Geometry in Slope Modeling and Design

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Abstract – The liquefaction is most important problem in geotechnical engineering. The ability of liquefaction is concern to the several factors. The pore water pressure is an important factor in liquefaction and slope geometry design. The author made an investigation on slope behavior subjected to underground water level. The slope models developed under compacted and optimum moisture content (OMC) condition with different ground water levels and geometries. In this regard using Geo-slope software several models have been analyzed. The result revealed pore water pressure ability has correlation with slope geometry and soil mechanical properties, it means pore water force at any earthen structure or area is specific.

Keyword: Slope Stability, Mixed Soil, Underground Water Level

1. Introduction

This research work deals with evaluation of mixed soil technique to understanding possibility of safe and stable slope construction. The slope stability and liquefaction are two important issues in geotechnical engineering. The liquefaction is one of the main reasons in the majority of slope failure.

There are several investigations on slope stability [1-5], and researches on mixed soil, deep soil stabilization techniques, approaching economical soil foundation, improvement of the permeability and strength of soil [6-9]. The liquefaction of soils has been responsible for the failure of many man-made and natural geotechnical structures. The liquefaction phenomenon of saturated soil has been subjected to many investigations in the past 80 years, many of these investigations have been based on the principle of subjecting representative soil elements to the same loading conditions in the laboratory as they would encounter in the field [10-17].

In this research work for developing models 31 mixed soil types have been used. The all mixed soils are under compacted condition with optimum moisture content (OMC). The computer modeling was used to evaluate the slopes behavior, suitability of material, soil mechanical properties, and slope geometry and under ground water levels.

2. Methodology and Experiments

The modeling is an applicable technique for solving Geotechnical engineering problems. From previous investigation 31 mixed soil types selected. These are evaluating for possibility of using as slope material. The experiments were carried out on Mysore local soils at the Geo-technical Engineering Laboratory, S. J. College of Engineering in Mysore [18]. For creating slope models the mixed soils angle of friction (Φ), unit weight (γ) and cohesion (C) have been used (Table 1-2). The 279 slope models base on geometry, under ground water levels and mixed soil mechanical properties have been developed. The Geo-Slope and origin software were used for studying models

characteristics and finding possibility improvement factor of safety from local and economical material. In application of the Geo-slope software Morgenstern-Price method with half-sine function was used to solving slope problem.
Formulas for calculation of normal stress, shear strength, shear stress and factor of safety by manually are the following:

1) $\sigma = \gamma H \cos^2 i$
2) $\tau_f = (\gamma H \cos^2 i)\tan\Phi$
3) $\tau = \gamma H(\cos i)(\sin i)$
4) $F_s = \tau_f / \tau = [\tan\Phi / \tan i]$

Table 1 Mixed soil models [18]

Sl. No	% Of Red Soil	% Of Sand	% Of Gravel 4.75 mm	% Of Gravel 2 mm	% Of Black Soil	% Of Green Soil	% Of Dark Brown Soil	% Of Yellow Soil	% Of 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	45	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

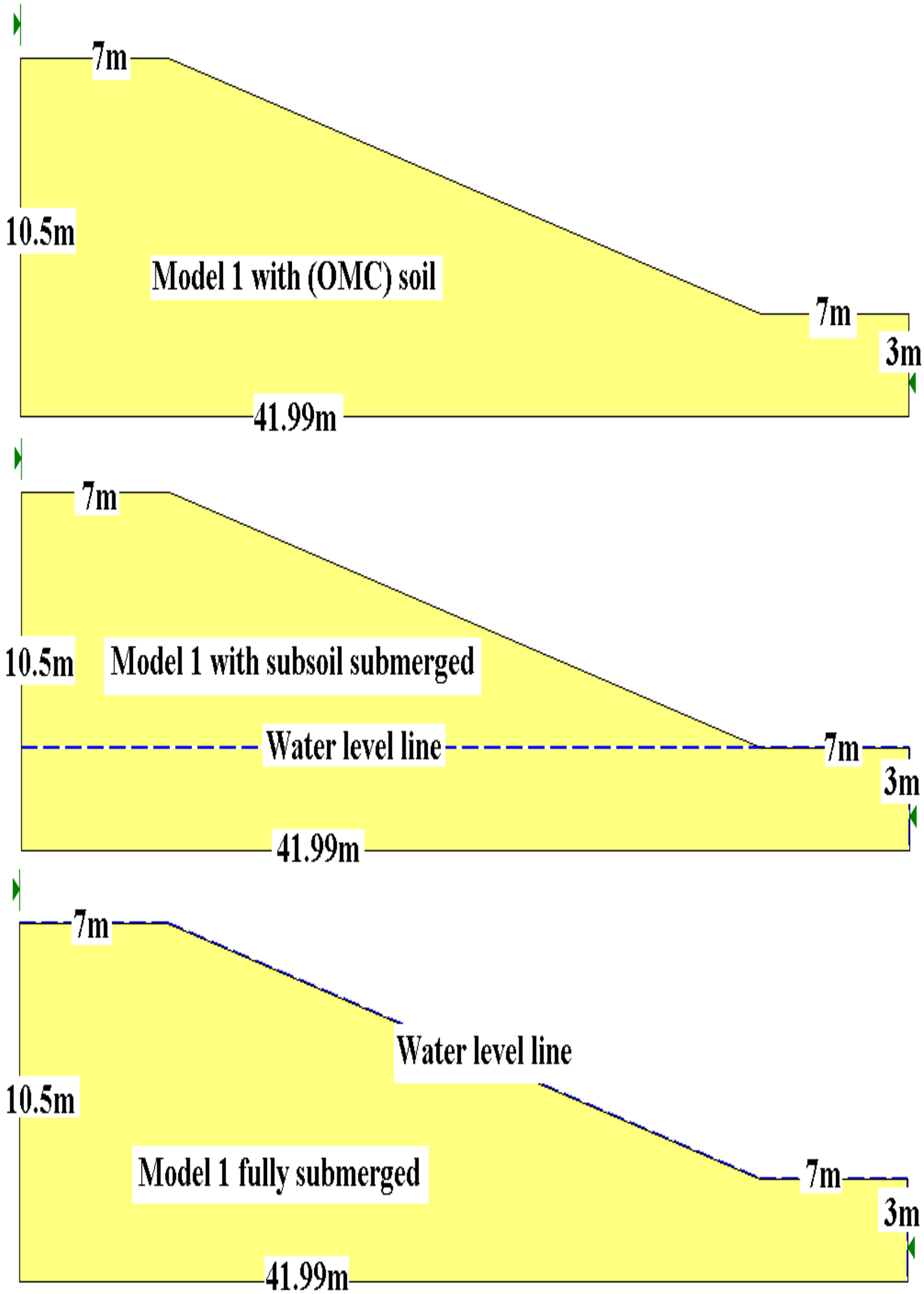

Fig 1 Models 1 with 15 degree inclined slope and different water level

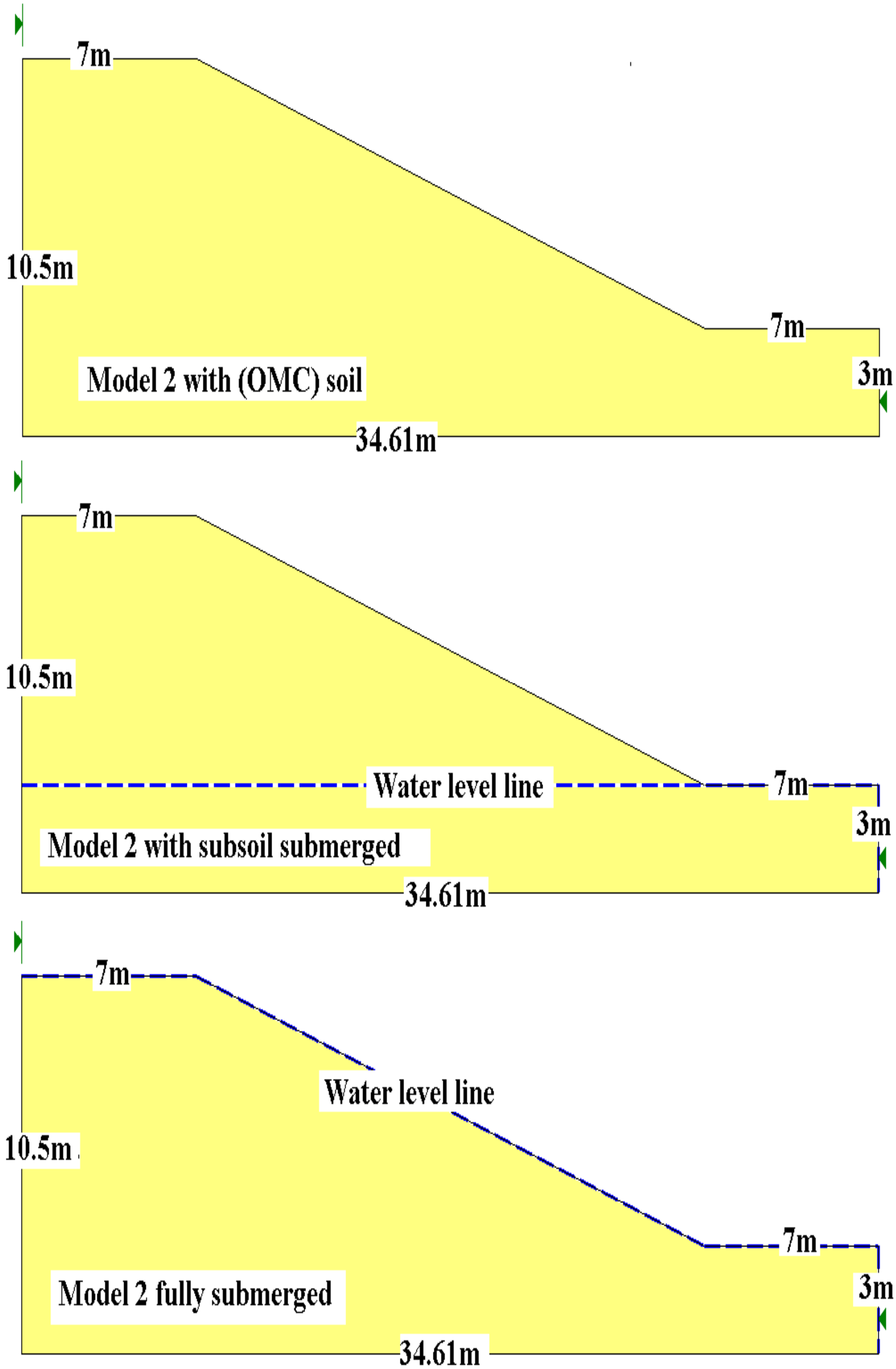

Fig 2 Models 2 with 20 degree inclined slope and different water level

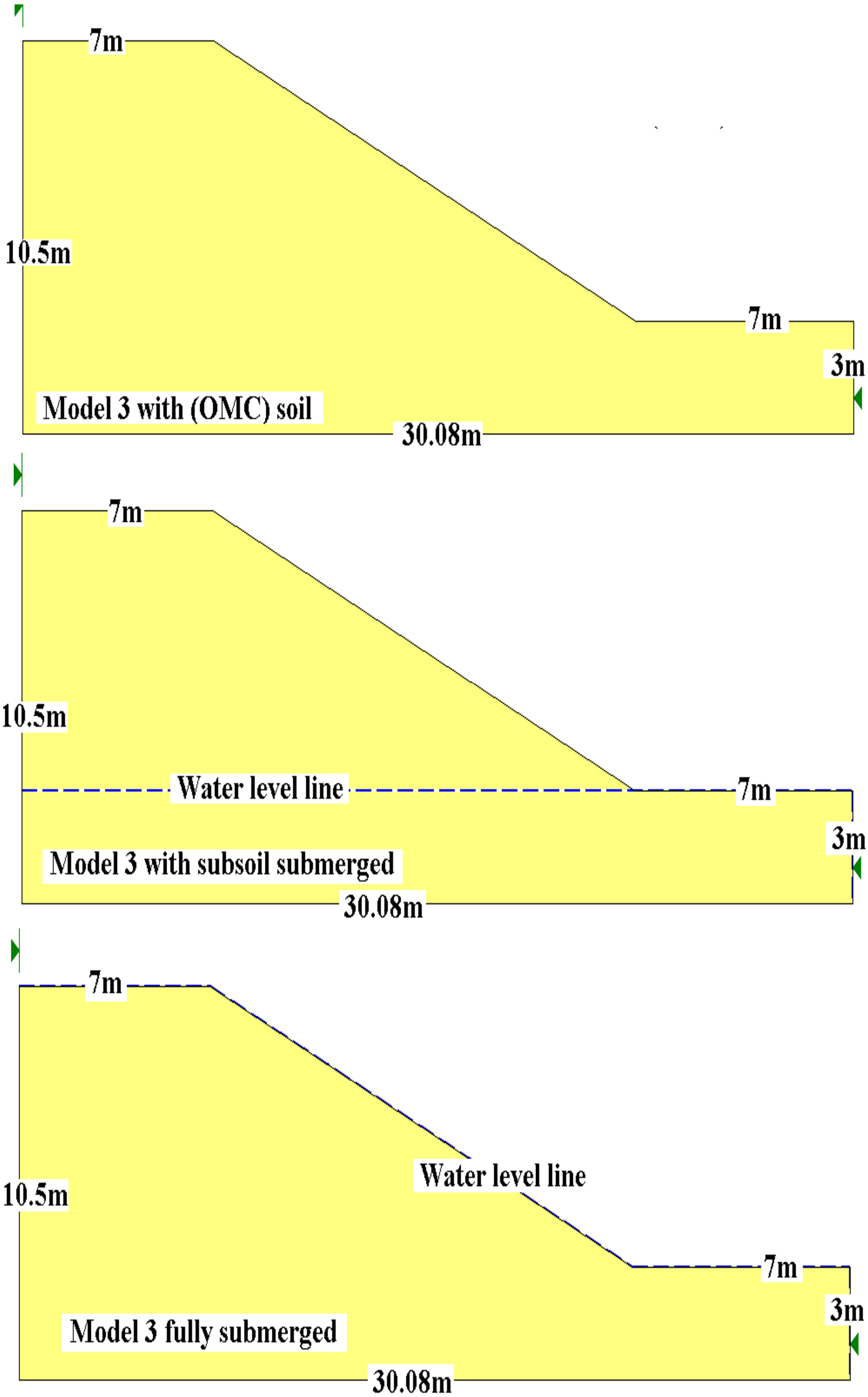

Fig 3 Models 3 with 25 degree inclined slope and different water level

3. Results and Discussion

For increasing slope construction quality application of mixed soil technique is an acceptable method. Selecting appropriate percentage of different types of soils leads to improving result. The factor of safety is defined as the ratio of shear strength to shear stress along the surface of failure. Table 3 and figure 4 are indicating manually analytical results of slopes under compacted optimum moisture content (OMC) condition. In the manually calculation of slope factor of safety the width of slope not come in the picture and only depth has influence on slope shear stress and strength. The table 3 indicated, when slope angle increased the factor of safety decreased, this is due to reduction of shear strength and increasing shear stress, it is occurs base on soil mechanical properties which is domains slope stability characteristics.

The tables 4-6 and figures 5-7 shown computerized analytical results of 279 slopes models in different underground water level, slopes geometry and soil mechanical properties positions. The factor of safety of all 279 models with increasing underground water decreased (Fig 1-3). The result indicated the shape of slope collapse has direct correlation with slope inclined angle. When the slope inclined angle is less than 20 degree types of failure is slope failure, and when slope angle inclined is 25 degree the type of failure may be slope failure, toe failure or base failure. This is could be deduced when slope inclined is up to 20 degree it is require to support of slope to avoiding failure but when slope inclined is higher than 25 degree it is needed to support of slope along with subsoil for increasing model stability. The computer modeling could be used for identifying slope behaviors and liquefaction characteristics which leads to selecting suitable material in slope construction and reduction of failure. This research is very useful in improving slope stability and understanding reduction of slope strength in rising under ground water. If modifying slope geometry could not be possible base on site characteristics for slope improving the application of mixed soil technique could be suggested.

Stability analyses are routinely could be performed in order to assess the safe and functional design of a slope. The analysis technique should be chosen depends on both site conditions and the potential mode of failure [19]. Proper selection of mixtures made of suitable material could significantly improve soil bearing capacity. It is possible for liquefaction mitigation to employ the soil mixing method. Soil mixing technique could seriously improve the ability of soil resistance if it is faces shear failure [20].

In this research work the application of the Geo-slope software Morgenstern-Price method with half-sine function was used to solving slope problem. The changing soil mechanical properties in interaction with the under ground water leads to changing soil mineralogy characteristics and resulted in changing slope strength material.

Addition of water from rainfall or snow melt adds weight to the slope. Water can seep into the soil or rock and replace the air in the pore space or fractures. When the material becomes saturated with water, the angle of repose is reduced to very small values and the material tends to flow like a fluid. Water can be adsorbed or aborted by minerals in the soil. Adsorption causes the electronically polar water molecule to attach itself to the surface of the minerals. Absorption causes the minerals to take the water molecules into their structure. If adsorption occurs then the surface frictional contact between mineral grains could be lost resulting in a loss of cohesion, thus reducing the strength of the soil [21].

Table 2 Experiments Results When Soil is in Compacted OMC Condition [18]

Sl. No	Model No 1	Optimum Moisture Content (%)	γ (KN/m^3)	Φ Degree	C (KN/m^2)
1	1	11.2	21.94	38	21
2	2	10.61	21.83	39	12
3	3	10.72	23.46	39	46
4	4	12.15	23.82	36	28
5	5	9.58	23.02	40	8
6	6	22.39	20.09	32	20
7	7	18.86	20.95	32	26
8	8	14.56	23.35	18	44
9	9	14.23	20.96	30	28
10	10	16.83	21.61	36	22
11	11	18.27	21.56	15	47
12	12	16.76	21.07	22	49
13	13	20.21	21.83	21	33
14	14	18.68	21.179	27	38
15	15	19.34	20.96	29	8.5
16	16	16.55	20.31	31	22
17	17	21.14	21.18	20	27
18	18	20.79	21.18	20	23
19	19	16.31	20.96	33.5	12
20	20	20.88	20.96	24	23
21	21	23	21.5	23	10
22	22	20.06	22.05	23	32
23	23	20.11	21.07	23	22
24	24	20.75	20.41	19	22
25	25	22.69	20.748	22	16
26	26	18.87	21.72	21	28
27	27	20.31	21.94	24	26
28	28	19.51	21.72	17.5	28
29	29	20.52	22.59	17	9
30	30	18.99	22.47	18	24
31	31	14.56	21.61	28	26

Table 3 manually analytical results of slopes under compacted [OMC] condition

Sl No	Model No	Model with 15degree inclined			Model with 20degree inclined			Model with 25degree inclined		
		τ_f (kPa)	τ (kPa)	F_s	τ_f (kPa)	τ (kPa)	F_s	τ_f (kPa)	τ (kPa)	F_s
1	1	119.87	41.12	2.92	113.46	52.86	2.15	105.55	63.00	1.68
2	2	123.62	40.91	3.02	117.01	52.60	2.22	108.85	62.69	1.74
3	3	132.85	43.97	3.02	125.74	56.53	2.22	116.97	67.37	1.74
4	4	121.03	44.64	2.71	114.55	57.39	2.00	106.56	68.40	1.56
5	5	135.08	43.14	3.13	127.85	55.47	2.31	118.93	66.10	1.80
6	6	87.80	37.65	2.33	83.10	48.41	1.72	77.30	57.69	1.34
7	7	91.55	39.26	2.33	86.65	50.48	1.72	80.61	60.16	1.34
8	8	53.06	43.76	1.21	50.22	56.26	0.89	46.72	67.05	0.70
9	9	84.63	39.28	2.15	80.10	50.50	1.59	74.52	60.19	1.24
10	10	109.80	40.50	2.71	103.92	52.07	2.00	96.68	62.06	1.56
11	11	40.41	40.41	1.00	38.24	51.95	0.74	35.58	61.91	0.57
12	12	59.54	39.49	1.51	56.35	50.77	1.11	52.42	60.50	0.87
13	13	58.61	40.91	1.43	55.47	52.60	1.05	51.61	62.69	0.82
14	14	75.47	39.69	1.90	71.43	51.03	1.40	66.45	60.82	1.09
15	15	81.26	39.28	2.07	76.91	50.50	1.52	71.55	60.19	1.19
16	16	85.35	38.06	2.24	80.78	48.94	1.65	75.15	58.32	1.29
17	17	53.92	39.69	1.36	51.03	51.03	1.00	47.47	60.82	0.78
18	18	53.92	39.69	1.36	51.03	51.03	1.00	47.47	60.82	0.78
19	19	97.02	39.28	2.47	91.83	50.50	1.82	85.43	60.19	1.42
20	20	65.27	39.28	1.66	61.78	50.50	1.22	57.47	60.19	0.95
21	21	63.83	40.29	1.58	60.41	51.80	1.17	56.20	61.74	0.91
22	22	65.46	41.32	1.58	61.96	53.13	1.17	57.64	63.32	0.91
23	23	62.55	39.49	1.58	59.21	50.77	1.17	55.08	60.50	0.91
24	24	49.15	38.25	1.29	46.52	49.18	0.95	43.28	58.61	0.74
25	25	58.63	38.88	1.51	55.49	49.99	1.11	51.62	59.58	0.87
26	26	58.31	40.71	1.43	55.19	52.33	1.05	51.35	62.37	0.82
27	27	68.32	41.12	1.66	64.66	52.86	1.22	60.16	63.00	0.95
28	28	47.90	40.71	1.18	45.34	52.33	0.87	42.17	62.37	0.68
29	29	48.31	42.34	1.14	45.72	54.43	0.84	42.53	64.87	0.66
30	30	51.07	42.11	1.21	48.33	54.14	0.89	44.96	64.52	0.70
31	31	80.36	40.50	1.98	76.06	52.07	1.46	70.76	62.06	1.14

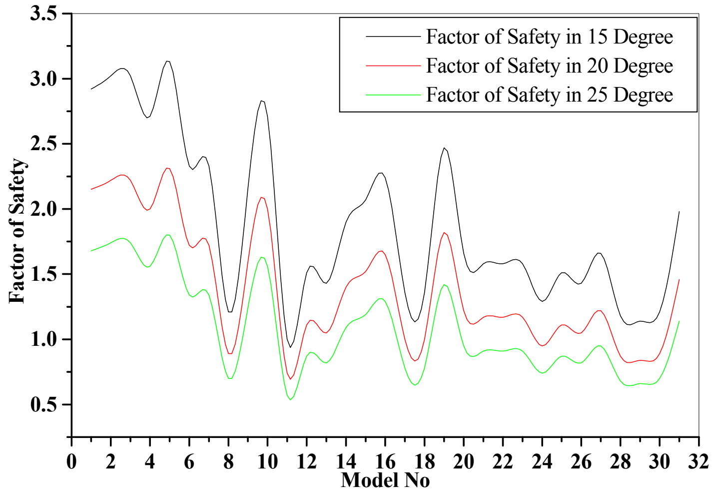

Fig 4 Factor of Safety Vs Model No

Table 4 computerize analytical results of model 1 with 15 degree inclined slope

Sl No	Model No	Model 1 with (OMC) soil		Model 1 with subsoil submerged		Model 1 fully submerged	
		F_s	Type of failure	F_s	Type of failure	F_s	Type of failure
1	1	5.98	SF	5.50	SF	3.85	SF
2	2	5.37	SF	4.89	SF	3.35	SF
3	3	7.59	SF	7.23	SF	5.52	SF
4	4	5.98	SF	5.65	SF	4.14	SF
5	5	5.04	SF	4.79	SF	3.17	SF
6	6	5.12	SF	4.78	SF	3.25	SF
7	7	5.47	SF	5.15	SF	3.68	SF
8	8	4.64	SF	4.49	SF	3.80	SF
9	9	5.33	SF	5.03	SF	3.67	SF
10	10	5.75	SF	5.35	SF	3.74	SF
11	11	4.74	SF	4.60	SF	3.98	SF
12	12	5.75	SF	5.54	SF	4.58	SF
13	13	4.45	SF	4.26	SF	3.38	SF
14	14	5.59	SF	5.34	SF	4.14	SF
15	15	3.75	SF	3.39	SF	2.28	SF
16	16	5.10	SF	4.78	SF	3.33	SF
17	17	3.99	SF	3.80	SF	2.95	SF
18	18	3.71	SF	3.53	SF	2.67	SF
19	19	4.65	SF	4.20	SF	2.84	SF
20	20	4.21	SF	3.89	SF	2.92	SF
21	21	3.15	SF	2.88	SF	1.99	SF
22	22	4.60	SF	4.39	SF	3.43	SF
23	23	4.01	SF	3.79	SF	2.80	SF
24	24	3.59	SF	3.40	SF	2.57	SF
25	25	3.49	SF	3.28	SF	2.32	SF
26	26	4.12	SF	3.93	SF	3.06	SF
27	27	4.33	SF	4.12	SF	3.11	SF
28	28	3.80	SF	3.69	SF	2.95	SF
29	29	2.38	SF	2.20	SF	1.57	SF
30	30	3.46	SF	3.30	SF	2.58	SF
31	31	4.87	SF	4.60	SF	3.39	SF

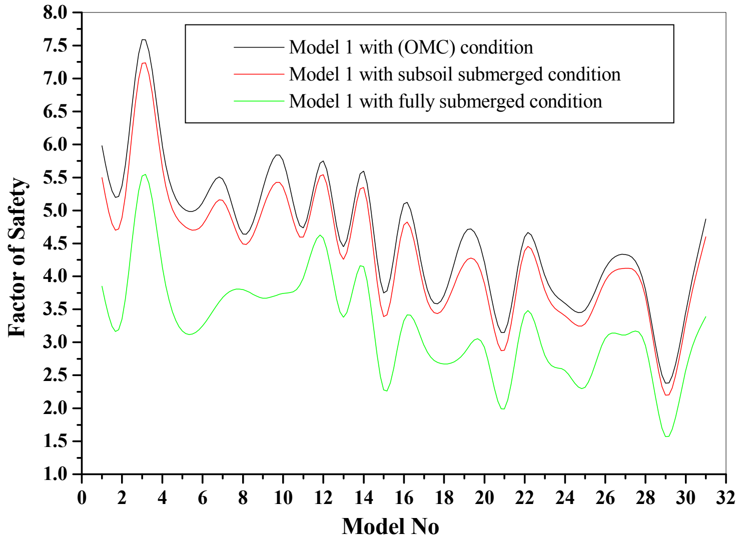

Fig 5 Factor of Safety Vs Model No

Table 5 computerize analytical results of model 2 with 20 degree inclined slope

Sl No	Model No	Model 2 with (OMC) soil		Model 2 with subsoil submerged		Model 2 fully submerged	
		F_s	Type of failure	F_s	Type of failure	F_s	Type of Failure
1	1	4.28	SF	3.93	SF	2.77	SF
2	2	3.86	SF	3.50	TF	2.36	SF
3	3	5.59	SF	5.25	SF	4.11	SF
4	4	4.32	SF	4.02	SF	3.02	SF
5	5	3.61	SF	3.32	TF	2.23	SF
6	6	3.70	SF	3.39	SF	2.37	SF
7	7	3.99	SF	3.69	SF	2.71	SF
8	8	3.59	SF	3.44	SF	2.99	SF
9	9	3.91	SF	3.64	SF	2.73	SF
10	10	4.13	SF	3.80	SF	2.71	SF
11	11	3.69	SF	3.56	SF	3.15	SF
12	12	4.40	SF	4.21	SF	3.57	SF
13	13	3.35	SF	3.17	SF	2.59	SF
14	14	4.19	SF	3.95	SF	3.15	SF
15	15	2.69	SF	2.43	TF	1.60	SF
16	16	3.70	SF	3.41	SF	2.44	SF
17	17	2.98	SF	2.81	SF	2.24	SF
18	18	2.76	SF	2.59	SF	2.02	SF
19	19	3.35	SF	3.03	SF	2.02	SF
20	20	3.10	SF	2.89	SF	1.19	SF
21	21	2.62	SF	2.06	SF	1.43	SF
22	22	3.44	SF	3.25	SF	2.61	SF
23	23	2.95	SF	2.75	SF	2.09	SF
24	24	2.67	SF	2.50	SF	1.96	SF
25	25	2.54	SF	2.35	SF	1.71	SF
26	26	3.08	SF	2.90	SF	2.32	SF
27	27	3.20	SF	2.99	SF	2.33	SF
28	28	2.80	SF	2.66	SF	2.18	SF
29	29	1.70	SF	1.57	SF	1.13	SF
30	30	2.58	SF	2.44	SF	1.96	SF
31	31	3.57	SF	3.33	SF	2.52	SF

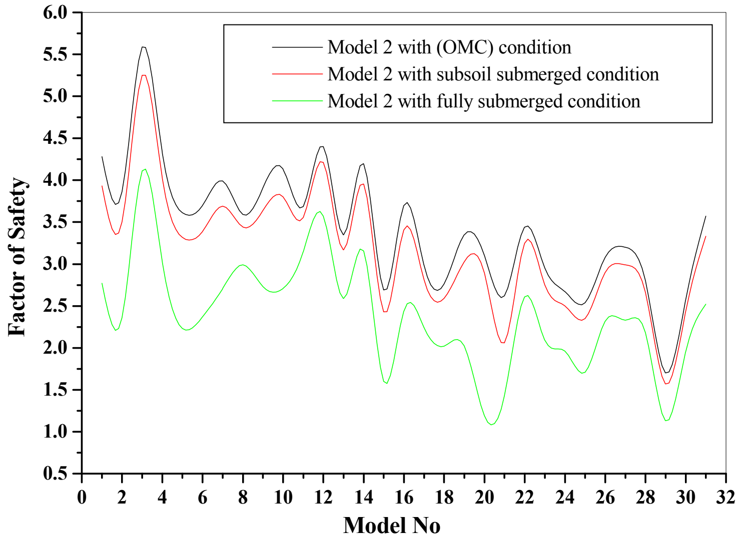

Fig 6 Factor of Safety Vs Model No

Table 6 computerize analytical results of model 3 with 15 degree inclined slope

Sl No	Model No	Model 3 with (OMC) soil		Model 3 with subsoil submerged		Model 3 fully submerged	
		F_s	Type of failure	F_s	Type of failure	F_s	Type of Failure
1	1	3.54	SF	3.25	TF	2.31	BF
2	2	3.00	TF	2.89	TF	1.89	SF
3	3	4.74	TF	4.43	BF	3.49	BF
4	4	3.63	TF	3.35	BF	2.54	BF
5	5	2.76	TF	2.65	TF	1.68	TF
6	6	3.11	TF	2.82	BF	1.99	BF
7	7	3.67	TF	3.09	BF	2.24	BF
8	8	3.07	SF	2.96	SF	2.49	SF
9	9	3.32	TF	3.06	BF	2.32	BF
10	10	3.46	SF	3.15	BF	2.27	BF
11	11	3.16	SF	3.11	BF	2.64	SF
12	12	3.80	SF	3.64	SF	3.00	SF
13	13	2.87	TF	2.71	BF	2.19	SF
14	14	3.58	TF	3.37	BF	2.67	SF
15	15	2.11	TF	2.00	BF	1.3	SF
16	16	3.12	TF	2.85	BF	2.06	BF
17	17	2.55	TF	2.40	BF	1.90	SF
18	18	2.35	TF	2.19	BF	1.72	SF
19	19	2.66	TF	2.48	BF	1.66	SF
20	20	2.63	TF	2.43	BF	1.86	BF
21	21	1.85	SF	1.70	BF	1.19	BF
22	22	2.94	TF	2.77	BF	2.21	BF
23	23	2.50	TF	2.32	BF	1.77	BF
24	24	2.28	TF	2.13	BF	1.65	SF
25	25	2.14	TF	1.97	BF	1.45	BF
26	26	2.62	TF	2.46	BF	1.94	SF
27	27	2.72	TF	2.54	BF	1.98	BF
28	28	2.41	TF	2.28	BF	1.84	SF
29	29	1.42	SF	1.30	BF	0.944	BF
30	30	2.20	TF	2.07	BF	1.66	SF
31	31	3.02	TF	2.80	BF	2.13	BF

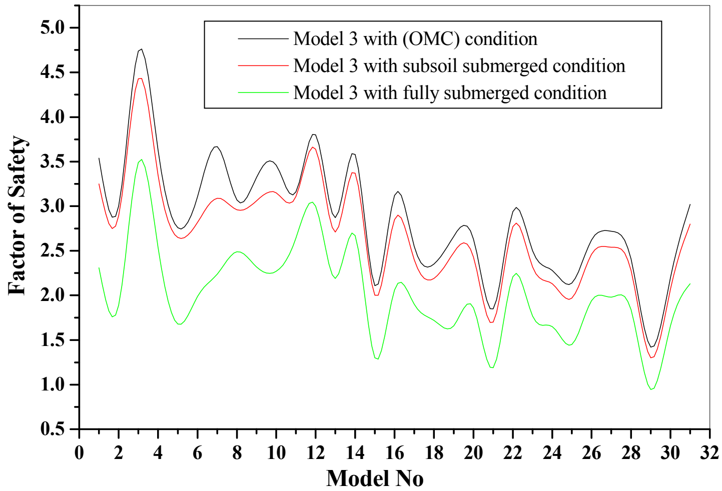

Fig 7 Factor of Safety Vs Model No

4. Conclusion

- The slope geometry, soil mechanical properties and under ground water level have direct correlation with slope stability and liquefaction ability, the liquefaction ability at any earthen structure or area is specific, it could be assessing by slope computer modeling
- The mixed soil is an novel technique could be applicable for modification of soil mechanical properties and improving slope stability and reduction of liquefaction ability
- The liquefaction could be mitigated if soil mechanical properties clearly identified
- To identification type of slope failure it is required to using computer modeling, this could not be find by manually calculation
- The type of failure is depending on slope geometry, under ground water level, pore water pressure and soil mechanical properties

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NOMENCLATURE

τ_f[kPa]	=Shear Strength
τ[kPa]	=Shear Stress
σ[kPa]	=Normal Stress
Φ [°]	= Friction Angle
C [kN/m^2]	= Soil Cohesion
OMC %	= Optimum Moisture Content
γ [kN/m^3]	= Unit Weight
F_s	=Factor of Safety
SF	=Slope failure
BF	=Base failure
TF	=Toe failure