superstructure will occur since the cable forces differ between the north and central girders. The north girder cables are stressed to a higher degree than the centre cables for this phase of construction, as a result of which the bridge deflects to the north due to the difference in forces. Since the deflection is not too large, a horizontal jacking operation will be used at the abutment bearings to bring the bridge back into alignment rather than horizontally cambering the superstructure. Once the superstructure cantilever reaches the abutment, it will be jacked laterally into position and temporarily supported until the permanent bearings are installed.

Larsa 4D was crucial in determining the amount of lateral deflection at the abutment locations and the amount of jacking force that will be required to move the bridge into its final position. During the south phase of construction, the stressing of the south plane of cables produced a lateral bending moment that is resisted by the permanent lateral bearings and horizontal deflection is not a concern. As the construction of the south phase progresses, the lateral force in the north and central girder bearings will be gradually reduced and eventually reversed in the opposite direction.

In addition to meeting all the geometry constraints, the stresses and capacities of all elements had to be checked during all stages of construction, and the end of construction member forces had to be in relative agreement with the original design. For global behaviour, Larsa 4D was used to compute stresses for the edge girders, deck, and towers and compared to the code limits. Load combinations and member capacities were calculated according to *CSA S6-06 Canadian highway bridge design code* and included dead, live, construction dead and live loads, wind, and snow loads.

The erection analysis and construction evaluation of the bridge was carried out using the Larsa 4D software with its time-dependent and geometric non-linear capabilities.

The north phase of the bridge is currently under construction and tower erection has been completed, with superstructure construction of the north phase now under way and set to progress through the year. The construction of this seemingly straightforward cable-stayed bridge is significantly complicated by the phasing requirements and the resulting asymmetric behaviour; however, these challenges were resolved with the advanced analysis tools offered by Larsa 4D

Thomas Peake and Robert Gaskins are senior bridge engineers and David Jeakle is principal at McElhanney Consulting

CASTING VOTE

Precast segmental construction was chosen for the three towers of the new cable-stayed bridge over the Nipigon River in Canada. Each tower consists of 24 match-cast segments, rising to a height of 51m above the bridge deck using a total of 1,240m³ of concrete.

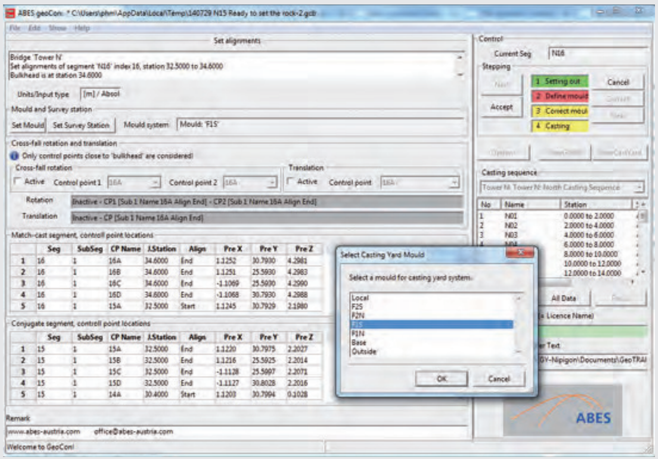
The towers taper towards the top giving each segment a unique geometry. Segments range from 2m to 3.6m in height, and weigh up to 74t. Eleven cables support each span of 139m and 112.8m respectively, and are anchored in pairs into the same number of tower segments.

Armtec is the precast concrete subcontractor for the tower segments, working for build-operate-transfer contractor Ferrovial Nipigon JV. Segment casting has now been completed and tower assembly on site is well advanced.

A vertical match-casting set-up was selected for the tower segments, whereby finished segments were carefully placed on the floor of the casting yard, and the formwork for the subsequent segment was positioned on top. The formwork was then adjusted to create the next segment, compensating for possible geometry imperfections of previous segments.

Twelve control points were placed on two opposing faces of each segment, and further control points were defined on the formwork. These were used to control formwork adjustments prior to casting and for quality control and error-correction purposes after casting of each segment. No bulkheads were employed and the upper surfaces remained open during concrete curing. A mobile total station was used to survey the control point positions.

ABES Software has the capability to address the specific challenges posed by this particular casting method and was therefore selected to support geometry control in the casting yard. Control points can be defined anywhere



Left: Tower construction progressing on site *(Ferrovial Nipigon JV)*
Above: Input screen to generate setting-out data for the casting yard

on the cross-section, and there is no limit to the number of control points per segment. In fact, the high number of 12 control points per segment created redundancies in the survey data, which was automatically used by the software to improve accuracy. The program provided setting-out data for new segments, including possible corrections for casting imperfections of previous segments and it also assisted in documenting the casting process for quality control purposes. Data that was generated was used at a later stage during assembly of the towers at the construction site.

This software has been developed by engineers with practical experience in precasting: it can be customised to support a large variety of casting and surveying methods. The absence of a bulkhead, the vertical alignment of casting coordinates, and the necessity to compute adjustments of the formwork relative to the position of the conjugate segment (instead of vice versa as is commonly the case) were the main parameters to be accounted for in this particular project.

Marc Robichaud (project manager, Armtec) and Martin Pircher (CEO, ABES Pircher & Partner)