PRESSURE ON RETAINING WALLS FROM COMPACTION EFFORT

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Received: 15.10.2012; Revised: 15.12.2012; Accepted: 15.12.2012

Abstract
Backfill compaction effort on the bending moments in the retaining wall appears to be neglected in engineering practice in Poland and other European countries. In Canadian practice it is assumed that even a lightweight compactor produces a significant bending moment in the wall. As has been shown in the present paper, such values of bending moments can be obtained only in the compactor operating plane for the wall that has no longitudinal rigidity. Assuming the engineering simplification of averaging of the bending moments, it has been shown that the bending moment in wall-plate connection is several times lower than the moment induced by backfill pressure. Therefore, compaction effort induced by light weight compacting equipment may be neglected in the designing of T-shaped retaining walls.

Streszczenie
Wpływ zagęszczania zasypki na momenty zginające w ścianie konstrukcji oporowej jest pomijany w praktyce inżynierskiej w Polsce i innych krajach europejskich. Uwzględnianie tego efektu jest zalecane w Kanadzie. Zgodnie z kanadyjskimi zaleceniami momenty zginające w ścianie oporowej wywołane zagęszczaniem zasypki nawet lekkimi wibratorami są znaczące. W pracy pokazano, że takie wartości momentów otrzymuje się tylko w płaszczyźnie pracy wibratora dla ściany nie mającej sztywności podłużnej.
Zakładając inżynierskie uproszczenie przy uśrednianiu wartości momentów zginających pokazano, że moment zginający w miejscu zamocowania ściany w płycie jest wielokrotnie mniejszy niż moment wywołany parciem zasypki. Zatem efekt zagęszczania zasypki lekkimi wibratorami może być pominięty przy projektowaniu płytowo-kątowych ścian oporowych.

Keywords: **Pressure on retaining walls; Compaction of backfill.**

1. INTRODUCTION

Usually, coarse grained soils are used as backfill behind retaining structures. Due to limited working space, the layers of soil are compacted by small-size compactors. The equipment used for compacting the soils in an embankment is usually not used for the compaction of backfill. The effects of compaction backfill are traditionally neglected in the calculations of retaining structures. In German practice it is assumed that the compacting equipment produces extra pressure on the wall; however, this is true only for the layer being compacted. These effects are to a large extent reduced by the compaction of upper layers. The effects under discussion are neglected also in Polish practice. However, Canadian engineers claim that the compaction effects should be taken into consideration in the upper layers of the fill [1].

The present paper analyses the influence of compaction on the values of bending moments in wall-plate connection of T-shaped walls. The values of horizontal stress produced by compacting equipment are calculated according to Canadian practice [1]. It has been shown in this paper that compaction effort depends on the height of a wall and on the equipment used for compaction.

2. TYPICAL COMPACTION EQUIPMENT

Different types of compactors are used for compacting the backfill behind retaining structures. Main parameters characterizing the equipment are the dimensions of the roller (or plate): roller width (L), static weight (P_s) and centrifugal force (P_d). Total unit roller load:

$$P = \frac{P_s + P_d}{L} \tag{1}$$

Table 1 presents characteristic values for some typical compactors used in Poland.

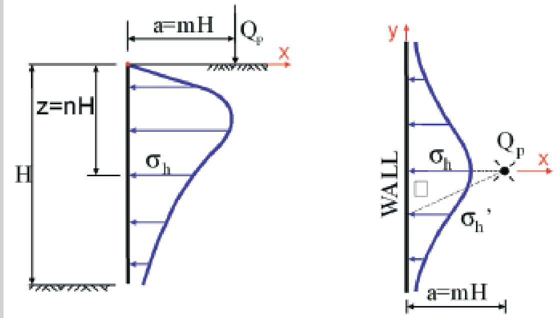

Figure 1.
Pressure on a wall due to point load surcharges

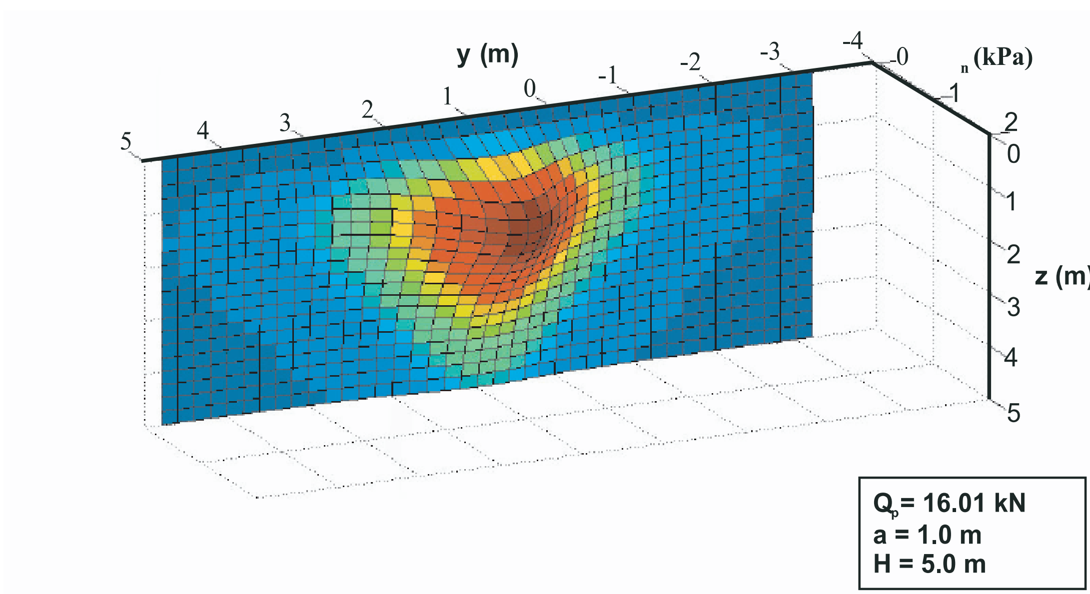

Figure 2.
The distribution of horizontal pressures on the retaining wall

Table 1.
The parameters of typical compactors

Equipment type		Static weight (P_s)	Centrifugal force (P_d)	Roller width (L)	Total unit load (P)
		kN	kN	mm	kN/m
VMS 71		4.4	11.61	710	22.5
RD 11A		10.19	13.0	900	25.8
CC 1000		17.5	17.0	1000	34.5

3. PRESSURE ON RETAINING WALLS FROM COMPACTION EFFORT

Figure 1 illustrates the distribution of compaction-induced horizontal pressures that are obtained from elasticity theory, and adjusted according to site investigation results [1].

For the wall height (H), the value of horizontal pressure (σ_h) in a cross-section of an operating compactor at a depth (z) is calculated from the following formula [1]:

$$\sigma_h = \frac{0.28\left(\frac{z}{H}\right)^2}{\left\{0.16+\left(\frac{z}{H}\right)^2\right\}^3}\frac{Q_p}{H^2} \qquad \text{for } \frac{a}{H} \le 0.4 \qquad (2a)$$

$$\sigma_h = \frac{1.77\left(\frac{a}{H}\right)^2\left(\frac{z}{H}\right)^2}{\left\{\left(\frac{a}{H}\right)^2\left(\frac{z}{H}\right)^2\right\}^3}\frac{Q_p}{H^2} \qquad \text{for } \frac{a}{H} > 0.4 \qquad (2b)$$

where

$Q_p = P_s + P_d$ is the maximum value of the effective weight of a compactor,

a – the distance between compactor centre and the retaining wall,

z – the location at a point below the operation level of the compactor.

Using the symbols given in [1], the distribution of horizontal pressures along the retaining structure at level (z) is marked as

$$\sigma'_h = \sigma_h \cos^2(1.1\theta) \qquad (3)$$

where θ is the angle defining the distance (y) of the point under discussion from the operating surface of the compactor (Fig. 1). Therefore,

$$\cos(\theta) = \frac{y}{a} \qquad (4)$$

The coefficient (1.1) in formula (3) is adopted as a modification of the theoretical solution resulting from the elasticity theory. This modification is based on the site investigation results [1].

Figure 2 shows a three-dimensional distribution of horizontal pressures on the wall as obtained from the formula (3).

Compactor-induced pressure on the wall depends on the wall height the static and dynamic characteristics of the compactor, and the distance from the wall.

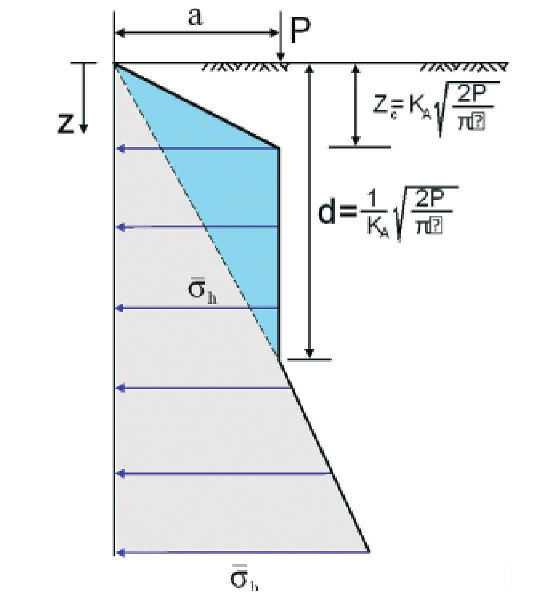

Figure 3.
Horizontal pressure on walls from compaction effort and soil pressure [1]

Figure 3 presents the simplified methodology of calculating the impact of compaction values of pressures exerted on the wall, as recommended by the Canadian Geotechnical Society [1].

The distribution of horizontal pressure on wall from compaction effort and soil pressure illustrated in Figure 3 is calculated in the following manner [1].

$$\bar{\sigma}_h = \sqrt{\frac{2P\gamma}{\pi}\frac{L}{a+L}} \qquad \text{for } z_c \le z \le d \qquad (5a)$$

$$\bar{\sigma}_h = K_a \gamma \; z \qquad \text{for } z > d \qquad (5b)$$

where $K_a = (45° - \varphi/2)$ is active pressure coefficient and γ is unit weight.

4. THE COMPACTION-INDUCED BENDING MOMENTS OF WALL–PLATE CONNECTION

Unit bending moment of wall-plate connection induced by compacting is:

$$M_c = \int_0^H \sigma'_h (H-z)dz \qquad (6)$$

Figure 4 illustrates a sample distribution of bending moments along the wall.

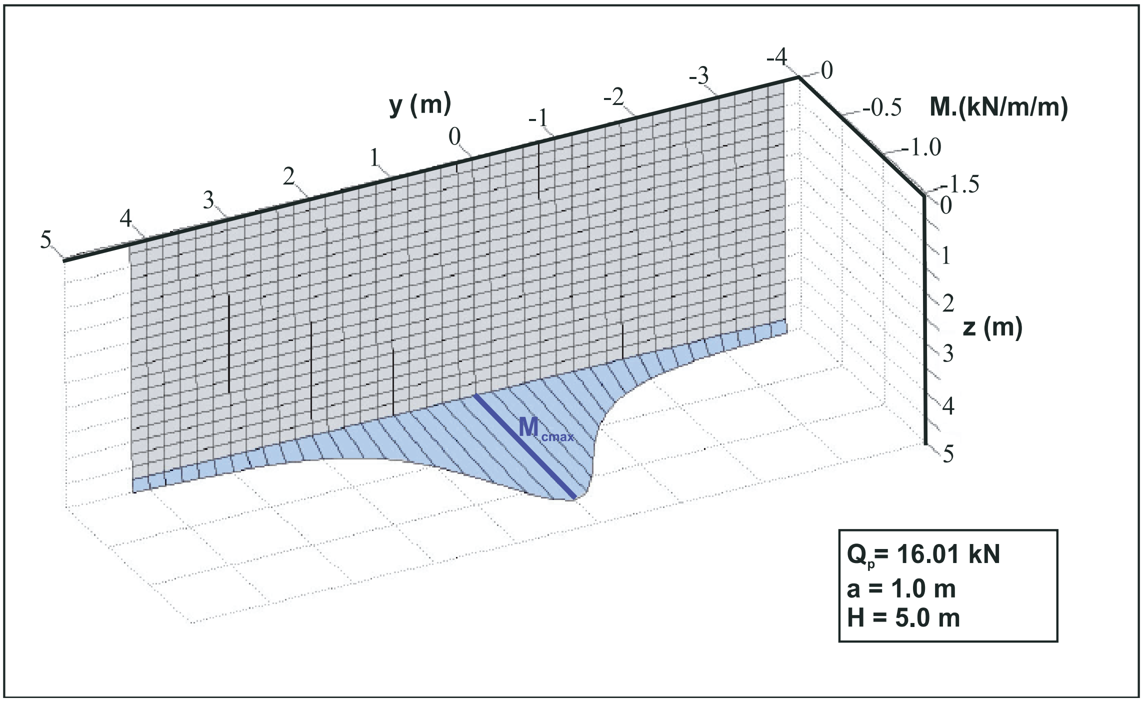

Figure 4.
Compaction-induced bending moment of wall plate connection

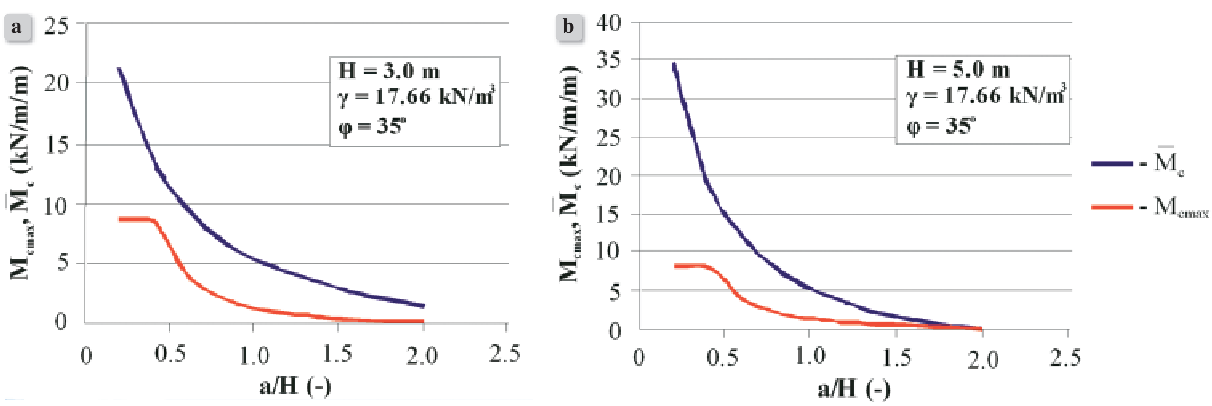

Figure 5.
Values M_{cmax} and $\overline{M}_c$ for wall height: a) H=3.0 m; b) H=5.0 m

The maximum value of bending moment (M_{cmax}) is the maximum value calculated for a wall characterized by no longitudinal rigidity. Usually, retaining walls are characterized by significant longitudinal rigidity and the distribution of bending moments is remarkably different from the distribution presented in Figure 4.

The compaction-induced bending moment of wall-plate connection calculated according to Canadian engineering recommendation, marked as $\overline{M}$ is:

$$\overline{M}_c = \int_0^d (\overline{\sigma}_h - \gamma \; zK_a)(H - z)dz \qquad (7)$$

Figure 5 presents the maximum values of bending moment calculated from equation (6) marked as M_{cmax} as well as the values calculated from equation (7) marked as $\overline{M}_c$.

The values of bending moments decrease rapidly with the increase of the compactor-wall distance (a). The values $\overline{M}_c$ are remarkably higher than M_{cmax} especially for a/H ≤ 0.4.

Engineering practice usually employs simplifications. Due to the rigidity of wall structure a median value of bending moment (M_c*) at the (L*) length of the wall-plate connection (Fig. 6) induced by compacting is:

$$M^*_c = \frac{1}{L^*}\int_{-\frac{L^*}{2}}^{\frac{L^*}{2}} M_c dy \qquad (8)$$

where L* = L + 2H.

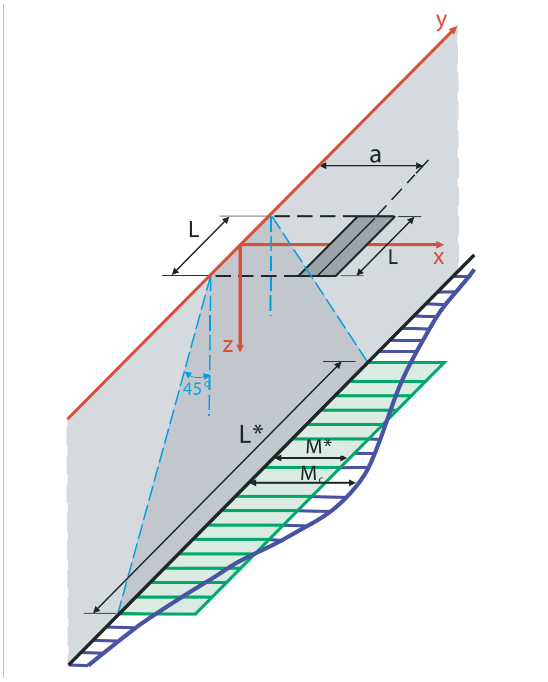

Figure 6.
Median compaction-induced bending moment of wall-plate connection

The total bending moment of wall-plate connection (M_t) is the sum of the moment resulting from the active soil pressure (M_γ) and the moment resulting from compaction (M_c).

$$M_t = M_\gamma + M_c \qquad (9)$$

where

$$M_\gamma = \frac{1}{6}\gamma K_a H^3 \qquad (10)$$

where $M_c = M^*_c$ or $M_c = \overline{M}_c$ or according to the author's proposal (8), or in line with the Canadian Engineering Society respectively (7).

Table 2.
Value of coefficient α* and $\overline{\alpha}$

Type of compactor	Wall high (H)	Distance from wall (a/H)	Coefficient	
			α*	$\overline{\alpha}$
	m	-	-	-
VMS 71	3	0.2	0.393	0.998
		0.4	0.393	0.636
		0.6	0.191	0.446
		0.8	0.102	0.330
		1.0	0.059	0.252
		1.5	0.018	0.134
		2.0	0.007	0.069
	4	0.2	0.161	0.579
		0.4	0.161	0.342
		0.6	0.077	0.226
		0.8	0.041	0.158
		1.0	0.023	0.113
		1.5	0.007	0.047
		2.0	0.003	0.012
	5	0.2	0.081	0.346
		0.4	0.081	0.191
		0.6	0.039	0.120
		0.8	0.020	0.078
		1.0	0.012	0.052
		1.5	0.004	0.013
		2.0	0.001	0.000
CC 1000	3	0.2	0.847	1.439
		0.4	0.847	0.995
		0.6	0.411	0.741
		0.8	0.220	0.576
		1.0	0.126	0.461
		1.5	0.039	0.283
		2.0	0.015	0.182
	4	0.2	0.346	0.956
		0.4	0.346	0.617
		0.6	0.167	0.438
		0.8	0.089	0.327
		1.0	0.050	0.251
		1.5	0.015	0.138
		2.0	0.006	0.075
	5	0.2	0.174	0.613
		0.4	0.174	0.374
		0.6	0.083	0.254
		0.8	0.044	0.182
		1.0	0.025	0.134
		1.5	0.008	0.064
		2.0	0.003	0.025

Relative increase of the compaction-induced bending moment of wall-plate connection may be represented by the following coefficient:

$$\alpha = \frac{M_c}{M_\gamma} \qquad (11)$$

The value of coefficient α calculated according to the Canadian Geotechnical Society [1] will be marked as:

$$\overline{\alpha} = \frac{\overline{M}_c}{M_\gamma} \tag{12}$$

while the same value calculated according to the author's analysis is marked as

$$\alpha^* = \frac{M^*_c}{M_\gamma} \tag{13}$$

The values of α^* and $\overline{\alpha}$ calculated for a wall height H = 3, 4, 5 m and low-moisture medium sand backfill of relative density I_D = 0.7 compacted by VMS 71 compactor are shown in Table 2.

The values γ = 17.66 kN/m^3 and φ = 35° have been assumed according to the PN-81/B-03020 [2] standard. The $\overline{\alpha}$ values are markedly higher than the α^* values.

According to Eurocode 7 [3.4], pressure must be considered as a permanent action, whereas the compaction effort – as an accidental action.

REFERENCES

[1] Canadian Foundation Engineering Manual, Canadian Geotechnical Society, 2006

[2] PN–81/B–03020 Grunty budowlane. Posadowienie bezpośrednie budowli. Obliczenia statyczne i projektowanie (Building soils. Foundation bases. Static calculation and design)

[3] Eurocode 7. Geotechnical design – Part 1. General rules

[4] *Bond A., Harris A.*; Decoding Eurocode 7. Taylor and Francis Group, New York, 2009