Bridge pier movements induced by micropile installations

Blake Leew
EllisDon Construction Inc. (formerly of Golder Associates Ltd. - Calgary)
Peter Thomson and Dennis Becker
Golder Associates, Calgary, Canada
Chris Bunce
Canadian Pacific, Calgary, Canada

ABSTRACT
This paper describes observed pier movements during and following completion of micropile installations to upgrade the foundation of an existing masonry pier. Pier movement (horizontal displacement and settlement) was monitored throughout the construction program. The movement was observed to correspond closely to the location of active drilling, with the bridge pier rotating towards the locations of the most recent micropile installations. The micropile installation sequence was varied to keep movement within acceptable limits throughout the project.
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RÉSUMÉ
Cet article décrit les mouvements observés d'un pilier pendant et après l'installation de micropieux pour renforcer les fondations d'un pilier de maçonnerie. Les mouvements du pilier (déplacement horizontal et tassement) étaient monitorés tout au long du programme de construction. Les mouvements observés correspondaient étroitement à la position du forage en cours, avec les piliers du pont montrant une rotation dans la direction des installations de micropieux les plus récentes. Une variation dans la séquence d'installation des micropieux a été suivie de façon à conserver un mouvement à l'intérieur des limites acceptables tout au long du projet.

1 PROJECT BACKGROUND

The Nipigon River Bridge was constructed by the Canadian Pacific Railway in the 1880s. It is a three span structure that conveys rail traffic over the Nipigon River. The bridge comprises a series of steel truss structures that are supported by abutments at the east and west ends, four steel truss pedestals at the west end, and three masonry piers. The distance between the east and west abutments is approximately 230 m and the train rails are about 36 m above the river thalweg. The original masonry piers were constructed on concrete caps that overlie timber mats. At the eastern and central masonry piers, the timber mats are supported on timber piles. At the western masonry pier (Pier 3), which is the focus of this paper, no timber piles were installed during the original construction.

Increasing rail traffic, combined with almost 130 years of use, required that the piers and their foundations be upgraded or a replacement bridge be constructed to convey the heavier train loads. It was originally anticipated that the existing bridge would have to be replaced to accommodate the longitudinal loads caused by the traction motors and loads of newer locomotives. For most railway infrastructure the ongoing operation of the railway during repair, modification, improvement or renewal of infrastructure is a critical aspect. Prolonged interruptions in rail service have a significant influence on the profitability of the company. As a result, work on a bridge must ensure ongoing satisfactory performance of the infrastructure during the work.

It was found that upgrading the existing piers and foundations via micropile underpinning was feasible, less expensive, and would result in less environmental impact than the alternative of a building a new bridge on a new alignment. The selected upgrade design included a structural concrete jacket (surround) constructed around each of the three masonry piers. These jackets were designed to transfer all of the pier loads to new pier foundation systems to be supported by a total of 100 micropiles installed around the existing three masonry piers. The foundations and micropiles would be subjected to substantial combined axial loads, lateral loads, and applied moments.

2 GROUND CONDITIONS

The anticipated subsurface conditions at the western pier (Pier 3) were based mainly on the investigation results from a borehole drilled during an investigation program carried out in 2003. The anticipated conditions consisted of a compact layer of sand in the upper 7 m and very dense lower sand from 7 m depth to the final depth of investigation of approximately 15.3 m. During construction, it was found that there was a fill layer overlying the timber mat, which was underlain by a dense sand and gravel layer that extended to the micropile tips, approximately 18 m below existing grade during construction. The fill layer consisted of sand and gravel, some cobbles and angular boulders. The boulders were made up largely of unused stone masonry that was presumably left over from the original bridge construction.

3 MICROPILE CONSTRUCTION

The installation of all micropiles was in accordance with the contractor's methodology, which had been previously approved by the design engineers from Canadian Pacific (CP) and Golder, based on the results of a pre-construction sacrificial pile load testing program (Thomson et al. 2007). The pile load test results demonstrated that the contractor could install micropiles capable of withstanding the design loads. The micropiles were installed by Geo-Foundations Contractors Inc. and the General Contractor was Leo Alarie and Sons Ltd. Hatch Mott MacDonald was the Contract Administrator on behalf of CP.

The selection of the drilling and micropile installation technique was judiciously made, based on consideration of demonstrated experience that has shown the technique to provide minimal disturbance to the ground. A duplex drilling system with a down-hole-hammer bit was used for all micropiles, with a tricone bit deployed to drill through the timber mat at some locations. The micropiles were installed by advancing a temporary steel casing to full depth using a reverse-circulation down-hole hammer. Air and water were used to lift the cuttings. Upon reaching the full depth, water was flushed through the drill rods for approximately 20 minutes to remove cuttings and potential slough. The casing was filled with water during retraction of the drill rods and hammer to reduce the potential for sloughing into the casing.

The micropiles were installed in a row of 12 piles along each of the western and eastern sides of the pier, as shown in Figure 1. All micropiles were 273 mm in diameter, with #20 Dywidag threadbar installed in the centre of the micropile along the entire micropile length of 18 m. The steel casing, with an outer diameter of 273 mm and a wall thickness of 13 mm, was designed to be installed from the micropile tops (approximate Elevation 78.0 m) down 9.2 m to Elevation 68.8 m. This permanent steel casing was required to resist against the lateral loads and applied moments in the upper portions of the micropiles.

The central steel reinforcement (with post-grouting tubing and instrumentation, as appropriate) was lowered into the steel casing, which was then tremie-grouted to surface. Approximately 1 m of the steel casing was retracted, followed by grout pressurisation (via a cap installed at surface). Additional pressure grouting was completed in approximately 3 m vertical intervals as the steel casing was withdrawn from the hole. The steel casing was retracted to its design tip elevation of the cased micropile portion, followed by one application of pressure grouting. Post-grouting was completed for selected micropiles. Post-grouting and pressure grouting for all micropiles was called for in the specifications and was carried out at the majority of the micropiles. Post-grouting was not achieved at some micropiles due to blockages in the post-grout tubes.

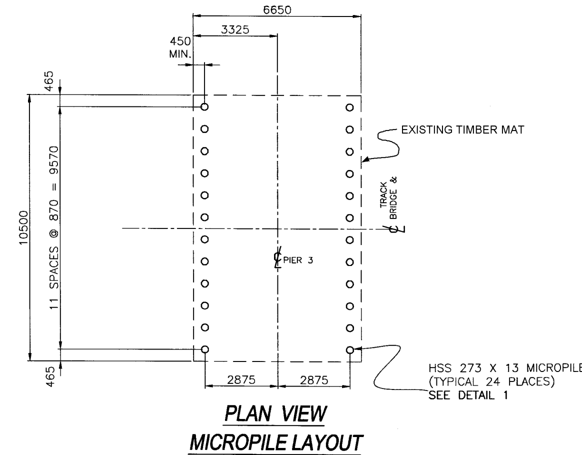

Figure 1. Plan view of micropile layout around the existing pier foundation.

4 PIER MONITORING

Pier movement monitoring was in place at Pier 3 throughout the micropiling program. Lateral and vertical movements were measured at least daily. As shown in Figure 2, the monitoring instrumentation consisted of six prisms fixed to the pier that were surveyed for northing and easting, and two level batter board targets that were surveyed for elevation. Installation and monitoring of all targets were performed by the general contractor, who submitted the data to the on-site engineer for data reduction and distribution. Data were reduced on a weekly basis, and more frequently during periods when lateral movement was seen to be accelerating or approaching pre-determined limits of 50 mm.

5 PIER MOVEMENTS

Pier movement data are shown on Figures 3 and 4. These figures show the measured easting of the uppermost prism targets and the elevation of the batter board level rods, respectively. Some statistical noise is evident on these figures, which is attributed to the effects of ambient temperature variations. Figure 3 shows that the pier underwent fluctuating movement in the east-west direction, with the direction of ongoing movement changing twice. These two changes in the direction of movement occurred when the micropiling was intentionally shifted from the east side of the pier to the west side, and then again when micropiling returned to the east side, as can be seen on Figure 3.

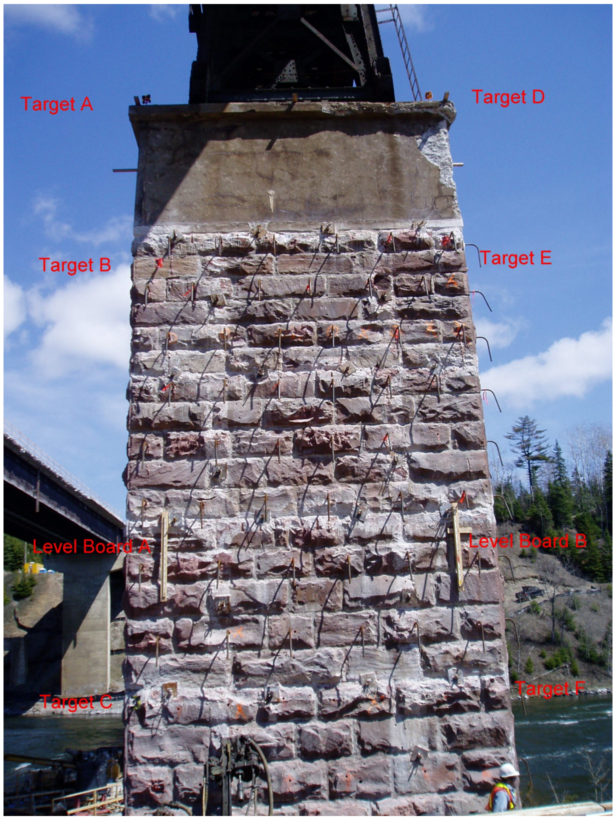

Figure 2. View along track direction towards Pier 3 showing level boards and prism targets.

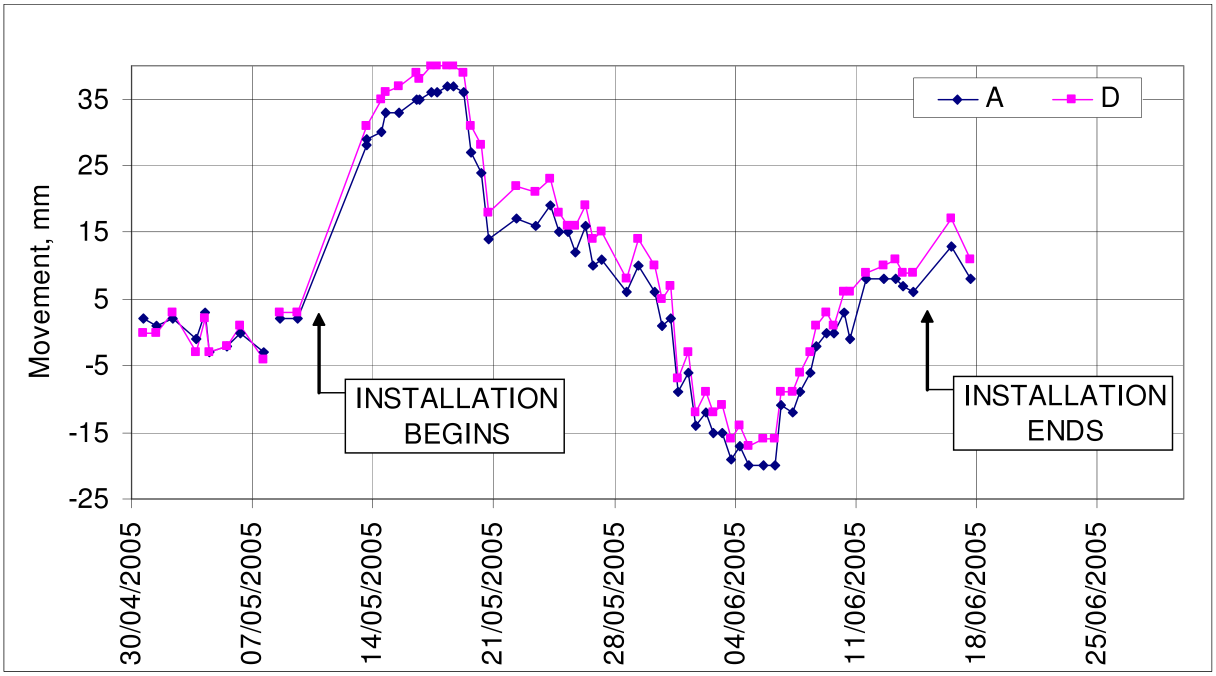

Figure 3. Measured easting of Prism Pair A and D during micropile installation.

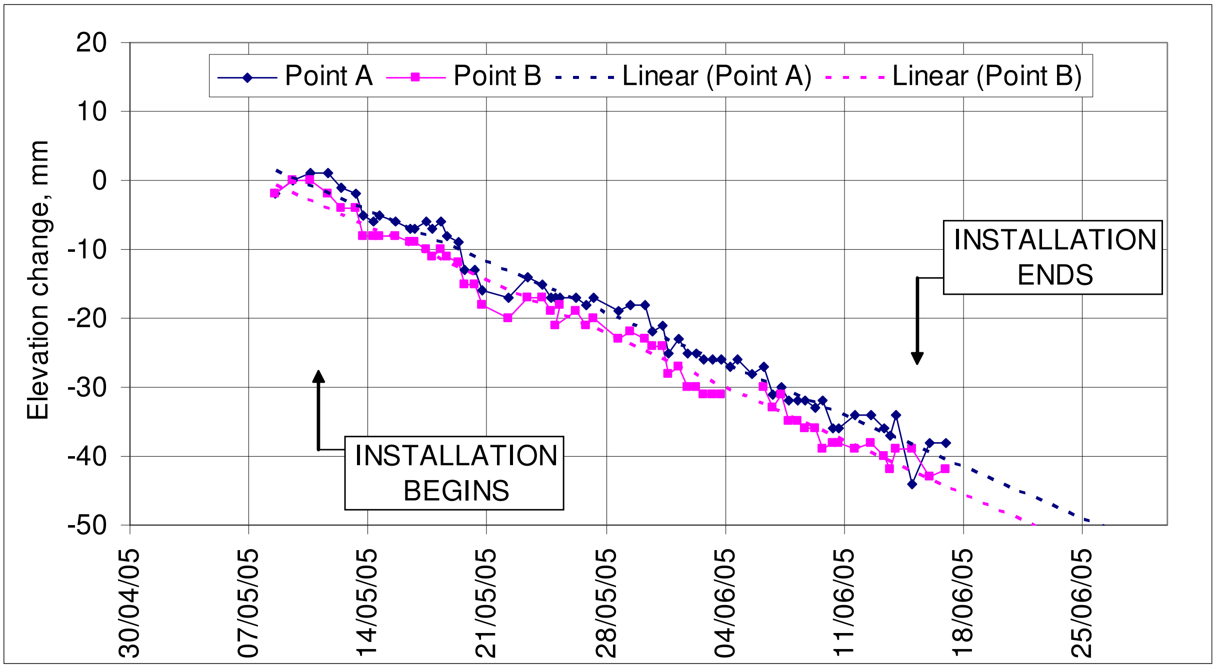

Figure 4. Measured settlement of Pier 3 during micropile installation.

Figure 4 shows that the pier generally experienced steady settlement throughout the piling program. The amount of settlement did not appear to be influenced by the location of piling.

In summary, the data show total vertical settlement of approximately 45 mm and total eastward movement of approximately 10 mm at the completion of micropile installations at the pier. Southward movement, which is not shown in this paper, was found to be approximately 10 mm at the end of the micropiling program. No further movements were measured between the completion of micropiling and the completion of the construction project.

The pier movement data, when compared against the drilling schedule, shows a strong relationship between the location of micropile installation and the nature of the movement experienced by the pier; drilling on the east or west side of the pier was accompanied by movement of the top of the pier in the east or west directions respectively (i.e. the pier rotation was in the direction of drilling and micropile installation). Changes in the direction of the movement correspond to when the drill was moved from the east side of the pier to the west side, or vice versa. The time lag between the change in the position of the drill and the change in the direction of pier movement was short (i.e. usually within a day or so).

Because of this relationship, the micropiling was scheduled to control the movement (rotation) of the pier and to limit the movement in any one direction. Thus, although total changes in the eastward and westward directions of Pier 3, over the course of the micropiling program, were 70 mm and 60 mm, respectively, the maximum net eastward and westward movements of Pier 3 were 40 mm and 20 mm, respectively. The total net movement of Pier 3 at the end of the micropiling program was 10 mm east. During construction, the top of Pier 3 had moved a total cumulated distance of 130 mm.

6 ANTICIPATED MOVEMENT MECHANISMS

Micropile records were carefully examined to determine if the movements could be explained by factors other than micropile location. Factors investigated included variations in grout takes, drilling conditions indicating looser ground, higher pressures during grouting, and other variations in the encountered subsurface stratigraphy. However, review of the construction records indicated that the ground conditions, grout takes and grout pressures were approximately equal for all pile installations around the pier. Therefore, no correlation other than micropile drilling location and pier movement was identified.

The correlation between the location of active drilling and the direction of movement was most simply and reliably explained by the hypothesis that drilling operations induced densification of the upper sand underlying the foundation. The drilling disturbance could have been due to drilling of the holes themselves, vibration of the existing timber mat, or a combination of these mechanisms. Ground loss due to drilling operations was not considered to be a factor because of the drilling method that was used.

Because the movement was explained due to the process of densification, it was presumed that the observed movements would have been greater had driven piles been used instead of micropiles. The vibrations from the driven piles would have likely induced greater densification compared to that produced by micropile drilling. In turn, the induced pier movement would have been greater.

7 CONCLUSIONS

Micropile installation in sandy soils was observed to result in lateral and vertical movement of the existing pier foundation being underpinned. The lateral movements (rotation) could be controlled by arranging the spatial order of the micropile installations. Pier settlement was observed to be largely independent of installation scheduling.

This case record shows that, even though judicious consideration was given in the selection of drilling and micropile installation technique to provide minimal disturbance to the ground, significant pier movement occurred. Although the micropile installations did induce movements, it is considered that the movements would have been greater if driven piles had been installed. Survey monitoring of the three-dimensional movement of the pier provided a means of understanding the nature of the movement that occurred as a result of physical changes induced in the ground during drilling of the micropiles.

By utilizing a detailed geotechnical investigation, micropile technology, pile load testing, and intensive monitoring the project team was able to successfully build new foundations for an existing bridge. The construction produced minimal influence on railway operations and no prolonged interruptions in rail service, while achieving significant cost savings compared to other construction options.

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