Jessica Torrey: [00:01] Welcome and good morning. My name is Jessica Torrey, I work in the Materials Engineering and Research Lab in the TSC and I'm here with Darryl Little. We're both part of the corrosion team.

[00:13] We also have Jake, who is from the research office and he's our technical adviser this morning. If you have trouble hearing or seeing anything, feel free to shoot a question through the questions box and he'll try to help you with that.

[00:25] I have about 30, 35 slides this morning and what we want to do is start this webinar series to try and give you some reference, and to inform you on the importance of corrosion, the importance of inspecting your structures for corrosion, and some things you might look for in the field. Also some things that we can do here in the TSC to help you, and when you might want to contact us to help you with your project.

[00:57] My presentation's not working...There we go. Today we are just going to start with a general introduction to corrosion. I'll go through some of the forms of corrosion, why corrosion is important, some things that you can look for, some things not to do.

[01:10] At the end we will talk a little bit about what our capabilities are here at the TSC and our new research lab that we've just been getting up and running.

[01:23] This is us, I am the redhead right there in the middle, Darryl is on the far, I guess your left, the right on the screen, and these are our contact information. There's four of us here that work in the corrosion department and you can feel free to contact us for any questions that you have on your corrosion issues or cathodic protection systems. I'll have this information up again at the end as well.

[01:54] What is corrosion? Corrosion is defined as the deterioration of a material and/or its properties caused by a reaction with its environment. This is basically any of your metals will corrode. The environment, in our case of the Bureau of Reclamation, is usually water or soil.

[02:13] Why is corrosion a major concern? I have three case studies here to show you what can happen. First and foremost, public safety. This is an example of a bridge, the Mianus River Bridge in Greenwich, Connecticut.

[02:22] This was in 1983, this bridge collapsed, and if you can see my pointer here, this is a collapse that actually killed three people, and it was blamed on corrosion. They had this pin-and-hanger design where they had this pin, here, and you can see in the schematic, in this actual photo of an example bridge.

[02:52] The design was compromised when this pin was displaced due to extensive corrosion. Water had gotten down into this space, here, and caused corrosion of these tins. The pin...One of them fell out and then the second one had a lot of load on it. It was corroded enough but it failed. This whole section of the bridge, now, had no support and it just fell.

[03:20] This was amplified by the salt on the road maintenance, and they also cited inadequate maintenance procedures. There had been some construction where they had plugged drain holes. At the end of the construction and maintenance these were not unplugged, so it caused pooling of water and the salt to get in there.

[03:41] Subsequent to this failure, extensive inspections were conducted on this type of bridge all across the country. They made design modifications. They called it, "a catcher's net" where they put a bar across this joint here. If something would happen and this were to fall there would be a secondary support mechanism, so it wouldn't be a catastrophic failure.

[04:08] A second example that I think a lot of people have probably heard about is a little hot airline accident. This was in 1988, and 18 seats of the cabin ripped off. A flight attendant was pulled out, causing her death, and there were also many injuries of the crew. This was attributed to corrosion-fatigue in the rivers, of this name.

[04:29] Here's a case from reclamation, [inaudible] , you can see here there is a gate trailer, the whole gate number three was damaged beyond repair. Luckily, there was no flooding and no loss of life. This could've been a lot worse. It was quite an expensive failure due to corrosion.

[05:01] You can see here the replacement of this gate, and the repair of the other gate, that were of similar construction, cost around $20 million. It required a 40 percent drainage of the reservoir. The cited cause of this failure was increase in corrosion at the trunnion pin-hub interface. I'll show you later, when a metal corrodes, the corrosion product or the oxide in the brush is actually less dense, so it expands.

[05:33] There was increased friction at that pin and those were the bending stress in that strut and the axel force, and then it's exceeding the limit of the gate. The failure you can see here. The gate was operating for nearly four years without problem. It's something that happened over time, as corrosion will.

[05:57] It'll start off a very small problem but eventually can lead to something like a failure, in this case. Also, what was noted was that the frequency of the regular maintenance, and especially the lubrication of these pins, has decreased over time due to budget constraints.

[06:13] We're in that phase again, where we have some serious budget constraints that we're facing, but we hope we can impress on you that trying to continue some maintenance and to note where there is corrosion and when you need to take action can be really important and, over the long run, save money and be more cost effective than having to wait for failure and to make extensive repairs.

[06:43] Going back to the economic costs, this is a study, and it's over 10 years old at this point. It was from 2002, from NACE International, which is our Corrosion Engineers Society. This was put out with the Federal Highway Administration a report that placed the estimated economic impact of corrosion is $276 billion annually. That's a direct cost of corrosion.

[07:08] That's about three percent of this country's PDP. It's really quite high. If you also take into account indirect cost of the corrosion, that goes up to about $550 billion a year. Some of the areas that they looked at and broke down, you could see here the corrosion of the general industries and then also the breakdown for infrastructure.

[07:35] One of the things they were looking at was the direct cost. This includes the public infrastructure and residential items direct repairs, replacements, and maintenance. Also, loss of products and production, loss of consumer confidence, and then increased regulations and fines.

[08:02] Again, we hope to show you that this is quite a large economic cost. It's estimated that 25 to 30 percent of these annual costs [inaudible] could be saved if optimum corrosion management practices were in place. Here are just a few things...Sorry. I'm trying to minimize my...Oh, there we go. OK, I'm good.

[08:33] Here's just a few of the things that this report identifies as preventative strategies. Increased awareness of corrosion costs and potential savings. That's what we're trying to do here. To let you know, some of the things that you should look for on your structures and be aware of so that you can make sure that you do the maintenance when needed.

[08:55] Change the misconception that nothing can be done about corrosion. As I mentioned in the previous slide, 25 to 30 percent of the cost can be saved just by doing annual maintenance. Change policies, regulations, standards, and management practices to increase corrosion cost savings. Use sound corrosion management. That's the same thing.

[09:15] Improve education and training of staff in the recognition of corrosion control. That's one of the things that we're hoping to do with this webinar. Implement advanced design practices for better corrosion management. That's one of the things that we do in the TSE. We do have NACE certified corrosion engineers who are capable of designing corrosion systems.

[09:39] When you have new projects, you can pull those through the TSE and we can help you design your product protection and corrosion [inaudible] . Those advanced place prediction and performance assessment methods, that's one of the things we're hoping to do with our new research lab.

[09:56] I'll talk a little bit about that at the end. Then, improve corrosion technology through research development and [inaudible] . Now we get into some of the technical aspects of corrosion. This a corrosion reaction. It's an electrochemical reaction between a metal and electrolyte.

[10:14] The electrochemical reaction is more often referred to as just rusting or oxidation. If you're familiar with electroplating or anodizing, these are also electrochemical reactions. A lot of the metals that we use -- steel, copper, aluminum, cast iron, for example -- in reclamation are electrolyte and specifically oil or water.

[10:37] When I point to the bottom metal, corrodes because they are chemically unstable in natural environments. The only metals that actually exist in nature in their metallic form are the noble metals. For example -- gold, platinum, also copper. Everything else exists in an oxide and has to be refined before you get the metal form.

[11:01] Some metals naturally pass the base, which means that they form a thin oxide layer on the outside. This helps protect them from corrosion. Material selection is often a big part of determining what type of structure. For example, pipeline, what type of material you would use on your pipeline in the soil or water environment that you are dealing with.

[11:25] Corrosion still has four requirements. You can see from these schematics, comprise an anode, which is what corrodes. This is typically pure metal. That cathode, which is a protective structure. Pipelines, for example, or tanks, or any kind of structure you often have anode and cathode directly next to each other in the same structure.

[11:48] As you can see from this diagram, you'd have an anodic area and a cathodic area right next to it. This area will corrode or rust, leaving a product. Then you need an electrolyte, which is your soil or your water, and your metallic return path. These are the four requirements. If you remove any one of these requirements you no longer have a corrosion cell.

[12:13] That's one of the things that we try and do with coating, is we try and remove your electrolyte. You put a barrier between your structure or your metal and your electrolyte and this inhibits corrosion.

[12:26] These are the forms of corrosion that I'm going to talk about today. I'll go through them each individually and give some examples, and then some things you might look for, and also ways to mitigate or try to deal with these different types of attack.

[12:44] The first one we're going to look at is general, or uniform, corrosion. This doesn't happen very often, but as you can see, the Statue of Liberty is one very famous example of general corrosion. This is where the reaction occurs uniformly over the surface. It is often very steady and very predictable. An example from acclimation would be that a lot of dams blew away.

[13:07] This is the most important form of corrosion based on weight of metal corroded. Most of the metal lost in this country due to corrosion is from general or uniform corrosion. Unfortunately for us, this is not often our most common. Especially in buried structures you don't see this very often.

[13:30] Some solutions for this problem, and you see these same solutions repeated throughout the talk. There's just a very few things that we focus on and that's why here, at PST, we have people that are specialists in these areas. These are the most common solutions to corrosion.

[13:49] Number one, select more corrosion-resistant material. Number two, apply protective coating. I spoke about both of these in the previous slide. Cathodically protect the structure. This is something that we do here in the corrosion group, is design these cathodic protection systems.

[14:03] We apply a current and use anodes that are sacrificial so that you corrode something other than your structure. You sacrifice a separate metal that you specifically put in your electrolyte, and you corrode that other metal preferentially to your structure. Also, just [inaudible] by a corrosion allowance.

[14:30] For example, you could say, "Oh, I'm using 314 steel or 316 steel. I know what my corrosion rate is going to be. I need this structure to last for X many years. I'm going to give it an extra quarter inch of thickness just to mitigate my corrosion or to [inaudible] my corrosion. These are calculations that we can do, here.

[14:55] A second form of corrosion that's very, very common in our structures is galvanic corrosion. This is corrosion due to a potential difference between two dissimilar metals in contact. For example, if you have stainless steel next to regular steel, or something like this, or copper next to steel, you have a potential difference between the two metals.

[15:41] Here's some examples of that. You have a mild steel washer and a stainless steel bolt, and the mild steel is corroding. This is a very common example that we see fairly often. Again, some of the solutions are fairly similar. Use electrochemically similar metals, and I'll explain that in the next slide. You want to avoid large cathode to anode ratios.

[16:11] If you do have to use two metals that are dissimilar, you want to make sure that the part that will corrode is larger than the part that's not going to corrode. You can also use insulating fittings to isolate these two. For example, [inaudible] a rubber gasket in between the two. Apply protective coating and apply [inaudible] .

[16:14] What does it mean by saying electrochemically dissimilar metals? This is the public galvanic series. This particularly, these numbers are taken in sea water. We also have them referenced in fresh water. There are some metals that are more noble or more cathodic and are less likely to corrode.

[16:33] You could include, for example, platinum. Also gold, palladium, iron [inaudible] like jewelry and materials. Titanium in steel. You have other metals that are more active or anodic. For example, zinc, aluminum, magnesium. These metals often are what's used as sacrificial anodes in our cathodic protection system.

[16:55] These numbers just give you an idea of where metals rank in relation to each other. For example, you could put nickel and bronze next to each other, but you might not want to put nickel and stainless steel, or stainless steel and mild steel. Here's a few other examples of where we've seen this.

[17:16] I've said a lot of times we see it with gold, so remember, this is the mild steel bolt and a stainless steel guide. You can see how that bolt is rusting away. Another thing that I'll talk about later is, if you embed it in concrete, as that steel rusts it expands a bit and it puts stress on the concrete and then starts cracking the concrete.

[17:39] Here's another example. The slide is a little bit busy, but what we want to show you is that you can also have this when you have the same materials.

[17:48] Say you have a mild steel pipe and you need to replace a section. When you have old pipe that already has some corrosion, and you put a new pipe in, that new pipe, which is nice and shiny, is actually going to be more active or more likely to corrode than the old pipe. This is due to activation, which I have mentioned before.

[18:10] When you have this old pipe, that oxide layer on the outside actually protects it somewhat from the environment. It's almost like putting a protective coating on. When you have a pipe that has protection next to a pipe that has nothing, this pipe will eventually start to corrode. This is one thing that we see a lot.

[18:32] The next type of corrosion is crevice corrosion. These are some examples...this is a recent example that we photograph from the Palo Verde Diversion [laughs] dam. You can see this started out as a crevice between two joints and it has corroded to the point where these are just flaking off and completely split apart from each other. These were two hole brackets that were right next to each other and they have completely corroded.

[19:00] Another example are here at these joints and with skip weld. You can also have crevice corrosion underneath coating. If you have, for example, a break in that coating and you get water underneath your coating, that is also considered crevice corrosion. It's basically intense localized corrosion.

[19:19] You have corrosion within these small confined spaces and it just really accelerates the corrosion rate in that space.

[19:31] Solutions are to avoid designs of crevices. Bolting or riveting, and use non-absorbent gaskets. You don't have these small spaces of electrolyte, because they need an electrolyte, example water, to have a corrosion reaction. Design equipment for complete drainage. Avoid areas where you have stagnation or pooling water.

[19:54] Close the crevices and lap joints by welding or caulking or coating, and inspect for and remove deposits.

[20:03] One of the things that we want you to look for in structures, or to avoid I guess, is skip welding. This is an example from Seminoe Dam, and this is actually my hand right here. This is one of my first corrosion inspections with the Bureau of Reclamation. You can see where they welded...they did skip welding here, here, here.

[20:23] In between on this L bracket in those crevices they have corrosion and it's actually starting...this is one of the better cases but in a lot of the cases on these gates they were actually then having corrosion and [inaudible] of the coating.

[20:39] Instead of doing skip welding, we would prefer that you do full welding of joints. For example, if you have something like this where you have joints or rivets or bolts, try and seal as best you can around those areas so that you don't have water going in there because the water will get in there and it won't easily dry out.

[21:00] For example if you submerge this, you'll get water in that area then when you take it out of the water that water is still going to be there causing corrosion. Try as best you can to seal around these types of joints.

[21:15] Next form of corrosion is pitting corrosion. This is localized attack on an otherwise resistant surface. This often occurs when you have holidays or break downs in your protective coating. You'll see little pits form and those will corrode preferentially to the rest of the structure and it can be quite bad. They can corrode quite deeply and cause failures that for example you see here of this leaky pipe.

[21:44] Solutions, again, still exclusively resistant materials. A 316 stainless steel versus a 304 steel, apply protective coatings and make sure you inspect those coatings so that there are no defects in the coatings because this is where pits can form. Apply cathodic protection and again avoid designs where stagnation or alternate wetting and drying can occur.

[22:13] The next form of corrosion is de-alloying or selective leeching. This is where you have a material that's an alloy and one of the elements from that alloy corrodes preferentially to the other.

[22:26] This happens...for example dezincification where zinc leeches out of brass and it leaves a poor [inaudible] copper. Or graphitic corrosion where the iron actually leeches from cast iron and you have a pipeline that's fairly porous, low strength graphite. This is an example down here.

[22:46] Graphitic corrosion and cast iron gas mains caused a fatal explosion in Allentown, Pennsylvania. This happened repeatedly. It started happening in 1979 and most recently this image was from 2011 and all these old cast iron gas mains just are experiencing de-alloying and selective leeching and they're not getting repaired. And so they're having catastrophic failures.

[23:15] Some solutions, again, material selection...Change the alloy that you're using. Use cathodic protection and apply protective coating. This example at the top is actually from the Denver Federal Center. Some of my previous [laughs] corrosion calling [inaudible] these when they were changing some of the piping here at the Fed Center.

[23:36] You can see these were cast iron pipes and they just had the iron leech out and they had these failure holes. Again, this bottom is a ductile pipe that has the same thing.

[23:57] Very often you cannot tell from looking at a pipe that it has the alloying occurring until you start tapping it. For example, these holes were made by just taking a small hammer and tapping at it and then it just starts to break down because it is so low strength that it will just come right off.

[24:20] The next form of corrosion is erosion corrosion. You often see this in backed up pipes where you have accelerated corrosion due to flow of a corrosive fluid across a metal surface. This is both an electrochemical and a mechanical process. This often results in very high corrosion rates. Some things that you might have heard of, for example cavitation, high velocity erosion corrosion, and abrasion.

[24:46] Solutions to this is to design your structure in a way to prevent turbulence or impingement or cavitation. Select suitably resistant materials. Again, apply protective coating or apply cathodic protection. Although a caveat, that is that. If you have high-flow rate, your CP system might require very large amount of current in order to actually protect.

[25:11] Thinking about this is the design stage is really the place to start for mitigating erosion corrosion. The next one is intergranular corrosion. This happens along reactive grain boundaries or segregating grain boundaries in alloys. One example is chromium depletion in austenitic stainless steel. Again, solutions are your material choice.

[25:36] Choose alloys that have been properly heat treated to prevent the segregation of the grain boundaries. Choose lower carbon steels. The next one is environmentally induced corrosion. This is where you have cracking and corrosion due to a mechanical stress and a corrosive environment. Here, you often have for example [inaudible] or something like that of a material. You have your mechanical stress.

[26:05] You also have your soil or your water electrolytes where you have a corrosive environment. Some examples of this are stress corrosion cracking, I have an example in the slide for 360 stainless steel, corrosion fatigue, hydrogen-induced cracking. Especially stress corrosion cracking is something that you'll hear us talk about a lot in our corrosion group at TSC.

[26:29] Solutions, same thing. Select suitably resistant materials, protective coating, cathodic protection. The other one is microbial corrosion. This is when you have bacteria on your structure, you can actually have some bacteria such as sulfate-reducing bacteria that produce chemicals which can accelerate corrosion.

[26:55] The biological actions from these microbes can actually accelerate your corrosion rate. You can do several things for this. Again, there are materials that are more resistant than others. You can also use cleaning or

BioScience, for example, to kill these types of bacteria in your structures or pipeline.

[27:18] Apply antifouling coating so that the microbes have no place to attach to a structure and also cathodic protection. Finally, we come to corrosion of reinforced concrete. We had quite a lot of questions about this in our corrosion school this last time. I have a couple slides on this, as it's something that we see quite a lot in reclamation structures.

[27:40] We have a lot of concrete structures and reinforced concrete. One thing about concrete is it's excellent in compression but quite poor in tension. You reinforce concrete for example, with rebar in order to provide that extra support if your structure is ever placed in tension. However, the corrosion of rebar, as I said before, when the material corrodes that [inaudible] there's an oxidation product is actually less dense which means that it has more volume.

[28:13] Your rebar will actually expand. This can cause these, first of all, small cracks in your structure. Eventually, they can lead to the exterior surface of your concrete. When that happens, that will only accelerate your corrosion. You'll start to usually see staining at the surface of your concrete.

[28:34] Eventually, as this continues to corrode it will cause too much stress on the concrete and you'll have [inaudible] . Here's some examples from some of our reclamation structures. As I said, the corrosion product from the seal can cause cracking or spewing of the concrete which then increases the exposure of the seal and leads to even faster corrosion rate.

[29:01] One example here is, as I said, you often see one of the first signs is the staining of the concrete, especially when you have embedded rebar. This is an example where you have a very small patch to start off with. That's what it looks like from the exterior, but when you come up, this is...One my colleagues came up with this small pen knife and started chipping away at that.

[29:26] You've already developed stress in your concrete, and that comes right off. You can see here your [inaudible] . Some of the solutions that we recommend for that are using galvanized steel or stainless steel or epoxy-coated steel rebar. These are all three either material choices or in the case of the epoxy, a protective coating to prevent corrosion in your rebar.

[29:55] You want to ensure proper curing of your concrete. If you end up with a more porous...If you have poor curing conditions, you can get a more porous concrete, and this will lead to more moisture that can get in there and start the corrosion in your rebar. Also, you can apply treatments to the surface of your concrete. There's an example right down here.

[30:18] Then apply cathodic protection. We're nearing the end. I'm going to switch gears just a little bit. I have a few slides on the capabilities of the other TSC corrosions. From this slide, these are some of our capabilities. We have a lot, so I had to make them very small, smooch them on one slide. I'll just go through the list and tell you some of the areas that we can help you with here at the TSC and the materials lab.

[30:49] Corrosion mitigation engineering. This is a no-brainer. We can help you design systems from the very beginning to prevent as much as possible corrosion in your system. This includes, for example, cathodic protection systems. As I mentioned before, there's a couple different types of cathodic protection systems depending on what type of structure you're using.

[31:15] We have engineers here who are certified by NACE to do designs of these types of systems. We can also develop sets for your structures, the corrosion sets for your structures, and help with material selection. We can help you by doing field inspections, testing, and monitoring of your cathodic protection systems or of your structures.

[31:42] For example, if you have an underperforming CP system, we can help you with some of the field testing and troubleshooting of that. We can also do training for your technicians or for yourself, your engineers, to do some of the field testing and troubleshooting. We can do inspections during and after construction and installation, for example, of the CP system.

[32:06] We can also help with inspections of aging and corroding infrastructures and even sale structures by doing failure analysis and finding out just where the problem was so that we can prevent these on similar structures in the future. We have two techniques that we are doing for corrosion mitigation and damage repair that are somewhat novel.

[32:28] One of these is electro-osmotic pulse technology. We have a presentation if you have an interest in that. We can give you some further information. There's two engineers here who would be happy to talk to you about that as well as we have been doing some fiber reinforced polymer repair particularly with concrete, but we can also do some steel structures.

[32:54] What I've been working on quite a lot is developing our corrosion research lab and some of our corrosion chemistry capabilities. This will allow us to do some quantitative analysis of your soil and water samples, particularly for sulfate and clay concentrations and compounds. When you're thinking of installing structures or designing structures, we can do those testings in-house.

[33:18] That instrument has been ordered. We should have those capabilities in a couple of months' time I hope. As well, we can do some new materials testing in our lab. We also have some resources for you as far as education and manuals, and I'll talk a little bit more about these. One of the things that we do every year in October is the corrosion and colluding school.

[33:45] This is a several-day class where you actually come here to Denver to the TSC. Many of you are on our corrosion mailing list because you have taken portions of the corroding school in some year or another. Many of the slides from this presentation come from that, and we have several other sections on coatings as well and corrosion as well as some hands-on demo.

[34:13] We have the corrosion webinar series, which this is the very first webinar. We are hoping to do this in conjunction with our coating corrosion school so that you can hear our voices and get some advice three times a year. Two webinars and then the school.

[34:30] We also have some online instructive videos that hopefully will be posted this summer that will be a resource for you.

[34:38] We are working on corrosion-related guides and manuals and then as well corrosion research. We do have one newly published manual, and this was published in December 2012. It's a guide for field installation of corrosion monitoring systems and cathodic protection systems. That is available. We have it in PDF.

[35:00] If you're interested, please send us an email, and we will get that out to you. We will also hopefully have that on the website soon. This is our corrosion research lab. We have two rooms in the back of the Building 66 here at the TSC in a little storage closet and have been working quite a lot to get this up and running again.

[35:22] We have some old instrumentation. We borrowed a few new [inaudible] equipment. Here we have a pH setup so we can do pH and collect ions, conductivity of the materials. We have a potentiostat so we can test, for example, different metals and their corrosion rates in soils and water.

[35:46] We have an empty bench over here, which is supposed to be our ion electrography system, which we're getting soon, which will allow us to do the clay and sulfate analysis. We have these new capabilities that we're hoping to...Some of you have some ideas or have some problems then we can start some small research projects and get those capabilities going again here in the materials lab.

[36:15] As I mentioned some of our capabilities of our lab are the clay and sulfate analysis for all fields do, for example, arsenic or selenium testing in water. We can do pH, dissolved oxygen, and conductivity, and corrosion rate testing in various environments.

[36:27] Right now we have one S&T-funded scoping study. This is effective coin versus forming treatment on degradation of infrastructure materials so taking a look at those two compounds and how they might affect the rate of degradation. Mostly are pipelines but also some coating materials.

[36:49] I also have this small project-funded program on concentration corrosion [inaudible] concrete cylinder pipe. Some ideas that we have for the future, looking at alternate power sources for cathodic protection systems. We often have pipelines that are quite far away from any of our AT electrical transmission lines.

[37:10] We would like to have cathodic protection on them, and we have rectifiers that need to have power. Some examples might be wind, solar, or hydraulic power for that. We also would like to look at carbonation of concrete and its effects on corrosion and rebar and working on developing a galvanic series as a reference for reclamation materials in fresh water.

[37:37] We also have a project partially funded by S&T on the effect of CLSM materials on pipeline degradation. We want to hear your ideas. One of the things that we'd like to get out there is that, if you do have any problems or ideas for research related to corrosion or material degradation, we'd love to partner with you.