LOADING-DEFORMATION COUPLING IN REPUTE

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Introduction

Pile-soil interaction is a three-dimensional problem, and each of the load components has deformation-coupling effects, i.e. axial loading induces lateral movements as well as axial movements.

The aim of this technical note is to illustrate the interaction between axial and lateral response in pile-group behaviour by means of a comparison between numerical analyses, including the software Repute (Bond & Basile, 2007).

Repute analysis

Repute is a software for the analysis and design of pile groups subjected to any combination of vertical loads, horizontal loads and moments. Repute's calculation engine, called PGROUPN (Basile, 1999, 2003), is based on a complete boundary-element (BEM) formulation which makes use of the fundamental solution of Mindlin (1936) to relate the stress and deformation fields within the soil.

With reference to the present problem, Mindlin's solution provides expressions to calculate the vertical (w) and horizontal (u) movements at any point within the soil continuum due to a vertical point load (V) acting at any other point of the continuum, as depicted in Figure 1. As a consequence, a vertical load acting (with no eccentricity) on a group of piles will generate horizontal movements of soil around piles (as well as vertical movements). This will produce lateral pressures on the surface of the piles, and therefore horizontal forces and bending moments on the piles.

It is worth noting that such interaction effects between the axial and lateral response of piles are neglected by other computer programs for pile-group analysis, generally based on the interaction-factor method (e.g. PIGLET by Randolph, 2000, and DEFPIG by Poulos, 1990) or the load-transfer approach (e.g. GROUP by Reese *et al*., 2000).

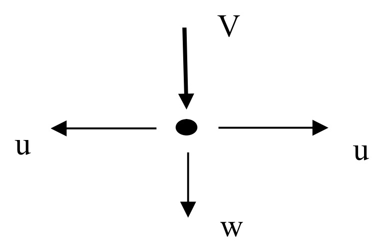

Figure 1: Load-movement effect in Mindlin's solution

Pile group under general loading conditions

In order to illustrate the loading-deformation coupling effect, the deformations and load distribution in a 3-pile group under a combination of vertical load, horizontal load and moment are examined (refer to Figure 2). Results from alternative numerical analyses are compared in Table 1 showing the loads taken by each pile head, the vertical head displacement of pile 3 (w_3), the horizontal cap displacement (u) and the rotation (θ) of the cap.

Regarding the resulting horizontal load distribution at the pile heads, all numerical analyses (DEFPIG, PIGLET, GEPAN, and Repute) predict that the central pile (pile 2) takes the smallest load as a consequence of group effects, as expected. However, it is worth noting that only the more rigorous GEPAN (Xu & Poulos, 2000) and Repute analyses, both based on a complete BEM solution, are also able to consider the loading-deformation coupling effects, thereby predicting a higher horizontal load on pile 3 than on pile 1. This is because the applied vertical load (V) acting at the cap centre will also produce outwards horizontal movements on piles 1 and 3 (as well as vertical movements), following the pattern of Fig. 1. Consequently the resulting horizontal load at the pile heads will be increased for pile 3 and decreased for pile 1.

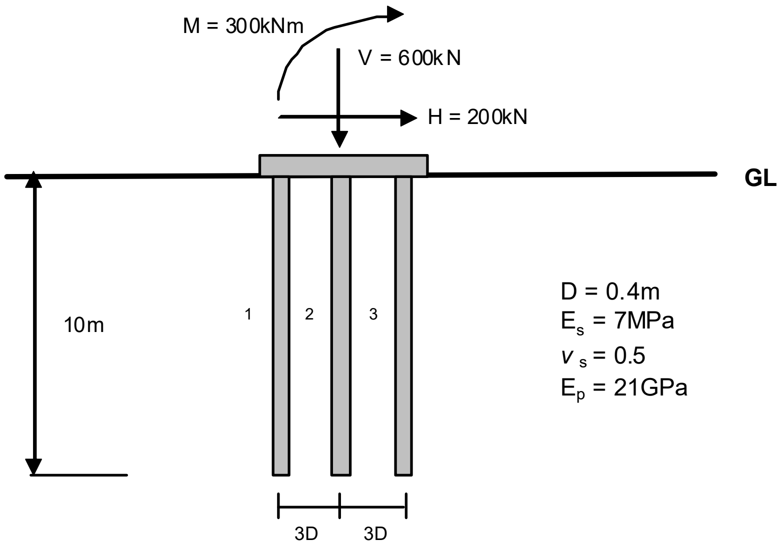

Figure 2. Group of 3 piles under general loading conditions

Table 1. Comparison of results

Quantity	Equivalent-bent analysis	DEFPIG	PIGLET	GEPAN	Repute
V_1 (kN)	67.2	55.8	55.7	54.0	49.6
V_2 (kN)	200.0	155.1	155.0	156.0	153.0
V_3 (kN)	332.8	389.1	389.3	390.0	397.0
H_1 (kN)	66.8	72.0	80.4	73.7	68.9
H_2 (kN)	66.7	56.0	39.3	50.9	53.5
H_3 (kN)	66.6	72.0	80.4	75.4	77.6
M_1 (kNm)	-6.2	-35.8	-42.0	-38.5	-41.5
M_2 (kNm)	-6.2	-28.5	-16.3	-26.1	-31.8
M_3 (kNm)	-6.2	-35.8	-42.0	-38.6	-44.0
w_3 (mm)	17.5	13.4	9.9	10.8	14.1
u (mm)	8.9	11.6	11.4	10.5	11.5
θ (rad)	0.00581	0.00242	0.00242	0.00241	0.00263

Comparison with field test data by Koizumi & Ito (1967)

Koizumi & Ito (1967) reported the results of a full-scale field test on a 9-pile group driven into a soft silty clay. The piles were closed end tubular steel pipes with Young's modulus of 210GPa, external diameter 300mm, wall thickness 3.2mm and a penetration depth of 5.55m. The group piles were connected by a ground-contacting rigid cap and were arranged in a 3×3 configuration with centre-to-centre spacing of 900mm. The undrained shear strength of the clay increased linearly with depth, about 25kPa at the foundation level and 40kPa at the pile base. Other soil parameters adopted in the Repute analyses are an Es/Cu correlation of 800 for the Young's modulus, a Poisson's ratio of 0.5 and an adhesion factor (α) of 0.9, while the hyperbolic curve fitting constants have been assumed to be 0.75 for the shaft and 0.99 for the base.

Figure 3 shows a favourable agreement between the computed and measured load-settlement behaviour of the pile group. It should be observed that Koizumi & Ito report that, at an applied load of 143ton, a considerable amount of settlement occurs and a sudden increase in the soil reaction at the bottom of the pile cap takes place. However, the influence of the ground-contacting cap cannot currrently be modelled in the Repute analysis and this might explain the differences between measured and predicted values at high load levels.

The lateral pressures acting on the inside face of the pile at the mid-side of the group are shown in Fig. 4, for different values of the applied vertical load. A favourable agreement between the values measured with earth pressure cells and those predicted by Repute is found.

Figures 5 and 6 show the distribution of shear forces and bending moments on the same pile as predicted by Repute. No measured values are provided by Koizumi & Ito. However, it is reasonable to expect that the agreement between "real" and predicted values is favourable (and similar to that shown for the lateral pressures) given that the shear forces and bending moments are derived by integrating the lateral pressures over the pile surface.

References

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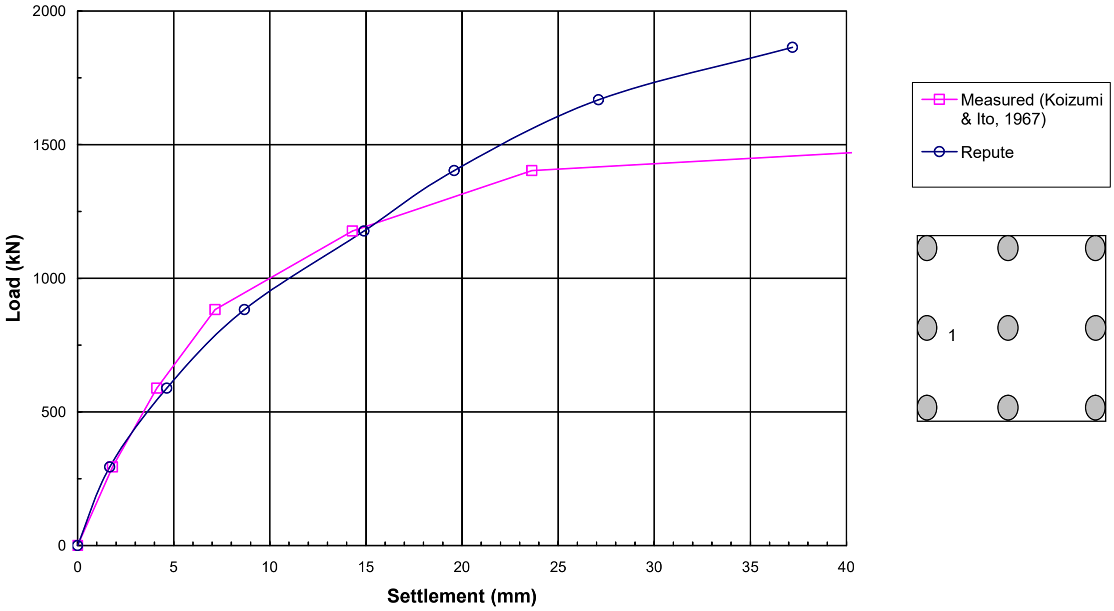

Figure 3: Load-settlement behaviour of 9-pile group

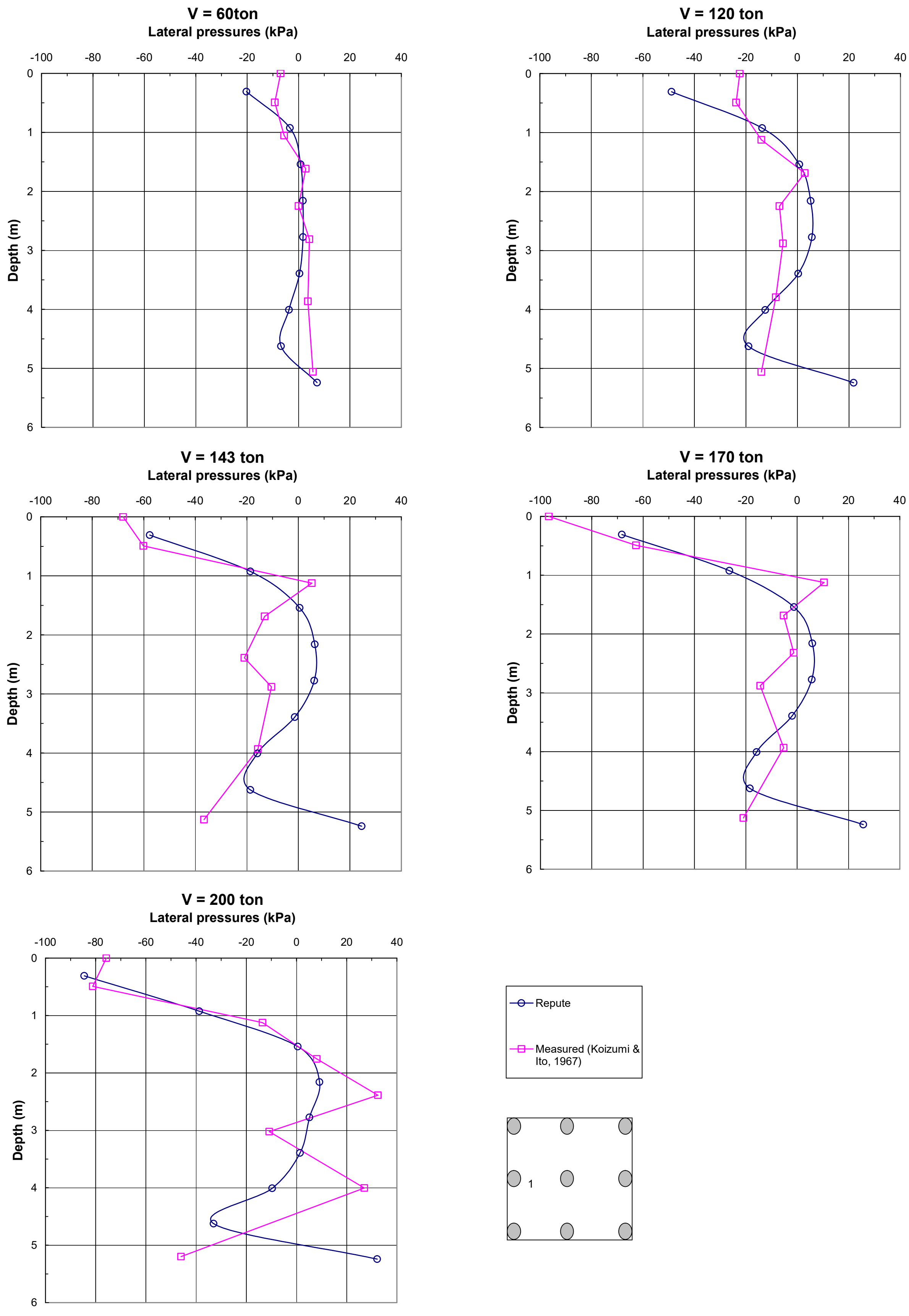

Figure 4: Lateral pressures on Pile No. 1 of 9-pile group

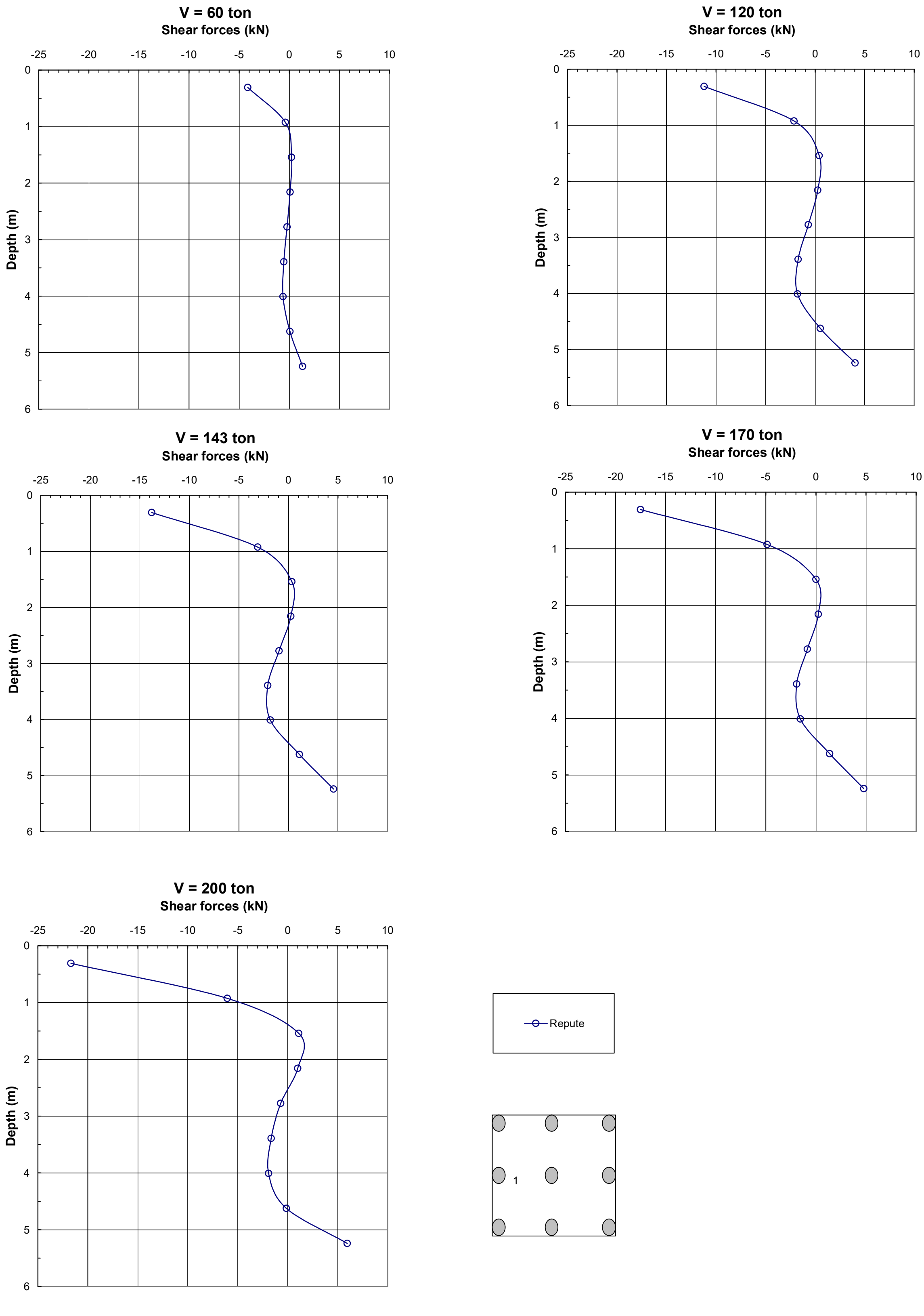

Figure 5: Shear forces on Pile No. 1 of 9-pile group

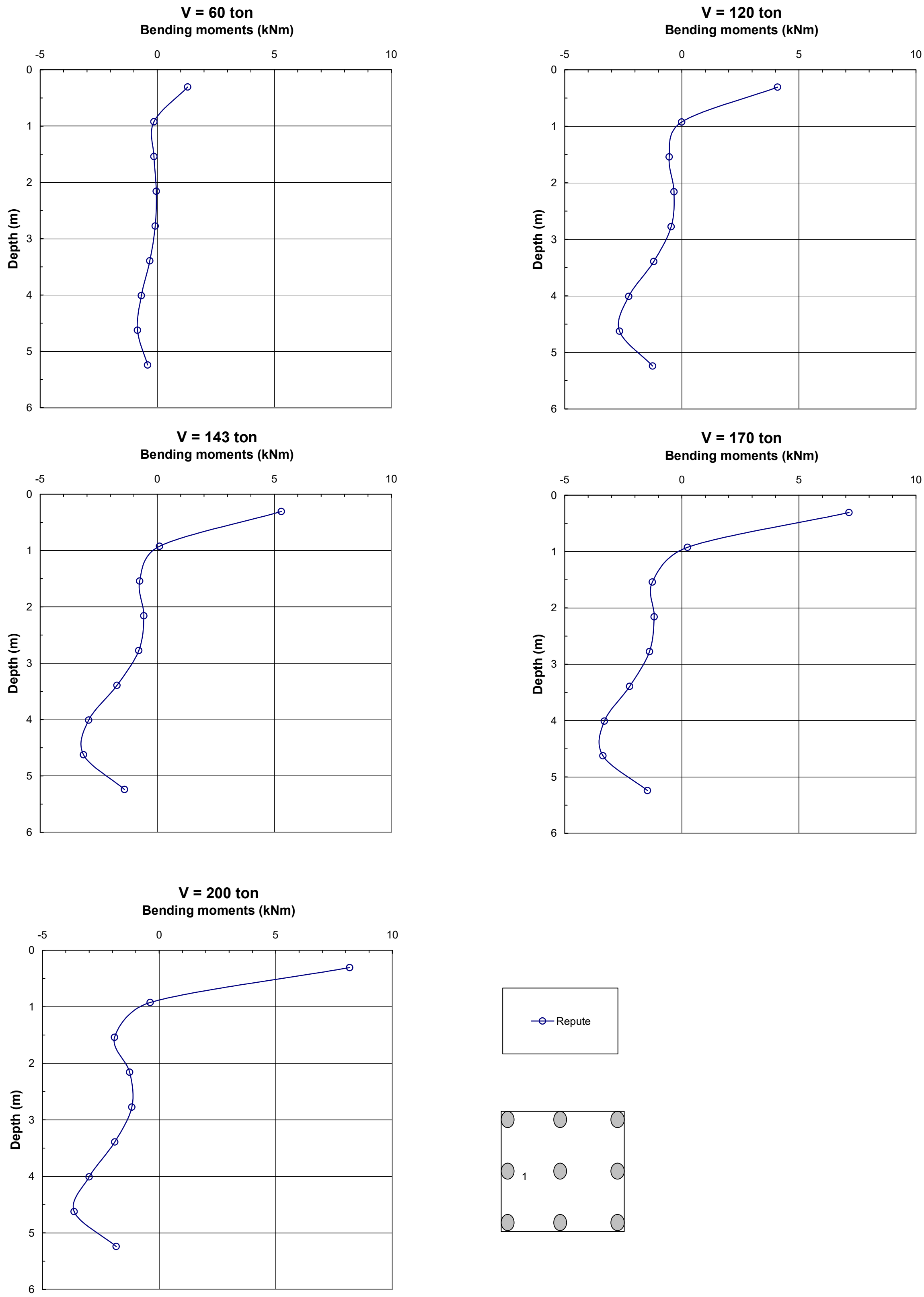

Figure 6: Bending moments on Pile No. 1 of 9-pile group