BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LVI (LX), Fasc. 2, 2010
Secţia
CONSTRUCŢII. ĂRHITECTURĂ

ANALYSIS OF SLOPE STABILITY USING LIMIT EQUILIBRIUM

BY

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Abstract. In achievement of slope load sustainability using mixed soil technique, is considered acceptable the method for slope construction technology. This paper deals with evaluation of mixed soil technique for construction of stable slope and proves the soil capability by analysis of computerized modeling, the revealed result of investigation, the possibility of using nearest local material, reducing project cost, solving the construction geotechnical problem and accurate understanding of soil property when it is developed under different types of geometry.

Key words: modeling; mixed soil; liquefaction and soil foundation geometry.

1. Introduction

Several methods could be applied in increasing slope stability, in a scientific work computer modeling and analysis of slope stability is advanced and accurate technique in construction of safe slope is utilized.

It has been reported a real-coded genetic algorithm (GA), used to find out the factor of safety for the soil slopes using wedge method. The analysis is formulated as constrained optimization problem to solve the nonlinear equilibrium equation and finding out the factor of safety [1]. There is an investigation on the stability of slope. It is one of the most important problems in stability analysis of geomechanics. The limit equilibrium method was used and it is considered as 2-D plane strain problem with no variation in geometry, material and surcharge in direction parallel to the crest of the slope. The problem lies in finding out the critical failure surface and its corresponding factor of safety (FOS) [2], [3]. It is presented the three-wedge method for stability analysis of slopes, which is a force equilibrium method [4]. There is a scientific research on different moisture contents of rock and soil, it can influence the slope stability, especially for the weathered state and it is much sensitive to water. Based on water character experiment of completely weathered state, and according to the wedge theory under plane strain condition, analysis is proposed on not only the stress field of the excavation of high cut slope but also on the excavation disturbance effect under different moisture content according to Mole-Coulomb strength criterion and uniaxial tensile strength criterion after safety margin, which could provide theoretical support to the actual excavation works and effective reinforcements [5]. It has been studied influence of root trees on slope stability and different factors like slope geometry and gradient, geologic materials, stratigraphy, hydrology, and the local effects of shore processes have been analysed too [6].

Table 1

Mixed Soil Models [7]

Sl. No	Red soil %	Sand %	Gravel 4.75 mm %	Gravel 2 mm %	Black soil %	Green soil %	Dark brown soil %	Yellow soil %	Light brown soil %
1	100	0	0	0	0	0	0	0	0
2	55	45	0	0	0	0	0	0	0
3	55	0	0	0	0	0	0	0	0
4	55	0	0	45	0	0	0	0	0
5	55	15	15	15	0	0	0	0	0
6	55	0	0	0	45	0	0	0	0
7	55	0	0	0	0	45	0	0	0
8	55	0	0	0	0	0	45	0	0
9	55	0	0	0	0	0	0	45	0
10	90	0	0	0	2	2	2	2	2
11	80	0	0	0	4	4	4	4	4
12	70	0	0	0	6	6	6	6	6
13	60	0	0	0	8	8	8	8	8
14	50	0	0	0	10	10	10	10	10
15	70	0	0	0	10	10	10	0	0
16	70	0	0	0	10	10	0	10	0
17	70	0	0	0	10	10	0	0	10
18	70	0	0	0	10	0	10	10	0
19	70	0	0	0	10	0	10	0	10
20	70	0	0	0	10	0	0	10	10
21	70	0	0	0	15	15	0	0	0
22	70	0	0	0	15	0	15	0	0
23	70	0	0	0	0	0	0	15	15
24	70	0	0	0	15	0	0	15	0
25	70	0	0	0	15	0	0	0	15
26	70	0	0	0	0	15	15	0	0
27	70	0	0	0	0	15	0	15	0
28	70	0	0	0	0	15	0	0	15
29	70	0	0	0	0	0	15	15	0
30	70	0	0	0	0	0	15	0	15
31	55	0	0	0	0	0	0	0	45

Characteristics of 31 mixed soils under loose optimum moisture content (OMC) condition in the laboratory have been determined and using computer modeling, characteristics of slopes have been evaluated.

2. Methodology and Experiments

The computerized mixed soil sample modeling is a novel method of solving geotechnical problems. It is quite clear that a mixed soil characteristic is totally different from individual soil.

Earth slopes are formed for railway formation, highway embankment, earth dam, canal banks and many earth structures. In slope construction from mixed soil for increasing slope stability, different types of soil with proper percentage is best option employed; in this regard 31 mixed soil types from red plastic soil and black, green, dark brown, yellow and light brown non plastic soils, sand, and two types of gravels (2 mm, 4.75 mm) developed, and also from previous investigation (Table 1) safe bearing capacity, angle of friction, unit weight and cohesive of mixed soils sample for computerize model have been used, the Geo-Slope software in identification of models behavior employed and the results of these modeling research work by interpretation of mixed soil types characteristics and slope computerized model evaluated.

3. Results and Discussion

Identification of laboratory developed mixed soil behavior in the construction activities is possible through the application of computerized modeling for safe, stable and reliable approaching any earth structure. Increasing dimension of slop has exhibited positive correlation with soil cohesion, pore water force, base shear force and base normal force (Figs. 1,…,7 and Tables 3,…,6).

Sand is very vulnerable against liquefaction but under loss condition if mixed with red plastic soil could results in reduction of liquefaction and pore water pressure. Mixture of gravel mitigated of pore water force as well as shear force. The result revealed when the level of soil cohesion force is half of cohesion strength, the maximum pore water pressure appeared, it could be empirical applicable at preanalysis of any slope construction. Due to complicate character of soil characteristics when it is under load and used for construction material, it is essential to evaluate the cohesion, pore water force, base shear force, base normal force and factor of safety of soil by computing modeling at any soil structure, these are deduced from different behavior of slopes model. Analysis of slope has close similarity with structure analysis, it is observed that all load sustainability, deformation, settlement, reliability and safety of soil structure not depend only on strength of material, but soil structure geometry also represents one of the important factors in the design and analysis of slope.

Table 2

Experiments Results of Mixed Soil under Loose OMC Condition [7]

Sl. No	Model No	OMC, [%]	γ, [kN/m^3]	Φ, [degrees]	*C*, [kN/m^2]
1	1	11.2	10.8	27	10
2	2	10.61	10.29	33.5	0
3	3	10.72	14.4	23	14
4	4	12.15	13.61	32	4
5	5	9.58	13.32	27	16
6	6	22.39	11.35	24	6
7	7	18.86	11.62	31	4
8	8	14.56	14.41	20	10
9	9	14.23	11.08	28.5	10
10	10	16.83	10.11	32	10
11	11	18.27	10.6	25	8
12	12	16.76	11.8	20	24
13	13	20.21	12.23	17	14.5
14	14	18.68	11.2	21	14
15	15	19.34	11.5	21	10
16	16	16.55	9.99	23.5	20
17	17	21.14	11.27	18	19
18	18	20.79	12.89	13	20
19	19	16.31	10.05	26.5	8
20	20	20.88	10.29	25	18
21	21	23.00	10.9	22	20.5
22	22	20.06	10.23	21	15
23	23	20.11	11.08	12	22
24	24	20.75	9.69	28.5	7
25	25	22.69	9.99	18	11
26	26	18.87	10.78	22.5	8
27	27	20.31	9.99	19.5	2
28	28	19.51	10.9	21	14
29	29	20.52	10.72	15	16
30	30	18.99	10.9	18	14
31	31	14.56	11.2	26	2

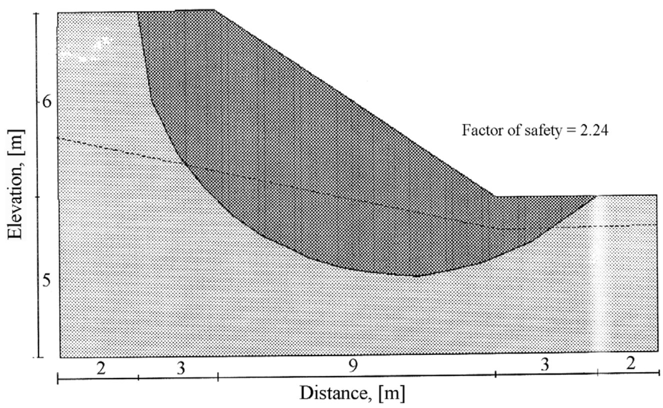

Fig 1. Shape of failure in the slope type 1.

Table 3
Analytical Results of Slopes Types 1 by Morgenstern–Price Method

Sl. No	Model No	Factor of safety	Total volume m^3	Total mass kg	Total resistance moment kN. m	Total activating moment kN. m	Total resisting force kN	Total activatig force kN
1	1	2.24	58.215	628.72	3,734	1,667.2	345.88	154.6
2	2	1.453	37.275	383.55	1,253.5	8,62.86	127.19	87.726
3	3	–	–	–	–	–	–	–
4	4	1.956	48.589	661.3	3,444.5	1,761.1	352.05	180.19
5	5	2.635	58.215	775.43	5,417.8	2,056.2	501.57	190.49
6	6	1.682	58.215	660.74	2,946.5	1,752.1	276.45	163.51
7	7	1.884	48.589	564.61	2,832.8	1,503.6	287.76	152.96
8	8	1.72	48.589	700.17	3,207.1	1,864.6	318.85	184.32
9	9	2. 311	58.215	645.02	3,953.3	1,710.4	367.27	159.19
10	10	2.546	58.215	588.55	3,973.6	1,560.7	368.45	144.77
11	11	1.942	58.215	617.08	3,177.4	1,636.3	295	152.6
12	12	–	–	–	–	–	–	–
13	13	2.057	58.215	711.97	3,884.3	1,887.9	353.74	172.02
14	14	2.294	58.215	652.01	3,965.6	1,728.9	362. 31	158.08
15	15	1.896	58.215	669.47	3,365.1	1,775.2	310.66	163.46
16	16	6.082	21.937	219.15	2,494.6	410.13	280.42	46.109
17	17	–	–	–	–	–	–	–
18	18	–	–	–	–	–	–	–
19	19	2.035	58.215	585.06	3,157.9	1,551.4	292.77	144.22
20	20	2.993	58.215	599.03	4,754.4	1,588.5	431.6	144.25
21	21	5.737	21.937	239.11	2,567.4	447.49	288.92	50.296
22	22	2.49	58.215	595.54	3,931.8	1,579.2	356.78	142.88
23	23	–	–	–	–	–	–	–
24	24	2.04	58.215	564.1	3,051.9	1,495.8	283.63	138.93
25	25	1.948	58.215	581.57	3,004	1,542.1	273.12	140.65
26	26	1.809	58.215	627.56	3,009.9	1,664.1	279.03	153.65
27	27	1.046	37.275	372. 37	876.61	837.7	86.947	83.595
28	28	2.32	58.215	634.54	3,903.6	1,682.6	355.91	153.9
29	29	–	–	–	–	–	–	–
30	30	2.176	58.215	634.54	3,661.8	1,682.6	332.55	152.97
31	31	1.396	37.275	417.47	1,311	939.17	132.06	94.717

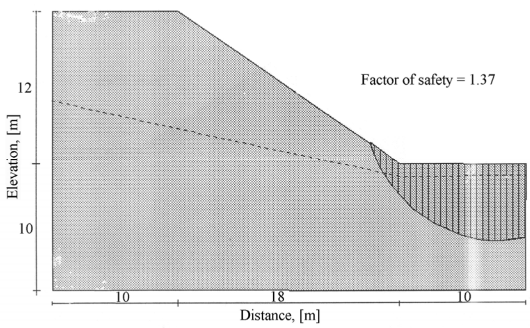

Fig 2 – Shape of failure in the slope type 2.

Table 4

Analytical Results of Slopes Types 2 by Morgenstern–Price Method

Sl. No	Model No	Factor of safety	Total volume m^3	Total mass kg	Total resistance moment kN. m	Total activating moment kN. m	Total resisting force kN	Total activatin g force kN
1	1	1.37	55.421	598.54	2,439	1,780.7	185.73	135.83
2	2	0.5766	55.421	570.28	978.19	1,696.6	81.615	142.15
3	3	1.62	123	1771.2	13,236	8,168.4	666.39	410.94
4	4	1.241	55.421	754.28	2,784	2,244	225.46	180.7
5	5	1.913	58.958	758.32	5,011	2,618.8	349.17	183.16
6	6	0.9826	55.421	629.03	1,838.8	1,871.4	142.69	146.08
7	7	1.015	55.421	643.99	1,945.3	1,915.9	155.82	152.51
8	8	1.28	123	1772.4	10,462	8,174	529.29	411.58
9	9	1.416	55.421	614.06	2,587.4	1,826.9	198.14	140.04
10	10	1. 405	55.421	560.3	2,341.2	1,666.9	178.07	126.92
11	11	1.134	55.421	587.46	1,982.4	1,747.7	151.38	133.59
12	12	2.147	167.22	1973.2	20,000	9,313.8	922.3	430.34
13	13	1.45	167.22	2045.1	13,995	9,653.2	652.46	449.05
14	14	1.575	123	1377.6	10,005	6,353.2	489.82	312.99
15	15	1.276	55.421	637.34	2,418.8	1,896.1	183.62	144.27
16	16	2.105	167.22	1670.3	16,601	7,885.1	761.2	361.9
17	17	1.794	167.22	1884.6	15,961	8,895.4	735.23	410.89
18	18	1.659	123	1585.5	12,127	7,311.8	589.67	355.73
19	19	1.118	55. 421	556.98	1,852.8	1,657	140.74	126.04
20	20	2.004	167.22	1720.7	16,278	8,121.9	750.81	375.19
21	21	2.049	167.22	1822.7	17,624	8,603.4	812.18	397.24
22	22	1.664	167.22	1710.7	13,432	8,074.6	619.1	372.84
23	23	1.917	123	1362.9	12,046	6,285.1	578.37	300.98
24	24	1.008	55.421	537.03	1,610.4	1,597.7	122.65	121.83
25	25	1.281	123	1228.8	7,256.5	5,666.8	352.15	273.5
26	26	1.101	55.421	597.44	1,956.1	1,777.4	149.04	135.55
27	27	0.4358	55.421	553.65	717.86	1,647.1	56.391	131.75
28	28	1.579	123	1340.7	9,763. 3	6,183	476.96	302.91
29	29	1.525	167.22	1792.6	12,908	8,461.3	591.96	388.68
30	30	1.484	167.22	1822.7	12,767	8,603.4	591.68	396.08
31	31	0.6853	55.421	620.71	1,265.6	1,846.6	102.61	148.46

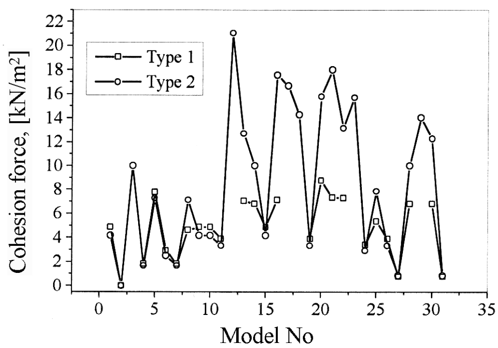

Fig. 3 – Cohesion force, [kN/m^2], *vs*. model No.

Table 5
Analytical Results of Slopes Types 1 by Morgenstern–Price Method

Sl. No	Model No	Cohesion strength kN/m^2	Cohesion force kN/m^2	Pore water pressure kN/m^2	Pore water force kN/m^2	Base shear force kN	Base normal force kN
1	1	10	4.8701	22.887	11.146	5.852	27.311
2	2	0	0	19.615	7.5443	3.1386	14.43
3	3	–	–	–	–	–	–
4	4	4	1.8434	17.893	8.2462	7.703	29.407
5	5	16	7.7921	22.887	11.146	7.3204	33.706
6	6	6	2.922	22.887	11.146	6.3351	28.512
7	7	4	1.8434	17.893	8.2462	6.3408	25.06
8	8	10	4.6085	17.893	8.2462	7.5179	31.109
9	9	10	4.8701	22.887	11.146	6.0642	27.991
10	10	10	4.8701	22.887	11.146	5.4452	25.538
11	11	8	3.896	22.887	11.146	5.759	26.772
12	12	–	–	–	–	–	–
13	13	14.5	7.0616	22.887	11.146	6.4197	31.248
14	14	14	6.8181	22.887	11.146	5.8807	28.521
15	15	10	4.8701	22.887	11.146	6.2098	29.123
16	16	20	7.1436	9.8	3.5	1.4743	7.6929
17	17	–	–	–	–	–	–
18	18	–	–	–	–	–	–
19	19	8	3.896	22.887	11.146	5.4011	25.381
20	20	18	8.7661	22.887	11.146	5.2931	26.319
21	21	20.5	7.3222	9.8	3.5	1.6221	8.4096
22	22	15	7.3051	22.887	11.146	5.2489	26.158
23	23	–	–	–	–	–	–
24	24	7	3.409	22.887	11.146	5.2088	24.44
25	25	11	5.3571	22.887	11.146	5.1505	25.535
26	26	8	3.896	22.887	11.146	5.837	27.227
27	27	2	0.769	19.615	7.5	2.7501	13.499
28	28	14	6.8181	22.887	11.146	5.698	27.822
29	29	–	–	–	–	–	–
30	30	14	6.8181	22.887	11.146	5.6301	27.868
31	31	2	0.769	19.615	7.544	3.3262	15.487

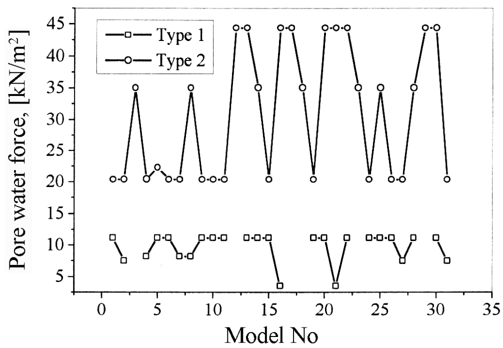

Fig. 4 – Pore water force, [kN/m^2], *vs*. model No.

Table 6

Analytical Results of Slopes Types 1 by Morgenstern–Price Method

Sl. No	Model No	Cohesion strength kN/m^2	Cohesion force kN/m^2	Pore water pressure kN/m^2	Pore water force kN/m^2	Base shear force kN	Base normal force kN
1	1	10	4.1668	49.032	20.431	5.8802	28.059
2	2	0	0	49.032	20.431	11.1	30.1
3	3	14	10	49.038	35.027	15.737	71.543
4	4	4	1.6667	49.032	20.459	10.553	38.716
5	5	16	7.2729	49.037	22.29	7.9468	37.859
6	6	6	2.5001	49.032	20.431	7.0303	30. 331
7	7	4	1.6667	49.032	20.431	8.8975	32.692
8	8	10	7.1429	49.038	35.027	16.197	72.117
9	9	10	4.1668	49.032	20.431	6.2723	29.117
10	10	10	4.1668	49.032	20.431	5.5503	26.237
11	11	8	3.3335	49.032	20.431	5.9335	27.715
12	12	24	21.054	50.584	44.374	14.425	71.628
13	13	14.5	12.72	50.584	44.374	15.123	74.478
14	14	14	10	49.038	35.027	10.692	52.838
15	15	10	4.1668	49.032	20.431	6.0394	29.645
16	16	20	17.545	50.584	44.374	11.693	60.637
17	17	19	16.667	50.584	44.374	13.644	68.418
18	18	20	14.286	49.038	35.027	11.996	59. 325
19	19	8	3. 3335	49.032	20.431	5.4807	26.032
20	20	18	15.79	50.584	44.374	12.106	62.54
21	21	20.5	17.983	50.584	44.374	13.085	66.205
22	22	15	13.159	50.584	44.374	12.016	62.165
23	23	22	15.714	49.038	35.027	9.8018	49.473
24	24	7	2.9168	49.032	20.431	5.4743	25.221
25	25	11	7.8571	49.032	35.027	9.1694	46.98
26	26	8	3.3335	49.032	20.431	0.4168	0.65123
27	27	2	0.8334	49.032	20.431	7.2061	26.946
28	28	14	10	49.038	35.027	10.309	51.381
29	29	16	14.036	50.584	44.374	12.829	65.022
30	30	14	12.281	50.584	44.374	13.076	66.293
31	31	2	0.83337	49.032	20.431	9.4541	32.006

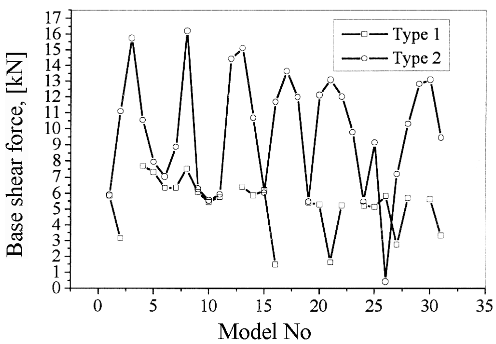

Fig. 5 – Base shear force, [kN], *vs*. model No.

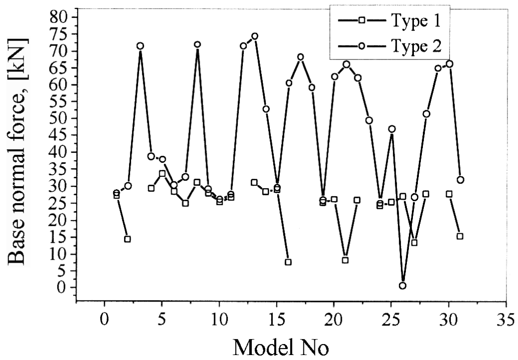

Fig. 6 – Base normal force, [kN], *vs*. model No.

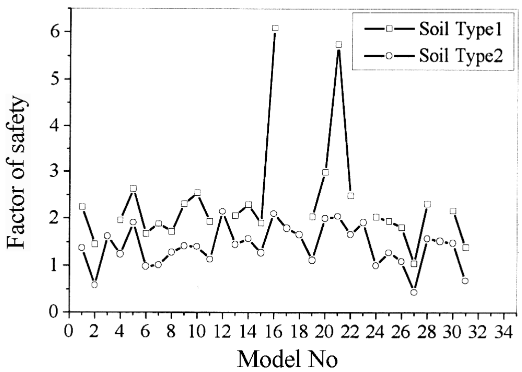

Fig. 7 – Factor of safety *vs*. model No.

4. Conclusions

1. Simulation technique could be acceptable for slope construction.
2. Application of suitable material significantly reduces liquefaction.
3. Soil characteristics in slope construction depend on slope geometry.
4. The factor of safety decreases when dimension of slope diminishes.
5. Soil structure geometry plays one of the important roles in the design and analysis of slope
6. Result of slope analysis could not be similar if a single parameter of soil or geometry changes.

Notations

Φ – friction angle, [°];
C – soil cohesion, [kN/m^2];
OMC – optimum moisture content, [%];
SBC – safe bearing capacity, [kN/m^2];
γ – unit weight, [kN/m^3].

Received, February 12, 2010

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ANALIZA STABILITĂŢII TALUZURILOR IN CONDIŢII DE ECHILIBRU LIMITĂ

(Rezumat)

În dezvoltarea durabilă prin construirea eficientă a terasamentelor, metoda de construire folosind amestecurile de pământ este considerată acceptabilă. Lucrarea de faţă studiază posibilitatea de sporire a stabilităţii pantelor utilizând amestecurile de pământuri. Aspectele teoretice sunt însoţite de simulări numerice ce evidenţiază faptul că procedeul poate fi aplicat cu succes folosind materiale locale sau care se află în imediata vecinătate a şantierului, reducând astfel costul total al investiţiei. Mai mult, metoda prezentată ajută la o mai bună înţelegere a comportamentului pământurilor atunci când este folosit în lucrări geotehnice cu geometrii şi forme variate.