the CONDUIT

Fall 2016

The Metal Never Lies

INSIDE THIS ISSUE

VOL 16, NO 2

COVER PHOTO

This issue's cover photo shows the manufacturing of a portion of a diffuser from a gas turbine exhaust system using gas tungsten arc welding (GTAW) . GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys. The process grants the operator greater control over the weld than competing processes such as shielded metal arc welding and gas metal arc welding, allowing for stronger, higher quality welds. However, GTAW is comparatively more complex and difficult to master, and furthermore, it is significantly slower than most other welding techniques.

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used, though some welds, known as autogenous welds, do not require it. A constant-current welding power supply produces electrical energy, which is conducted across the arc through a column of highly ionized gas and metal vapors known as a plasma.

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We hope you enjoy reading **the *Conduit*,** our quarterly newsletter offering technical information, insight, and case studies.

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the CONDUIT

Broken Obelisk

Catherine A. Noble, P.E., *Consulting Engineer*
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Occasionally we have the opportunity to look at something other than boiler tubes, gas turbine blades, and broken shafts. In Spring of 2015 we had the opportunity to evaluate a metal sculpture - the Broken Obelisk that is part of The Menil Collection at the Rothko Chapel located in Houston, Texas.

Photograph shows the Broken Obelisk over the reflecting pool in November 2014.

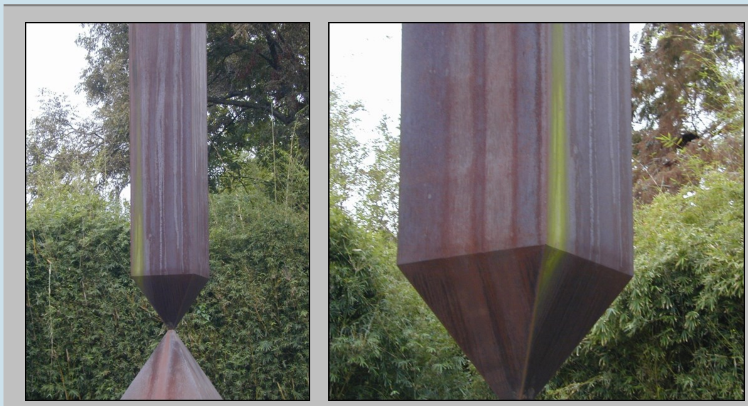
The sculpture has had a history of corrosion issues since its installation, and a conservation plan was being implemented within the next year to restore the condition of the sculpture. However, the museum required a metallurgical assessment of the current condition and corrosion mechanism to ensure that the planned restoration would address the cause of the corrosion.

Background Information

Broken Obelisk was designed in 1963 by Barnett Newman, and the Houston version of the sculpture was manufactured in 1967. Three other editions of the sculpture exist, one is located at the Museum of Modern Art (MOMA) in New York, one is at the University of Washington in Seattle, and only recently did the Newman Foundation allow the latest copy to be manufactured, which is located in Germany. The installation that was examined by M&M Engineering is outdoors next to the Rothko Chapel in Houston, Texas and was installed in 1970. The sculpture consists of an inverted obelisk that connects to a base pyramid. The base pyramid is on a skirt/platform that sits over a shallow reflecting pool, and the sculpture itself is twenty-six feet tall. Original construction was completed using Cor-Ten material, which is a weathering steel.

There have been two major conservation efforts since its original installation, one in 1985 and one in 2005. The first restoration included modification of the pin connection joining the obelisk and pyramid, replacement of the Cor-Ten sheet metal on both pyramid sections, and reinforcing the base with an I-beam. In addition, a rubber bladder was placed in the pyramid and spray foam was used to fill the obelisk to try to alleviate internal pressure and corrosion. Since the sculpture was hollow and not airtight, thinning of the sheet metal was occurring from both the inside and the outside. This is why these modifications were added on the inside.

The second restoration involved replacing the inner, structural framework of the sculpture with stainless



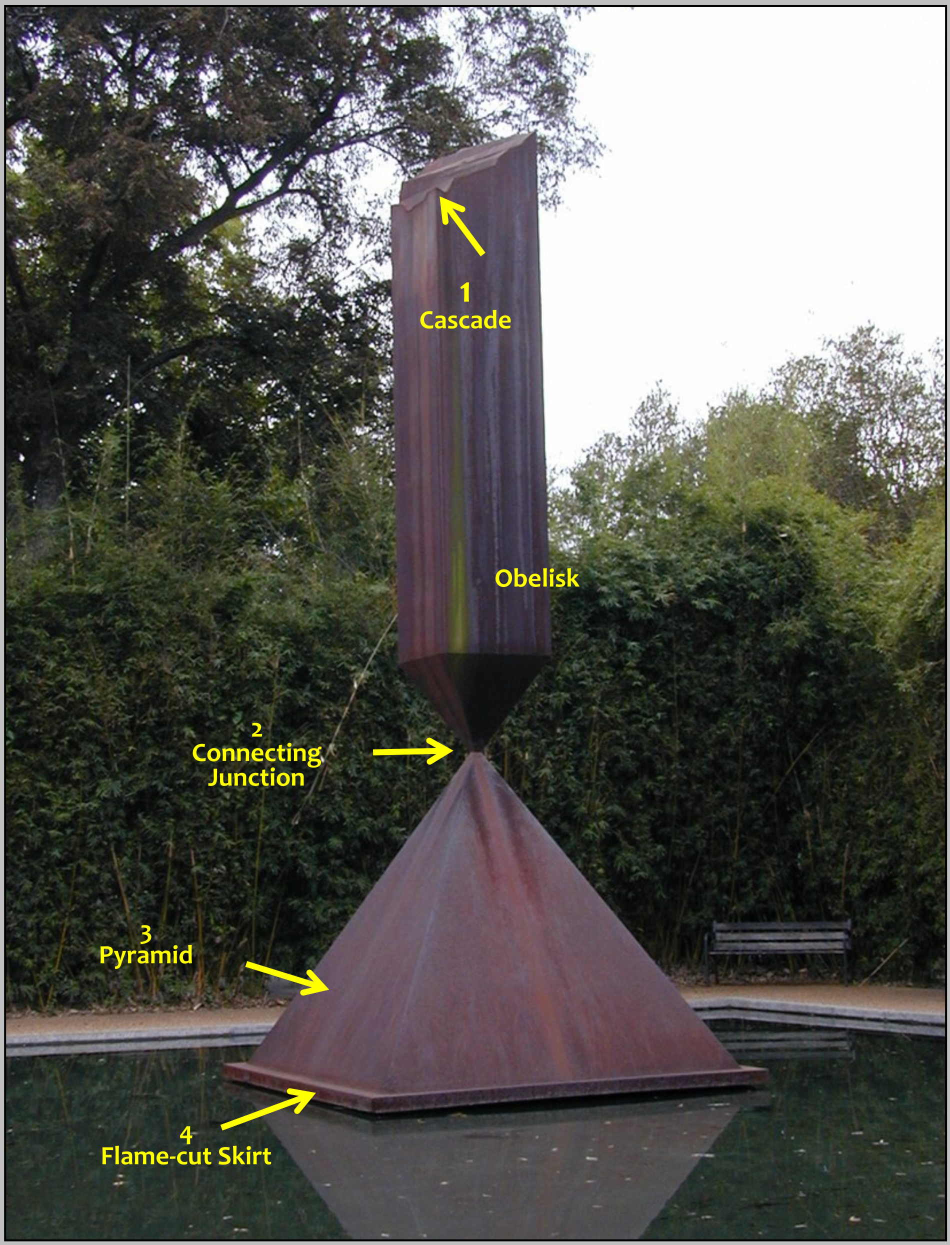
Photograph shows the condition of the obelisk in November 2014.

steel brackets. The I-beam and several areas of Cor-Ten that had severe corrosion were also replaced. The internal bladder and foam had increased internal corrosion, so those were both removed and replaced with an epoxy primer. A vent was also cut into the top to allow better airflow and easier inspections of the inside.

The reflecting pool was treated with chlorine/bromine and sand filtration until 2006, when it was switched to treatment with a salt cell and sand filtration. In 2010, the salt cell was eliminated and replaced with UV filtration.

Visual Examination

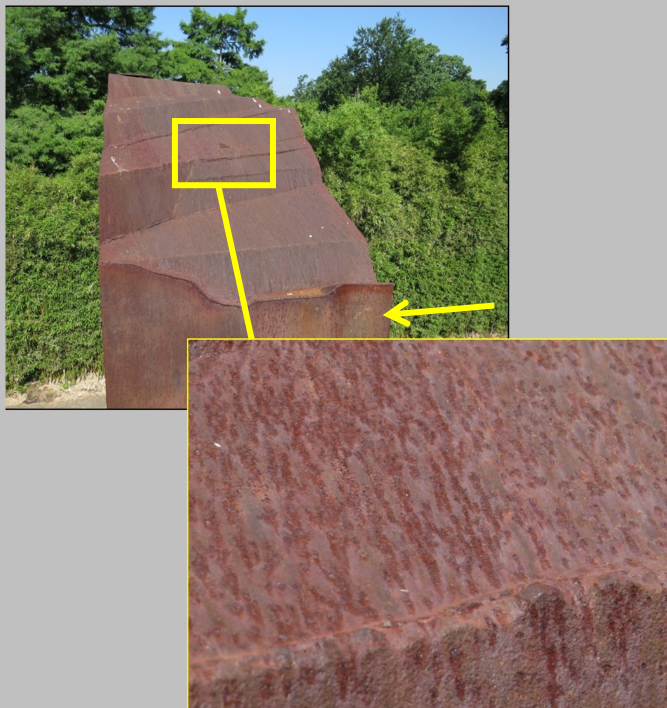
The Broken Obelisk sculpture was visually examined and photographed during the initial on-site visit. There were several streaks of darker rust down the sides of the obelisk and the middle of each side of the pyramid in line with the obelisk.



Photograph shows the sections of the sculpture and the four locations where deposits were collected for analysis.

It appeared that there was more corrosion than just the typical surface patina of weathering steel, but it was difficult to tell from the edge of the reflecting pool. In addition, there was a green streak near the bottom of the obelisk on the North side. This was likely biological in nature, as there had been reports of bird feces needing to be cleaned off of the sculpture.

The sculpture was visited again several months later and examined up close using an elevated work platform. Four locations were examined: 1) the cascade (top of the obelisk), 2) the connecting junction between the obelisk point and the pyramid, 3) the bottom of the pyramid, and 4) the flame cut edge of the skirt just above the water line.



Photographs show the condition of the cascade obelisk. Arrow indicates one of the epoxy patches in the panel.

In general, the corrosion deposits/oxide layer was not as thick as anticipated based on the initial inspection conducted from the side of the pool. Houston had experienced a significant (record setting) amount of rain in the last six months prior to the re-examination, and it was possible that some of the deposits were washed away.

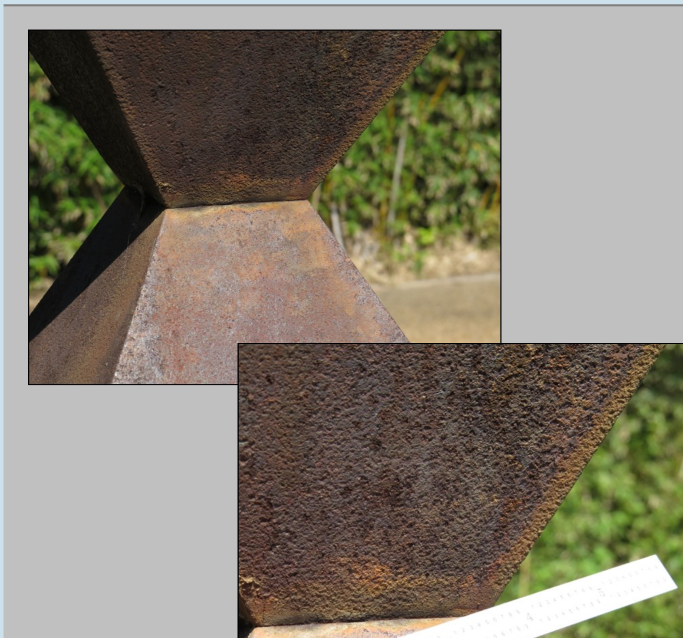
Along with a general maroon-colored oxide layer, some pitting and corrosion deposits were noted on the cascade. A small hole was noted on the narrow section that was horizontal and welded to the vertical East side. The hole was about $1/10^{th}$ of an inch in diameter, and this location was selected for deposit collection. In addition, there were two epoxy-patched areas just below the top on the East face of the obelisk. Corrosion had progressed through-wall in these areas that had necessitated patching in between prior restorations.

The connecting junction between the obelisk point and pyramid was examined next. The faces on both pyramids had a general maroon and gray color with pitting covering most surfaces. Along the edges of the pyramids and right at the junction, there was a brighter, rust-orange deposit. The streaks down the center of the pyramid faces that were observed during the previous visual examination were still present, but were somewhat fainter. These were likely due to drainage off of the obelisk.

The bottom area of the pyramid was similar in appearance to the area near the connecting junction. Pitting was present with some brighter orange rust in a few areas.

The skirt had the most rust and deposits, making deposit collection much easier. Pitting was present, but it was difficult to distinguish some of this from the texture of the flame-cut edge as part of the artist's design. The water was several inches below the skirt at the time of the inspection.

At the upper corner of the cascade, there is a vent with a removable plate. This plate was removed and the interior of the obelisk was also inspected. Multiple blisters with rust along the edges were observed in the coating on the internal surface. Blistering could have occurred due to moisture wicking in between the metal and coating or improper surface preparation prior to the coating application. The coating was installed during the 2005 restoration and was nearing the end of its life.



Photographs show the connecting junction between the inverted pyramid and the base pyramid.

Photographs show the flame cut edges of the skirt where deposits were collected.

At the time of the inspection, Menil personnel placed a recording device inside the sculpture to monitor temperature and humidity to better understand the interior environment contributing to the internal corrosion. This data was not analyzed by M&M Engineering.

Corrosion Deposit Analysis

Deposits were collected from the four examined locations described above by mechanical scraping, cotton swab, or adhesive tape (depending on which was appropriate). They were prepared for analysis by energy dispersive X-ray spectroscopy (EDS) to determine their elemental compositions.

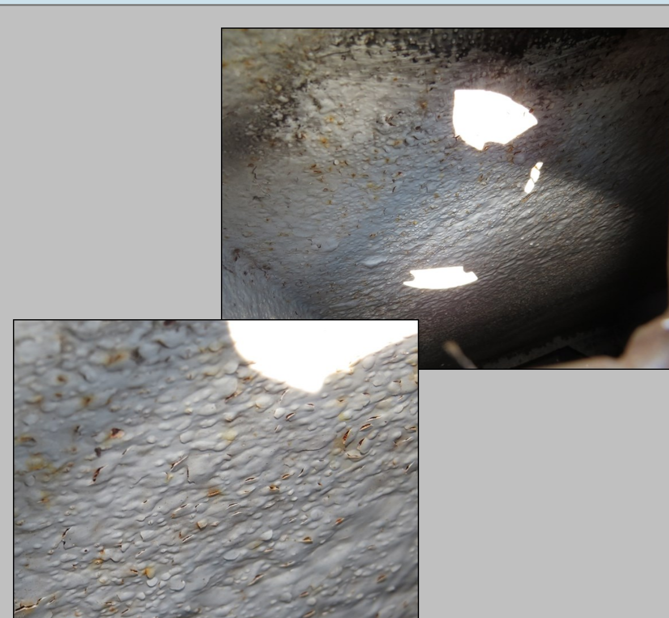
EDS analysis showed that all of the deposits consisted primarily of iron and oxygen, likely in the form of iron oxide. Lesser to trace amounts of magnesium, aluminum, silicon, phosphorus, sulfur, chlorine, potassium, calcium, chromium, manganese, copper, and bromine were also noted. Sulfur was present in all of the locations, and sulfur-containing compounds such as sulfides are known corrodents to carbon steel. Chlorine was also found on the two lower locations. Chlorides are also known corrodents to carbon steel, particularly for pitting corrosion. Chlorine and bromine were likely present from the previous water treatment program.

The deposit sample from the skirt was also analyzed using x-ray diffraction (XRD) to determine what crystalline compounds were present. This type of analysis takes into account the EDS results when looking at the diffraction patterns. The major phase present in the deposit was copper magnesium iron oxide. This is a spinel structure that best matched the peaks based on the EDS results. Possible trace phases included quartz, lepidocrocite, goethite, and hematite, the last three of which are iron oxy-hydroxide and iron oxide phases.

Sculpture Location

The next task was to review corrosion literature and humidity data for Houston in order to determine if the sculpture could be kept over the reflecting pool after the restoration with little change to its corrosion rate, or if it needed to be placed over the ground.

The temperature in Houston ranges from an average low of 45°F in January to an average high of 92°F in August. The humidity on average ranges from 49% to 95% in a given day, with the average high above 90% for the entire year. Average chance of rain ranges from 30% to 46% on a given day, with about 50-52 inches of rain per year. This type of climate is considered humid subtropical.



Photographs show the condition of the internal coating at the vent in the cascade.

Cor-Ten is a weathering steel and will function as so only in particular climates. It requires alternating cycles of wet and dry conditions to form an adequate protective oxide/patina. Therefore, areas of high rainfall and humidity, such as Houston, are not good locations for weathering steel. Originally, Cor-Ten was proposed as a good steel for structures that would rust a certain amount and then stop. However, later studies and experience proved otherwise, such as in this case.

Marine salts may also be an issue in corroding the sculpture and disrupting the protective oxide layer. A geographic location is typically considered susceptible to a marine environment if it is less than 50 miles from a body of salt water. The Menil Collection is located in roughly the center of Houston and is about 32 miles from Trinity Bay off of the Gulf of Mexico. It is also only 25 miles from the Houston Ship Channel, which is mostly salt or brackish water. Therefore, it was likely that the steel was exposed to some amount of salt spray from these bodies of water.

Cor-Ten is also not recommended for outdoor use where there are high concentrations of pollution and industrial fumes, in particular sulfur dioxide. The high concentration of oil & gas and petro-chemical industrial sites near Houston likely contributed to the accelerated corrosion of the sculpture, especially in the years right after installation before EPA regulations came into effect.

The reflecting pool underneath the sculpture was previously treated with bleach, as well as salt tablets. Both of these chemicals would have deposited on the lower part of the sculpture from escaping water droplets. Chlorides formed from the chemicals would have interfered with the protective patina as well as caused pitting corrosion in the steel.

Given the information above, the question of where to locate the sculpture in the future depended on whether placing the sculpture over a pool increased the humidity significantly enough to cause concern, or if the humidity and environment was already detrimental enough that the pool would not have a significant impact. Based on the data and literature reviewed, it was found that placing the sculpture over the reflecting pool only increased the humidity very slightly. Based on the general climate of Houston, it was not believed that the pool was much more damaging to the Cor-Ten than what it would experience on “dry” land.

There was one caveat to this statement – the water treatment to control biological growth could contribute to accelerating the corrosion and therefore the proper treatment needed to be selected. A non-oxidizing biocide, such as a polymer treatment and/or UV filtration, was recommended in order to eliminate any contribution to further corrosion. Oxidizing biocides, such as bleach and salt tablets, were part of what had contributed to the rapid deterioration of the sculpture and should continue to be avoided. The current biocide being used was copper II sulfate, which is a non-oxidizing biocide and was deemed acceptable for continued use.

Another option recommended for consideration was draining the pool periodically to lessen the contribution to corrosion. The Stark Collection drains the pool on one of their sculptures over night for this purpose. Draining the pool altogether would eliminate the corrosion variable and maintenance cost, and would be an easy option. However, it was noted that this would detract from the artistic vision of the sculpture and change the installation significantly. Retaining the reflecting pool just requires maintenance in a way that minimizes the contribution to the corrosion of the sculpture.

Conservation Plan Review

The conservation plan was reviewed from a materials standpoint. Overall, the plan to restore the sculpture was found to be reasonable. It included addressing galvanic corrosion due to the use of dissimilar metals, coatings, and venting.

Reconfiguration of the junction between the Cor-Ten skirt deck and stainless steel support to eliminate the connection between dissimilar metals was part of the conservation plan. Having carbon steel (Cor-Ten) and stainless steel touching with an electrolyte present (water) could lead to galvanic corrosion due to the different corrosion potentials of these materials. Even though they are both steel, the difference in composition is enough to create a problem. It was recommended that direct contact between stainless steel and Cor-Ten be eliminated through the use of gaskets, coatings, or other methods.

Ship-2-Shore Industrial coating had been recommended for the interior and exterior surfaces of all Cor-Ten surfaces along with the stainless steel structural parts. The information available on this coating was reviewed and found to be a suitable coating for the sculpture. It was recommended to strictly follow the manufacturer's recommendations for coating thickness, application techniques, and reapplication schedule based on the service environment. Surface preparation is critical to proper coating adhesion, and surfaces should be as clean as possible before applying any coating. Testing was also recommended to be conducted to ensure that there were not any holidays in the coating, as this could also lead to premature coating failure and accelerated corrosion at any small, anodic holes in the coating.

There was a slight concern with the plan to remove the vent to replace it with a cover plate. While it would have kept rain out of the obelisk, it would not have allowed airflow through the sculpture that could help abet internal condensation. As long as the interior coating was in good condition and the planned drain basket caught any debris to allow for drainage, the cover plate was found to be fine. It was recommended to inspect the basket periodically and clean it out, as proper drainage was considered to be very important.

There were a few additional items that were recommended for consideration during the conservation efforts. First, some outdoor sculptures in other locations have been coated in wax to reduce corrosion. Wax could require more frequent recoating, which would have to be taken into consideration.

Anodic protection was also recommended for consideration, especially if it remained over the reflecting pool. This would involve attaching a sacrificial anode to the sculpture that would preferentially corrode instead of the Cor-Ten. The anode would be made of a material with a significantly higher corrosion potential in the galvanic series than the material that was being protected from corrosion. This difference in potential ensures that the anode will "sacrifice" itself to protect the sculpture. Magnesium and zinc are common anode materials that can be used to protect carbon steels such as Cor-Ten. The anodes would have to be inspected periodically and replaced when they corroded away for continued protection.

A recommendation was also made to measure the wall thickness of the Cor-Ten panels before and after application of the coating to obtain a reliable set of base-level thickness readings. The data could then be used to monitor any thickness losses due to corrosion after reinstallation of the piece. If possible, it was recommended that the same equipment be used in the shop that is used in the field to ensure equivalent readings. A template for reading locations was recommended as a good tool to use to help with consistency.

Finally, a recommendation to consider rinsing the sculpture periodically to keep it clean from corrodents and other biological contamination that may disturb the coating was made. The cleaning would have to be done in accordance with the coating manufacturer's guidelines. While the interior surface could also be rinsed, that did not seem very practical. If the seal at the top was good, then there should not be much contamination to rinse off, making it acceptable to forgo rinsing of the internal surface. Periodic inspection of the interior coating should reveal if this practice is acceptable.

Since performing the evaluation, the sculpture has been removed and sent to Lippincott, the Connecticut foundry where it was made. It is currently undergoing the planned repairs.

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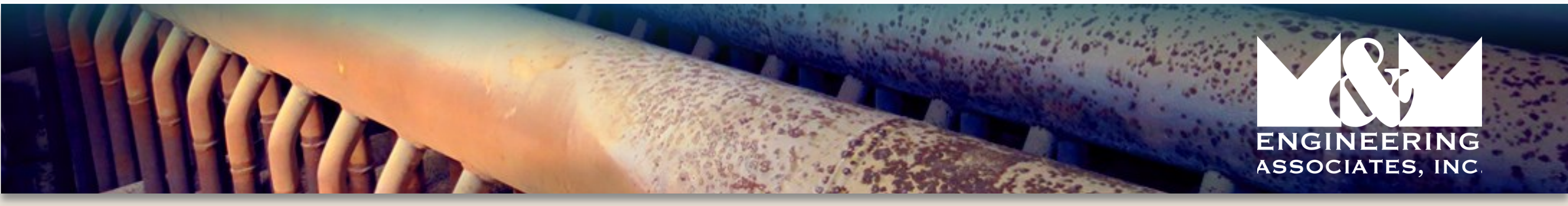

PREVENTING FAILURES IN STEAM GENERATING EQUIPMENT

Thank you to all who participated in our 2016 Workshop.
You helped to make this year's event a great success!

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Our 6th Annual Workshop will be held in August, 2017

By design, seating is limited, so be on the lookout for our registration announcement and reminder to submit your ticket.

The two day workshop focuses on the issues most common in steam generating systems, and is applicable to many industries including pulp and paper, refining, petro-chemical, and power generation.

Failure Analysis vs. Root Cause Analysis

Oscar Quintero, *Senior Engineer*
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M&M Engineering has worked with many of our readers throughout the years, helping them in performing failure analyses in many cases, and in others, a root cause analysis (RCA). There's a key distinction between them: a failure analysis is the first step of an RCA. A typical failure analysis relies on one main objective: identifying the failure mechanism. Once a failure mechanism is identified, then the theories behind what caused the failure mechanism can be explored. This is where an RCA investigation can be very helpful.

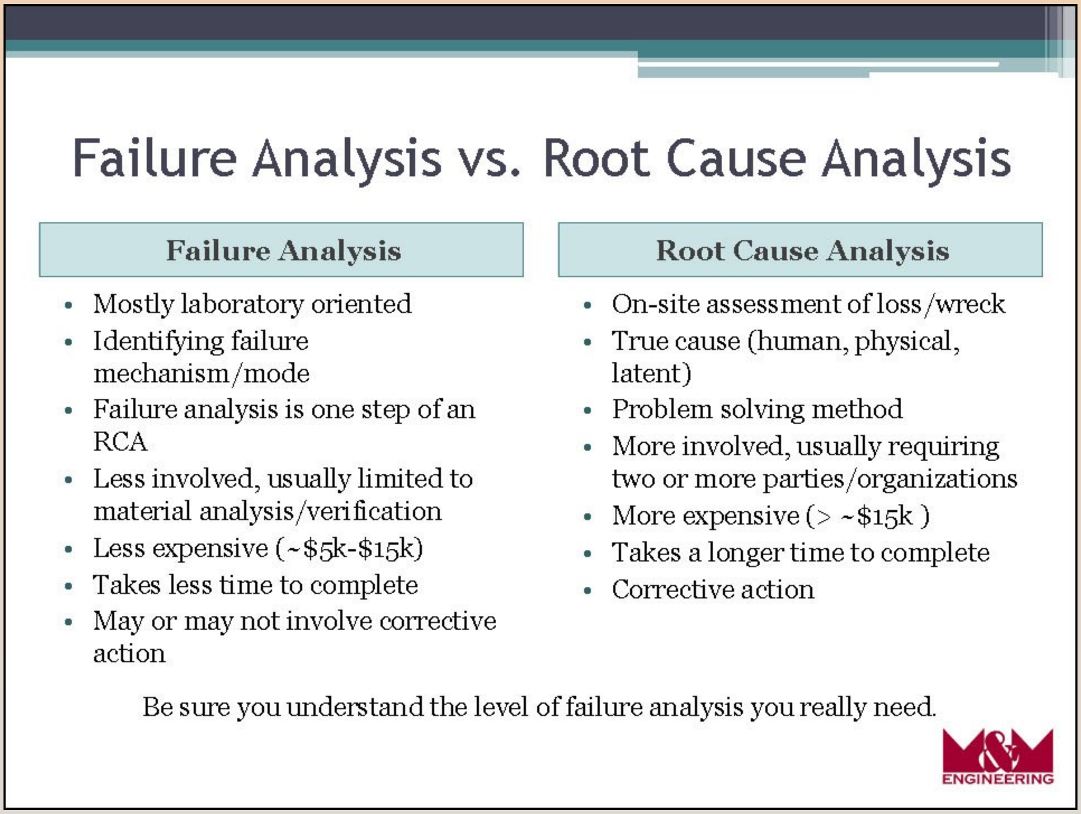
The RCA process is much broader and explores not only such contributors as operational or design causes, but the process can also include other factors that could have contributed to the failure, such as human influence, organizational, and physical factors. The physical factor is what the failure analysis process tries to identify (i.e. the failure mechanism). An RCA also looks into the human factors, which could include working conditions, operator's health, lack of proper equipment, lack of training, etc. Latent factors include cultural or organizational rules that lead to the human cause. Such factors include the lack of an operating manual, operating practices or training, etc.

One other difference between the failure analysis and the RCA is the cost associated with each analysis. A typical failure analysis can cost somewhere between $X and $3X and is usually more laboratory oriented, where a metallurgical analysis and material testing are performed and the material properties are verified. An RCA is more expensive and can run anywhere between $3X and $10X, sometimes even more. One of the main reasons behind this is the level of effort required to investigate all potential contributing factors. It may include hiring experts in the field of equipment or machinery. Consultants charge by the hour, and the value of their services are in the expertise and knowledge which they have accumulated throughout their years of experience. Consultants can add invaluable pieces of information that aid in the RCA process. For example: if you, the reader, work in a power generation company (combined cycle plant), you know that some of the most important pieces of equipment in your facility are the prime movers: the gas turbines and the steam turbines. Without those, you are not producing power, and it is more than likely that you would be losing money. If your plant suffers a catastrophic loss of the turbine, then this would be an ideal situation to bring in a consultant with the experience and turbine expertise. They may have worked before with the original equipment manufacturers like General Electric, Siemens, Mitsubishi, or Alstom, and perhaps has experience working at a power plant or with repair service overhaul vendor before becoming a consultant. A consultant would bring his or her experience in the gas and/or steam turbine world, and would most likely use the RCA process.

Depending on the failure, the RCA process could take weeks, months, and sometimes years; unlike failure analysis which usually takes a few weeks.

If you work within a large organization, chances are your company has an RCA team. Hiring an external consultant could still prove to be beneficial, but not be as expensive, since your in-house team would be leading the RCA and would bring the consultant in only when needed. You would probably hire an outside company (like M&M

Engineering Associates) to perform a failure analysis as most companies do not have the laboratory facilities to examine the physical damage. Once the mechanism of failure has been determined, then your RCA team could take the investigation from there with or without the consultant. This collaborative approach is a very common practice and leverages the benefits of specialized engineering knowledge from the consultants, and the equipment/process/ operational familiarity from in-house.



One very important party that should be invited to be part of the RCA process is the manufacturer. The manufacturer knows the equipment and component design better than anybody who would be involved in the RCA. As such, it is best that they be invited to participate; and here are a few reasons why:

- They have the design and manufacturing information, which can be very critical in the RCA process. Usually a non-disclosure agreement (NDA) is required to gain access to this information.
- They can personally benefit from the RCA by receiving the results of the failure mechanisms (maybe this was the first time this component failed by this specific failure mechanism and could help them in future product improvement).
- Customer service. Sometimes you can get a partial credit on a replacement, or the failed equipment might be covered by the warranty. You may not have to pay to get it replaced.
- Inviting the OEM manufacturer shows good faith in the relationship.

In short, a failure analysis may stand alone, or be part of an RCA investigation. While an RCA arrives at the root cause(s) of failure, a failure analysis only identifies the failure mechanism. But let's not undervalue the importance of a failure analysis. The failure analysis will dictate the direction your RCA investigation will go. If a failure mechanism is identified, you will have a better chance at arriving at the root cause and solutions to prevent future failures. Often times the failure mechanisms have been speculated instead of verified. Identifying the actual failure mechanism(s) is the most important step of the RCA process. If it is not properly identified, your RCA process will suffer, and the root cause may not be correct and, as such, preventative solutions or mitigating actions may not work.

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SAY HELLO TO THE NEW MEMBER OF OUR TEAM

Jody Havard

Jody joined M&M Engineering Associates as a Laboratory Metallurgical Technician in September 2016.

Originally from Mississippi, Jody moved to Austin at the young age of six. An alumnus of the University of Texas at Austin, Jody received a Bachelor of the Arts Degree in Geography.

Prior to joining the M&M Engineering team this year, Jody spent more than twenty-five years in the information technology industry working as an Account Executive and Technical Product Specialist for companies such as Dell, IBM, and Microsoft. Jody holds many certifications in that field such as PC/ Hardware Specialist, and Global Sales Specialist.

Jody enjoys hobbies such as hiking and camping, but he is most passionate about running. “I love the challenge of long distance running. So far I've run in several Marathons, an UltraMarathon, and a Half Ironman Triathlon. My favorite race is, of course, the Austin Marathon!”

We are thrilled to have Jody as part of the M&M Engineering family and look forward to having his eye for detail in our laboratory.

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The success of our clients is a direct reflection of their consistent dedication and hard work.

Join us as we recognize all of our team members who celebrated anniversaries in 2016, since our last issue.

Congratulations to you all, and thank you for your contributions!

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Background image, Page 8: http://www.houstonchronicle.com/local/gray-matters/article/Experts-still-trying-to-fix-what-s-broken-with-6801865.php

Happy Holidays

from our family to yours!

Trail of Lights – Austin, Texas