A review on the effective use of Artificial Intelligence for the analysis of cyclic loading on pile foundation

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Abstract

A competent alternative approach to the conventional modelling techniques is artificial intelligence (AI). AI is about the computer science division that creates human intelligence machines and applications. AI-based solutions are great substitute where research is not feasible to evaluate engineering design parameters and therefore contribute to substantial human-time and effort savings in experiments. AI can also speed up the decision-making process, minimize errors and improve performance. AI can also make the decision-making process faster, reduce error rates and improve computing efficiency. Reinforced pile embankment is a useful technique used in soft soil construction, because of its advantages in reducing settlement, building time, and economic efficiency. The response of deep bottoms subjected to a uniform static surcharge was considered in most of the existing research. Very few researchers have studied the cyclical load effect or the effect of variation in depth. An experimental analysis was carried out on the impact of cyclical loading at a specific area of unreinforced and reinforced embankment of differing heights. During the initial stages of cyclical loading, soil arching, regardless of the height of the embankment, was adversely affected. However, the arching of the soil started to improve somewhat by increasing the number of cycles. The magnitude of the loads transferred to piles was increased by the reinforcement layers. But for a thinner embankment, the improvement was more obvious. The main purpose of this report is to identify the AI techniques that can be used to analyze the behaviors of pile foundation undergoing cyclic loading by making models which will help in testing different kinds of failure patterns and the solutions with which these problems can be mitigated.

1. Introduction

For structural engineers, the building of embankments on soft ground is challenging due to the possibility of failure, unwarranted settlement, and soil instability. Reinforced piles embankments offer cost-effective solution to these issues, which are often desirable to other methods like preloading, vertical drainage, and grouting[1]. A broad scope of engineering structures uses reinforced piled embankments such as roads, bridges construction, railways construction, and underground structures[1]. With the incorporation of geosynthetic pile reinforcement within and under the terrain, bearing capacity is significantly increased, differential and total settlements decreased, and construction delayed reduced. Both the arching process in the filling materials and the reinforcement layers' layer effects can cause loads to be transferred to reinforced piled embankments. The mass of the embankment soil over the compressible soil tends to move downward as the stiffness of the pile foundation exceeds the stiffness of the bearing soil, which partly countered by the shear resistance along the columns above the piles of the soil, which
reduces the soil arching mechanism's pressure on the soil. Due to the resulting membrane effect, the load transfer to the piles is enhanced by inserting layers of geosynthetic reinforcement into the soil.

The various challenges which are faced during the construction of embankment on soft ground are bearing failure, excessive settlement, and ground instability. reinforced pile embankment provides a valuable solution for this problem. Highways, bridges, railways, and underground structures are various engineering structures in which reinforced piles are used. By using geosynthetic strengthening with piles in and beneath the ground, the carrying capacity increases significantly, the total and differential settlements are reduced, and delay in construction reduced[2]. “There are several design approaches to inspect the performance of reinforced piled embankments such as Terzaghi [3]; Guido [26]; Hewlett and Randolph [28]; Low et al.[2]; BS 8006 [27]; Russell and Pierpoint [29]; Love and Milligan [4]; Russell et al.[5]; Abusharar et al. [6]; BS 8006 [27]; EBGEO [30]; Van Eekelen et al. [7], [8]. The arching mechanism that occurs from the reinforcement layers in the filling material and membrane effect may transfer load on the reinforced pile reinforcements [1].”

As the rigidity of piles goes beyond the rigidity of the soil, the mass of the embankment ground above the unconsolidated ground appears to be lowered, and which is partly counteracted by resistance due to shear in the soil columns above the piles. Soil arching is the mechanism that is responsible for reduce in the pressure on soil [1]. Most of the experimental analytical and numerical investigations is studied the behavior and the load transfer mechanism off the piled embankment with or without reinforcement layer. Reported that the height of the reinforced and nonreinforced pile embankment has an important effect on its behavior. “In this study it is seen that all the previous studies by Han and Gabr[9]; Murugesan and Rajagopal [10]; Yun-min et al.[11]; Deb and Mohapatra [12]; Jenck et al. [31]; Le Hello and Villard [13]; Zhao et al. [14] Under static loading conditions, the effect of embankment height has been investigated. The settlement of the embankment had also been examined under uniform load e.g., excess pressure and/or a uniform overload on the whole embankment surface. However, applying external load on an embankment area may lead to various non-researched deformation patterns [1].”

The studies by. Van Eekelen et al. [1] and Heitz et al. [15] tells us about the relation of soil arching the traffic or cyclic load and the height of embankment, as the cyclic load goes on increasing and the embankment height also increased the soil arching effect degrades but these studies were carried out on whole area which is not practically accepted . Also, the soft soil has not been examined in this study for pressure and deformation. The effect on the distribution of stress in granular soil was studied by repeating active and passive arching in succession by using a trap door test setup.by Aqoub et al [16]. A quantitative laboratory analysis of reinforced and unreinforced pile foundation with varying height & layers of reinforcement has been carried out under different cyclic loads in the K. Aqoub study. The term “AI ”was first coined in 1956 at Dartmouth college [17]. AI’s an effort to mimic the potential of human perception by using symbols and symptom-structured information to overcome engineering issues by traditional approaches. AI was built based on the interface between different disciplines, including informatics, knowledge theory, cybernetics, linguistics, and neurophysiology. It’s a method of
Computation that tries to mimic manipulation of human intellect through symbolic handling and allegorically designed knowledge to overcome engineering challenges by using conventional methods. Built on the interface between different fields, information theory, computer science, cybernetics, neurophysiology and linguistics, AI has been established.

In the literature there are several terms that relate to artificial intelligence, and they’ve been further identified and explained in a state-of-the-art manner. Machine intelligence is a part of that (MI). The cognitive functions of humans can be imitated by a machine to perform work in a smart way that mimics human thinking and reasoning, cognitive systems can solve problems. These techniques are centered on the capacity of systems to assess, reason, and adjust to the information.

One of the major advantages of artificial neural networks (ANNs) that include both shallow and deep neural networks (DNNs) is the absence of feature extraction and feature engineering, since relatively unprocessed data can be utilized to train the network directly with highly successful results. This type of problem has been addressed by classical artificial intelligence (AI), capturing the essence of human cognition at the highest possible level.

![Fig. 1. Research publications on the use of different AI branches in structural engineering [18].](image)

The analysis document is formulated as follows. Section 2 describes AI in general. In section 3 principles involved in the study and analysis of pile foundation is discussed. In section 4 experimental process and results are discussed from previous studies done on analysis of pile foundation under monotonic loading, and under cyclic loading. In addition, Section 5 identifies new research directions and use of AI methods in model analysis to reduce time & cost taken by physical experimentation. Finally, in Section 6, conclusions are made.

2. Machine learning
It is a sub-field of AI concerned with the analysis, design, and development of systems that can understand the data themselves and predict outcomes using the data analyzed by it. Machine Learning refers to machines' ability to study without being programmed directly. The predictive or descriptive models based on Machine Learning can be used to gather knowledge. Since this is an AI branch that is found in a wide variety of fields, such as computer science, information theory, mathematical complicity control, probability and economics, capital markets, and theory and philosophy [18].

PR and Machine Learning are typically closely connected, as their scale varies fundamentally. However, PR is focused on classification methods, and Machine Learning is focused on learning algorithms. The main role of PR is the recognition and classification of patterns and does not imply innate comprehension. In the other hand, Machine Learning systems are structured for self-learning. Deep Learning is often known as a subclass of Machine Learning of which the computer will learn the characteristics from the data. In reality, deep learning is a way of learning how data is perceived. The Machine Learning problem will be solved before the representation has been determined. Deep learning is converting the highly dimensional problem/representation into a smaller dimension. Machine Learning is described as supervised, unattended, or enhanced learning based on training dataset tools. Thanks to their tremendous capability to recognize relationships between input & output data, which is nonlinear or difficult to formulate mathematically, mechanical learning techniques are constantly used in last decade to model real world structural engineering difficulties. The first use of Machine Learning techniques in structural engineering answers concerns including the manufacture of structural safety control methods and the collection of information for steel part building [18].

In geotechnical engineering, the stochastic nature of soil activity has warranted extensive use of Artificial Intelligence methods, and research on both deep and shallow foundations have been carried out. Amezquita-Sánchez et al (2014). Several subjects, comprising structural system identification, structural sanitary safety, structural vibration control, structural architecture & design optimization, predictive applications, constructive engineering, and geotechnical engineering, have been studied for recent applications for ANNs in civil infrastructure.

Firstly, the analysis of seismic risk consists of studies estimating magnitude of the earthquake and the resulting local volatility. The use of Machine Learning instruments is also considered in this area for the assessment of the potential for soil liquefaction and for the prediction of lateral proliferation induced by liquefaction. Another topic is a double area in which device detection consists of a series of studies using Machine Learning to imitate a system of structure and guess its seismic response and then use Machine Learning models to find, identify & quantify civil structure seismic risk. Third, the evaluation of seismologic fragility which incorporated numerous sources of vulnerability indicates that Machine Learning approaches were used to construct PSDMs and parameterized fragility functionality. The assessment was productive and popular. The fourth concern is active and semi-active system control with Machine Learning devices, mitigating the negative impact of seismic hazards. ANN has a lot of deployments, showing its vigor in the resolution of multiple kinds of earthquake challenges.
2.1 Pattern recognition

Over the last decade, interest in structural engineering application of pattern recognition (PR) has grown for the purposes of structural health management, earthquake, design of seismic resistant structures, structural integrity, structural detection, and performance assessment. The definition reveals that SHM and damage detection in structural engineering is the major application of PR. The reverse approach, known as system recognition and the forward approach which depends on the collection of information from a tracked structure, is considered widely as two primary methods for the detection of damage. The sophistication of the calculation and the physical utility of model changes have motivated researchers to examine approaches of the second type.

Furthermore, [19] implemented an auto-regressive moving average harm model for a benchmark structure evaluation which showed that the algorithm is able to recognize and localize small to extreme harm levels. The authors have also modelled the function vectors with a Gaussian mixing model which has been combined with a time series algorithm of SHM harm detection [20]. “Time series-based damage detection and localization algorithm with application to the ASCE benchmark structure [19]. Time series based structural damage detection algorithm using Gaussian mixtures modeling[20].”

2.2 Artificial neural networks

The "shallow" ANN is typically a three-step approach, first is the input level, then the hidden level, and lastly the output level which was first created by McCulloch and his colleagues (Perlovsky, 2000). The input layer model variables are then weighed and inserted into a large layer containing several non-linear associations, such as sigmoid functions, which are further weighted and integrated into the output layer for a regression or classification model. The forward spread of link weights is learned and revised through a training mechanism, which usually reverses the estimation error. A deep neural net or DL, which has several hidden layers, may be applied to the classical ANN (LeCun et al., 2015).

The most important thing about a trained neural network is that, after the data is provided as input, the generation of output data is made very efficient and easy by multiple orders of magnitude resulting in very less effort computationally. In problem areas where computing is very intensive, such as numeric optimization, the benefits can therefore be important. Nevertheless, we must not overlook the cost of generating training data.

The DNN's profound architecture consists of many processing layers and non-linear transformations that allow the model to be effective without the inputs having the proper characteristics. ANN's structure is best suited to model the behavior of non-linear and complex sequence problems that are unsettled. However, it can be difficult to find the right design, orientation, and over-fitting templates, if not properly qualified [21].

2.3 Support vector machines

SVM is a binary grading algorithm that uses kernel features to render data indirectly projected into a wide space. A separation hyperplane that raises the margin between hyperplane and the supporting vector, which form the closest data point to hyperplane, is used to establish an optimal
margins classification for separable data. SVM can also be employed by the key characteristics of the algorithm in this analysis as a regression tool called SVR (Support Vector Regression, SVR). In analogy with SVM, SVR is accomplished by a loss function that determines an area that is susceptible to the true reactions of the training sites (Vapnik, 1998). For all points in the e-insensitive field, the errors are called zero. SVR takes a linear regression in its high dimensional functions space by non-linear kernel mapping, while slack variables are implemented to quantify the variance of exercise samples from the e-insensitive region [21].

3. Soil arching

The soil arching of the ground, in the soil and laboratory (Terzaghi 1943), is one of the most universal phenomena and usually exists when soil interacts with structural components, e.g., tunnels, retentive walls, piles and pipes. “Terzaghi (1943) defined soil arching as a transfer of load from the yielding soil mass onto adjoining stationary parts in response to relative displacement between these two media [1].” The following can be classified as ground arching centered on the direction of the shear stress and the relative displacement. (1) a positive soil arching, where the yielding element moves downwards and the stationary parts cause upward shear stress, and (2) negative soil arching, where the movement of the soil and the shear stress is opposite to that of a positive arching of the soils [1].

“Trap Door test was conducted by many researchers to make a similar ground conditions to study the effect of soil arching on reinforced pile embankment for example, Terzaghi (1936), McNulty (1965), Ladanyi and Hoyaux (1969), Evans (1984), Rui et al. (2016), and Bhandari and Han (2018), to study the behavior of soil arching. To evaluate the degree of soil arching, McNulty (1965) defined a soil-arching ratio r as follows; [1].”

\[
P = \frac{\gamma_v}{(\gamma H + q)}
\]

where \( \gamma_v \) = average vertical pressure acting on the trapdoor; \( \gamma \) = unit weight of soil; and \( H \) = height of the soil; \( q \) = surcharge on the surface; \( \rho = 0 \) represents complete soil arching, whereas \( \rho = 1 \) represents no soil arching.

The soil arching ratio for positive soil arching over a single horizontal hard trap door under fill self-weight can be divided into three theories.

1) silo theory: Based on the assumption that the moving soil surfaces above the trapdoor are vertical and that soil arching load transfer is analyzed considering the equilibrium of the moving soil mass.

2) physical arch theory: consider the physical arch formation.

3) plasticity theory: Which assumes that the trapdoor force is derived from the free body in the soil's plasticity field.

Bhandari in 2010 carried out a numerical research using the discrete element method to study the effect of a confined cyclic load on soil arching and found that cyclic loading reduced soil arching, but geosynthetic reinforcement stabilized soil arching. Another study in 2015 by Lai et al. Demonstrate that the effect of uniform cyclical loading gradually degraded, and after some time, a steady state with uniform loading, by using a discrete numerical element solution. Thus, all the
above studies were based on numerical solutions for the soil arching effect which could not completely record and test the behavior of soil arching.

Xu et al [22] - Testing of the trapdoor the effect of loading conditions on soil arching was investigated under cyclical loading with different magnitudes, frequencies, and loading areas. Furthermore, in trapdoor tests, fill height was varied. The particulate image velocimetry (PIV) technique was used to analyze deformation patterns in model fill tests.

4. Experimental Test

The scaling rule was not applied to stresses, as Van Eekelen suggested, which could lead to stress-dependent behavior. K. Aqoub, M. Mohamed*, T. Sheehan [1] Set up experiment with a low reinforced and non-reinforced embankment as loads of overloads could be transferred across a smaller area of the embankment at the shallow height, leading to a non-uniform pile and soft ground pressure. In the area under the loading area, thus, high stresses are concentrated. An Eekelen & Bezuijen[23] Suggested it can also be considered a shallow embankment if the embankment height is equal to or less than 3m, and The pressure exerted on shallow embankments with traffic loads could range from 43,0 kPa to 79,0 kPa. “K. Aqoub, M. Mohamed*, T. Sheehan [1] studied by applying the load on a solid plate above the embankments to simulate the characteristic of rigid paves.”

| Parameter                  | Dimension | Scale ratio |
|----------------------------|-----------|-------------|
| Length                     | m         | 1:x         |
| Area                       | m²        | 1:x²        |
| Stress                     | kPa       | 1:1         |
| Force                      | kN        | 1:x²        |
| Tensile strength of reinforcement | kN/m | 1:x         |
| Deformation and distances  | m/m       | 1:1         |

Table 2 Property of soft soil used in this study [1].

| Property                        | Measured Value |
|---------------------------------|----------------|
| Dry unit weight, kN/m³          | 15.95          |
| Moisture content, %             | 22.00          |
Liquid limit (LL), %  
28.00

Plastic limit (PL), %  
20.20

Undrained cohesion, kPa  
13.00

Angle of friction, degree  
0

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**Fig. 2.** Schematic illustration of the testing rig and measurements (a) Vertical cross section (b) Plan view [1].

### 4.1. Test technique

In this study three embankment of 200-millimeter, 400 millimeters, and 600-millimeter height have been investigated with reinforcement layers present and absent. The various phases of loading are shown in fig. 2. At steady rate of 0.42 kN/s till 28 kN, the applied load was gradually increased, and then retained for 200 s. The cyclical loading was supported by three phases, each of them had been applied with the same frequency, 0.5 Hz with a different amplitude and average
loads. The loads applied in stage 2, 3, and 4 at minimum and maximum were 8-48, 8-68, and 8-88 kN equivalent to 9-53, 9-76 and 9-98 kPa respectively surface load. Following completion of the three cyclical loading phases, the loading in stage 5 was reduced to 0.42 kN/s, which is identical to the loading rate used in the monotonous test stage earlier.

Fig. 3. Different stages of maximum monotonic and cyclic loadings [1].

Table 3 Summary of experimental program [1].

| Test Number | Fixed parameter | Variable parameter |
|-------------|-----------------|--------------------|
|             | Height (mm)     | Number of reinforcement layer |
| 1-4         | 200             | 0,1,2,3            |
| 5-8         | 400             | 0,1,2,3            |
| 9-12        | 600             | 0,1,2,3            |

5. Results

These tests focused on the effect on the transfer of load mechanism, heaving & settlement of the soft ground and embankment under the different height of embankment & the different layers of reinforcement material.

5.1. Analysis for unreinforced different heights embankments
The link in pile and soft ground soil pressure and the time in between various loading phases of unreinforced embankments, measuring three distinct heights: 200 millimeters, 400 millimeters and 600 millimeters, is presented in Fig. 3.

5.1.1. Stages of monotonic and static loading

When the embankment height was increased, considerable pressure was observed in pile foundation. This showed that ground arching was being developed and increased by the variation in height of embankment. And at maximum height the best arching mechanism was seen. This was due to the increased shear resistance accumulation with increased embankment height and improved the probability of development of arching of soil layer.

The stress applied on soft soil and pile foundation began to surge when monotonous load was applied in stage 1, which was not based on embankment height. In comparison to the stress on the soft soil, the increase in rate of pressure in pile foundation was found to be very significant. “The findings obtained in this study concur with previous results by Girout et al [24].” When additional loads were applied in comparison to self-weight, it was observed that stress on pile foundation increased. There has been a significant reduction of the stress on the central pile and a very minor rise in the soft ground strata.

When the pressure is applied to ground if it is self-weight then there will be uniform distribution of stress, but it is monotonic load is applied then it will be concentrated to a specific place which could result in uneven distribution of pressure on pile and adjacent soil. but the allocation of stresses on the pile foundation and the soft soil depth enhanced by increasing the depth of embankment resulting in lower pressure on central piles.

![Maximum pressure on pile caps and soft soil for unreinforced embankments with different heights](image)

Fig. 4. Maximum pressure on pile caps and soft soil for unreinforced embankments with different heights, Where; ASMP = Applied Surface Mean Pressure, Amp = Amplitude and Freq = Frequency [1].

5.1.2. Cyclic loading and unloading stages:
A pressure values between 8.9 kPa and 53.2 kPa were used for cyclic loading (Stage 2), due to the collapse of arching mechanism, which was formed earlier, the reduction in the stresses present on pile cap took place when the pressure on soft soil was increased regardless of the height of the embankment. The pressure decrease is considerably in the first cycles and as the number of cycles increases, the pressure decreases gradually, as the bank height increases, the cycles for stable pressure at 200mm 400mm and 600mm were 600, 280 and 80 respectively, during additional cycles during this stage there was no change in stresses at the pile foundation as shown in Fig. 3. Furthermore, the effect of cyclic loading decreased on soil arching as the height of the embankment increased.

In the stage 2nd and 3rd, the pressure on the piles increased significantly during the 1st 100 cycles as shown in fig 3 and later again goes increasing at gradual rate which means the soil arching was established again. This could be because of soft soil deformation under an ever-larger cyclic load, as noted by Van Eekelen [1] and by Elshesheny [25].”

![Graph showing variation of pressure on piles and soft soil of different embankment heights during cyclic stages](image)

**Fig. 5.** Variation of pressure on piles and soft soil of different embankment heights during cyclic stages (A) 200 mm (B) 400 mm(C) 600 mm [1].

5.2. Analysis of variation of height of embankment with reinforcement present:

“Fig. 5 Presents the impact on the stress concentration ratio of the number of reinforcement layers versus the number of cycles for embankment with different heights during the different loading stages. The stress concentration ratio (SCR) is defined as the ratio of the pressure on the piles to the pressure on the soft soil in the central area.

\[
SCR = \frac{\sigma_p}{\sigma_s}
\]  

(2)
here, SCR is the stress concentration ratio, \( \sigma_p \) is the gauged pressure on piles in kN/m\(^2\) and \( \sigma_s \) is the gauged pressure on the soft soil in kN/m\(^2\) [1].

Fig. 6. Stress concentration ratio of unreinforced and reinforced embankments for different embankment heights versus number of cycles (A) 200 mm high embankment (B) 400 mm high embankment (C) 600 mm high embankment [1].

5.2.1. Monotonic and Static loading stages:

It is possible to observe that ratio of pressure during the static load stage, due to arching mechanism of soil layer, tensional effect in membrane, and effects of stiffening of embankment layer, with the rise of embankment and the number of reinforcement layers, with the rise in the depth of embankment the concentration of ratio of stresses has decreased by the incorporation of the reinforcement layers as a result of a better stress distribution. Nevertheless, as shown in Fig. 5, increasing the number of reinforcements led to the reduction by increase in the depth of embankment.

5.2.2. Cyclic loading and unloading stages:

A substantial decline in stress intensity was noticed when the loading pattern was cyclic in stage 2. This implies that, inclusion of strengthening reinforcement tiers, led to the transmission of stresses in the cyclical loading stage was increased, which led to loads on the piles being increased,
as shown in Fig. 5. The membrane under tension regulated the process of loads being transferred to the piles by including a tier of reinforcing material. However, the enhanced reinforcement would behave as heavily strengthened slab that is the similar finding of Mohamed by increasing the number of reinforcement levels [1]. The introduction of reinforcement layer does not work the same way as we introduce the same reinforcement layer in thinner member when raising the height of embankment. This meant the increase in the stress concentration rate seems to be made a little easier by inclusion of multiple tiers of reinforcement in heavier embankments compared to using one reinforcement layer. The better bonding between reinforcement and surrounding material of embankment which is result of the material densification embankment could be attributed to this.

In the end, the calculated stress ratio is relatively low, can be seen from Fig. 5. This is because experiments on a piled reinforced retaining slope with large pile distances and a shallow retaining led to a lower arching degree and therefore a lower stress ratio, found in this study by Abusharar et al. [6].

The depth of embankment when kept around 200 millimeters, the improvement was slightly higher and with the embankment height increased it was reduced, as illustrated in Fig 5. The surrounding soil and the reinforcement interacted with each other in such a way that the densification of the material of embankment could be attributed to this soil & reinforcement interaction. In the end, the calculated stress ratio is relatively low, can be seen from Fig. 5. this is because spacing of pile was wide and depth of embankment was shallow, resulting in a lower arching grade and thus a low concentration ratio of stress as discovered by Abusharar et al.[6] and the soil strength and fatigue of reinforcement layers is significantly impacted by dynamic loads, reported by Zanzinger et al [1].

**Fig. 7.** Tension force in reinforcement layer versus number of cycles for one layer reinforced embankment of different heights [1].

**5.3. Deformation in reinforcement tiers due to tension force:**
“Figure 6 shows the tension force variation on one-layer, reinforcement in different heights of embankment during cyclic loading (stages 2, 3, and 4)” [1]. Connection of four load cells with the reinforcement tier made up of geotextile, measured the forces in the reinforcement layers.

It can be concluded from the results seen above when the load cycles got amplified the tension increased in the strengthening layers within the increase in embankment height. In this test authors relating the reduction in tension force during the 3rd and 4th cycle with the creep behavior of reinforcement layer. And the reduction in tension force was reduced when the embankment height was increased.

**Fig. 8.** Maximum deformations in the bottom reinforcement layer versus number of cycles for one layer reinforced embankment of different heights (point 1) [1].

**Fig. 9.** Maximum deformations in the bottom reinforcement layer versus number of cycles for one layer reinforced embankment of different heights (point 3) [1].

Fig 7,8 shows that the deformation in the central panel is more than that in the adjacent panels which can be due to concentrated pressure due to cyclic loads on central pile than that in adjacent piles. But it cannot be omitted that the deformation does not increase with the increase in the height of pile. It can also be incurred from the figures above that the percentage change in the deformation
was also high in central pile as compared to adjacent piles where the 50 percent of the deformation
was incurred in the initial 15 cycles [1].

5.4. Analysis of settlement for different depth of embankment:

![Graph showing settlement versus number of cycles for different depths of embankment.](image)

**Fig. 10.** Maximum settlements of loading plate versus number of cycles [1].

We can conclude, from Fig 9, it represents the relationship between the maximum settlements of
varying depth of embankments & the number of cycles. From the above figure, we can conclude
that the measured surface settlement increases when embankment depth increases. At origin, at the
end of stages I and Stages 0 (static loads) the settlements were 3.50, 7.70 and 11.30 mm, for 200,
400- and 600-mm terrains. However, it is observed that in the initial phase of cyclic loading the
settlement significantly increased by 50 per cent during the initial 100 cycles, irrespective of the
depth of the embankment. But the surface settlement increased at a low rate as we increased the
loading cycle and amplitude. It was obvious by observing the increase in settlement with the
increase in height of the embankment. Because of the soil volume increment. This Fig is found in
accordance with Houda et al's finding [1].
Fig. 11. Settlement ratio of loading plate versus embankment height at the end of third stage of cyclic loading [1].

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Fig. 12. Soil surface settlement after removing the applied loads versus the box test length of unreinforced embankments [1].

The soil height was reduced by the incorporation of reinforcement layers, especially for the 200 mm high embankment. In the 400 millimeter and 600-millimeter height embankments, Fig. 12 as shown above, almost no heaving was observed. This could be due to soil confinement due to increase in reinforcement layer which is due to shear stress created by the tiers.
Fig. 13. Soil surface settlement after removing the applied loads versus the box test length of reinforced embankments; A) 200 mm, B) 400 mm and C) 600 mm [1].

6. Conclusion

During the first stage of test i.e., static loading (self-weight) step, the stress on the central pile increases because of the effect of soil arching with increase in height of the embankment, as we move to move to monotonic loading stage it again increases with the low rate due to proper distribution of stresses take place as we increase the height of embankment. but as we progress towards cyclic loading stage (initial cycles) the pressure in the central pile started to decrease due to disturbed soil material under effect of cyclic load the arching mechanism does not work properly and as we starts to increase the pressure and the pressure in the central piles started to increase due
to increase compressibility of soil structure but as we increase the embankment height this improvement gets slow.

As we introduce the layer of reinforcement, they effectively transferred the load to central piles irrespective of height of embankment but as we increase the height of embankment it gradually decreases the effect of mechanism of reinforcement layers but in this condition, we can use a greater number of layers of reinforcement to transfer the load.

It is also studied that as the increased embankment height results in increased settlement of surface and heaving of the soil is decreased, and more than half the settlement and heaving of the surface takes place during initial cycles of cyclical loading but as we introduce and increase the number of reinforced layers, they control the settlement and heaving behavior of soil irrespective of height.

In this study we observed that physical model building, and analysis can be a very challenging task, as it takes up a lot of time, resources, and space for setting up a testing rig for every load scenario and for different material conditions. That is why it is very essential to use Artificial Intelligence to make a computational model of this setup,

So that we can analyze huge amount of data in a short span of time without using a lot of space and resources to improve the efficiency of testing.

The results of the computational model can then be compared to the results of all the previous tests to check the computational model's efficacy. Implementing Artificial Intelligence can help in formulating a better theory through all the data that has been analyzed for the study.

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