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# Prediction of the Geological Condition for Pipe jacking Based on the Data Collected in the Shafts

Keh-Jian Shou[1], Fu -Kang Tang[1]
[1]*Department of Civil Engineering, National Chung-Hsing University, Taiwan*
*E-mail*: kjshou@dragon.nchu.edu.tw

**ABSTRACT:** No -Dig method often encounters difficult geological problems, which makes the excavation in difficulty and thus affecting the construction schedule. Central Taiwan area is majorly covered by gravel alluvium, in which the strata contains large gravels. Those large size gravels often result in excessive wear and increase in construction cost. In this paper, we took samples from the launch shaft and arrival shaft pipe-jacking and carried out sieve analyses. Then we transformed the size distribution into borehole data by the newly derived formula. The obtained borehole data was applied to the T-PROGS geostatistic analysis. The purpose of the geostatistic analysis is to building a 3D geological model from data from pipe-jacking shafts, then we can obtain the geological and size distribution along the pipe-jacking alignment. In this study, the analysis was performed for different scenerios and the impact of material changes on the pipe jacking rate. The results show that the change of gravel particles larger than 20 cm is highly correlated with pipe jacking rate. The results suggest that it is feasible to apply the image sieve analysis in the geostatistcs analysis.
**Keywords:** pipe jacking, geostatistics, geological condition, T-PROGS, Markov chain model.

## 1. INTRODUCTION

For a no-dig project, it is not easy to explore the geologic condition around the construction area in advance, due to environmental factors such as heavy traffic, residential area, and high density of existing pipelines. This can lead to many unexpected situations during construction, such as cutter head damage due to excessive wear caused by large size gravels and collapse of soft soil at the cutter head of shield machine. Nevertheless, it is common to conduct geologic investigation in a test pit or in the launch shaft directly.

By using the geostatistical approach, we can deduce geologic conditions and the parameters of the strata formation encountered during the excavation. This way, pipe jacking preparations can be more efficiently made in terms of machine parameters, staff scheduling, and intermediate shaft location, etc. This study applied a geostatistical method by entering drilling data into the software T-PROGS (Transition Probability Geostatistical Software) to simulate and obtain the three-dimensional geological model between the launch and arrival shafts.

Since this study focuses on the pipe jacking in the gravel formations of Taichung area, part of the work site was rededicated to finding information on distribution of particle size within the strata formation, which can help to re-adjust work parameters. Soil samples obtained from the site can be immediately analysed through sieve analysis. Then a conversion of particle size distribution can be input into the software for strata formation simulation. It is hoped that through the effective use of estimation and simulation, this method can better predict the strata formation encountered during a pipe jacking, such that the operation of the construction can be more efficiently and more economically.

## 2. LITERATURE REVIEW

Jones, Walker, and Carle (2002) used the transition probability approach under the software MODFLOW during random simulation. Transition probability geostatistics is superior to the traditional indicator kriging method in a number of ways, such as its ability to use a simpler and more intuitive approach to enable a better understanding of the relationships among various geological frameworks, and in its ability to simulate a number of geological correlations in more details. Weissmann (2005) used the geological model in the Kings River alluvial fan as an example to outline various geological features according to data from drilling, the geophysical log, and rock core classification. The geological model was simulated by the transition probability method, in conjunction with the Markov chain. Seeboonruang (2006) studied the lower reaches of the Chao Phraya River in central Thailand, where complex strata conditions are simulated based on transition probability theoretical equations.

The study of Li, Shao, Jin, and Cui (2009) presented that the modelling process should also consider the heterogeneity of hydro-geological structure. The spatial distribution pattern of hydro-geological parameters and the level of sophistication determine the accuracy of the simulation. For the sedimentary rock formation, the spatial distribution pattern of the rock is the most important control factor. Using a large amount of drilling data, the researchers employed the Markov chain transition probability sequence with an indicator kriging model as the primary method for the analysis. Theodossiou and Latinopoulos (2009) used the T-PROGS in GMS to conduct a probability analysis on the distribution of soil in an aquifer, and similarly used the input of existing drilling data into T-PROGS to calculate a three-dimensional transition probability model. The results obtained were used for further modelling of the aquifer.

## 3. METHODOLOGIES

### 3.1 Sampling and Sieve Analysis Testing

The laboratory test was based on the Taiwan specification CNS10989 on "the method to obtain the laboratory testing sample from the bulk sample from the field", and the testing specification CNS486 on "the method for sieve analysis of fine and coarse aggregates". Sieve analysis can be appropriately applied to soil particles of a size greater than 75 μm (# 200 meshes). For particles smaller than 75 μm, a hydrometer test must be used. The study was designed to use sieve analysis testing for particles of a size larger than 75 μm. The test aimed to enable soil samples to pass through a series of sieves of various mesh sizes, to obtain the weight of particles within each particle-size category, and to draw the particle size distribution curve.

### 3.2 Conversion of Particle Size Distribution

Considering a three-dimensional penetration through a volume of gravelly soil, we have to assume that the penetration may not go through the center of every single particle, but instead through at a point that is 1/8 of the projected area at the bottom. Looking down from the z-axis, the centroid position was as shown in Fig. 1(a), and the side view was as in Fig. 1(b). Let R ' equal the cut-through length, R equal the radius of the spherical particle, and $\bar{y}$ equal the distance CO from the center of 1/8 of the sphere to the center of the sphere to obtain R. Here, we must first find $\bar{y}$ . First of all, by looking from the direction of the z-axis, the sphere is divided by the x and y axes into four sectors of equal area at the xy plane of the projected area (z = 0). The equation for the sector area is:

$$Ac = \frac{\pi\left(R^2 - y^2\right)}{4} \tag{1}$$

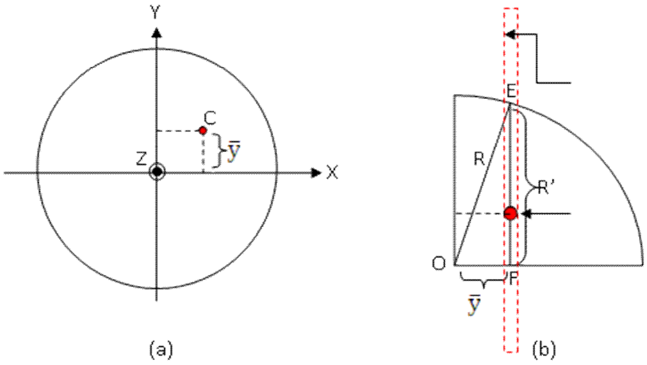



Figure 1 Top view (a) and side view (b) of a penetration through a sphere

The sector area Ac is integrated along the z-axis and divided by 1/8 the volume of the sphere to obtain the distance from the center of sphere to the three axes; which, after some calculation adjustments, we obtain $\bar{y}$ =3R/8, as shown in Fig. 1(b). Applying the geometry, we obtain R' (distance EF from the starting point to the end point). Applying the Pythagorean Theorem, we obtain:

$$R^2 = \left(\overline{EF}\right)^2 + \bar{y}^2 \tag{2}$$

Substituting the known $\bar{y}$ =3R/8 into Eq. (2) and obtaining:

$$\overline{EF} = R' = \sqrt{R^2 - (3R/8)} = \frac{\sqrt{55}}{8}R \tag{3}$$

which is the penetrating length of 1/8 sphere. The total penetrating length is the combination of the two 1/8 spheres (1/4 sphere). Thus, it becomes 2R'≅1.854R. This shows that the penetrating length formed by penetrating through the center of the 1/4 sphere is shorter than the radius 2R of the sphere. Since the cut-through did not go through the center of all the particles that were cut, but instead only went through them at the center of their 1/8 sphere, the size of these penetrated-through particles were underestimated.

The particle size distribution obtained from a sieve analysis is referred to as the raw particle size distribution. Since the penetration of drilling will cause the value for the original effective particle size to be underestimated with the ratio of Ru=1.854R/2R=92.7%. Multiplying this ratio to the raw particle size distribution, we can obtain the adjusted particle size distribution, which represents the particle size distribution of inside the drill hole, i.e. the core log.

### 3.3 T-PROGS Analysis

Transition Probability Geostatistical Software (T-PROGS) is a geological statistical method based on transitional probability (Carle, 1999). A combination of an indicator co-kriging model and a 3-D Markov Stratigraphic sequence model is created to simulate the spatial variability of the model.

T-PROGS is composed of many sub-programs, including GAMEAS for calculation in bivariate statistics (transition probability and indicator variogram), MCMOD for development of Markov chain model, TSIM for three-dimensional and cross-correlation conditional simulation, etc. The theoretical background of T-PROG is briefly described as below.

Transition probability tjk (h) is defined (Carle and Fogg, 1996) as follows:

tjk(h)=Pr{ k occurs at x+h | j occurs at x} (4)

where x is a specified location; h is the separation vector; and j and k are independent geological units, rock formations, or marked categories of materials.

In the classification of variables the Markov chain (Carle and Fogg, 1997) provides a simple and powerful stochastic mathematical model. In time series applications, the theoretical Markov chain model assumes that the future depends on the present, not the past. The assumed occurrence of a spatial Markov chain depends entirely on the most recent data. The reason that the Markov chain model has become an applied method in geostatistics is because it provides the most direct method of development that uses regional patterns to describe all the spatial cross-correlations.

## 4. RESULTS AND DISCUSSION

### 4.1 Analysis of the Actual Cases

The analysis of the pipe jacking project with a configuration plane diagram, as shown in Fig. 2. The diameter cross-section corresponds to an actual drill machine head of 0.6 m as actual case 1 (extrapolated) and actual case 2 (interpolated). The sieve analysis data of shaft Bi43 and shaft Bi46 were used to establish the 3D geological model and estimate the probability of jacking through large-size gravel particles. Then these probabilities of encountering the large-size particles (greater than 20 cm) were used to explore their correlation with the advancing rates of actual pipe jacking work.

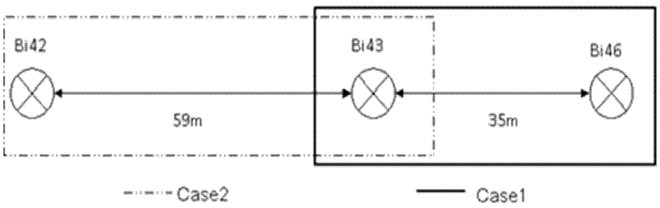



Figure 2 The alignment of the study cases

Since the location and depth of the on-site sampling points are different, the modelling position was separated into two primary active wells, with the depth of each active well equal to 11 m. The two active wells were further divided at 5.5 m in depth as the boundaries for upper and lower intervals, for a total of four section blocks, as shown in Fig. 3. The particle size distribution of the Blocks I, II, III, and IV are represented by Bi43_-5.5 m, Bi46_-6.5 m, Bi43_-9.0 m, and Bi46_-8.5 m, respectively. The sieve analysis results were then converted to the adjusted particle size distribution, as shown in Fig. 4. For a better practical application, the particle size were classified into three categories: (a) Particle size greater than 200 mm; (b) Particle size less than or equal to 200 mm but greater than 20 mm; and (c) Particle size less than or equal to 20 mm.

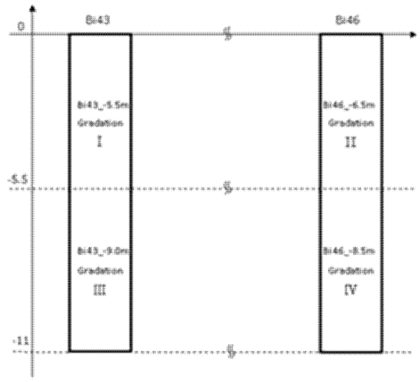
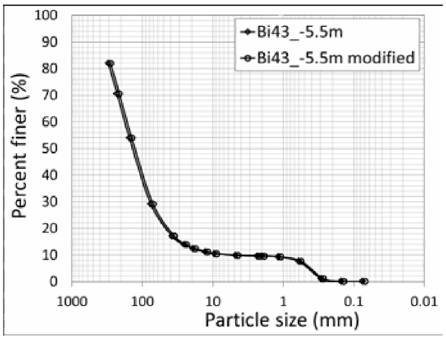
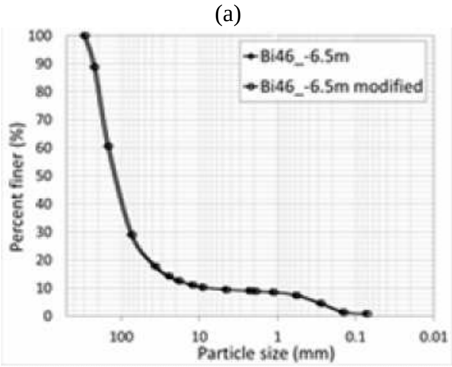



Figure 3 The data blocks of the pipe jacking shafts.




(a)

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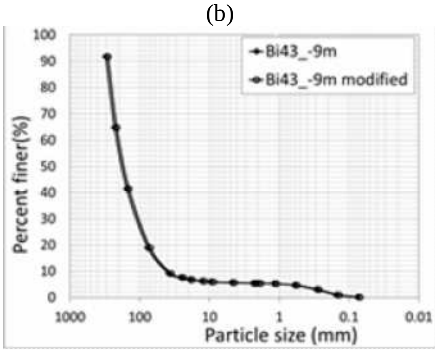


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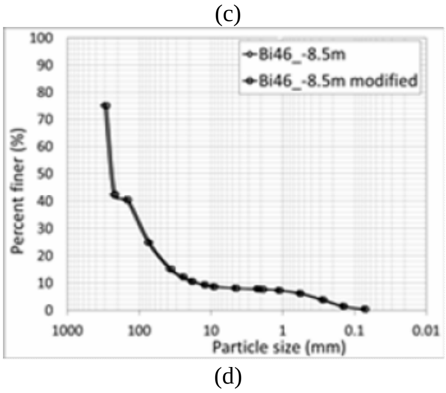
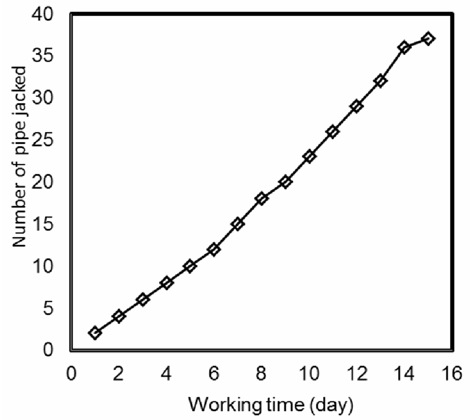



(d)

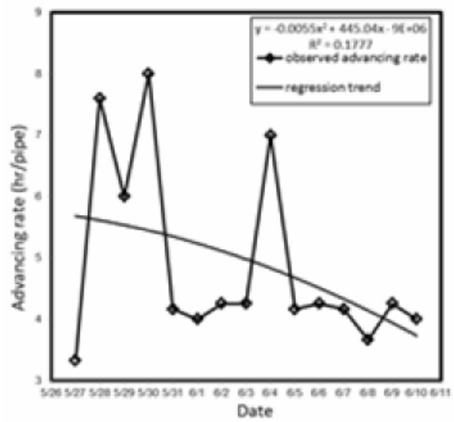
Figure 4 The gradations of the four data blocks, (a) Bi43 -5.5 m, (b) Bi46 -6.5 m, (c) Bi43 -9 m, and (d) Bi46 -8.5 m

**4.2 Comparison with the Advancing Rate**

The pipe jacking project records for the sections Bi42 to Bi43 and Bi43 to Bi46, including daily work record, the history of pipe jacking, and the number of jacked pipe count, were used to obtain the advancing rate, as shown in Fig. 5~6. The data were also converted into advancing rates in hours per pipe jacked. Such that we can analyse the relationship between the number of hours spent and the change in the geological materials can be obtained. However, the figures show that the advancing rate increases as the end of the work nears.

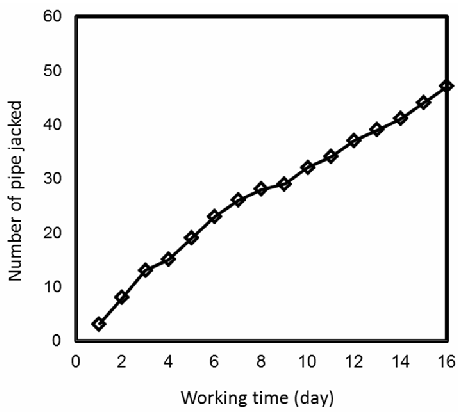



(a)

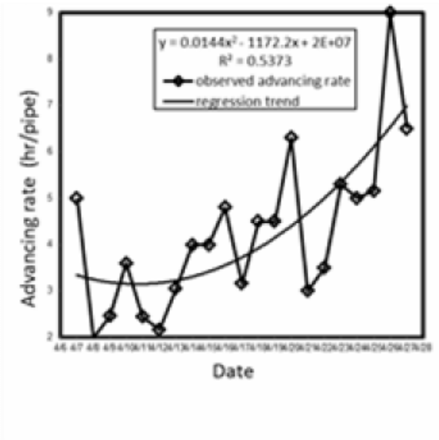



(b)

Figure 5 Progress and advancing rate of pipe jacking section Bi43 to Bi46




(a)




(b)

Figure 6 Progress and advancing rate of pipe jacking section Bi42 to Bi43

The three-dimensional geological model for case I, i.e., section from Bi43 to shaft Bi46, was illustrated in Fig. 7, with a regression trend line of particle size change. Comparison of the results found that the tendency of large size particle (greater than 20 cm) to gradually decline (representing a decreasing number of grids for particle size greater than 20 cm) is very consistent with the tendency of the advancing rate to increase. In contrast, grids for particle size between 2 cm and 20 cm tend to rise at the same position (representing an increase in finer materials). This finding is quite consistent with fact that the reduction of large pieces of gravel in the strata, leading to an increase in advancing speed.

Similarly, the material change for the section from Bi42 to Bi43 in the three-dimensional geological model (Fig. 8) added to the trend line obtained Fig. 5-6. Comparison of results showed that the position of grids greater than 20 cm tended to increase gradually (represent an increasing number of grids greater than 20 cm), which is very consistent with the tendency of the position of the drilling rate to increase (representing a decrease in drill rate speed). However, the trend of grids for size between 2 cm and 20 cm is to decline at the same place (representing a decrease in finer materials), which is quite consistent with the increase in large size gravel in the strata, leading to a decrease in advancing speed.

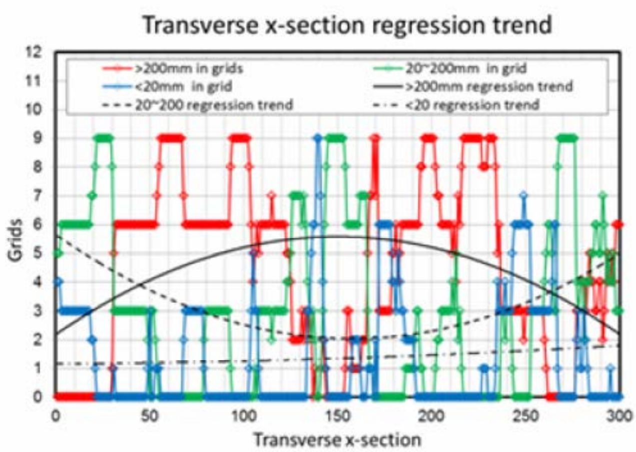



Figure 7 The results of three-dimensional geological modelling for case I, section from Bi43 to Bi46.

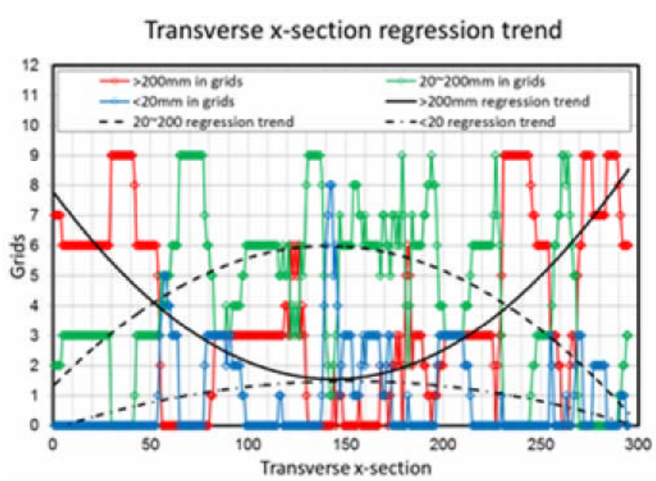



Figure 8 The results of three-dimensional geological modelling for case II, section from Bi42 to Bi43.

## 5. CONCLUSIONS

The alluvium in Taichung area is mainly gravel deposits, containing a substantial amount of large sized gravel, which has a significant impact on the success of any no-dig project. This study conducted an on-site sieve analysis of geomaterial launch and/or arrival shafts. After obtaining sieve analysis data, a derived formula is applied to adjust and convert the data into drilling core log. Then a GMS sub-program T-PROGS is used to perform three-dimensional geological modelling to analyse the vertical and horizontal material changes. The analysis results were compared with pipe jacking data of the study cases.

Comparison of the simulation results with advancing rates of actual cases showed that the trends in material change and advancing rate have a high degree of correlation. When the number of grids of size greater than 20 cm decreased, and those grids of less than 20 cm but greater than 2 cm increased, the advancing rate also increased. Conversely, when the number of grids of size greater than 20 cm increased, and those grids of less than 20 cm but greater than 2 cm decreased, the advancing rate also decreased. They highly correspond to the actual pipe jacking situation: when the cutter head of a shield machine encounters large sized gravel rock, its speed will slow down due to cutting wear.

From the diameter point of view, the larger the diameter cross section, the greater the number of grids encountered of size greater than 20 cm; the smaller the diameter cross section, the smaller the number of grids encountered of size greater than 20 cm. Since the parameters for the shafts of the two study cases are the same, the trends in material change in the longitudinal section from the two cases are consistent. The results show that the material change in grids of size less than 2 cm in each case is scattered. The reason for the inaccuracy might be due to the size of the analysis grid, i.e., the unit grid size of 0.2 m by 0.2 m by 0.2 m far exceeds the particle size of less than 2 cm.

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