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Hydro Mechanical Division Final Report

Prepared for Department of Energy ERIP Project # 624

Final Report

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Abstract

DOE/ERIP project # 624 “Fluid Flow Release Regulating Device” designed, constructed, tested, and installed a rubber crest gate for regulating water levels at an impoundment such as a hydroelectric dam. A 92 foot long by 27 inch high rubber panel was installed in January 1997. Initial results were good until fabric degradation internal to the rubber caused loss of stiffness. Substitutes for the failed fabric are being tested. The project will continue after DOE participation terminates.
Executive Summary

The grantee saw a need for, and patented, a form of self regulating spillway control device to boost power production at hydro electric sites. The Department of Energy presented grant #624 under its energy related inventions program to help develop the device. Under this grant a method was devised to predict numerically the loads imposed on such a device. Three full scale prototypes were manufactured and tested in a large flume at the Federally owned Conte Anadromous Fish Laboratory. The test results showed an overall increase of stiffness was necessary to overcome viscous drag.

A working hydro electric site in southern New Hampshire was chosen for a pilot installation. Steel castings for the anchor plates were manufactured as well as a 92 foot long by 27 inch high 3000 pound slab of rubber to be mounted vertically on the dam crest. Construction on the dam crest was begun in early December of 1996 and despite bitter cold, ice and flooding was completed in January of 1997.

Initially the rubber crest gate performed well, although there were some manufacturing defects resulting in weaker areas in the rubber that had to be reinforced. After long term exposure to heavy ice loading the gate began to lose rigidity and develop small buckles running horizontally along the base in the areas of highest loading. Microscopic examination of the material showed delamination of the internal stiffening fabric due to the high compressive loads. Wooden boards were placed along the dam’s crest to retain the pond's elevation and power generation that may have been lost due to the rubber’s failure.

The project is continuing with testing of steel and monofilament nylon fabric being used to replace the polyester fabric that failed. The failed gate will be removed and another installed during the winter/spring of 1998.

Much interest in the device was generated by the project, most notably the largest owner of independent hydro electric projects in the country. The delamination problem is currently being surmounted and should prove to be the last obstacle before full commercialization of the device.
A computer program to quantify the static loads on what is basically a cantilever beam with eccentric loading was developed under this grant. Using the data from this program, three full height samples were fabricated by the Goodyear Tire & Rubber Company. The samples were manufactured to have stiffnesses of 90% of theoretical, 100% of theoretical and 110% of theoretical as designated by the program.

The three samples were shipped to the Conte Anadromous Fish Research Laboratory in Turners Falls, Massachusetts, where they were mounted in a 10 foot wide flume with sufficient flow to provide full design flood overflow conditions of four to five feet above the rubber gate mounting point. The facility was chosen for its ability to provide precise flow control and use its complement of underwater cameras and lights to study the actual position of the rubber gates under full overflow conditions. Attending the tests were two engineers and a technician from Goodyear, two Conte personnel, and myself. The first trial instantly swept away the wooden mounting apparatus built by the Conte personnel. We then built a second, much sturdier, mounting device which performed well for the remainder of the tests. Each gate was run to full overflow condition, and the height of the water and corresponding position of the rubber gate were observed through the underwater cameras. During the first set of trials we discovered that the base for the rubber gates was slipping from between the two pieces of steel angle iron that was being used to clamp the rubber in an upright position on the mounting platform. We found some saw tooth pattern aluminum strips at a local hardware store and inserted them between the rubber and the angle iron to provide a “bite” into the rubber. This modification worked well and testing continued. As I had expected, the combination of viscous drag and downstream vacuum behind the gate increased the load above the theoretical model, causing the gates to bend further over. The gate with 110% of the theoretical stiffness performed well.

During the design phase Goodyear informed me that the rubber composite material would probably take an initial “set”, or lean after its first cycle. We were prepared with hardwood wedges which could be inserted underneath the mounting brackets to remedy this. After the initial trials, the set was apparent and 15 degree wedges inserted under the mounting brackets. Further trials were run and no additional set was noticed. After three days of testing an order was placed with Goodyear for 110 feet of the stiffest material.

The foundry and pattern maker for the cast iron clamping pieces to be used in the field installation were each visited to discuss addition of sawtooth pattern teeth on the squeezing faces of the clamp bars and a 15 degree upstream slant to be added to the same surfaces. These changes to the pattern were made and casting continued on schedule.

Watson Dam in Dover, N.H. was chosen for installation of the pilot project. Watson Dam provides the head water for a 250 kw independantly owned hydro electric facility. The dam has historically operated with 2 foot high wooden breakaway flashboards and has two segments each about 100 feet long. Holes were drilled every foot along one of the dam sections and ½” threaded rod epoxied into the holes to anchor the upstream clamping plate. After the epoxy set, leveling grout was used to smooth out some of the dips in the dam crest. Some of the difficulties encountered at this time were finding an epoxy that would set both
underwater and at sub freezing temperatures, and completely tenting and heating the dam crest to cure the leveling grout.

The spool of rubber was lifted onto the dam crest with a crane and set into an axle yoke. Holes were drilled into the upper edge of the rubber and shackles installed into the holes. A 1 ton come-along was affixed to each shackle and run up to a pulley hung from a ½" dia cable previously suspended above the dam at a height of about 6 feet. The rubber gate was winched out over the dam crest until it was completely deployed and hanging above its anchor plates. The rubber was then lowered down by slackening each winch until it was level and just touching the crest. ¾" dia. holes were drilled every 6 inches along the rubber gate base to match corresponding holes in the cast iron anchor plates. (at times the Porter Cable drill we used was partially submerged during this process, yet continued to work well) 5/8" dia. bolts were run through the clamping plate/rubber/clamping plate sandwich, tightened, and the shackles and come-alongs removed.

Soon after installation, the two outside corners began to sag downstream. Their thickness was measured and found to be 0.10" thinner than the rest of the rubber. Stiffening blocks were added behind the rubber at these areas and the gate ends again became vertical. Ice had been forming on the pond during this entire process and was becoming thicker rapidly. By the time the ice had become 4 to 6 inches thick the rubber gate had taken a downstream lean of about 15 degrees. A channel was cleared of ice for several feet upstream of the gate which then regained a vertical position. Six inch by six inch rubber stiffening blocks were added to the base of the gate every 8 feet to further stiffen the structure. This temporarily improved the performance of the material, however it became apparent that the rubber material had lost some of its original resilience. Small horizontal bulges were noted running horizontally along the rubber on the back of the gate just above the clamping plate. Goodyear was consulted and two engineers from Akron visited the site. Samples were cut out of the rubber and returned to Akron for analysis. Towards the end of February, deterioration of the gate was hurting performance of the hydro electric site, so the wooden boards were replaced upstream of the rubber to maintain pond level.

Meanwhile, back at Akron, Goodyear R&D were microscopically analyzing the portion of rubber removed from the site. This analysis revealed that the woven fabric used to stiffen the gate had split and crumpled under the extreme compression experienced in this area. The rubber compound itself still retained its original resilience.

In spite of the failure, the hard data generated by this pilot test and the fact that the rubber gate could actually be installed generated considerable enthusiasm at Goodyear. Experimentation is currently under way using more resilient rubber compounds and reinforcing materials of steel belting such as used in heavy equipment tires and a nylon monofilament fabric that will not split or buckle under the extreme compression loading. I expect to return to Akron, Ohio in late January or early February to see tests in their R&D labs of these composites and choose one for the next installation which will be in late spring of 1998.
CONCLUSIONS

- The tests at Conte labs and the initial results at Watson Dam prove that we can predict the required stiffness of the rubber gate.

- The underwater cameras at Conte showed that the degree of bend and resulting bulge of the gate over the fixed dam crest are acceptable.

- The anchoring and clamping system works well.

- Installation of the system is not only possible but inexpensive compared to the costs of installing other forms of crest gates.

- The woven polyester fabric used at Conte and the pilot site is not capable of long term performance due to splitting and crumpling under extreme long term compression loading. Steel belting and monofilament nylon should both prove capable of resisting this splitting, and are currently being tested at Goodyear R&D.
• RECOMMENDATIONS

Work on this project should and will continue. Many valuable lessons have been learned and the concept proven to work and be installable at a competitive price. The tools and materials purchased under the D.O.E. grant should be used for completing the project and bringing the Rubber Gate to the market.
EQUIPMENT INVENTORY

The following list of equipment was purchased using the D.O.E. grant funds and was and still is being used to pursue the goal of bringing the rubber gate to the market.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Estimated Value</th>
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<tbody>
<tr>
<td>pentium 100 computer</td>
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<tr>
<td>hand drill</td>
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<tr>
<td>concrete drill</td>
<td>150.00</td>
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<td>(12) hand winches</td>
<td>240.00</td>
</tr>
<tr>
<td>video camera</td>
<td>250.00</td>
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</tbody>
</table>

The remainder of the purchases made under this grant were installed at Watson Dam for the pilot project, with the exception of the casting patterns for the anchor plates. Although still very serviceable, they are useful only for this project and have no resale value.