



MORRISON HERSHFIELD

**2012 Canadian Consulting
Engineering Awards Submission**

**Capilano CLIFFWALK
North Vancouver, British Columbia**

Presented to:

**Canadian Consulting Engineer
Association of Consulting Engineers of Canada**

May8, 2012

PROJECT HIGHLIGHTS

CAPILANO CLIFFWALK

PAGE 1



Prepare for a nature walk like none other. As you make your way through the thick West Coast rainforest, past streams, giant ferns and old growth trees thousands of years old, the trail ends abruptly, stopping at the lip of a 90 meter high canyon. Far below, Vancouver's Capilano River rages at Vancouver's oldest tourist attraction, the Capilano Suspension Bridge Park. And here's where things really get interesting ... with some trepidation, you step off into the abyss. Grasping tightly to the railing of a narrow steel path suspended in midair, you enjoy the views that were previously reserved only for eagles.

Welcome to CLIFFWALK, the balcony where fear lives and the newest eco-attraction. The CLIFFWALK structure is the culmination of several years of brainstorming innovative designs combined with environmentally friendly surveying techniques, construction methods and materials. Engineers at Morrison Hershfield have leveraged innovative techniques and technologies to design and construct a unique narrow pedestrian pathway off the edge of the pristine Capilano Canyon.

The unique 0.5 meter wide pathway starts at the lip of the 90 metre high canyon above Vancouver's Capilano River, winding through previously unexplored sensitive cliff face areas. Extending for 213 m, a series of cantilevered and suspended walkways follows the contour of the canyon walls, supported only by steel brackets anchored into the sheer face of the cliff. In some spots, a narrow glass floor is all that separates you from the canyon bed hundreds of feet below. The structure includes seven straight bridges, eight sets of stairs and seven platforms (two of which incorporate new technologies that allowed innovative anti-skid glass floors to be used).

Not for the faint of heart, CLIFFWALK has delivered on its promise of providing visitors with a unique and exhilarating perspective on Vancouver's wild West Coast geography. Kent LaRose, P.Eng., the project's engineer of record and the lead design engineer from Morrison Hershfield, comments, "CLIFFWALK is definitely a first-of-its-kind in the world. There has never been anything constructed like this in modern history that we are aware of."

Early in the CLIFFWALK project it became evident that the design, fabrication and construction techniques would be heavily interconnected. A significant amount of collaboration occurred from project start to completion between the structural engineer, rock engineer, erector, owner and surveyor, who were all directly contracted to the owner. The CLIFFWALK project engineering team who worked together to design and deliver this unique, environmentally friendly attraction consisted of: Engineer of Record and Lead Structural Engineer, Morrison Hershfield; Survey/Design, McElhanney Consulting Services Ltd.; Rock Engineer, Wyllie & Norrish Rock Engineers; Environmental Consultant, Phoenix Environmental; Rock Climbing Professionals including Dave Edgar and Rock Contractors, Pacific Blasting & Demolition. Marc Luc Lalumière provided overall Project Management services and fulfilled the role of Main Contractor.

There were many difficulties to overcome on this project. One of the first was how to obtain the District of North Vancouver's approval for a building permit for such a unique structure. How would the structure be constructed in a rainforest, with minimal impact on the environment, with limited construction access, all the while providing a safe structure that was envisioned to be thin, slender, light & airy, and "thrilling", and provides an experience that was comparable to the other structures in the park? What about the rock fall hazards or constructing in a park setting without negatively impacting the guests' experience? What alignment should the Cliffwalk take and exactly where on the cliff face should the structure be located? These are only some of the many technical challenges that were addressed.

Because CLIFFWALK is a "first-of-its-kind" structure, there was no independently applicable building code that could be followed. As a result, both the Canadian Highway Bridge Design Code and the 2005 National Building Code of Canada were considered in determining the unique design criteria. Additional guidance was taken from the Transportation Association of Canada and state-of-the-art technical literature to cover aspects that were not considered in either code.

With the rock being so variable all potential anchor points needed to be mapped, installed and tested before the structural design could be finalized. Prior

PROJECT HIGHLIGHTS

CAPILANO CLIFFWALK

PAGE 2



to and throughout the design process, survey personnel, who were trained in fall protection and vertical lifeline techniques, undertook much of their rock mapping while rappelling over the cliff.

The reliance upon 3-D survey data in conjunction with having to constantly update the model as foundation elements were installed and tested, were considered to be ground breaking by the steel fabricator. A computer generated 3-D model was developed of the entire cliff-face. Confirmation of CLIFFWALK anchor points minimized the environmental impact. In some instances, these anchor points needed to be relocated on-site during construction as incompetent rock was identified. As a result, the structure in some areas needed to be re-designed to fit the new anchor locations. The continuous improvement process led to the adoption of a philosophy of letting the rock dictate where anchors should be placed.

A number of structural forms were investigated during the design process including a series of suspension bridges, suspension supported staircases, pure cantilevers and others. The final unique arrangement was determined to offer the optimal process to fabricate and install the steel framework with the highest level of confidence and minimal environmental impact. The majority of CLIFFWALK is constructed from steel, North America's top recycled material. Other major material groups used in the construction are concrete and glass, which are recyclable materials; and timber, a renewable resource.

The design development of the guard-rail and posts required innovative and iterative solutions to confirm and provide a safe guard for CLIFFWALK visitors while at the same time being as transparent as possible. A number of concepts including glass and horizontal tensioned cables were considered and prototypes developed. The final system selected was from Décor-Cable, made from stainless woven wire mesh that resembles chain-link mesh. The system was designed to conform to the 3-D shapes and woven onto the CLIFFWALK cables. This application satisfied the safety and transparency architectural requirement, staying true to the original concept.

Construction was equally complex. The design was initially based on erecting all the structural steel

without a crane. It was originally envisioned to be installed using block and tackle, rope and cables all attached to the large old growth trees growing at the base of the cliff. As construction evolved, innovative access methods were realized that would allow small, light and high capacity all-terrain cranes on site. To protect the delicate natural environment, a dedicated team of builders handcrafted the bridge and walkway sections off-site, assembling them on-site with the minimally invasive construction equipment.

The project was the first to use a 'true' Dual Corrosion Protection rock anchors and required Morrison Hershfield's engineers to develop fabrication/ installation techniques in conjunction with the rock engineer and steel fabricator. Adding to the complexity was the fact that the project, including rock drilling, needed to happen in an operating park that sells natural beauty and we are proud to say that the project did not receive one complaint from the guests due to the original rock drilling gear and techniques.

With an environmental footprint of just 11m², the CLIFFWALK route is unobtrusive as it winds its way alongside the cliff through rainforest vegetation. The habitat loss for the entire project, including trails, is a mere 100 m². The footprint is so small; CLIFFWALK barely touches the natural environment.

Through its partnership with the David Suzuki, CLIFFWALK also serves as an educational tour. Hundreds of thousands of visitors per year are provided with area-specific information through interactive signage and exhibits along the CLIFFWALK highlighting the natural water cycle, characteristics and formation of the canyon, aquatic life, and natural vegetation, which can be seen down to the river below.

CLIFFWALK has allowed the Capilano Suspension Bridge Park to reclaim and transform over two acres of land into usable park space by terraforming an old gravel landing and installing a new trail and water features. Since its opening, revenues have increased by 37% and the average time of stay has lengthened to nearly three hours, exceeding the business plan developed for the project. The construction was finished almost two months ahead of the scheduled Grand Opening of June 1, 2011.

A scenic view of the Capilano Suspension Bridge in Vancouver, British Columbia. The bridge is a long, narrow suspension bridge made of steel and wood, stretching across a deep canyon. A person is walking on the bridge, providing a sense of scale. The canyon is filled with dense evergreen trees, and a river flows at the bottom. In the background, snow-capped mountains rise against a blue sky with scattered clouds.

Capilano CLIFFWALK

A Breathtaking Marriage of Nature and Engineering

"I found myself standing in a world of giant ferns and moss-covered trees, framing amazing views of the canyon. I knew then that I had to figure out a way to get our guests down there."

John Stibbard, VP of Operations,
Capilano Suspension Bridge

FULL PROJECT DESCRIPTION

CAPILANO CLIFFWALK

PAGE 1



CLIFFWALK – REACHING NEW HEIGHTS IN ENGINEERING

Prepare for a nature walk like none other. As you make your way through the thick West Coast rainforest, past streams, giant ferns and old growth trees thousands of years old, the trail ends abruptly, stopping at the lip of a 90m-high canyon. Far below, Vancouver's Capilano River rages. And here's where things really get interesting ... with some trepidation, you step off into the abyss, grasping tightly to the railing of a narrow metal path suspended in midair.

Welcome to CLIFFWALK, the newest eco-adventure at Vancouver's oldest tourist attraction, the Capilano Suspension Bridge Park. Engineers at Morrison Hershfield have leveraged innovative techniques and technologies to design and construct a unique narrow pathway off the edge of the dizzying Capilano Canyon. Extending for 213 m, the 0.5 m wide path follows the contour of the canyon walls, supported only by steel brackets anchored into the sheer face of the cliff. In some spots, a narrow glass floor is all that separates you from the canyon bed hundreds of feet below.

Not for the faint of heart, CLIFFWALK opened in June 2011, and has delivered on its promise of providing visitors with a unique and exhilarating perspective on Vancouver's wild West Coast geography. It is the brainchild of John Stibbard, Capilano Suspension Bridge's VP of Operations. John knew that he wanted to create another exciting attraction – one that

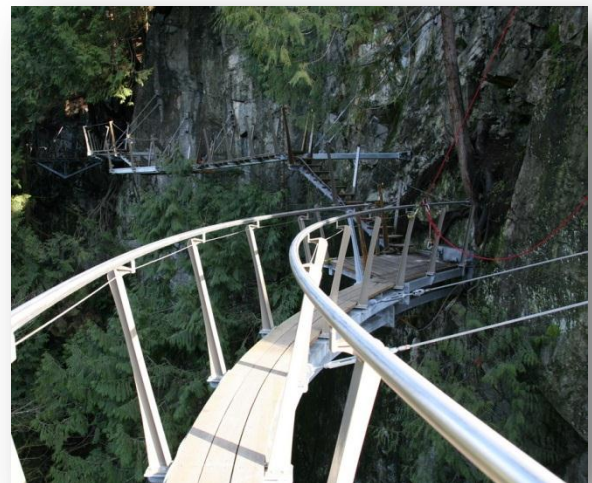
would bring visitors closer to the Capilano River – but it wasn't until he was rappelling down the east face of Capilano Canyon that he had his epiphany.

"I found myself standing in a world of giant ferns and moss-covered trees, framing amazing views of the canyon. I knew then that I had to figure out a way to get our guests down there."

John realized that the breathtaking views from the cliff-face would be a great attraction but it would not be feasible to enable the 750,000 annual visitors to safely access the cliff-face using standard rock climbing techniques and without destroying the sensitive ecosystem. These two factors became key to the innovative design and construction approach implemented by the CLIFFWALK team.

THE TEAM

Early in the project it became evident that the design, fabrication and construction techniques would need to be heavily interconnected in order to realize the full vision of the CLIFFWALK. A significant amount of collaboration was required between the structural engineer, rock engineer, erector, owner and surveyor from start to completion, and this could not be adequately managed with a conventional procurement process. As a result, every member of the CLIFFWALK team was contracted directly to the Capilano



FULL PROJECT DESCRIPTION

CAPILANO CLIFFWALK

PAGE 2



Suspension Bridge Park.

The project engineering team who acted together to design and deliver the unique and remarkably environmentally friendly CLIFFWALK consisted of: Engineer of Record and Lead Structural Engineer, Morrison Hershfield; Survey/Design, McElhanney Consulting Services Ltd.; Geotechnical/Rock Engineer, Wyllie & Norrish Rock Engineers; Environmental Consultant, Phoenix Environmental; Rock Climbing Professionals including Dave Edgar (Rope Specialist); and Rock Contractors, Pacific Blasting & Demolition. Marc Luc Lalumière provided overall Project Management services and fulfilled the role of Main Contractor.

WHAT IS CLIFFWALK?

CLIFFWALK is a pedestrian walkway like no other. It is located within the Capilano Suspension Bridge Park, in the District of North Vancouver, BC. It travels along the granite cliff on the east face of the Capilano Canyon. At its highest point, it is 30 stories above the Capilano River. This series of cantilevered and suspended walkways takes visitors through previously unexplored sensitive areas providing access to the rainforest vegetation and the canyon ecosystem in a manner that practically eliminates any impact on the surrounding sensitive environment. In fact, one of the significant successes of the Cliffwalk is that the structure was constructed by only impacting 11 square metres of

rock face area for the foundation supports while avoiding key areas of the rock face that are covered by grass, moss or ferns.

The 213m long steel structure is 0.5m wide and is cantilevered approximately 3m out from the cliff face. It has an approximate plan area of 160m². The structure brings visitors down along the cliff by a spiral stairway, eight bridge spans, five straight stairways, seven observation platforms (two of which incorporate new technologies that allowed innovative glass floors to be used) and a 30m long cable supported semi-circular bridge.

The resulting attraction is not only thrilling, it acts as a medium for sharing information and educating guests about the ecological nuances of the area. Through its partnership with the David Suzuki Foundation (a non-profit organization that works with government and businesses to conserve the environment by providing science-based education, advocacy and policy work), CLIFFWALK also serves as an educational tour. Visitors find informative interactive signage and exhibits along the way that provide them with information about the natural water cycle, characteristics and formation of the canyon, aquatic life and natural vegetation, which can be seen down to the river below.



FULL PROJECT DESCRIPTION

CAPILANO CLIFFWALK

PAGE 3



GETTING STARTED

Prior to doing any construction of the CLIFFWALK, a building permit was required from the District of North Vancouver. This presented a challenge since the permit application requires a number of reports and surveys of the site including a topographic and cadastral survey (which is the base of the application design drawings), an environmental report, input from the landscape architect, a tree survey by a professional arborist and a geotechnical report.

Survey control was established and refined throughout the initial stages of the project. For the initial topographic survey, a closed traverse was run along the base of the cliff and closed to the existing survey control at the top of the cliff. As the project progressed, additional survey control points (including several custom built cliff mounted brackets) were installed and surveyed and a least squares adjustment was performed. This survey control was used for the remainder of the project.

Typically, rock face surveys are undertaken using an automated scanner, set up in a stable location with clear sightlines to the cliff. However, the proposed CLIFFWALK alignment and surrounding cliff face is mostly obscured by the dense coastal rainforest vegetation which made using this technique impossible. Instead, a topographic survey using a total station was conducted with the main challenges being access and clear sightlines to the cliff face.

Topographic surveys mapped the features of the cliff face including any ledges, overhangs, trees, gullies, major cracks or caves that should be noted for accommodation during the design. The survey mapped additional features such as the park's existing deck and the foundations of the existing building at the top of the cliff. In addition, a full ground profile was surveyed from the base of the cliff to the Capilano River at the canyon bottom.

Accessing the cliff face and the sloped ground at the canyon was yet another challenge faced by the team. Survey crews gained access by using ladders, ropes and advanced vertical lifeline techniques for this unusual setting. The challenge was overcome with a combination of good planning, experience, training and patience.

For ease of access, lightweight equipment was required for surveying along the face of the cliff. A Leica TCRA 1103 total station was selected for its relatively low weight within its class of instrument, and customized survey legs were built for setting up the instrument on very high angled ground. A majority of the survey data was collected using the reflectorless capability of the total station; however, it was not always possible to have direct sightlines to all features on the cliff. At these instances, a surveyor would rappel down the cliff face with a target reflector to gather additional data that could not be seen directly from the ground.



FULL PROJECT DESCRIPTION

CAPILANO CLIFFWALK

PAGE 4



The initial survey was the first of many iterative surveys throughout the project. As the walkway alignment was further developed, more detailed data was collected around foundation locations, anchor points for cantilevers, tree locations and locations of unsuitable rock. Survey brackets were mounted onto the rock face at critical locations such as the rock anchors for the curved bridge. These allowed high density survey data to be collected for design and also allowed high accuracy layout to be conducted at these important sites during the construction stage.

Due to the complex geometry of the cliff face, conventional drafting techniques for producing a 3D digital terrain model (DTM) could not be used. Overhangs present a problem in the software used to create the common DTM, therefore an innovative drafting technique was devised to overcome this problem. Individual 3D faces were manually created from the survey points gathered to establish a 3D model of the entire cliff face. This required close communication and constant quality control checks between the field staff and the drafting personnel. Drafting in this way is a complicated process that requires excellent 3D visualization skills and the resulting 3D model was used effectively by the engineering team to design the CLIFFWALK.

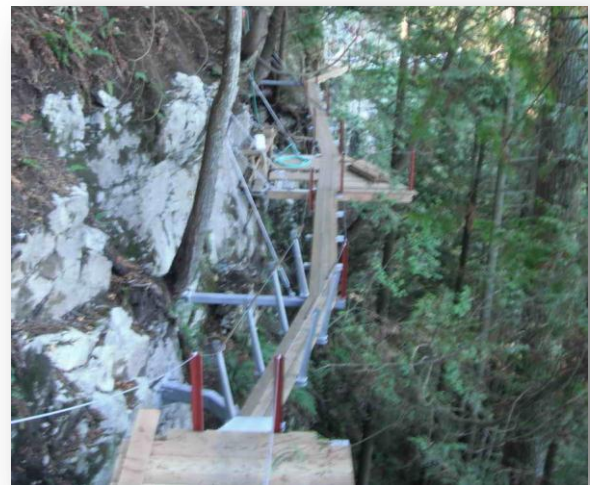
Besides using surveying equipment, the cliff face was also studied by rock and structural engineers using high angle rope techniques and rappelling to

establish the walkway alignment by finding suitable foundation locations and areas that required rock stabilization. This was done every 3m to 6m along the length of the cliff face above the canyon to map and evaluate the rock. It was found that the rock throughout the canyon is very strong and massive 160 million year old granite. It took months of work to survey and map out the cliff face in order to produce enough useful information to complete the design of the CLIFFWALK.

The permit application also included an environmental report, input from the landscape architect, a tree survey by a professional arborist and a geotechnical report. A presentation of the project was made to the engineering staff at the District by the project team, and a number of discussions were held to establish the permitting process. In the end conventional British Columbia Building Code schedules were issued by the design professionals and a completely Independent Review Engineer was required to review the design and construction.

DESIGN & CONSTRUCTION

There was no precedence for the design of the CLIFFWALK structure and concurrently no clearly defined strategies for maintaining the environmental sustainability for this type of structure. As a result, a true synthesis of the approaches to sustainability, planning, design and construction techniques was



FULL PROJECT DESCRIPTION

CAPILANO CLIFFWALK

PAGE 5



required. Design criteria were established to satisfy the primary concern of public safety, both during the construction phase and for future maintenance activities.

How would the structure be constructed in a rainforest, with minimal impact on the environment, with limited construction access, all the while providing a safe structure that was envisioned to be thin, slender, light & airy, and “thrilling”, and provides an experience that was comparable to the other structures in the park? What alignment should the CLIFFWALK take and exactly where on the cliff face should the structure be located?

Because of the unique nature of CLIFFWALK, there was no independently applicable building code that could be followed. As a result both the Canadian Highway Bridge Design Code and the 2005 National Building Code of Canada were considered in determining the design criteria for this unusual structure. Additional guidance was taken from the Transportation Association of Canada and state-of-the-art technical literature to cover aspects that were not covered in either code.

As noted, it was determined early in the project that a significant amount of collaborations were needed between the owner, rock engineer, structural engineer, surveyor and erector since the design, fabrication and construction techniques were all going to be heavily interconnected and

interdependent. The unique nature of the steel structure required an iterative combination of survey, design, fabrication, and erection methods.

For example: the cliff face had to be surveyed to determine the pathway alignment by establishing suitable anchor locations; next, the proposed anchor locations were surveyed in detail to design the anchors; rock anchors were then installed into the predetermined locations and their positions surveyed and updated in the 3D structural detailing model to finalize the geometry. This iterative process and the unique nature of fabricating and erecting the steel on the cliff face are considered to be the first of its kind in the world.

12 different alignment designs of the CLIFFWALK were considered before arriving at the final design. The initial alignment’s design required almost 20 stories of vertical difference in elevation since it went from the top of the cliff down to its base, allowing visitors a closer look into the Capilano River, but the amount of stairs needed would have been too overwhelming for the average visitor. The rock fall hazard would also be higher for the alignment being at the lower point of the cliff due to the exposure of a larger rock face area above the walkway. Some alignment configurations were also discounted because of poor conditions of the rock at anchor locations. The entrance of the CLIFFWALK was originally located just beside the entrance of the



FULL PROJECT DESCRIPTION

CAPILANO CLIFFWALK

PAGE 6



main suspension bridge; however, the owner of the park thought this would create congestion of visitors and desired to passively distribute visitors into different areas of the park.

The final design consists of a descent of 8.8m (3 stories) down from the entrance of the CLIFFWALK to the curved bridge, and then an ascent of about 17.6m (6 stories) back to the trail system at the exit of the structure.

Once the alignment was finalized, additional topographic survey was needed for collecting more detailed information of the locations of interest. This survey would provide accurate data to be used for the design of the steel structure as well as foundations and landscaping areas. Custom built anchor brackets were mounted on the rock face at the anticipated anchor locations to allow for a surveyed fitting on the uneven rock face and to provide a clear location in some hard to see areas.

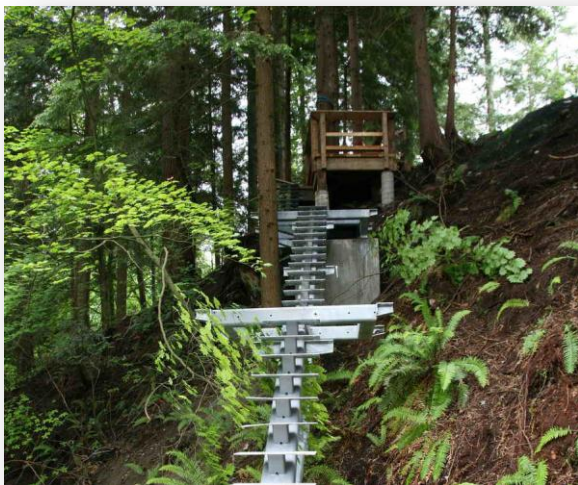
Once the final locations of the anchor plates were established, 3D lines were created in AutoCAD to model the steel anchors that would be attached to the rock face. These lines were projected in the field and marked at the intersection of the model with the rock face by surveyors. This was a critical step since the directional accuracy of rock bolts and steelwork was a key element in the design of the walkway.

THE ENGINEERING

A number of structural forms were investigated during the design process including a series of suspension bridges, suspension supported staircases, pure cantilevers and others. Using timber as structural members was discounted because of durability requirements. The use of concrete structural members was also deemed not feasible due to the construction nature of the material as discussed with the contractor and the environmental concerns such as spills of concrete into the river.

The final unique arrangement for CLIFFWALK was selected to be the optimal process to fabricate and install the galvanized steel framework with the highest level of confidence and minimal impact on the environment. It is a combination of galvanized steel frames with mostly propped cantilever supports from the cliff face. Each of the propped cantilever supports has two tension ties to provide a measure of redundancy in the load path. There are also a few pure cantilever supports at the platforms where the overhead tension ties would have conflicted with pedestrians or unsuitable rock was located.

The deck and walkway designs were similar to the bridge structures that made up the Treetop Adventures, one of the other attractions of the park. Considerations were focused on safety, aesthetics, and practicality. An example of this was the design of the railing and post system. The 0.5m wide deck has



FULL PROJECT DESCRIPTION

CAPILANO CLIFFWALK

PAGE 7



hand rails set at 1.2m above the deck with inclined posts, providing 0.8m of clearance between the hand rails. This is wide enough to allow two people to pass each other, a requirement when visitors are stopping to enjoy the scenery of the canyon. The local fire department was consulted during the design, and these access requirements were deemed satisfactory in conjunction with the emergency plans.

The design development of the guard-rail and posts also required innovative and iterative solutions to confirm and provide a safe but visually transparent guard, giving users a feeling of floating above the Capilano Canyon. The use of glass panels for the entire length was considered suitable at the beginning of the project, however, the maintenance required to keep this material clean and wind load consideration soon rejected the possibility of glass guardrail panels.

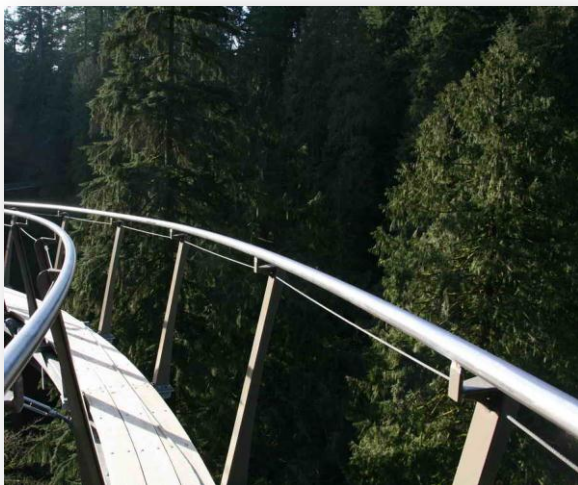
Initially, a non-climbable guardrail using a system of horizontal tensioned cables was conceived and a prototype was developed and fabricated in the shop. This system provided the desired transparency but proved to have a number of deficiencies in its safety and was subsequently abandoned.

The final design utilizes a proprietary system X-TEND© available from Carl Stahl® DécorCable. This system is a stainless steel woven wire mesh resembling chain link mesh that can be designed to take on any tensioned 3D geometric shape and provided a barrier system that conformed to the ever changing geometry of the

CLIFFWALK. The woven wire mesh is treated with a black oxidation process and the mesh became virtually transparent when viewing from all angles, meeting the visual requirements of the project while providing a very durable and safe barrier. Morrison Herhsfield's engineers had to keep track of over 90 distinct mesh panels. The barrier system also consists of more than 460m of continuous 50mm diameter polished stainless steel handrail along both sides of the entire walkway. An example of the level of customization is the fact that there are 236 distinct posts that needed to be designed, checked and tracked during the field installation.

Anchor points for CLIFFWALK needed to be confirmed to minimize the impact on the existing environment and for the strength of the rock. In some instances, these anchor points needed to be adjusted onsite as potential environmental impacts were identified. As a result, the structure in some areas needed to be re-designed to fit the new anchor points, requiring MH's engineers to redesign the steel framework while it was being fabricated and installed on the fly to keep the project on schedule.

There are two viewing platforms on the structure with glass decks to provide a more thrilling experience. Morrison Hershfield's engineers worked with suppliers from Austria to provide a floor with a baked-ceramic anti-skid coating that could be exposed to the elements while still providing a safe experience for guests wishing to walk the glass platforms. Glass



FULL PROJECT DESCRIPTION

CAPILANO CLIFFWALK

PAGE 8



guardrail panels are also installed at these glass deck locations for a better viewing experience.

Rock engineering was an important part of the CLIFFWALK design. The primary issues were to determine the location of stable anchorages for each of the foundations and to assess and mitigate the stability of the rock face. Safety from rock falls was achieved by placing the structure high on the canyon wall to limit the area of cliff face that would be a source of rock falls. In addition, by having the CLIFFWALK located a minimum of 3m from the vertical cliff, rocks would be expected to fall close to the face and not bounce out on to the walkway.

The geotechnical investigation involved rappelling down the face over the full length of the alignment to map the rock and locate geological features such as faults, open tension cracks and areas of fractured rock. For each of these features, a decision was made as to the most appropriate remedial measure. That is, either the foundation was moved to a stable location, or the rock was stabilized by a combination of hand scaling to remove loose blocks of rock and installation of rock bolts. In some instances, this remedial measure was not determined until the rock drilling was underway, requiring structural solutions to be designed while components were already being fabricated.

The rock bolts are all galvanized steel bars, either 25mm or 32mm diameter and up to 6m long, depending on the rock conditions and the loads

applied by the structure. The bolts are anchored with cement grout over the full length of the bar so that the combination of galvanizing and embedment in cement provides corrosion protection for the steel. The total length of rock bolts, installed for both rock reinforcement and securing the foundations, is 510 meters.

The District of North Vancouver Noise Regulation Bylaw was followed for the rock drilling, ensuring that the construction operations did not emit a continuous sound level that exceeded 80 decibels when measured at the point of reception. The largest source of noise was caused by rock drilling with pneumatic equipment and required that this equipment was muffled and drilling operations limited to the daytime hours. Other special measures included that the rock drilling equipment was covered to contain the rock dust created from the rock drilling and that the dust was captured and disposed.

Adding to the complexity was the fact that the project, including rock drilling, needed to happen in an operating park that sells natural beauty and we are proud to say that the project did not receive one complaint from the guests due to the original rock drilling gear and techniques.

Access to the cliff face was limited to basic workers and their light equipment, all supported on ropes. It was accomplished with rappelling equipment and



FULL PROJECT DESCRIPTION

CAPILANO CLIFFWALK

PAGE 9



static lines. The heavier drilling equipment and materials complicated the access, particularly for the rock stability work prior to the start of construction. The rappelling equipment was planned and arranged to avoid areas with flora and fauna that needed to be preserved.

At each foundation location, rock bolts were installed to support the applied loads – either tension at the guy cables or compression at the cantilever beams. The installation procedure was to first install the bolt and conduct a pull test to verify the capacity of the grout anchorage. Then the anchor plate was attached to the face and the bolts were tensioned against the plate to a load about 10 per cent greater than the design load. The objective of post tensioning the bolts was to prevent any movement of the foundation once the bridge load was applied. The steel framework was installed as the foundations and rock bolts were established

THE CONSTRUCTION

Construction of CLIFFWALK was complex. To protect the delicate natural environment, a dedicated team of builders handcrafted the bridge and walkway sections off-site, assembling them on-site with minimally invasive construction equipment.

Each piece of the CLIFFWALK was custom built in a step-by-step process of surveying, engineering and fabricating with no two sections being alike. There

was a high degree of accuracy required for all construction layout as all walkway components were pre-fabricated off-site and never dry fit in the shop prior to shipping to site. Highly accurate as-built surveys were required to continually update the digital model of the walkway and to finalize design dimensions for pre-fabricated steel components. Remarkably, the 213 m long walkway was designed, fabricated and installed with only a 15 mm misclosure on the last piece, without the luxury of dry-fitting any of the steel components in the shop, as is the usual practice. The success of the field installation was due to the accuracy and precision of the survey and quality control measures taken with the review of the ProSteel detailing 3 dimensional model.

The design was initially based on erecting all the structural steel without a crane. It was originally envisioned to be installed using block and tackle, rope and cables all attached to the large old growth trees growing at the base of the cliff. As construction evolved, innovative access methods were realized that would allow small, light and high capacity all-terrain cranes on site.

Erection of the 30 m long curved bridge presented several challenges, including site access and precision of installation. Initially, it was envisioned that the entire bridge could be lowered into place in one piece, however, crane size, crane position and



FULL PROJECT DESCRIPTION

CAPILANO CLIFFWALK

PAGE 10



existing trees quickly ruled out this possibility. Existing large trees were present at both ends and the middle of the curved bridge layout, preventing a straight lift out into the canyon. Site access constraints also limited the size and type of crane that could be brought in to the site. In the end, the curved bridge was divided up into six segments, and a staged erection plan was developed.

In the end, a 30 step erection plan was developed to allow the six main segments of the curved cable supported bridge to be installed with only a single crane, which required a number of temporary members to be designed by Morrison Hershfield's engineers. Two temporary adjustable compression bracing members were designed to help maintain the geometry of the semi-circular curve while also resisting the tension in the main support cables prior to all the segments of the compression ring being installed.

The construction started with the installation of the end segments which were cantilevered from the rock face. The steel plates of these end segments were anchored with five rock bolts that were drilled and grouted at the abutment location of the curved bridge on the cliff face. The Link-Belt crane was used to support the bridge end segments while a jib crane was used to install the compression bracing and the first set of cables. The compression bracing and cables were adjusted throughout to bring the geometry of the bridge into position. The process of

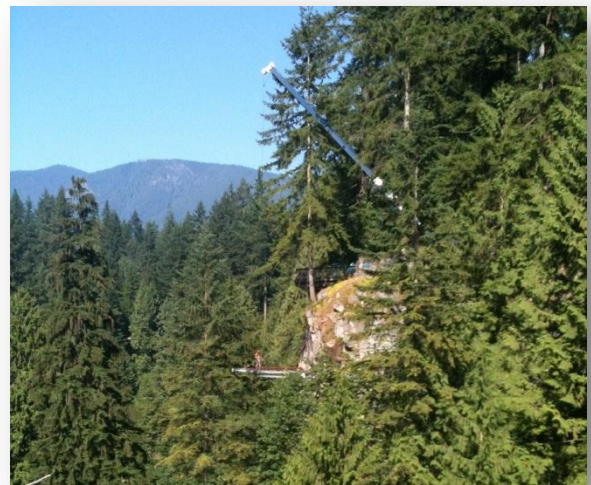
installing the segments and adjusting the cables was repeated for all six bridge segments.

Nondestructive load testing was performed on the curved bridge and on two of the straight bridge sections to evaluate the load capacity and deflections of the structure. The straight bridge sections chosen for load testing produced the largest reaction comparing to other strut beam foundations on the project. Both the straight bridges and curved bridge structures performed very well and the measured forces in the cables were found to agree closely with the predicted values.

THE SUCCESS

According to tourism expert Peter Williams, Ph.D., survival in the tourism business depends on innovation. Several factors contribute to the need for innovation in tourist destinations including a widespread orientation toward environmental sustainability. The new CLIFFWALK was added to the Capilano Suspension Bridge Park with these goals in mind. CLIFFWALK was also conceived in an effort to reflect visitor interests that had shifted from a focus on the landscape's history to the task of preserving the natural environment for future generations. CLIFFWALK is delivering on each of these key goals.

The unique experience of CLIFFWALK is the culmination of innovative design and cutting edge technology. Due to its first-of-a-kind design and site



FULL PROJECT DESCRIPTION

CAPILANO CLIFFWALK

PAGE 11



constraints, each piece of the CLIFFWALK was custom designed and built through an intricate step-by-step process of surveying, engineering and fabricating. As a result, the plans for the project were updated 12 times in two years until it was successfully opened to the awaiting public in June 2011. The site geometry dictated the highly complex structure and required that each piece of the CLIFFWALK is total customized, requiring Morrison Hershfield's engineers to be extra vigilant in the Quality Control process to ensure that there were no errors in the steel fabrication.

The challenging design and construction of CLIFFWALK has resulted in a visually appealing and unique 'bridge' structure that reinforces the sustainable ecotourism model already in place at the Capilano Suspension Bridge Park. The owner describes it as "a breathtaking marriage of nature of engineering".

The narrow width of the walkway allows people to look down both sides of the deck, providing an exhilarating experience and also kept the structure light and airy, minimizing the loads. It also illustrates that structures can be successfully constructed to serve a purpose that goes above and beyond the utilitarian nature of most modern bridges. The unique engineering of the CLIFFWALK has expanded the engineer's role in society via a documentary on the Discovery Channel as well as a number of articles in mainstream media sources. The project further serves to reinforce that teamwork on infrastructure projects is the best foundation for success, as this project was truly a collaborative effort.

Since its opening, revenues have increased by 37% for the Capilano Suspension Bridge Park and the average time of stay has lengthened to nearly three hours, exceeding the business plan developed for the project. The construction was finished almost two months ahead of the scheduled Grand Opening of June 1, 2011.

