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Publisher’s version / Version de l'éditeur:

Canadian Geotechnical Journal, 13, 1, pp. 21-26, 1976-02

NATIONAL RESEARCH COUNCIL OF CANADA
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BY

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Reprinted from
CANADIAN GEOTECHNICAL JOURNAL
Vol. 13, No. 1, February 1976
p. 21–26

Research Paper No. 659
OF THE
DIVISION OF BUILDING RESEARCH

Price 10 cents OTTAWA NRCC 15122

Mud Creek Bridge foundation movements

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Received October 8, 1975
Accepted November 26, 1975

A 400 ft (122 m) long, five-span concrete bridge over Mud Creek, supported on end bearing steel piles, was instrumented to measure horizontal movements of its foundations. Fifteen years of observations show that the abutments and piers have moved downslope and rocked back and forth through a small vertical angle about their bases. The net convergence of the abutments is about 4 cm. The horizontal movements were caused by soil creep in the marine clays of the steep valley slopes. The change in verticality of the piers was attributed to the expansion and contraction of the bridge deck due to seasonal temperature variations. The steel end bearing batter piles were ineffective in maintaining the piers and abutments in their original positions.

Le pont sur le Mud Creek, d'une longueur de 400 pieds (122 m), et constitué de cinq travées en béton supportées sur des pieux d'acier à résistance en pointe, a été instrumenté pour mesurer les mouvements horizontaux de sa fondation. Quinze années d'observations montrent que les culées et les piles ont subit une translation vers le bas des talus et de faibles rotations autour de leur base vers l'avant ou l'arrière. La convergence nette des culées est de 4 cm. Les déplacements horizontaux ont été causés par le fluage de l'argile marine dans les talus raides de la vallée. Le changement de verticalité des piles a été attribué à l'expansion et la contraction du tablier du pont par suite des variations saisonnières de température. Les pieux en acier inclinés, à résistance en pointe, se sont avérés incapables de maintenir le piles et les culées dans leur positions originales.

[Traduit par la revue]

Can. Geotech. J., **13**, 21 (1976)

Bridges and highway overpasses are sometimes seriously affected by horizontal movements of abutments and foundations. Dillon and Edwards (1961) reported that the abutments of two bridges over the Thames River in London, Ontario, were affected by freezing of bridge bearings causing them to seize up in winter. These abutments were founded directly on the soil, and when the bridge deck contracted in cold temperatures the abutments were pulled inward towards each other. In summer the bearings functioned normally so that subsequent expansion of the deck did not push the abutments back. Eventually this process closed all the expansion joints causing heavy damage which necessitated costly repairs.

Abutments supported on vertical and battered piles driven through compressible soils have also been observed to move. Marche and Lacroix (1972) reported on 15 bridges in which some of the abutments converged and others diverged. The cause was related to consolidation of the compressible clays due to the weight of the approach embankments. In some cases the resulting settlement of the approach fills pushed the abutments forward. In others the consolidating clays reacted on the piles causing them to bend and deform, tilting the pile cap and forcing the superimposed abutments backward into the approach embankments. This type of movement can be very large. Stermac *et al.* (1968) observed that some structures over Highway 401 near Cornwall, Ontario, were close to collapse when the abutments pulled away almost completely from the bridge decks.

In 1959 the Geotechnical Section of the Division of Building Research, National Research Council of Canada, instrumented a new bridge over Mud Creek about 1.5 mi (2.4 km) east of Cyrville in the Township of Gloucester. This structure replaced an old bridge whose wood pile foundations had been damaged from soil creep of the steep valley slopes. The new bridge was supported on end bearing steel piles and had low approach embankments. This paper gives the results of foundation movements measured for 15 years.

Site Conditions

Mud Creek is a tributary of Green Creek which flows into the Ottawa River. At the site, Mud Creek traverses a flat clay plain and

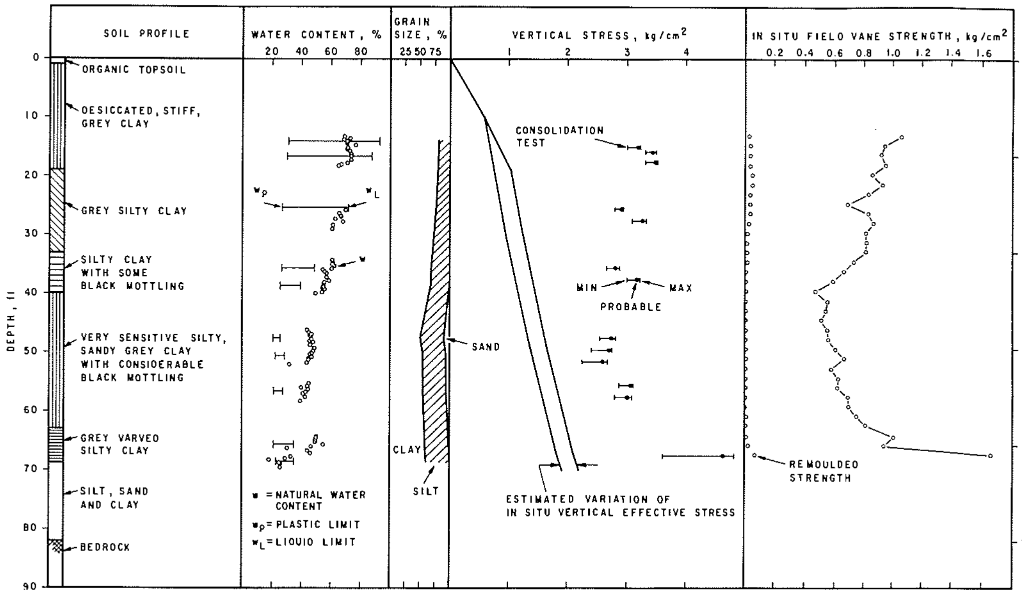

FIG. 1. Summary of soil tests near west abutment of Mud Creek Bridge.

has cut a steep sided 'V'-shaped valley. Numerous landslide scars in the area indicate that the slopes are quite active. The most recent slope failure occurred in the east bank about 100 yd (100 m) north of the bridge in the spring of 1973.

The soil profile obtained from a test boring 400 ft (122 m) west of the west abutment is shown on Fig. 1. A desiccated stiff grey marine clay extending to a depth of 19 ft (5.8 m) is overlain by a thin organic soil. Below this is 50 ft (15.2 m) of grey silty clay, silty clay with some black mottling, very sensitive silty sandy clay with considerable black mottling, and finally grey varved silty clay. The lower 13 ft (4.0 m) is a mixture of silt, sand and clay overlying bedrock, encountered at a depth of 82 ft (25 m).

The engineering properties of the soil are given in Fig. 1. The plasticity index decreases from 60% at 15 ft (4.6 m) to 6% at 47.5 ft (14.5 m), then gradually increases to about 12% at 68.5 ft (20.9 m). The percentage clay sizes reflects this trend, decreasing from 82% at 14 ft (4.3 m) to 50% at 47.5 ft (14.5 m), then increasing to 60% at 68.5 ft (20.9 m). The natural water content of the desiccated clay is about 70%, which is less than the liquid limit. Below 35 ft (10.7 m) it is less than 60%, but this is considerably greater than the liquid limits of the soil.

The consolidation tests indicate that the profile is overconsolidated by more than 2 TSF (kg/cm^2) near the ground surface, and by about 1 TSF (kg/cm^2) at 50 ft (15.2 m). The *in situ* shear strength measured with a field vane decreases from 1.1 kg/cm^2 at 18 ft (5.5 m) to 0.5 kg/cm^2 at 40 ft (12.2 m), then increases again to 1 kg/cm^2 at 65 ft (19.8 m).

The geodetic elevation of the ground surface is about 215 ft (65.6 m), of the creek bed 150 ft (45.7 m), of bedrock 110 ft (33.5 m), and of the bridge deck 210 ft (64.0 m).

Description of Structure and Instrumentation

The bridge designed to carry H20-S16 loading consists of a reinforced concrete deck supported by steel beams (Fig. 2). It consists of five sections, has a total length of 370 ft (112.8 m) and is 36.5 ft (11.1 m) wide. The sections are separated by steel finger plates which provided a total separation of 5.42 in. (13.77 cm) when constructed. The deck is supported on concrete abutments and four concrete piers. They in turn are supported on 82 steel end bearing piles (12BP58) driven to bedrock, of which 29 are battered to resist

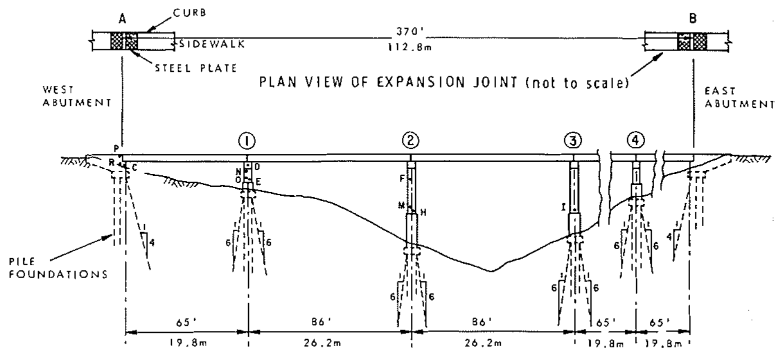

FIG. 2. Instrumentation of Mud Creek Bridge.

TABLE 1. Change in verticality of bridge piers and abutments from 1959 to 1973

Abutment or pier	Reference pins	Vertical spacing	Range of angular movement (top *vs.* bottom pin)
West abutment	P–R	5 ft (1.52 m)	0.76 mm west to 1.02 mm east
Pier No. 1	N–O	5 ft (1.52 m)	7.44 mm west to 3.30 mm east
Pier No. 2	F–M	16 ft (4.88 m)	1.78 mm west to 3.30 mm east

horizontal forces in the direction of traffic. The abutments are backfilled with 6 to 10 ft (1.8 to 3.1 m) of earth fill which loads the subsoil to about 30% of its preconsolidation pressure.

To measure the tilting of the piers and abutments, and the relative horizontal movements between them, permanent reference points were established at the locations shown in Fig. 2. Steel pins driven with a Ramset gun were installed in pairs, one directly above the other at the vertical spacings given in Table 1 to measure tilting. Measurements were made with a plumb bob connected to a washer with a fine steel wire and suspended from points P, N, and F to the respective points R, O, and M. Vertical grooves cut into the lower pins established the original vertical reference line of the piers. Subsequent surveys indicated the change in verticality with time.

To measure the relative horizontal movements between the abutments and piers, steel pins were established at the points C, D, E, F, H, and I (Fig. 2). The eye of a 100 ft (30.49-m) steel tape was bolted in turn to the pins at D, F, and I. The chain was then stretched horizontally, under an applied tension of 30 lb (13.6 kg), to the respective pins C, E, and H respectively, and the distance measured. Air temperatures were also measured so that the taped distances could be corrected for temperature differences between surveys.

The relative horizontal movements between the abutments were measured by chaining over the bridge deck between steel finger plates A and B on the abutments (Fig. 2).

Field Observations

It was necessary to measure the inclination of the piers on calm days because the slightest breeze would set the plumb bob in motion and thus affect the observations.

The surveys showed that the west abutment and Piers 1 and 2 did not remain vertical after construction. The maximum range of horizontal movement of the top pins relative to the lower ones for the period 1959 to 1973 is given in Table 1. The inclination of the west abutment varied from 0.76 mm west of vertical to 1.02 mm east, over a vertical distance of 5 ft (1.52 m). The angular rotation of Pier 2 was about the same, whereas that of Pier 1 was about five times as much as that of the abutment.

In addition to rocking about their bases, the abutments and piers converged horizontally. Measurements of horizontal distances between

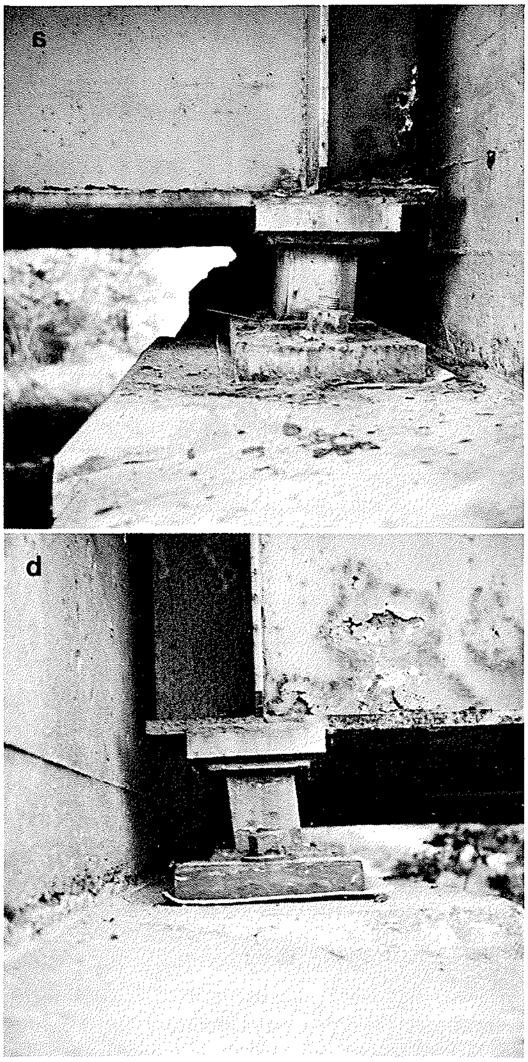

FIG. 3. Inclination of bridge bearings due to horizontal movements of the abutments. (a) Tilted bearing at southwest corner of bridge. (b) Tilted bearing at northwest corner of bridge.

the established points from 1959 to 1973 showed that the west abutment and Pier 1 converged 0.70 cm, Piers 1 and 2 converged 1.77 cm, and Piers 2 and 3 converged 1.61 cm.

A photograph of one of the bridge bearings (Fig. 3) taken in 1975 illustrates the magnitude of the abutment movements. The total convergence of the two abutments was almost 4 cm, causing the bearings to tilt about 10° from the vertical. The decrease in horizontal distance between abutments from 1959 to 1975 is shown on Fig. 4. If this rate of convergence continued, the 13.77 cm of original clearance between finger plates would disappear in 40 to 50 years. The movements, however, are not regular with time. Comparing this figure with the total annual precipitation record in Fig. 5 (obtained from the weather station at the Ottawa International Airport, 8 mi (13 km) southwest of Mud Creek Bridge) showed that the larger movements occurred during periods of high precipitation. Prolonged periods of abnormally high precipitation could therefore accelerate the closure of the expansion joints. A wet period also precipitated the landslide that occurred in the west slope of the creek, north of the bridge, in the spring of 1973.

Discussion

The clay slopes were known to be moving at the site because the foundations of the original bridge were damaged by soil creep. This behaviour is not restricted to this location. Mitchell and Eden (1972) instrumented a number of natural slopes in marine clay in the Ottawa area with slope inclinometers and measured soil movements varying from 0.3 to 1 cm/year. They concluded that the magnitude of soil creep is directly related to the climatic conditions; the wetter the year the greater the movement. Landslide activity is similarly related to climatic conditions, with the greatest number occurring during wet years when the natural ground water table is at its highest elevation.

The horizontal movement measured on Mud Creek Bridge is of the same magnitude as the 'creep' measurements reported by Mitchell and Eden (1972). As the bridge bearings functioned normally in cold weather, the movements could not be attributed to this cause. Furthermore, the applied loads from the approach embankments were insufficient to cause appreciable consolidation of the foundation soil, and the characteristic 'bump' often encountered when an approach fill settles relative to an abutment did not materialize at the site. Therefore, the settlement of the backfill and consolidation of the subsoil was also eliminated as a major cause. This left soil creep along the valley slopes as the principal cause of the foundation movements.

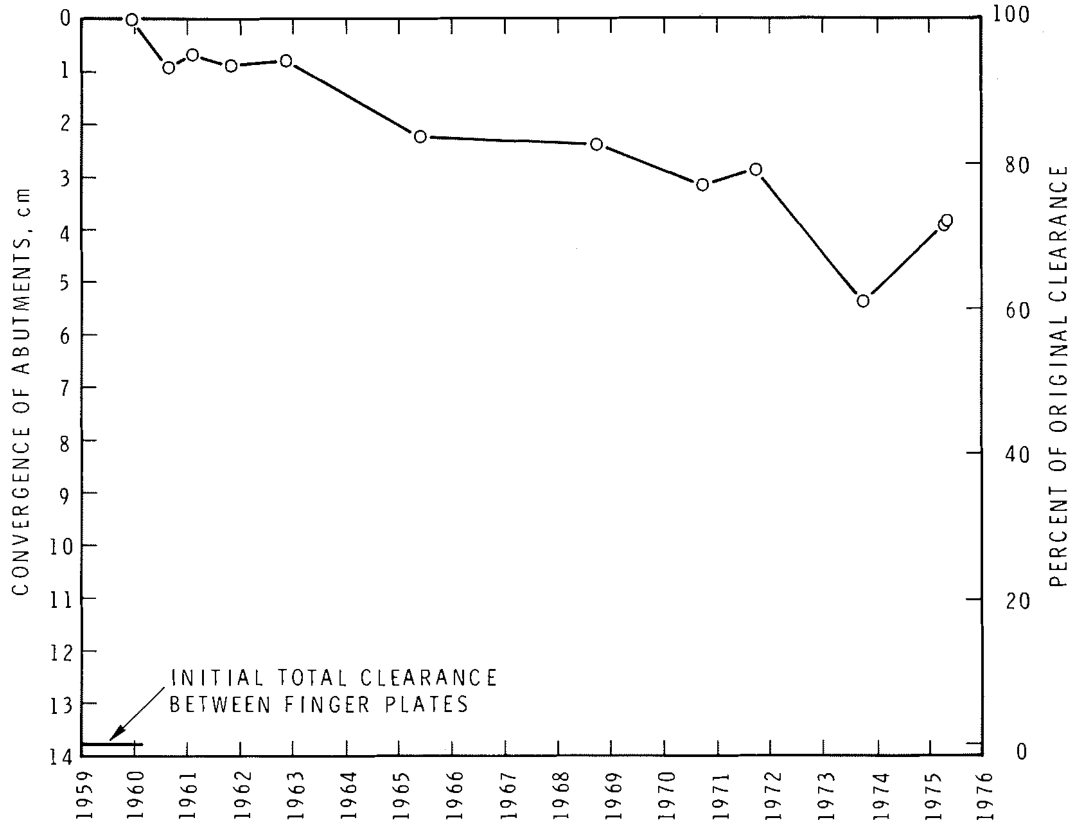

FIG. 4. Horizontal abutment movements at Mud Creek Bridge.

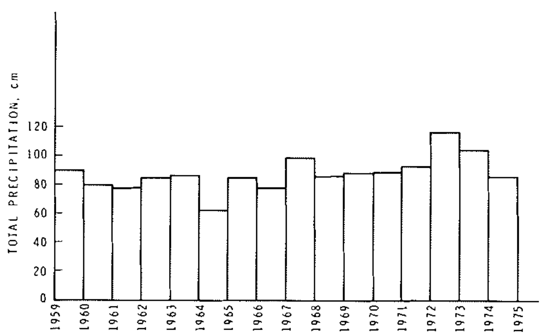

FIG. 5. Total annual precipitation at Ottawa International Airport, 8 mi (13 km) southwest of Mud Creek Bridge.

The 29 battered piles installed to resist horizontal forces and movements in the direction of traffic obviously were not effective in maintaining the piers and abutments in their original positions. They did appear to provide some restraint, however, when some of the large movements measured in 1973 were recovered. The questions then arise of what would the horizontal movements have been had battered piles not been provided, and how many battered piles would be required to anchor the piers and abutments in their original positions?

The change in inclination of the piers and abutments could be due to seasonal temperature changes. As the bridge deck expanded or contracted, some of the forces were transmittted through the bearings, causing the piers and abutments to rock through a vertical arc about their bases.

Conclusions

The principal cause of the horizontal foundation movements is soil creep occurring along the valley slopes, which in turn is related to the total annual precipitation for the area. The change in verticality or 'rocking' of the piers and abutments is probably due to the expansion and contraction of the bridge deck caused by seasonal temperature changes.

End bearing batter piles were not entirely effective in maintaining the piers and abutments in their original positions.

Acknowledgments

The Roads Department of the Regional Municipality of Ottawa–Carleton provided the opportunity for performing the observations, and the paper is published with their permission. Thanks are due to the technical staff of the Geotechnical Section who carried out the surveys.

This paper is a contribution from the Division of Building Research, National Research Council of Canada, and is published with the approval of the Director of the Division.

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