International Conference on Case Histories in Geotechnical Engineering
(1993) - Third International Conference on Case Histories in Geotechnical Engineering

02 Jun 1993, 2:30 pm - 5:00 pm

Ground Anchors Stabilize Highway Bridge Abutments

N. H. Wade
Monenco Inc., Calgary, Alberta, Canada

G. W. Davies
Monenco Inc., Calgary, Alberta, Canada

Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 2.31

Ground Anchors Stabilize Highway Bridge Abutments

N. H. Wade
Assistant Chief Geotechnical Engineer, Monenco Inc., Calgary, Alberta, Canada

G. W. Davies
Senior Civil Engineer, Monenco Inc., Calgary, Alberta, Canada

SYNOPSIS Calgary's Glenmore Causeway, constructed in 1962 across the Elbow River, consists of an earthfill embankment with a waterway spanned by a 43 m long bridge, the abutments of which are supported on spread footings founded in the embankment fill. Between the 25 m deep sand and gravel embankment fill and the sub-horizontal bedrock surface is a compressible clay layer up to 5 m thick. To improve abutment stability during peak river flows, 126 post-tensioned Dywidag ground anchors up to 60 m long were installed through the concrete slabs armouring the abutment slopes. Twenty-two anchors were terminated in the embankment fill and the rest were grouted into bedrock. After a series of lift-off tests and anchor re-tensioning to compensate for ground consolidation, a procedure for predicting the rate of anchor load relaxation was developed. It was concluded the anchors are performing satisfactorily although periodic re-tensioning will be required.

INTRODUCTION

Glenmore Trail, a major highway artery in the city of Calgary, Alberta, crosses the Elbow River via a causeway and bridge. The structure was built in 1962 to handle four lanes of traffic and widened to seven lanes in 1979. The causeway is an earthfill embankment, with its waterway protected by riprap and concrete revetment slabs. A 43 m long composite steel and concrete bridge superstructure spans the waterway. Both bridge abutments, as well as the bridge approaches, are supported on spread footings founded in the embankment fill.

The City of Calgary engaged the authors' firm in 1986 to design and supervise construction of causeway modifications as part of a program to upgrade the Elbow River infrastructure to accommodate the Probable Maximum Flood (PMF). Hydraulic model studies of the waterway predicted deficiencies in the erosion protection when subjected to design flow. In addition, stability analyses showed the factors of safety for the existing embankment slopes were low.

The causeway modifications subsequently developed included placing high slump concrete in riprap voids to increase scour resistance, overlaying the existing revetment with a new 600 mm thick concrete revetment slab to resist higher hydrodynamic forces, and installing ground anchors to increase overall slope stability. A cross-section through the modified causeway is shown on Figure 1.

Based on engineering data reported elsewhere (Monenco, 1991a; Monenco, 1991b), this paper outlines the main aspects of the anchor design and installation, summarizes subsequent anchor performance and ground behaviour, and describes a method for predicting the rate of anchor tension relaxation arising from ground settlements beneath the collar plate.

GROUND CONDITIONS

Ground conditions at the abutments consist of a layer of riprap 2 m thick directly beneath the concrete slab armouring the embankment slopes beneath the bridge supports. The riprap in turn is underlain by loose to medium dense sand and gravel fill of varying thickness up to 25 m. Sandwiched between the sand and gravel strata and the gently eastward dipping bedrock is a relatively compressible layer of clayey sediments with a maximum thickness of about 5 m. Because of the sloping bedrock profile, the thicknesses of both the clay and granular units are greater at the east abutment than at the west. Accordingly, while all 60 anchors installed at the west abutment were grouted into bedrock, 25 of the 66 anchors installed in the east abutment were terminated in granular soils to avoid the drilling difficulties associated with long inclined holes through loose sand and gravel strata below the water table.

ANCHOR DESIGN

Slope stability analysis of the unmodified revetments determined the critical slip circles passed through the toe of each bridge abutment. Several concepts to increase the shearing resistance along the slip circles or reduce the abutment loads exerted on the embankment were studied. The use of ground anchors to introduce a clamping force

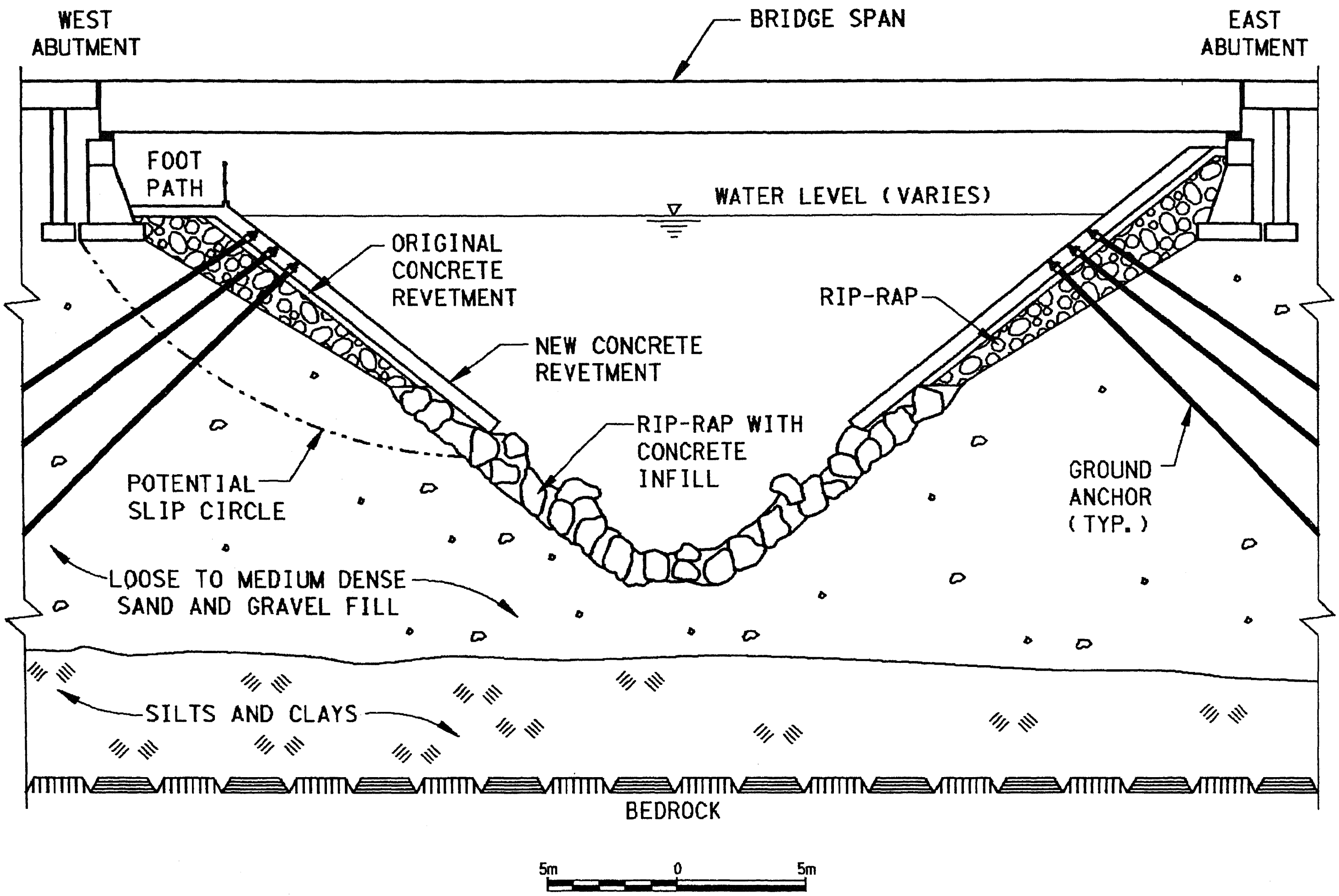

Fig. 1. Section Through the Modified Causeway

perpendicular to the potential slip circles was adopted. Further slope stability analyses were then performed to determine the most effective configuration of ground anchors and the anchor loads required to ensure a minimum factor of safety of 1.5 for normal and 1.2 for abnormal conditions.

Dywidag bar anchors, 36 mm diameter with double corrosion protection, were selected. The anchors were configured in a pattern of three horizontal rows spaced 1.5 m apart. Anchors within each row were located on 2 m centers. Sixty anchors were required for the west bank and 66 for the east. Each anchor had a working load of 500 kN, a lock-off load of 800 kN, and an ultimate load of 1050 kN. Anchor installation details were prepared for both soil anchors and rock anchors so contractors could tender for either alternative. Soil anchors would be shorter but would require more grout. The ground anchors varied in length from 20 to 60 m, of which 8 to 12 m was the grouted anchorage length. The design required periodic re-tensioning of the anchors during the life of the structure to compensate for anchor creep and embankment settlement.

ANCHOR INSTALLATION

The riprap voids were filled with high-slump concrete in 1988. Subsequently, the ground anchors were installed and individually load tested, new concrete revetment slabs were poured over the original revetments, and finally all anchors were tensioned and the loads locked off. Construction was completed in 1990.

The contractor had planned to grout all the anchors in rock, but difficult drilling conditions required a switch to soil anchors for the top row on the east bank. Subsequent monitoring and analysis work therefore distinguished between three groups of anchors, namely, west bank rock anchors (3 rows), east bank rock anchors (2 rows) and east bank soil anchors (1 row).

The lift-off tests which immediately followed the initial locking-off of all anchors indicated anchor tensions had decreased considerably, apparently due to settling or seating of the individual concrete panels comprising the revetment slab. A second series of tensioning, locking-off and lifting-off was then performed to achieve the specified lock-off load. Finally, the anchors were capped for corrosion protection and the revetment anchor block-outs covered with steel plates.

Movement monitoring devices were also installed during construction: survey pins on the abutments and revetments to measure surface vertical settlement, and a vertically oriented inclinometer tube in each bank to measure horizontal movement with depth.

ANCHOR PERFORMANCE

A third and fourth series of lift-off tests was conducted in 1991 to determine how much anchor load relaxation had occurred since initial load lock-off. Since all of the anchors had experienced load reduction, all were re-tensioned and the lock-off load re-established. Results of these procedures on each anchor were plotted on natural logarithm scale as "creep ratio" versus elapsed time from lock-off. The creep ratio, expressed in kN/day, is defined as the ratio of the measured drop in anchor load after lock-off to the elapsed time since that lock-off. A typical plot is shown on Figure 2 for the rock anchors in the east abutment.

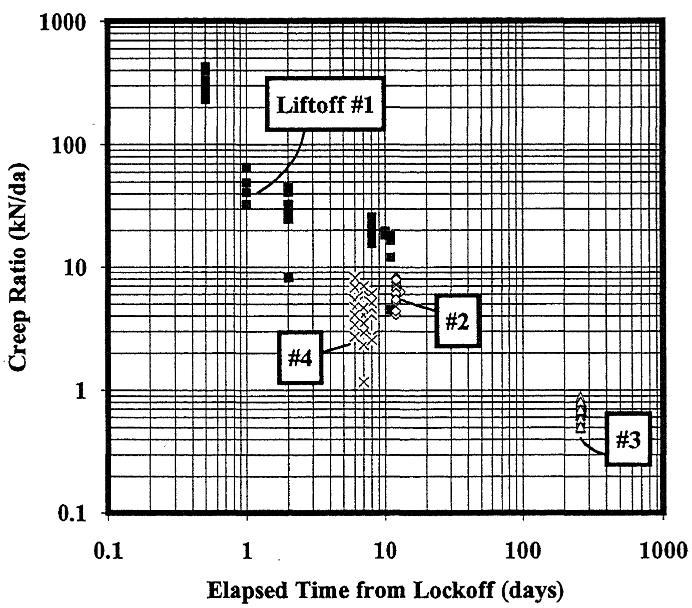

Fig. 2. Rock Anchor Creep - East Abutment

To assess overall anchor performance for each of the three anchor groups, average values of creep ratio and elapsed time were computed at each lift-off for each group. The averaged values were plotted and, neglecting the high creep ratios for

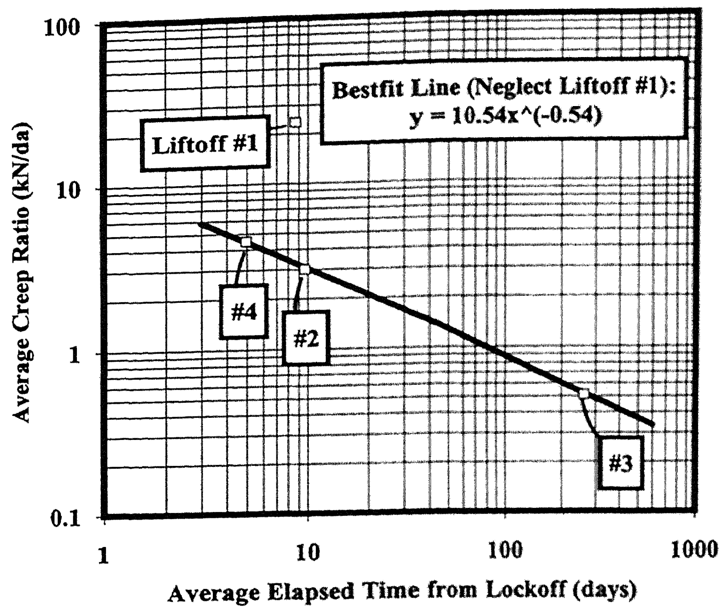

Fig. 3. Creep Summary - East Abutment Rock Anchors

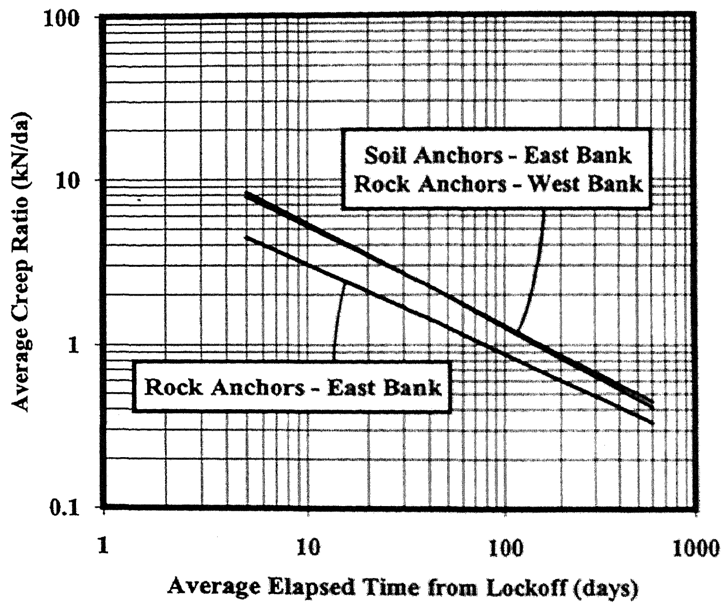

Fig. 4. Creep Summary - All Anchors

Lift-off #1 which can be attributed to seating phenomena, best-fit lines determined by regression analyses (see Figure 3). As indicated on this figure, creep ratio versus time is linear when plotted on a log-log basis. Data for the other two anchor groups also show the same high degree of linearity (Figure 4). Based on these creep rates, the anchor loads are expected to drop from the most recent lock-off load of about 800 kN to the 500 kN working load in two to four years (i.e. between June 1993 and June 1995) as illustrated on Figure 5.

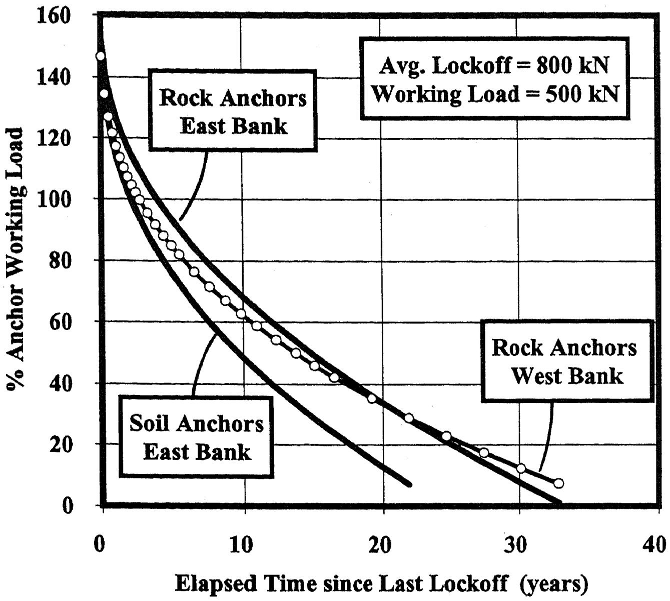

Fig. 5. Predicted Anchor Load Reduction with Time

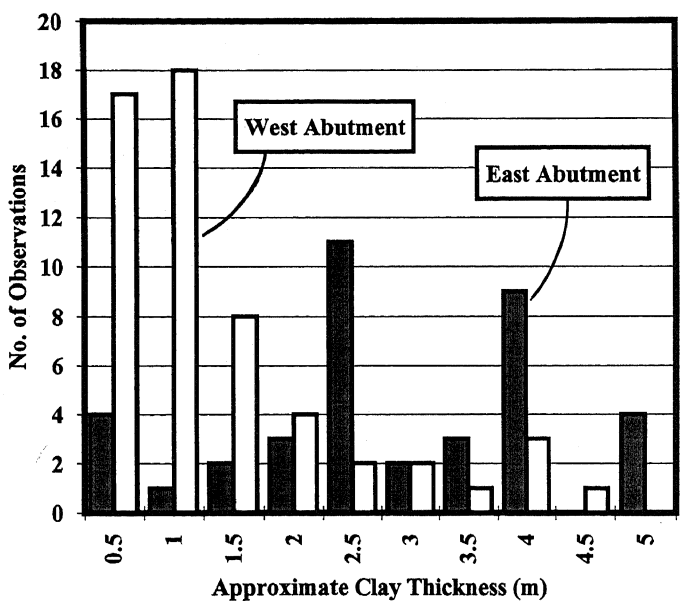

Fig. 6. Variation in Clay Thickness Beneath Abutments

Ground conditions at both abutments are similar except that the clay sediments overlying bedrock are somewhat thicker beneath the east abutment (Figure 6). Given the pervious nature of the causeway embankment materials, groundwater levels in the abutments will generally correspond to the reservoir level. Since anchor installation, the reservoir level has risen about 2.7 m above that prevailing during installation.

In view of the above, settlement of the ground under the revetment slabs was considered probable and would arise primarily from two different mechanisms:

1. consolidation of the loose granular soils and soft clays due to the stress increase caused by the anchor loading; and

2. collapse settlement of the granular materials due to wetting or flooding after being subjected to stress increase from anchor loading.

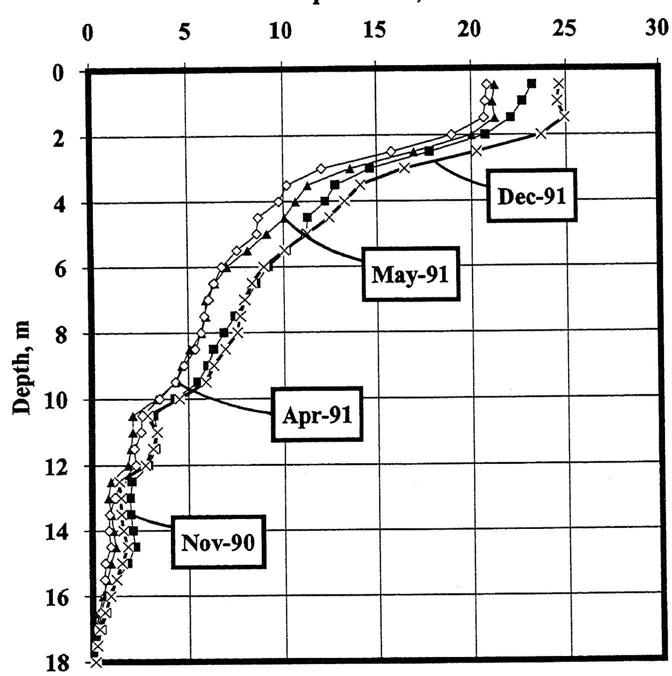

Fig. 7. Horizontal Movement Profile - West Abutment

GROUND BEHAVIOUR

In both soil and rock anchors, load relaxation would result from ground settlement due to soil consolidation. Displacement of the ground is governed by the type of materials present, the magnitude of the anchor-induced stress increase in the ground as well as any change in groundwater level.

Confirmation that ground settlement had occurred was obtained from readings taken on the survey pins installed on the abutments and revetments which indicated vertical displacements ranging from 20 to 27 mm during the first six months of service. The trend of horizontal displacements recorded by the inclinometers in each abutment was also consistent with predictions. Typical horizontal movement profiles are shown on Figure 7 for the west abutment. The corresponding plan view (Figure 8) shows the horizontal component of movement is towards the abutment, which is compatible with the direction of anchor pull. The most recent survey results, taken 18 months after anchor installation, indicate minimal vertical settlement of the revetment slabs during the previous 12 months.

CONCLUSIONS

No yielding of the grouted anchorages was evident after eight months in service and all anchors are performing satisfactorily. The relaxation in anchor tension, which was experienced after lock-off of the tension load, was determined from movement monitoring devices to be the result of consolidation of the soil deposits between the grouted anchor zone and the anchor plate collared in the revetment slab. The tension creep behaviour exhibited by the individual anchor groups, whether terminated in soil or bedrock, was similar and can be characterized as a linear relationship that declines with time when plotted on a log-log basis. Lower creep rates can therefore be expected in the future as ground consolidation diminishes.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the City of Calgary for permission to publish this paper.

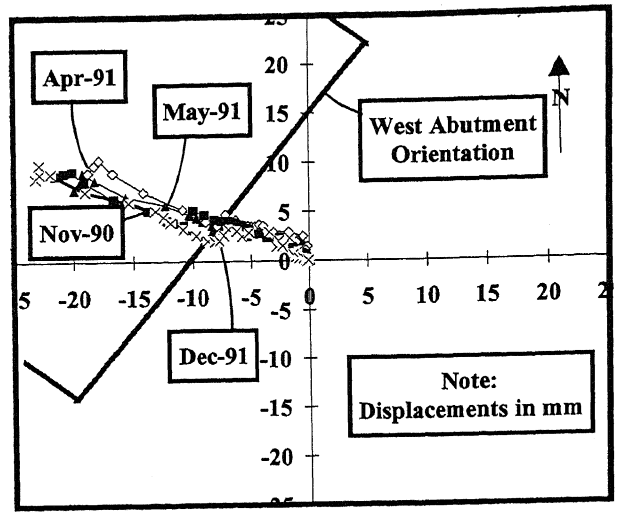

Fig. 8. Horizontal Movement Plan View - West Abutment

REFERENCES

Monenco (1991a), "Ground Anchor Monitoring for Glenmore Causeway Revetment Improvements", Report to The City of Calgary by Monenco Consultants Ltd.; Calgary, Alberta; Sep.

Monenco (1991b), "Completion Report Glenmore Causeway Revetment Improvements", ibid; Feb.