DECISION SUPPORT SYSTEM FOR LAND RECLAMATION USING PREFABRICATED VERTICAL DRAINS

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Abstract: The need for additional port capacity has rapidly risen over the last few years due to globalization. Due to high cost of land procurement, land reclamation has become a very promising alternative for expanding and constructing new ports. The presence of soft marine clay poses a major challenge for port development as it requires ground improvement. The use of Prefabricated Vertical Drain(PVD) with preloading has become a popular method of ground improvement because of the ease and speed of installation. The process to establish PVD design is complex and involves tedious calculations. If this is done manually, the designer has little opportunity to explore different design options and hence might not determine the most economical solution. A decision support system which automates aspects of the design process will enable the designer to arrive at a better solution taking into consideration project schedule, cost and construction method. This paper discusses the development of a DSS for PVD design using the MATLAB environment.

Keywords: Prefabricated Vertical Drains, Decision Support System, Smear effect, Preloading

1. INTRODUCTION

With the growing need for port capacity, and high cost of land, land reclamation has become an attractive alternative for port development. But the presence of soft clay deposit makes land reclamation a challenging task. Low shear strength, high water content, high compressibility and large settlement of the soft clay make it impossible to do construction on soft clay without ground improvement.

It may take a very long time for a soft marine clay deposit to undergo settlement and gain sufficient strength. Hence it becomes imperative to improve the ground using accelerated methods. There are different methods to accelerate ground improvement based upon the different soil conditions. Use of vertical sand drains became very popular in the 1930's. The evolution of plastics as a construction material has led to the use of Prefabricated Vertical Drains (PVDs) for ground improvement. The speed and ease of installation has made the PVDs popular and economical.

Generally the design of PVD's involves arriving at some spacing in order to meet shear strength requirements within the scheduled time. For economic design of the PVD requires detailed calculations considering the variations of the soil data and bathymetry of the site are required. When design is done manually, such variations are not considered due to the tedious and time-consuming nature of the calculations involved. The availability of a decision support system, which can model the detailed site data and perform calculations, will assist the designer in comparing alternate design options rapidly.

The objective of this work is to develop such a decision support system. The inputs to the system are borehole soil data, bathymetry data, grid spacing, construction method, project requirements and schedule and PVD properties. The outputs from the system are rate and intensity of preloading, PVD pattern and, spacing for the specified inputs. The model used in this work accounts for the smear effects during installation of the PVDs.

2. CONCEPTUAL MODEL

The conceptual model involves the process of finding the different elements of design, the constraints and the parameters affecting them. The design methodology that has to be adopted is also described

2.1 Constraints:

The main constraints for land reclamation include time, cost, space as shown in Figure 1. Time is the essence of any project. Different parts of the land may be required at different time.

Space may be another constraint. There may be a requirement that part I (shown in Figure 2) be reclaimed before the rest of the land depending on the functional utility of that particular area. If preloading is carried out, the activities for preloading might also require space for access etc.

The ultimate aim of the project is to minimize the cost as much as possible and finish within schedule. There could be constraints in the site like the availability of material, equipment etc.

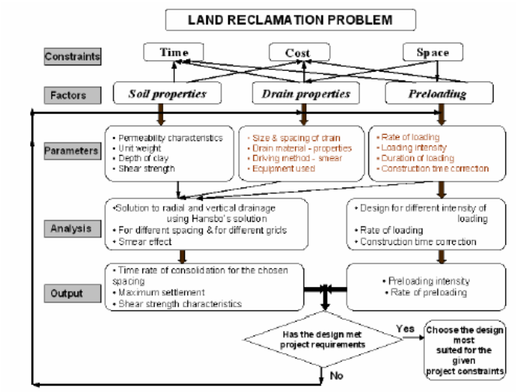

Figure 1.Conceptual Model for Land Reclamation

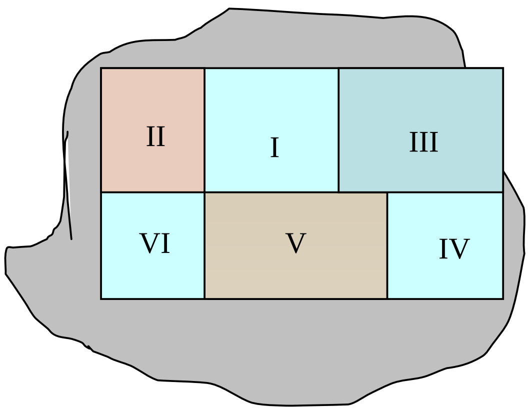

Figure 2. Land to be Reclaimed

2.2 Analysis:
The consolidation analysis is carried out using Terzaghi's classical analysis for vertical consolidation and Barron's theory for the radial consolidation. Smear effect (Atkinson: 1981) has been taken into account. The decision on preloading is discussed in the next section. The settlement is calculated for both staged and single time loading assuming 1m interval of the clay according to the procedure described in Das (1996)

2.3 Output:
The various design elements like the spacing of the drain and the pattern can be arrived and the preloading at different time can be determined. The time dependent settlement due to the preloading can also be calculated and the most appropriate design can be arrived for specific project requirements.
If the arrived design is not safe, the variable parameters like the drain properties and the preloading rate are varied to arrive at a safe design.
As the variants involved in the design are many, a system that can automate the design process will help in better decision-making.

3. DECISION MAKING ON PRELOADING

Preloading is usually followed by drain installation. The shear strength gain is a function of the height of preloading. The height of preloading will have to ensure that the required shear strength is developed within the available time. The ground is first filled up to the required ground level. Preloading should also not cause any bearing capacity failure, which may lead to mud wave formation. In order to ensure that the post construction settlement is within allowable limit, the ground will have to be preloaded to the height equivalent to the load intensity on to the structure after construction.

Preloading proceeds at a phase at which the material is available in the site (productivity). It could be done in stages if the rate of gain in shear strength is not sufficient to take the required load at a specific time. The different criterion considered for the height of preloading at different time has been discussed below

H_r - This is the height required for the shear strength to develop within the considered time. It is assumed that this height will have to be provided for the target shear strength to develop within the considered time.

Ha - This is the height of the fill that can be allowed at any point of time in order to avoid the bearing capacity failure. This does not consider the slope failure as criteria. The allowable height is the maximum height that can be provided taking the shear strength and consolidation into consideration.

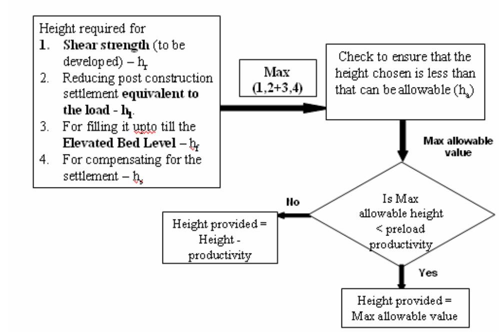

Figure 3 Decision Making on Preloading

H_l - This is the height equivalent to the load coming on to the improved ground after construction. This minimum preloading has to be provided to ensure that the post construction settlement is well within the specified limits.
H_{pp} - It is often the case in the site that the construction productivity for the preloading may be limited to few metres a month or so. In order to account for such a constraint, this height will have to be considered.

H_p - This is the height of preloading that is provided at any given time to satisfy the different constraints for preloading.

H_s - The height of preloading that has to be provided in order to compensate for the consolidation settlement. This height will be provided if the ground settles below the Elevated Bed Level

H_f - This is the preloading height that has to be provided in order to fill up the present elevation to the expected ground level. This varies at different grid point. This height is assumed to be the same throughout the project.

H_s is provided with time to compensate for the settlement

4. IMPLEMENTATION

The conceptual model was implemented to develop a Decision Support System using MATLAB

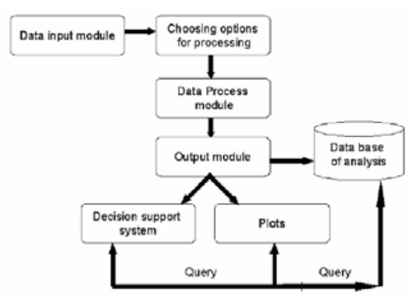

Figure 4 Implementation of Conceptual Model

4.1 Options:

Options for carrying out the analysis include the consideration of smear. It also includes the option to choose between single and double drainage. The choice of assigning uniform soil parameters for all bore hole data is also available. In order to interpolate data for the grid points from the bore log data, either the nearest interpolation method or the Inverse Distance Weighing method can be used.

4.2 Input data module

This module is used to obtain the project data, soil parameters, bore log data, and drain parameters from the user. The gird size for the analysis can be varied according to the need of the user.

4.3. Process module

The process module is designed for the consolidation analysis explained in the conceptual model. The time taken for the analysis depends on the size of grid chosen and the spacing range given by the user. The output from the analysis is stored in database from which any information can be retrieved by querying.

If the bathymetry data is available then the elevation at various grid points may be interpolated from the bathymetry data. (Figure 6).

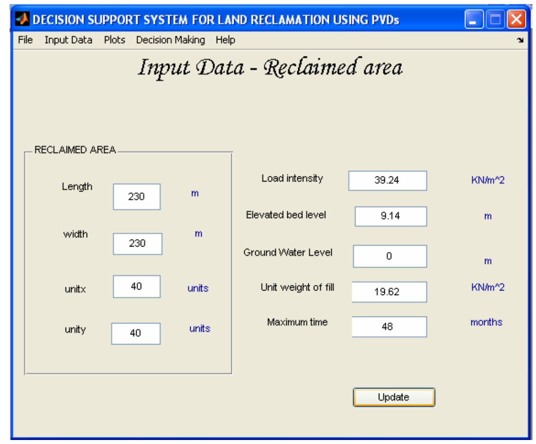

Figure 5 Input Data for the Project

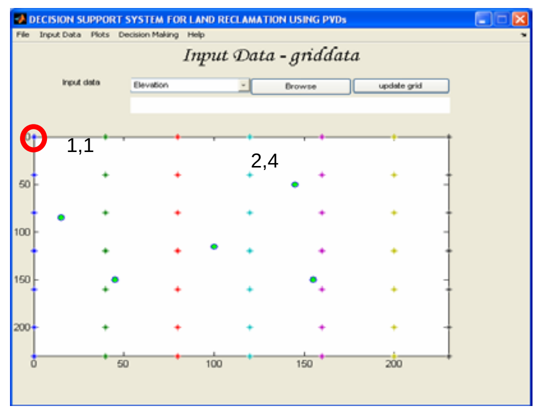

Figure 6 Typical Grid Layout

5. PROBLEMS AND ISSUES ADDRESSEDBY DSS

The following aspects of PVD based ground improvement are covered by the DSS.

1. The minimum time required to achieve the specified consolidation.
2. Maximum spacing that can be used to satisfy project constraints.
3. Feasibility of the different spacing, pattern for different grid points.
4. Patch/zone that can be reclaimed in a particular time and the drain configuration for such a design.
5. Consequences of improvement without installation of drains.
6. The most feasible and economical alternative for the land reclamation.
7. Preload that can be provided at different time intervals at various grid points.
8. Preload that can be provided at a particular grid point at different time intervals.

6. DECISION SUPPORT SYSTEM – SYSTEM USAGE

Hypothetical data have been used to illustrate the features of the system below.

6.1 Plots

The different plots that can be used for decision-making include the U (%) vs. time, Time vs. settlement, preloading plots. The different plots are as shown below.

6.1.1 U (%) vs. time plot:

This plot can be obtained for any chosen grid data for any spacing and pattern. The influence of the different spacing and pattern on the rate of the consolidation can be studied easily.

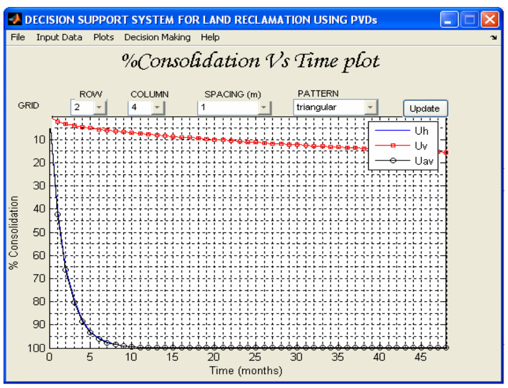

Figure 7 U (%) vs. Time Plot

6.1.2 Preloading plots

The preloading requirements for the different grid points can be plotted against time. This plot can help us in deciding the critical criteria for preloading at different time. The preload productivity that can be achieved on site has been taken into consideration. The decision-making on the height of preloading to be provided at different time is discussed earlier.

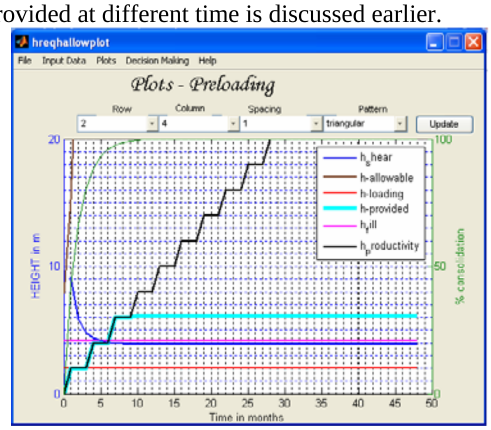

Figure 8 Preloading Plot

6.1.3 Volume plot

Linear interpolation method has been used to calculate the elevation at closer grid points. The total volume of cut and fill can be calculated. The volume can be calculated considering a small stretch of the total area. The excess volume that has be filled due to settlement with time at different gird points can also be obtained

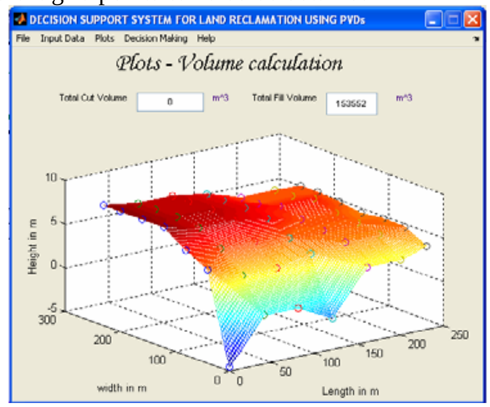

Figure 9 Volume Plot

6.1.4 Time vs. settlement plot

The time vs. settlement plot helps in finding the rate of settlement that might occur at different gird points. The time vs. settlement plot for the stage wise preloading can be compared with that of preloading provided at a stretch. The settlement at any time due to stage wise preloading will be less as compared to a single time loading. Similarly the settlement due to providing larger spacing will also be less at a considered time due to slower rate of consolidation. Hence a balance will have to be stuck between the post construction settlement and the spacing that has to be provided. The choice of spacing apart from satisfying the consolidation requirements should also satisfy the post construction settlement limit.

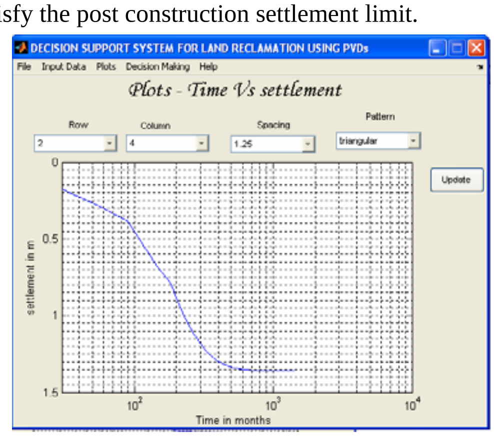

Figure 10 Time vs. Settlement Plot

6.2 Decision support modules

The variants involved in the design and constraints for the land reclamation project may be different for the different projects.

Projects could be time driven or cost driven. The DSS modules can be used to find solution for such problems.

The different features of the DSS that aid in decision making has been explained below

6.2.1 Calculating maximum spacing

There could be situations where we may require complete consolidation to occur within the project time. For examples, let us assume that we want complete consolidation (90%) to occur in 12 months. The maximum feasible spacing that can meet our requirements for the different grid points has been determined and is shown in the figure 11. It can bee seen that there is variation in the maximum spacing provided in the grid points because of the variation in the thickness of the clay at different grid points.

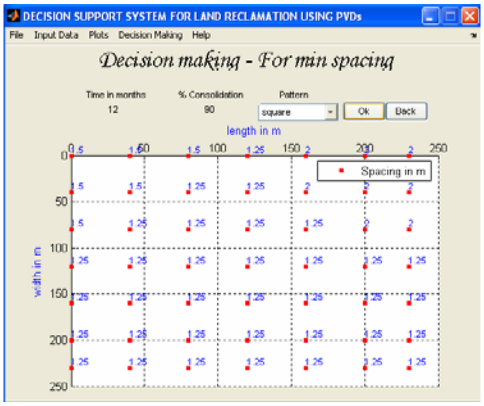

Figure 11 Minimum Spacing

6.2.3 Calculating minimum time

The DSS module for calculating the minimum time required for achieving the desired degree of consolidation at different grid points has been show in Figure 12. The variation in time required for complete consolidation for the different spacing is large. Hence depending on the time available, the most feasible spacing will have to be chosen. If there is enough time available then the most economical spacing might be chosen to meet the project requirements.

6.3 Zonal reclamation

The space constraints and the time constraints may allow us to reclaim different part of land at different time. Hence in order to save cost, we can divide the area in the form of zones and reclaim the different zones with different spacing so that the time available is utilized properly and at the same time the resources like the equipments are also utilized. The feasibility of the different spacing at different gird points can be check using the DSS module given below (figure 13). The cost saving that can be achieved is substantial.

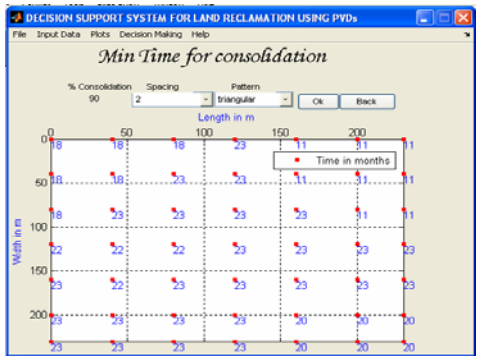

Figure 12 Minimum Time

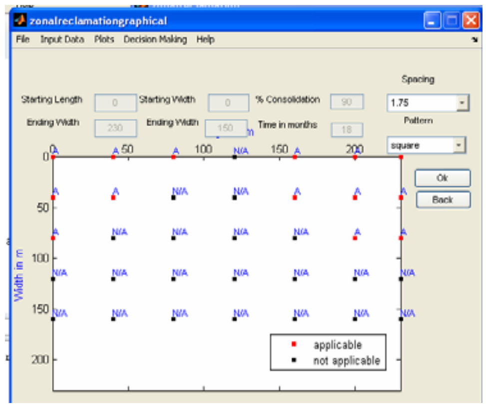

Figure 13 Zonal Reclamation

6.4 Without ground improvement

If there is sufficient time available for consolidation (few years) and the thickness of the clay is small, as in case of grid: Row 1: Col 5 etc, then complete consolidation will occur over a couple of years without any ground improvement. The consolidation that can occur at the different grid points over the specified time can be worked by the DSS (figure 14)

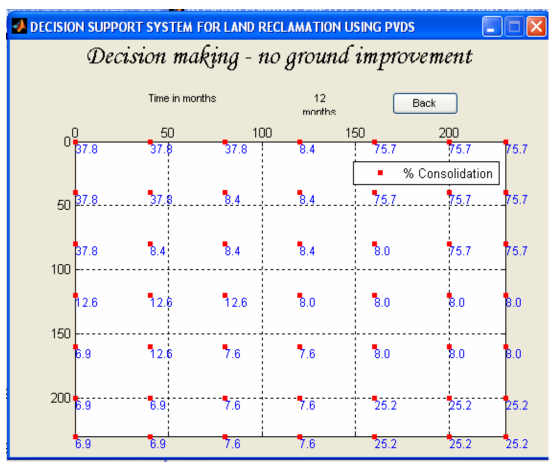

Figure 14 Without Ground Improvement

7. DISCUSSION

The Decision support system helps in taking effective decisions and in deciding the most feasible spacing and preloading for a given project requirements. Some of the salient features has been discussed below

7.1. Effect of smear

The consolidation analysis was carried out with and without smear and the results were compared. From figure 15, it is seen that the rate of consolidation varies drastically if the effect of smear is considered. This reduction is due of the reduction in the permeability of the soft clay around the drain due to the compaction of the clay caused around the mandrel during driving.

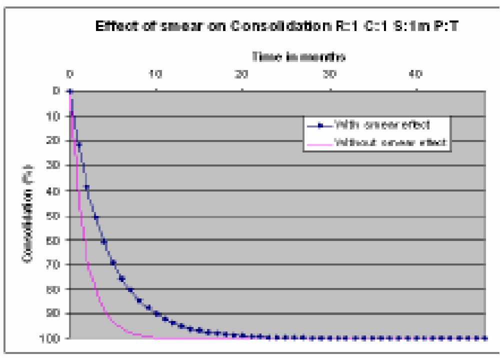

Figure 15 Effect of smear

7.2 Effect of the interpolation method:

The suitability of a particular interpolation method for a project depends on the field condition. Hence both the interpolation method can be used and the results may be compared with the field data and the best suited method can be chosen.

7.3 Cost savings.

The DSS helps in accounting for the variation in the soil properties and the soil strata and helps in overcoming the limitations of the manual computing as well as that of average data. This approach helps in saving the total cost of the project.

The most economical drain spacing can be obtained using the DSS. Hence the cost due to providing spacing that is lesser that that required for the given project condition can be greatly reduced.

If the land reclamation is planned well, then the zonal reclamation can be implemented. This would result in huge savings because the most appropriate spacing would be provided in different zones and hence the time available for the reclamation can be utilized properly. The indirect costs like the equipment idling charges or the extra cost incurred due to mobilizing repeatedly can be avoided.

The decision on providing a particular spacing with a particular preloading can affect the cost and the post construction settlement Depending on the specific requirements, the design provided should ensure that the post construction settlement is within permissible limits even after providing the most feasible spacing. This can also save cost that would be wasted in resolving the problem of post construction settlement when it is not assessed properly.

10. CONCLUSION

Using the system, the consolidation analysis is more realistic and the error due to assuming an average data for soil for the entire area as considered in manual computation may be reduced. The phenomenon of smear reduces the permeability of surrounding clay and affects the rate of consolidation which has to be considered in the analysis.

The method proposed enables quick review of results for different parameters and helps in effective decision making which might not be possible with manual computation. Thus the model of the DSS proposed in the study could be extended to any problem of land reclamation using Prefabricated Vertical Drains. The most feasible spacing for the given project constraints can be established easily. The effect of spacing and pattern on settlement can be used to arrive at the decision on preloading to ensure that the post construction time settlement is within the safe limits.

If the thickness of clay is not uniform in the considered area and if the construction scheduling permits different parts to be reclaimed at different time period, a zonal reclamation pattern can be established. The results obtained from the DSS can compare well with the manual computation but the comparison with actual measurement in the field will depend on how closely the design (PVDs, preloading) is executed in the site. The cost saving by using a comprehensive decision support system can justify its usage.

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