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Hydraulic Model Study of Gwinnett County Georgia Y15 Dam Overtopping Protection

U.S. Department of the Interior
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14. ABSTRACT
This report documents the findings from the hydraulic model study of the RCC overtopping protection designed for Gwinnett County Y15 embankment dam in Georgia. The performance of the stepped overtopping design over the existing dam with 3:1 downstream slope was investigated for overall adequacy of performance under the 2/3 and PMP events. The protection had a straight broad crest with angled section on both ends. A large flat section was located below the crest. The protection then continued down the 3:1 slope to basins at various elevations.

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Mission Statements

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Acknowledgments

The author would like to acknowledge the contributions of Gregg Hudock from Golder Associates, Inc. Georgia for providing the design drawings and technical assistance during the study. Also, the contributions of the NRCS technical staff in Fort Worth and Georgia, and Gwinnett County staff during the study and in peer review were invaluable.

The innovative model construction technique for the steps and drawings were provided by Rudy Campbell, Engineering Technician, in the Water Resources Research Laboratory. Neal Armstrong, Lead Craftsman, expertly constructed the model. Peer review was also provided by Leslie Hanna of the Water Resources Research Laboratory.

Hydraulic Laboratory Reports

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Disclaimer

The study was paid for by funding provided by Gwinnett County, Georgia through Golder Associates, Incorporated.

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TABLES

FIGURES

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Executive Summary

This section summarizes the findings of the hydraulic model study performed to investigate the adequacy of the roller compacted stepped spillway overtopping protection designed for Y15 dam in Georgia. The study results are documented in the report HL-2006-05 entitled "Hydraulic Model Study of Gwinnett County Georgia Y15 Dam Overtopping Protection" by Kathleen H. Frizell. The entire report is available on the Water Resources Research Laboratory website at: http://www.usbr.gov/pmts/hydraulics_lab/pubs/HL/HL-2006-05.pdf.

The study was performed at a 1:24 Froude scale which modeled the 1-ft-high prototype steps as ½ inch. The model included a portion of the upstream embankment, the entire stepped overtopping protection, and about 250 ft of the downstream channel.

The study produced the following results:

- The broad crest with ends angled downstream and low flow section produced a discharge of 44,335 ft^3/s under the maximum reservoir head of 7.96 ft above crest El. 966 as per the equation fit to the measured values, figure 4.
    - A discharge of 483 ft^3/s was measured through the 45 ft low flow crest under reservoir El. 965.28 meeting the design discharge of 481 ft^3/s at El. 466.
- The angled crest adjacent to the stepped sloping side walls seemed to reduce the run out along the steps, but also produced additional flow concentration in the groin areas that exited the basin without significant energy dissipation.
- Attempts were made to reduce the flow concentrations using fillets, walls to divert the flow from the side slopes, and high sills on the flat upper bench. The walls and high sills created aesthetic issues at the necessary height to entirely spread the flow throughout the basin, and were; therefore, not pursued. The recommended solution was to install 3-ft-high sills at the downstream end of the upper flat bench with dimensions as shown on figure 18.
    - The sill length on the left side at the 2-ft-height is 72 ft from the intersection of the flat bench with the side wall step. The left side sill extends out from the intersection of the side slope a distance of 66 ft at the 3-ft-height.
    - The sill length on the right side at the 2-ft-height is 59 ft from the intersection of the flat bench with the side wall step. The right side sill extends out from the intersection of the side slope a distance of 53 ft at the 3-ft-height.
        - The width of the sill in the flow direction is arbitrary and should be structurally designed by Golder Associates, Inc. to ensure proper anchoring as near to the downstream edge of the flat bench as structurally feasible.

        - The left and right sides may be made of identical length, and, if so, matching the left side would be preferable.

- Velocities were measured under the 2/3 and full PMP events at seven locations below the end of the protection where the jets from the flow concentrations exited the basin and other points laterally (table 3). The velocities were measured both with the end sill as originally designed in the lowest basin and with a 2-ft-high sill installed across the entire end of the protection.

    - Velocities under the PMP of about 21-22 ft/s occurred at locations 6 and 7 from the flow concentration exiting the right side of the structure. On the left side of the basin the velocities reached 17 -18 ft/s at locations 1 and 2.

    - The flow conditions appeared to be very similar with or without a 2-ft-high end sill located across the entire structure. The end sill will reduce recirculation of material into the basin until the zone downstream from the sill fills with material.

- Flow run out was investigated along the 3:1 sloping side walls below the angled crests. Two tactics were taken; 1) extend the side wall protection higher up the slope to El. 967 and mark the maximum run out, 2) look at stops to prevent the flow from extending beyond the original extent of the protection.

    - The extent of the protection would need to be increased throughout the entire height of the structure to contain the run out under the PMP without a mechanism to prevent the flow (figure 22).

    - Stops can be used to contain the flow along the upper portion of the wall at the break point in the RCC lift turn around, then out on the lower portion at the locations shown in figures 24 and 25. This would still require extension of the RCC on the lower portion of the wall to the location of the stops on the lower portion.

    - Figures 26, 27, and 28 show the containment stops forming a smooth wall-like surface along the break point in the RCC lift turn around. Use of these steps would require no additional extension of the side wall protection. They were modeled at 1-ft-high from the top down to El. 966 and 2-ft-high below that to the tailwater. Another option would be to start forming the stops from the bottom up and over widen the placement providing an overlap on each step run to prevent water from potentially passing at each stop edge.

Video documentation was obtained and may be requested by contacting Kathy Frizell at kfrizell@do.usbr.gov.

Background

Reclamation's Water Resources Research Laboratory in Denver, CO was contacted by Terry West of Gwinnett County Department of Public Utilities regarding the possibility of performing a hydraulic model study of a roller-compacted concrete (RCC) stepped overtopping protection for dam Y15. The dam was originally designed and constructed by the Natural Resources Conservation Service (NRCS) and is now the responsibility of Gwinnett County, Georgia. The overtopping protection was designed by Golder Associates, Inc. to provide safe passage of the routed Probable Maximum Precipitation (PMP) now that the dam has been reclassified as a high-hazard structure. Prior to acceptance of the proposed design, the NRCS National Design, Construction, and Soil Mechanics Center, Design & Construction Staff recommended that a model study be performed to verify the proposed design. Reclamation's Water Resources Research Laboratory (WRRL) was contacted to perform the model investigations.

Hydraulic Model Objective

The objective of the study is to confirm the adequacy of the designed overtopping protection to protect the embankment dam during passage of the PMP. This will require investigation of the discharge capacity, flow along the sloping side walls, flow conditions within the stepped spillway chute, and stilling basin. The principal spillway was not modeled.

Hydraulic Model Description

The model was constructed to a 1:24 Froude scale. The model scale was driven by the desire to maximize the size of the model, particularly the step size, to prevent scale effects as much as possible. In addition, the structure width needed to fit into a single bay of available laboratory space. The model scale produced a ½ in step size in the model for the 1-ft-high prototype step and allowed purchase of ready milled material for the steps.

The hydraulic model included the entire three-dimensional stepped overtopping protection on the downstream 3:1 face of the existing 36-ft-high embankment dam as shown on figure 1. The design drawings and the hydraulic parameters for the modeling effort were provided by Golder Associates, Inc, Georgia. The control for the overtopping section was comprised of a broad crest at El. 966 with a 45-ft-wide low stage crest at El. 964 aligned with the existing principal spillway conduit. (The model did not include the principal spillway conduit or the embankment drainage features.) In plan view, the crest had a 360-ft-long straight center section with 57-ft-long sections on both ends that were angled downstream. The design flow rate for the overtopping protection was predicted to be 37,962 ft^3/s under reservoir El. 973.96 with the top of the embankment at El. 974. A short run of 1-ft-high steps on a 3:1 slope led to a long, wide flat section at El. 956. The 3:1 sloping stepped protection then led to the primary stilling basin at El. 930. A sample section of the PVC sheet material cut into strips and mounted on a plywood template that was used to construct the steps in the model is shown on figure 2. The main stilling basin is dual purpose

providing for discharge from both the existing principal spillway with a discharge of about 120 ft^3/s under the maximum water surface El. 973.96 and the additional overtopping flow from the low flow notch. Flow from the primary stilling basin with an end sill discharges directly into the river channel downstream. The 3:1 sloping walls of the overtopping protection were constructed with steps on various slopes over the rock foundation and downstream embankment. The remaining portion of the basin was of varying elevation with no end sill. The tailwater was set at the end of the model to produce levels associated with existing conditions caused by downstream culverts.

In addition to the overtopping protection, a short section of the upstream embankment topography, and about 250 ft of the downstream river channel below the stilling basin were included. The downstream river channel is composed of minimal alluvial cover over good quality rock. Non erodible topography was modeled. The RCC will be covered with soil and seeded after construction, which, was of no concern in the model. An overall view of the 1:24 scale model as originally constructed is shown on figure 3.

Water was supplied to the model using the laboratory permanent Venturi system.

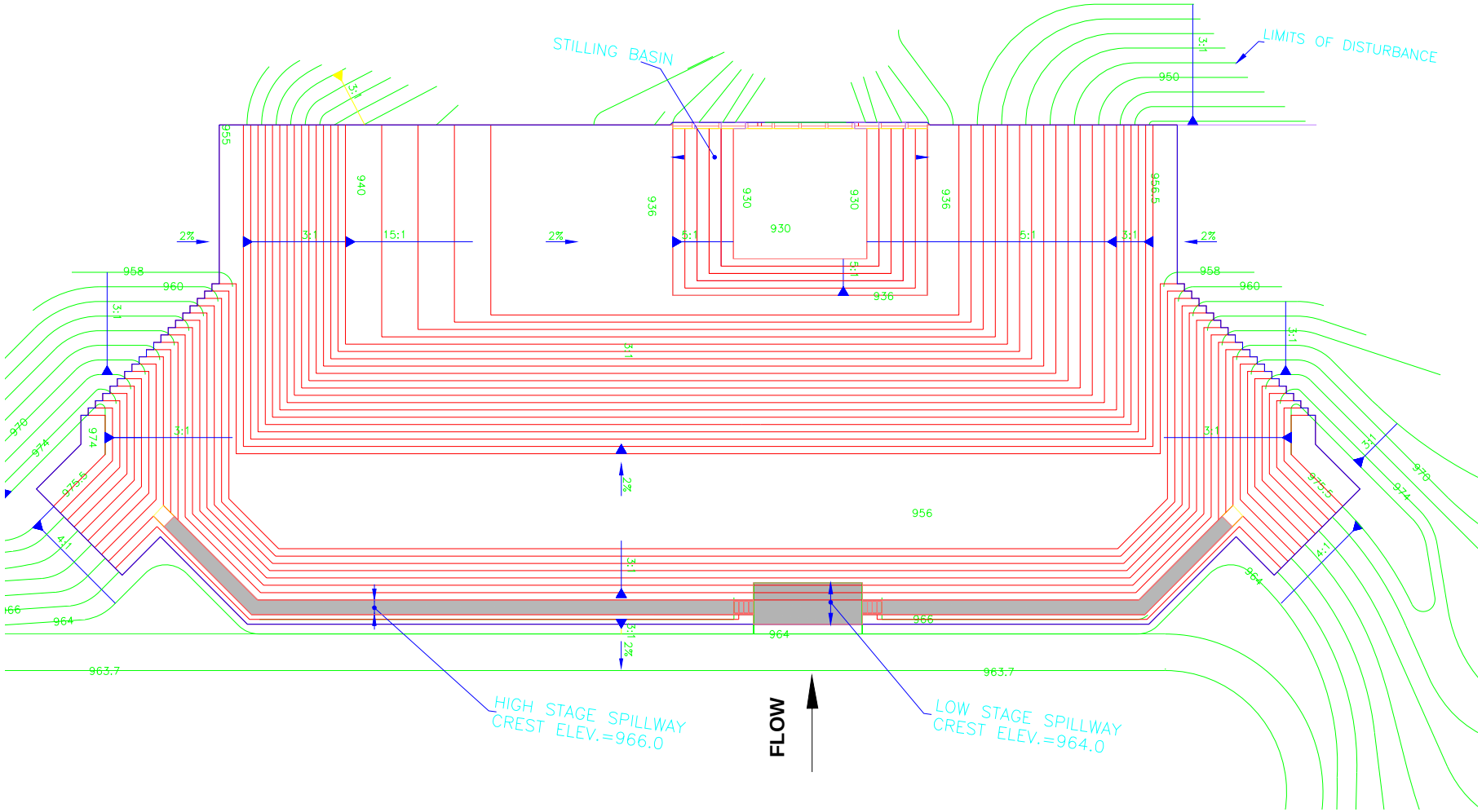


Figure 1. - Overall view of the RCC stepped embankment dam overtopping protection for Y15 dam.

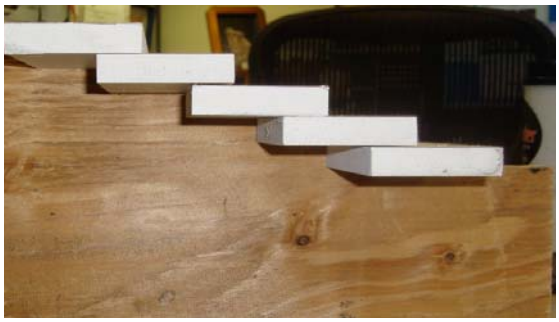


Figure 2. - View of the PVC sheet material cut into strips and mounted on a sample template.

Figure 3. - Overall view of the 1:24 scale hydraulic model of the Y15 dam stepped overtopping protection.

Test Plan

The scope of work for the hydraulic model included construction of the model based upon the initial design provided, testing and discussion of the initial findings, potentially two minor modifications to the model to produce an improved design, analysis, and reporting. Golder Associates, Inc, Gwinnett County personnel, and the NRCS jointly provided the direction for the test plan.

The requirements for performance of the overtopping protection were based upon NRCS guidelines and Gwinnett County DPU guidelines. Under the NRCS guidelines [1], the protection for the existing embankment must be adequate under the PMP event and some peripheral damage may occur under the 2/3 PMP event. Therefore, the test program focused on the 2/3 and PMP events.

The model investigations provided:

- A discharge rating for the existing crest configuration.
- Initial documentation of the performance of the stepped protection under the 2/3 and the PMP flow events.
    - These events would be documented under the flow conditions given in table 1.
- Suggestions to improve performance of the overtopping protection and stilling basin within the time frame and needs of the client.
- Information on adequacy of the walls to contain the PMP flow
- Information on flow conditions downstream from the stilling basins for the 2/3 and full PMP events.
- Results of the study in a hydraulic model study report and video.

The model will be operated for the client to review. During the review, suggestions will be discussed to improve performance as necessary. Construction of two small modifications to the model and limited testing to document performance of the modifications were estimated.

Table 1. - Discharge and tailwater information for Y15 dam based upon routing of the various flood frequencies and assumptions about whether the downstream road culverts wash out or not during the event.

Event Frequency	Discharge (ff^3/s)	El. with downstream culverts (ft)	El. w/o downstream culverts(ft)
10 yr	103	933	932.93
25 yr	234	934.22	934.09
50 yr	403	935.38	935.15
100 yr	581	936.41	936.04
500yr	2110	942.06	939.78
0.25 PMP	2726	944.68	940.58
0.5 PMP AMC II*	11576	951.83	946.57
0.5 PMP AMC III*	15190	952.94	948.05
0.67 PMP	20203	954.2	949.81
PMP	38046	957.37	955.09

*AMC II and AMC III denote different flood events based upon routing techniques.

Investigations

The following sections provide a discussion of the model investigations and results.

Discharge Rating

The investigations began with determining the rating curve for the compound broad crest structure controlling the overtopping. The crest consisted of a 45-ft-wide low notch section at El. 964 to pass the expected flood of 581 ft^3/s under the 100-year frequency event with the principal spillway. The main broad crest section at El. 966 is angled on both ends of a long straight section. The angled crest sections were designed as a result of extensive run out along the steps that was seen in a previous model study with a crest normal to the side walls [2]. The angled crest and intersection with the 3:1 sloping side walls produced a different crest length depending upon where the measurement was taken. Along the upstream side, the straight crest section was 368.33 ft and the 45 degree angled crest section were each 57.14 ft for a total length of 482.61. Along the downstream side of the crest the center section was 363.36 ft with the both angled sections at 54.66 ft for a total length of 472.68 ft.

The rating data in table 2 and the curve on figure 4 show that the PMP flow condition is passed under the expected reservoir elevation and the flood will not overtop the remaining portion of the dam. The head was referenced to the main crest at El. 966. The maximum reservoir elevation necessary to pass the overtopping flow PMP of 37,926 ft^3/s, plus the principal spillway flow of 120 ft^3/s, was computed to be El. 973.96 under a head of 7.96 ft above crest El. 966.

Table 2. – Discharge rating data from the hydraulic model for Y15 dam with the reservoir head referenced to El. 966. When the head value is negative the flow is entirely through the low notch in the crest.

Discharge (ft^3/s)	Reservoir Head (ft)	Reservoir El. (ft)
0.000	0.000	964.000
483.284	-0.720	965.280
1849.445	0.168	966.168
2628.975	0.480	966.480
2725.852	0.696	966.696
3740.473	0.936	966.936
4547.521	1.224	967.224
5731.099	1.560	967.560
7870.809	2.160	968.160
11687.621	3.024	969.024

Discharge (ft^3/s)	Reservoir Head (ft)	Reservoir El. (ft)
11574.997	3.144	969.144
13828.491	3.480	969.480
15189.705	3.816	969.816
18233.629	4.464	970.464
20204.473	4.824	970.824
27075.710	5.568	971.568
32035.281	6.168	972.168
38040.186	7.440	973.440
39667.651	7.512	973.512
35224.668	6.864	972.864

Figure 4 also shows the data fit to the weir equation equal to:

$$Q = 1974.155 \times H^{1.5}$$

where the head value is referenced to El. 966 of the main crest. The equation fit was not performed for the low flow and head values below El. 966. The actual flow through the low flow notch at El. 964 had an impact on the fit to the rating curve, particularly in the lower portion of the curve. The fit with the weir equation improved as the amount of flow through the notch became relatively less with increasing total flow. The discharge equation produces a flow rate of 44,335 ft^3/s over the crest under a reservoir head of 7.96 ft. This flow is quite a bit more than the predicted discharge under the PMP event.

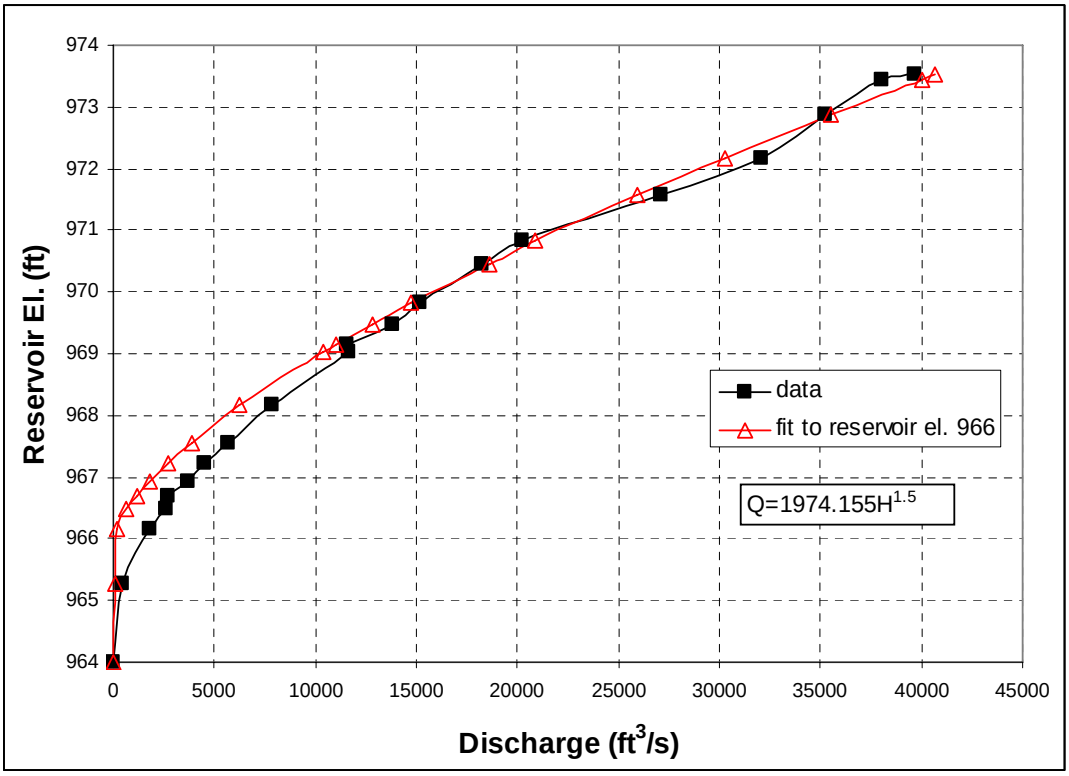


Figure 4. - Rating curve for Y15 overtopping protection with a curve fit to the free flow weir equation. The head was referenced to El. 966. The design discharge is passed below the top of the dam. The fit to the curve in the low flow range is not particularly good because of the relative amount of flow through the low flow notch compared to the total flow over the main crest.

Initial Flow Conditions

Initial flow conditions were observed and documented based upon the information in table 1 for further discussion during the client visit. The initial flow conditions were documented for the 1/4, both AMC II and AMC III 1/2, 2/3, and PMP flow conditions both with and without the culverts in the downstream road controlling the tailwater. The representatives for Gwinnett County later stated that they expect the roadway culverts to wash out at any flow rate exceeding the 25 year event as per their separate design capacity.

Low Flow Notch

Flow through the low notch section at El. 964, 2 ft below the main crest elevation, is shown operating on figure 5. The 45-ft-long notch was not centered on the crest length but along the centerline of the existing principal spillway. The flow through the notch was very small with the scale used in the model and an attempt to exactly determine the flow capacity of the notch prior to spilling over the main crest was not made. The 100-yr event was computed to be 581 ft^3/s including 120 ft^3/s through the principal spillway. A discharge of 483 ft^3/s was measured through the low flow notch at El. 965.28; therefore, it seemed that the expected flow rate could be passed through the notch without concern. Figure 5 shows that the flow through the notch spreads significantly along the flat bench.

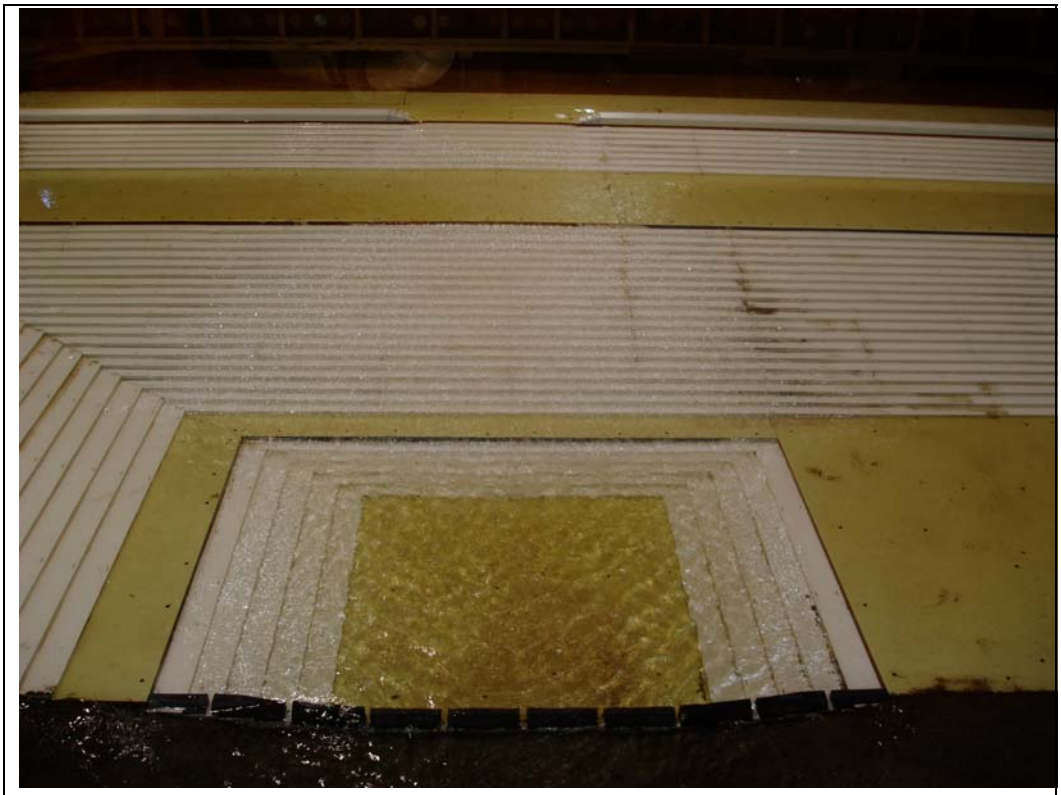


Figure 5. - Flow through the low notch section designed to pass the 100-year event.

1/4, 1/2, 2/3, and PMP Events

The initial flow conditions for the ¼, ½, and 2/3 PMP events are discussed in this section for each event. The flow conditions are very similar with the magnitude of the observed flow conditions increasing as the flow increases. Two separate tailwater elevations were set initially according to the values listed in table 1. The influence of tailwater was evident on the relative magnitude of the jets exiting the basin.

The following points were apparent from observations of the flow conditions:

- There was always more flow concentrated in the low flow notch as the discharge increased.
    - The flow in the stilling basin below the low flow notch was always easily contained with the hydraulic jump forming at the toe of the 3:1 slope and never extending to the end of the protection.
        - The 2-ft-high end sill never took an impact from the basin flow and did not seem to be necessary.
- Flow passed over the main straight crest, down the initial 3:1 stepped face, traveled across the flat bench at El. 956, and flowed down the remainder of the 3:1 slope without springing free from the stepped invert at any location.

    - The hydraulic jump formed at the toe of the 3:1 slope for all flow conditions and tailwaters with the extent of the jump easily contained within the basin limits, except in the groin areas.

- The downstream angled crests on either end of the main broad crest at El. 966 turned the flow inward toward the middle of the protection and generally away from the 3:1 sloping side walls.

    - The flow from the angled crest section met with the flow from the main crest section, and concentrated in the groin areas, and in the basin.

    - The flow from the angled crest flowed out along the side walls, but not to the extent that would be expected from flow from a crest at right angles to the side walls.

- Flow conditions improved downstream from the protection with the deeper tailwater associated with no washout of the downstream culverts.

    - Non uniform conditions existed downstream from the basins with more recirculation occurring on the left side than the right due to the influence of the topography blocking the exit of the flow on the left side.

The flow conditions for the initial overtopping design are shown in figures 6 through 14 for the 1/4 to PMP events.

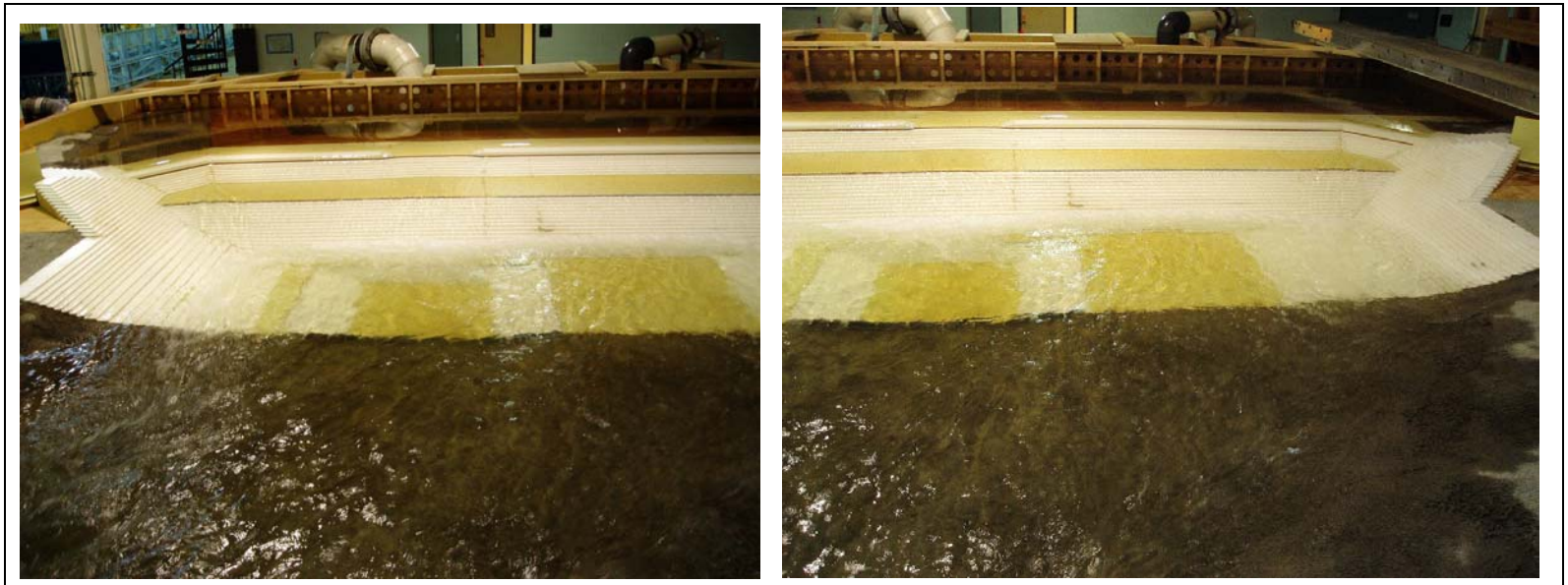


Figure 6. - One-quarter PMP event, looking downstream, operating over the initial design and the tailwater with culverts.

Figure 7. - One-half PMP AMC II event operating over the initial design and the tailwater without culverts

Figure 8. - One-half PMP AMC II event operating over the initial design and the tailwater with culverts.

Figure 9. - One-half PMP AMC III event operating over the initial design and tailwater without the culverts.

Figure 10. – One-half PMP AMC III event operating over the initial design and tailwater with culverts.

Figure 11. - Two-thirds PMP event operating over the initial design and tailwater without the culverts.

Figure 12. - Two-thirds PMP event operating over the initial design and the tailwater with the culverts.

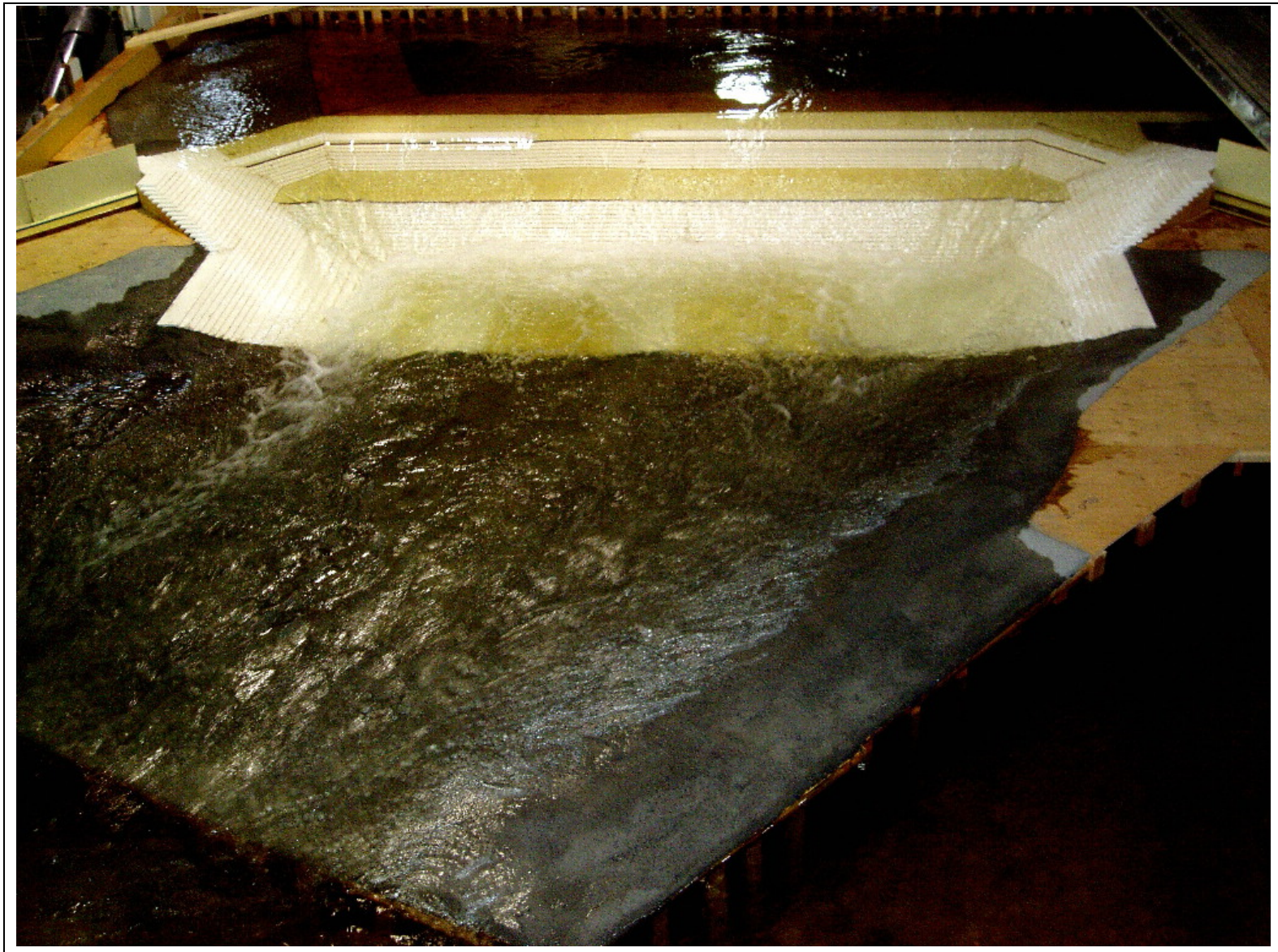


Figure 13. - Full PMP event with the initial design operating under a tailwater without the culverts.

Figure 14. - Full PMP with the initial design operating under the tailwater with the culverts.

Modifications to the Overtopping Protection

The flow conditions were observed by the clients during a visit to the WRRL on May 10, 2006. The overall impression during this visit was that the flow concentrations and run out along the walls was a potential problem but that these might not require too much modification to the design. In addition, the representatives from Gwinnett County outlined some past history and current concerns about the project relating to aesthetics that will restrict modifications in the design of the project to those that could be easily hidden or would be viewed as unobtrusive by the homeowners surrounding the lake.

The stilling basin area must perform adequately under the two-thirds PMP, while the embankment must not be exposed to flow that could cause dam failure under the PMP event. Given the tight schedule to investigate the design, the client requested that minor modifications be constructed primarily within the limits of the existing protection while improving the flow conditions enough to meet these criteria. Therefore, the approach was taken to look at improvements within the structure that would produce improvements, but not necessarily ideal flow conditions.

Initial Options Investigated to Reduce Flow Concentrations

Fillet on Upper Bench below Angled Crest

While the angled portions of the crest were designed to reduce run out on the side walls, they produced additional flow concentrations in the groin areas when joining with the flow from the straight crest and the restriction of the sloping side walls. Initial investigations tried to redirect the flow concentrations inward towards the middle of the structure to spread the flow. Figure 15 shows the right and left fillets installed below the angled crests that were the initial attempt to reduce the flow concentrations. This geometry did not redirect the flow significantly and other options were investigated.

Figure 15. - Initial investigations with fillets below the angled crest sections on the upper flat bench. Left photo is the right fillet looking upstream.

Additional Options

There were several other options that were perhaps only discussed and discarded because of aesthetic reasons or other design reasons:

- Raise the angled crest portions to minimize the flow concentrations as the reservoir head and flow increase. This would cause an increase in the reservoir lake level during flood stages. In addition, the top of the dam is going to be used as a path and the County thought that homeowners would be against it.

- Construct a wall to the height of the flow depth at the downstream end of the flat bench that would continue up the 3:1 side slope to redirect all the flow from the side walls more toward the middle of the structure. This was tried in the model and was effective; however, the County thought this would be unacceptable aesthetically.

- Construct high sills at the downstream end of the flat bench to divert more of the flow to the middle of the structure.

    - During the client visit 4-ft-high sills were investigated briefly. Figure 16 shows the flow conditions associated with the partial 4-ft-high sill located on the left or right side of the structure operating under the PMP. The sill worked quite well and led to the final recommended geometry. Further investigation also led to the conclusion that the sills would need to be considerably higher than a 3 or 4-ft-high sill to substantially improve the downstream flow conditions and this would be unacceptable from an aethetics and construction standpoint.

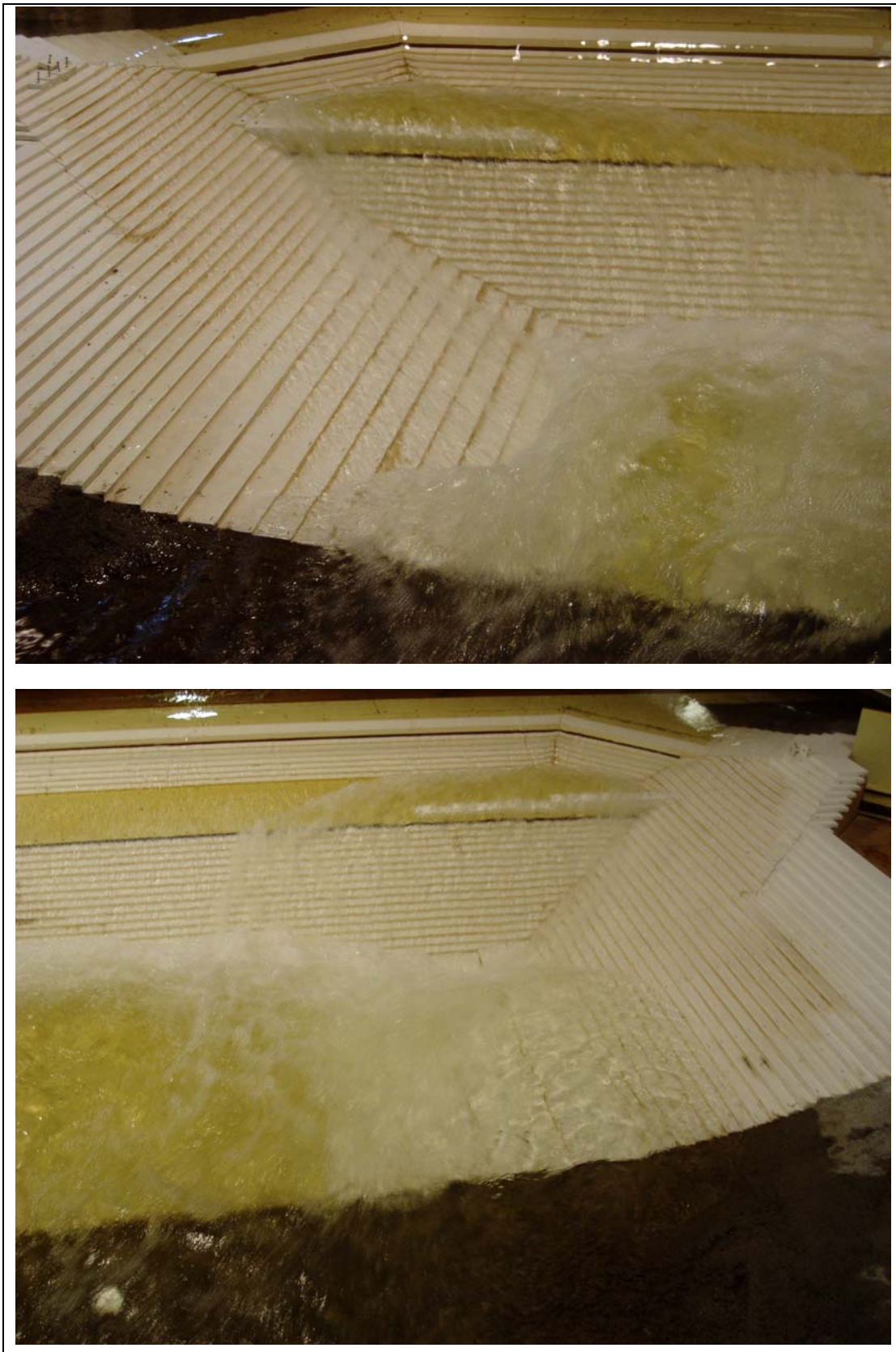


Figure 16. - Sill investigations with the partial 4-ft-high fillet shown operating under the PMP event.

- Construct a fillet with the recommended sill on the upper bench. This option is shown on figure 17 and shows minimal improvement while operating under the PMP event.

Figure 17. - Recommended 3-ft-high sill with the previously tested fillet installed first extending the influence of the sill out toward the middle of the structure operating under the PMP and tailwater without the culverts.

Recommended 3-ft-high Sill on the Flat Upper Bench at El. 956

The result of the client visit was a clear understanding of the situation at the site, including very strict aesthetic requirements that they are trying to meet. The sill concept seemed to work the best and have the least objectionable appearance. Further investigation continued with stops up the side slopes, with slightly different lengths and with significantly different heights. The result of these tests is the recommended maximum 3-ft-height which seemed to satisfactorily spread the flow in the basin and still be short enough to cover with fill upon completion of the construction.

The left and right sill geometries were slightly different, only because of the scraps of material used during the investigation. The sill dimensions are shown on figure 18. The sill length on the left side at the 2-ft-height is 72 ft from the intersection of the flat bench with the side wall step. The left side sill extends out from the intersection of the side slope a distance of 66 ft at the 3-ft-height. The sill length on the right side at the 2-ft-height is 59 ft from the intersection of the flat bench with the side wall step. The right side sill extends out from the intersection of the side slope a distance of 53 ft at the 3-ft-height. The width of the sill in the flow direction is arbitrary and should be structurally designed by Golder to ensure proper anchoring. In addition, the sill should be placed as near to the downstream edge of the flat bench as possible and structurally feasible. Preferably, the left and right sides may be made identical to match the left side geometry.

Figures 19-21 show the recommended sill geometry operating under the 2/3 and full PMP events operating under the tailwater without the culverts. A hydraulic jump forms on the bench behind the sills during flow rates up to the 2/3 PMP event. The jump sweeps out as the flow rate increases to the PMP with the 3-ft-high sill. The higher 4-ft-sill maintained the jump upstream during the PMP, but did not appear to spread the flow significantly better. As mentioned earlier, with aesthetic issues and the need for a much higher sill to spread significantly more water, the 3-ft-high sill was recommended. Velocities measured for the 3-ft-high sill did not seem excessive, as discussed in the next section.

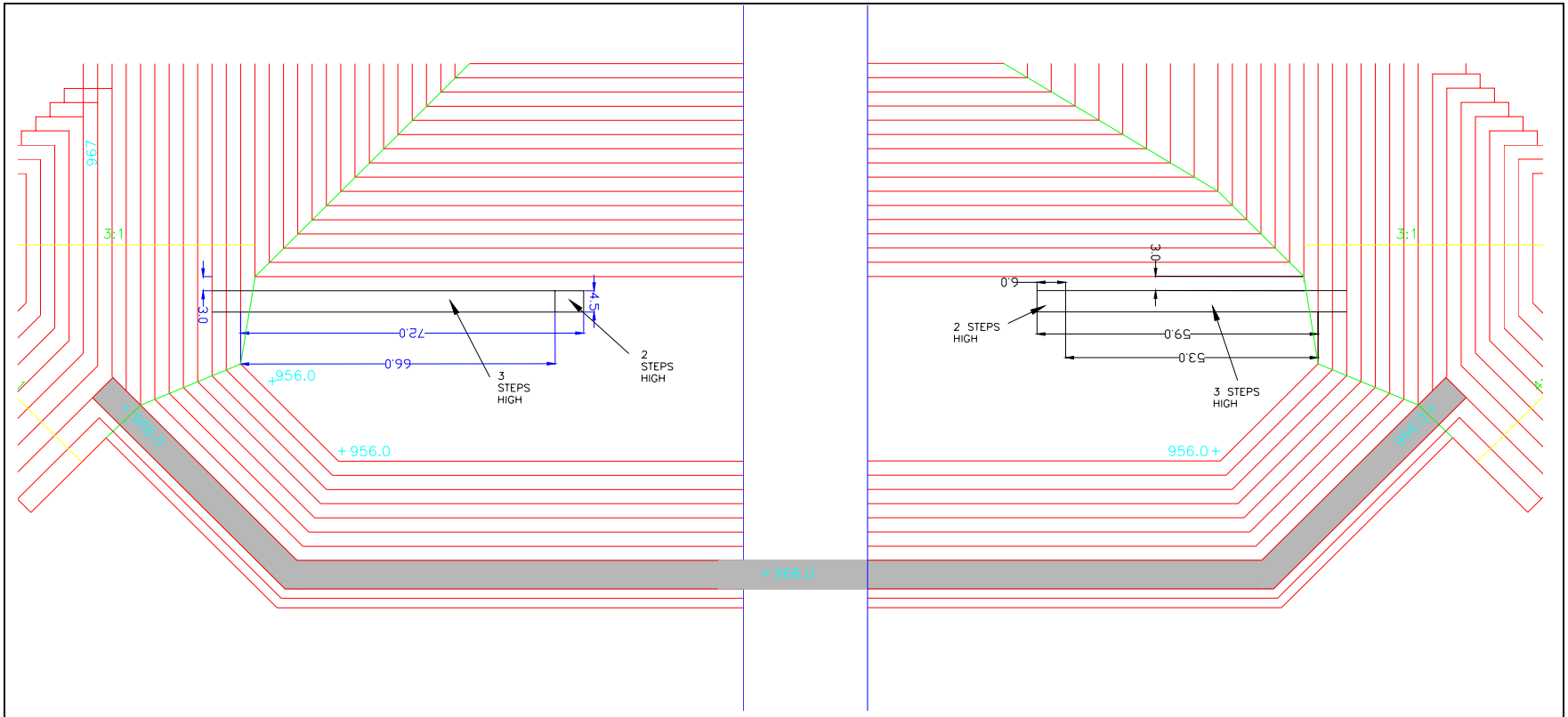


Figure 18. – Recommended 3-ft-high sill geometry to help spread the flow into the basins.

Figure 19. - Operation under the two-thirds PMP with the recommended sills on the flat upper bench and the tailwater without the culverts.

Figure 20. - PMP flow rate over the RCC protection with the recommended sills installed on the upper bench and the tailwater without the culverts.

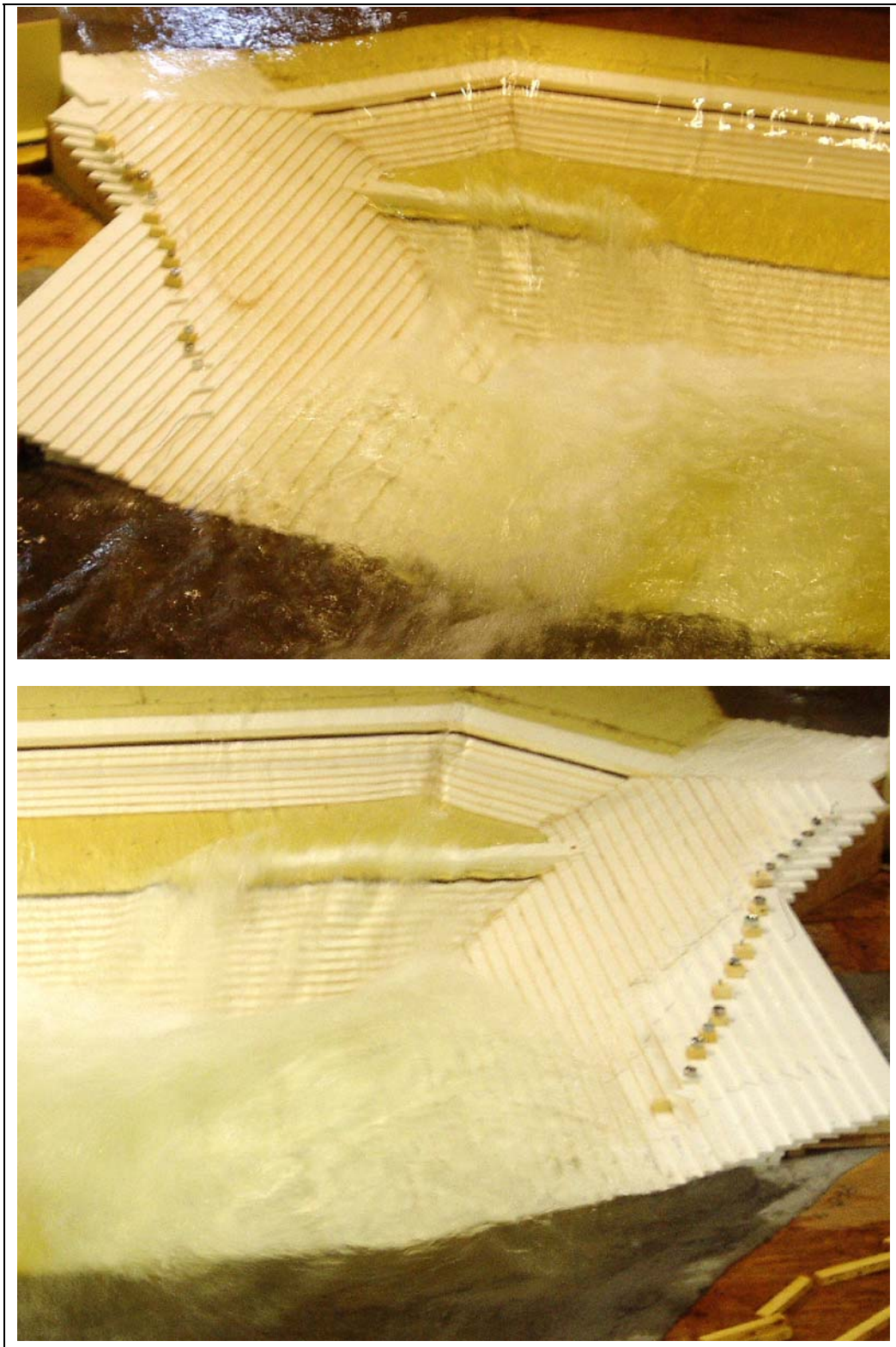


Figure 21. - Close up views of the right (top) and left (bottom) looking downstream sill arrangements and basin flow conditions under the PMP and the tailwater without the culverts.

Flow Velocities Exiting the Structure

Velocities were measured at seven locations just downstream from the end of the structure with the recommended 3-ft-high sills installed on the upper flat bench. The velocities were first measured with the basin end sills only located below the principal spillway basin as in the initial design. Upon completion of these initial measurements, a 2-ft-high end sill was installed along the entire end of the structure and flow conditions documented and velocities measured. The locations were chosen to measure velocities where the flow concentrations were exiting the structure and where the flow exited the approximate center of the various basin elevations. Velocities were measured for the two-thirds PMP and PMP events under the tailwater elevations expected with and without the downstream culverts washed out during the floods at El. 949.81 and 955.09, respectively. Velocities were measured with a hand-held Swoffer propeller meter at 0.6 depth due to the shallow flow depths in the model. Table 3 shows a schematic of the measurement locations below the structure protection with the prototype velocity magnitudes.

Maximum velocities were measured under the PMP event. Velocities of about 21-22 ft/s occurred at locations 6 and 7 from the flow concentration exiting the right side of the structure. On the left side of the basin the velocities reached 17 -18 ft/s at locations 1 and 2. The flow conditions appeared to be very similar with or without a 2-ft-high end sill located across the entire structure. With very shallow depths the velocities were slightly higher with the end sill due to the location of the measurement and the lesser flow depth over the sill. Under the 2/3 PMP, the flow seemed to dive downstream from the end sill where the flow exited the right side of the basin. The end sills will reduce recirculation of material into the basins until the zone downstream from the sill fills with material. There was not any noticeable improvement in the velocities or the flow conditions by adding the end sill in the locations of the concentrated jets exiting the structure.

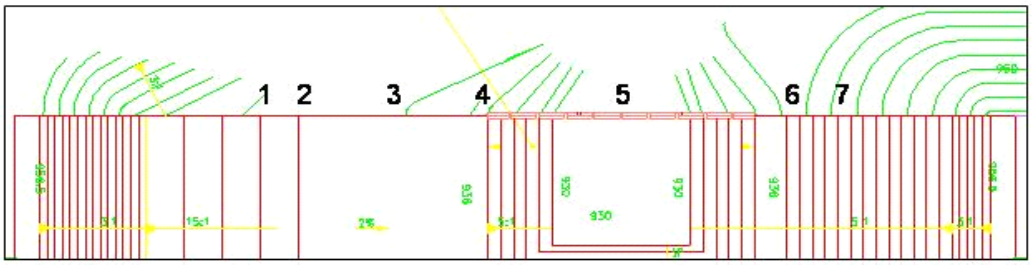
Velocities were also measured with 4-ft-high sills on the upper bench, both with the initial sill at the end of the lowest basin and the full sill across the apron. Unfortunately, the tailwater was set slightly low during these tests, but comparison with the 3-ft-high sills showed a slight shift in the velocities. Velocities on the left side were slightly lowered near the downstream left bank but increased to the right across the other measurement locations. On the right side, the reverse occurred with the most right bank experiencing a slight increase in velocity and a decrease to the left with the 4-ft-high sill. Velocity differences were not significant enough to warrant utilizing the 4-ft-high sills given the other

The velocities did not seem excessive given the description of competent rock below the structure and the infrequent nature of the flood event provided by design engineers, Golder Associates, Inc. Golder Associates Inc. engineers will be conducting an erosion analysis to determine whether the downstream rock will scour.

Table 3. - Velocities measured below the basin for the 2/3 PMF and PMP events, with the recommended 3-ft-high sills on the upper bench, assuming the culverts downstream had washed out.

PMP flow rate with no culverts
tailwater = 955.09

location #	invert El. (ft)	0.6 depth below water surface (ft)	Velocity (ft/s) with entire sill	Velocity (ft/s) original sill only
1	938	6.84	15.08	16.73
2	937	7.24	17.87	16.86
3	936	7.64	7.62	5.07
4	936	7.64	2.60	2.21
5	930	10.04	4.94	
6	937	7.24	20.45	21.84
7	939	6.44	20.55	13.53



Plan view of the end of the Y15 structure showing the levels of the basins and the locations for the velocity measurements at the end of the RCC protection.

2/3 PMP with no culverts
tailwater = 949.81

location #	invert El. (ft)	0.6 depth below water surface (ft)	Velocity (ft/s) with entire sill	Velocity (ft/s) original sill only
1	938	4.80	9.51	5.03
2	937	5.04	7.85	7.38
3	936	5.52	7.52	6.34
4	936	5.52	6.88	4.77
5	930	7.92	4.26	4.09
6	937	5.04	14.78	13.42
7	939	4.32	6.66	4.39

Side Wall Run Out Under the PMP

The crest of the overtopping protection was designed with the angled sections on both ends to minimize the run out on the steps parallel to the crest as demonstrated during model testing of the Big Haynes Creek Watershed Dam No. 3. [2]. The intention was to reduce the run out by angling the flow away from the stepped side walls, thus reducing the tendency for run out along the step tread. However, the stepped surfaces necessary for holding soil on the surface over the RCC also prevents gravity from aiding in turning the water down the slope and reducing run out.

The model was initially constructed to the design shown on figure 1. Run out was documented along the steps and appeared fairly minimal; however, enough run out occurred over fill areas that it was of concern.

Therefore, the model side walls on both sides above the basin area were extended up to El. 967 the full length of the downstream overtopping protection to allow documentation of the maximum run out of the flow under the PMP event

Figures 22, 23, and 24 show the plan views of the run out experienced over the stepped side walls, and two methods for containing the run out as investigated in the model under the PMP flow condition.

Figure 22 shows the plan view of two flow lines under the PMP event. The flow arrows on the upper portion of the protection show that the flow will run out over the end of the protection from the reservoir water surface at the crest. The run out will continue over the extended wall area also until about 16 to 20 ft from the downstream end of the structure. The profile for where the majority of the flow travels was then marked and measured producing the more upstream profile. Figure 23 shows the PMP flow event with the water flowing down the left side wall with the profiles marked. Flow profiles on the right side wall were identical.

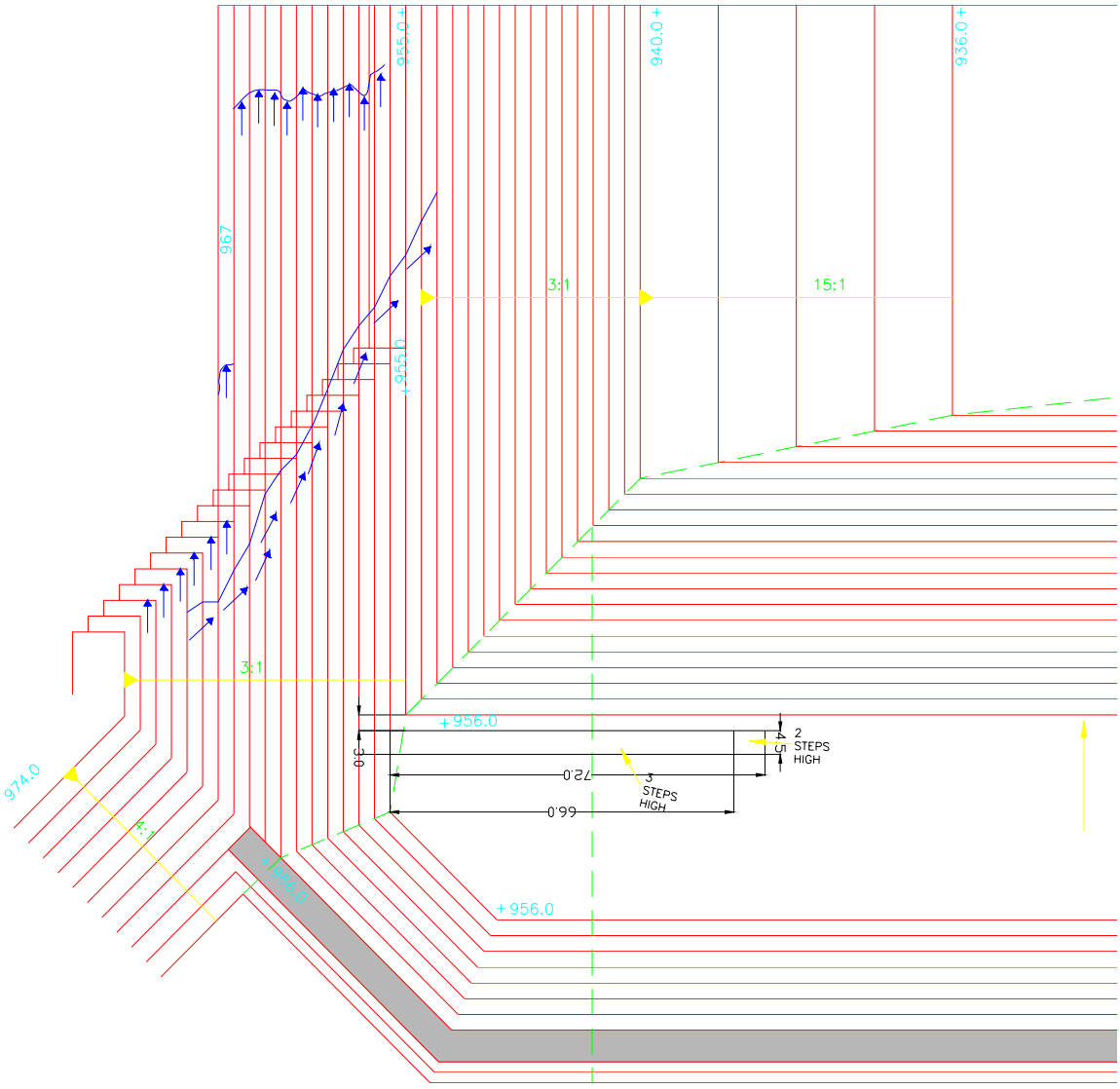
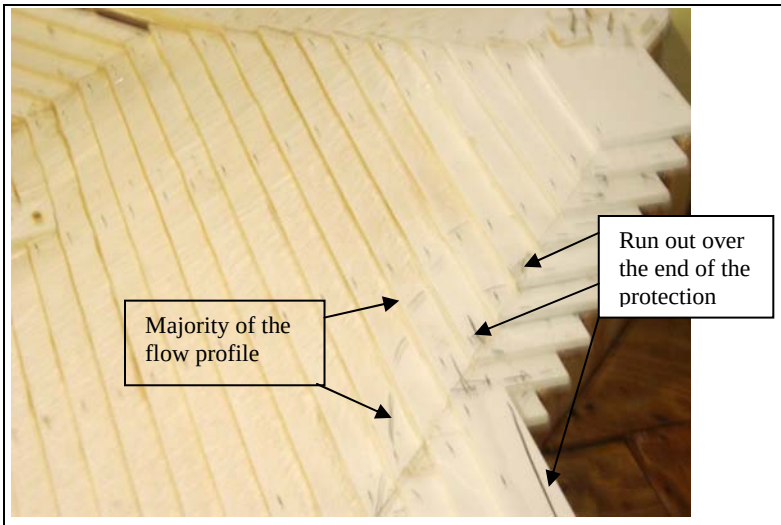
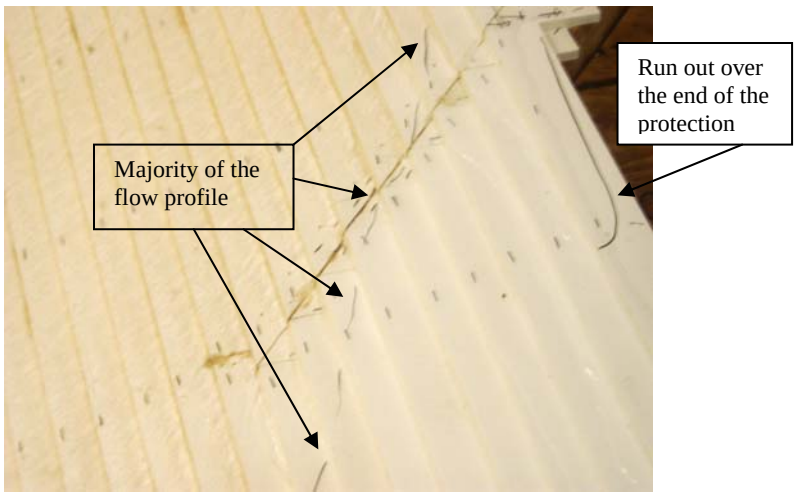


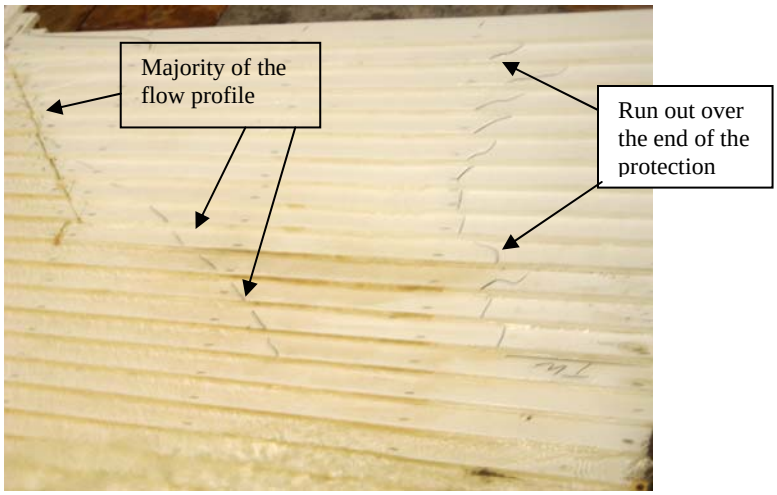
Figure 22. - Profiles of the maximum run out and the general flow boundary on the left abutment under the PMP event. These profiles are without any restriction on flow run out and the extended side walls. (Note: Flow profiles would be identical on the right side wall.)



Upper left side wall majority flow profile and run out flow.



Flow profile of the majority of the flow over the left side wall.



Flow profile of the majority of the flow and the downstream end of maximum run out.

Figure 23. - Three views of the maximum run out marked with arrows and the main flow marked with dashed lines under the PMP.

Figure 24 shows the stops to contain run out of the PMP flow event. Dimensions are given from the break line for the turn on each RCC lift. The stops are located on the extension of the RCC protection, but are only 1 ft high. Figure 25 shows the PMP flow event with the stops located on the left and right side walls above the tailwater. This option would contain the flow above El. 967 and require extension of the side walls between El. 967 and the original elevation of 955.

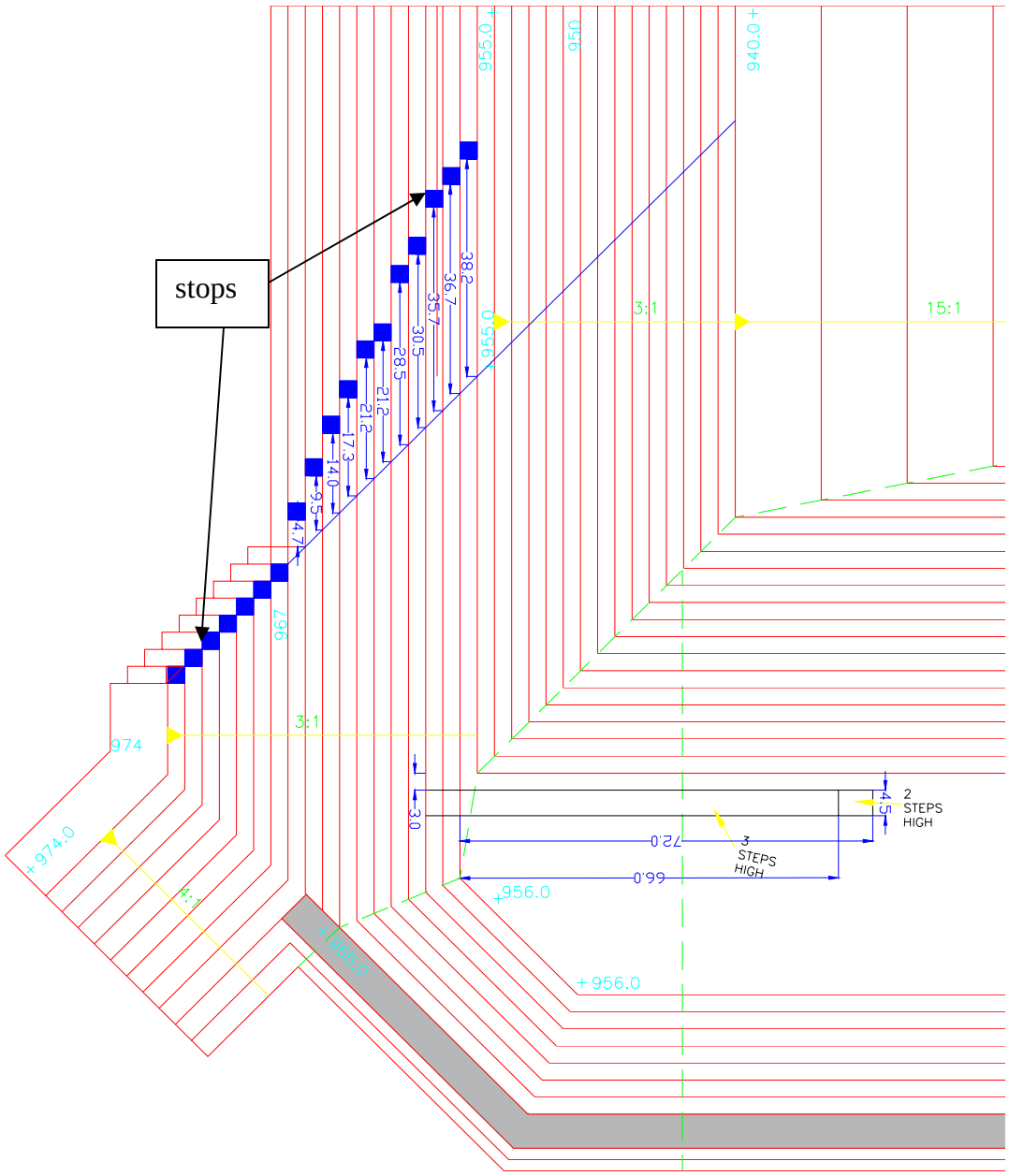
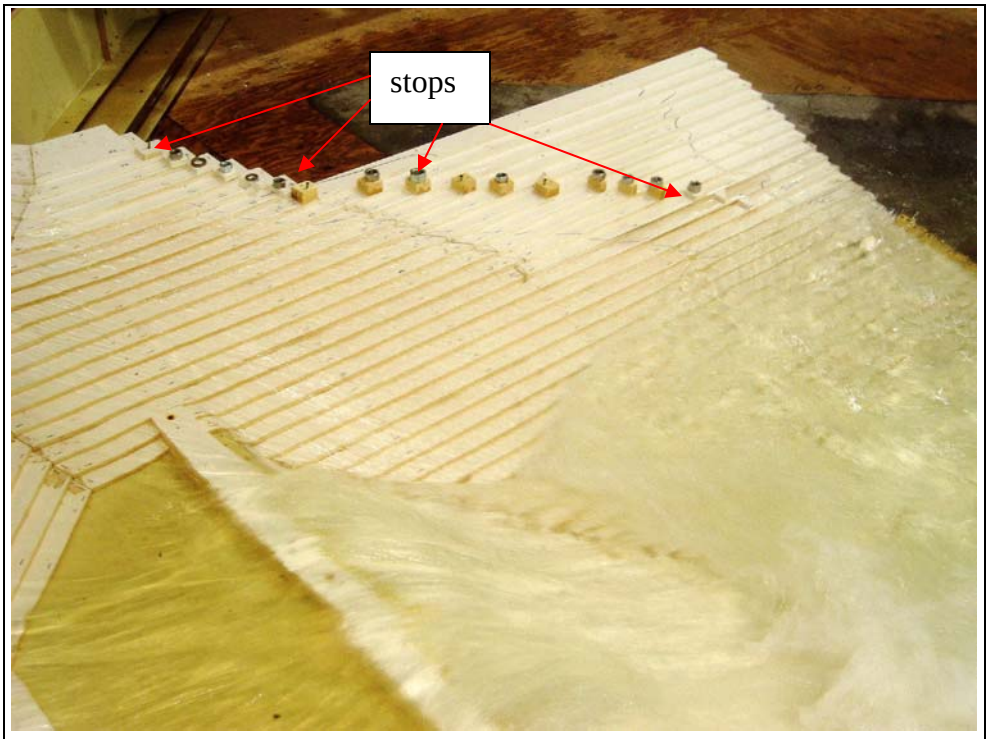


Figure 24. - Location of stops on the left abutment to contain the flow run out during the PMP flow. The stops would need to be 1-ft-high all the way down the slope since they are moved back away from the majority of the flow. (Note: Stops would be identical on the right side wall.)



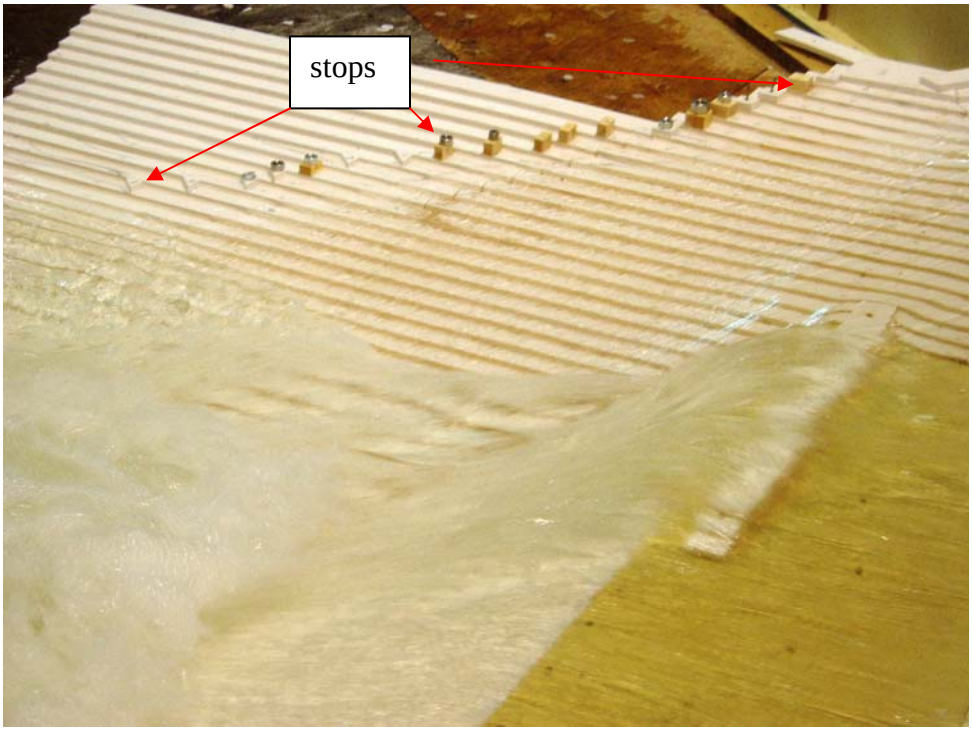


Figure 25. - Left (top) and right (bottom) side wall stops shown with operation under the PMP. (Note: The nuts over the blocks are only weights.)

Figures 26, 27, and 28 show the containment stops forming a smooth wall-like surface along the break point in the RCC lift turn around. They would require no additional extension of the side wall protection. They were modeled at 1-ft-high from the top down to El. 966 and 2-ft-high below that to the tailwater. Another option would be to start forming them from the bottom up and over widen the placement providing an overlap on each step run. This would make a continuous wall instead of a break where water could potentially pass at each stop edge as shown in the schematic on figure 27. In addition, the downstream edges of each stop would not need to be formed. The back side of the stops could be any shape. Figure 28 shows this wall stop arrangement operating under the PMP event.

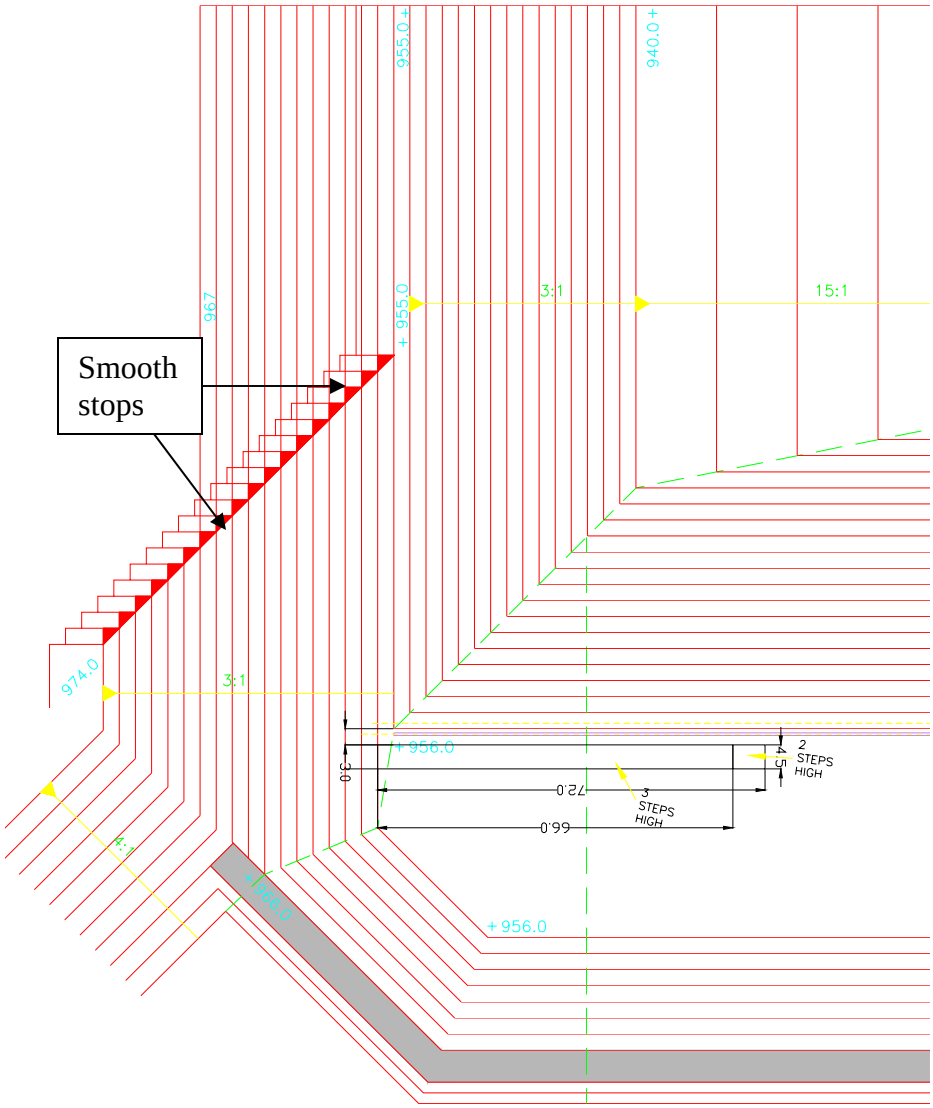


Figure 26. - Location of the smooth surface of stops on the left abutment along the break line for the RCC protection under the PMP event. The face of the stops forms a smooth surface next to the water but the back shape may be of any shape. The stops are 1-ft-high from the top to El. 964 and 2-ft-high from El. 965 to the tailwater. They may overlap from step to step to be wider than the step run for an extra factor of safety or constructability. (Note: Stops would be identical on the right side wall.)

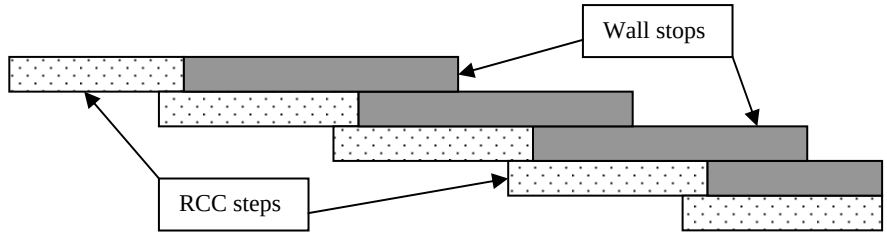


Figure 27. - Schematic of proposed smooth wall stops over existing 1-ft-high steps.

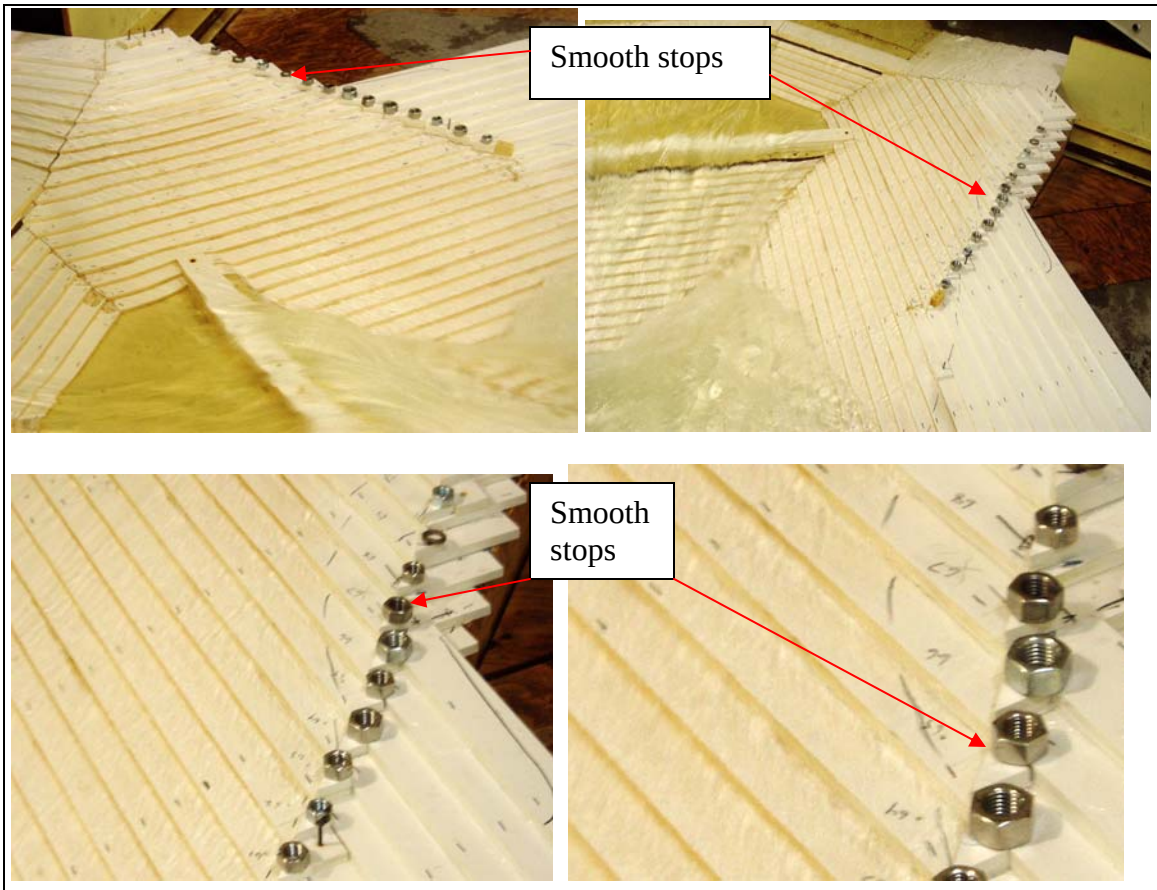


Figure 28. - Photos of containment of the PMP with a continuous smooth wall next to the flow surface on the left side wall. (Note: The nuts are only for weight.) The back side of the stops may be any shape.

Conclusions

In general, the overtopping protection performed quite well. The crest sections pass the desired flow rate under a lower reservoir elevation than needed. The extent of the protection was mostly adequate with some mechanism needed to prevent run out along the side wall steps from eroding the embankment. The side walls may be extended to the locations indicated from the study or stops may be constructed at various locations to prevent the run out. The magnitude of the flow concentrations was reduced by installing sills on the flat bench below the angled crests. The flow concentrations did produce jets that left the basin protection, but measured velocities did not seem to indicate erosion of the rock foundation material. End sills did not appear to be necessary along the downstream end of the protection due to the design of a cut off wall and expectation of an adequate rock foundation.

References

1. "Earth Dams and Reservoirs, TR-60, US Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division, July 2005

2. Hunt, Sherry L., Kadavy, Kem C., "Final Report on Big Hynes Creek Watershed Dam No. 3 Gwinnett County, Georgia Specific Model Study", US Department of Agriculture, Agricultural Research Service, Natural Resources Conservation Service, Project No. 6217-13000-007-20, September 22, 2005.