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FORWARD THINKING:

A CASE STUDY ON UNDERWATER INSPECTION OF NEW GENERATING ASSETS AND HOLE PLUGGING IN AN ACTIVE SURGE SHAFT

Underwater inspections at hydroelectric dams are a hot topic amongst major power producers when it comes to identifying potential issues with their structural assets. For many years now, owners of hydroelectric dams have been performing inspections on their older underwater assets in order to set up proactive maintenance plans and to achieve regulatory compliance. In these cases, the older assets are inspected utilizing dive teams and remotely operated vehicles (ROVs), potential problem areas are identified, and rehabilitation plans are carried out to mitigate risks to the structure. This is an accepted course of action for most owners and is a good way to extend the usable life of their assets.

However, while regular inspection is usually part of the standard plan for older facilities, it is considerably less common to see power producers performing detailed underwater inspection on their newer assets. Despite the assets being newer, conducting thorough inspections once the plant has been commissioned can be beneficial in several ways:

The plant can be examined to see if it is operating properly after a short period of running allowing for the identification of premature wear, leaking, or of areas that might have been negatively affected during the commissioning process.

If there are areas of concern that are discovered that were not seen during dry walkthroughs, swift resolution can occur between the ownership, construction companies, and insurers to mitigate the hazard.

If there are no areas of high concern found, the inspection can be used as support detail for agreement between the owners and the insurer as well as to support acceptance of the structure from the construction companies.

The following case study will examine a generating facility in Bhutan where this type of forward thinking with a newer facility allowed the owner, Druk Green Power Corporation, to identify issues very early on so that a plan could be put in place to mitigate a potential disaster.

PHASE 1: INSPECTION

In 2010, due to equipment capabilities and previous inspection experience at hydroelectric plants, Hibbard Inshore was hired to inspect two facilities in Bhutan utilizing their fleet of ROVs equipped with video cameras and multiple types of sonar. The purpose of these inspections was to look at the underwater structures of each plant to determine how well they were holding up after they had been commissioned. While one of the plants, Chukha Hydro, had been in operation for some time, the owner decided to also proactively inspect their newer Tala Hydropower Plant. While both facilities had been inspected in a dry state prior to commissioning, the owner thought it prudent to also inspect them now that they had been operating to determine whether any conditions of concern were present after the introduction of water. This would be the first inspection of these structures since they had been filled. In order to perform the inspections, Hibbard Inshore used two ROVs, a Long Range Sub-Atlantic Navajo with 5 kilometres of tether and a 600 meter depth rated LBV600-6. The combination of these two vehicles allowed Hibbard Inshore to inspect the internal portions of each plant's underwater structures to look for signs of wear and degradation such as concrete spalling, out of round conditions, cracking, holes, sediment buildup, and debris. During the inspections of the head race tunnels, surge shafts and pressure piping, the Hibbard Inshore ROV saw several small anomalies that were considered "areas to watch" for the future to make sure further degradation wasn't occurring, and the ROV detected several small holes in the concrete in the bottom of the surge shaft at the newer Tala Facility. After observation with the ROV cameras, it was clear that particulate in the water was being sucked through each of the holes meaning that there were flow paths from inside of the Surge Shaft to underneath the structure. This finding was of great concern to the future stability of the structure.

Figure 1 Hole with Protruding Material from Initial Inspection

Figure 2 Hibbard Inshore 5 km Sub-Atlantic Navajo and 2 km Seabotix LBV for Initial Inspection

PHASE 2: HAZARD MITIGATION

Very shortly after the discovery of these holes with flow, the plant owner, the construction company responsible for the original construction of the surge shaft, and Hibbard Inshore all proactively looked for solutions to permanently stop the flow through these holes to prevent further degradation. Since the plant provides a great source of power and revenue for the region, it was determined that solutions to plugging the holes that would allow the plant to maintain its normal 8 hour shutdown windows each day would need to be designed. The access to the holes was through the surge shaft, which was accessible through a tunnel and was 180 meters in height with approximately 100 meters of water depth under normal operating conditions. Because the flow through this area of the plant under operating conditions is around 10 meters per second, all materials would need to either be securely in the hole or completely removed from the surge shaft each day prior to the scheduled generation, so that no risk would be introduced that could have a negative impact on the turbines. A project of this exact nature to make a permanent hole repair without dewatering at 100 meters of depth, with the restriction of 8 hour outage periods, confined location, and high flow periods in between outages to the team's knowledge had not previously been performed without manned entry. However, due to the short outage times, the confined nature of the work, and the depths involved, it was determined that utilizing an ROV provided safety and economic benefits over attempting to use a commercial dive team.

Upon conferring with the Hibbard Inshore team which included Dr. Ray Henn of The Colorado School of Mines and Brierley Associates, the first option that was discussed was to devise a ➤

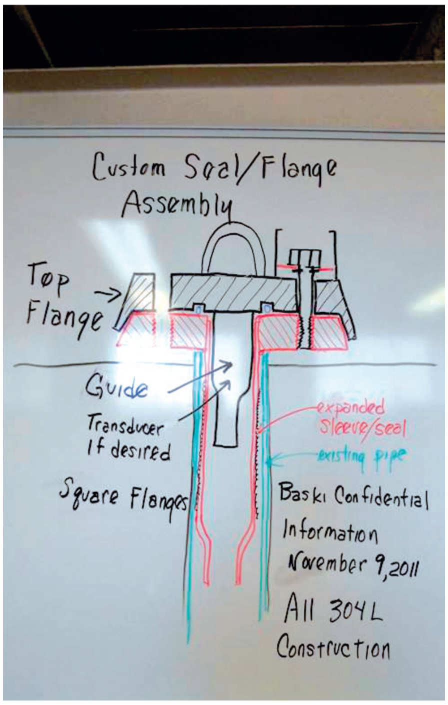

Figure 3 Packer Initial Concept Drawing

method to pump grout from the surface into each hole while leaving the shaft flooded. In this scenario, the Hibbard Inshore ROV would be able to prepare each hole for grouting by clearing it of debris using an onboard saw and a hydraulic drilling system. Once the hole was cleaned out, a customized grout packer would be inserted to allow the ROV to attach the grout hoses from the surface and the grout to be pumped into each hole.

It was determined that this approach would be very risky due to the fact that it was unknown how large a void existed underneath the surge shaft slab, and therefore it was unknown how much grout would be needed to sufficiently fill each hole. What was also unknown was whether each of the holes communicated with the others under the shaft. There were concerns that the grouting would need to be performed in a single 8 hour shift at each hole. If so, pressure differentials would need to be closely monitored to avoid inadvertently placing forces on the slab that would result in cracking or heaving, which would be disastrous. Because the grouting of each hole needed to be completed in a single 8 hour shift,180 meters below where the grout system would have to sit at the top of the surge shaft, the engineering issues for grouting were deemed to be complex. Understandably, the owners were looking for a low risk option that could be completed quickly to reduce or eliminate the flow through the holes as through additional investigation, the owners found the exit path of the water from inside the surge shaft which was now exiting through the side of the mountain. Because of this and the complexity of the grouting scenario, and the accelerated timeline of the project, that option was set aside in favour of providing customized plugs to fill each hole.

It was determined that the concrete placed to create the slab at the bottom of the surge shaft was M20 concrete and that specialized plugs based on grouting packers could be placed into each hole and inflated using high pressure water to complete a seal. These packers were specially designed to be inserted by the ROV, have the water hoses hooked up and unhooked by the ROV and then be epoxied into place by the ROV. Each packer was made from stainless steel and was coated in vulcanized rubber to provide a sealing surface. The packers were specially designed in order to create a seal while not exerting forces that would exceed the compressive or tensile strengths of the concrete and still requiring great force to remove them from each hole, thereby allowing them to remain in place safely during operations. After discussing other possibilities, it was determined by the owner and construction company that this was the best method for repair, and the Hibbard Inshore team was hired to design the packers with Baski Inc. of Denver, Colorado so that they could be inserted by the Hibbard Inshore Sub-Atlantic Mojave ROV.

The packers were designed, manufactured and tested by Baski Inc. with guidance from Hibbard Inshore and Dr. Henn, and were shipped to Bhutan for installation in early April of 2012. Several sets of packers were manufactured in order to account for the possibility of varying sizes of holes. The hole sizes were estimated from the previous inspection, but it was not known how the holes might have changed since that time, and due to the urgency of the project, the owner, construction company and Hibbard Inshore all agreed that Hibbard Inshore should come prepared for a variety of scenarios.

Upon arrival at site, the Hibbard Inshore ROV was deployed to first measure the holes to determine if there had been any noticeable change from the previous inspection in 2011. The ROV was deployed to the bottom of the surge shaft, and measured each of the holes to confirm that they had not changed in size or nature since the previous inspection. Upon confirming the current size of each, the proper packer sizes were selected for each hole, and the ROV set forth to prepare each hole to receive its own packer plug. This preparation included inserting a measuring tool into each hole to determine if there was anything blocking the path of the packer as the packers had a minimum insertion length required to make a proper seal. Differential pressure tests were performed to evaluate communication between the holes and learn more about the nature of the leaks. A ROV operated drill was brought in case any of the holes needed to have lodged debris cleaned out, and a ROV operated saw was also brought to deal with a piece of protruding material sticking out of one of the holes.

Once the holes were inspected and measured, two packers were inserted one at a time by the ROV, inflated to seal from the surface while monitored by the ROV, epoxied into place. The hoses and interface piece were then removed to minimize any material protruding from each hole.Only enough epoxy was inserted into each packer to aid the seal, and grouting under the slab was not performed from inside the shaft due to the previous concerns. Two of the three existing holes had packers inserted during this operation, and a fourth smaller hole was filled with epoxy. A packer fill of the third larger hole was attempted multiple times, but the monsoon season had begun by the end of the project, reducing visibility in the bottom of the surge shaft to almost zero and making it impossible to perform the third insertion until the water clears up. This insertion will occur once the water does clear; however, positive results were found from the insertion of the initial 2 plugs as it was found that the flow rate through the side of the mountain had reduced by approximately 60%, meaning that these holes were the primary source of leakage and the packer insertions worked properly.

Figure 4 Packer CAD Model

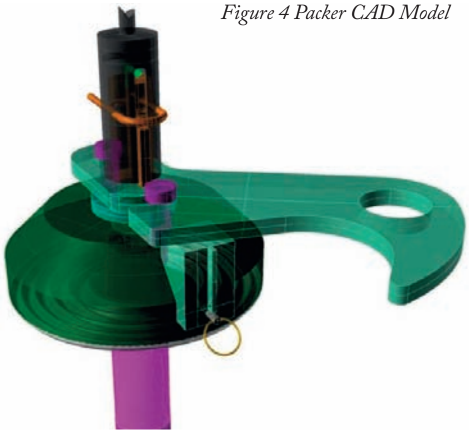

Figure 5 Packer Final Construction

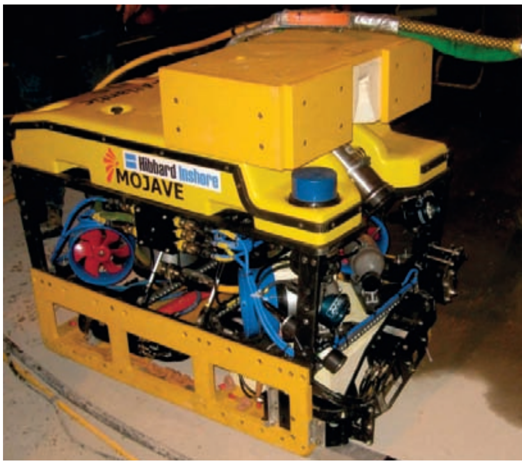

Figure 6 Hibbard Inshore Sub-Atlantic Mojave for Packer Insertion

Figure 7 Hibbard Inshore Mojave Monitoring Packer Epoxy Fill

Figure 8 Packer Cap with Floats for Retrieval after Disconnect

In conclusion, this was a case that started with the plant owner thinking proactively about their new generating assets. Because of this forward thinking, they were able to find an issue that could have become very serious had it not been addressed. With the facility still being new, the owner was able to enlist the help of the original construction company to work together to make appropriate repairs to the structure, and they accomplished this through hiring Hibbard Inshore to design and implement a repair method for their unique circumstance performing the work safely and without significantly interrupting the regular plant operating schedule.

'IN 2010, DUE TO EQUIPMENT CAPABILITIES AND PREVIOUS INSPECTION EXPERIENCE AT HYDROELECTRIC PLANTS, HIBBARD INSHORE WAS HIRED TO INSPECT TWO FACILITIES IN BHUTAN UTILIZING THEIR FLEET OF ROVS EQUIPPED WITH VIDEO CAMERAS AND MULTIPLE TYPES OF SONAR. THE PURPOSE OF THESE INSPECTIONS WAS TO LOOK AT THE UNDERWATER STRUCTURES OF EACH PLANT TO DETERMINE HOW WELL THEY WERE HOLDING UP AFTER THEY HAD BEEN COMMISSIONED.'