Rehabilitation of the Otis Reservoir Dam: Improving Cost Effectiveness by Including Bridge Placement

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Abstract

The Massachusetts Department of Conservation and Recreation (DCR) owns and operates the Otis Reservoir Dam in Otis, Massachusetts, for recreational purposes. In 2006, the 145-year-old, 31.5-foot-tall, earthen embankment dam with downstream masonry wall and stone masonry spillway was found to be in "Poor" condition due primarily to the deteriorating/leaking spillway and downstream masonry wall and the erodibility of the "emergency spillway" over the main embankment section of the dam. To address most of the main dam safety concerns, a reconstructed spillway with a hydraulically actuated crest gate was chosen as the preferred alternative. The crest gate option provided additional hydraulic capacity while also improving the DCR's ability to manage the reservoir level, most importantly, during the annual winter drawdown. During the planning stages of the project, maintaining access to the west side of the reservoir during construction was identified as a critical component in the viability of the project. At the time, the bridge over the spillway was a one and one-half lane, temporary "Bailey bridge" installed in 1995. It was supposed to have been replaced with a permanent bridge in 1998. Given that the dam is a large, high hazard structure, the dam repairs needed to move forward to protect the public safety. To expedite the project, the DCR elected to incorporate the bridge replacement into the dam rehabilitation project. The dam rehabilitation project was transformed, by necessity and creative planning, into a combined dam and bridge replacement project that ultimately benefited the DCR and the town of Otis.

Keywords: Spillway Design Flood, probable maximum flood, Potential Failure Mode Analysis

1. Project Background

Otis Reservoir Dam is located within Tolland State Forest on the Fall River in the town of Otis, in Berkshire County (see Figure 1). The dam was originally constructed in 1866 by the Farmington River Water Power Company in order to provide supplemental water to power mills on the Farmington River in Connecticut. The Commonwealth acquired the reservoir in 1967. Otis Reservoir is a 1,000-acre impoundment with a 16-square-mile drainage area that encompasses portions of three towns (Otis, Tolland and Blandford). Having a storage capacity of 22,000 acre-feet (7.1 billion gallons) at normal pool, it is the largest recreational body of water in the Commonwealth of Massachusetts.

Tolland Road, owned by the town of Otis, passes over the dam and provides the only access to the western side of the reservoir during the winter months. The majority of the residents on the western side of the impoundment are seasonal, with only four full-time residents present during the winter. Because of the recreation industry supported by the reservoir, the population in the town of Otis swells from a few thousand in the winter to near 10,000 during the summer months.

The Otis Reservoir Dam consists of an earthen embankment with a downstream stone masonry wall. The dam has a maximum structural height of about 31.5 feet and a length of about 630 feet. The exposed portion of the downstream masonry wall of the dam is approximately 480 feet in length. Tolland Road, a paved public roadway, traverses the top of the dam. In 1955/1956, after Hurricane Diane, the top of the embankment was lowered by about 3 feet to create an "emergency spillway," although no erosion protection, other than the asphalt pavement roadway, was provided. The dam was originally built with a 38-foot-long stone masonry primary spillway located near the dam's left (west) abutment. The spillway was divided into two, 19-foot-long segments by a stone masonry pier.

In 1995, MassHighway replaced the deteriorating original bridge over the spillway with a temporary one and one-half lane Bailey bridge. This bridge was intended to be in service for three years. A permanent, two-lane bridge was slated for construction in 1998. However, the project was delayed and postponed,

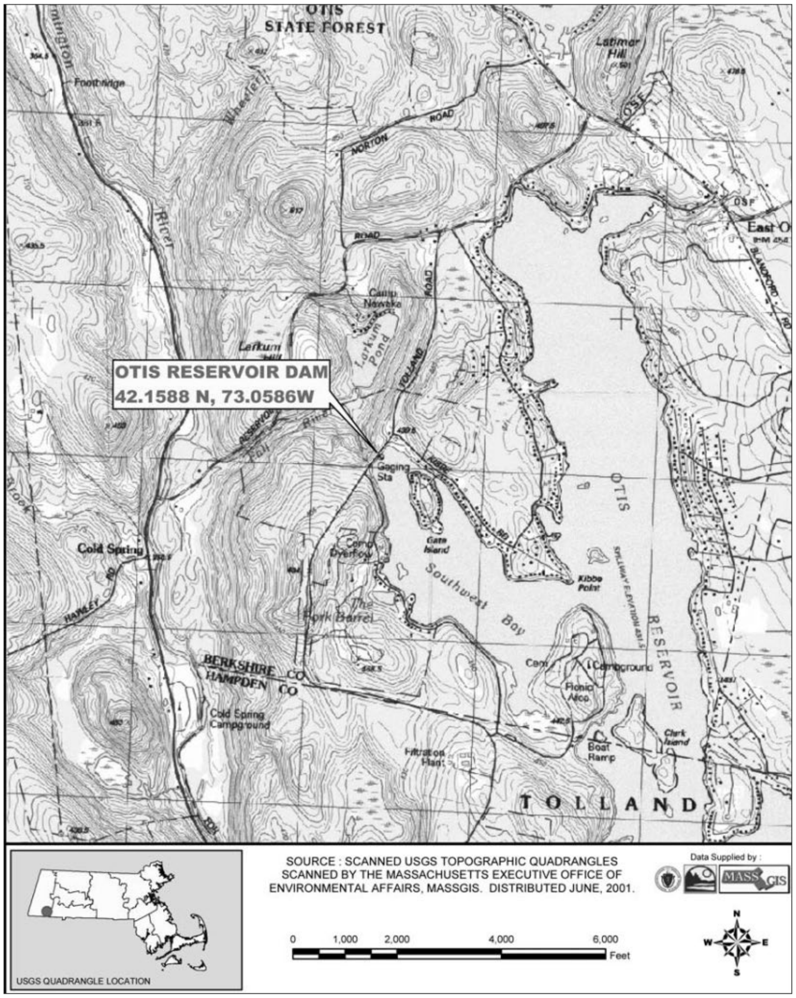

Figure 1. The location of the Otis Reservoir and dam.

apparently due to MassHighway's bridge project prioritizations. By 2009, the permanent bridge replacement at the Otis Reservoir Dam had been officially postponed until 2014.

Prior to the recent dam rehabilitation, there were two gatehouses/outlet structures at the dam. The original gatehouse, located in the middle of the upstream side of the embankment, was taken out of service in 1984 when the outlet works at the dam were rehabilitated. The original sluice gates, stems and operators were removed and a 4-foot-high by 8-foot-wide intake conduit, with an upstream steel trash rack, was installed within the reservoir. The intake conduit extends into the reservoir about 40 feet upstream of the dam. A downstream outlet tower was constructed in 1984 with a second gatehouse opposite to the original upstream gatehouse. The outlet tower has two, 48-inch-square slide gates. One gate serves as a low-level outlet and the other serves as a mid-level outlet. The outlet tower also has a 10-foot-wide by 3-foot-high overflow weir at the same elevation as the primary spillway crest (with the flashboard in place). The two original 30-inch-square stone sluiceways through the dam had been retrofitted with 26-inch-square steel conduits and then grouted in place.

The Otis Reservoir is operated by the DCR's park staff according to an order of conditions from the Otis Conservation Commission, which defines the target seasonal reservoir levels and governs the rates of reservoir drawdown and refill. In October of every year, the DCR opens the low-level outlet gate to provide a flow of around 300 cubic feet per second (cfs) into the Fall River for an annual weekend canoe race. The DCR subsequently dials back the release to lower the reservoir to about 2 inches per day until the winter pool elevation (6 to 8 feet below the primary spillway crest elevation) is reached. The purpose of the annual drawdown is to allow for the inspection of the dam structure, to prevent ice damage to the shoreline docks and piers, and to provide meltwater storage and discharge control during the spring freshet. Beginning in January of each year, the DCR begins to raise the reservoir level. The reservoir is raised to within 4 feet of the summer pool level by April, depending on the ice conditions on the reservoir. The goal is to have the reservoir level restored to the summer pool level by July 4th each year. The 1984 outlet works configuration requires constant adjustment to manage the reservoir level, especially prior to or after storm events.

With the winter pool being maintained by releasing water from the low-level outlet in the downstream outlet tower, the DCR could not easily monitor the water level below the ice. An excessive water release could cause the development of a void between the bottom of the ice and the surface of the reservoir. The presence of such a void would be a major safety concern, given the year-round recreational use of the reservoir, which includes ice fishing and snowmobiling on the reservoir. The DCR's staff would use a chain saw to cut holes through the ice in order to evaluate the reservoir level. Obviously, this practice was not an ideal approach. So, the DCR indicated that the dam rehabilitation project should also include provisions to improve the reservoir operation procedures.

2. Engineering Evaluations & Alternative Analyses

Following an inspection of the dam in May 2006 by an engineering consulting firm, the dam was judged to be in "poor" condition. The primary deficiencies of the dam were:

- The deteriorated masonry and leakage conditions at the spillway (see Figure 2) and the downstream masonry wall; and,
- The erodibility of the "emergency spillway" over the main embankment section of the dam.

Figure 2. View of the deteriorated and leaking conditions at the spillway prior to rehabilitation.

In 2007, the engineering consultant performed a Phase II Engineering Evaluation and Alternatives Analysis of the dam. This study included field investigations covering wetlands delineation, a topographic survey of the dam and nearby areas, rare species determinations, diving inspections of the intake conduit and interior of the downstream outlet tower, subsurface explorations with test borings and taking additional readings from the existing instrumentation (piezometers and inclinometers) at the dam. The consultant's engineering evaluations included interpretation of the subsurface conditions from the test borings, geotechnical laboratory testing (grain size analyses) and existing instrumentation readings, as well as conducting engineering analyses including detailed hydrologic and hydraulic analyses, liquefaction and seismically induced settlement analyses, seepage analyses, slope stability analyses and gravity wall stability analyses.

With Otis Reservoir Dam categorized as a large, high hazard dam per the Massachusetts Dam Safety Regulations, its spillway design flood (SDF) is one-half of the probable maximum flood (½ PMF). The results of the detailed hydrologic and hydraulic analyses revealed that the original spillway was capable of passing only 10 percent of the SDF and overtopping of the dam by about 3.3 feet was predicted. The seepage and stability analyses indicated that the dam met most of the stability requirements set forth in the dam safety regulations except for the case where the dam was overtopped during the SDF event. The factor of safety against sliding for the downstream masonry wall was below the recommended minimum value of 1.3 due to the likelihood for erosion occurring at the base of the wall attributed to overtopping during the SDF.

In concert with the detailed engineering analyses, a potential failure mode analysis (PFMA) was performed with several members of consultant's dam engineering team and representatives from the DCR who were responsible for the operation and maintenance of the dam. The objective of the PFMA was to assess possible failure modes and to determine the most likely failure mechanisms, thereby allowing the design of the rehabilitation project to address each of these deficiencies.

Using the information obtained from the detailed engineering evaluations and the PFMA, an alternatives analysis was performed to evaluate the repair/rehabilitation options that could address the dam safety issues. These alternatives included:

- no action;
- breach/remove;
- raise the dam;

- construct an emergency spillway; and,
- spillway modification/reconstruction.

Spillway reconstruction, along with raising the crest of the dam, were selected as the preferred alternatives.

3. Selection of the Preferred Alternatives

To address both the dam safety issues and operational issues, reconstructing the spillway with a bottom-hinged, 7.5-foot-tall by 38-foot-wide steel crest gate was selected as a preferred alternative. When the crest gate is in the "up" or "closed" position, the top of the gate is at the current normal summer pool elevation for the reservoir. The invert of the new spillway (i.e., with the crest gate in the "down" or "open" position) was set at the winter pool elevation so that once the reservoir was drawn down it could "self-regulate" the reservoir level without constant assessment and adjustment by the DCR staff.

To safely pass the SDF, the DCR staff would need to lower the summer reservoir level by 2 feet in advance of the ½ PMF event and then operate the gate throughout the storm to prevent overtopping of the dam. Without proper gate operation, the dam will be subject to overtopping during the SDF. However, the proposed dam modifications would allow the spillway to safely pass the 500-year flood event with about 2 feet of freeboard without lowering the crest gate.

Typically, relying on human operations to pass the SDF is not a recommended dam safety practice. The reason it is not recommended is the potential for improper or lack of operation that can result from human error. However, Otis Reservoir Dam is not a typical dam since it has a full-time dam operations staff in the DCR's Tolland State Forest Office at the right abutment of the dam. The DCR also has staff who live locally who are "on-call" should an emergency situation develop at the dam. Therefore, the design of the new spillway was able to take advantage of the DCR's somewhat unique on-site staffing situation.

Other improvements included in the dam rehabilitation, as shown in Figure 3, were:

- adding a new gatehouse on the left abutment of the dam;
- raising the top of the dam by adding up to 3 feet of embankment fill;
- repointing the downstream masonry wall;
- extending the downstream toe drain;
- adding a reinforced concrete splash pad at the base of the downstream masonry wall;
- restoring the rip-rap slope protection on the upstream and portions of the downstream slopes; and.
- installing new slide gates on the inside upstream face of the downstream outlet tower.

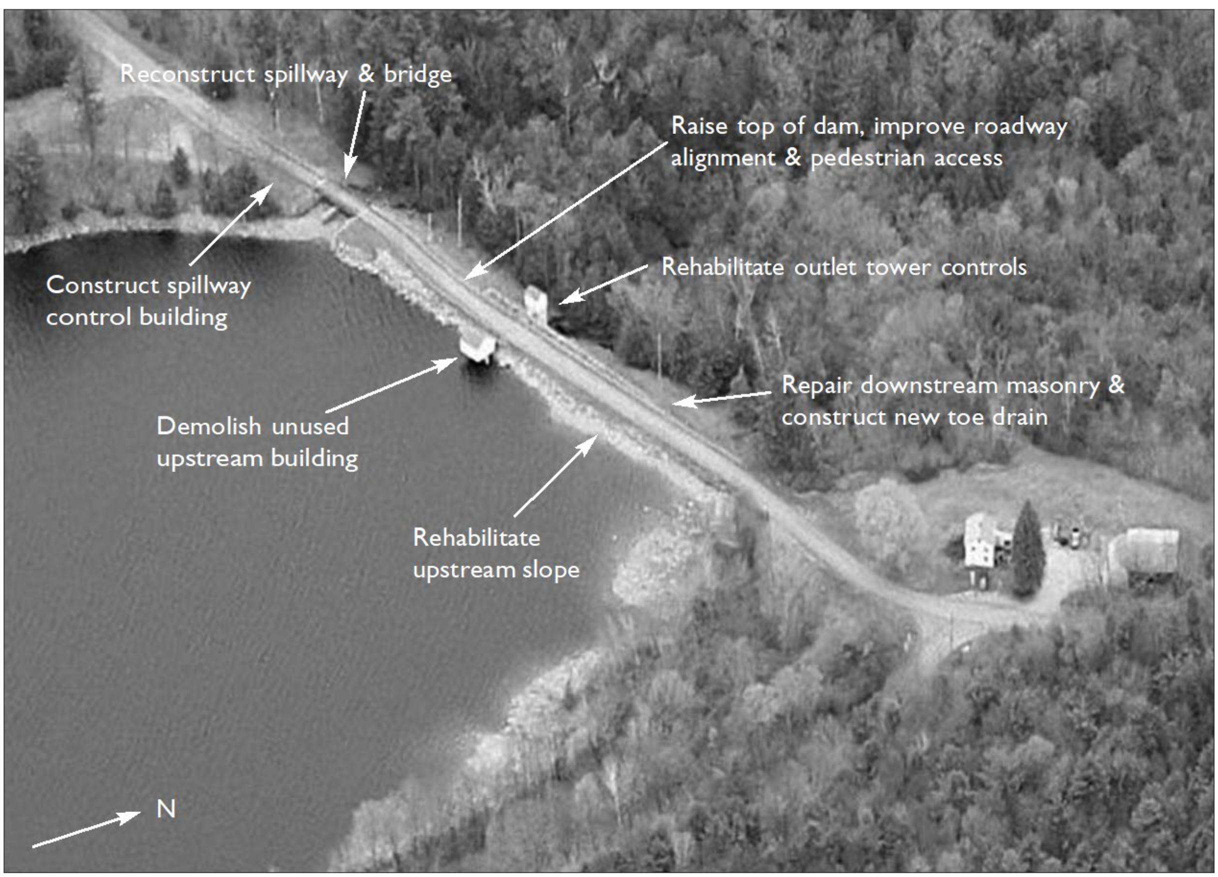

Figure 3. The locations of repairs/improvements on the dam.

4. Solving Resident Access Issues

Access to the west side (left side of the dam) of the reservoir was identified as a critical issue early in the project development. The towns of Otis and Tolland fully understood the benefit of the project. However, residents of both towns were concerned about the potential for short-term impacts on the recreational-based economy. Several concepts and options were evaluated by the project team in order to address this concern.

Initially, a bypass route upstream of the spillway was evaluated. A temporary earthen embankment was considered that would convey traffic around the spillway construction while also serving as a temporary cofferdam for the work area. A significant amount of fill would have been needed to be placed in wetlands area fro the embankment. This option was eliminated when the constructability, cost and permitting requirements were evaluated more closely.

A second approach that was considered was to construct the spillway in two segments: upstream and downstream. The existing Bailey bridge would be left in place initially to allow the upstream portion of the spillway to be constructed. The Bailey bridge would then be moved to the upstream side of the dam and the downstream half of the spillway would be constructed. However, this option was also eliminated when the costs associated with the phased construction, the extended construction duration, the need for a more robust temporary cofferdam capable of remaining in place throughout the higher summer pool season and the additional risks were evaluated more closely.

To limit the impact of the project on the recreational use of the reservoir, it was decided that the majority of the work needed to be performed in off-season (i.e., winter construction). It was also obvious that with the significant improvements being considered for the spillway, it did not make sense to reinstall the temporary Bailey bridge over the newly reconstructed spillway. Therefore, the DCR decided to incorporate a permanent bridge replacement into the dam rehabilitation project. In exchange for adding the new bridge to the project, the DCR was granted permission from the towns of Otis and Tolland to close Tolland Road for five months (from October 2010 to March 2011) in order to facilitate construction.

To address the access issue to the west side of the reservoir, the DCR offered to establish and maintain a detour route around the reservoir during the five-month period when the bridge was closed. The detour route (see Figure 4), which was about 8 miles in length, included a 2.8-mile section of gravel road that was typically not plowed during the winter. The DCR included a construction contract provision for liquidated damages to be levied against the contractor if the bridge over the spillway was not reopened on time. The town of Otis accepted the DCR's offer for the new bridge and the temporary detour route, and granted the DCR permission to close Tolland Road for five months.

5. Dam & Bridge Design Considerations

The design of the dam rehabilitation and the bridge replacement occurred between 2007 and 2010. The engineering consultant retained another engineering firm to provide structural, mechanical and electrical engineering design services for the new crest gate and for two new slide gates in the outlet tower. Under a separate contract, the Massachustts Department of Transportation (MassDOT) engaged another consultant to perform the bridge design. The DCR supervised the bridge designer and reported progress to MassDOT. As overall project manager and the dam engineer-of-record, the contracting engineering consultant was responsible for providing engineering design for the dam, including the hydrologic/hydraulic, geotechnical and civil designs, in addition to coordinating the other project team design responsibilities and merging of the contract documents into a single bid package.

A performance-based specification was created for the crest gate. Two Massachusetts-based gate manufacturers were consulted to provide input in establishing the crest gate design criteria and to understand the implications of the DCR's intended operation procedures. The DCR was committed to providing redundancy with the crest gate operations. The DCR wanted the gate to have twin top-mounted actuators, but the DCR also wanted to have the ability to operate the gate with a single actuator in the event that one failed. Based on this requirement, a hydraulically actuated operation system was selected for the project. Velocity fuses (i.e., a hydraulic valve used to stop flow if the maximum speed of the fluid is exceeded) were also added to the system to prevent the gate from opening unintentionally in the event of a power loss or a break in the hydraulic system. The gate system also included provisions to raise or lower the gate manually in an emergency situation. A new gatehouse was also added on the left (west) abutment of the dam to house the crest gate's hydraulic system.

With the reservoir's annual drawdown schedule, there is a need to operate the gate in cold-weather months. However, the rubber side and invert seals could be damaged if the crest gate is operated while it is subjected to ice accumulation. As such, robust electric side seal and invert heaters were incorporated into the structure. Operational procedures to turn on the heaters in advance of any winter gate operations were also written into the dam's new operations and maintenance plan. The new gatehouse constructed near the spillway to house the crest gate controls included provisions for connecting a portable generator if spillway operations were required during power outages.

The existing masonry spillway was removed and replaced with a reinforced concrete structure to support the crest gate and to convey the spillway flow through the dam. The new spillway structure served dual purposes: spillway training wall and bridge abutments. (In addition to the hydraulic loads imparted due to the spillway flows, the new concrete walls were also required to support the lateral loads from the embankment, vertical dead forces from the bridge structure and HS-25 vehicle

Figure 4. The 8-mile detour route that was used during construction.

loading, and earthquake loads.) The training walls/abutments were to be founded directly on bedrock, which provided adequate bearing capacity and erosion resistance.

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- Several types of superstructure for the new bridge were considered in the early part of the project. Initially, the bridge types considered included:
- Single span, precast, prestressed concrete spread box beams with cast-in-place concrete deck.
- Single span, rolled steel stringers with a cast-in-place deck.
- Single span, built-up steel plate girders with a cast-in-place deck.
- Single span, rolled steel stringers with a timber deck.

The initial recommendation for a bridge type was for a single span, precast concrete spread box beams with a cast-in-place deck. However, the winter construction schedule and the necessity for limited road closure precluded any of the bridge types that used cast-in-place decks. Therefore, a decision was made by the project team to only consider bridge types that used prefabricated elements, since they could be brought on-site and lowered into place once the spillway training walls/bridge abutments were completed. The prefabricated bridge types that were considered included:

- Prefabricated concrete/steel composite superstructure units (formally known as Inverset);
- NEXT beam system;
- Fiber reinforced polymer (FRP) deck on steel stringers;
- Full depth precast concrete deck panels on concrete or steel stringers; and,
- Butted boxes/deck slab with no cast-in-place deck.

The effects of each system on the hydraulic performance of the spillway, their relative maintenance costs and their impact on construction schedule (if any) were evaluated. The first alternative — prefabricated concrete/steel composite superstructure units with an asphalt wearing course — was chosen. The composite system included steel stringers and a precast concrete deck. The main benefits of this bridge type included design flexibility, adaptability to the winter construction schedule and quick installation.

5. Improving Constructability by Modifying the Spillway Design

The winter-only construction schedule, coupled with the five-month road closure limitation, dictated that the total construction schedule for the project occur over a two-year period. And, with the crest gate design, submittal review process and fabrication requiring up to six to eight months, the crest gate installation was not scheduled until the second winter construction season. This schedule would have not been possible if the project had been awarded in the fall since the spillway construction would have needed to have been completed during the winter road closure of the first construction season. In order to accommodate this scheduling issue, the decision was made to add stop logs bays to the spillway upstream of the proposed crest gate. The addition of the upstream stop logs provided the following benefits:

- The stop logs provide a permanent mechanism to allow the crest gate to be taken off line for servicing and maintenance.
- The stop logs could be installed early in the spillway construction in order to limit the amount of time needed for a temporary cofferdam for the project.
- The stop logs could be installed and kept in place to serve as the water control mechanism until the crest gate was fully installed. Doing so would allow the crest gate design, submittal review and fabrication to proceed without the added pressure of being the critical path element for the project.
- The stop logs would also be used to create a controlled upstream water condition that would allow testing of the crest gate and the training of the DCR operations staff.

Figure 5. Improvements to the dam crest and upstream slope.

6. Combined Dam & Bridge Design Benefits Project Financing

With the project design and constructability issues resolved, the next step was to figure out how the project would be funded. The initial construction cost estimate was on the order of $2 million. The DCR Office of Dam Maintenance used this figure in their capital planning for FY2010/2011. However, the initial cost estimate did not include a new bridge nor did it consider a two-season construction schedule. Consequently, the updated project cost estimate was about $1 million higher than originally estimated. In order to address the cost increase, the DCR needed to look at other funding options.

Because this "dam" now included a new bridge, it became obvious that it should qualify for "bridge monies." The bridge and portions of the spillway construction that served a dual capacity (both spillway training walls and bridge abutments) were funded via the MassDOT Accelerated Bridge Program and not solely through the DCR's Office of Dam Maintenance dam rehabilitation budget. Second, by extending the project to two construction seasons, the project was also extended over two fiscal years. Consequently, the DCR was able to spread the project budget out over two years, which provided the DCR with greater fiscal flexibility when compared to the initial approach when the dam rehabilitation was scheduled to occur over one construction season.

Even though the project scope and budget were increased by the addition of the bridge replacement to the project, the DCR, the town of Otis and the general public benefited in a greater way with the expanded project scope and the DCR's ability to see the big picture.

7. First-Year Construction Highlights

The project was advertised for bid in the summer of 2010. The project was awarded to the low bidder, with a bid price of $3,057,496.50. Seven prequalified contractors submitted bids on the project. The four lowest bidders were within $150,000 of each other, and all four of these bids came within $300,000 (roughly 10 percent) of the engineering consultant's estimate for the project.

On September 15, 2010, the DCR and the contractor began first construction season. Approximately one month later, the portion of Reservoir Road across the top of the dam was officially closed and the detour route around the site was established. The first-year construction work included:

- the construction of the toe drain and splash pad;
- raising of the embankment crest by 3 feet;

Figure 6. Bedrock excavation at the spillway.

- placement of new upstream and downstream riprap slope protection (see Figure 5);
- demolition of the masonry spillway;
- construction of the new reinforced concrete spillway/bridge abutments;
- installation of the new stop logs;
- installation of the new bridge;
- demolition of the upstream gatehouse; and,
- construction of the new crest gate gatehouse at the left abutment.

Questions of interest to state transportation policymakers and DOT officials relate to the potential impacts or consequences of such approaches. Examples of these questions are:

- What will be the capital and operating costs to implement toll-based approaches on interstate highways on which tolls are not currently charged?
- What are the potential levels and natures of the revenues that can be collected with these tolls and how do these revenues compare to other funding approaches such as fuel taxes?
- What changes in demand can be expected? Will mode shifts and route diversion occur and at what levels?
- Will there be equity and privacy concerns that may lead to additional challenges in gaining public acceptance?

Because the invert of the new crest gates was almost 8 feet lower than the original spillway crest, bedrock excavation and removal within the spillway footprint was required for foundation construction. The excavation required for the new spillway foundations was approximately 100 by 80 feet in area, and required cuts into the bedrock of up to about 7 feet.

Excavation of the gneissic bedrock was accomplished with a combination of ripping with an excavator and hoeramming. Due to the fracture patterns in the bedrock, controlled blasting was not required. Figure 6 shows an example of typical rock excavation at the spillway. Because the bedrock was fractured and rippable, the contractor utilized line drilling techniques on the outer perimeter of the excavation area to control the limit of the rock removal. Construction-induced vibrations were limited to the criteria set forth in 527 CMR 13.00, which provide vibration limits based on a relationship between peak particle velocity and frequency. Continuous and event-specific vibration monitoring was performed for the existing downstream masonry face of the dam, the downstream gate ouse/outlet tower, and at locations where new concrete was being poured.

The bedrock conditions in the area of the spillway were generally less competent than it was anticipated during design. Because the top of competent bedrock was generally about 1 to 4 feet deeper than the design bottom of footing grades, approximately 150 additional cubic yards of concrete were required to reach the design footing subgrade elevations. The final bedrock surface was cleaned out with compressed air prior to the placement of the concrete. At the east bridge abutment, a “shear key” into the bedrock subgrade was added because of the lower than anticipated competent bedrock surface. This shear key was added to increase the passive resistance for the training wall/bridge abutment foundation.

Figure 7. Concrete work during winter 2010 / 2011 at the spillway.

December 2010 marked the beginning of concrete placement for the new spillway. It also marked the beginning of one of the coldest winters in recent years in the Berkshires.

As shown on Figure 7, concrete was formed and poured in heated tents, and was typically allowed to cure for at least three days within the heated tents prior to stripping forms. Diligent maintenance of the heating system by the contractor allowed for concrete placement to occur relatively unimpeded despite the cold weather. Rock excavation was not allowed for 24 hours after concrete had been poured on the site, and backfilling was not permitted until the concrete had achieved its required 28-day compressive strength. Field-cured cylinders were used to determine whether required 28-day compressive strengths were achieved, which, thus, allowed backfilling to be performed at an accelerated schedule. The stop log bays foundations, crest gate foundation, as well as upstream and downstream training walls/bridge abutments were all poured throughout the winter in this manner with great success. Side seals and heating elements for the hydraulic crest gate were installed as part of the training wall construction.

By February 2011, work on the spillway had progressed sufficiently to allow backfilling between the existing embankment and spillway training/abutment walls. Freezing temperatures required a diligent effort on the contractor's part to provide ground heaters and frost blankets. The specifications for backfill material were geared toward providing control of seepage through the embankment, as opposed to the free-draining materials commonly associated with roadway and bridge construction. Because of the relatively high fines content (between 15 and 30 percent) of the off-site embankment fill material, moisture content significantly impacted the contractor's ability to compact the material to the required density. The backfill material was brought from an off-site borrow pit to the site with a moisture content that was typically well over its optimum moisture content. This condition, in addition to the rainy/wet weather that became more prevalent in the early spring of 2011, caused delays in the backfilling operation. The wet backfill issues were addressed primarily by providing better control of moisture in both the on-site and off-site borrow area stockpiles. In some instances where moisture could not be properly controlled, the amount of fill placed in a single day had to be limited to allow porewater to dissipate prior to the placement of the next lift of fill. Despite the adverse conditions, the backfilling was completed, the stop logs were installed and the temporary cofferdam was removed in time for the scheduled bridge/road reopening in March 2011.

The new bridge has a 20-foot-wide roadway (curb-to-curb) and a 6-foot-wide sidewalk on the north side, resulting in an overall width of 29 feet. The bridge can accommodate two travel lanes, where the previous "temporary" Bailey bridge could not accommodate travel in both directions. The wider bridge required the location of the new bridge to be shifted southward, with respect to the previous bridge, which resulted in a straightening of the layout of Tolland Road.

Figure 8. New spillway bridge installation.

The bridge installation was performed using a 60-ton crane set up at the east (right) abutment of the spillway (see Figure 8). Completing the spillway backfilling operation was critical since it needed to be completed ahead of the bridge installation in order for the bridge and Tolland Road to be reopened to the public by March 2011. The bridge was fabricated in the three sections, which were trailered individually to the dam and staged on the dam crest. The crane was able to set each bridge section into place in one day. The grouting of the bridge sections and the installation of the bridge railings were completed over a two-week period and the bridge was opened on schedule on March 18, 2011.

8. A Little More Than Just a "Wet Test"

Between the first and second construction seasons, on August 27-28, 2011, Otis Reservoir received between about 7 and 10 inches of rain from Tropical Storm Irene. In anticipation of the storm, the DCR began to lower the reservoir level with the outlet gate two days prior to the storm's arrival in the area. The outlet tower slide gate was kept open during and after the storm to help control the reservoir level. By the time the storm hit, the DCR had removed up to three rows of stop logs (1.5 feet). The reservoir level eventually rose to about 12 inches over normal pool (as seen in Figure 9) on August 29, 2011, which is about 6 inches above the maximum reservoir level used to design the stop logs. On September 1, 2011, the DCR reported that the three rows of stop logs had been replaced and gate in the outlet tower was closed. The DCR inspected the spillway and did not observe any noticeable damage.

9. Second Year Construction: The Home Stretch

The contractor re-mobilized to the site fulltime in October 2011 in order to begin construction on the last parts of the project. Final pavement of the road and bridge was placed and the pedestrian railings were completed. Construction of the new gatehouse began concurrently with the installation of the hydraulically actuated crest gate. The new gatehouse was constructed on the left (west) side of the spillway:

- to house equipment and controls associated with the hydraulic crest gate;
- to house the remote water level instrumentation system; and,
- to provide secure storage for the aluminum stop logs.

The crest gate (shown in Figures 10 & 11) was installed by the end of December 2011. The hydraulic system was installed and tested as part of the "dry test" in January 2012. A "wet test" of the crest gate system was also performed shortly thereafter. Although the reservoir was at the winter pool elevation, water could be pumped from the reservoir into the area between the stop logs and crest gate. So, once again, the inclusion of the stop logs provided a benefit to the project that went beyond their primary objective.

The crest gate system was substantially complete by mid-March 2012 when a training session was held for the DCR personnel who would be operating the new system.

The new slide gates were installed "in-the-wet" inside the downstream tower on its upstream face. The new slide gates included new electric actuators (with manual backup). These new slide gates were installed with new nchor bolts drilled into the downstream face of the outlet tower, with cement grout bedding installed between the gate flange and the outlet tower wall. However, the contractor had problems during the installation of the new gates. During startup testing, the slide gates leaked significantly through the grout bedding and flowed behind each gate's flange and through several of the anchor bolt holes. The reason for the leakage was attributed to problems encountered by divers used during the installation of the grout bedding. Several repair attempts were made. However, the leakage remained beyond the specified allowable limit. As of 2013, the DCR is evaluating repair options to address the slide gate leakage.

9. Summary

The Otis Rehabilitation Dam and Bridge Rehabilitation Project (see Figure 12) was a success. The planning efforts, which were initiated by the dam safety inspections, led to a project that ultimately benefited the DCR, the town of Otis and the general public. The crest gate spillway provides the needed hydraulic capacity to the dam in order to mitigate overtopping and the potential failure of a high hazard dam. The crest gate also provides a self-regulating winter pool level that significantly improves the DCR's reservoir operations. The new bridge replaces a temporary one-lane bridge that was in place for approximately 15 years beyond its intended service life and provides a permanent two-lane bridge that will benefit the users of the Otis Reservoir. Even though the project initially started out with the primary goal of addressing the dam safety issues at the dam, the evolution of the project ultimately provided a broader and more substantial benefit to each of the project stakeholders.