed. It is preferable to schedule Annual Inspections in conjunction with Intermediate or Extended Inspections when they coincide.

Table II.1 Inspection Cycles (years)

Facility Area	Annual	Intermediate	Extended	Additional
Subsea Structure	1	3-5	6-10	As needed
Subsea Equipment	n/a	3-5	n/a	As needed
Above Water Structure	1	3-5	n/a	As needed
Above Water Systems ¹	n/a	n/a	n/a	n/a
Blades	1	3-5	n/a	As needed

¹Above water mechanical and electrical system inspections are driven by maintenance cycles determined by equipment manufacturers.

These recommended cycles are not intended to preclude other rational approaches to defining the inspection program including using risk techniques or other methodologies. However, alternative approaches should be well documented so that reviewing authorities can identify and approve the program.

Multi-Unit Wind Farms

Once a target inspection cycle has been chosen from the suggested range, it should be understood that not all units within a wind farm, if they are all given the same frequency, must be inspected at the same time. For instance, if the Intermediate Underwater Inspections are to be held on a four year cycle, not every unit in the wind farm must be inspected at the same time. In fact, it may be logistically impossible. But all of them must be inspected during that four year cycle. A certain number could be inspected each year so that by the end of the four years, all have been covered. Such a program has the benefit of providing virtually continuous inspections so that if problems do occur, they are identified in a timely manner, rather than waiting years before the next inspection cycle. The implementation of the inspection scope is up to the operator and as long as all the requirements are met, the scheduling is flexible.

III. Subsea Structure

The subsea structure is that portion of the facility that supports the above water components, including the tower, nacelle and blades, and is founded on the sea floor. These structures are likely to be pile founded monopiles or braced frame structures that extend from the mudline to some distance above the water line where the tower structure is attached. These structures are expected to be similar in design and performance to oil

and gas platform structures. Useful references for inspections of subsea structures are the API RP 2A document for steel structures and ISO 19903 for concrete structures.

a. **Critical Inspection Areas**

The following areas should receive primary attention when developing an inspection program due to their importance to maintaining structural integrity:

Steel Substructures

- Circumferential welds on monopiles
- Welded connections on braced structures
- Major vertical members (e.g., legs, braces)
- Splash zone

Concrete Substructures

- Splash zone
- Construction joints
- Penetrations
- Embedded plates

All Substructures

- Cathodic Protection (CP) systems
- Areas of previous repair or damage
- Seabed scour
- Settlement/subsidence

b. **Inspection Cycles**

Annual Inspections:

- CP measurement using drop cells from above water

Intermediate Inspections

This inspection cycle should be performed at a 3 to 5 year interval and documented with a written report including video and photographs.

- General visual underwater inspection (GVI)
This level of inspection includes a visual inspection performed by divers or ROV to detect any of the following:
 1. Corrosion
 2. Damaged or missing members
 3. Scour, seabed instability, exposed seabed cables within visual range of diver or ROV
 4. Cracks or indications at welded joints or circumferential welds
 5. Cracks or spalling of concrete especially at joints, penetrations and around embedded plates
 6. Excessive marine growth
 7. Damaged risers/cables attached to structure

8. Damaged riser/cable clamps or attachment devices
9. Other anomalies

Extended Inspections

This inspection cycle should be performed at a 6 to 10 year interval (at twice the interval chosen for the Intermediate Inspections) and documented with a written report including video and photographs.

- General visual underwater inspection (GVI) as described above for Intermediate Inspections
- Close visual underwater inspections (CVI)

This level of inspection includes a visual inspection from no further than arm's length of an area pre-selected by engineers (e.g., welded joints of the underwater structure determined by analysis to be critical to structural stability). The area to be inspected should be cleaned of any marine growth so clear examination of the underlying material can be made. Close visual inspection is primarily intended to detect:

1. Cracks, indications or pitting at welded joints or circumferential welds
2. Deterioration of concrete surfaces (e.g., cracks, spalling)
3. Structure condition at area of interest
4. Other anomalies

Additional Inspections

When anomalous conditions are identified it may be necessary to expand the inspection scope or implement techniques that are able to provide more information for review of the extent of the anomaly. Of primary importance is the adequate documentation of the anomaly before the inspection team is demobilized. Photos, video, sketches and measurements of the anomalous condition that can be made with the available equipment should be taken so that proper response can be determined.

A qualified engineer should be consulted to determine the scope and technique of the any additional inspections. Typical additional inspections, which may require mobilization of specialized technicians, include:

- Close visual underwater inspections (CVI), as described in the Extended Inspections section, in the area of the anomaly and as directed by a qualified engineer
- Non-destructive testing (NDT) inspections such as magnetic particle inspections (MPI), ultrasonic testing (UT), or other to determine crack depth, material thickness or other data needed to evaluate the anomaly
- These additional inspections should be thoroughly documented in a written report with details gathered including video and photos.

IV. Subsea Equipment

The subsea equipment includes non-structural items related to the operation of the facility. This includes cables, risers and j-tubes to protect the cables, junction boxes, other umbilicals and similar equipment that is located below the waterline. Typically risers and cables are attached to the subsea structure through clamps or other devices. Away from the structure they are buried though in some cases they may be stretched along the sea floor without being buried.

a. Critical Inspection Areas

The following areas should receive primary attention when developing an inspection program due to their importance to maintaining operability:

- Risers/J-tubes and attachments to the substructure
- Electrical and control cables within field
- Electrical cables to shore
- Connectors and junction boxes
- Areas of previous repair or damage

b. Inspection Cycles

Intermediate Inspections

This inspection cycle should be performed at a 3 to 5 year interval and documented with a written report including video and photographs.

- General visual underwater inspection
This level of inspection includes a visual inspection performed by divers, ROV, or other appropriate equipment (e.g., side-scan sonar) to detect any of the following in the area directly adjacent to the facility, and along the cable routes to shore and other facilities:
 1. Exposed cables where cables should be buried
 2. Long unsupported sections of cable (e.g., caused by scour, anchor dragging, displaced J-tubes, etc.)
 3. Damaged cables or other equipment (e.g., from anchor dragging, impact, etc.)
 4. Other anomalies

Note that accurate maps of the “as laid” cable routes should be maintained by the operator in order to facilitate these inspections.

Additional Inspections

When anomalous conditions are identified it may be necessary to expand the inspection scope or implement techniques that are able to provide more information for review of the extent of the anomaly. Of primary importance is the adequate documentation of the anomaly before the inspection team is demobilized. Photos, video, sketches and measurements of the anomalous condition that can be made with the available equipment should be taken so

that proper response can be determined. A qualified engineer should be consulted to determine the scope and technique of the additional inspection.

V. Above Water Structural and Access Systems

The above water structural and access systems include the tower structure mounted on the subsea structure and supporting the nacelle and blades, the nacelle itself and helicopter abseil platforms, lifting devices, walkways, access ladders and stairs, boatlandings, swing ropes, etc. Depending on the design, some of the access systems may be inside the tower structure and shielded from the elements.

a. Critical Inspection Areas

The following areas should receive primary attention when developing an inspection program due to their importance to maintaining structural integrity:

- Tower to substructure attachment (e.g., welds to monopole)
- Access systems (e.g., ladders, walkways, boatlanding, swing ropes, handrails, helipads, helicopter abseil platforms, etc.) and lifting systems
- Nacelle structure integrity
- Overall facility deflection (i.e., does the facility lean due to structural deformation, differential settlement, or other causes)
- Areas of previous repair or damage

b. Inspection Cycles

Annual Inspections:

- General visual inspection (GVI)
This level of inspection includes a visual inspection performed by qualified personnel and documented with a written report including video and photographs. It is permissible, where required by access restrictions, to accomplish these inspections with binoculars or other similar equipment if they can provide sufficient detail to identify the following anomalies:
 1. Corrosion or coating breakdown
 2. Damaged or missing members
 3. Cracks or indications at welded joints
 4. Damaged risers/cables attached to structure
 5. Loose bolts
 6. Evidence of lateral deflection or lean
 7. Other anomalies

Intermediate Inspections

This inspection cycle should be performed at a 3 to 5 year interval and documented with a written report including video and photographs.

- Non-destructive testing (NDT) at the connection between the tower structure and the substructure. The welds or bolts at this connection must be examined to determine their integrity.
 1. Where bolts are used, their proper tensioning shall be determined using a torque wrench or similar device.
 2. Where welds are used, appropriate NDT techniques (e.g., magnetic particle inspection (MPI), eddy current inspection, etc.) shall be used at key areas as determined by a qualified engineer to identify indications.

Additional Inspections

When anomalous conditions are identified it may be necessary to expand the inspection scope or implement techniques that are able to provide more information for review of the extent of the anomaly. Of primary importance is the adequate documentation of the anomaly before the inspection team is demobilized. Photos, video, sketches and measurements of the anomalous condition that can be made with the available equipment should be taken so that proper response can be determined.

A qualified engineer should be consulted to determine the scope and technique of the additional inspection. Typical additional inspections include:

- Close visual inspections (CVI) from at least arms length with cleaning of the area as necessary with measurements of the anomaly and other investigation as directed by a qualified engineer
- NDT inspections such as MPI, UT, or other to determine crack depth, material thickness or other data needed to evaluate the anomaly
- These additional inspections should be thoroughly documented in a written report with details gathered including video and photos.

VI. Above Water Electrical and Mechanical Systems

These systems, including turbines, electrical cabling, junction boxes, panels, transformers and generators, hydraulic systems and control systems should be inspected and maintained in accordance with manufacturer recommendations to ensure efficient and safe operations.

It is recommended that these maintenance activities be coordinated with the inspections defined in this document and, where possible, the same personnel should implement the activities. Where the same personnel are used, qualifications for maintenance and inspection activities must be demonstrated and special training to complete some of the structural tasks may be necessary.

It is also recommended that use of remote monitoring systems be implemented to provide regular feedback on equipment function to identify anomalous conditions without the need to have maintenance crews on the facility.

VII. Blades

Blade damage is difficult to identify with general visual inspection techniques even when augmented with binoculars or similar equipment. Remote monitoring of blade performance (e.g., through power performance data analysis) should be planned and implemented by a qualified engineer to provide regular feedback on blade performance and proactively identify potential blade issues.

a. Critical Inspection Areas

The following areas should receive primary attention when developing an inspection program due to their importance to maintaining blade integrity:

- Blade attachment bolts
- Blade condition
- Areas of previous repair or damage

b. Inspection Cycles

Annual Inspections:

- General visual inspection (GVI) documented with a written report including video and photographs

By necessity, general visual inspection of blade will be assisted by binoculars or other equipment to provide sufficient detail to identify the following anomalies:

1. Material degradation (e.g., fiber or matrix failure, delamination, stress fracture, stiffness degradation, etc.)
2. Blade damage (e.g., impact, lightning, etc.)
3. Erosion particularly at leading edge
4. Corrosion at attachment points
5. Other anomalies

Where possible to access the blades from the nacelle, this vantage shall be used to observe the entire blade remotely and as much of the blade root exterior and interior as possible looking for the anomalies identified above.

Intermediate Inspections

This inspection cycle should be performed at a 3 to 5 year interval and documented with a written report including video and photographs.

- Non-destructive testing of the connection bolts connecting the blades to the turbine system is required.

Additional Inspections

When anomalous conditions are identified it may be necessary to expand the inspection scope or implement techniques that are able to provide more information for review of the extent of the anomaly. Of primary importance is the adequate documentation of the anomaly before the inspection team is

demobilized. Photos, video, sketches and measurements of the anomalous condition that can be made with the available equipment should be taken so that proper response can be determined. A qualified engineer should be consulted to determine the scope and technique of the additional inspection, keeping in mind the access and safety issues involved in getting personnel and equipment close to the blades. Typical additional inspections include:

- Close visual inspections (CVI) from no more than arm's length of the area as necessary with measurements of the anomaly and other investigation as directed by a qualified engineer
- Non-destructive testing (NDT) inspections suitable for identifying damage to blade material

With respect to turbine blades, power performance data analysis may be used, in addition to visual inspections, to identify potential blade anomalies. Appropriate NDT techniques should be employed to further evaluate the condition of the blade and the blade material if either of the following is true:

- the anomalous visual or power performance results are not due to anticipated blade wear, material buildup or other mechanism considered in the design of the blades
- the operator cannot demonstrate that the anomalous condition will not result in a loss of structural integrity prior to the next scheduled inspection cycle

Of particular importance to blade integrity is evaluation of the shear web bonds, and the leading and trailing edge bonds.

VIII. Post-Event Inspections

It is prudent to plan in advance how to inspect a facility if it is subjected to extreme event loads. For instance, in the Gulf of Mexico, the controlling loading on a facility is likely to be a hurricane storm event. If, following a storm, it is determined that the wind and wave levels were close to or above the design values, an inspection should be initiated to proactively look for damage to the system. Such assessments have historically been mandated by the MMS in the Gulf of Mexico after major storm events.

Depending on where the facility is installed, the controlling design event may vary. While hurricanes dominate the gulf coast regions, earthquakes are more likely to control west coast facilities. Whatever the controlling event, the post-event goal is the same, identify damage from high load levels.

It is possible to pre-select the areas of most concern that should be focused on during these post-event inspections. Areas of the structure with the highest loads from design analysis are likely to be the first to experience loading above yield and will likely be the first to present deformation damage after a high load event. Having these plans laid out in advance will save time and allow for a more efficient inspection process in a sometimes hectic post-event environment.

In addition to structural inspections, cable routes should also be examined after design events, especially in areas where design events may lead to cable damage such as from anchor drags during hurricanes or at fault crossings after earthquakes, in order to identify damage or anomalies that could affect power transmission.

It is also important to consider how to determine remotely whether or not the facility is safe to board and if it is not, how to conduct adequate inspections to determine what can be done to either make it safe to board or conduct inspections without boarding. Experience in the Gulf of Mexico has shown that access systems such as boat landings and ladders are prone to damage and are not always safe to use following a storm. Alternative access may need to be arranged and planning for this in advance can save time and allow for a safer inspection.

IX. Engineering Evaluation

It is vital that all inspections described in the previous sections should be documented in a written report augmented with sketches, photos and videos. These reports should be reviewed by a qualified engineer familiar with the inspection program and evaluated to determine:

- That the inspections were performed as planned and have been adequately documented
- That results of the inspection are incorporated into integrity management plans and future inspection priorities and plans are updated as necessary with the latest inspection results
- Any anomalous conditions are dealt with in a timely manner including:
 - Cleared as-is with follow-up inspections scheduled as needed
 - Identified for further investigation either through additional inspections or analysis to determine further action (e.g., repairs)

This ensures that the cycle of integrity management is maintained so that anomalies are adequately addressed and future inspections are planned based on the information gathered from previous inspections.

X. Data Requirements

The collection and use of data generated as a result of the inspection process is as important to the long-term integrity management of a facility as the inspection process itself. The responsible engineer planning and interpreting the inspection data requires current information on the condition of the facility in order to rationally plan the inspections and make decisions regarding adequate response to anomalous conditions found during the inspections.

There are various levels of sophistication in data management approaches. It is not the role of this guideline to define what level is chosen by an operator. But some data management methodology must be defined by the operator in order to track the information on the condition of the facilities they manage. Currently in draft form, the API RP 2-SIM document contains useful guidance (see Section 4.2, Data) on what data should be maintained and what approach should be followed for managing that data. Also, the ISO 19902 document, Section 23.2, contains information on data gathering and evaluation as part of an integrity management program that is applicable here.

As a minimum, checklists (see Appendix A for examples) should be developed to track inspection activities and results. These provide a useful means of both prompting the inspector to gather the required information and a recording mechanism to ensure that the data is reported back to the responsible engineer in a uniform and repeatable manner. Appendix A also contains an example of a reporting chart that should be developed for all units managed by an operator for submittal to the MMS on an annual basis. This is similar to the OSTs report required to be submitted for oil and gas production facilities in the Gulf of Mexico.

It is also important that inspection activities both above and below water be documented with photographs and video. These are often invaluable references for allowing the responsible engineer to evaluate the structure's condition and any anomalies identified.

XI. Regional Variations

Different areas of the country will have different environmental factors affecting the condition and operations of wind turbine facilities. These regional variations should be considered when evaluating where and how to inspect different parts of the structure. These variations go beyond loads that will dominate the design of the facilities (e.g., hurricanes in the Gulf of Mexico or earthquakes offshore California). The following list provides some guidance on factors that could affect facilities in different regions but each operator will need to evaluate how local factors impact condition and review their data to determine dominant degradation mechanisms.

Northeast Region (Atlantic)

- Low Temperatures with potential for icing, especially affecting blade performance
- Loading dominated by hurricane storms

Southeast Region (Atlantic)

- More aggressive corrosion environment at higher temperatures and humidity
- Loading dominated by hurricane storms

Gulf of Mexico Region

- More aggressive corrosion environment at higher temperatures and humidity
- Loading dominated by hurricane storms

Northwest Region (Pacific)

- Potentially higher fatigue damage in more demanding operational wave environment
- Loading dominated by earthquake events
- Effect of tsunamis

Southwest Region (Pacific)

- Potentially higher fatigue damage in more demanding operational wave environment
- Loading dominated by earthquake events
- Effect of tsunamis

Alaska Region

- Low Temperatures with potential for icing, especially affecting blade performance
- Loading dominated by earthquake events
- Effect of tsunamis

Hawaii Region

- More aggressive corrosion environment at higher temperatures and humidity
- Potentially higher fatigue damage in more demanding operational wave environment
- Loading dominated by hurricane storms
- Effect of tsunamis

XII. Startup Inspections

Though these guidelines address in-service inspections it is recommended that an inspection be performed of the facility prior to startup. Guidance for these inspections can be found in ISO 19902, Section 21, covering topics such as inspection scope, inspection methods, and documentation. The goal is to ensure that installation was performed according to the standards set forth in the design documents and installation plan, and that the facility is fit-for-purpose.

Appendix A

Sample Checklists and Data Reporting

**Minerals Management Service
Offshore Wind Turbine Facility Annual Inspections Checklist**

Note: This checklist is not a substitute for an integrity management program and data recording system for offshore wind turbine facilities. It is a data summary requested by the MMS.

Operator: _____ Facility ID: _____

Report Year: _____ Year Installed/Water Depth _____

SAFETY / SIGNAGE / MARKINGS

Indicate Yes or No to each item and whether or not Corrective Action (CA) was taken

No.	Item	Y	N	CA
1.	Are walkways, ladders, handrails, stairs and other access systems in good working condition?			
2.	Are warning/safety/instructional signs visible and legible?			
3.	Are markings showing facility identification, water level markings, etc. visible and legible			
4.	Are there obstructions to egress paths (e.g., equipment stored on stairs)?			
5.	Are fall protection anchorage points in good condition?			
6.	Are navigation and aviation warning lights operational?			
7.	Are fire protection systems operational?			
8.	Are there other anomalies noted?			

SUBSEA CATHODIC PROTECTION

Indicate Yes or No to each item and whether or not Corrective Action (CA) was taken

No.	Item	Y	N	CA
1.	Are CP measurements within acceptable range?			
2.	Are there other anomalies noted?			

TOPSIDES STRUCTURE INSPECTIONS

Indicate Yes or No to each item and whether or not Corrective Action (CA) was taken

No.	Item	Y	N	CA
1.	Are there any signs of coating breakdown and/or corrosion?			
2.	Are there any signs of physical damage including dents, holes or other deformation to structural members or nacelle housing?			
3.	Are there any cracks or visible indications at welded connections?			
4.	At bolted connections are nuts noticeably loose?			
5.	Are cables and risers, and their attachments in good condition?			
6.	Are there other anomalies noted?			

BLADE INSPECTIONS

Indicate Yes or No to each item and whether or not Corrective Action (CA) was taken

No.	Item	Y	N	CA
1.	Is there any sign of blade material degradation (e.g., de-lamination)?			
2.	Are there signs of blade damage or erosion?			
3.	Are there signs of corrosion especially at the blade attachment points?			
4.	Are there other anomalies noted?			