Scientific Journal Impact Factor (SJIF): 5.278
International Journal of Modern Trends in Engineering and Research
ISSN (ONLINE) : 2349 - 9745 ISSN (PRINT) : 2393 - 8161

SOFTWARE ANALYSIS AND MODEL STUDY OF SOIL NAILED WALL

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Abstract-In the recent past, urbanization is increasing in geometric proportion .This calls for the optimum utilization of available land, which is limited, by providing underground structures and tall buildings. This makes the need for deep excavation, which is a technically challenging problem. The use of the "NAILED SOIL WALL" technique is proved as one of the economical temporary retaining structures for deep excavation and is being practiced worldwide. In this project "SNAILZ software" which is a widely used computer program developed by CALTRAN division of materials and foundation is used to analyze a nailed soil wall. It uses soil and nail parameters such as nail diameter and inclination to arrive at the minimum factor of safety. Analysis of selected nailed wall was carried out with software program and is compared with the experimental results. The difference in working load calculated using SNAILZ software and from experiments was found to be less than 10%.Which shows a good agreement between the experimental results and the results obtained from numerical analysis.
Keywords- Snailz software, Nailed soil wall, Caltran, Model tank.

I. INTRODUCTION

In the recent past the demand on land for various infrastructure developments is increasing exponentially and this problem is severe particularly in urban cities. Rapid urbanization calls for optimum utilization of available space. This has been achieved by way of providing underground structures and tall buildings or in combination. All these activities call for deep excavations in the well developed and congested areas. The execution of deep excavation works in the urban environment is a technically challenging problem. It involves many steps including specifications of responses to construction difficulties, field observation and monitoring and ensuring stability of existing neighbouring facilities. Nailed soil wall is proved as one of the economical temporary retaining structure for the deep excavation and are being practiced worldwide.

Soil nailing is an insitu soil reinforcement technique that has been used during the last two decades mainly in France and Germany to retain excavation or slopes. The origin of soil nailing can be traced to a support system for underground excavations in rock referred to as the "New Austrian Tunnelling Method". One of the first applications of soil nailing was in 1972 for a railroad widening project near Versailles, France, where an 18m high cut slope in sand was stabilized using soil nails. The first research program on soil nail walls was undertaken in Germany from 1975 to 1981 by the University of Karlsruhe and the construction company Bauer. In France, the Clouterre research program involving private and public participants was initiated in 1986.The first published applications of soil nailing in the United States was the support of the 13.7m deep excavation in dense silty lacustrine sands for the expansion of the Good Samaritan hospital in Portland.

II. ANALYSIS OF NAILED SOIL WALL USING SNAILZ PROGRAM

GENERAL

Engineers at CALTRANS Division of materials and foundation have developed a soil nailing program SNAILZ (3xx) which uses a 2 or 3 part wedge analysis for determining the minimum factor of

safety in a one to seven layer soil system with interstice forces included. The factor of safety is determined by iteration. The problem includes options for two surcharges, water table, earthquake loading, two slopes below the toe of the wall, failure surfaces day lighting from points below the toe of the wall, and an externally applied horizontal or inclined wall force. The Program can also be used for slope stability analysis with and without reinforcement.

III. ANALYSIS OF NAILED SOIL WALL HOMOGENOUS SOIL

A soil profile of the selected case study consists of one number layer. It is difficult to interpret the influence of friction angle, nail diameter, nail inclination, spacing of nails in the global and nail factor of safety for a layered soil profile. Hence to understand the above influence single layer soil nailed wall was considered. The input parameters for the single layer soil nailed wall are briefed below.

INPUT PARAMETERS

1. Wall geometry
   Wall height = 9m
2. Soil parameter

No of layer = 1
Unit weight = 18 .5 kN/m^3
Friction angle = 38°
Cohesion intercept = 0

3. Reinforcement parameter

No. of reinforcement level = 9
pacing Sh and Sv 1 = 0.5 m
Dia of reinforcement = 16, 20 and 24mm bar
Yield stress = 415 N/mm^2
Dia of grouted hole = 100mm
Reinforcement length = 7.2 m

4. Bar driving inclination = 10°, 20°, 30°
5. Surcharge load = 10 kN/m
6. Search limit = 27m

OUTPUT RESULTS

The parameters like nail diameter, inclination degree were varied in the analysis. The output includes the stress in the each nail, maximum nail stress, average working load for factor of safety equal to one and a complete graphical illustration with all details such as critical failure surface and global factor of safety. Table1. shows the global factor of safety of the nailed wall with varying design factors such as nailing inclination and nail diameter.

Table1. Constant Spacing 0.5m with varying inclinations and diameter of reinforcement for friction angle 38^0

S.No	Inclination	Global Factor of Safety		
		16mm Dia	20 mm Dia	24mmDia
1	10	1.95	2.17	2.34
2	20	1.74	1.95	2.11
3	30	1.52	1.74	1.88

- Increase in nail diameter increases the global factor of safety. For 10° inclination, global factor of safety for 24mm diameter is 2.34 and it reduced to 2.17 for 20mm diameter and 1.95 for 16mm diameter nail bars.

- Increase in inclination of nail reduces the global factor of safety. For 16mm diameter nail, global factor of safety for nails inclined at 10° is 1.95 and it reduced to 1.74 and 1.52 for 20° and 30° inclination of nails.
- From the above observation, the global factor of safety for 16mm diameter nail inclined at 30° is close to the recommended value (1.35) compared to other sizes of nails and inclination and hence this parameter of soil nailed wall is considered to proportionately design the model tank.

PROCEDURE TO CALCULATE THE DESIGN LOAD FROM SOFTWARE ANALYSIS

- Use the nail diameter and nail inclination calculated in SNAILZ program preliminary design as the input nail
- To achieve a balanced design for all internal failure modes, the soil strength must be fully mobilized consistently with the full mobilization of the nail tensile strength at the same time. In other words, when FSG = 1.0 (full soil mobilization), the safety factor for the tensile strength, FST = 1.0 (full nail tensile mobilization). The nail tensile force for this condition is the maximum design force in the nail (Tmax-s). It is intuitive that when the loads kept constant, the design force Tmax-s will increase when FSG > 1.0. This is caused because for FSG >1, the soil strength is not fully mobilized and the tensile forces must compensate to achieve equilibrium. Therefore, calculating Tmax-s directly from the global stability analysis giving FSG > 1 is more conservative.
- The program SNAILZ automatically reports the average nail tensile force, but not the maximum tensile force corresponding to FSG = l. Thus, to estimate the maximum nail tensile force for a FSG = l without performing an additional stability analysis, the following simplified method can be used.
- This procedure is based on the fact that the ratio of the maximum nail load calculated by SNAILZ, Tmax, to the average nail load, Tavg, for FSG > 1, is similar to the ratio of the maximum nail load for FSG = 1, Tmax-s, to the average nail load, Tavg-s, for FSG =1. Therefore, a good approximation of the maximum design nail load (Tmax-s) can be obtained by the following relationship.

Tmax-s = (Tavg -s/Tavg) x Tmax..... (1)
Tmax-s = Design soil nailed load in kN.
Tavg–s = Average working load for factor of safety equal to one.
Tavg = sum of individual nail force / number of nails.
Tmax = maximum nail force.

IV. EXPERIMENTAL PROGRAMME

In the experimental investigation, there is in a difficulty to exactly replicate the procedure that followed in the field. The main objective of the experimental investigation was to study the load carrying capacity of soil mass with and without nail and compare its working load with the design load calculated using SNAILZ software program. Hence nailed soil wall was constructed as briefed below and loaded to observe ultimate load carrying capacity of model wall. It is assumed that the difference in the procedure in the field and laboratory will not have or have little effect.

Experimental facility that is available to carry out model test on nailed soil wall consists of

- Model tank
- Instrumentation
- Loading System
- Facing
- Nail
- Test media

Model tank

The tank was made up of 4 mm Mild steel sheets welded together and stiffened with suitable angle sections. The size of the tank was 700mm x 300mm x 300mm. One of its shorter faces was provided with hole of 10 mm diameter to insert nail.

Instrumentation

When the load was applied, the structure may move both vertically and horizontally. The arrangements were made to measure the vertical movements of soil and to measure the horizontal movements of nails by using dial gauges.

Loading System

A steel plate of size 650mm x 300 mm x 4mm and 300mm x 150mm x 4mm was kept over the model wall in horizontal and vertical direction respectively. The plate was rigid and distributed the applied load equally over its entire area. The load was applied on the plate by loading frame arrangement.

Facing

In actual soil nailed cuts, where the soil can stand unsupported for excavation depth of about 0.5 m to 1.0 m, a shotcrete or precast panel facing is commonly used. Since dry sand was used in these tests, a vertical excavation face could only be maintained using as a rigid facing. A 10 mm thick ply board was used as a pre-placed continuous facing. Circular holes of diameter 9 mm were made on preplaced continuous facing. Fig.a shows the diagram of the model tank with vertical facing.

Nail

An 8mm mild steel rod is used as nail material in this model study. A nail placed in model wall is shown in Fig.c

TEST MEDIA

Medium dry sand, classified as SP in the Indian Classification System, is used as test media. Figure.c presents the grain-size distribution curve for the sand. The minimum dry density of the sand is determined as 18.50 KN/m^3. The properties of sand are summarized in Table 2.

Figure. 1 - Model tank with vertical facing Figure. 2 -Tank filled with sand

Figure. 3 - Nail placed in model tank

EXPERIMENTAL PROCEDURE

Preliminary analysis of soil nailed was conducted in SNAILZ software to select the dimension of model tank for experimental investigation. The procedures followed for carrying out the experiment were briefed below. Height of the structure was selected as 300mm.

Table 2. Properties of Sand

S.No	Property	Symbols and Units	Values
1	Specific gravity	G	2.67
2	Coarse sand	%	12
3	Medium sand	%	73
4	Fine sand	%	15
5	Effective size	D_{10}	0.31
6	Coefficient of uniformity	C_u	3.23
7	Coefficient of curvature	C_c	1.16
8	Classification	SP	Poorly graded
9	Angle of internal friction	φ	38

Test Procedure

The following procedure was adopted for the construction of nailed soil wall. Ply board facing was placed vertically across the tank at a distance of 650mm from rear end of tank as shown in Fig.a. The facing was brought to absolute vertical position with help of tri-square and was clamped at the top to avoid the lateral movement of facing during filling of tank. Support was also given at the bottom of board during construction.

The narrow gaps between the facing and the tank sides were closed properly along the length. The sand was filled at a density of 18.5KN/m^3.

When the tank was filled, top surface of sand was leveled properly as shown in figure. b and predetermined numbers of nails was placed.

After the construction of nailed wall, the clamps holding the wall and also support placed at the bottom were removed. After the construction of nailed soil wall, the load test was carried out using load frame assembly. The load versus settlement was recorded at zero surcharges and at the each increment

in the surcharge of loading till the failure of nailed wall occurred. Figure.d shows the loading arrangement of nailed wall.

Similarly procedure is carried in the same model earth wall without placing nail and loading arrangement is shown in Figure.e

Figure.4 Loading arrangement with nails

Figure.5 Loading arrangement without nails

V. RESULT AND DISCUSSION

GENERAL

Main objective of this research is to compare the working load calculated from SNAILZ software with experimental result. Laboratory test were carried out in model tank of size 700mm x 300mm x 300mm. Physical properties of soil are presented in Table.2 .Results of model test is summarized in Table.3 to 4. The load versus settlement was recorded at zero surcharges and at the each increment in the surcharge of loading till the failure of earth wall occurred and results are shown graphically in figure.f and g.

After construction of model soil nailed wall, test is carried out and results obtained are shown below.

Table 3. Load versus Settlement Tabulation (with nails)

LOAD kN	SETTLEMENT mm
0.1208	0.8
0.2416	1.95
0.3624	2.95
0.4832	4.25
0.604	6.78
0.7248	8.52
0.8456	11.55
0.9664	14.55
1.0872	16.55
1.208	19.56
1.3288	22.147
1.4496	24.5

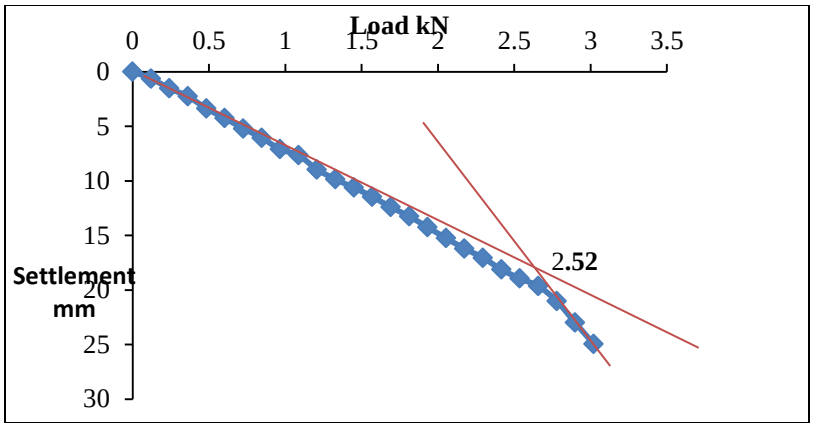

Figure 6 Load versus Settlement graph(with nail)

Similarly the test procedure is carried out In the model tank without inserting the nail and result is shown below.

Table 4. Load versus Settlement tabulation (without nail)

LOAD kN	SETTLEMENT mm
0.1208	0.8
0.2416	1.95
0.3624	2.95
0.4832	4.25
0.604	6.78
0.7248	8.52
0.8456	11.55
0.9664	14.55
1.0872	16.55

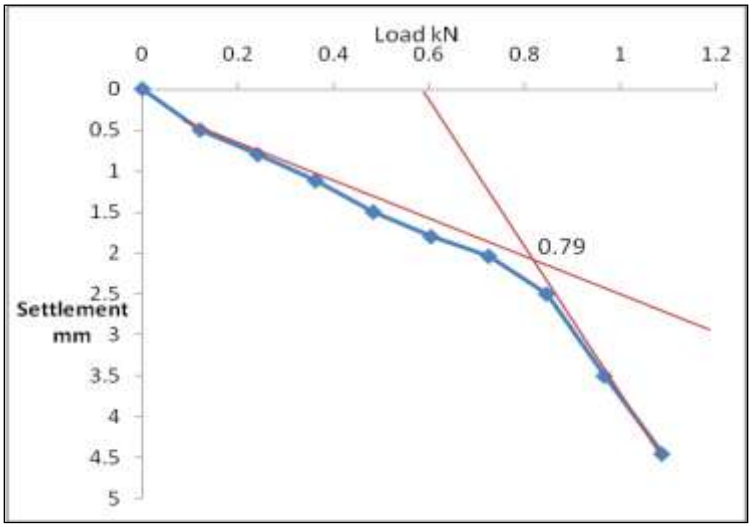

Figure.7 Load versus Settlement graph(without nail)

From the Figure.f and g ,the ultimate load carrying capacity is calculated for both the cases and it shows that ultimate capacity of soil mass is increased from 1.02 to 2.36 when nail is inserted.

Experimental Results

From Figure.f the ultimate capacity of model soil nailed wall is found as 2.52 and with factor of safety as 1.52,working load for soil nailed mass is calculated using following relationship

Working load = Ultimate load / factor of safety

- Working load = 2.52/1.52 = 1.65 kN

SNAILZ Result

From equation.1, design load computed is shown below

- Tmax = (35/232.412) x 349.914
- Design load = 52.69 kN
- Ratio 1:30
- Design load = 52.69/30 = 1.75kN

Comparison of experimental and numerical results

Working load of soil nailed wall is calculated, using SNAILZ SOFTWARE and also by conducting a load test on proposed model soil nailed wall, working load is 1.75 kN and 1.65 kN respectively. Error in working load calculated using software and experimental program is found as 6%.

VI. CONCLUSIONS

Following conclusion were drawn from the present study.

1. In the analyses of nailed wall, influences of nail diameter and nail inclination were studied using SNAILZ software program. Result showed that the increase in nail diameter decreases the global factor of safety and increase in nail inclination increases the global factor of safety.
2. Global factor of safety for 16mm diameter nail and 30^o inclination is close to the recommended value of 1.35 compared to other diameters of nail such as 20mm, 24mm and inclination of 10^o, 20^o. Hence, nail with diameter of 16mm and 30^o was considered to be optimum design parameter.
3. Laboratory scale test was conducted on soil with and without intrusion of nail to find the working load. The result shows that the load carrying capacity of earth wall increases when nail is introduced.
4. Based on the SNAILZ output, working load is calculated based on FHWA (2003) guidelines for soil nailed wall and this is compared with the experimental result.
5. The working load of nailed wall using the software was found to be 1.75 kN and from experimental study was observed to be 1.65 kN.
6. The result were compared and found that there was a good agreement in the carrying capacity of a nailed wall from the numerical and experiment study.

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