CORROSION RESISTANCE IN EARTHMOVING MACHINES: VIABLE MODIFICATIONS FOR MARINE ENVIRONMENTS

S. P. Rutherford[1]

ABSTRACT

Earthmoving machines used in dredging and marine construction environments can benefit from some degree of modification to optimize performance within the harsh and extreme conditions associated with a marine environment. Although a minimal level of corrosion protection can be achieved simply with a quality paint solution, resistance is best achieved when coupled with other minor modifications to the machines themselves.

When contemplating corrosion resistance and whether or not to invest in modified equipment, there are a few key factors the authors will discuss, including: identification of key areas of vulnerability, identification of solutions to adequately address the areas of concern, and the analysis of each solution and the associated costs therein to determine the most affordable level of protection and resistance to apply. Using the aforementioned key factors, the authors will describe examples of post-delivery modifications that can result in more corrosion-resistant earthmoving equipment suitable for dredging applications and for use in the marine environment. Further, two examples will be outlined, where modifications, based on voice of customer, have been integrated into a production option. This enables significant alterations to be economically completed, and minimizes the need for further modifications.

Keywords: Coatings, Paint, Maintenance, Rust, Dredging

INTRODUCTION

Consumers often modify items to better suit their needs and extend the useful life of products and machinery. It is also becoming common for manufacturers to complete these modifications in production rather than post-delivery, by the consumer. Earthmoving machines used in dredging and marine construction environments can often benefit from some degree of modification to better handle the corrosive nature of this industry. Well established as a challenge, there is considerable knowledge that can be cost-effectively deployed, leading to measurable improvements with machine reliability and durability, increased uptime and reduced failure rates.

COATINGS

Coatings serve to slow electrochemical corrosion. They do this by reducing the current flow in the corrosion process. While pure water does not serve well as an electrolyte, seawater and salt spray are a good electrolyte, thus steel machines exposed to salt air, salt spray and seawater will corrode rapidly and must be protected with coatings. All coatings, even the best applied ones, can be damaged, breached, or otherwise compromised. These surface defects in barrier coatings can lead to the formation of local anodes and result in a high rate of localized corrosion. In other words, a defective or damaged coating can produce more rapid corrosion than if there had been no coating at all. Therefore, coatings must be periodically inspected and reapplied as needed.

Crevice corrosion is a very common form of corrosion that can result from the shape or form of a component. Holes, pockets and unfilled lap joints concentrate the harmful species in an environment because the crevice prevents the environment from being flushed out.

Post-delivery, owners and operators can inspect machines destined for marine service and coat or seal areas of concern. Even if crevices cannot be entirely eliminated, they can be minimized by the avoidance of pockets and sharp corners which would tend to collect and hold moisture and contaminants.

The simple schematic diagram below (Figure 1) shows examples of the types of locations to focus your attention. The right angle bend on the right shows a sharp intersection, while the equivalent shape on the left shows a more gently radius which is less likely to create a "dead" zone. Similarly, the two pieces of sheet metal joined into an acute angle show how the example on the right is more likely to create a crevice than the joint on the left, which is partially filled to minimize the crevice effect.

Figure 1. Examples of Crevises

Other examples of geometries that can lead to the creation of moisture traps are shown below. These designs can be filled or modified to allow for drainage as illustrated in Figure 2.

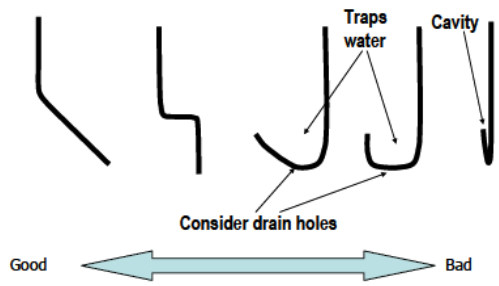

Figure 2. Geometry Examples

Components are frequently made by joining simpler pieces together, usually through fusion welding, but also by brazing, soldering, adhesive bonding, or bolting. Various joint geometries are illustrated in Figure 3. It is easy to see how crevices can be fabricated into the component if no provision is made to seal or enclose the whole joint. For example, for the fillet weld pictured below, the mating corner opposite the weld can serve as a crevice to collect moisture and begin rusting preferentially. A solution to this is to use a sealing compound on the side that is not welded. Skip or tack welds are also common on construction machinery for a variety of reasons. However, the crevices between the welds should be sealed or corrosion will occur at those sites.

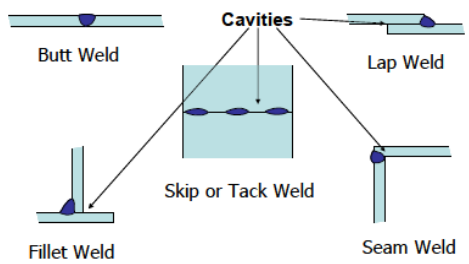

Figure 3. Weld Examples

Paints

Paints reduce corrosion by breaking or slowing the current flow between two dissimilar metals through an electrolyte. Paints must be applied and maintained in accordance with the manufacturer's instructions. Epoxy coatings and polyurethane coatings are generally the coatings used in severe applications such as earthmoving machinery. While painting a machine post-delivery is not cost effective nor generally feasible, owners of machines in marine applications should pay particular attention to maintenance. Additionally, some machines leave areas unpainted during the manufacturing process, such as cab internals, if not required in the standard environments. As these are identified, they should be coated with a high-quality paint of one of the other means described in the sub sections below. Particular attention should be made to edge coverage. By nature, these products tend to pull away from edges. Often it is from an edge that the initial barrier failure occurs.

Primer Paint

The main purpose of primer paint coatings is to optimize the performance of the overall coating system. A multi-layered system is comprised of a primer layer and a topcoat paint layer. The functioning of this system relies heavily

on the properties of the previous coating; for example, the performance of the UV-resistant topcoat finish quality and durability is directly affected by the primer paint layer. The primer finish promotes adhesion of the system to the metallic substrate and helps to provide chemical resistance to compromised or damaged painted parts.

Topcoat Paint

Topcoat paint finishes primarily affect total system performance by providing UV protection to the primer coating. They enhance the corrosion and chemical protection in two-coat systems and provide physical external properties associated with the product's overall finish. Examples of these are:

- Hardness – less susceptible to damage during handling and assembly
- Flexibility – as needed for substrate material
- Impact resistance – as needed for application
- Gloss – as needed for aesthetics
- Color – as needed for aesthetics
- Weathering – as needed for aesthetics and substrate protection.

Common types of topcoat finishes can be in powder, liquid, water-based, or solvent-based formulations utilizing various resin chemistries, including but not limited to:

- Polyurethane (Good Performance)
- Alkyd (Standard Performance)
- Polyester (Powder Finishes)

Electrodeposition Primers (E-coat)

Radiators can be susceptible to early life failures in marine environments. In certain applications, it has been found that e-coating the radiator, ensuring complete coverage, can increase the longevity of the radiator cores. E-coating components is a very good method of coating components that have a lot of edges and therefore are more difficult to coat.

Sprays, Coatings, Tapes, Sealants and Vapor Corrosion Inhibitors (VCI)

Protection of wiring, connectors, fittings and tubing can be gained with the application of sprays and tapes in certain areas.

To prevent corrosion of wires and connectors, one must ensure that the terminations on any cabling are hermetically sealed. Most machine wiring is manufactured with high-quality sealed connectors but even these can leave the wire exposed to moisture, and eventually corrosion will begin. Corrosion in wires wicks via capillary action. By using aerosol coatings, corrosion resistant tapes and heat-shrink tubing, an owner can cost-effectively seal the ends of all the exposed harnesses.

Bare steel will corrode rapidly in marine environments and the zinc in traditionally galvanized hose fittings will be quickly depleted. Aerosol coatings, corrosion-resistant tapes and heat-shrink tubing applied and maintained regularly will reduce the rate at which corrosion occurs.

Rust-Preventive Sprays

Liquid electrical tape, or other rust preventive aerosol spray, provides reasonably long-term protection for previously uncoated metal parts such as hose fittings, as well as additional protection to weld joints and sheet metal seams as seen in Figure 4. Electronic Control Modules (ECM), ground straps, wiring connections and other surrounding components shown in Figure 5 can benefit from improved integrity gained through coatings. Owners can also periodically coat areas of routine abrasion, such as bottom sides of castings, the engine oil pan, or step points.

Figure 4. Compartment Seams & Joints Coated in Loctite® Maxi-Coat™

Figure 5. Various Electrical Components Coated in a Liquid Spray Tape

Typical commercially available products include Loctite® Maxi-Coat™ Rust Inhibitor #51211, LPS® Premier Rust Inhibitor and CRC® Industrial SP-400™ Corrosion Inhibitor.

Soft Coatings

Many temporary and permanent soft coatings are available to provide additional surface protection. Soft coatings can often provide both corrosion protection and lubricate. Due to their soft nature, these products can often be applied with minimal surface preparation. An example of this type of product is Fluid Film™ Gel BEW. Soft coatings are also often used for shipping or storing of equipment, where conditions otherwise could lead to corrosion. Many manufacturers use these types of products to preserve the appearance and quality of their products during shipment.

Tapes

Galvanized fittings will corrode very rapidly in a marine environment when connected to a steel machine. These items can also be difficult to evenly coat with aerosol spray. Protection from corrosion, impact and abrasion for fittings and tubes can be achieved with corrosion-protective tape (Figure 6). These products can also be applied to electrical connectors and wiring, but small circumferences and the angular nature of many connectors make tight seals difficult and reinforce the use of aerosol sprays. Tape is also effective in areas where wiring and tubing are submerged in water and sand.

Figure 6. Taped Hose Couplings

Typical commercially available products include 3M™ Scotchrap ™ and Temflex™ Corrosion Protection Tapes, Shurtape® PW 100 Corrosion-Resistant PVC Pipe Wrap Tape and Danco™ 59804 Pipe Wrap Tape

Seam Sealers

Many manufacturers offer high solids urethane seam sealers capable of adhering to painted and unpainted surfaces. These products are good for filling voids and joints in order to prevent crevice corrosion issues.

Heat-Shrink Tubing

Similar to tape, in certain applications connectors can be sealed with silicone and protected with heat-shrink tubing (Figure 7). There are also heat-shrink products that contain adhesives which are activated during the shrink process. Utilization of heat-shrink proves beneficial in areas that do not lend themselves well to aerosol products and the associated overspray.

Figure 7. Shrink Tube & Sealed Connectors

Vapor Corrosion Inhibitors (VCI)

VCI capsule diffusers can be placed in sealed compartments and difficult-to-access enclosures to protect electrical components. Locations that typically benefit from these products are generally located in and around the operator environment (Figure 8), and are generally clean and have restricted airflow. Increased airflow will remove the protective vapor barrier from the space and diffuser will not be able to maintain a protective coating. In certain cases, multiple diffusers are placed strategically throughout enclosures that are not completely sealed. Manufacturers such as Zerust® offer a variety of products that provide different protected volumes and effective lives.

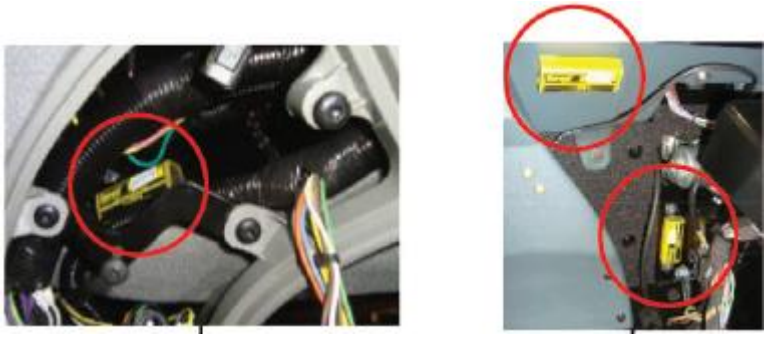

Figure 8. Example of Commercially Available VCI Difussers Inplace

BASIC MODIFICATIONS

There are quite a few opportunities to cost-effectively prepare machines, post-delivery, for harsh marine environments. It could be the addition of essential safety equipment such as mounting a glass-breaking hammer in the operator environment or the utilization of non-metallic materials, stainless steel, or admiralty brass in place of standard carbon steel and aluminum components for improved corrosion resistance. In this section we cover simple solutions to improve the durability and corrosion resistance of earthmoving machinery.

Breathers

Many systems in earthmoving machinery require breathers. This includes fuel tanks, hydraulic tanks, engines and transmission cases. These breathers are generally located in close proximity to the compartment/component to minimize plumbing and only far enough away to prevent any overflow situations if applicable. Relocating the air intake and breathers to a high location, such as the cab (Figure 9), will minimize the chances of water or material intrusion. Owners can also install (if not previously installed) filtered air breathers on all system tanks. These are likely available from the manufacturer or an aftermarket supplier. Always ensure the correct micron rating is installed.

Figure 9. Breathers Reloacted High on the Cab

Engine Air Intake

Engine air intake pre-cleaners, to remove dust and sand, are also available and recommended. Most machines built today can be equipped with various options from the factory (Figure 10), or can be retrofitted. Generally, these pre-cleaners operate by creating a spiral air flow, where centrifugal force causes heavy solids to be separated from the clean intake air. Not only do they serve to remove a significant amount of the dust and sand in the air, but they can help to relocate the air intake to an area with reduced dust. Pre-cleaners that use scavenging, through the use of an exhaust airflow ejector, generally can remove the greatest amount of material. Removing this material serves to not only ensure maximum engine life, but also leads to extended air filter maintenance intervals.

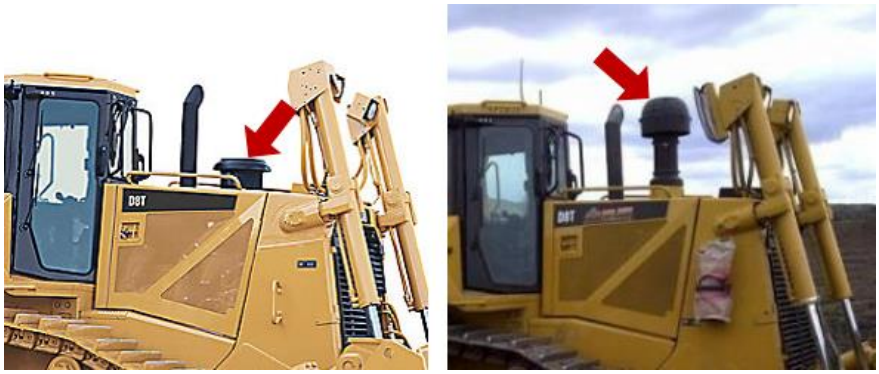

Figure 10. Various Options for Pre-Cleaners

Engine Enclosure

Optional engine enclosure configurations (Figure 11) are produced by OEMs for many different reasons. Often the OEM is working for a balance of engine noise attenuation and cooling air flow. Consider options that meet these needs, but also reduce the ability for sand and water to enter the engine compartment. Aftermarket modifications can be made to assist, but care must be taken to not create an excessive restriction to required airflow. Further, ducting (Figure 12) can be installed to minimize sand and sea water from being drawn into the engine enclosure.

Figure 11. Engine Enclosure Options

Figure 12. Standard (left) and Ducted (right) Engine Enclosures

Removal of some types of protective screens (Figure 13) to improve airflow and associated cooling system performance, can be considered.

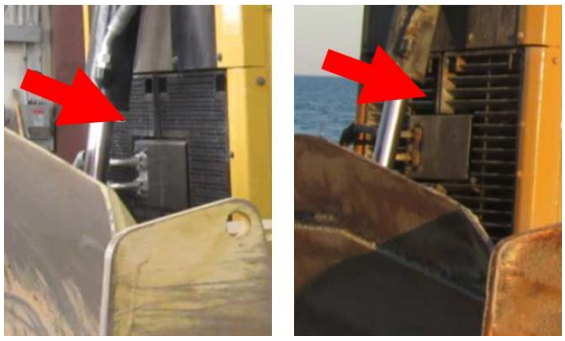

Figure 13. Radiator Screen Installed (Left) and Removed (Right)

Hinges

In modern earthmoving machinery it is not uncommon for joints such as cab door hinges, maintenance access door hinges, body panels joint and pins, and fold-out service access points such as radiators and cooler bundles to be dry or "greaseless." However, in certain environments, it is required that some creative thought be put into enabling the application of a marine lubricant for these various machine body and cab hinge points. The solution could be as simple as periodic maintenance or the installation of a grease fitting.

Green Fluids

While most manufacturers specify fluids by brand name, there are very few instances where the fluids are not categorized by industry standards. Determination of the standard will allow end users to investigate biodegradable options for their equipment and thus limit risk should the inevitable spill occur.

ADVANCED MODIFICATIONS

Body panel and frame cavities can be sealed or the machine designer can construct them to encourage drainage and the free transfer of material and water. This section will cover modifications that take special tools and/or knowledge, like torch work on thick steel plates, for example. Items in this section might require a deeper understanding of the machine or could be point-of-order decisions.

Guarding

Installation of boots or guarding can minimize or eliminate the abrasion from sand and salt that wears on cylinder surfaces. When practical, owners should strive to protect cylinders from sand abrasion. Focus should be placed on cylinder rods close to the material, such as track tensioning cylinders, blade lift and tilt cylinders and excavator/material handling bucket cylinders.

Belly Pans and Skid Plates

Understanding how and where material collects can help determine the best options. Generally, if an area or cavity can be completely sealed (after painting), that is good. Earthmoving machines are routinely heavily armored, with the undersides of the machines protected with heavy access plates and covers, which allow technicians to gain access for repairs and maintenance but protect vital machine components. On most jobsites significant dirt accumulations can develop. In a marine environment this should generally be avoided where possible as the addition of a good electrolyte (like salt water) can lead to significant rust that will make removal for service and maintenance difficult and could render the guarding ineffective. Drainage holes can be cut into these plates to allow the area to drain and vent (Figure 14).

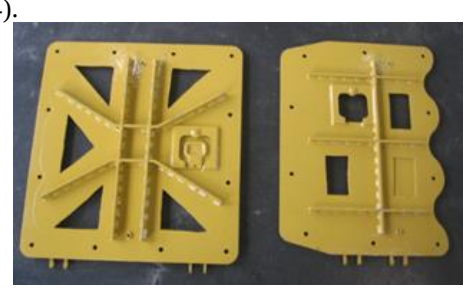

Figure 14. Modified Plates

Abrasion-Resistant Material (ARM)

ARM can be placed as needed around the machine. NOTE: All welding procedures, methodology and materials should be approved by the OEM. ARM wear plates or "doublers" (Figure 15) made of wear-resistant steel such as T-1 or better are often placed on the push-arms of track-type tractors.

Figure 15. TTT Push-arm Subject to Abrasive Environment That Could be Doubled

Undercarriage

Highly abrasive underfoot conditions reduce undercarriage life and increase undercarriage cost per hour. This effect is compounded when moisture is present, enabling abrasives to stick to mating components. To help reduce the effects of these abrasives on undercarriage life, Rotating Bushing Track (RBT) is designed for these applications. RBT (Figure 16) incorporates bushings that rotate (turn freely) when in contact with the sprocket. This eliminates bushing wear as the critical limiting item of the undercarriage system and it reduces track noise. Bushing and

sprocket segment wear can exceed the life of the link, eliminating the need for a bushing turn and sprocket segment replacement over the life of the link assembly. The results are longer link/roller system life and reduced undercarriage cost per hour. In effect, Rotating Bushing Track is doing an ongoing bushing turn as the machine works.

Figure 16. Rotating Bushing Track

Feature Selection

Machines often have many variants and, as such, most do not include all the available options. In some cases certain features should be selected over others or actions should be taken to prevent issues due to features selected or not.

Unused open and tapped holes, for track bottom guard mounts (Figure 17), in the track roller frames allow sea water to enter the frame, resulting in rusted bottom roller mount bolts. Prior to assembling the track, these holes can be filled with silicone and closed off with a bolt and washer.

Figure 17. Location of Unused Bottom Guard Mounting Holes

A serviceability feature on track-type tractors is a segmented drive sprocket (Figure 18). It has been found that in certain applications, such as beach reclamation, the segmented sprocket can work loose causing damage to the final drive and subsequent downtime. It is recommended that a solid sprocket be installed on machines in these applications.

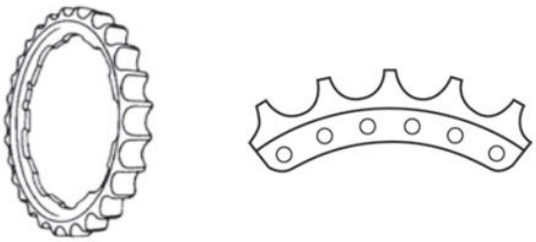

Figure 18. Solid Sprocket (Left) and a Segmented Sprocket Section (Right)

Electrical

The same electronics that have helped improve machine efficiency are particularly vulnerable in marine environments. Utilization of coatings, tapes and the like that have already been discussed should be carried over to some specific components as well.

Alternators

Heavy-duty alternators can be protected by removing cover plates and coating internal terminals with silicone. In addition, heat shrink tubing can be applied to terminal joints to prevent wicking.

Disconnects

Heavy-duty disconnects should be used and have terminals protected by silicone or similar product.

Wire

Most construction and earthmoving machinery is manufactured with high-quality copper wire. It is common in the marine industry to utilize boat cable/wire which is tinned copper wire. While without exposure to moisture or salt air, the un-tinned copper wire will last as long as the tinned, utilization of marine-grade tinned copper wire or boat cable along with sealed connectors when making repairs or attaching new technologies can pay substantial dividends.

EXAMPLES OF MODIFICATIONS COMPLETED AT POINT OF MANUFACTURE

By listening to Voice of Customer (VOC), manufacturers are able to collect many aftermarket modifications being completed on machines, and work to integrate those alterations in the design and manufacturing of their offering. This can enable significant changes to be made that otherwise might be cost prohibitive. It also enables changes to be made, that can then be supported by their dealer network.

Cat® D7E Dredging Arrangement Dozer

Initially, modifications to this machine were completed at the direction of the customer, by their dealer. With guidance from the customer and dealer, these requested changes were implemented in the design and manufacturing of the tractor, leading to reduced waste and machine delivery time. Many are items as described in the sections above, including improved surface and wiring protection, guarding to keep sand and water from entering, and openings to allow sand and water to exit system cavities. Several of these changes are easily seen on the machine (Figure 19), where the side panel ducting and air intake pre-cleaner are indicated. Other internal changes are not so obvious, but included in the following text.

Figure 19. Cat D7E Dredging Arrangement

Improved Surface and Wiring Protection

Internal hydraulic lines, drive module, oil tank and brake lines are coated with corrosion-resistant paint. Access to many of these internal items is tough, making aftermarket modifications difficult.

Drain Holes Cut into Lower Access Plates

Saltwater and sand are able to flush out the bottom of the machine by designing holes into several of the lower belly pan access panels.

Undercarriage Components Selected for Corrosion and Abrasive Environment

Rotating Bushing Track (RBT) reduces wear in water and sand environments. One-piece sprockets are used to improve bolt retention, and seal saver boots are installed to improve track tensioner performance and life. Equipping a machine from the factory with the most optimal undercarriage options for the application reduces costs for further required modifications after the sale.

Cat 966M Corrosion-Resistant Wheel Loader

In some instances, lessons learned from other industries can be applied beneficially to the dredging segment. An example of that is the 966M Corrosion-Resistant Wheel Loader, a product that was initially focused on the challenging application of bulk salt handling. Corrosion-resistant related changes to this machine are outlined below.

Figure 20. Cat 966M Corrosion Resistant

Wiring Protection

Silicon is applied to all electrical terminals at the alternator, disconnect switch, starter, engine ground and battery cables. Exposed connecters are treated with shrink wrap tubing.

Additional Grease Points

Grease points are added to the cab door, engine hood hinges and cooling module access.

E-Coated Cooling Group

By using e-coat process, intricate areas of the cooling package are able to be coated, without applying excessive (and head transfer restricting) layers.

Additional Paint and Surface Protection

Extra primer and polyurethane top coat are applied. Paint thickness is more than two times the thickness of a standard machine. Varnish protection is applied to engine compartment and non-painted metallic parts.

Turbine Engine Intake Pre-Cleaner

As common in this and many industries, any effort to minimize dust ingested by the engine is valuable. This is particularly beneficial in sea water mist and sand environments.

Autolube Lubing System

Ensuring proper lubrication is essential in corrosive environments. The 966M can be equipped from the factory with an autolube system.

CONCLUSIONS

Deploying a machine constructed of primarily steel into an arduous environment such as beach reclamation and dredging applications will no doubt lead to corrosion and wear. By leveraging readily available corrosion-resistance solutions, owners can recognize measurable improvements to machine reliability and durability. When combined with a rigorous maintenance schedule, on-the-job uptime can be optimized.

As an industry, we must continue to work to identify those areas of concern where the "standard" configuration will suffer in the marine environment. We must identify viable and cost-effective solutions to remedy or slow the development of these concerns. We can then work to implement these improvements in the most cost-effective manner, either with the OEM in the design and building of the machine, or by developing creative post-delivery solutions. While our industry may identify certain weak links faster than other applications, all involved can benefit from these activities in the long run.

Caterpillar, Inc. (2015). "The Design Guide for Corrosion Prevention." Caterpillar, Inc. Technical Information Library, 100 NE Adams ST, Peoria, Illinois 61629, USA. www.cat.com

Rockwell Automation (2009). "Corrosion Resistance of Electrical Wire Terminals Used in Harsh Industrial Environments." *Rockwell Automation, 1201 South Second Street, Milwaukee, WI 53204, USA*. www.rockwellautomation.com

Carlsten, Roy. "Understanding Corrosion and How to Protect Against it." *IMPOMAG*, http://www.impomag.com/article/2002/03/understanding-corrosion-and-how-protect-against-it. Accessed 11 January 2017.

CITATION

Rutherford, S.P. "CORROSION RESISTANCE IN EARTHMOVING MACHINES: VIABLE MODIFICATIONS FOR MARINE ENVIRONMENTS," *Proceedings of the Dredging Summit and Expo '17, Vancouver*, BC, June 26-29, 2017.

ACKNOWLEDGEMENTS

G. M. Mitchell, Caterpillar Paint Engineering, Caterpillar, Inc., 100 NE Adams St, Peoria, Illinois 61629, USA, 309-675-1000

R. P. Murphy, Industry Solutions, Caterpillar, Inc., 100 NE Adams St, Peoria, Illinois 61629, USA, 309-675-1000

J. L. Kirkton, Dredging Industry Steward, Caterpillar, Inc., 300 Hamilton Blvd, Peoria, Illinois 61629, USA, 309-675-4899