INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

Vertical Buffer Plates Simplify Bridge Abutments

Plaque de Butée Simplifié Appui l'About des Ponts

H.RATHMAYER Technical Research Centre of Finland, Geotechnical Laboratory, Finland

SYNOPSIS The Kalliomäki railway bridge (one rail) differed in both design and work performance from the usual construction scheme. The existing railway embankment had to be replaced with a bridge of four spans. The bridge beam was fitted out with vertical end plates ("buffer plates"), which replaced the usual abutment. The earth pressure acting on these hanging end plates in dependence on the thermal strains of the beam and the static and dynamic loading conditions was the object of the investigation reported here. It was during the compaction of the backfill, that the maximum earth pressures on the end-plates were registered. Owing to the small displacement, the design method of end plates using a horizontal subgrade reaction coefficient does not seem applicable. The structural solution presented here is more advantageous in comparison with a traditional bridge abutment.

INTRODUCTION

Recently, a new trend in the design of railway bridge abutments has been observed. Those elements of the abutment that traditionally took the horizontal loads were now fixed to the bridge beam (buffer plate)(see fig. 1). So the bridge support becomes simple and light. Since the bridge itself functions as a support for horizontal forces, no heavy abutment construction for reasons of stability is necessary. In addition, part of the horizontal forces caused by dynamic and static loads can be transmitted via the buffer plates to the joining embankments. As a characteristic of the new construction approach the horizontal differential movements will appear at the joints between the embankments and the bridge structure, a fact that has to be taken into account when designing other than railway bridges.

At the crossing of the Sköldvik industrial railway line with the Helsinki-Porvoo express way, the existing railway embankment was replaced with a bridge of four spans and a total length of 77 m. The bridge was founded on cast-in-place bored piles (1200 mm Ø), which were constructed through the existing embankment down to the bedrock. The bridge was fitted out with vertical end plates (buffer plates), which had to perform the function of the usual bridge abutment. But they also have to reduce considerably the horizontal movements of the bridge caused by the forces of inertia of a heavy train. Owing to the substantial horizontal forces acting on the bridge, there was ample justification to check the assumptions on which the design was based as regards the earth pressures acting upon the buffer plates, the horizontal movements and subgrade reaction coefficients.

DESIGN CRITERIA

For the static design according to Fig. 2, the bridge was treated as a uniform framework. The elastic earth support of the bored piles and the buffer plates were substituted in the calculations by springs. As the horizontal design load (braking stage), 25 % of the standard vertical train load was used. The calculation of the thermal strains of the bridge beam was based on temperature changes of ± 20°C. Taken further account were the horizontal loads caused by shrinking of the concrete and those resulting from a collision.

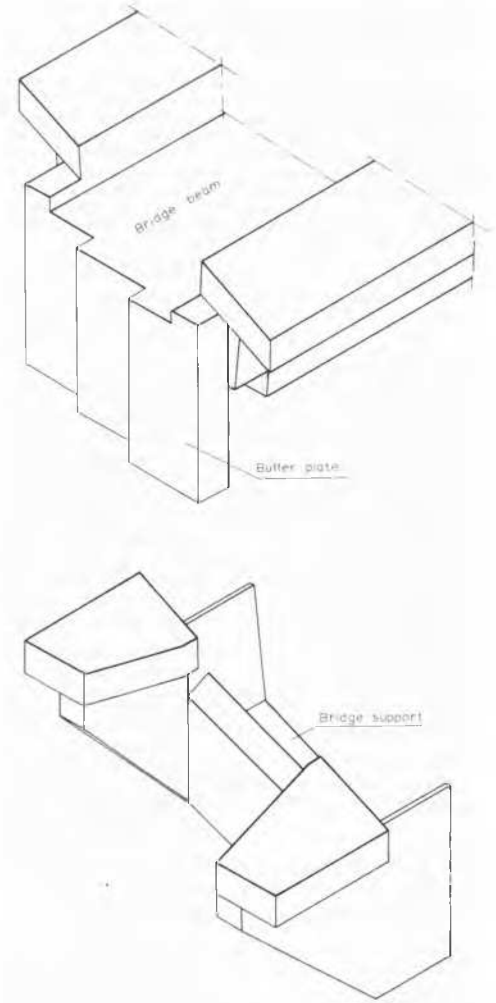

Fig. 1. Elements of the bridge abutment according to the new construction scheme

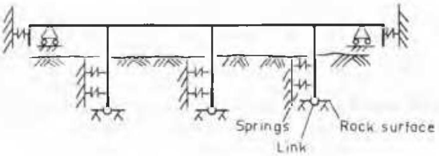

Fig. 2. Design assumptions for the bridge framework.

DESIGN OF THE BUFFER PLATES

To achieve maximum economy and to minimize the horizontal movements of the bridge, the buffer plates and the piers must resist in equal parts the maximum horizontal forces of 1680 kN. The buffer plates must therefore mobilize sufficient passive earth pressure, the amount of which depends on the dimensions, the embedding depth and the horizontal movement of the buffer plates. Owing to the vibrations caused by the traffic load, no wall friction can be taken into account; hence the resultant of the passive earth pressure is assumed to act perpendicularly to the buffer plate. As the bridge beam is trough-shaped, the upper edge of the buffer plate remains 0.7 m below the surface, which means a more effective mobilization of passive earth pressure. However, the whole system is designed to enable both the buffer plates and the pillars to bear the total horizontal forces alone. The correlation between the resistant forces to be mobilized and the horizontal movements expected is presented in Fig. 3 for the different alternatives. The maximum horizontal movements at the buffer plates were expected to be ± 20 mm. According to the design assumptions, the thermal strains caused by temperature changes of ± 20°C will produce movements of ± 8 mm, and the horizontally acting traffic load will contribute ± 12 mm.

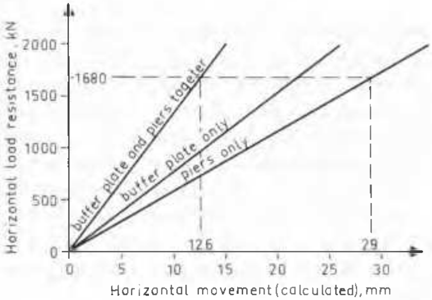

Fig. 3. Horizontal load resistance and related horizontal movements of the different resistive elements.

COEFFICIENTS OF SUBGRADE REACTION

The coefficients of subgrade reaction (k_n) are calculated with equation (1)

$$k_n = n_h \cdot z/B \qquad (1)$$

B...diameter of the constructive element (pile or pier), m

z...depth, m.

The following factors n_h, which are typical of non-cohesive materials at medium density, were used:

n_h = 12 MN/m^3 for the backfill of the buffer-plate, provided a compaction to 97 % improved Proctor-density,

n_h = 8 MN/m^3 for the original deposits above ground-water level and

n_h = 5 MN/m^3 below GW-level.

In the static dimensioning of the system the spring constants K (MN/m) were used for the elastic supports:

$$K = k_n \cdot A \qquad (2)$$

A...projected surface area of the pile or buffer plate, m^2.

SITE CONDITIONS AND INSTRUMENTATION

Used as the backfill of the abutments was the original embankment fill, a gravelly-sandy till with a uniformity coefficient of U = 50. In the triaxial tests, the stress-strain properties and the shear parameters (ϕ'=15 kN/m^2) were determined at a dry density γ_d =21 kN/m^3, which corresponds to a modified Proctor-density of 98 %, and an optimal water content of w = 7.6 %.

Fig. 4. Instrumentation of the northern buffer plate with Glötzl-type earth pressure cells.

Both buffer plates were fitted out at different depths with inlayed hydraulic earth pressure cells of the Glotzl type (Fig. 4). These cells, of the size 0.2 x 0.3 m, were placed mainly on the central step of the buffer plates. As the measuring plane of these cells coincides with the concrete wall, load concentrations toward the cells were avoided.

To measure both the relative and the absolute horizontal movements of the buffer plates and the bearings, permanent reference points (steel pins) were established at the locations shown in Fig. 5 and also in the bedrock in the vicinity of the bridge. The measurements were performed with a high-quality theodolit. Air temperatures were also measured to correlate the thermal strains of the beam to the horizontal movements measured. During the braking tests, the absolute horizontal movements were observed by means of piezoelectric acceleration transducers, the relative ones with displacement transducers (LVDT).

FIELD OBSERVATIONS

During the compaction of the backfill, observations were made only of the earth pressure acting on the buffer plates. Both the earth pressures and the horizontal movements (relative and absolute) were measured at regular intervals over a period of one year, covering a temperature range from +20°C to -30°C. In addition the earth pressure changes and the horizontal movements during two braking tests were followed up. There braking tests with a heavy train were run in such a way that the maximum horizontal forces were developed either on the joint embankment or on the bridge. Thus both the active and the passive earth pressure could be mobilized on both sides of the bridge.

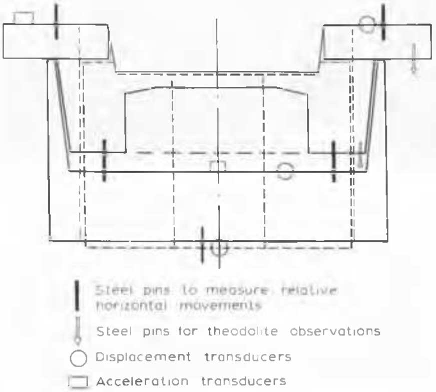

Fig. 5. Instrumentation at the northern abutment for measurement of horizontal movements.

TEST RESULTS

The distribution of the horizontal earth pressure on the buffer plates is presented in Fig6 for different stages. Fig. 6a shows how the pressure was built up during the compaction of the backfill. The efficiency of the compaction with a vibrating plate of 50 kN/m^2 static contact pressure was clearly restricted to the uppermost layer, where the horizontal pressure reached the vertical pressure (K = 1). The re-

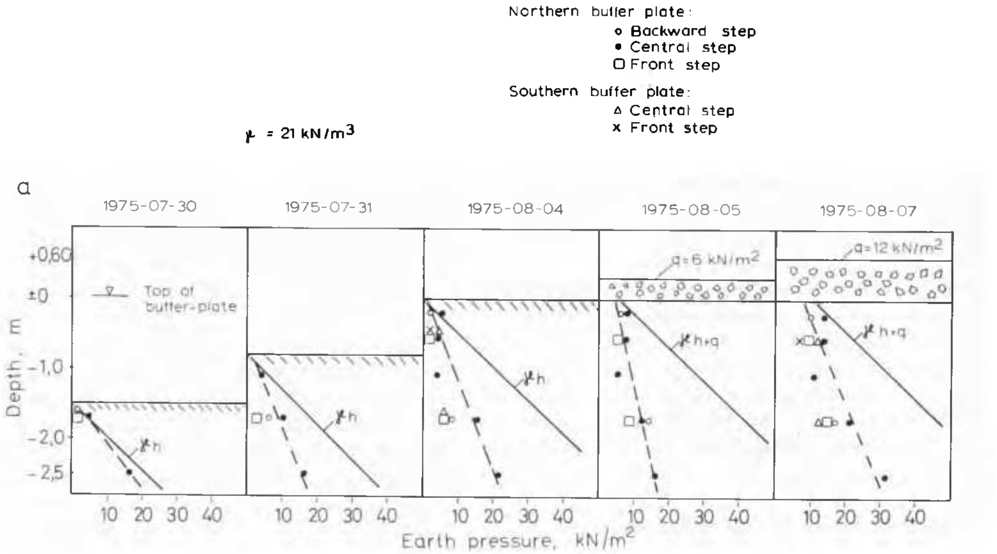

Fig. 6. Horizontal earth pressure at the buffer plates. a) during compaction of the backfill.

sults of the horizontal earth pressure measurements during a period of one year are summarized in Figures 6b and 6c. Freezing and thawing of the joint embankment in January and April-May was probably the reason for the 100...200% increase of the horizontal pressure in the upper layers. Coincident results were registered at both buffer plates.

A typical result of the earth-pressure increase during a braking test, which developed a horizontal load of about 1130 kN, is presented in Fig. 7. Only at a level of o.8 m below the tracks does the horizontal exceed the hydrostatic pressure. On the average, the measured earth-pressure coefficients K_a (active) and K_o (at rest) were both twice the theoretical values and especially high in the uppermost 0.8 m. This leads to the conclusion that the buffer plate bent in the lower part, and this is confirmed by the measured displacements.

As compared with the expected values, much smaller horizontal movements were measured. Only the deformation of the bridge beam itself, caused by temperature changes, coincides with the theoretical values. At the top of a buffer plate, deformations of 0.8 mm were registered during the braking test, while at the lower

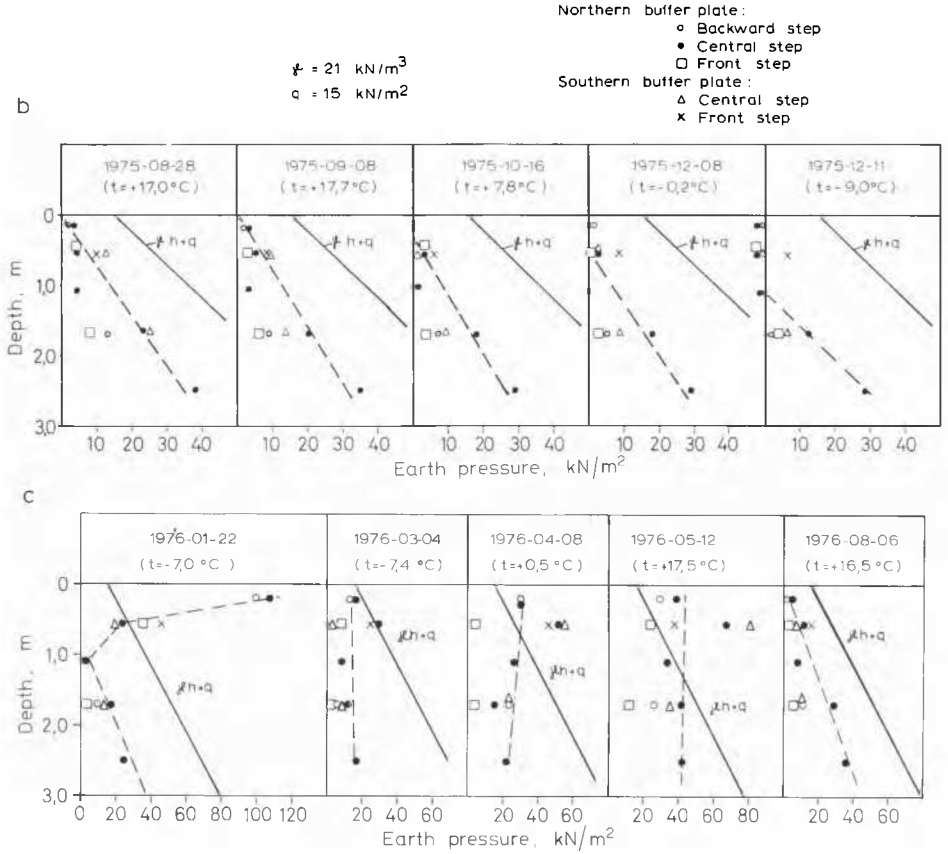

Fig. 6. Horizontal earth pressure at the buffer plates. b)c) during a period of one year.

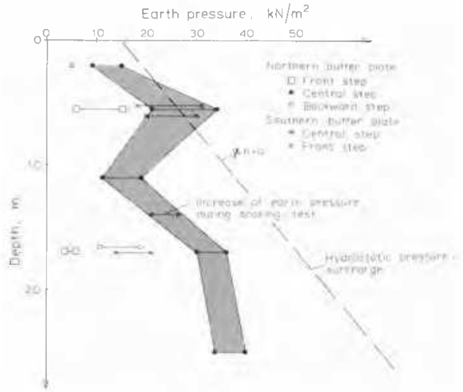

Fig.7. Earth pressure increase during a braking test.

edge only 0.06 mm were measured. Simultaneously, an absolute horizontal movement of 0.45 mm could be observed at the abutment. These results indicate that the horizontal forces, which should have been transferred toward the piers and the opposite embankment, were transferred in part toward the piled abutment, partly effected by the forces of friction at the bearings and partly by the bending of the buffer plate.

CONCLUSIONS

Although during the braking tests relatively large horizontal forces could be mobilized (ca. 1100 kN), only movements smaller than 1 mm were registered. According to the design calculations, the horizontal movements should have been in the range of 7...8 mm in the case where both the buffer plates and the piers resisted equally the horizontal forces (see Fig. 3). The mobilized horizontal forces were calculated on the basis of retardation measurements, which were performed in the train during the braking test, and of empiric friction coefficients for the friction between tracks and wheels. As these values appear to be reliable, the only reasonable explanation for the small movements observed has to be that the piers resisted to the greatest extent the horizontal forces. At any rate, in this case the design subgrade reaction coefficient used for the piers seemed to "work" successfully, assuming that we accept such an overdimensioning. But then the buffer plates cannot be designed by means of eq. (1). According to Broms (1965), this equation gives reliable results only if the height of the designed structure is 5 times its width. The coefficients of horizontal subgrade reaction, which were calculated on the basis of the observed horizontal earth pressures and movements, scatter within the values 7.5 and 18.3 MN/m^3. Owing to the extremely small movements, these coefficients are of no practical value.

The author had the opportunity to check the design assumptions only as regards the horizontal earth pressure at the buffer plates and only to make observations of the bridge movements. These measurements were started at a stage where the backfill was compacted towards the already built bridge. The evaluation of the measurements performed made clear the need for additional measurements, primarily for the study of the behaviour of the piers and piles. Such information will lead to more economical design, but it can be gained only through further trials.

REFERENCES

Broms B.,1965 , Beräkningsmetoder för sidobelastade pålar, Statens Geotekniska institut, Särtryck och preliminära rapporter No. 9, pp. 1...15.

Broms B., Ingelsson I., 1967, Resultat från mätning av jordtryck mot brolandfeste, Statens Geotekniska Institut, Särtryck och preliminära rapporter No. 22, pp. 1... 16

Broms B., Ingelsson I., 1973, Lateral earth pressure on a bridge abutment, Statens Geotekniska Institut, Särtryck och preliminära rapporter No. 52, pp. 117...123,163,164.