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Upgrading Pikes Creek Dam Spillway with a Fusegate System(*)

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1. INTRODUCTION

The use of Fusegates has become one of the most viable options to increase discharge capacity, especially for the rehabilitation of spillways with little available freeboard. Fusegates offer a more accurate and reliable solution to replace flashboards and fuse plugs, and can significantly reduce construction costs when considered as an alternative to labyrinth weir type spillways or gated spillways.

Upon assessment of various alternatives including construction of a fixed-labyrinth weir at the auxiliary spillway and embankment overtopping protection, Pennsylvania American Water Company (PAWC) selected a labyrinth-type Fusegate System. The Fusegate system consisted of a 76.20 m wide auxiliary spillway that was equipped with eighteen 2.84 m high pre-cast concrete labyrinth-type Fusegates. The Fusegate System installed at Pikes Creek Dam is the first labyrinth-type Fusegate System to be installed in Pennsylvania. A straight sharp-crested Fusegate System was installed at Muleshoe Dam in 2014 which was the first Fusegate System in Pennsylvania.

2. DESIGN STAGE

2.1 PROJECT BACKGROUND

Pikes Creek Dam is located on Pikes Creek, about five miles northwest of Wilkes-Barre in Luzerne County, Pennsylvania. Built in 1911, the dam is owned and operated by PAWC and is used for water supply.

The dam is a 19.8 m high and 657 m long homogenous earthfill embankment with a reinforced concrete core wall. The principal spillway is a 22 m long ogee crest located

(*) *French translation*

on the right abutment. The auxiliary spillway consisted of a 74 m long ogee crest equipped with 0.6 m high flashboards. The dam is as a high hazard structure (Class 1) due to the potential for economic damages and loss of life should it fail. Therefore, the design flood was established as the Probable Maximum Flood (PMF).

In 2008, PAWC engaged Gannett Fleming, Inc. to assess the dam. Hydrologic and hydraulic analyses determined that the combined principal and auxiliary spillways were capable of passing only 23 percent of the PMF.

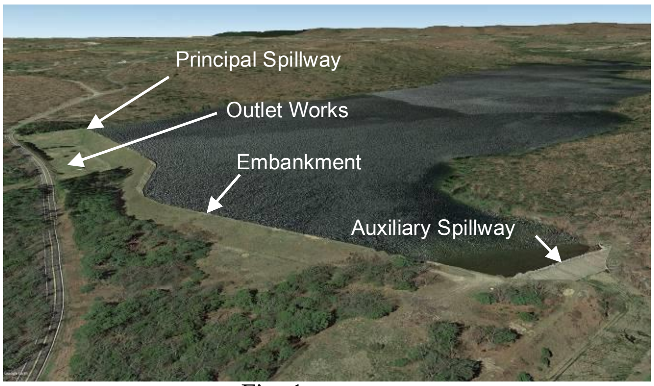

Fig. 1
View of Pikes Creek Dam before construction
French translation

Fig. 2
View of auxiliary spillway
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2.2 *DAM SAFETY DEFICIENCIES AND REMEDIATIONS*

Hydraulic analyses of the principal spillway determined that the spillway chute had a discharge capacity less than the principal spillway weir. Modifications to the principal spillway included construction of a riprap-lined berm along the left chute wall to confine the flow to the chute and increase the capacity of the principal spillway. Concrete deterioration of the principal spillway ogee crest, chute walls and slabs were also repaired.

Fig. 3
Principal spillway chute and left wall berm (looking upstream)
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Stability analyses for the downstream slope of the dam embankment revealed that the factor of safety against slope failure was less than the required factor of safety of 1.5. Unfiltered seepage also existed at several discrete locations throughout the length of the dam embankment. To remedy the embankment stability and seepage issues, a filtered chimney drain was installed and the downstream embankment slope was flattened.

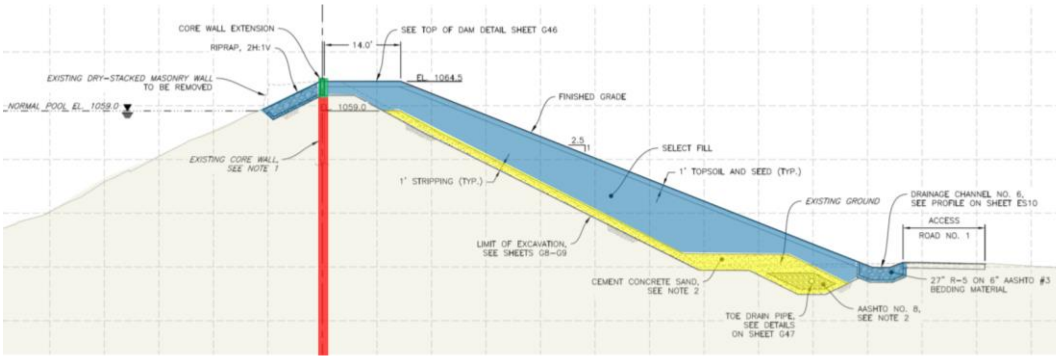

Fig. 4
Slope stability and seepage collection solution
French translation

To meet Pennsylvania Department of Environmental Protection (PADEP) dam safety requirements, the three 76.20 cm water supply conduits that penetrated the dam's embankment at its maximum section were modified to provide upstream closure by installing pneumatically-operated knife gate valves. This work was performed with a full reservoir under 20 meters of water.

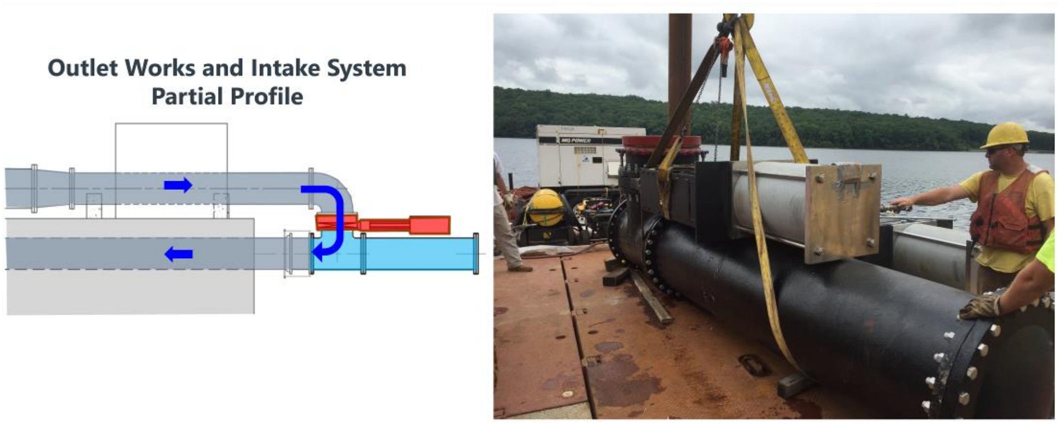

Fig. 5
Upstream closure pneumatically-operated knife gate valve installation
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2.3 *DISCHARGE CAPACITY DEFICIENCY AND PROPOSED SOLUTIONS*

The maximum capacity of the auxiliary spillway after all flashboards collapsed was 341 m^3/sec. In order to increase the capacity of the spillway to pass the PMF inflow of 1,110 m^3/sec, significant modifications to the existing auxiliary spillway were required. Project design restrictions applied to all rehabilitation alternatives considered included not changing any of the following:

- Top of dam elevation of El. 1064.5 ft.
- The normal pool elevation of El. 1059.0 ft.
- The spillway inflow/outflow stage-discharge characteristics up to the 100-year flood.

These restrictions therefore required that the spillway capacity be increased with very little freeboard above the 100-year flood (< 1 meter of freeboard).

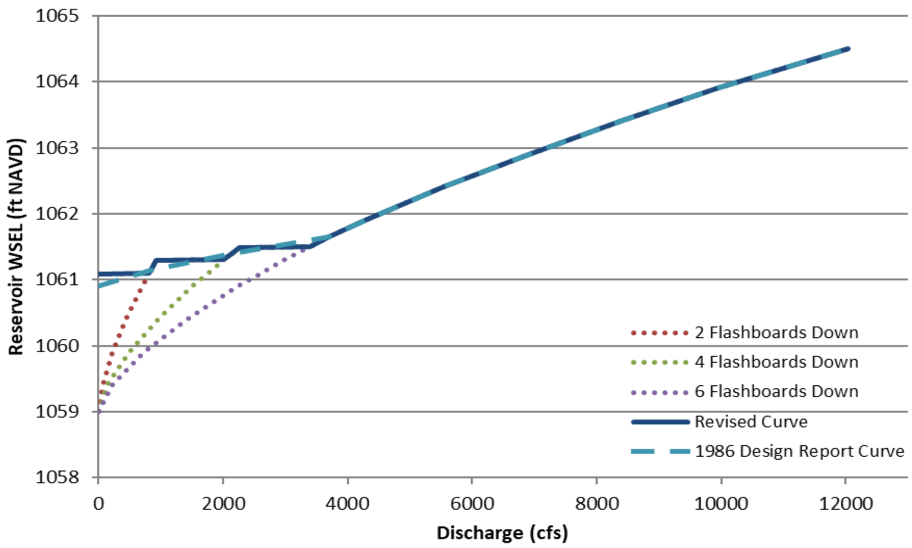

Fig. 6
Existing auxiliary spillway discharge rating relationship
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Flashboards or earthen fuse plugs are no longer allowed by PADEP because of their history of unpredictable and poor performance. Installation of gate systems, incuding Obermeyer Gates, inflatable rubber dams, bascule gates, and hydraulically-operated crest gates are also generally discouraged due to the need for human interaction, reliable power supply, and the potential for misoperation of the gates. The following four alternatives were evaluated to increase the discharge capacity at Pikes Creek Dam:

Labyrinth Spillway: A 114.50 m wide fixed labyrinth weir spillway with 13 cycles and a 700 m long weir was considered. The labyrinth structure would be built in a fanned or dog-leg footprint. This alternative included complex hydraulic conditions as well as displacement of a portion of the existing embankment.

Armoring the Embankment to Allow Overtopping: This included construction of a fixed labyrinth weir within the existing auxiliary spillway footprint to pass 50% of the PMF prior to overtopping the dam embankment. Embankment overtopping protection consisted of armoring the entire embankment using roller-compacted concrete (RCC) or articulating concrete block mats (ACB's) to convey the remaining portion of the PMF. This alternative was determined to have complex hydraulics of overtopping flows caused by the curved dam alignment, and the lack of room for a stilling basin due to the presence of State Route 29. Armoring a dam embankment to allow overtopping is also generally only considered when other economical alternatives are not available.

Fusegates with Curved Alignment: This involved construction of a 91.50 m wide curved broad-crested weir equipped with 2.47 m high and 3.81 m wide labyrinth type Fusegates. This alternative was developed to reduce the excavation required for the spillway.

Fusegates with Straight Alignment: This alternative included the construction of a 76.20 m wide straight broad-crested weir equipped with 2.84 m high and 4.23 m wide labyrinth-type Fusegates. This solution simplified the hydraulic conditions, incorporated the existing grout curtain, and reduced the overall spillway footprint and construction materials.

2.4 SELECTED ALTERNATIVE

The Fusegates with the straight alignment was determined to be the most economical and technically feasible solution. The Fusegates were designed to limit their initial tipping sequence to an extreme flood event (~23% PMF) which was estimated to be less frequent than a one in a 2,000-year event as shown in Figure 7.

The configuration and sizing of the auxiliary spillway channel for the Fusegate modification was performed using two-dimensional hydraulic modeling. The channel was designed to contain the PMF outflow from the auxiliary spillway, maintain hydraulic control at the Fusegate sill, minimize the potential for submergence effects at the weir crest, and limit tailwater elevations at the Fusegates to allow them to tip as designed. The integrity of the auxiliary spillway and downstream channel were analyzed using the Natural Resources Conservation Service (NRCS) SITES software. The erodibility of the channel was not a concern based on the boring data and geophysical surveys. Even though some amount of headcutting and damage to the bedrock channel was possible, there was no risk of breaching the concrete spillway structure.

Water supply impacts were analyzed using a custom computer model to simulate the operation of the system for an 80-year period of historical data to understand the consequences of tipping one or more Fusegates. With the reservoir at full pool, the tipping of a Fusegate would result in the loss of approximately 30% of the total reservoir storage. While this loss could impact long-term water availability during a drought, it would not interrupt normal supply operations. In the rare event that any Fusegates tipped, provisions were incorporated into the design to allow installation of a temporary stoplog cofferdam system to enable refilling the reservoir until the tipped Fusegates were replaced.

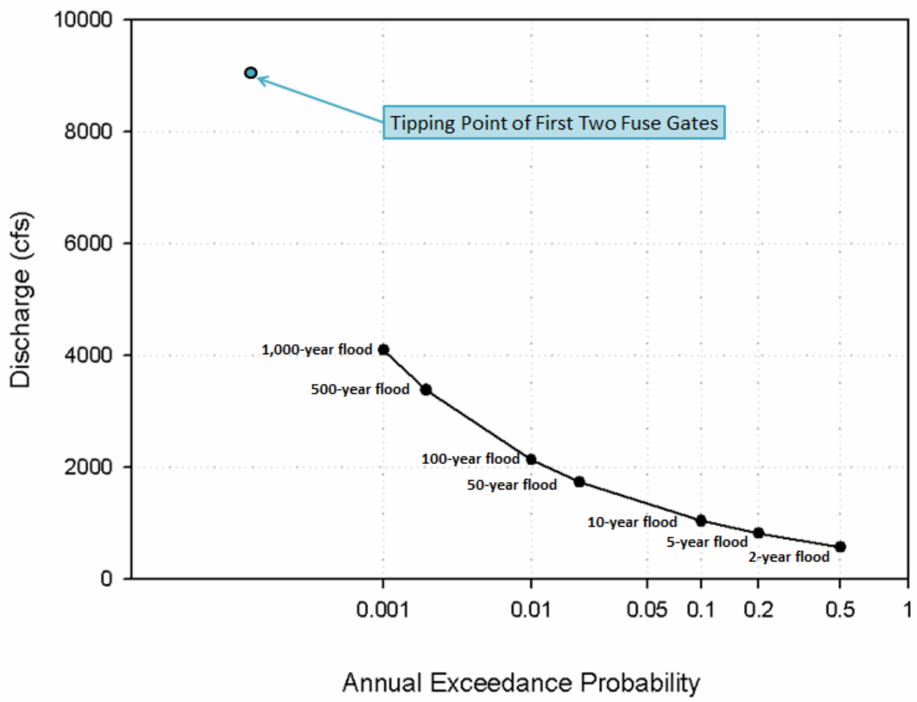

Fig. 7
Initial tipping point for Fusegates relative to estimated flood recurrence intervals
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2.5 *FUSEGATE DESIGN*

At Pikes Creek Dam, a total of 18 labyrinth Fusegates were designed, each 2.84 m high and 4.23 m wide. The Fusegates were founded on a broad-crested weir control sill having an upstream to downstream length of 3.69 m. Each Fusegate included two stainless steel toe abutment blocks embedded into the control sill to enable the Fusegates to pivot or rotate during a tipping sequence.

During exceptional floods, one or more Fusegates would tip progressively when the reservoir level reached predetermined elevations. Five tipping sequences were designed for the Fusegates. The first two tipping sequences involve the tipping of two Fusegates each, whereas the third tipping sequence involves four Fusegates. The last two tipping sequences involve five Fusegates each. Fusegates equipped with an inlet well were referred as “Master Fusegates”, while Fusegates equipped with a deflector were referred as “Ancillary Fusegates”. In order to design just one inlet well for each tipping group of Fusegates, pipes or “deflectors” were installed within the concrete sill to allow the uplift pressure from the chamber of the Master Fusegate to be transmitted to the Ancillary Fusegates.

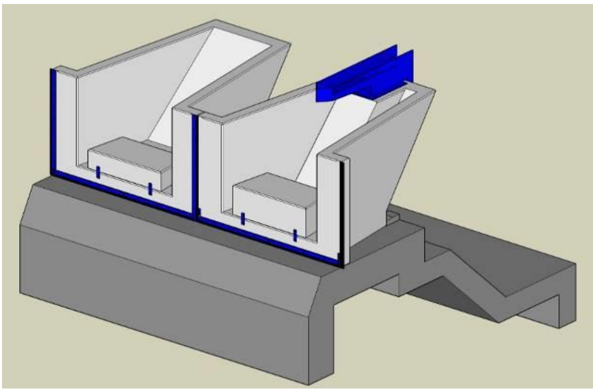

Fig. 8
Isometric view of the spillway sill and Fusegate
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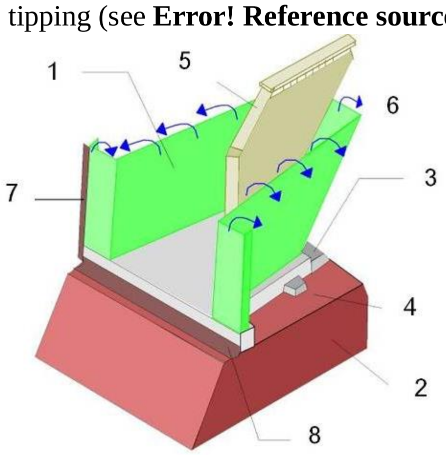
The Fusegates were designed as modular freestanding units installed side-by-side on the spillway sill (the sill is level to provide the necessary flat surface to support the Fusegates). All Fusegates have a vertical face equipped with a watertight seal between the gate and the sill and the sides of the adjacent Fusegates. The weight of each Fusegate was adjusted using concrete ballast blocks to provide the required factor of safety against tipping (see **Error! Reference source not found.** & 12).

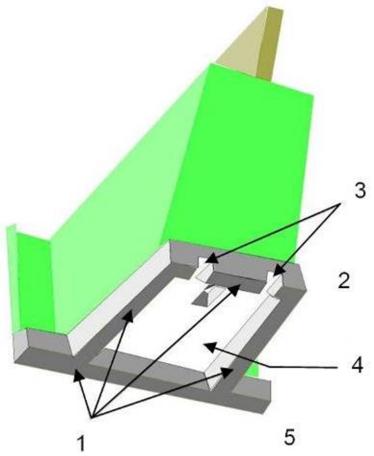


1 Bucket	1 Auge
2 Concrete sill	2 Seuil en béton
3 Downstream abutment block	3 Butée avale
4 Downstream bucket side	4 Butée latérale
5 Inlet well	5 Puits d’admission
6 Overspilling crest	6 Crête déversante
7 Side seal	7 Mur latéral
8 Upstream seal strip	8 Joint étanche amont

Fig. 9
3-D view of top of a Fusegate
Vue en perspective d’une hausse fusible

Fusegates come in two crest types; straight-crested and labyrinth-crested. Straight crested Fusegates provide resistance to significant spill-over (up to three times their own height). Labyrinth-crested Fusegates can discharge greater flows for a given overflow depth.

The central part of the horizontal slab underneath each Fusegate is hollow, forming a chamber equipped with drain holes. The chamber is connected to the reservoir via an inlet well that admits water to the underside when the headwater reaches the top of the inlet well. The watertight configuration of Fusegates allows water storage up to their crest. Ordinary and average floods are discharged over the crest of the Fusegates. The hollow chamber under the Fusegates is equipped with a drain to discharge all accidental flows (due to a problem with the seals, for example) to ensure no uplift pressure develops in the base of the hollow chamber.



1 Base	1 Base
2 Downstream	2 Aval
3 Drain holes	3 Purges
4 Pressure chamber	4 Chambre de mise en pression
5 Upstream	5 Amont

Fig. 10
3-D view of bottom of a Fusegate
Vue de dessous d'une hausse fusible

Until the reservoir level overflows the inlet wells, the Fusegates provide a high stability margin against overturning. Once the reservoir overflows the inlet wells, it overwhelms the drain and creates sufficient uplift pressure in the hollow chamber to destabilize the Fusegate and causes it to tip. Each inlet well is set at a different elevation to ensure that the Fusegates tip in sequence, thus ensuring progressive discharges and preventing sudden flash floods downstream.

3. CONSTRUCTION

3.1 PRODUCTION WORKS

The Fusegates at Pikes Creek Dam were made of pre-cast reinforced concrete and weighed approximately 36 tons each. The Fusegates were fabricated by Old Castle Precast located in Telford, Pennsylvania. After each Fusegate was fabricated, it was weighted to verify the concrete ballast requirements. A hydraulic jack was used to weigh each Fusegate.

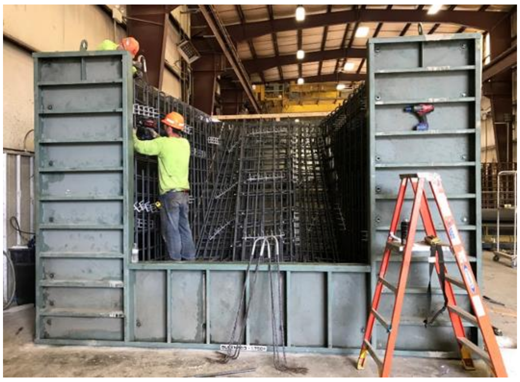


Fig. 11
Custom-made formwork and steel placement
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Fig. 12
Fusegate jacking to verify ballast requirements
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The steel components of the Fusegates were manufactured at Johnson Machine Works plant in Charito, Iowa. Figure 13 shows the completed inlet wells.

Fig. 13
The production of the steel Fusegate components
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3.2 FUSEGATE INSTALLATION

KC Construction company was hired by PAWC in Spring 2016 to rehabilitate the dam. Prior to installing the Fusegates, the new spillway sill was cleaned, and the exact location of each Fusegate was outlined on the sill.

When the Fusegates were delivered to the site, they were placed on the spillway sill using a mobile crane. The inlet wells, ballast blocks and deflectors were installed after the Fusegates were placed on the spillway sill.

The watertightness system was installed last. This involved installing stainless steel angle bars on the Fusegates to allow EPDM rubber compression seals to be wedged between the angle bars and the foundation. After completion of the seals, leakage tests were performed on selected Fusegates by enclosing the upstream 30 cm section of the Fusegate up to its crest using formwork and sandbags. Compression seals were adjusted and additional sealant was applied when necessary. The Fusegates were installed by December 2017.

Fig. 14
Fusegate Installation at Pikes Creek
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Fig. 15
Completed Fusegate System at Pikes Creek
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Fig. 16
Completed Auxiliary Spillway at Pikes Creek
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3.3 *ENHANCEMENT OF TRADITIONAL FUSEGATE DESIGN*

The first two years after the Fusegates were installed, the Fusegates performed as designed with one unexpected incident. In February 2019, following a prolonged and severe cold period, ice on the reservoir formed that approached 0.3 m in thickness. It was observed that the Fusegates tilted slightly in response to the expanding ice cover as was detected by seepage emanating under the gates. The gates responded as expected and settled back as the ice cover broke in front of the gates in response to the Fusegate deflection, with minimal seepage afterwards. Approximately two weeks later, two pairs of Fusegates deflected in response to the ice load and subsequently settled back, again with minimal seepage afterwards. The performance of the Fusegates during the second event was unexpected and became a concern as any releases of flow through the auxiliary spillway were undesirable as they could adversely impact the drainage systems for the downstream highway. Up to this event, all of the existing Fusegate installations in cold climates showed no evidence of movement or leakage from ice loads.

In response to the unexpected performance of the Fusegates to the ice load, the Fusegate manufacturer (Hydroplus) responded immediately by developing an innovative solution that consisted of equipping the existing Fusegates with pedestrian access (see Figure 17) along with a simple but effective "ice-eater" system to eliminate future ice loads from acting on the Fusegates. A prototype of the "ice-eater" system was installed in 2019 and found to maintain a 100-foot ice-free zone upstream of the Fusegates. Modifying the Fusegates to provide pedestrian access is a new feature not previously offered on Fusegate Systems. Additional enhancements to improve the performance of Fusegates for extreme ice loads continue to be investigated by Hydroplus.

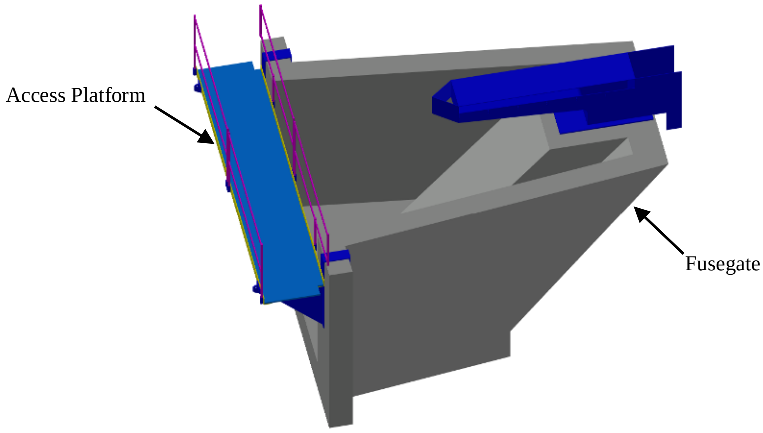

Fig. 17
Fusegate access platform
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SUMMARY

Pikes Creek Dam presents a classic example of a dam with significant spillway inadequacy and modification restrictions that limited available options to an innovative non-traditional solution. The use of Fusegates provided the most economical and practical solution. In addition to providing additional spillway capacity that maintained the existing inflow/outflow characteristics up to the 100-year flood and without raising the crest of the dam, it greatly improved the reliability and performance of the auxiliary spillway as compared to the previous flashboard system. This project also advanced the understanding of Fusegates in cold weather applications where significant ice loads are a concern and provided an opportunity to enhance the next generation of Fusegates to better accommodate ice loads.

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RÉSUMÉ

French translation

KEY-WORDS – Delhi Congress

ANGLAIS	FRANÇAIS
Abutment	Appui
Active storage	Réserve utile
Analysis	Calcul
Base	Base
Behavior	Comportement
Benefits of dams	Bienfait des barrages
Block	Plot
Body of dam	Corps du barrage
Pikes Creek Dam	Barrage de Pikes Creek
Cement	Ciment
Chute	Coursier
Concrete	Béton
Conduit	Conduite
Construction phase	Phase de construction
Crest	Couronnement
Dam failure	Rupture de barrage
Damage	Dégâts
Dead storage	Réserve morte
Density	Densité
Design	Calcul
Design flood	Crue de projet
Discharge	Débit
Diversion works	Ouvrage de dérivation
Downstream face	Parement aval
Drainage	Drainage
Earth	Terre
Earthfill dam	Barrage en terre
Economic study	Etude économique
Effects of dams on environment	Effets des barrages sur l’environnement
Emergency spillway	Evacuateur de secours
Erosion	Erosion
Excavation	Fouille
Fill dam	Barrage en remblai
Flood	Crue
Flood control	Maîtrise des crues
Flood storage	Réserve de crue
Flooding	Inondation
Flow	Débit
Formwork	Coffrage
Foundation	Fondation
Freeboard	Revanche
Gate	Vanne
Gated spillway	Evacuateur avec vanes
Geology	Géologie
Hydrology	Hydrologie
Intake tower	Tour de prise
Muleshoe Dam	Barrage de Muleshoe
Leakage	Fuite
Lining (reservoir)	Revêtement (réservoir)
Maintenance	Entretien
Materials	Matériaux

Metal	Métal
Monitoring	Auscultation
Open channel	Canal à écoulement libre
Overtopping	Submersion
Placing of concrete	Mise en place du béton
Quality control	Contrôle de qualité
Rehabilitation	Réhabilitation
Reinforcement	Armature
Reservoir	Retenue
Reservoir capacity	Reserve totale
Rockfill dam	Barrage en enrochement
Safety of dams	Sécurité des barrages
Seepage	Infiltration
Sill	Seuil
Slab	Dalle
Spillway	Evacuateur de crue
Stability	Stabilité
Stilling basin	Bassin d'amortissement
Uplift	Sous-pression
Upstream face	Parement amont
Water level	Niveau hydraulique