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ANALYZING PARAMETERS IN CONCRETE THRUST BLOCKS OF HORIZONTAL BENDS IN UNDERGROUND PVC WATER PIPELINES: A REGRESSION APPROACH

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ABSTRACT:

The dispersion of drinking water is regarded as a key service offered by countries. In piping networks, concrete blocks are applied to increase the stability of tees and bends which help to change the direction of water length. The purpose of this study is to enhance a parameter estimation model for concrete blocks of horizontal bends by developing a conceptual framework.

The height and width of the trench are quantified to identify the horizontal and vertical positions of the bend. A combination of cube and slump tests produces a quadratic regression model to estimate the maximum load a concrete block can bear. A compaction test then establishes a linear relationship between moisture content and dry density, aiding in determining the maximum load of compacted soil. Leaks in pipes and bends are assessed through pressure testing to calculate head loss and thrust force. The factor of safety for the bends is critical in estimating concrete block parameters. Seven algorithms, each with pseudo code and diagram, were developed in MATLAB to assess key factors and two approaches are used to compute the mean values of block parameters based on conceptual framework.

Keywords: bends, concrete blocks, conceptual framework, head loss, factor of safety

INTRODUCTION

A vast network of underground infrastructure makes up the underground water pipeline system. There are primarily two sub-networks that make up the piping network. These are transmission main and distribution main. Transmission lines are larger pipelines designed to transport huge volumes of water from a supply source, like a treatment plant, to storage. Smaller pipes called distribution lines are used to transport water from storage to a sink, such as a city [1]. PVC pipes are used for the distribution main and DI pipes for the transmission main.

Concrete thrust blocks are installed to prevent the movement of pipelines and maintaining the stability of pipelines. The stability of the bend is impacted by two load capabilities. They are the thrust block's (concrete) load capacity and the load capacity of compacted soil [2]. And also thrust blocks are critical components used in pipeline systems to resist the forces generated when the flow of liquid changes direction, such as at bends, dead ends, tees, and wyes. Their primary purpose is to safely transfer the force created by the fluid's hydrostatic pressure to the surrounding ground [3]. The objectives of the study mainly focus on following the regression analysis and constraints analysis using industrial tests highlighting a conceptual diagram. Objectives can be divided into two categories as follows:

Main Objective:

Analyzing to improve methods for estimating parameters in concrete blocks of horizontal bends in underground PVC water pipelines by using regression analysis.

Sub-Objectives:

1. Developing an algorithm to estimate parameters in concrete blocks of underground horizontal bends by generating pseudo codes, mat lab codes, and diagrams (flow charts).
2. Determining the ideal equations to take maximum load of the concrete cube and maximum dry density of soil with the support of regression analysis.
3. Constructing an inequality for maximum bearable load of the concrete block using force distribution method and geometrical techniques.
4. Constructing an inequality for factor of safety for bends using fluid dynamics concepts and geometrical techniques.

METHODOLOGY

Introduction of sample

The analysis is based on the secondary data that was collected from the test reports of the Katana (Negombo) water supply project. The optimum selection of parameters is found by testing thirty different sets of data. Those data sets will contain the maximum load of the concrete cube, the mass of the concrete cube, the slump of concrete, the maximum dry density of soil, optimum moisture content of the soil.

Methods of analysis:

According to the statistical method that shows the relationship between two or more variables, analysis was divided into two main categories. These are preliminary analysis and advanced analysis.

In the preliminary analysis,
Descriptive statistics of all graphical representations are made and **SPSS** Software is used for the findings of the analysis.

In advanced analysis,
The relations using correlation analysis and the relations between the independent variable and the dependent variable using the multiple linear regression method are found. Then, two models are fitted to the maximum load of the concrete cube and maximum dry density of soil separately. After that, **SPSS** Software is used for further calculations and findings of the analysis. Finally, pseudo codes are written for the entire process of the study [4].

Method of developing algorithm:

One equation and algorithm are built up to identify the placement of the bend in trench. Then, the constraints of slump test, cube test, compaction test and pressure test are identified and three algorithms are built up for satisfying the constraints of each test. The suitable multiple linear regression models are developed for the load of the concrete cube and maximum dry density of soil. Then, the regression equations are used for further calculations of the study. After that, two inequalities are derived using force distribution method, geometrical techniques and fluid dynamics concepts. Another two algorithms are built up for satisfying the both inequalities. Finally, an algorithm is built up to average the parameters of the concrete block as optimum set of values.

RESULTS AND DISCUSSION

Regression analysis 1

In regression analysis 1, a statistical technique is used to analyze the relationship between mass of the concrete cube, slump of the concrete and maximum load of the concrete cube. Mass of the concrete cube and slump of the concrete (independent variables) are manipulated to predict the changes in the maximum load of the concrete cube (dependent variable).

Distribution of dependent variable by independent variables

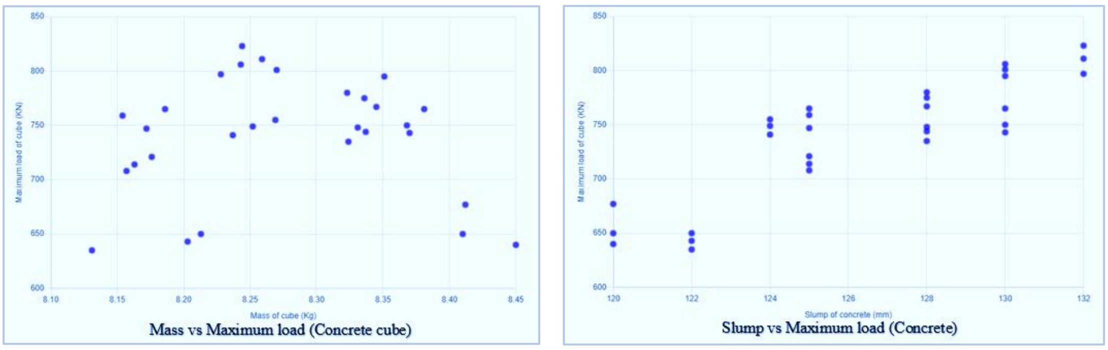


Figure 3.1: Graphical representation of mass and slump vs. maximum load of the concrete cube.

Figure 3.1A shows that the mass of the concrete cube doesn't have a linear relationship with the maximum load of the concrete cube since the plotted graph has a curly shape. Therefore, we consider squared term of the mass of the concrete cube.

Figure 3.1B shows that the slump of the concrete mixture has a positive linear relationship with the maximum load of the concrete cube.

Significance of the coefficients

Mass of the concrete cube and its squared term are used in the regression model as independent variables. But the mass of the concrete cube is not statistically significant because its p-value is not less than the usual significance level of 0.05. Only the squared term is significant. So, the mass of the concrete cube was dropped from the regression model.

Table 3.1: p - values and coefficients of Regression Analysis 1

Predictor	Symbol	Coefficient	P-value
Constant	β_0	-682.542	0.025
Mass of the concrete cube (Sq.)	β_1	-2.725	0.042
Slump of the concrete mixture	β_2	12.730	<< 0.001

According to the p - values of **Table 3.1,** we can conclude that there is a statistically significant association between the constant and the maximum load of the concrete cube since the p - value of the constant is less than the level of significance ($p = 0.025 < 0.05$). Also, we can conclude that there is a statistically significant association between the slump of the concrete mixture and the maximum load of the concrete cube since the p - value of the slump of the concrete mixture is less than the level of significance ($p = 0.001 < 0.05$). Also, we can conclude that there is a statistically significant association between the mass of the concrete cube (Sq.) and the maximum load of the concrete cube since the p - value of the mass of the concrete cube (Sq.) is less than the level of significance ($p = 0.042 < 0.05$).

Identified Regression model

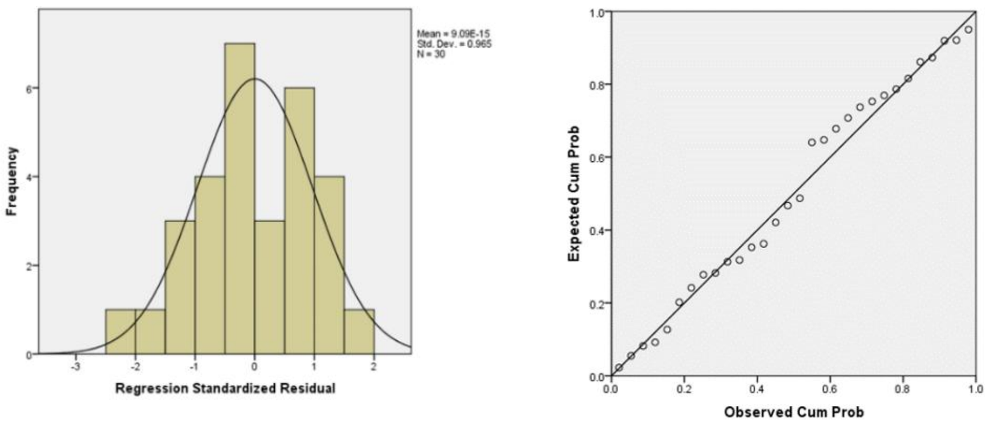
The curvilinear regression model takes the form of

$$y = \beta_0 + \beta_1 x_1{}^2 + \beta_2 x_2$$

$y -$ Maximum load of the concrete cube
$x_1 -$ Mass of the concrete cube
$x_2 -$ Slump of the concrete mixture
$\beta_0, \beta_1, \beta_2 -$ Constant and coefficients of independent variables

According to the stepwise method of curvilinear regression analysis, the **regression model:** $y = -682.542 - 2.725 x_1{}^2 + 12.73 x_2$

Normality checking for Analysis



A B

Figure 3.2: Histogram and Normal P-P Plot of the Residuals for Regression Analysis 1

Figure 3.2A shows that the histogram of the residuals has the symmetrical bell-shaped pattern of the Maximum load of the concrete cube and **Figure 3.2B** shows that the Normal probability plot of the residuals of the Maximum load of the concrete cube has the high density of points close to the diagonal line. Therefore, the residuals appear to be approximately normally distributed. Also, no outliers can be detected [4].

Homoscedasticity checking for Analysis

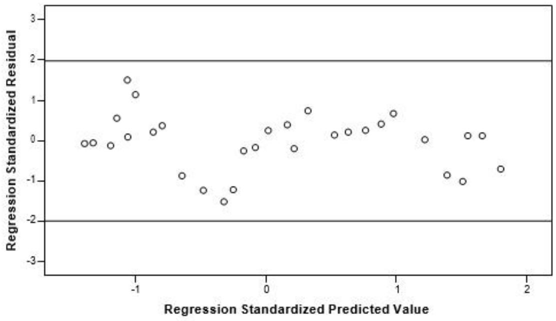


Figure 3.3: Scatter plot of the residuals for Regression Analysis 1

Figure 3.3 shows a random scatter of the points with a constant spread. Also, there is no clear pattern visible. No outliers and all residual points are between -2 and +2. Therefore, we can conclude that the residuals are homoscedastic [5].

Regression analysis 2

In regression analysis 2, a statistical technique is used to analyze the relationship between optimum moisture content of the soil and maximum dry density of the soil. Optimum moisture content of the soil (independent variable) is manipulated to predict the changes in the maximum dry density of the soil (dependent variable).

Distribution of dependent variable by independent variables

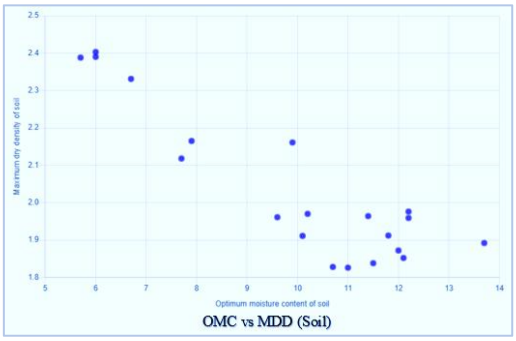


Figure 3.4: Graphical representation of OMC vs. MDD.

Figure 3.4 shows that the optimum moisture content of soil has a negative linear relationship with the maximum dry density of soil since the plotted graph has a linear decreasing shape.

Significance of the coefficients

Table 3.2: p - values and coefficients of Regression Analysis 2

Predictor	Symbol	Coefficient	P-value
Constant	β_0	2.78	<< 0.001
OMC of the soil	β_1	-0.075	<< 0.001

According to the p - values of **Table 3.2,** we can conclude that there is a statistically significant association between the constant and the maximum dry density of soil since the p - value of the constant is less than the level of significance ($p = 0.001 < 0.05$). Also, we can conclude that there is a statistically significant association between the optimum moisture content of soil and the maximum dry density of soil since the p - value of the optimum moisture content of the soil is less than the level of significance ($p = 0.001 < 0.05$).

Identified Regression model

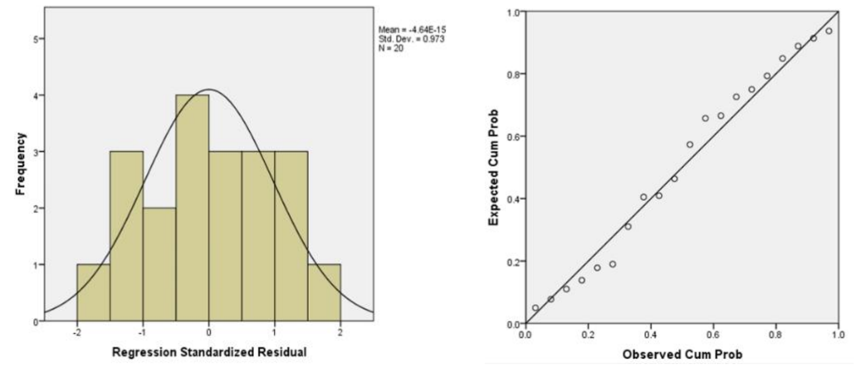
The linear regression model takes the form of

$$y = \beta_0 + \beta_1 x$$

$y -$ Maximum dry density of soil (MDD)
$x -$ Optimum moisture content of soil (OMC)
$\beta_0, \beta_1 -$ Constant and coefficient of the independent variable

According to the stepwise method of linear regression analysis, the **regression model:** $y = -0.075x + 2.78$

Normality checking for Analysis



A **B**

Figure 3.5: Histogram and Normal P-P Plot of the Residuals for Regression Analysis 2

Figure 3.5A shows that the histogram of the residuals has the symmetrical bell-shaped pattern of the Maximum dry density of soil. **Figure 3.5B** shows that the Normal probability plot of the residuals of the Maximum dry density of soil has the high density of points close to the diagonal line. Therefore, the residuals appear to be approximately normally distributed [4].

Homoscedasticity checking for Analysis

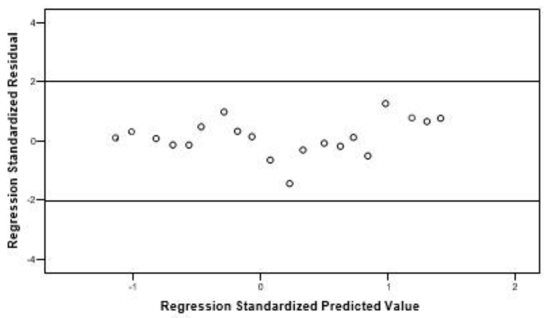
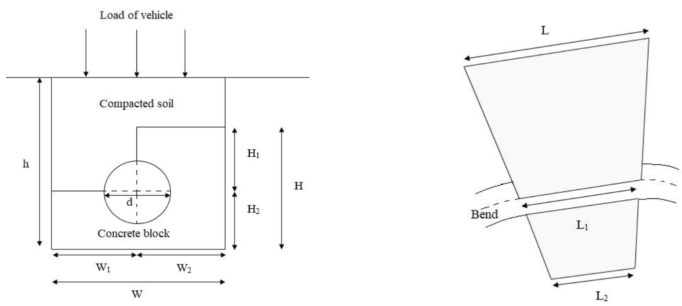


Figure 3.6: Scatter plot of the residuals for Regression Analysis 2

Figure 3.6 shows a random scatter of the points with a constant spread. Also, there is no clear pattern visible. No outliers and all residual points are between -2 and +2. Therefore, we can conclude that the residuals are homoscedastic [5].

Parameters and derived relationships



A **B**

Figure 3.7: Sketch of load capacities on concrete block with dimensional lengths.

Figure 3.7A shows the vertical cross-sectional image of the concrete block, compacted soil and water bend. And also, **Figure 3.7B** shows the horizontal cross-sectional image of the concrete block and water bend.

Parameters of the concrete thrust block

$\lambda_1, \lambda_2, \lambda_3, \lambda_4$ denote all the dimensional parameters of concrete thrust block. And also, L, H, W denote the length, height and width of the concrete block respectively. H and d denote the height of the trench and diameter of the bend respectively. Length of the concrete block is divided into L_1 and L_2. Height of the concrete block is divided into H_1 and H_2. Width of the concrete block is divided into W_1 and W_2. The ratios are given below.

$0 < \lambda_1, \lambda_2, \lambda_3, \lambda_4 < 1$

L_1/L_2 $= \frac{\lambda_1}{\lambda_2}, \frac{H_1}{H_2} = \frac{\lambda_3}{(1-\lambda_3)}, \frac{W_1}{W_2} = \frac{\lambda_4}{(1-\lambda_4)}$

Relationship for the bearable load of the concrete block

The following inequality is derived using the force distribution method and geometrical techniques.

$$\left\{\begin{matrix}\text{Maximum}\\ \text{bearable}\\ \text{load of}\\ \text{concrete block}\end{matrix}\right\} \geq \left\{\begin{matrix}\text{Maximum}\\ \text{load of}\\ \text{compacted soil}\end{matrix}\right\} + \left\{\frac{1}{4} \times \left\{\begin{matrix}\text{Maximum}\\ \text{load of}\\ \text{container}\end{matrix}\right\}\right\} + \left\{\begin{matrix}\text{Load of}\\ \text{water length}\\ \text{through bend}\\ \text{at maximum speed}\end{matrix}\right\}$$

$\left(\frac{A}{A_1}\right)(-682.542 - 2.725M^2 + 12.73l) \geq 1.3V(-0.075\,\mathrm{OMC} + 2.78)g + \frac{1}{4}G_{max} + V_1\rho g$

A_1 = Surface area of one side (concrete cube), A = Surface area of the top of the concrete block, M = Mass of concrete cube, l = Slump of concrete mixture, V = Volume of soil on the concrete block and bend, OMC = Optimum moisture content, G_{max} = Maximum load of the container, V_1 = Volume of water length through bend per second, ρ = Wet density of compacted soil

Relationship for the factor of safety of bends

The following inequality is derived using the fluid dynamics concepts and geometrical techniques.

Factor of safety $= \frac{\text{Weight capacity of (concrete block+soil)} + \left(\frac{1}{4}\right) \text{weight capacity of vehicle}}{\text{Internal resultant force}}$

$\mathrm{FOS} = \left[\frac{V_1\left(\frac{M}{V_0}\right)g + V_2(WD)g + \left(\frac{1}{4}\right)K}{2PA\sin\left(\frac{\beta}{2}\right)}\right]$

FOS > 1.5

$$V_1\left(\frac{M}{V_0}\right)g + V_2(WD)g + \left(\frac{1}{4}\right)K > 3PA\sin\left(\frac{\beta}{2}\right)$$

V_1 = Volume of concrete block on the bend, V_2 = Volume of soil on the concrete block and bend, M = Mass of concrete cube, V_0 = Volume of the concrete cube, WD = Wet density of soil, K = Weight of the vehicle, P = Internal pressure of the bend, A = Cross-sectional area of the bend, β = Bending angle

Comparison of the parameters

The derived two inequalities produce relevant series of $\boldsymbol{\lambda}$ values in topic **3.3.2** and **3.3.3**. But, the main aim of this comparison is to estimate the best value of each $\boldsymbol{\lambda}$ parameter ($\lambda_1, \lambda_2, \lambda_3, \lambda_4$). The ultimate output will indicate the mean-valued $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ series or at most two series. So, this series gives the best values for the parameters of the concrete thrust block. The optimal equation is given below.

$\lambda_n = \frac{\text{Total summation of } \lambda \text{ parameters}}{\text{Total number of } \lambda \text{ parameters}}$, Where n = 1, 2, 3, 4

Conceptual Framework for development of Algorithm

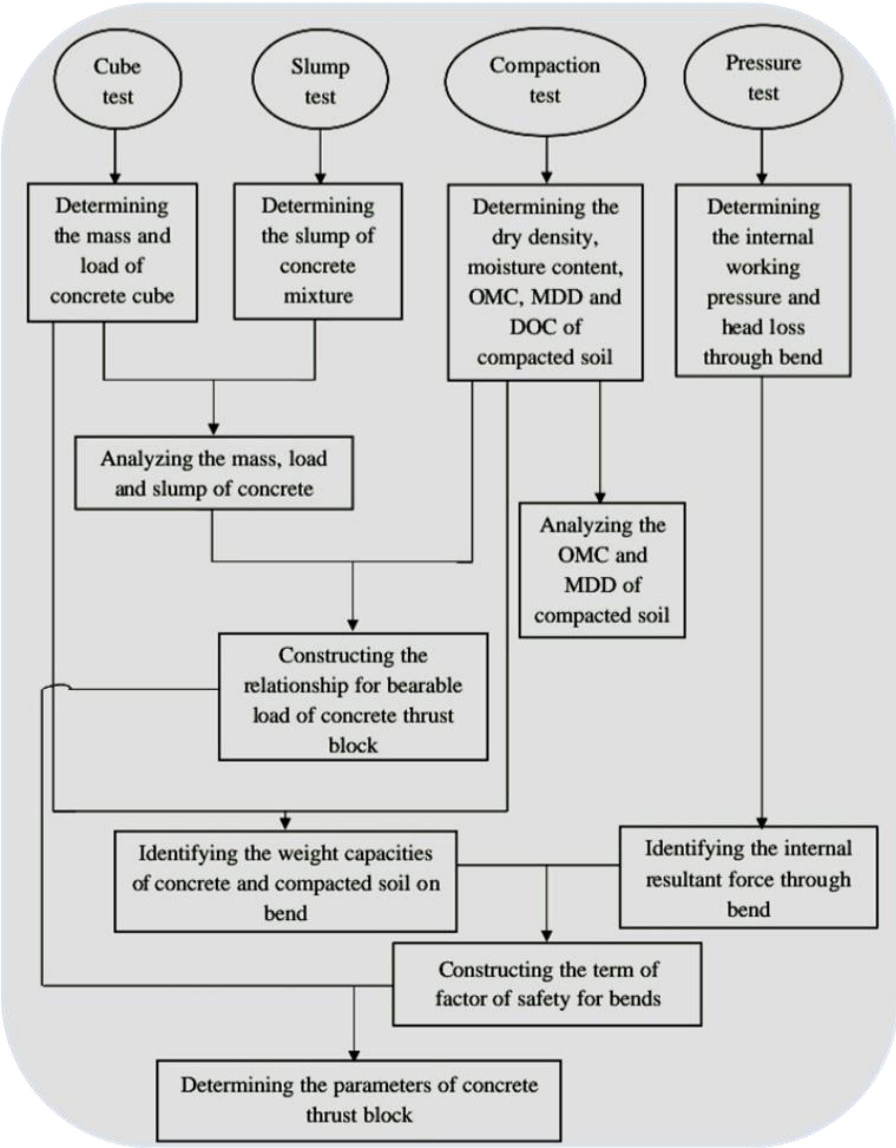


Figure 3.8: Conceptual framework.

Figure 3.8 shows a visual model for the development of algorithm in our study. This framework is an organized set of ideas and principles that guides the research. It acts as a foundational plan for comprehending and examining the research study. The framework describes how the central concepts are connected. It details the relationships among various ideas and clarifies how they impact one another. Every branch of the framework has its own pseudo code set and diagrammatic representation (flow chart). All flowcharts represent the mechanisms of seven pseudocodes.

CONCLUSIONS

We should always consider the safety and toughness of bends when laying concrete blocks in trenches and doing other particular tests like pressure tests, slump tests, cube tests, and compaction tests. Because the quality of the applied concrete block and the tests utilized both affect how safe bends are. The bearable load of the concrete cube is primarily determined by its mass and slump, and it should be greater than the load of compacted soil, a quarter of the load of a vehicle, and the weight of water traveling through a bend. The maximum load of the concrete cube is strongly correlated and statistically significant with the concrete slump. However, neither a strong linear relationship nor a statistically significant association exists between the mass of the concrete cube and its maximum load. The optimum soil moisture content and the maximum dry density of the soil are statistically significantly associated with one another. The weight capacity of the concrete block, the weight capacity of the soil, a quarter of the weight capacity of the vehicle, and the inner resultant force of the bend are the key components that affect the safety factor value for bends.

The seven algorithms were developed to estimate parameters in concrete blocks of underground horizontal bends by using mat lab codes as source codes and the diagrammatic representations of the algorithms were also given. The pseudo codes of these algorithms cover the entire process of conceptual framework. The height and width of the trench, the maximum bearable load of the concrete block, factor of safety of bends, degree of compaction of soil is provided through the processing of constructed algorithms. These algorithms have more benefits such as increasing time efficiency and cost effectiveness, easy to understand for anyone, just need to enter the data, not necessary a mathematician when working on algorithm, not dependent on the other programming languages, easy to convert into an exact program. By averaging the results from the two approaches, the fundamental solutions of parameters of concrete blocks are determined.

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