TEAM GUSHUE HIGHWAY-TECHSPAN OVER WATERFORD RIVER St. John's, Newfoundland and Labrador

Thomas Brunet and Bill Demers Reinforced Earth Company Ltd. Mississauga, Ontario, Canada.

Abstract: This paper will outline the Newfoundland and Labrador Ministry of Transportation and Works project, of a TechSpan concrete arch culvert, constructed over the Waterford River to support a 19 m high embankment for the Team Gushue Highway Extension. Named in honor the 2006 Olympic Gold medalist curling team, The Team Gushue highway once completed will provide a vital link to the NW Avalon Peninsula. The Waterford river crossing was a major technical and construction challenge on this project. The 10 m wide river runs in a 19 m deep meandering gorge and has a swift current, making work in and around the river challenging. Access to the site was extremely difficult. Two very steep grade construction roads on each side of the river connected by a temporary bridge provided access to the bottom of the gorge and the erection site. A temporary diversion of the river permitted for excavation and site casting of two 5.35 m wide footings and the erection of the concrete arch culvert in the dry. The 63m long, 11m span, 4m high concrete arch structure supports 19 m of overburden and the highway road base, allowing the highway a level crossing of the gorge and river. This paper highlights the purpose of this significant new work, the creek sensitivity and diversion, and the design and construction of an arch structure supporting hydraulics and very high overburden.

1. INTRODUCTION

Team Gushue Highway was first identified in a comprehensive regional development plan completed and gazetted over 45 years ago. Since that time, population and infrastructure growth have exacerbated the need for this project to improve traffic flow, goods movement, and safety in the urban region. It is integral to fostering continued growth in tourism, business investment and overall economic development within the St. John's region.

The Team Gushue Highway was the initial Outer Ring Routing identified in the St. John's Urban Region Regional Plan. In the 1978 Amended version the Route was known as the East-West Arterial. In the earlier 1966 St. John's Metropolitan Area Municipal Plan the route was known as The Expressway. The first 2.1 km section of the Team Gushue Highway was developed in the year 2000 as part of the final Out Ring Road development which was funded under the Roads for Rails agreement with the federal Government. The completed 2.1 km section of Road was opened in 2005 and named the Team Gushue Highway after the 2006 Gold Medal win of the Canadian team represented from Newfoundland at the debut of the sport of curling in the Olympics.

Team Gushue Highway provides an alternate north-south arterial route connecting the Outer Ring Road to Pitts Memorial Drive. This connection will alleviate traffic congestion on the existing north-south arterial (Columbus Drive) and improve safety and access to and from the Cities of St. John's and Mount Pearl with the surrounding regions.

The Waterford River Crossing structure was not considered in great detail until just before the project was under review for Environmental Approval. The initial Hydrology study indicated an arch pipe would suffice hydraulically and be comparable to upstream structures on the river. The initial structure was conceived to be longer but due to pressures from DFO to lessen the footprint of the structure to have a lesser impact on the river the structure was shortened and headwalls were increased to retain more fill. Further changes were made during construction to make the constructability smoother so the location of the structure and wall configuration was again revised resulting in the final configuration.

2. PRECAST ARCH DESIGN

The precast arch extension is an 11 m span with an internal rise of 4 m and a thickness of 0.25 m. The earth cover over the crown to highway is approximately 16.5 m with the side slope on the embankment. The principle concept depends on the development of a finite element program based on funicular curve theory for which the bending moment at any point is zero. The arch is a 3 hinged arch shape that minimizes tensile stress in the concrete. The design of the arch considers all loads anticipated on the arch elements during transportation, erection, and backfilling and in-service.

The precast concrete arch shape was calculated by a finite element method and formed in special flexible moulds to fit the existing shape of the structure and MSE walls were used as the wing walls and head walls while the structures were designed to sustain the high overburden. The innovation of precast concrete arch is to utilize a product with a sophisticated and individual design approach incorporating the optimum arch geometry and individually suited to the various loading situation for unique structures like this.

The precast arch used on this project is the TechSpan® product by the Reinforced Earth Company Ltd. (RECo) and is built by assembling prefabricated concrete elements in a staggered and symmetrical way and it allows a fast installation without disrupting the traffic below.

2.1 Finite Element Method (FEM)

The governing phenomenon in the behaviour of an earth-filled precast arch is the relative stiffness of the concrete structure compared with the soil behind it. For a precise analysis of the behaviour of the concrete arch, in relation to the fill during backfilling and in its service stage, a finite element analysis is required.

The state-of-the art design program developed by RECo, called Aztech, uses a finite-element-method to optimize the arch shape and minimize the bending moments in the concrete. It is necessary to model the relative stiffness between backfill and concrete. The soil behaves in a non-linear manner. The numerical analysis of any non-linear problem involves an incremental and iterative process. The displacements are analysed by increasing the loads in set increments. In each increment there is a corresponding iterative process which form an initial approximate solution, through a series of corrections, then presents a final result.

The first stage corresponds to the forces and moments in the arch elements under their own weight without any backfill. The subsequent stages are applied in asymmetrical loading of backfill placement (Figure 1, 2). Finite element mesh is generated in relation to the number of backfill stages depending on the height of the arch and height of fill above the crown.

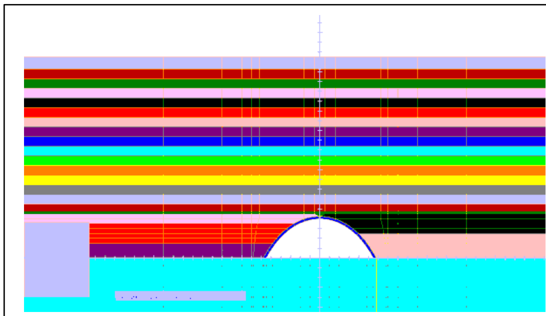

Figure 1. Subsequent stages applied in asymmetrical loading of backfill placement using FEM program.

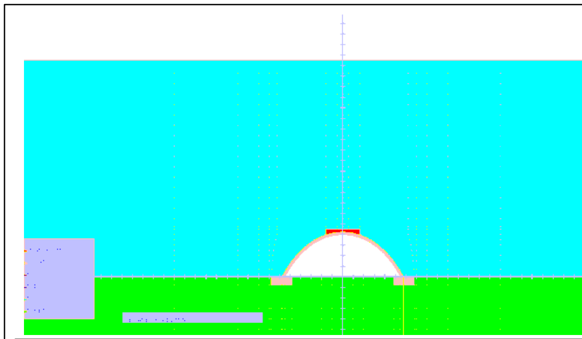

Figure 2. Different Types of materials shown

The final step is the application of the loading surcharge, which is applied to only on one side of the arch for more critical load than applying both sides. In this project, 23 load cases for backfilling stages plus different loading surcharge of the highway surcharge including horizontal axis breaking force, standard traffic surcharge and combination of the forces. The use of a FEM program is commonly considered to be the most effective way to analyze the soil and structure interaction of buried arches.

2.1 Structural Design of Arch Element

The concrete arch elements are designed in accordance with the limit state method and according to specifications and design codes. Critical loads and moments at each point along the concrete segments generate an interaction diagram and the required quantity of reinforcing steel is determined by the governing cases from the moments-axial load envelopes (Figures 3, 4, 5).

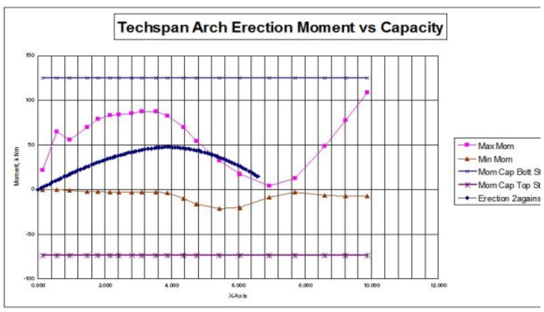

Figure 3. Erection Moment envelope along the arch directrix

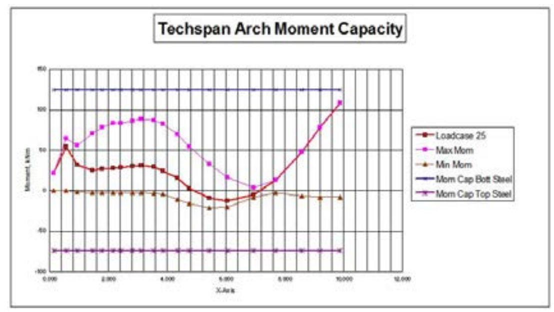

Figure 4. Moment Envelope along arch directrix

The analysis includes all of the various load cases which include stripping & handling during fabrication, cases for all combinations, the arch was optimized for both thickness and rebar design for the required design codes and specifications. The thickness of the arch was selected as 250 mm.

2.1 Foundation and Head wall design

The foundation soils at the site were relatively good and had been surcharged. The footings were design to sustain and support horizontal and vertical dead load plus traffic surcharge. The critical issue of the design of footing was to limit the deflection of the footing. The deflection of the footing was specified to be less than 5 mm on each side so that the arch design would not be compromised. (Figure 6)

MSE retaining wall precast panels were used for head walls to retain the soil surrounding the concrete Arch. With capable foundation soils, this width of volume was adequate to satisfy external stability. The soil reinforcement strip lengths were set 70% of height of the wall rounded up to the nearest 0.5 increments.

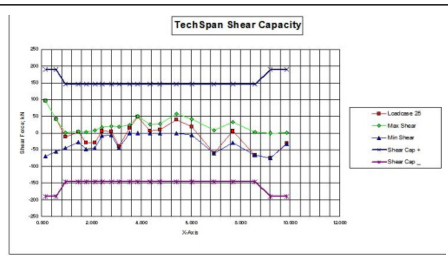

Figure 5. Shear capacity envelope along arch directrix

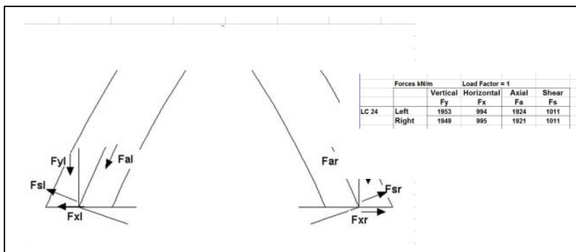

Figure 6. Footing loading detail.

3. FABRICATION OF ARCH ELEMENTS

Casting a concrete arch element whose cross section is based on a funicular curve requires special formwork and precasting techniques. The resulting curve is not a semicircle or parabola but a curve of constantly changing radius. Segmental adjustable formwork has been developed that is capable of casting a whole range of arches with varying lengths and changing curvature.

The design output arch shape from the FEM program is converted to machine language and a CMC cutter is used to create very precise template that is an exact full size replica of the arch cross section (see Figure 7). The resulting template is then used as a guide for the rebar tying jig and form set-up.

At the precast plant the adjustable steel forms are curved to match the template. The template remains in place throughout casting and is re-used to re-position the striped forms each day. Dimensional quality control checks are performed on each cast element to confirm the required precast tolerances are achieved.

The elements are cast vertically which provides a smooth steel form finish on the exposed face. A vertical cast is also the most favorable position for stripping of the element because it reduces the bending moments experienced while the concrete strength is relatively low and reduces the amount of handling when curing, yarding and loading (see Figure 8).

Figure 7. Steel forms are set to the design curve by matching the template.

Figure 8. Precast Arch elements being stripped from mould.

Elements for this project were cast with a 45 MPa concrete mix. This mix was selected to ensure early strength gain and make certain that the elements reached their required stripping strength within 8 hours to allow stripping and recasting each day. Self-consolidating concrete simplified the casting of the tall narrow sections by reducing the amount of vibration needed to avoid unwanted honeycombing while providing a superior finish. A rebar tying jig is setup using the same template as the form. Vertical steel pipe stands are erected to provide a framework that allows the rebar to be tied together in a cage that has the same shape and curvature as the form work. Horizontal support bars are attached to the stands to hold the pre-bent longitudinal rebar and secure the rebar at the proper spacing. The longitudinal rebar (20M) is pre-bent to the curvature of the arch. Pre-tying the rebar in a jig ensures the resulting cage will follow the arch curvature. Rebar chairs are used to provide the proper 50mm concrete cover (See Figure 9)

Figure 9. Rebar Cage is assembled on a jig to match archelement curvature

4. Site access

Before work could begin in and around the river site access was required to bring in workers, equipment and materials. Two very steep access roads were constructed from opposite sides of the valley, which were joined by a temporary bridge over the river. To provide a suitable work area for the arch construction the Waterford River was diverted to the East using a variation of the traditional sand bagged river diversion, extra-large polyester bags were filled with sand and placed in a checker board fashion to form an artificial river bank (See **Figure 10 and 11).** The other bank was formed by the natural slope of the valley to the East. Diverting the river allowed for the excavation, forming and pouring of the footings in the dry.

The river would eventually be returned to its preconstruction location through the arch; however MOE had a special design for that portion of the river bed between the footings that would ensure that in times of very low flows a channel would remain to permit the free movement of fish population and wildlife through the structure.

Figure 10. Waterford river diverted to east to permit in the dry construction.

Figure 11. In background delivery truck descends steep grade to work site.

5. Footing construction.

With the river diverted and the site drained work began on the footings in the dry. Two trenches were excavated to reach good bearing soil and the footings were formed and cast using conventional methods. Relatively large footings were required due to the weight of the high fill above the arch structure. The arch structure and footing were designed to follow the grade of the river with a slope of 1.4% or a drop of ~ 900 mm over its length. Once the footings were completed work could began on the preparation of the stream bed. Re-construction of the steam bed prior to the assembly of the arch, allowed the contractor to remove unwanted material and to place new bedding using heavy equipment **(see Figure. 12).**

Figure 12. Site casting two parallel 1.250 x 5.350 m -70m long footings complete with keyway for Arch placement.

6. Arch Construction

6.1 Arch element Erection. To facilitate the speed of erection and safety, a proprietary insert system was used for the stripping and erection of the arch elements. Anchors were cast into the precast arches, which were easily connected to the crane rigging using quick connecting ring clutches. Using the same anchors for the side lifting and the placement lifting reduced and amount of rigging required and contributed to an organized lifting sequence. The first stage of the erection operation is to transfer the arch elements from the delivery vehicle in the side storage position to the inverted position, and to then re-connect the rigging for hoisting and placement (**see Figure 13**).Due to site access trucks could not bring arch elements directly to the placement site. A hydraulic excavator off loaded and stockpiled elements onto the footings and subsequently transferred the elements to within easy reach of the crane. The crane assisted by the excavator rotated the elements from the storage position to an inverted position for final hoisting and placement (**see Figure 14**). Pre-determined sling lengths allow for the arch elements to be seated in the footing keyway and then the rotated to engage with the elements on the opposite side. At the start of the arch erection, two cranes are required to place the initial pieces. Arch units are placed in a longitudinally staggered fashion, and the previously placed elements provide support the subsequent element at the crown of the structure. Once the first four elements are in place, they provide sufficient support for placement of subsequent elements. The second crane can be released and removed from the site and one crane can now place the balance off the elements, buy alternating placement on each side, using the previously erected elements as support at the crown **(see figures 15, 16, 17)**. Overall the 66 m structure was erected in 5 days.

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Figure 13. Arch elements are positioned for hoisting and placement.

Figure 14. Two cranes place the first two elements. After placing 4 elements work can proceed with one crane and the second crane can be released.

Figure 15. Rigging is pre-set to place the element at the 1.4% down grade slope.

Figure 16. Single crane places elements alternating side to side.

6.2 Grouting, Crown beam and Joint covering.

Once the arch elements are fully erected, the remaining stages before backfilling include grouting elements into the keyway crown, casting longitudinal crown beams and covering all joints with filter fabric. Arch elements are permanently secured in place at the base by grouting them into the keyway. A Fluid non-shrink grout is poured into the keyway which surrounds the arch elements and forms a direct connection to the footing. Two longitudinal side by side beams are cast at the crown to join all the adjacent elements on each side. Lastly filter fabric is placed along all the vertical and horizontal joints to allow drainage and to prevent the passing of fine backfill material through the joints.

Figure 17. Arch element erection is complete. Grouting of footing keyway, casting of crown beams and placing filter fabric over joints is must be completed before backfilling.

7. Backfilling and retaining wall construction. With erection of the arch structure completed, the river was diverted back its original path through the arch. Work began on backfilling and construction of the head walls and wing walls. Backfilling operations must proceed in a balanced fashion maintaining a maximum backfill differential between each side of the arch of not greater than 1 m (see figure 18)

8. Summary and Conclusion. The Team Gushue highway crossing of the Waterford river was a major challenge due to the depth of the gorge, river size and flow, and the restricted access. The selected solution provided cost effective alternate to a bridge structure and will have further maintenance advantages over the course of the life of the structure. The major advantages is the level of post construction service maintenance that will be reduced by the elimination of the bridge deck, expansion joints and the opportunity for bridge icing that has been eliminated resulting in less salt use. Techspan arches are a cost effective method for new construction. The entire structure was constructed with local labour and without having to bring in specialty contractors (Figure 20.)

Figure 18. River is returned to natural alignment. Backfilling of headwalls and wing walls begins

Figure 20. Arch structure complete with head walls, wing walls and embankment.

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