Predictive Maintenance for Infrastructure

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The nuclear industry is a leader in implementing proactive maintenance programs for process equipment. Repairs, maintenance, and replacements are aggressively addressed because there is a direct correlation to production and profitability.

Civil and structural infrastructure that supports process equipment is often given a much lower priority and often not budgeted until operability is jeopardized. Environmental factors not considered in the original design process often negatively impact the service life of civil and structural infrastructure. The principles of predictive maintenance can prevent or rehabilitate infrastructure challenges before they spread to the critical process equipment they support.

Asset Predictive Maintenance Program

The United States Nuclear Regulatory Commission (NRC) published the "Maintenance Rule" on July 10, 1991, as 10CFR50.65, *Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants*. 10CFR50.65 requires nuclear power plants to, "monitor the performance or condition of structures, systems, or components, against licensee-established goals, in a manner sufficient to provide reasonable assurance that these structures, systems, and components…are capable of fulfilling their intended functions."

Regulatory Guide 1.160, *Monitoring the Effectiveness of Maintenance at Nuclear Power Plants*, provides information to licensees on what the NRC feels is an acceptable approach to meet the requirements of 10CFR50.65 and encourages the use of reliability-based methods for developing maintenance programs. Predictive maintenance programs create a systematic and proactive approach to identifying, prioritizing, and repairing assets throughout a facility or for a particular unit or structure. A program should incorporate:

- Condition assessments
- Determination of the probable cause(s) of deterioration/distress
- Nature and severity of deterioration/distress
- Realistic design and performance objectives
- Estimated service life of the repaired structure
- Selection of appropriate monitoring, rehabilitation and maintenance methods
- Preparation of engineering design and specification documents
- Rehabilitation and maintenance programs

Monticello Nuclear Generating Plant, located in Minnesota incorporates predictive maintenance practices into their corporate culture. Predictive maintenance tools used on process equipment indicated weaknesses in a pump support system. Subsequent investigations revealed cracks and voids in the grout between the pump's foundation and the supporting steel plate. Repairs were able to be implemented while the plant remained in operation and before any challenges to performance spread to operating process equipment.

Some other unique infrastructure components and examples below highlight the benefits of predictive maintenance.

Reinforced Concrete

Nuclear plants have reinforced concrete structures that are vital to process equipment performance and functionality. Corrosion diminishes structural integrity and may affect plant operations if not addressed promptly. Corrosion in concrete is the electrochemical reaction of the reinforcement steel exposed to a corrosive environment resulting in its progressive degradation or failure, commonly seen as rust. In reinforced concrete, where steel is embedded below the surface, the symptoms of corrosion may not be noticed immediately.

Contaminants can permeate through the concrete porosity reaching the embedded rebar and initiating corrosion. Cracking, spalling, and delamination are outward signs of a serious corrosion problem. Corrosion of reinforcing steel in an intake structure caused an incident at an East Coast nuclear facility. Extensive rehabilitation of the deteriorated reinforced concrete was required for the walls, floor slabs, circulation water bowls, and salt water pits.

After rehabilitation was completed an Impressed Current Cathodic Protection (ICCP) system was installed as part of a preventative maintenance and monitoring program to prevent future corrosion. Rather than entering in the reactive maintenance cycle of repairing as needed and risking another incident, this long-term protection solution was developed to extend the life of these structures.

Underground Piping

Underground piping is exposed to degradation from various types of corrosion. As piping systems age, corrosion, deterioration, and failures, including leaks and ruptures, can occur.

Developing a predictive maintenance program for piping should consider incorporation of a variety of condition assessment techniques including visual inspections, wall thickness measurements, pressure testing, leak detection and an assessment of coatings and cathodic protection systems.

A Northeast nuclear facility has been proactively addressing their buried piping through inspection and targeted repairs for decades. This risk-ranking process identifies repairs needed in the Circulation Water system piping. Recently, seven segments of 144 inch-diameter pre-stressed concrete cylinder pipe (PCCP) were rehabilitated during a refueling outage. As a result of predictive maintenance practices this facility is able to evaluate, prioritize, plan, and implement repairs before leakage or structural issues challenged operations.

Cooling Towers

Original construction practices, poor quality construction materials, harsh environmental condition exposure and changes to process streams can culminate in failures to cooling towers structural components. Regardless of whether the cooling tower is natural or mechanical draft, deterioration is predictable and preventable with regularly scheduled inspections and maintenance. Potential reinforced concrete maintenance issues on Cooling Towers include:

- Cracks in the reinforced concrete walls and base slab
- Adhesion/cohesion joint sealant failures
- Embedded waterstop leakage
- Expansion joint deterioration and leakage
- Mechanical penetration leakage
- Anchor bolt and fastener corrosion
- Degraded foundation support for the

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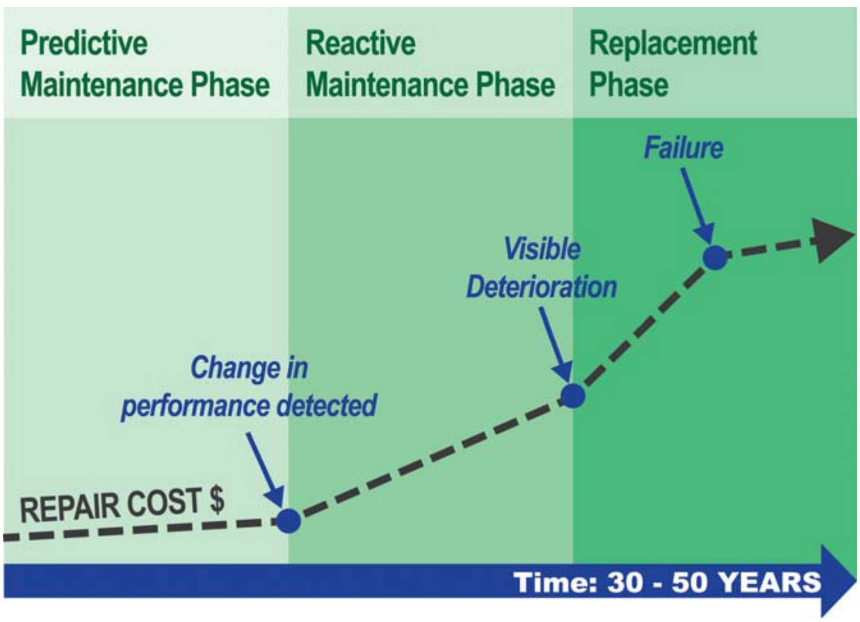

This figure shows a graph of the cost of repair versus time. This figure illustrates the three observed phases describing the natural evolution of the structural and civil infrastructure deterioration process and the influence of maintenance on this process:

1) **Predictive Maintenance Phase: In this phase, the owner may spend a fixed annual maintenance cost to assess conditions and install systems such as protective coatings to slow down the deterioration process. Investment in the predictive maintenance phase will extend the duration of the phase over time by slowing or mitigating the root cause of deterioration if identified early.**
2) **Reactive Maintenance Phase: In this phase, the deterioration mechanisms are in place, but will not be visible in the early stages. With many types of structural and civil infrastructure, deterioration rates are rapid and irreversible.**
3) **Replacement Phase: In this phase, "wholesale" deterioration occurs throughout the structure at such a rapid rate that repair costs may exceed the costs of replacing the entire structure. However, total replacement of the structure may not be an option because of interruption to the function of the structure.**

Predictive Maintenance...

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cooling tower superstructure
- Embedded reinforcing steel corrosion leading to structural degradation
- Erosion of concrete surface paste
- Differential settlement of the cooling tower basin wall/base slab
- Algal growth and vegetation obstruction

Predictive Maintenance for Concrete Structures

Understanding deterioration mechanisms well in advance of deficient structural behavior is important. When developing a predictive maintenance program for concrete structures, the Locating, Qualifying, and Quantifying (LLQ) methodology can help evaluate deterioration and cause mechanisms. Once cause mechanisms are identified a maintenance program can be formulated and rehabilitation methods can be planned without interrupting operations to meet end-of-life or extended service criteria.

Tools utilizing Risk Based Inspection (RBI) Programs developed for mechanical and electrical systems are also available for civil and structural assets. These tools provide an indication of the current condition of structures and assist in prioritizing maintenance.

Building Envelope

The building envelope of nuclear structures provides critical protection for process equipment. Nuclear power plants, like many other industrial and energy processing facilities that use water for cooling are built close to a body of water. Facilities are built with heavily reinforced concrete and located in wet environments below grade with walls and floors exposed in active water above grade often in harsh and corrosive environments.

Water infiltration below-grade can damage interior surface treatments, spread nuclear waste contaminants, corrode metal structures and components.

Water infiltration above-grade through roofs and walls can be destructive. Uncontrolled water allows mold to propagate and degrades material properties like thermal conductance, fire resistance and adhesion of fireproofing materials. Water infiltration and increased vapor transmission can also cause paints and coatings to de-bond. Water intrusion can become a safety issue if floors become wet.

Roofing Systems

Roofing systems at many nuclear facilities are often 30 to 40 years old and the service life of these roofing systems are close to or have already expired. Recently, a roof leak resulted in an electrical fault causing loss of power to reactor coolant pumps and both units of a nuclear facility automatically shut down. The roof leak allowed water to seep down the outside of a conduit into a current transformer enclosure for a reactor coolant pump 13-kV supply breaker. This caused a phase-to-ground fault and reactor coolant pump to trip. The fault was not cleared by the supply breaker because of an overcurrent relay failure, so fault current was exposed to the service transformer which isolated causing an unplanned unit trip.

As a result of this event and unplanned outage, this facility developed an extensive roof survey and prioritization program. The roof replacement and prioritization process was based on a thorough analysis of current conditions, as well as the current risk levels to ongoing operations.

Predictive Maintenance for Building Envelope Components

Building envelope components can be incorporated into a water management predictive maintenance program. Development of the inspection protocols and routine maintenance programs can be based on manufacturer recommendations for material life, industry experience and subject matter expert expertise. To avoid unplanned events it is important to gather information about each component, including date of installation, repair history, leak history and the location of penetrations and equipment.

Conclusion

Despite the perception of a long life, civil and structural assets should be part of a comprehensive predictive maintenance program because they are essential in the functionality of process equipment and related operating assets. There are numerous benefits of predictive maintenance since maintenance is performed when it needs to be done helping to eliminate unplanned outages, keep repair costs lower and the service life of the facility will be achieved or possibly extended.

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