EVALUATION, DESIGN AND CONSTRUCTION OF AN AVALANCHE PROTECTION STRUCTURE AT THE MICA DAM, CANADA

Greg Johnson, P.Eng.1*, Alan Jones, P.Eng.2 and Owen Williams, P.Eng.3

1WSA Engineering Ltd., Castlegar, BC, Canada
2Dynamic Avalanche Consulting Ltd., Revelstoke, BC, Canada
3BC Hydro, Burnaby, BC, Canada

ABSTRACT: The “Great Wall of Mica” was constructed in 2011 at the base of BC Hydro’s Mica Dam, 130 km north of Revelstoke, Canada. This barrier was designed to stop avalanches, which will protect workers, vehicles, equipment and structures. This 89 m long avalanche defense barrier stands 3.75 m tall by 3 m wide, and was constructed using 1,218 interlocking and freestanding concrete lock-blocks. It was designed to be overtopped, but withstand impacts from a minimum 30-year design avalanche.

A Structured Project Decision Matrix was used to evaluate 12 risk treatment alternatives, 6 of which were unique structural barrier types. This Decision Matrix considered 10 discrete requirements, including: health and safety (risk to workers during and post-construction), costs (construction, maintenance, decommissioning), environmental impacts, footprint and impact to the work area, and the project schedule. Aesthetics and value were intangible criteria also considered in the evaluation.

Through this structured evaluation process, the best solution was determined to be a barrier made of interlocking and freestanding concrete lock-blocks. Although more complicated solutions were considered, the lock-block barrier provided the best combination of aesthetics and value, and most importantly one that could be constructed within the tight project schedule. The evaluation, design and construction of this barrier was completed in summer and fall of 2011.

KEYWORDS: Avalanche protection, Avalanche risk, Project management

1. INTRODUCTION

In 2011 an avalanche protection structure was constructed at the base of BC Hydro’s Mica Dam, located on the Columbia River, 130 km north of Revelstoke, British Columbia, Canada (Figure 1). This structure was designed to stop avalanches that initiate on the dam face, protecting workers, vehicles, equipment and buildings during the BC Hydro Mica Generating Station Units 5 and 6 Dam Upgrade Project. BC Hydro is increasing capacity by installing two additional 500 MW generating units into the dam, with an estimated capital cost of CAD $800 million.

The worksite requires 24-hour, 7-day per week access, including during the winter months. The project started in 2011, is in its third year of construction, and is forecast to be completed in 2015.

This paper describes the processes used to evaluate avalanche risk and treatment options for this project. A Structured Project Decision Matrix was used as a primary tool to help the project team to objectively evaluate options and select the most effective risk treatment solution.

Figure 1: Location of the Mica Dam.

2. BACKGROUND

When the Mica Dam was completed in 1973, it was considered the largest earth fill dam in the world (Figure 2). The dam rises 170 m from its
base to the dam crest at 765 m elevation and its face is steep enough to produce avalanches. The upper section of the dam was constructed at an angle of 34° for a slope distance of 100 m. The lower section was constructed at 27° for a slope distance of 257 m. The total slope length from the top to the toe of the dam is 357 m.

![Figure 2: The Mica Dam observed from the south. Powerhouse portal located at lower left edge of dam.](image)

The dam is 750 m wide at its top, narrowing to 240 m wide at its base. An area of approximately 9.5 hectares (ha) on the dam face could potentially contribute to avalanche hazard to the base area.

Below the dam face is a 1.2 ha flat area where avalanches will terminate, but this area is also designated for use as a laydown area that is critical for the construction program. This laydown area is used for vehicle parking, access to the underground powerhouse, equipment storage and temporary offices.

2.1 Historical Avalanches

Prior to 2011 when a formal avalanche monitoring program started, avalanche observations for the dam were few.

The first significant recorded avalanche occurred in January, 2011 while planning was underway for the upcoming construction project. The avalanche was Destructive Size 2.5 with a deposit up to 2.5 m deep, and highlighted the potential risk to the laydown area. The avalanche impacted approximately ten vehicles parked at the base of the dam (Laurilla, 2011), but there were no resulting injuries. In response to this event, BC Hydro temporarily closed the laydown area to protect workers and vehicles.

2.2 Safety Standards

Following the January 2011 avalanche, BC Hydro recognized the avalanche risk and committed to providing a safe work environment for its workers, protecting equipment and minimizing costly construction delays for the upcoming project.

The Canadian Avalanche Association’s (CAA) Guidelines for Snow Avalanche Risk Determination and Mapping in Canada (CAA, 2002) sets the standard that WorkSafeBC accepts for worksites in avalanche terrain. The CAA guidelines state “Work sites are typically assessed for avalanche return periods in the range of less than 30 years to 100 years with a critical size of 2 or greater.” This means that where risk to a worksite exceeds the criterion, as is the case at Mica Dam, risk may be mitigated by a number of means, including monitoring and preventative closures and/or permanent structural risk treatment.

Given the large number of personnel on foot potentially exposed to avalanche risk at the Dam Portal/Laydown Area over a period of at least four years (there are typically 200-300 workers present at the nearby Mica Village camp), a relatively high standard of care was expected for this worksite.

3. DESIGN REQUIREMENTS

The design of any avalanche risk treatment program is an iterative process. In this case, the project team started with the general assumption that risk treatment might include the following broad options: an avalanche protection structure designed to stop Destructive Size 2 to 3 avalanches, an avalanche forecasting program to close the area if larger avalanches were expected, starting zone retaining structures and explosive avalanche control on the dam face.

The avalanche velocity and location of impact forces are the critical variables that determine how an avalanche will interact with a protection structure located near the toe of the dam. The velocity and impact load will be highest at the toe of the dam and then decrease with distance from the toe. The corresponding run-up height on the structure also decreases as a structure is moved away from the toe of the dam. If a protection structure were to be selected as the preferred option, it should be located as close as practical to the toe of the dam because of the importance of maximizing useable space at the base of the dam and minimizing impacts to the construction program.
The frequency and magnitude estimates of avalanches at the base of the Mica Dam were primarily based on modeling and judgment, with limited historical observations. Table 1 lists the theoretical runout positions for 10-year and 30-year avalanche events relative to the dam’s toe. These positions are shown approximately in Figure 3 to illustrate the potential area of effect of a design avalanche within the laydown area.

Table 1: Theoretical runout positions for 10 – 100 year avalanche events

<table>
<thead>
<tr>
<th>Avalanche Event (years)</th>
<th>Runout Position (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>23</td>
</tr>
<tr>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>100</td>
<td>113</td>
</tr>
</tbody>
</table>

The estimated maximum velocity of a 30-year return period avalanche was determined to be 23 m/s. The velocity of a 10-year return avalanche was estimated by using the January 2011 event for calibration, when a vehicle was pushed approximately 5 m from the toe of the dam where it was parked (Laurilla, 2011). The impact force required to push the vehicle corresponds to a velocity of 8 m/s, which was consistent with the modeled velocity of a 10-year avalanche.

Avalanche impact loads were estimated by using velocity and the density of a flowing avalanche. The reaction of any protection structure will vary depending on whether it is flexible (e.g. a ring-net structure) or rigid (e.g. concrete wall) and whether or not there is a degree of free flow around or through the structure. Table 2 shows the estimated avalanche impact loads for 10-year and 30-year return period avalanches at distances away from the dam toe, and solid or flexible walls. The loads listed in Table 2 include a factor of 1.5 to account for uncertainty.

![Figure 3. Mica Dam Portal/Laydown Area showing the approximate runout positions for the observed 2011 avalanche and 10, 30 and 100-year design avalanches.](image)
Table 2. Estimated avalanche impact loads on structures adjacent to the toe of dam

<table>
<thead>
<tr>
<th>Toe Distance (m)</th>
<th>Velocity (m/s)</th>
<th>Density (kg/m³)</th>
<th>Impact Loads (kPa)</th>
<th>Run-up height (m) against a barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solid Wall</td>
<td>Flexible Wall</td>
<td>Flexible Wire Mesh</td>
<td>HS (m)</td>
</tr>
<tr>
<td>10 – Year Return Period</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>150</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>7</td>
<td>150</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td>6</td>
<td>150</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>30 – Year Return Period</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>17</td>
<td>150</td>
<td>65</td>
<td>39</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>150</td>
<td>53</td>
<td>32</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>150</td>
<td>51</td>
<td>30</td>
</tr>
</tbody>
</table>

The project team considered impact loads and the protection structure’s distance from the dam toe and determined the following design parameters:

1. 10-year return period (Size 2-2.5) avalanches should be prevented from affecting personnel working and equipment stored at the Portal and Laydown Area (i.e. avalanches are stopped and contained by any proposed structure); and

2. Protection structures should be designed to withstand impacts from a minimum 30-year return period Size 3 avalanche. Avalanches could flow over or around the protection structure but should not critically damage or destroy the structure.

4. EVALUATION OF RISK TREATMENT OPTIONS

Numerous risk treatment options were considered for the Laydown area both during previous studies and by the project team. Following field reviews and project team meetings, 12 alternatives were identified that could satisfy the design parameters. Conceptual designs and cost estimates were completed for each of these options, then each type of protection structure, start zone retaining structures, or monitoring and control methods were evaluated in terms of ten design criteria:

1. Minimize risk of injury or loss of life to people working in the main portal area;
2. Minimize risk of injury or loss of life to people during construction and maintenance of avalanche protection structures;
3. Minimize the cost required to remove the avalanche protection structure at the end of the project or design life;
4. Minimize risk of damage to the dam resulting from construction or maintenance;
5. Maximize area available for construction activities;
6. Minimize risk of delays to Mica 5/6 construction;
7. Minimize duration to design, procure and construct the avalanche barrier;
8. Minimize capital costs;
9. Minimize maintenance and repair costs; and
10. Minimize the amount of demolition and debris required to construct the protection structure (i.e. environmental impact).

4.1 Avalanche Protection Structures

The project team initially evaluated six unique protection structure types, as well as start zone snow support structures and avalanche monitoring and control as risk treatment solutions. Different lengths and combinations of the structures with snow catching fences were also considered.

Three of the protection structure types considered were gravity structures that did not require foundation anchors. Gravity structures considered included concrete lock blocks, rock filled gabion baskets, and metal shipping containers (Sea-Cans) filled with soil and rock. The other three protection structures considered require foundations to anchor them. These protection structures included a snow catching fence, a cast-in-place concrete wall, and a wall constructed of large wood beams held in place by large steel H-piles.

Anchored structures function by transferring avalanche impact loads to their foundations and were attractive because they have a smaller footprint compared to gravity structures. However anchored systems were found to have relatively higher capital costs compared to gravity structures.
### Table 3 Avalanche risk treatment decision matrix.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Criteria</th>
<th>Measure (unit)</th>
<th>Weight (%)</th>
<th>Option #1: Monitoring and Control</th>
<th>Option #2: Escalate Risk Basket Wall</th>
<th>Option #3: Escalate Risk Lock Block Wall</th>
<th>Option #4: 100 m Smoke Catching Fence</th>
<th>Option #5: 100 m Concrete Wall</th>
<th>Option #6: Escalate Risk and Wood Beam Barrier</th>
<th>Option #7: 100 m Sea Can Barrier</th>
<th>Option #8: Starting Zone Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health and Safety Conditions</td>
<td>Minimize risk of injury to workers</td>
<td>Risk of injury or loss of the project working in the main portal area</td>
<td>Likelihood of health &amp; safety risk</td>
<td>2.0</td>
<td>Partial barrier production, intermediate between No Option #1 and Option #8</td>
<td>Partial barrier production, intermediate between No Option #1 and Option #8</td>
<td>All structural 100 m long barrier systems should be built</td>
<td>All structural 100 m long barrier systems should be built</td>
<td>All structural 100 m long barrier systems should be built</td>
<td>High risk than other barriers since sea-can height is limited to 2.4 m (8’)</td>
<td>Lowest risk of all mitigates fully avalanche risk</td>
</tr>
<tr>
<td>Health and Safety Conditions</td>
<td>Minimize risk of injury to workers</td>
<td>Risk of injury or loss of the project working in the main portal area</td>
<td>Likelihood of health &amp; safety risk</td>
<td>5</td>
<td>No risk to workers because nothing constructed</td>
<td>Risk should be low for all options, but can be low as low as Option #1: Monitoring and Control</td>
<td>Risk should be low for all options, but can be low as low as Option #1: Monitoring and Control</td>
<td>Risk should be low for all options, but can be low as low as Option #1: Monitoring and Control</td>
<td>Risk should be low for all options, but can be low as low as Option #1: Monitoring and Control</td>
<td>Risk should be low for all options, but can be low as low as Option #1: Monitoring and Control</td>
<td>Construcions required in this face steep slope (highest risk to workers)</td>
</tr>
<tr>
<td>Minimize Decommissioning Costs</td>
<td>Minimize decommissioning costs</td>
<td>Cost (E)</td>
<td>No decommissioning required</td>
<td>Difficult to deconstructable, gopheral, deplanar materials, smaller substructure than Option 3a</td>
<td>Lock blocks can be reused and/or sold, smaller substructure than Option 3a</td>
<td>Catching house placement difficult to remove</td>
<td>Would likely not remove stuff, easy demolition</td>
<td>Remove piling/banks</td>
<td>Relatively easy removal from site, pile containers only, construction can be re-used</td>
<td>Difficult to remove from site</td>
<td></td>
</tr>
<tr>
<td>Dimly safety: minimum to long</td>
<td>Risk of damage to the dam resulting from maintenance</td>
<td>Likelihood of long safety risk</td>
<td>No risk</td>
<td>3</td>
<td>Gravity structure, cease no anchoring required, low consequence distance</td>
<td>Gravity structure, cease no anchoring required, low consequence distance</td>
<td>Anchoring required for fence, piles and/or tie-back anchors</td>
<td>Foundation required, sub-excavation</td>
<td>Anchoring required for fence, piles and/or tie-back anchors</td>
<td>Anchoring may be required, or can add weight to can</td>
<td>Anchoring required on dam face</td>
</tr>
<tr>
<td>Minimize area available for construction activities</td>
<td>Minimize area available for construction activities</td>
<td>Available area required for the avalanche barrier and management of East Access Road Area available for use (ha, m²)</td>
<td>15 (ha)</td>
<td>Wide (3.75 m/footprint), less than 1800 m² (10% of usable area)</td>
<td>Wide (3.75 m/footprint), less than 1800 m² (10% of usable area)</td>
<td>Wider footprint, approx. 3 m, less than 20 m (13% of usable area)</td>
<td>Narrow footprint, approx. 0.9 m, less than 20 m (6% of usable area)</td>
<td>Wide footprint, approx. 3 m x 160 m = 720 m² (13% of usable area)</td>
<td>No footprint in portal area, no less of area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimize schedule impacts to Mine 9 construction</td>
<td>Minimize schedule impacts to Mine 9 construction - planned or unplanned schedule delays</td>
<td>Time (days)</td>
<td>20</td>
<td>Short-term closure possible for extreme events (1.5-2 years)</td>
<td>Short-term closure possible for extreme events (1.5-2 years)</td>
<td>Short-term closure possible for extreme events (1.5-2 years)</td>
<td>Short-term closure possible for extreme events (1.5-2 years)</td>
<td>Short-term closure possible for extreme events (1.5-2 years)</td>
<td>No closure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimize schedule to implement</td>
<td>Duration to design, construct and implement the avalanche barrier</td>
<td>Time (days)</td>
<td>20</td>
<td>Nothing required</td>
<td>5-6 weeks</td>
<td>5-6 weeks</td>
<td>6-8 weeks</td>
<td>8-12 weeks</td>
<td>11-15 weeks</td>
<td>4 weeks</td>
<td>12 weeks</td>
</tr>
<tr>
<td>Minimize capital costs</td>
<td>Cost estimate (in 2014)</td>
<td>Cost (E)</td>
<td>No capital cost</td>
<td>$460,006</td>
<td>$460,006</td>
<td>$1,242,900</td>
<td>$1,242,900</td>
<td>$499,999</td>
<td>15 m core vs. $700,000 vs. $135k + $140k transport + $35k for KC - KNC moving costs $75k</td>
<td>$1,150,000. Higher capital cost of all options</td>
<td></td>
</tr>
<tr>
<td>Minimize operations &amp; maintenance costs</td>
<td>Minimize maintenance and repair work</td>
<td>Cost (E)</td>
<td>No maintenance cost</td>
<td>Minimal maintenance required (5%/yr)</td>
<td>Minimal maintenance required (5%/yr)</td>
<td>Minimal maintenance required (5%/yr)</td>
<td>5% of capital cost = $27,050/yr</td>
<td>Minimal maintenance required (5%/yr)</td>
<td>5% of capital cost = $77,000/yr</td>
<td>5% of capital cost = $85,000/yr</td>
<td></td>
</tr>
<tr>
<td>Minimize environmental impact</td>
<td>Minimize the amount of demolition and debris required to construct the avalanche barrier</td>
<td>Cost (E)</td>
<td>No impact</td>
<td>Excavation of basement fill material</td>
<td>Concrete materials, water runoff, etc</td>
<td>Driving piles for fence, low impact from materials</td>
<td>Concrete materials, water runoff, etc</td>
<td>Driving piles for fence, materials, etc</td>
<td>Anchoring may be required, structure, disturbance of soil</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Notes:
1. Score shall be entered as 1 = Low (Poor) to 5 = High (Good). The option with the highest Overall Score is the recommended alternative.
2. This paper presents a simplified decision matrix where risk treatment alternatives are shown. The project included 12 risk treatment alternatives that include different lengths and combinations of avalanche protection structures.
4.2 Structured Project Decision Matrix

A Structured Project Decision Matrix provides an objective and transparent platform to make risk-based decisions. A decision matrix establishes a set of criteria that are scored for each project alternative. Weighting is applied based on priority for each criteria, as determined by the project team. The scores are summed and then project alternatives are ranked allowing objective selection of a risk treatment solution.

Decision matrices fit within an International Standards Organization (ISO) 31000 framework. The ISO 31000 identifies a number of principles that need to be satisfied to make risk-based decisions effective and achieve project success. Some government and corporate organizations prefer following the standard.

A simplified decision matrix that includes 8 alternatives subjected to criteria listed in Section 3 is shown in Table 3. Evaluation criteria weights were based on worker safety and the potential effect each criteria had on the Mica 5/6 Upgrade construction period. Assigned weights varied from a minimum 5% for criteria considered of lesser relative priority, and up to 20% for those of highest priority, namely minimizing schedule impacts to the construction project and implementation time (Items 6 and 7 in the list above).

The low weighting of criteria such as risk of injury to workers, safety to the dam, or environmental impacts does not necessarily reflect their importance. In these cases any risk treatment alternative was expected to meet a high minimum safety standard. Examples of how these evaluation criteria were considered are: the energy to produce materials such as concrete, transportation of construction materials and construction waste were environmental concerns.

From a safety standpoint, it was assumed all of the considered alternatives would adequately protect workers. From a dam safety perspective, consideration was given to how a protection structure might affect dam infrastructure (e.g. monitoring instrumentation at the base of the dam). Dam stability was not considered an issue for any of the options.

4.3 Decision Matrix Results

The decision matrix ranked the risk treatment alternatives with a score based on weighted evaluation criteria. The rankings gave the project team an objective selection process. The top ranked alternatives were:

1. Lock block wall 85 m long,
2. Monitoring and control,
3. Gabion basket wall 85 m long.

The avalanche monitoring and control option was evaluated from a public perception perspective. Avalanche monitoring alone would not achieve the project objectives of minimizing impacts to the construction project. Explosive detonations on the dam face were determined by geotechnical engineers to have no effect on the stability of the dam; however the project team believed that the public may perceive explosive use on the dam negatively. Thus, explosive control on the dam as a risk treatment was eliminated for further consideration.

The decision matrix narrowed the selection to a lock block or gabion basket avalanche protection structure. At this stage, management wanted to reduce the cost of the protection structure. It was determined to move it from the distance of 3 m from the dam to 10 m away from the toe. Moving the structure further away reduced the design requirements of impact pressures from 65 kPa to 53 kPa and run up heights from 5.0 m to 4.1 m respectively, for a 10-year design avalanche.

It was also determined the protection structure would have an 89 m length, which only protected approximately half of the laydown area. This decision reduced costs and construction time over constructing a full (180 m) wall across the base of the dam; residual risk of a partial wall length would be managed by implementing winter usage safety restrictions in areas not protected by the wall.

With a revised design criterion, four configurations of the lock block and gabion basket protection structures were considered:

- Solid lock block wall;
- Lock block faced wall with an earth filled core;
- Solid gabion basket wall; and
- Gabion basket with an earth filled core.

The reason earth filled cores were considered was fill material is commonly inexpensive and it reduced the overall material costs of each structure. Ultimately earth filled structures were not selected because the fill material required each structure be wider which reduced the laydown area and building them would have significantly extended construction times. There was a short construction window because the design was completed in Au-
gust and the project was tendered in September. Winter typically starts at the Mica Dam by early-November.

Since the decision matrix already helped refine the avalanche protection structure, the final solution was simple to determine and was based primarily on minimizing the construction time and cost. The design team determined the risk treatment solution was an 89 m long solid lock block wall (Figure 4).

Figure 4. Construction of the lock block avalanche protection structure.

4.4 Lock block protection structure final design

The lock block protection structure was designed to be freestanding and consists of 1218 interlocking concrete lock blocks. A regular size lock block in Canada has dimensions of 1500 mm long x 750 mm wide x 750 mm high. Each block has a mass of approximately 2000 kg. The wall was designed to resist sliding and overturning by avalanche impact loads. It was also designed to withstand a 30-year return period avalanche overtopping it. This was achieved by placing the top course of the blocks longitudinally to make it more difficult for an avalanche to dislodge or overturn them. The design also carefully considered interlocking the blocks so the wall would act as unit. The lock block layout patterns for each course were determined by building a scaled model of the wall with Lego blocks.

The dimensions of the structure are: 3 m wide, 3.75 m tall, and 89 m long. Table 2 shows an avalanche run-up height on the wall of 4.1 m for a 10-year return avalanche, which theoretically may overtop the wall. BC Hydro agreed that during periods of low avalanche risk, snow would be removed from the behind the wall which would lower the required run-up height by approximately 1.0 m.

5. EVALUATION CONCLUSIONS

Determining an avalanche protection structure to treat avalanche risk is a complex and iterative process. A Structured Project Decision Matrix was used for this project to consider multiple avalanche risk treatment solutions. The decision matrix was relatively easy to use and facilitated communication among team members, allowed the team members with different backgrounds to effectively apply their expert judgment for each evaluation criteria, and ultimately helped determine an objective solution. Decision matrices are not fail safe. The scores can be misleading if the wrong criteria are used or improper weights are applied. If the scores are taken literally they can point to the wrong risk treatment solution. Thus it’s essential that all project team members are part of the process and critically assess the results at each step of the process.

6. CONSTRUCTION PERIOD

Construction of the lock block avalanche protection structure was relatively simple. A foundation for the wall was not necessary because it resists avalanches by its mass. Preparing the construction surface included stripping a small area of asphalt and sub-base material. A 100 mm thick layer of crushed rock, which was compacted, replaced the sub-base material. A layout survey provided the protection structure’s extents. The lock blocks were then delivered and placed in the patterns shown on the construction drawings. Only two construction inspections were necessary. The total construction time was approximately 1 month.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the important contributions of Chris Stethem, Chris Argue, Dan Sahlstrom P.Eng., Bryan Woods, P.Eng., Sean Constain, Thomas Chalmers, P.Eng., and the BC Hydro project management team (Janet Bremner, PMP; Rebecca Papadopoulos, PE) for their contributions to the successes of this project.

REFERENCES
