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REINFORCED GRANULAR BED OVERLYING PILES IN WEAK GROUND

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1. ABSTRACT

A reinforced granular bed (RGB) over piles in weak ground is suitable in subsiding environment. It can deform in accordance with that of the subsiding ground and behave as a semi-rigid piled-raft system (SRPRS). In the case of RGB on weak ground, the reinforcements in the fill help to improve its stiffness and shearing resistance. Settlements are also reduced. In case of RGB over piles in weak ground, the piles help to further improve the load carrying capacity and reduce the settlements.

The performance of RGB over floating piles is being studied from both laboratory-scale model tests and full-scale field tests. The relevance of RGB and RGB over piles in poor ground conditions in the Dakshina Kannada district of coastal Karnataka in peninsular India is also being looked into.

2. INTRODUCTION

A rigid piled-raft system (RPRS) is commonly used as foundation for light and medium structures in clays and other weak grounds. However, it is practically well suited in non-subsiding grounds, for e.g. in stiff clays. In soft subsiding grounds, a gap could be left between the bottom of the raft (or the cap) and the subsiding ground, which will unduly load the piles excessively. For e.g., in the case of cross-drainage (CD) works such as sluiceways built on end-bearing piles across highway embankments on soft Ariake clay in the Saga Plain in Japan, cavities are found to be formed beneath sluiceways, as also cracking of embankment near the shoulders. The embankment load causes the soft soil to settle while the piled foundation prevents the downward movement of the sluiceway, thus creating a void. The cracking of the embankment near its shoulders arises from the large differential settlements. To alleviate this problem a reinforced granular bed (RGB) over piles in weak ground which is particularly well suited for consolidating or subsiding grounds and soft clays is therefore recommended.

A RGB over piles in weak ground has the stiffness to transfer the loads to the piles and at the same time has the flexibility to deform in accordance with the subsiding ground unlike a RPRS, thereby not loading the piles unduly excessively. In addition, replacing the end bearing piles with floating piles makes the foundation consistent and compatible with the soft soil and the sluiceway deformations (2). Therefore in this study, a RGB over piles in weak ground with a densely reinforced granular bed, is envisaged to behave as a semi-rigid piled-raft system (SRPRS).

Placing the polymer geogrid reinforcements in one or more layers in the granular fill has been found to be more effective than placing the reinforcements at the interface in which case it acts more as a separator. The granular soils in the fill develop good shearing resistance with the reinforcement. Reinforcements in the fill improve its stiffness. Many parametric studies are available in literature with the RGB overlying sands. With the soft soil underneath, the settlements will be considerably larger and hence the soil-reinforcement interaction in the RGB overlying soft and weak soils will also be more intense.

3. LABORATORY SCALE MODEL TESTS

Laboratory-scale model tests were performed with (a) RPRS in clay and (b) model footings resting on unreinforced and reinforced granular fill overlying reconstituted Ariake clay with or without floating piles. The detailed testing procedure and results are discussed elsewhere (3). Figure 1 shows a typical experimental set-up. Two series of tests were conducted. In Series I tests, the reconstituted Ariake clay had an undrained cohesive strength of 5 kPa and the overlying well-graded angular sand had a relative density of 50 % corresponding to a dry unit weight of 15 KN/m^3. In Series II tests, the undrained cohesive strength of clay was 2.75 kPa and the overlying sand had a relative density of 60 % corresponding to a dry unit weight of 16 KN/m^3. The test results indicated that efficiency of RGB over piles in clay (RGBPC) is comparable with that of RPRS in clay. The improvement in bearing capacity was quantified in terms of the Bearing Capacity Ratio or the BCR.

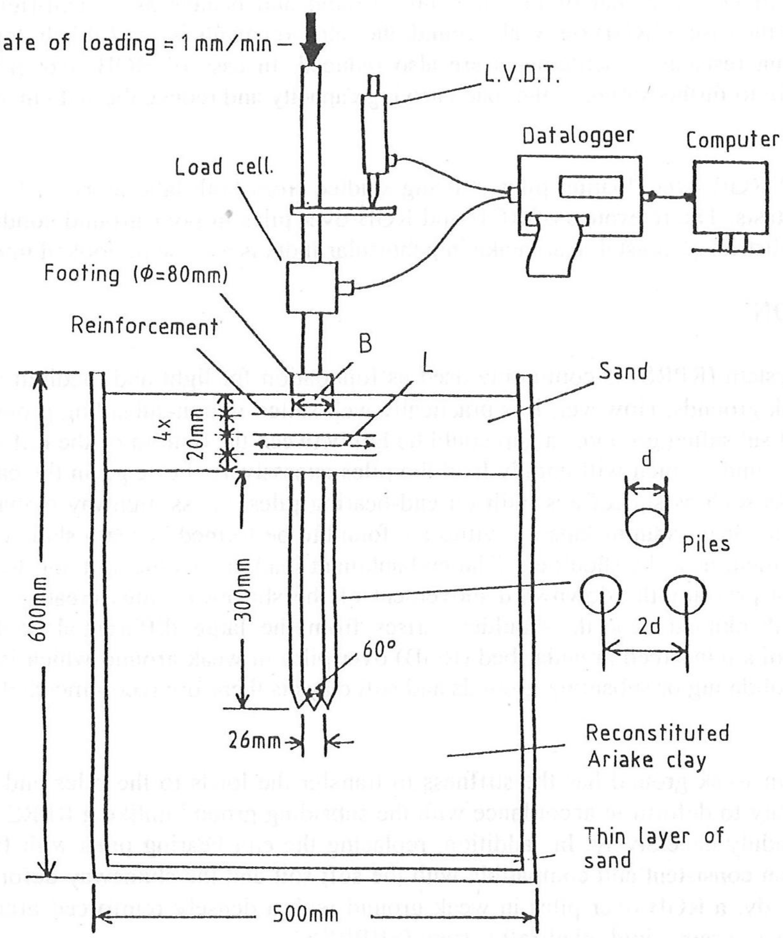

Figure 1. Typical Laboratory-scale Experimental set-up

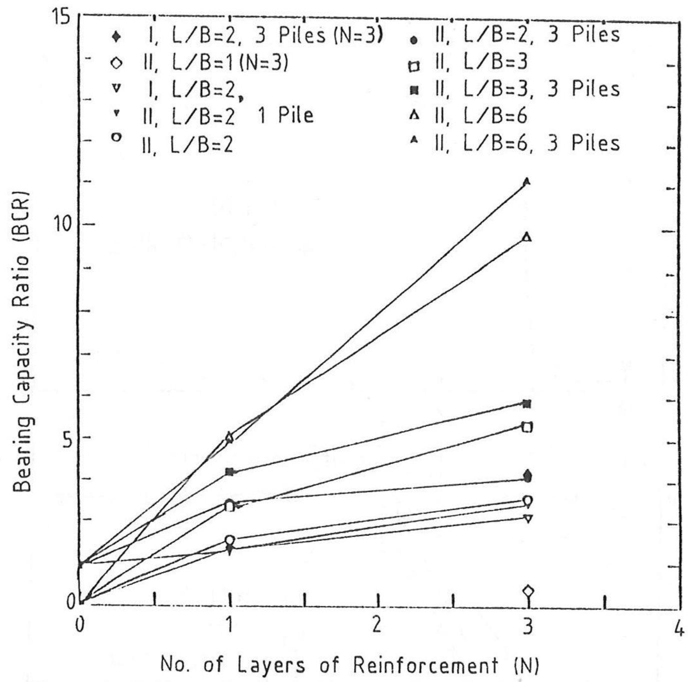

Figure 2. Effect of L/B and N on BCR (Series I and II tests)

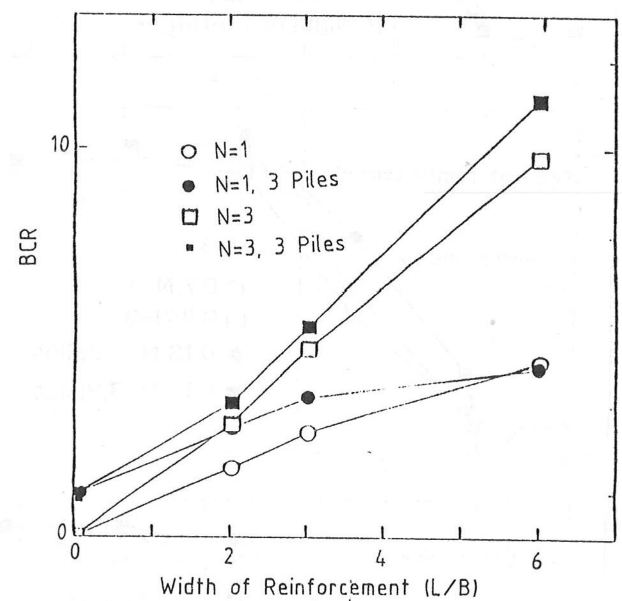

Figure 3. L/B vs. BCR (Series II tests)

From the laboratory-scale model tests, the effect of reinforcement was found to be more predominant than the effect of the pile (Fig. 2). This is because the model piles used had a very low bearing capacity compared to the prototype piles, owing to the scale effect. However, in actual practice, the contributions from both the pile effect and reinforcement effects could be substantial and maybe that the pile effect could be more predominant. From earlier studies (RGB on sands), the optimum value of the width of reinforcement (L) has been found to be around 2 to 2.5 times the width of the footing (B). However, from the results of this study, indications are that this optimum value of L could be much higher, larger than 6, especially if the RGB overlying clays is densely reinforced (Fig. 3).

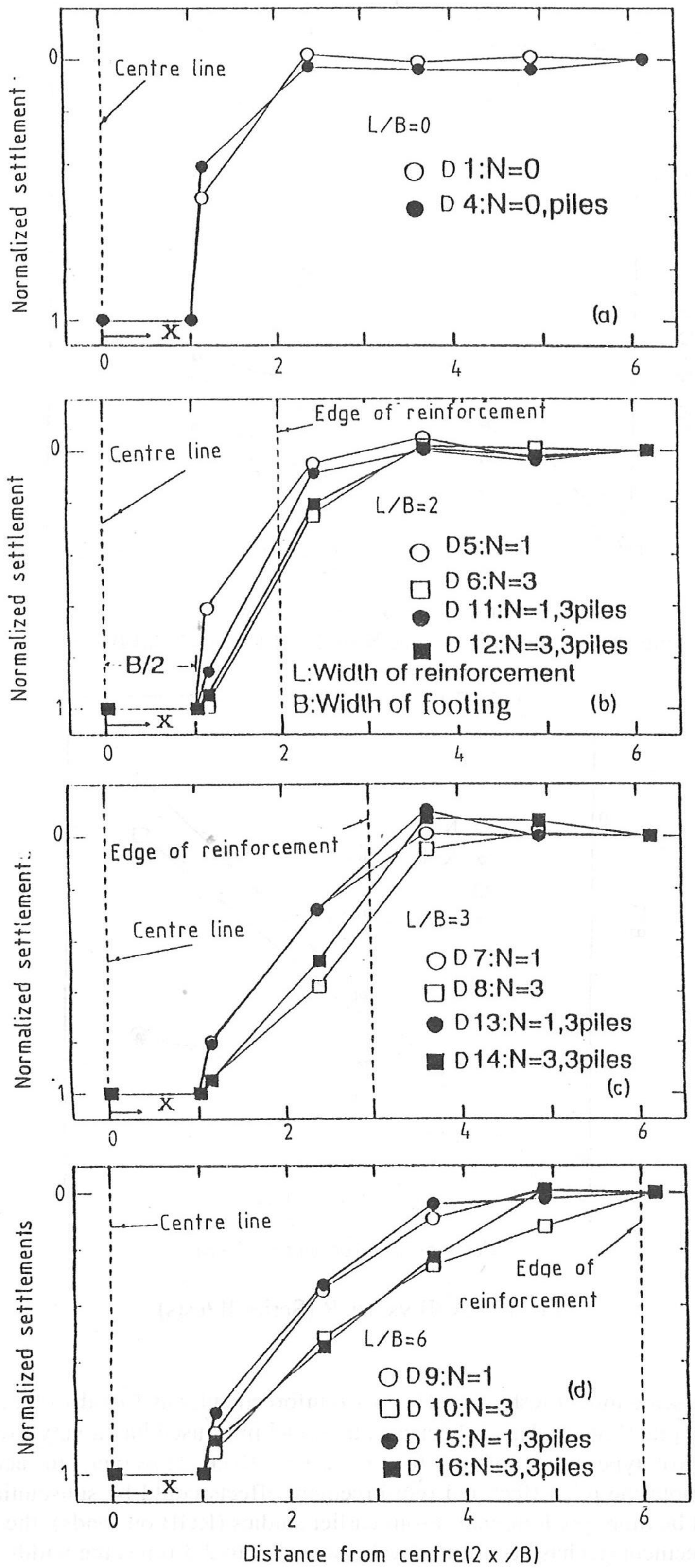

Figure 4. Settlement Profiles at Clay-Granular Fill Interface after the Test

From settlement observations, it was observed that greater the width (diameter) of the reinforcement, larger would be the diameter of the crater (at the interface) as also smoother i.e., the settlements would be smaller and spread over a larger area. The diameter of the crater was found to be larger than the width of reinforcement for L/B values of 1, 2 and 3. The settlement profiles obtained in this study for both the cases i.e. RGB and RGBPC (with piles only directly beneath the footing) were found to be nearly the same (Fig. 4). In Figure 4, all the tests i.e., D1, D4 to D16 are Series II tests with varying L/B ratios and number of layers of reinforcements (N) as indicated therein. Tests D4 and D11 to D16 had three piles in the reconstituted Ariake clay.

4. FULL SCALE TESTS

The performance of two design alternatives for sluiceway foundations in Saga (1) were studied from full- scale tests at site.

Design alternative (A) [Fig. 5a] used timber piles of length 8 m at a spacing of 1.5 m in a square grid pattern. The raft on top of piles consisted of a 1.5 m thick granular fill in which two layers of geogrid reinforcement were provided. Initial camber at the centre was 30 cm.

Design alternative (B) [Fig. 5b] had piles by the Dry Jet Mixing (DJM) method in which the in-situ soil was mixed with cement in dry powder form. The DJM piles were 1.0 m in diameter and 7.5 m long. They were spaced at 1.6 m in a square arrangement. The improvement ratio defined as the area covered by the DJM piles to that of the treated ground, was 30%. A reinforced granular layer 0.6 m thick with a single layer of polymer grid laid over the DJM piles. The camber provided was 20 cm at the centre in this case.

The sluiceways were made flexible by constructing in the form of blocks and connecting them by flexible and multilayer rubber joints respectively for the two designs. Settlement of the untreated ground due to 4 m high embankment was estimated to be about 190 cm. The estimated settlements for design alternatives A and B were 80 cm and 50 cm respectively. The settlements at the end of one year are about 72 cm and 36 cm for the two alternatives [Fig. 6]. Fitting a hyperbolic plot to the observed time-settlement curves, the final settlements were estimated to become 96 cm and 61 cm, respectively, which are about 20% larger than the predicted ones. The sluiceways appear to deform and take the profile of the ground underneath after settlement [Fig. 7].

5. Relevance of RGB on piles in weak grounds in Dakshina Kannada district of coastal Karnataka in peninsular India.

RGB on piles in weak soils is also relevant for infrastructure constructions (light to medium structures) in and around the Mangalore City. Due to rapid urbanisation and paucity of good sites, lowlying and marshy agricultural lands are being fast converted into estates by filling up 3 to 5 m with the locally available poor silty soil called locally as the 'Shedi' soil. Structures built on such fills are likely to undergo large total and differential settlements. Similarly, a number of large diameter oil storage tanks, 20 to 25 m, are coming up in lowlying areas with Shedi soil outcrop having low bearing capacity, especially at the Mangalore Refineries and Petrochemicals (MRPL) site. Usually these tanks rest on merely a sand pad foundation and are likely to undergo considerable settlements. A good solution for foundations in such a case would be provide granular (stone) columns, with or without geotextile-geogrid skirting, with RGB over it. This will provide an improved ground or a ground with improved bearing capacity.

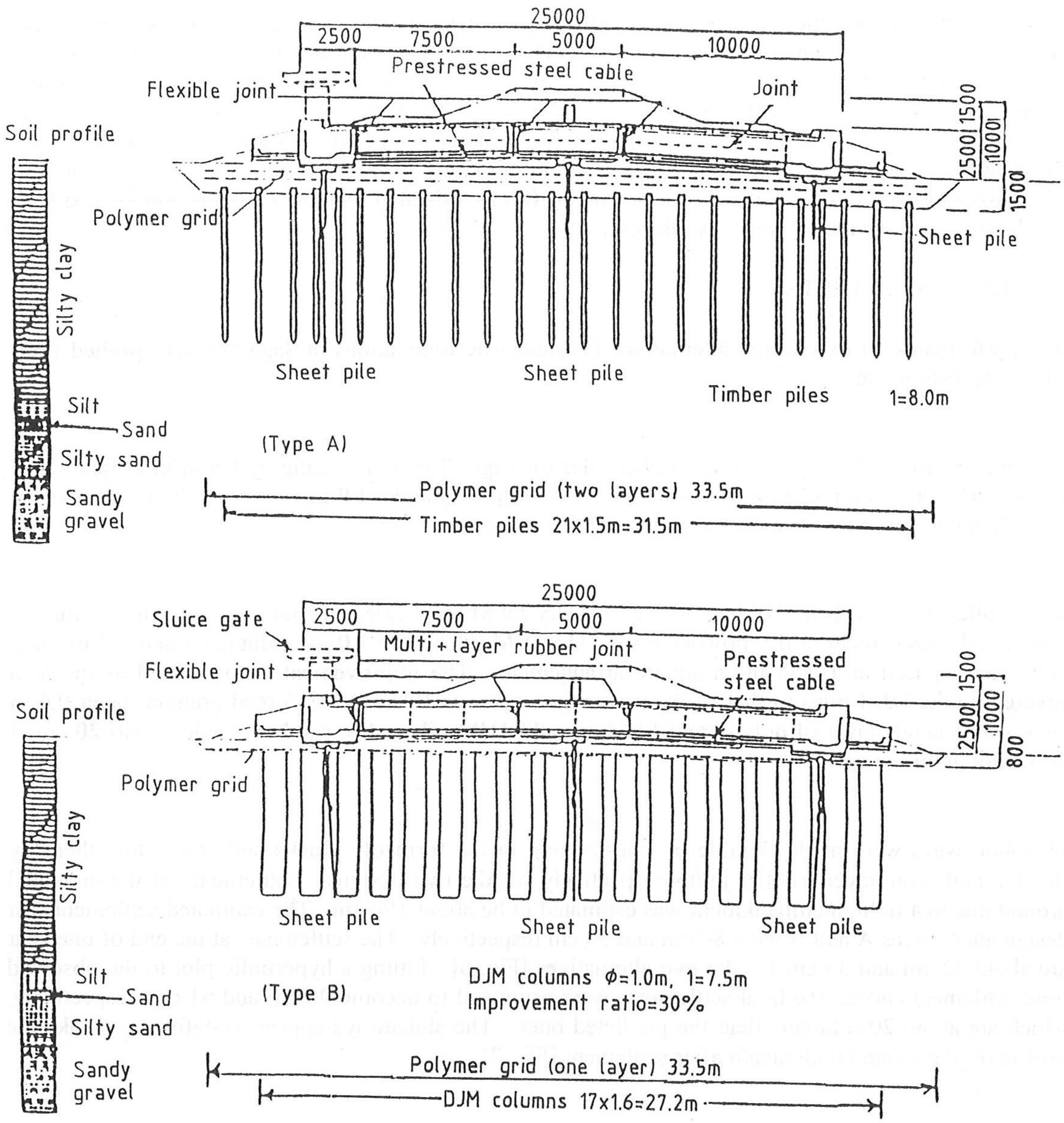

Figure 5. (a) Design Alternative A of Full-Scale Field Test
(b) Design Alternative B

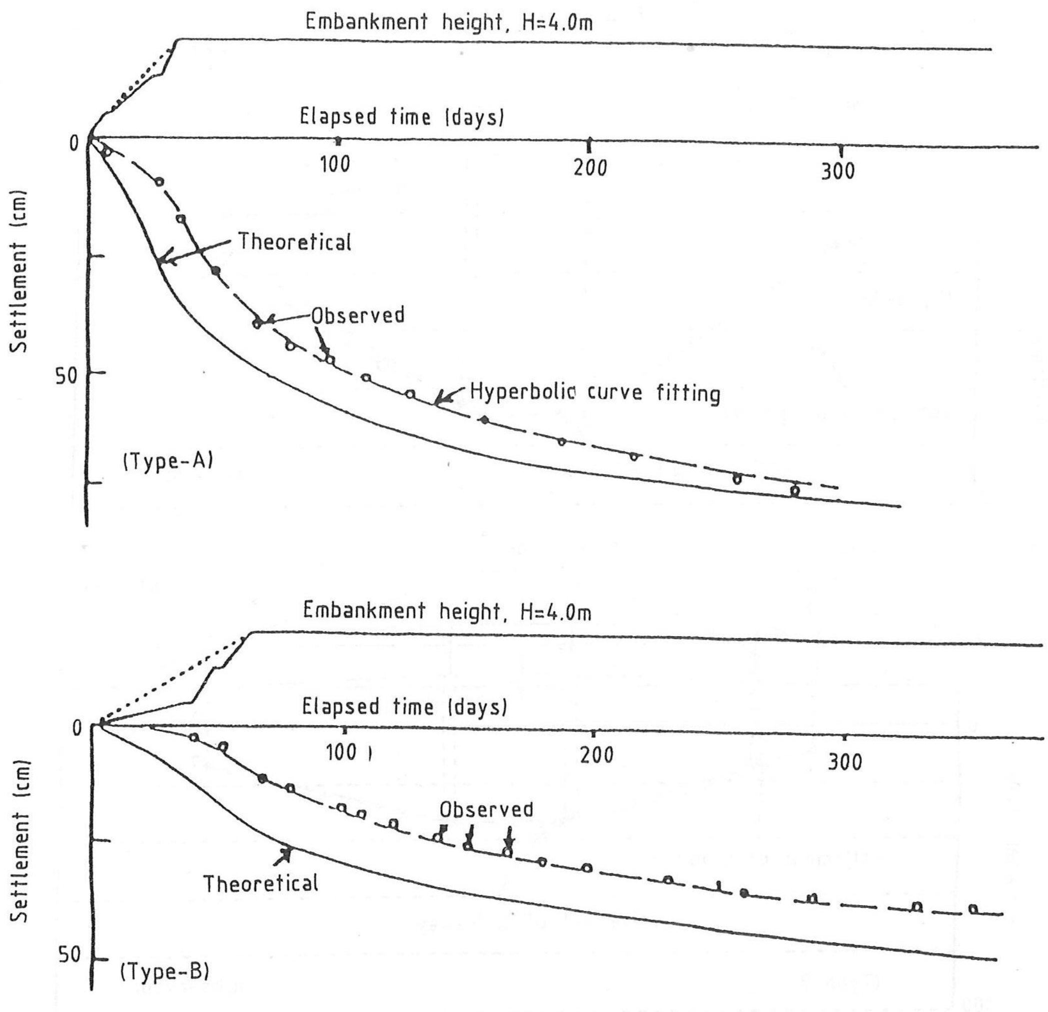

Figure 6. Observed and Predicted Settlements with Time

6. CONCLUSIONS

RGBPC behaves similar to a piled-raft in clay. Geogrid reinforced granular fill rafts function as flexible plates transmitting loads to the piles and at the same time deforming with the ground so that part of the load is transmitted to the soil directly (soil between the piles). The whole system with the piles could be said to behave as a SRPRS, which is very suitable in soft grounds.

A RGBPC is very effective in improving the load carrying capacity and reducing the settlements of the clay. The presence of piles in the clay will improve the stiffness of the system significantly. Reinforcements in the granular fill, on the other hand, help to improve the BCR significantly and also allow for larger settlements of the footing.

Both the design alternatives, discussed under full scale field tests, gave far less settlements than embankments resting on untreated ground. The sluiceways were also found to deform in conformity with the ground deformation.

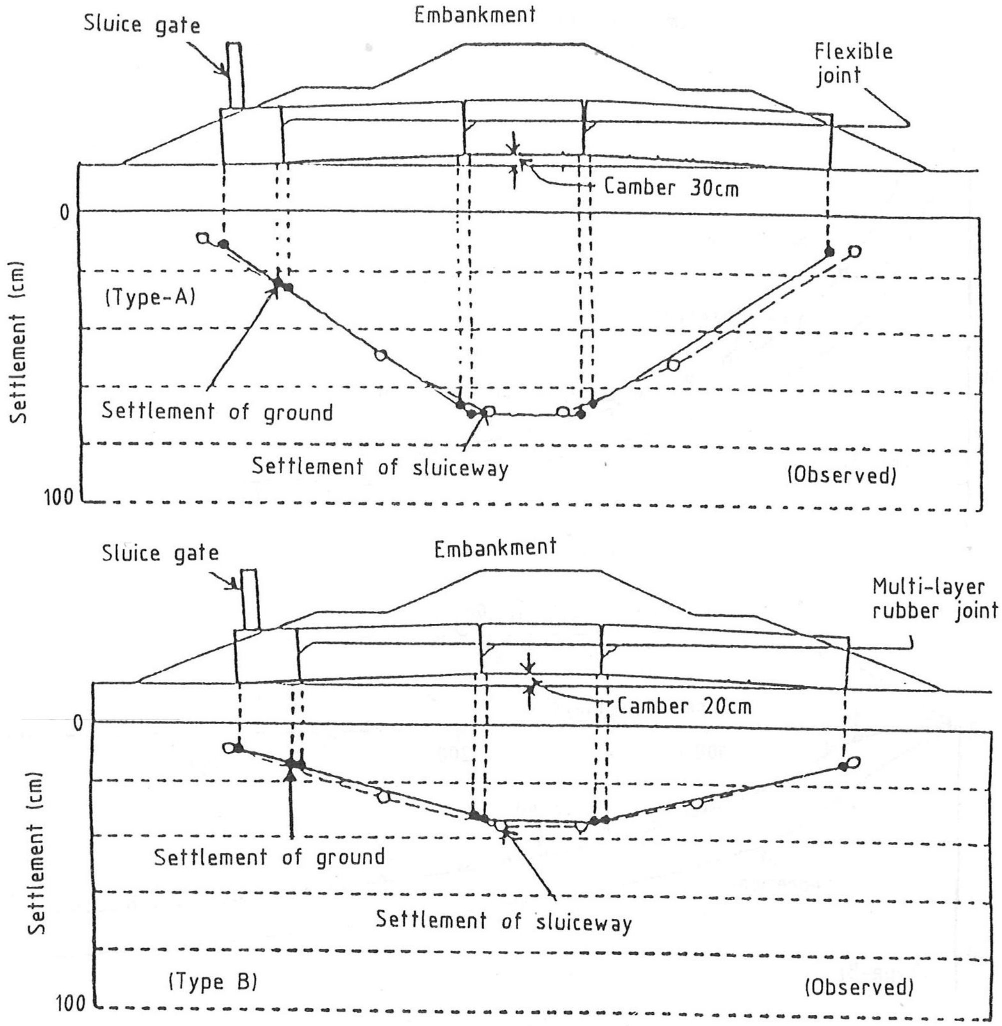

Figure 7. Settlement Profiles of the Sluiceways and the Ground Underneath

7. REFERENCES

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